A PROPOSED SYSTEM
FOR ALL WEATHER ATTACK
ON MOVING VEHICLES

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December 1952

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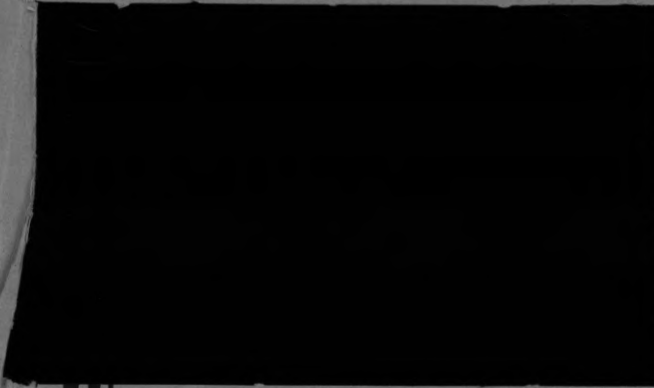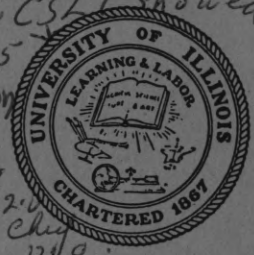
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ALL WEATHER TACTICAL OPERATIONS

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SECTION I: INTRODUCTION

The following study was undertaken at the request
of the AFDAP 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 engineer-
ing 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 character-
istics 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 nagivational 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

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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 informa-
tion would come to the artillery from the MSQ-1 cab, which
could then either scram 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.

Sinufly 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 INTERDICTION

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 con-
ditions, there is no need for the receivers to have
identical dynamic responses. Either of these would

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give more continuous data than conical scan systems,

but also, either requires more development than modify-

ing 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 present-ation 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 require-
ments 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.) This is considered sufficient for trucks, locomotives,

and all but armored vehicles. Since the targets may
be considered to be extended along a highway for dis-
tance greater than the base of a 20 mil cone (106
feet radius under the conditions cited) the probabili-
ties 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 condi-
tions 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 θ 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_o, 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 θ 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 cock-pit. 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.

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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 excape 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. Mono-
pulse 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.

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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, "θ", and the
"G" loading on the wings for the rate of turn toward
the target.

TURN AND APPROACH
V = 400 KNOTS
T_A = 20 SEC.

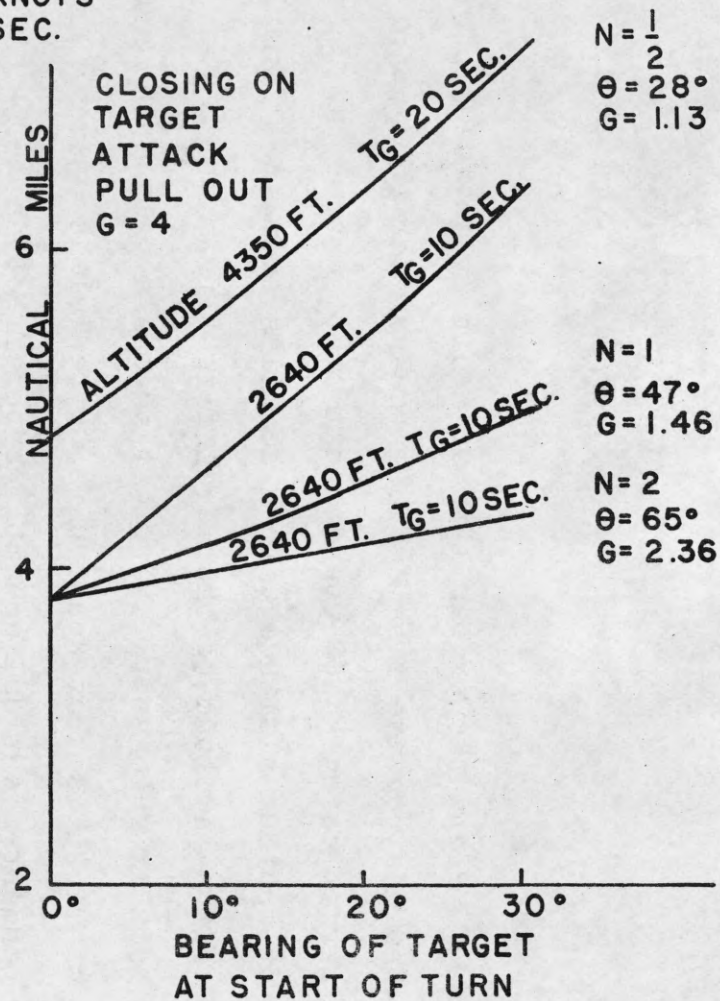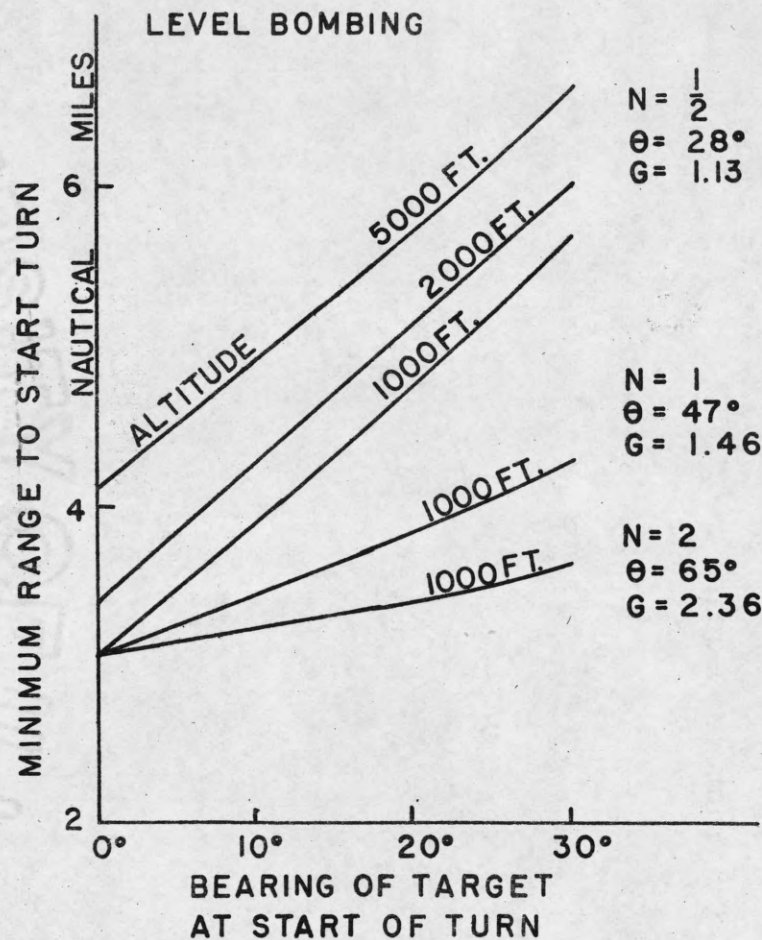FIGURE 1

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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 given the number
of missiles that would have to be released under inde-
pendent identical conditions to effect an 85 per cent
probability of a hit by an average of one destructive
fragment per square foot.

