PROJECT RAND

RESEARCH MEMORANDUM

PRESERVATION OF TACTICAL AIR COMBAT
POTENTIAL IN WESTERN EUROPE
GUIDED MISSILE DEFENSE POTENTIAL

R. E. Tuck

RM-1312
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Declassification of this document is authorized by the Air Force Declassification Office.
SUMMARY

This report investigates surface-to-air guided missiles as a means of augmenting air defense of Allied tactical air bases in the time period 1955 to 1958. Since NIKE I appears to be the most available missile system for this task, it is singled out for intensive study as to its compatibility, deployment and kill potential in Western Europe.

The three major problems connected with the employment of NIKE I in Western Europe are:

1. Identification of friendly and hostile aircraft
2. Acquisition of land for missile sites
3. Protection against low altitude air attacks

Lack of effective centralized fire control and rapid means of identifying aircraft severely limits the ability of friendly fighters and defense missiles to work together in the same area. In addition friendly air offense missions and air evacuation of bases may have to be limited in the missile defended area.

Since missile sites require considerable land for launching and booster disposal areas and because Western Europe is relatively densely populated, the acquisition of land for very many sites may present a considerable problem.

NIKE I is relatively ineffective below 1000 feet altitude and completely ineffective below 400 feet so that some means of complimenting missile defenses at low altitudes would be very desirable.
The best method of deploying NIKE I for air defense of tactical air bases appears to be in some form of uniform area deployment. This type of deployment generally inflicts higher bomber attritions and is less sensitive to enemy bomber tactics than a point or barrier type of deployment.

For eight NIKE battalions, the best deployment for air defense of TAC bases appears to be by batteries over an area of approximately 200 by 150 n. miles in England or over an area of approximately 150 by 250 n. miles in the 4th ATAF area on the Continent. Because of the identification problem, friendly fighters are displaced from the missile defended area. The fighters thus displaced are diverted to bolster fighter defenses in other areas.

For more than eight NIKE battalions, an increasing deployment area size with increasing number of battalions is indicated as optimum assuming that the fighter force is held constant.

The bomber attritions calculated for NIKE I against the type of Soviet attack assumed in this study seem to indicate that NIKE can be expected to make a significant contribution to the air defense of Western Europe at a relatively small cost. With eight NIKE battalions, the defense potential of present Western European air defenses could be bolstered by at least 70 per cent against a mass high altitude IL-28 bomber attack and by at least 45 per cent against a low altitude TU-4 bomber attack.

Even with the large expected increase in Western European air defense potential by the addition of eight NIKE battalions, the level of attrition against mass Soviet air strikes would still fall short of that necessary to insure in itself that a large part of the Allied tactical air forces would survive a surprise atomic attack. Against a mass high altitude IL-28 bomber,
the best NIKE and fighter combination is expected to inflict only a 40 per cent inbound attrition.

In order to obtain a 70 per cent inbound attrition against a mass high altitude IL-28 bomber attack, it is estimated that on the order of 35 NIKE battalions at an initial cost of slightly over a billion dollars would be required in Western Europe. This defense would however still be relatively ineffective by itself against very low altitude one-way IL-28 bomber raids.
There has been growing concern within the Air Force over the vulnerability of Allied tactical air forces in the face of an increasing Soviet atomic capability. At the request of HQUSAF, RAND has undertaken a broad study of possible ways to preserve Allied tactical air combat potential in Western Europe against this Soviet threat during the 1955-1958 period. This Research Memorandum is part of that study.

The over-all study is in two parts. The first analyzes the vulnerability of Allied tactical air forces to Soviet atomic attack; the second compares the effectiveness of a number of defense measures designed to preserve the combat potential at an acceptable level.

The vulnerability analysis includes a number of interconnected topics: the potential character of Soviet air attack; conditions of D-day warning and effects of surprise; likely response of Allied forces to warning; the effectiveness of European active air defense system; physical damage to air bases caused by atomic weapons; and the effects of damage on the sortie capability of surviving forces.