LEVEL   BOMBING
100 LB. FRAG BOMB
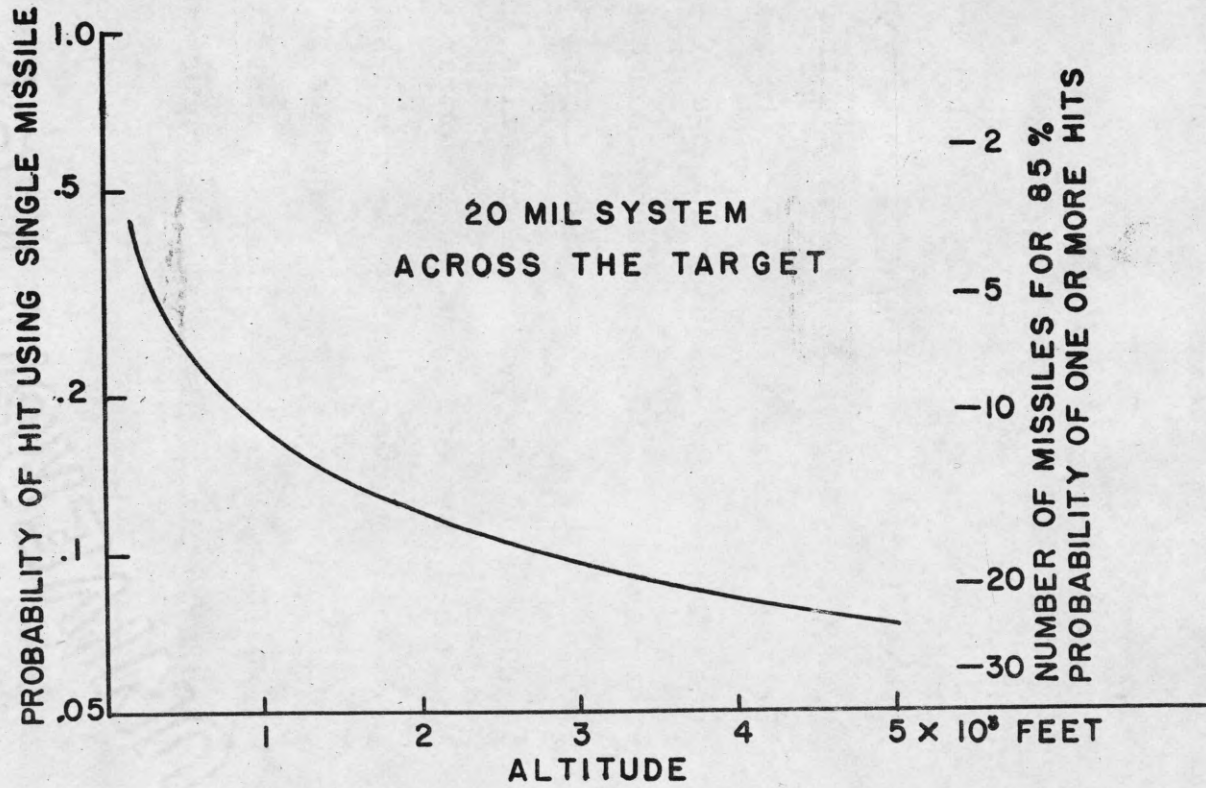
20 MIL SYSTEM
ACROSS THE TARGET

FIGURE 2

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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
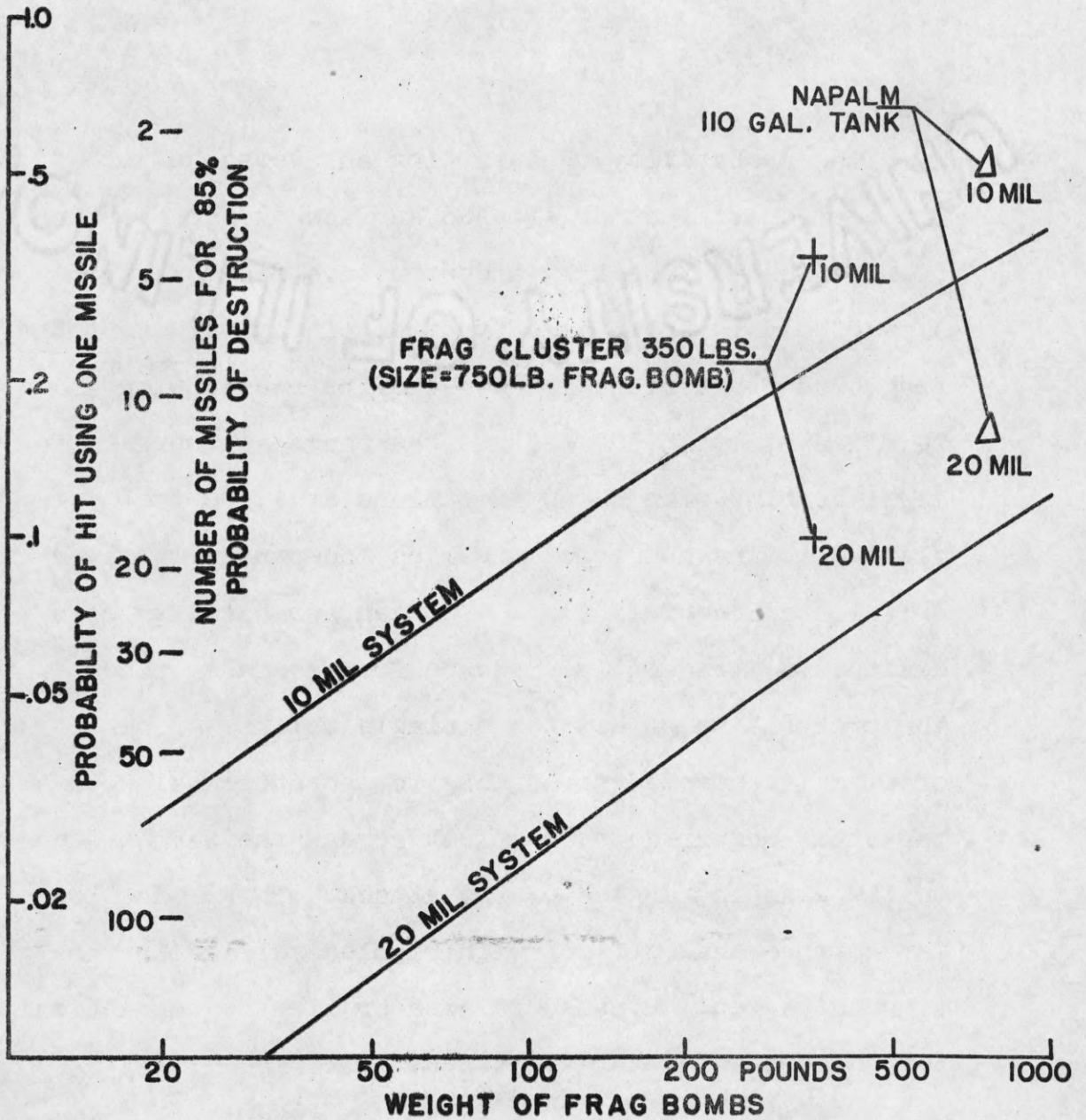
FIGURE 3

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Figure 4

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
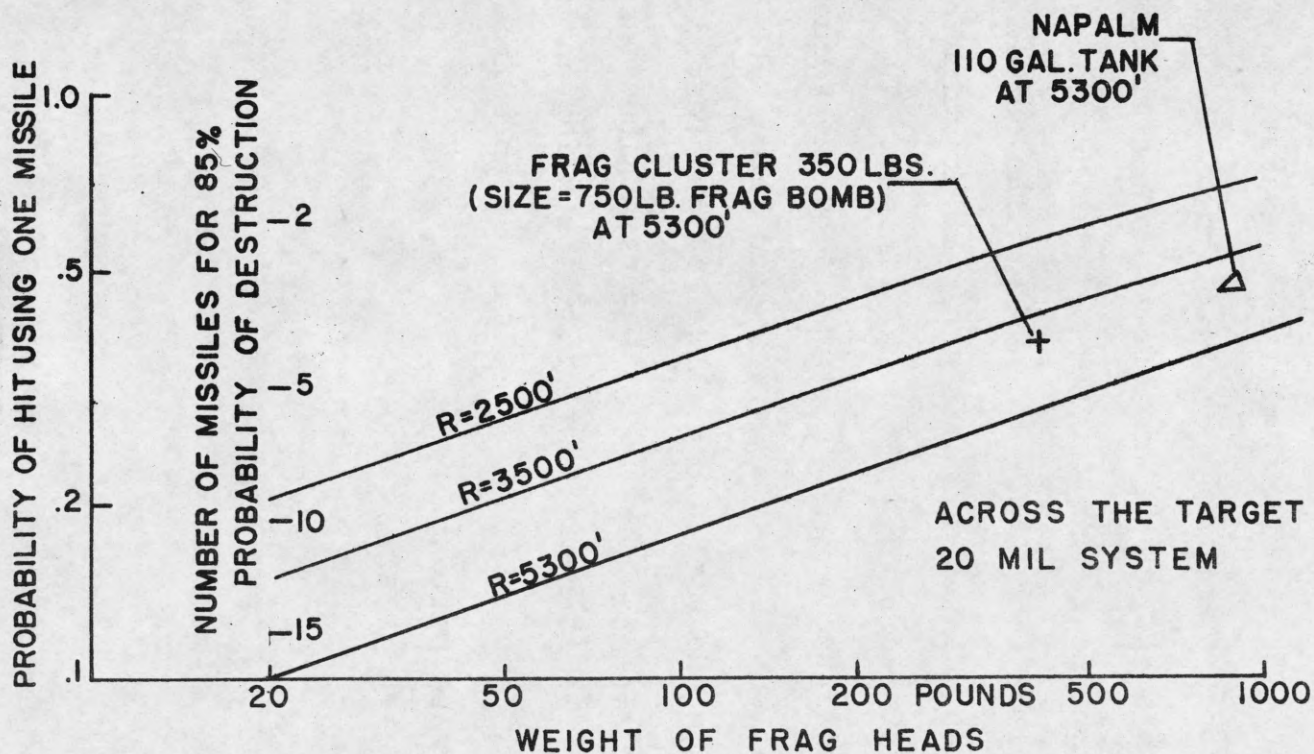
FIGURE 4

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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_o" show the slant distance from the target at which the pullout must start for a 750 feet minimum. The curve "h'_n" 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.
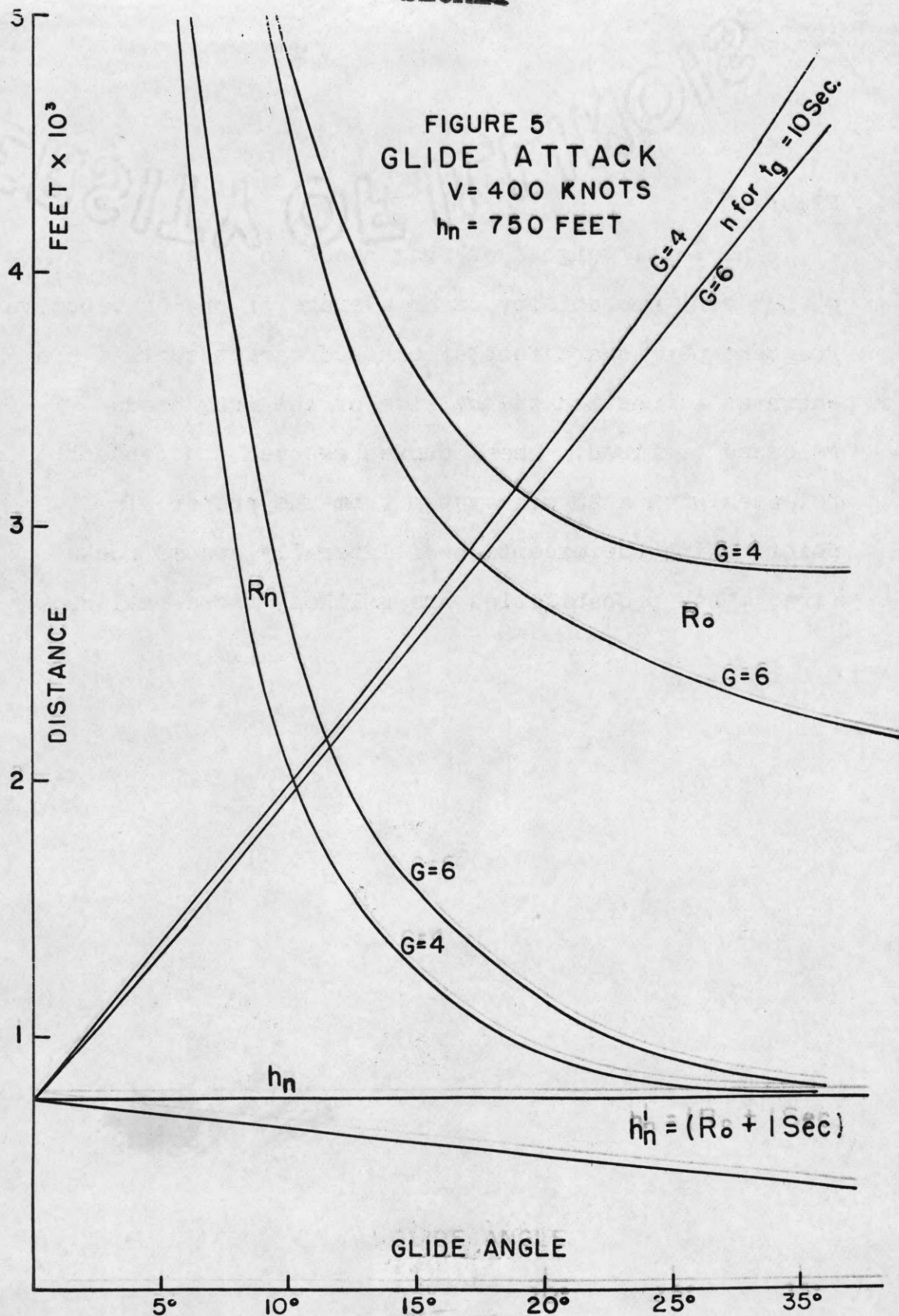
FIGURE 5
GLIDE ATTACK
V = 400 KNOTS
h_n = 750 FEET

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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
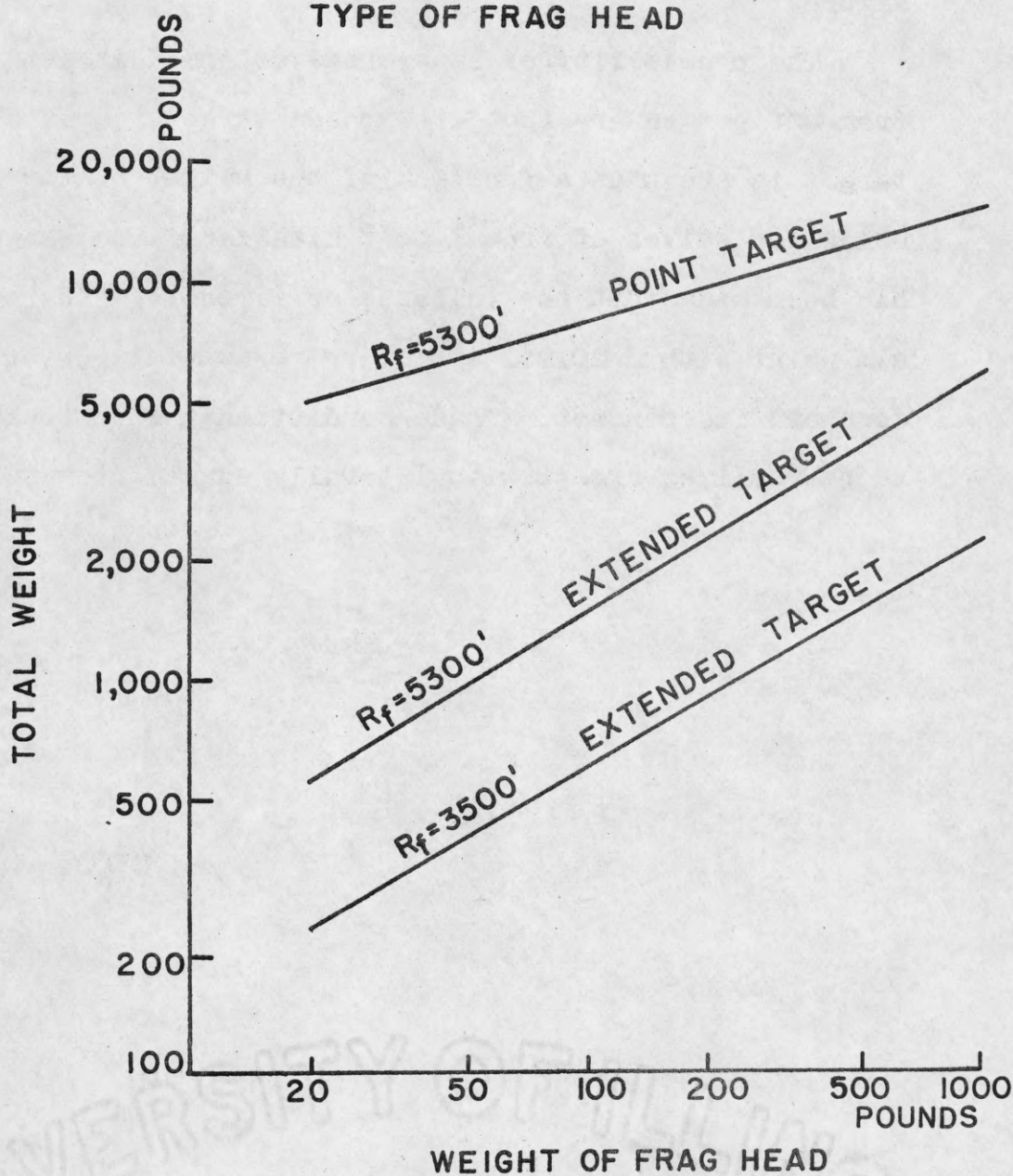
FIGURE 6

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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 simultan-
eous and independent. These conditions are unlikely
to be realized except with laterally spaced rockets.
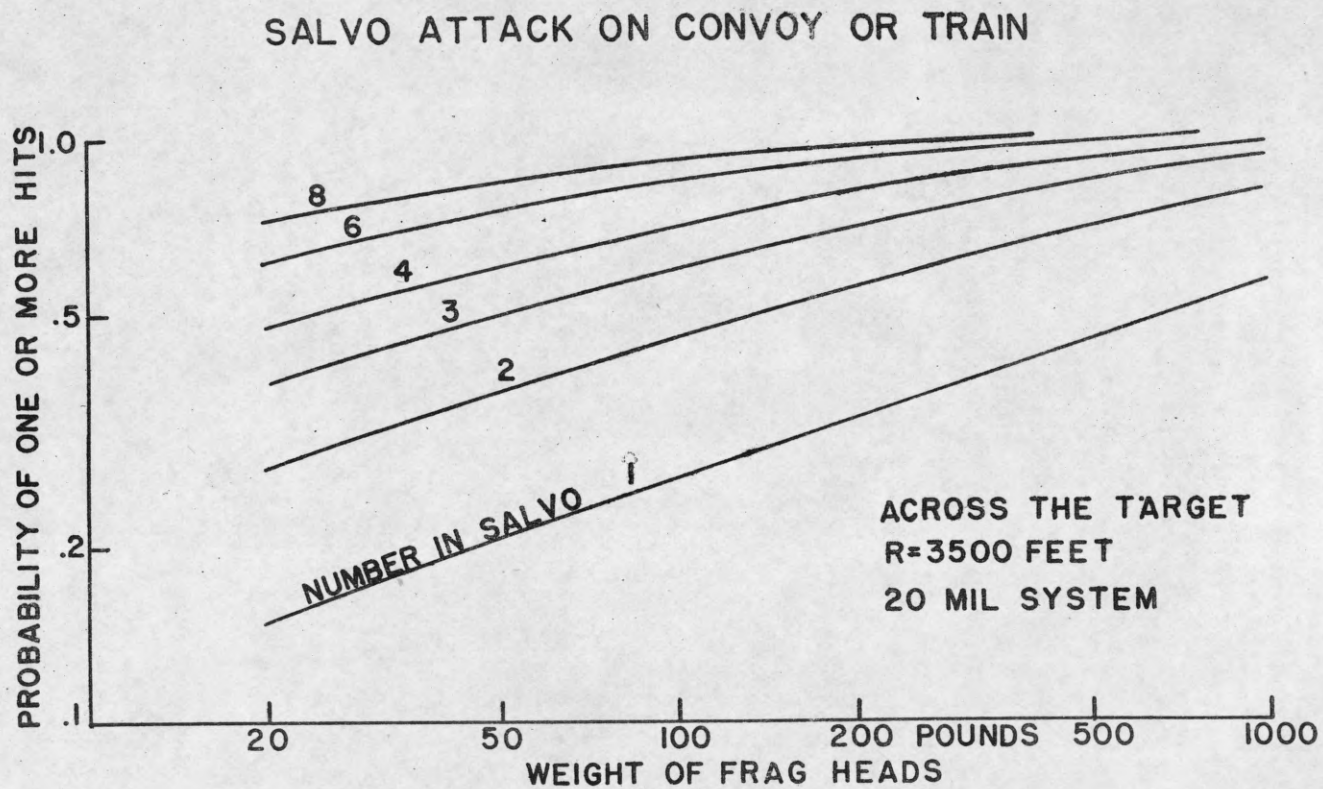
SALVO ATTACK ON CONVOY OR TRAIN

Vertical axis: PROBABILITY OF ONE OR MORE HITS

Axis values: 1.0, .5, .2, .1

Curve labels: 8, 6, 4, 3, 2, 1

NUMBER IN SALVO

ACROSS THE TARGET
R = 3500 FEET
20 MIL SYSTEM

Horizontal axis values: 20, 50, 100, 200 POUNDS 500, 1000

WEIGHT OF FRAG HEADS

FIGURE 7

Fig. 8

UNITED STATES AIR FORCE

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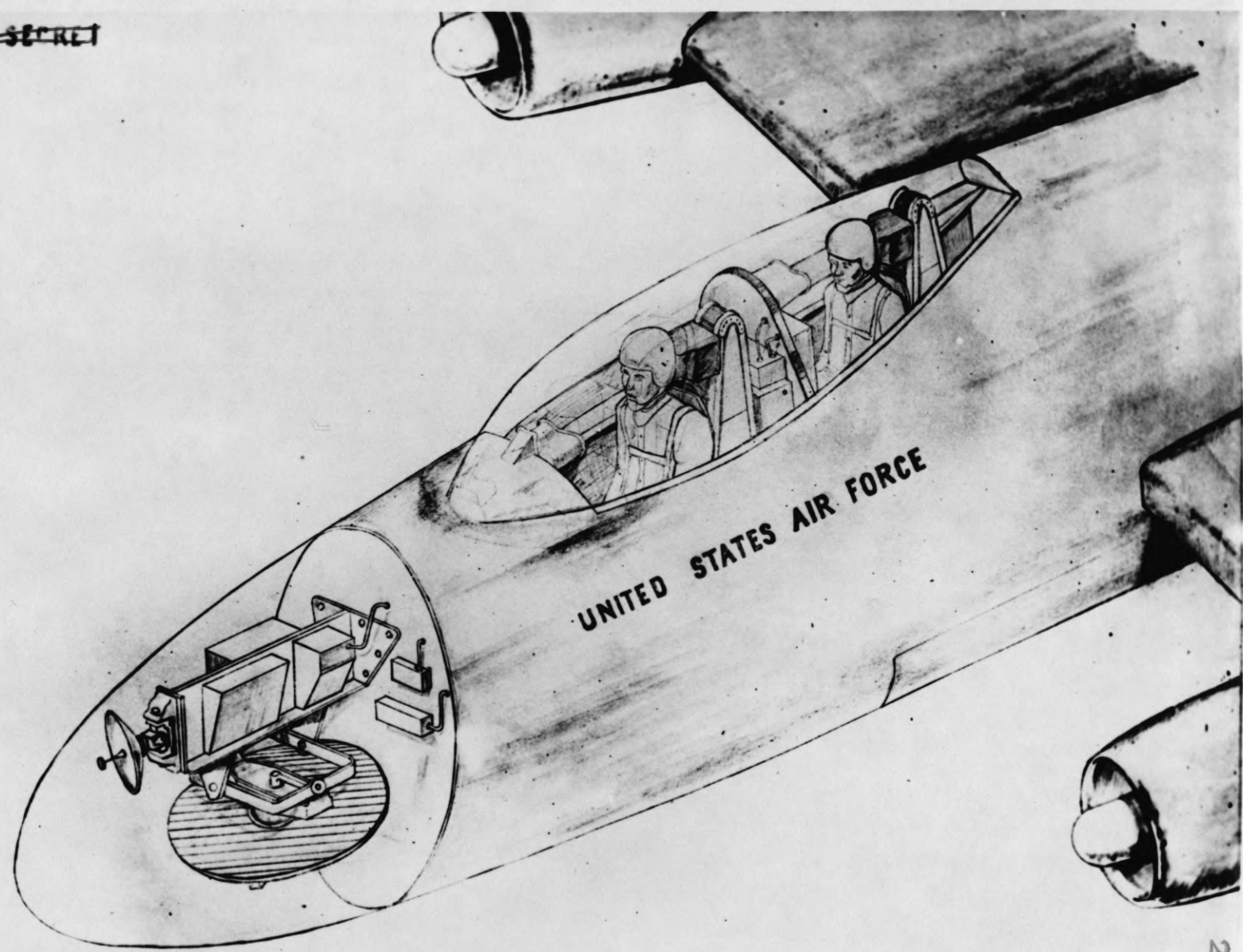
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SOME FACTORS IN THE DESIGN OF AN
ALL WEATHER ATTACK SYSTEM

Report Number R-28
Appendix I

December 1952

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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 naviga- tion 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.

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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 K_u-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,

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of about 800 pps. Furthermore, the pulses should be moderately long, that is of the order of 1 μsec. Pulse lengths greater than 1.9 μsec 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 μsec. 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

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Appendix I

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 monitor-
ing 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 K_u-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.

SECRET

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

SECRET

conical scan the output of which will be "Butterflied",

and the Butterfly output used to control the servos

determing 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-1 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-1 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.

RADOME

LOCK-ON
ANTENNA

**AXIS OF PITCH
STABILIZATION**

AXIS OF ROLL
STABILIZATION

SEARCH ANTENNA

LEGEND:
———— LEVEL FLIGHT
------ CLIMB LIMIT
— — — DIVE LIMIT
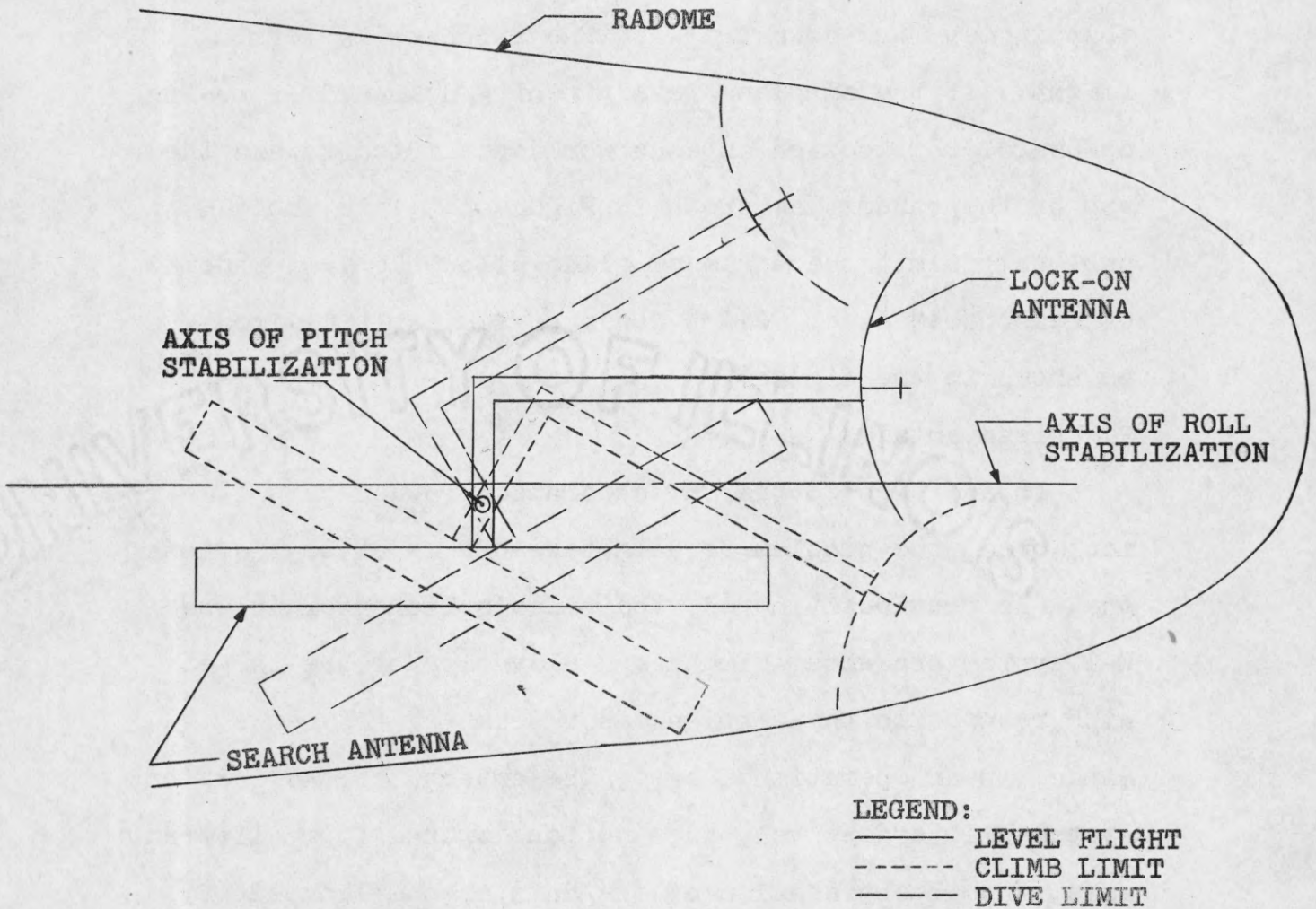
Figure 1. Sketch to show interference between lock-on

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

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 contain-
ing 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

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 stabiliza-
tion 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.

CONFIDENTIAL

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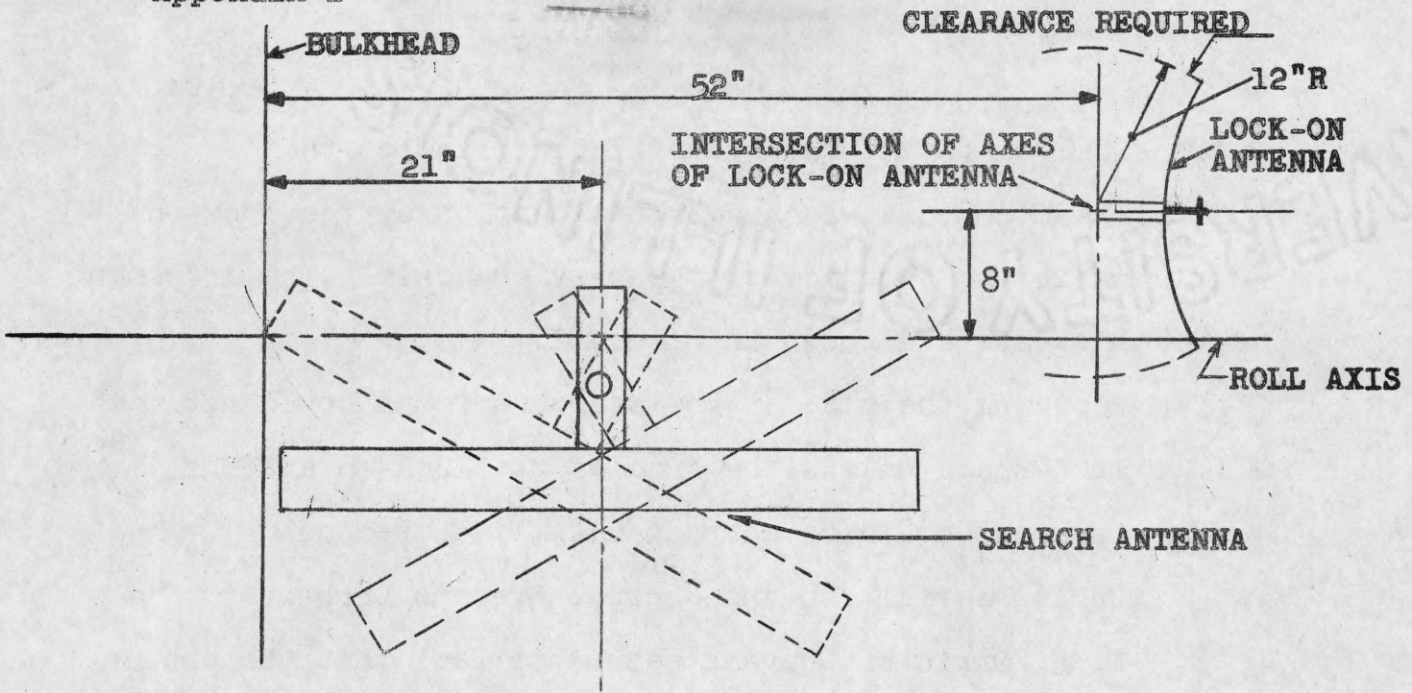
(a) Longitudinal section showing extreme positions of pitch.
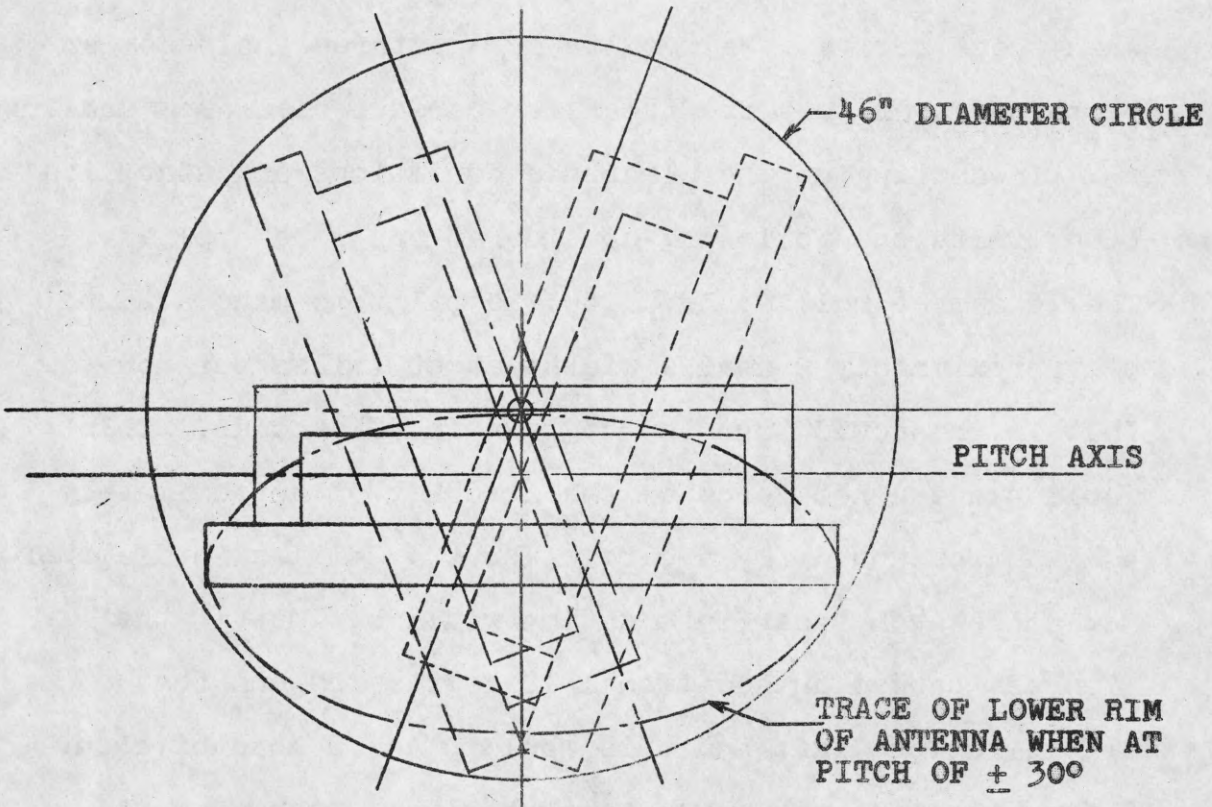
(b) Cross section showing extreme positions of roll, with trace of 30-degree pitch for the no-roll position.

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.

SECRET CONFIDENTIAL

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 $\pm$ 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 trans-
mitter 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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Appendix I

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 $\pm$ 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.

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[*] 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.

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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.*

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* 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 cancallation 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.

Am 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

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.
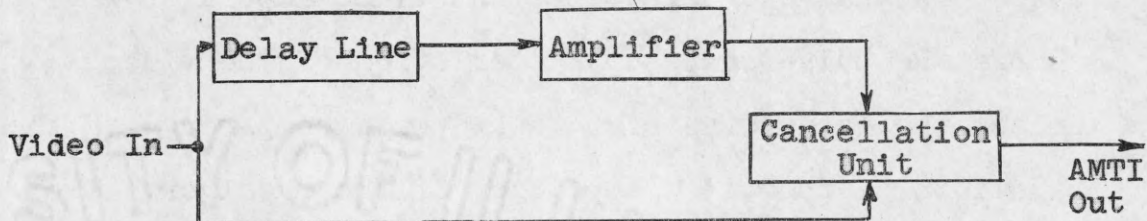
Figure 4a. Simple AMTI Circuit
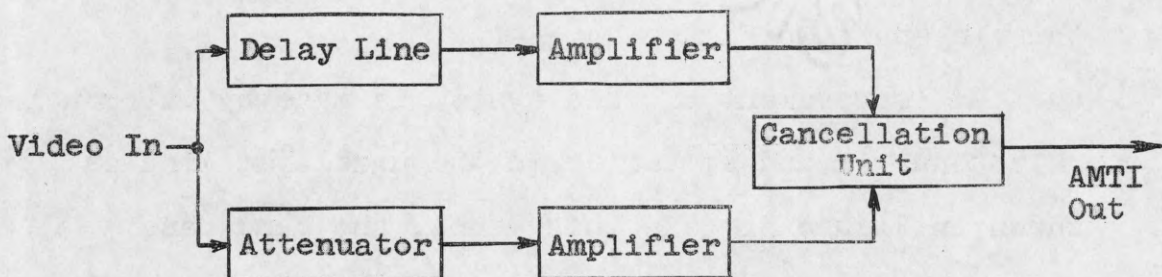
Figure 4b. An AMTI Circuit With
Matched Channels

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

TO MODULATOR

SYNCHRONIZER

TRIGGER   TRIGGER

DELAY
LINE   AMPLIFIER   VARIABLE
                                      VIDEO
                                      DELAY

VIDEO

VIDEO IN

UNDELAYED   CANCELLATION
PATH   UNIT
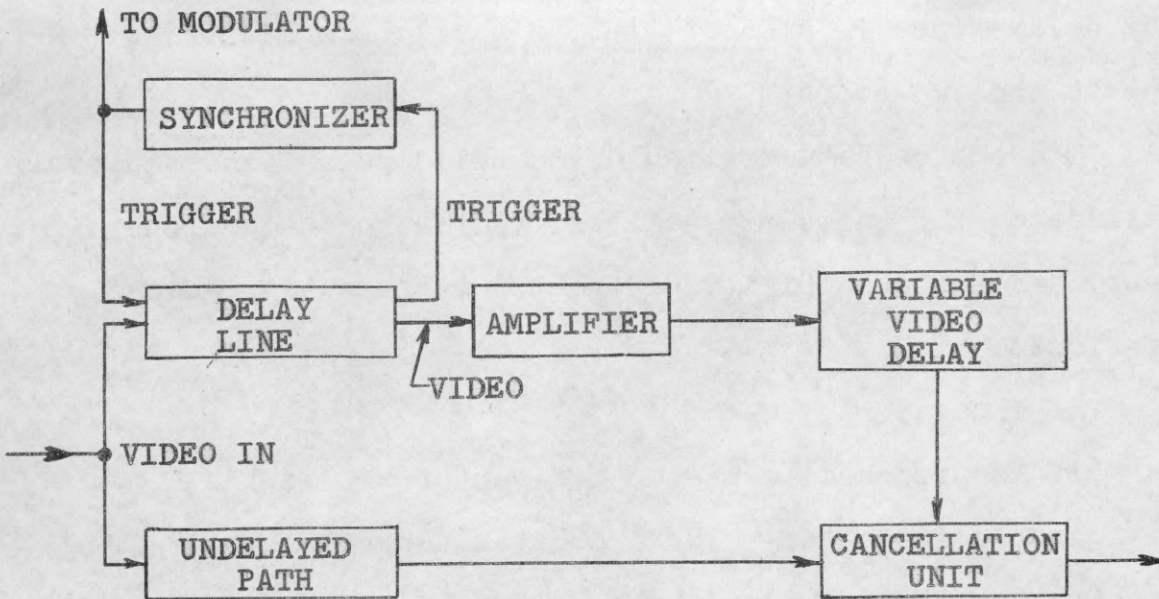
Figure 5a: AMTI SYNCHRONIZER WITH VARIABLE VIDEO DELAY

TO MODULATOR

SYNCHRONIZER   VARIABLE
                  DELAY

TRIGGER   TRIGGER

DELAY
LINE   AMPLIFIER   FIXED
                                      VIDEO
                                      DELAY

VIDEO IN

UNDELAYED   CANCELLATION
PATH   UNIT
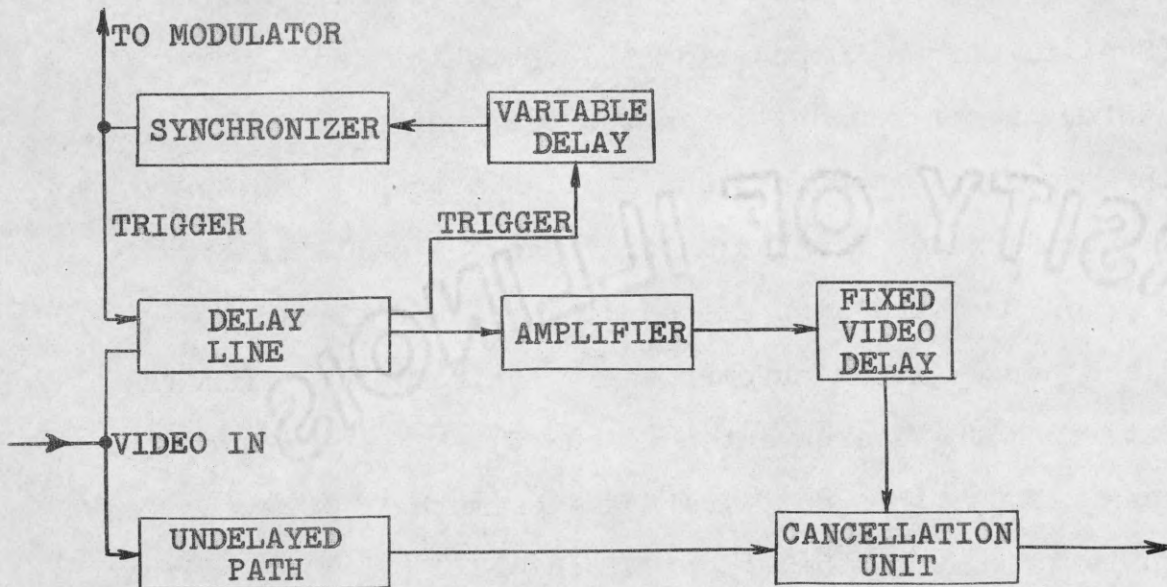
Figure 5b: AMTI SYNCHRONIZER WITH FIXED VIDEO DELAY

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 develop-
ment, 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 respect-
ively. 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

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 fre-
quency 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

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.

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* 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.

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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 π times the ratio of the modulation
frequency to the PRF. This is a maximum when the modula-
tion 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 genera-

tion 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 ampli-
fied, 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 1/4 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 nieghborhood 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

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 head-
phones 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 appro-
priate 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

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Appendix I

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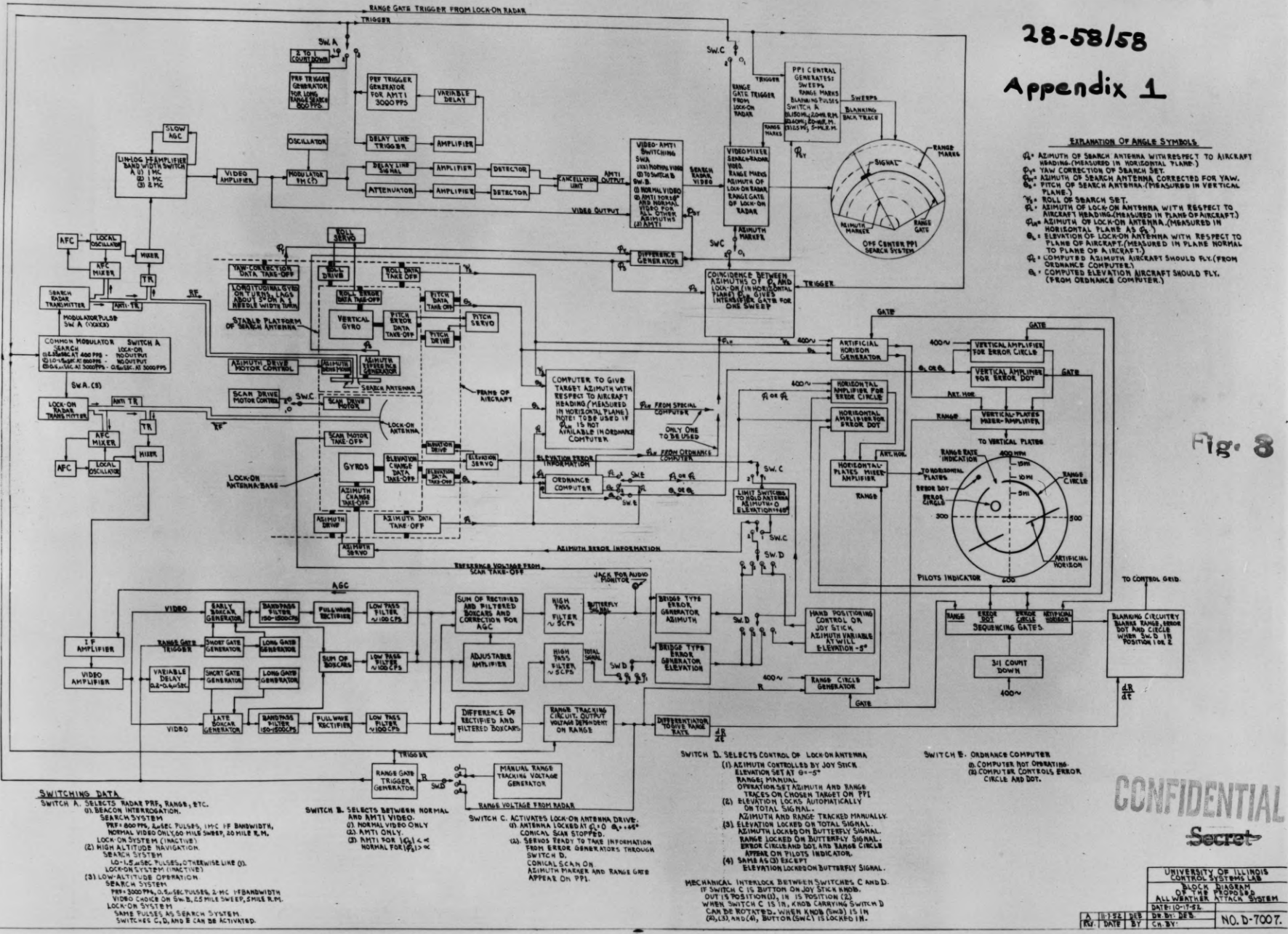
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Appendix 1

Fig. 8

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CONSIDERATIONS ON ARMAMENT FOR AN
ALL WEATHER ATTACK (AWA) SYSTEM

Report Number R-28
Appendix II

December 1952

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SECURITY INFORMATION

TABLE OF CONTENTS

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 represent-
ing 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 effective-
ness, E, has been found:

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

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

E_o 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 I

Size and Kind of Bomb	Damage Radius for E = 1	Damage Area for E = 1	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.		
			20	10	5
20 lb. Frag	13 ft.	530 ft.^{2}	.0075	.030	.11
100 lb. Frag	25.5 ft.	2,050 ft.^{2}	.029	.11	.37
260 lb. Frag	29.5 ft.	2,750 ft.^{2}	.037	.14	.55
500 lb. Frag	43.0 ft.	5,800 ft.^{2}	.078	.28	.74
750 lb. Frag	48 ft.	7,250 ft.^{2}	.097	.34	.81
750 lb. Frag-Cluster	43.5 ft.	7,400 ft.^{2}	.10	.35	.82
750 lb. Napalm	-----	(13,000) ft.^{2} *	.17	.52	.95

* Napalm has no E value, as defined.

Conditions of Level Bombing

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

$$x = \sqrt{\frac{2hV^2}{g}}$$

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

$$P = \frac{1}{\rho^2} \int_0^{\bar{x}} r\, e^{-\frac{r^2}{2\rho^2}}\, dr = 1 - e^{-\frac{(\bar{x})^2}{2\rho^2}}$$

This can be written $P = 1 - e^{-B}$

where $B = \dfrac{(\bar{x})^2\, 10^6}{2R^2 M^2}$ $= \dfrac{A\, 10^6}{2\pi R^2 M^2}$ $= \dfrac{9.9\, W^{0.72}\, 10^6}{R^2 M^2}$

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 ρ = 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:

$$R = 5,300 \text{ feet}$$

$$M = 20, 10, 5 \text{ mils}$$

$$A = 1.3 \times 10^4; \ 7,400; \ 7,250 \text{ feet}^2$$

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

$$P_{\frac{1+}{N}} = 1 - e^{-NB}$$

where B is defined as above. From this expression, one can calculate N for $P_{\frac{1+}{N}} = 0.5$ 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:

$$P_{1/1} = \frac{2}{\pi \rho^2} \int_0^Y e^{-\frac{y^2}{2\rho^2}} dy \int_0^W e^{-\frac{w^2}{2\rho^2}} dw$$

where Y and W are rectangular coordinates, and ρ 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.

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Appendix II

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.

$$P_{1+} = 0.5 \text{ and } E = 1$$

Size and Kind of Bomb	20 mil system		10 mil system		5 mil system	
	No. of Bombs	Total wt. of Bombs	No. of Bombs	Total wt. of Bombs	No. of Bombs	Total wt. of Bombs
20 lb. Frag	92	1840 lb.	23	460 lb.	5.8	115 lb.
100 lb. Frag	23	2300 lb.	6	600 lb.	1.5	150 lb.
260 lb. Frag	18.5	4700 lb.	4.6	1200 lb.	1.1	288 lb.
500 lb. Frag	8.5	4250 lb.	2.1	1050 lb.	0.52	260 lb.
750 lb. Frag	6.7	5000 lb.	1.7	1280 lb.	0.42	315 lb.
750 lb. Frag Cluster	6.5	2280 lb.	1.7	580 lb.	0.41	145 lb.
750 lb. Napalm	3.8	2900 lb.	0.96	720 lb.	0.24	180 lb.

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.

$$P_{1+} = 0.85 \text{ and } E = 1$$

Size and Kind of Bomb	20 mil system		10 mil system		5 mil system	
20 lb. Frag	254	5080 lb.	63	1260 lb.	16	320 lb.
100 lb. Frag	65	6500 lb.	17	1650 lb.	4.1	410 lb.
260 lb. Frag	50	13000 lb.	13	3250 lb.	3.2	830 lb.
500 lb. Frag	23	11500 lb.	5.8	2900 lb.	1.4	700 lb.
750 lb. Frag	18.6	14000 lb.	4.6	3450 lb.	1.2	875 lb.
750 lb. Frag Cluster	18	6300 lb.	4.5	1580 lb.	1.1	395 lb.
750 lb. Napalm	10.5	7900 lb.	2.7	2000 lb.	0.66	500 lb.

Integrating W from $-\infty$ to $+\infty$ gives:

$$P_{1/1} = \frac{\sqrt{2}}{\rho_o \sqrt{\pi}} \int_0^Y e^{-\frac{y^2}{2\rho_o^2}} \, dy = \frac{2}{\sqrt{\pi}} \int_0^Z e^{-z^2} \, dz$$

where $z = \dfrac{y}{\rho_o \sqrt{2}} = \dfrac{\bar{x}\, 10^3}{\sqrt{2}\, RM} \qquad \dfrac{3.16\,(10^3)\, W^{0.36}}{RM\, E^{0.4}}$

This follows from the fact that $\rho_o = RM$ and $y = \bar{x}$ 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.
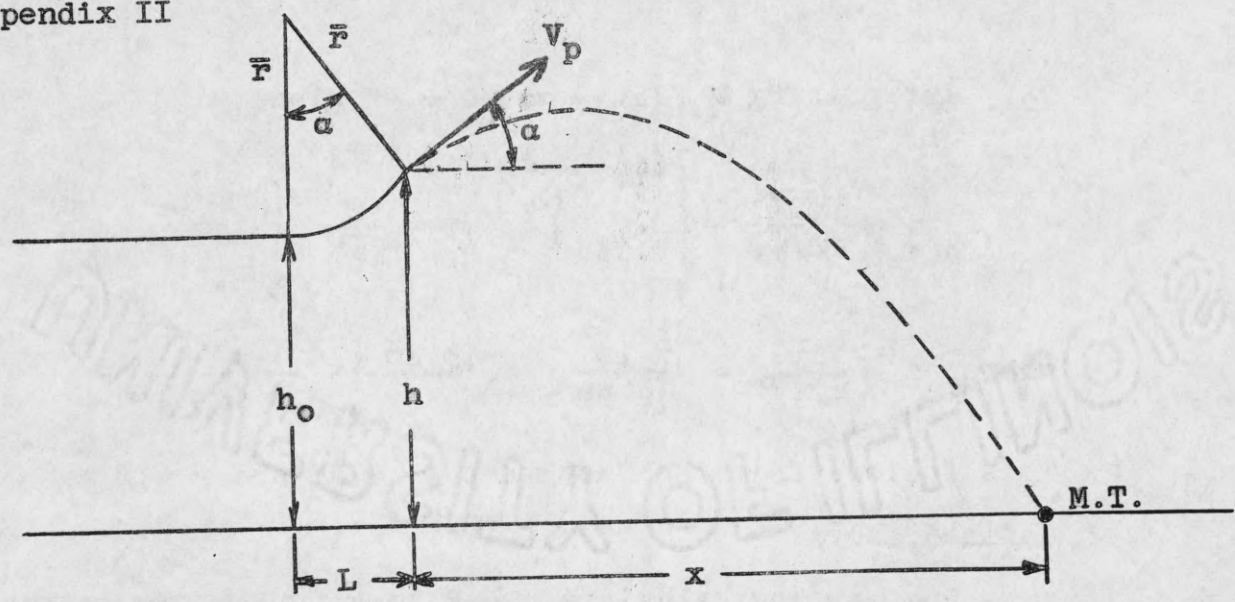
Then $x = \dfrac{v^2}{g} \cos\alpha \left[\sin\alpha + \sqrt{\sin^2\alpha + \dfrac{2gh}{v^2}} \right]$

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

or $\dfrac{dx}{d\alpha} = \dfrac{v^2}{g} A$

for $\alpha = 0$ $x = \sqrt{\dfrac{2h\,v^2}{g}}$

and $\dfrac{dx}{d\alpha} = \dfrac{v^2}{g}$

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:

$$h = h_o + \bar{r}\,(1 - \cos\alpha)$$

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

$$\dfrac{dx}{d\alpha} = A\,\dfrac{v^2}{g} = A\,(1.36 \times 10^4) \text{ feet per radian.}$$

TABLE III

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

$$h_o = 1,000 \text{ ft.}$$

$$v^2 = 43.5 \times 10^4 \text{ ft}^2/\text{sec}^2$$

$$\bar{r} = 12,700 \text{ ft. for } G = 2$$

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

where A is given in column below.

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

Figure 1 gives a plot of x and A versus α.

r̄, the radius of "pull-out" has been taken as 12,700 feet. This is the average r for G = 2 and for V = constant = 660 feet per second. It is based on the follow-ing simple derivation.

Assume V constant

Then $F = \dfrac{mV^2}{r} + mg \cos \omega$

Let $G = \dfrac{F}{mg} = \dfrac{V^2}{gr} + \cos \omega$

Then $r = \dfrac{V^2}{g(G - \cos \omega)}$
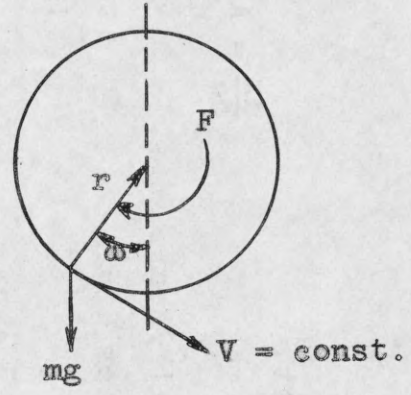
Thus r varies with G and ω. Since "pull-out," in general, will occur between ω = ± 30 degrees an average value of r, over this region will be accurate enough. Table IV gives values of the "pull-out" radius, in units of $\dfrac{V^2}{g}$. Figure 2 shows a plot of these data. Values for r̄ were taken from the data given by the graph in Figure 2.

TABLE IV

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

ω \ G	1.5	2	3	4
0°	2.000	1.000	.500	.333
30°	1.36	.882	.468	.319
60°	1.00	.666	.400	.285
90°	.666	.500	.333	.250
120°	.500	.400	.286	.222
150°	.413	.348	.258	.206
180°	.400	.333	.250	.200

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 $d\alpha$ materially. This will apply both to level and toss bombing.

Tables V and VI give the hit probability, P, for $\alpha = 5^\circ$ and $\alpha = 10^\circ$. 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 $\alpha = 5^\circ$, the probabilities are roughly 1/2 of those for level bombing and for $\alpha = 10^\circ$ 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.

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Data for Table V

Range (for α = 5°) = 6,720 ft.

M (for α = 5° = 20A = 23.4 mils

10A = 11.7 mils

5A = 5.85 mils

A = 1.17

Data for Table VI

R (for α = 10°) = 8470 ft.

M (for α = 10°) = 20A = 24.6 mils

10A = 12.3 mils

5A = 6.2 mils

A = 1.23

TABLE V

Hit Probabilities for Toss-Bombing with α = 5°

Size and Kind of Bomb	Bomb Damage Area	Values of P (α = 5°)		
		23.4	11.7	5.85
Napalm	13,000 ft.²	.081	.32	.79
750 lb. Frag Clusters	7,400 ft.²	.044	.17	.51
500 lb. Frag	5,800 ft.²	.037	.14	.45

TABLE VI

Hit Probabilities for Toss-Bombing with α = 10°

Size and Kind of Bomb	Bomb Damage Area	Values of P (α = 10°)		
		24.6	12.3	6.2
Napalm	13,000 ft.²	.046	.17	.53
750 lb. Frag Clusters	7,400 ft.²	.027	.10	.35
500 lb. Frag	5,800 ft.²	.021	.081	.29

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_o = 1,000 feet.

Bomb Release Point
V_p
V_b
Bomb Flight Path
h_o
M.T.
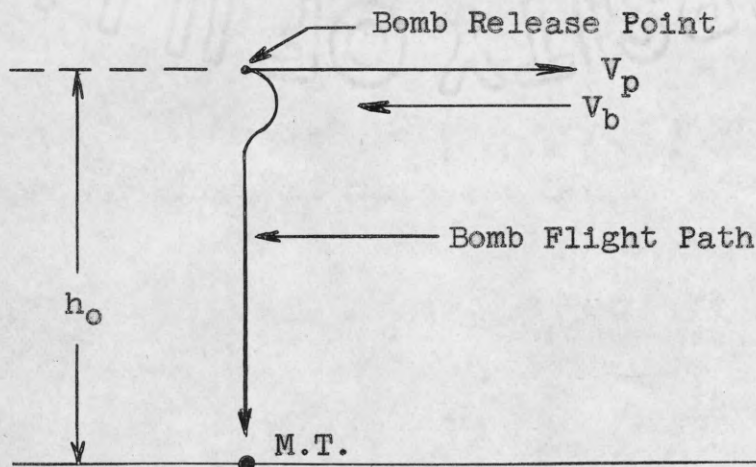
Let a = acceleration of bomb during firing (or rocket during burning).

t_b = burning time (or firing time)

t_f = time of fall after burning

D = distance plane goes in t_b

D_b = distance rocket goes in t_b

ΔD = distance between firing point and bomb after t_b

$t = t_b + t_f$ = total time of fall

Then: $x = D - D_b - \Delta D$

$\qquad = V_p t_b - 1/2\,(at_b^2) - (at_b - V_p)\,t_f$

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

We wish $x = 0$.

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

It follows that

$$\frac{t_b + t_f}{\dfrac{t_b}{2} + t_f} = \frac{2t}{2t - t_b} = \frac{V_b}{V_p} > 1$$

Thus t_b must $\rightarrow 0$ i.e. as $\dfrac{V_b}{V_p} \rightarrow 1$

For our conditions $t = \sqrt{\dfrac{2h}{g}} = 7.9$ sec.

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

also
$$\frac{dx}{dt_b} = V_p - a\,(t_b + t_f) \qquad\qquad (a)$$

$$\frac{dx}{dV_p} = t_b + t_f \qquad\qquad (b)$$

$$\frac{dx}{dt_f} = (V_p - at_b) \qquad\qquad (c)$$

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

t_b sec	Burnt Vel. V_b	Acceleration During Burning a	Distance Plane Goes in t_b D	Distance Projectile Goes in t_b D_b	$\Delta D = D - D_b$	$\frac{V_b}{V_p}$
1/32	661 ft/sec.	21,150 ft/sec^2	20.62 ft.	10.33 ft.	10.3 ft.	1.002
1/16	662.5	10,580	41.25	20.7	20.55	1.0045
1/8	664.5	5,315	82.5	41.5	41	1.0075
1/4	671	2,682	165	83.8	81.2	1.017
1/2	682	1,364	330	170.5	159.5	1.033
1	705	705	660	352	308	1.068
2	757	378.5	1,320	757	563	1.146
4	883	221	2,640	1,768	872	1.338

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

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[*] 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 Troups".

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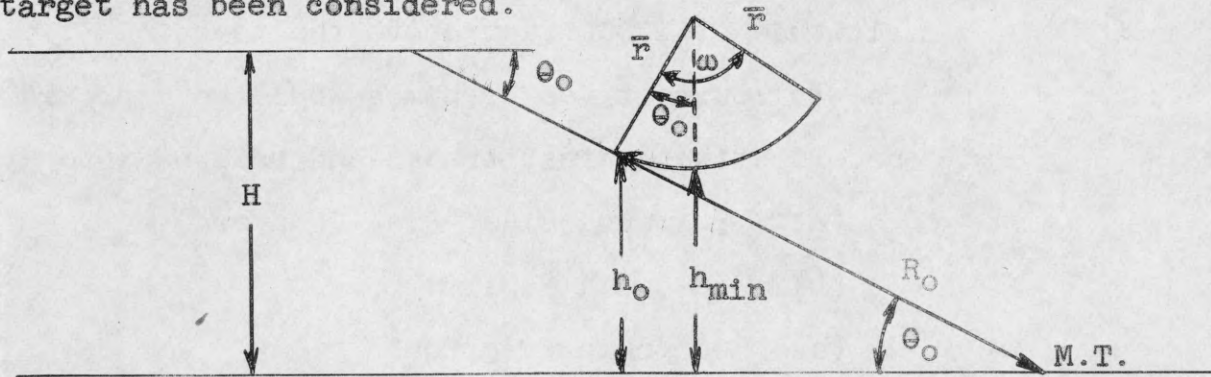
The plane is flown level at some altitude H, until the target appears at some depression angle θ_o, ($\theta_o \cong 10^o$). Then the plane goes into a dive at angle θ_o until the range, R_o, of rocket fire is reached. Thereafter, the plane pulls out on an assumed circular path.

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

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 $\dfrac{dh_{min}}{dt} = -V \sin \theta_o = \text{constant} = 114.5$ 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_{min} values

in Table IX.

From the above equations and with the following

assumptions, one calculates the data in Table IX.

Assume $\theta = 10^o$

$V_p = 660$ ft/sec

R_o = Range at firing

G = Number of g's on pull-out

$R_o \sin \theta = h_o$

The "squash" included in h_{min} in Table IX is that for an

F-89-C plane.

TABLE IX

Minimum Heights On Pull-Out After Firing At Range

R_o, and $\theta_o = 10^o$

G	r Average	R_o = 6000 ft. h_o = 1042 ft.		R_o = 5000 ft. h_o = 870 ft.		R_o = 4000 ft. h_o = 695 ft.	
		calc. h_{min}	h_{min} including "squash"	calc. h_{min}	h_{min} including "squash"	calc. h_{min}	h_{min} including "squash"
1.5	21,900 ft.	709 ft.	625 ft.	534 ft.	450 ft.	363 ft.	285 ft.
2	12,700 ft.	849 ft.	780 ft.	674 ft.	610 ft.	501 ft.	435 ft.
3	6,520 ft.	943 ft.	910 ft.	768 ft.	735 ft.	595 ft.	560 ft.
4	4,380 ft.	975 ft.	935 ft.	800 ft.	780 ft.	627 ft.	605 ft.

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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_O = 5,000 feet is permissible at $G \geqq 2$

R_O = 4,000 feet is permissible at $G \geqq 4$

Therefore, R_O = 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 = $\pi R^2 = \pi \, 40^2 \cong 5,000$ 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_O = 5,000 feet and 3,000 feet.

$$E = 0.17$$

A \ M	$P_{1/1}$ for R_O = 5,000 feet		
	20 mils	10 mils	5 mils
5,000 ft.^{2}	.08	.27	.72
	$P_{1/1}$ for R_O = 3,000 feet		
5,000 ft.^{2}	.2	.6	.97

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 20_g) 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.
<u>One must wait for the completion of the tests at Inyokern</u>
<u>before one can decide on the desirability of this rocket,</u>
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 <u>one</u> 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 θ_f.
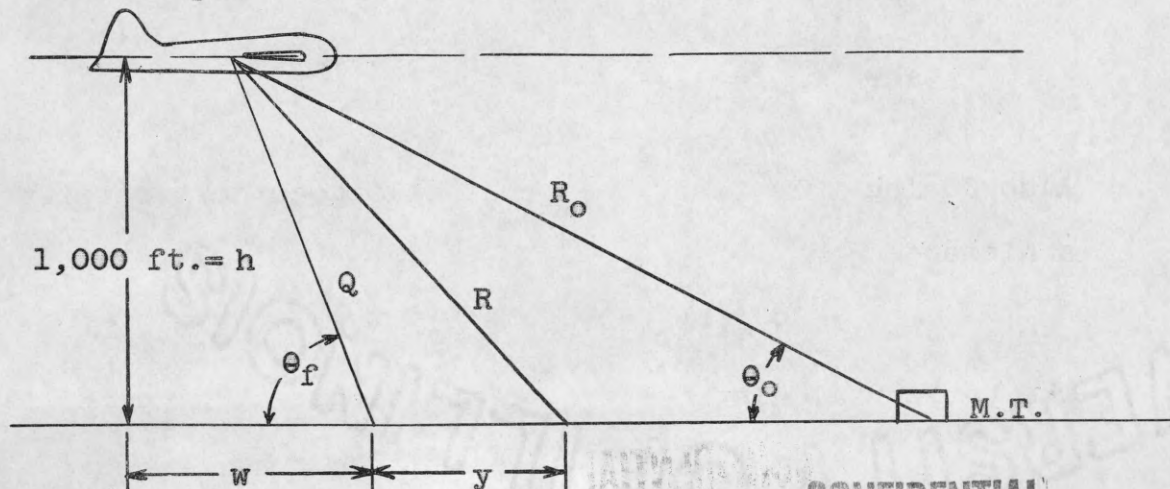
Firing guns in this manner at trucks or railroad stock

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 ft/sec.

b) V_b = 3,500 ft/sec.

c) Θ_o = 20° (30°) (Θ_o is limited by false moving
targets which appear when Θ_o
is too large).

d) h = 1,000 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 $t_\perp \approx$ .4 sec. and $V_b \sin \Theta_f \gtrapprox$ 1,800 feet/sec. for

$\Theta_f \geq 30°$, 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, Δt (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 $\Theta_f = 90°$ (vertical firing) this reduces to

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

For this case

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

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

$\Delta t = 3.89$ seconds

$\quad t = t_\perp + \Delta t = 4.17$ seconds

Thus a computer must keep the plane on the correct course for a time Δt 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 Δt.

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

$h = 1,000$ feet

$A = \text{Area} = 10 \times 20 = 200 \text{ feet}^2$

Calculations give

$R = 1,018$ feet for $\Theta_f = 90^\circ$

$R = 1,615$ feet for $\Theta_f = 45^\circ$

$R = 1,476$ 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 Θ_f and R are given. The target area is assumed to be 200 square feet.

Θ_f	Altitude	R	mils 20 $P_{1/1}$	10 $P_{1/1}$	5 $P_{1/1}$	20 $P_{1+/3}$	10 $P_{1+/3}$	5 $P_{1+/3}$
45°	1,000 ft.	1,615 ft.	.030	.11	.38	.087	.31	.77
50°	1,000 ft.	1,475 ft.	.036	.14	.44	.10	.36	.83
90°	1,000 ft.	1,020 ft.	.074	.26	.70	.20	.60	.97
90°	500 ft.	509 ft.	.27	.72	.99	.62	.97	.99+

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 $\theta_f = 45°$ has a smaller probability than the system with $\theta_f = 90°$ 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 $\theta_o = 30°$. Under these circumstances $R = R_o$ in the figure on page 26 and

$$w = Q \cos \theta_f = h \cot \theta_f$$

$$y = \frac{V_p\, h}{V_b\, \sin\Theta_f}$$

$$D = w + y = h \left\{ \cot\Theta_f + \frac{V_p}{V_b\, \sin\Theta_f} \right\}$$

$$R = R_o = \sqrt{h^2 + D^2}$$

and from the law of sines

$$\frac{R_o}{\sin\Theta_f} = \frac{h\, V_p}{\left[V_b\, \sin\Theta_f\right]\, \sin\left(\Theta_f - \Theta_o\right)}$$

Calculations give:

Θ_f	Θ_o	$R_o = R$
35°	28° 30'	1664
45°	38° 17'	1615

Next, ask what M is necessary for range tracking to $\Theta_o \cong 30°$ 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 feet^2).

Then: $\qquad R_1^2\, M_1^2 = R_2^2\, M_2^2$

So $\qquad 1000^2\, (20)^2 = 1660^2\, M_2^2$

and $\qquad M_2 = 12$ 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

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Appendix II

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)

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

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:

	Minimum Weight		Possible Maximum Weight
One Napalm or Frag Bomb	750 lbs.	One Napalm	750 lbs.
One Frag Cluster	350 lbs.	Two Frag Clusters	700 lbs.
Two HVAR or Sidewinder Rockets	330 lbs.	Four HVAR Sidewinder Rockets	600 lbs.
Two guns with ammunition installed	1400 lbs.	Four guns	5200 lbs.

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 $\geq$ 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:

Electronic gear:	800 pounds to	900 pounds
Armament:	3,000 pounds to	5,000 pounds
2 Men:	1,200 pounds	1,200 pounds
Total Useful Load	5,000 pounds	7,100 pounds

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

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

* 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!

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Appendix II

Figure 1 shows x, the horizontal distance from the point of release of the bomb to the moving target, plotted against α, where α 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 $\frac{dx}{d\alpha} = A \; 1.36 \times 10^4$ feet/radian. The curve showing A versus α indicates the increased error for toss bombing as α increases.

FIGURE 1

CURVE FOR x vs α

$\frac{dx}{d\alpha} = A1.36 \times 10^4$

A FOR $\frac{dx}{d\alpha} = A1.36 \times 10^4$

X → FEET

α, THE ANGLE BETWEEN THE HORIZONTAL & THE PLANES AXIS AT TIME OF RELEASE OF THE TOSS BOMB
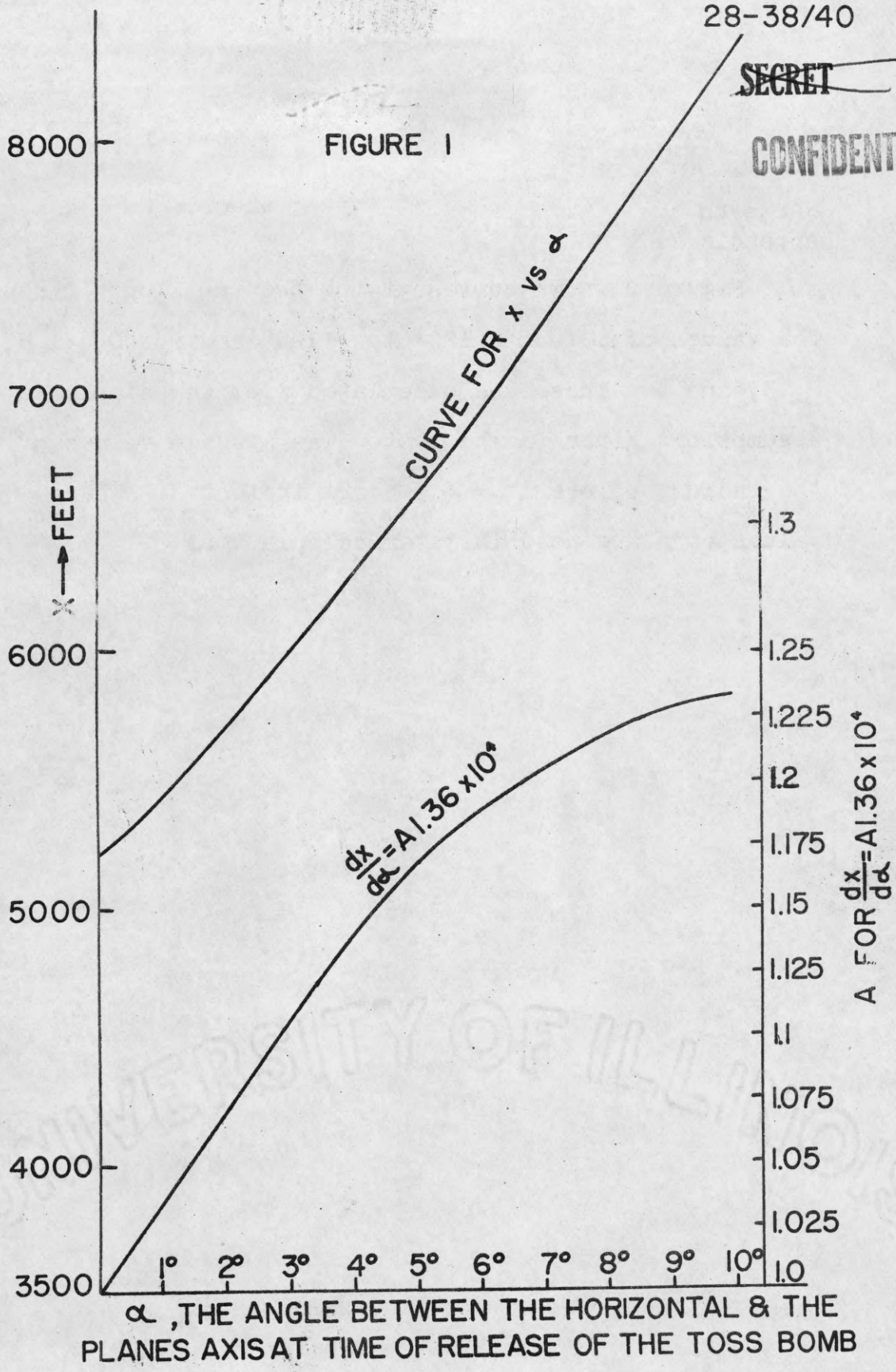
28-39/40
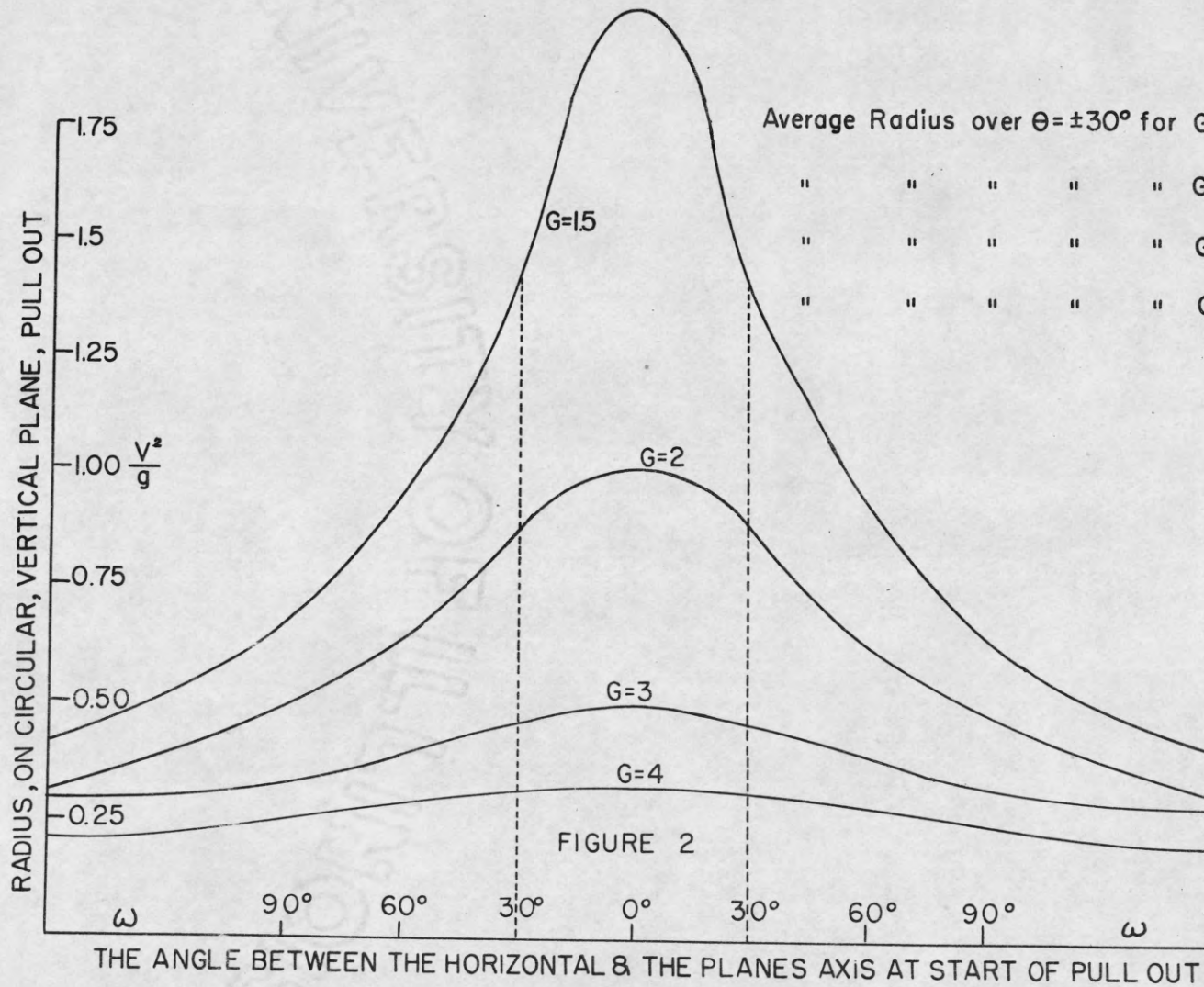Appendix II

Figure 2 shows curves giving the "pull out" radius for values of ω from $-120°$ to $+120°$ 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 $\omega = \pm 30°$ are indicated. These values of $\bar{r}$ are used in later calculations.

FIGURE 2

Average Radius over $\theta = \pm 30°$ for G=1.5 $=1.6\dfrac{V^2}{g}$

"   "   "   "   " G=2 $=0.925\dfrac{V^2}{g}$

"   "   "   "   " G=3 $=0.475\dfrac{V^2}{g}$

"   "   "   "   " G=4 $=0.320\dfrac{V^2}{g}$

G=1.5

G=2

G=3

G=4

RADIUS, ON CIRCULAR, VERTICAL PLANE, PULL OUT

1.75

1.5

1.25

1.00 $\dfrac{V^2}{g}$

0.75

0.50

0.25

ω   90°   60°   30°   0°   30°   60°   90°   ω

THE ANGLE BETWEEN THE HORIZONTAL & THE PLANES AXIS AT START OF PULL OUT

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COMMENTS ON NAVIGATION EQUIPMENT
FOR AN AWA SYSTEM

Report Number R-28
Appendix III

December 1952

Prepared by:

Lawrence Johnston
CAB

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

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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:

hours	1	2	5
miles accuracy	2	5	15

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 develop-
ment 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.

SOURCES OF INFORMATION FOR THE AWA SYSTEM

Report Number R-28
Appendix IV

December 1952

CONTROL SYSTEMS LABORATORY
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Contract DA-11-022-ORD-721

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The following personnel of the indicated organizations
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Armament Laboratory, Wright Air Development Center

Mr. P. E. Koenig	general discussion of attack system, radar characteristics and procurement
Lt. Col. G. C. Clementson	gunsights, ordnance.
Lt. Col. J. T. Prendergast Col. G. T. McNew Mr. Ed Bando	ordnance effectiveness, bombing data
Lt. Col. J. H. McClennon Major W. G. Fort Mr. E. W. Underhill	ordnance, attack techniques, use of AN/APS-27

Cornell Aeronautical Laboratory, Buffalo, New York

Mr. William M. Duke Mr. R. H. Kluge Mr. George Cash	relations between airframes and other parts of attack system
Mr. Robert Kell Mr. J. H. Doolittle Dr. Seville Chapman	radar and navigation problems
Mr. W. O. Breuhaus	dynamic stability of aircraft.
Mr. R. H. Shatz	airframes, ordnance, philosophy of attack system

USNOTS, Inyokern

Dr. Newton E. Ward Dr. Howard A. Wilcox	Sidewinder (I. R. homing rocket) characteristics and performance
Dr. I. H. Swift	fire control systems, aircraft stability
Dr. E. L. Ellis	rockets, retrobombs

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Appendix IV

California Institute of Technology, Pasadena

    Dr. C. C. Lauritsen   ordnance systems

North American Aviation, Downey, California

    Dr. R. B. Horsfall   inertial navigation
                                  equipment (MX-1688A)

Armour Research Foundation, Chicago

    Dr. S. Raynor   T110E3 gun and T131 rocket
    Mr. K. Jacobs
    Mr. J. Pinsky

Instrumentation Laboratory, Massachusetts Institute of
Technology, Cambridge, Massachusetts

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    Dr. Joseph Aronson   A-1 sight
    Dr. B. H. Feldman

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