The defense analysis deals with defense measures on two command levels. At the wing level, the measures consist of modifications to the base and its operations to improve base response to atomic attack. At the theater command level, measures include improvements in an air defense and changes in the deployment and operational concepts to reduce the over-all effectiveness of enemy attack.
A list of the publications describing this study is on page vii. This memorandum is one of two describing the analysis of active defense as a means of protecting theatre air forces. RM-1311 examines the effectiveness of interceptor aircraft defenses. This RM is concerned with the potential effectiveness if defense missiles such as NIKE I were added to the active defense forces. Several methods of deployment and employment are considered in conjunction with interceptor aircraft forces.
LIST OF DEFUTAC REPORTS

"Preservation of Tactical Air Combat Potential in Western Europe" is used as the first part of the title of all reports in this series. In each case this is followed by the subject titles as given below.

RM-1309  Pro D-Day Warning and Alert in an Atomic War, H. I. Ansoff and F. M. Sallagar (Top Secret)
RM-1218  Soviet Attack Strategies, T. A. Holdeman (Top Secret)
RM-1311  Fighter Defense Potential, J. W. Ellis, Jr. (Secret)
RM-1312  Guided Missile Defense Potential, R. E. Tuck (Secret)
RM-1292  The Sortie Potential of an Undamaged Wing, W. W. Baldwin and D. J. Davis (Secret)

RM-1239  Measurement of Allied Sortie Capability, A. L. Skogstad and R. N. Snow (Top Secret)
RM-1315  Vulnerability and Defense of Allied Sortie Capability, A. L. Skogstad, and R. N. Snow (Top Secret)
RM-1299  A Preferred Plan of Operations for B-61A Squadrons, R. L. Stewart, Jr. (Secret)
RM-1230  Underground Hangars for Fighter Bomber Operations, A. C. Stockton, (Secret)
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I. INTRODUCTION

The surface-to-air guided missile is a relative newcomer to the family of air defense weapons and its potentialities and shortcomings are not fully known and tested. Two defensive guided missile systems, the NIKE I and the Terrier I, have successfully completed the development and testing stage and are now operational.

NIKE I battalions are already deployed in defense of several major cities in the United States, and Terrier I units are being employed on specially designed naval cruisers for air defense of the fleet. However, neither of these guided missiles has been tested under battle conditions and estimates of their effectiveness must be based entirely on proving ground tests and theoretical studies. Some of the characteristics of the NIKE and Terrier missile systems are listed in Table 1.

Other surface-to-air guided missiles under development such as the NIKE B, the Talos series of missiles, the Hawk and the Bomarc are not expected to be operational before 1958. Thus only the NIKE I and Terrier I guided missiles show any promise of being available for air defense of Allied tactical air forces in the time period 1955 to 1958.

During the latter part of the time period of concern, NIKE I guided missile units might be made available for deployment to Western Europe. Delivery schedules and programmed utilization indicate that about eight battalions could possibly be spared by mid 1957 for air defense of the tactical air bases in Europe. Since there is no indication that Terrier I is being considered for other than shipboard employment by the Navy, only the NIKE I system is investigated in this study for augmentation of European air defense in the time period 1955 to 1958.
<table>
<thead>
<tr>
<th>Missile</th>
<th>Speed (Mach No.)</th>
<th>Range (Nautical Miles)</th>
<th>Maximum Effective Altitude (ft)</th>
<th>Targets</th>
<th>Guidance</th>
<th>Propulsion</th>
<th>Warhead</th>
<th>Fuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrier I</td>
<td>1.8 to 1.3</td>
<td>10</td>
<td>35,000</td>
<td>600-knot Aircraft</td>
<td>Beam rider</td>
<td>Solid Rocket</td>
<td>220 pound Fragmentation</td>
<td>V.T.</td>
</tr>
<tr>
<td>NIKE I</td>
<td>2.5 to 1.2</td>
<td>25</td>
<td>60,000</td>
<td>1100-knot Aircraft</td>
<td>Command</td>
<td>Liquid Rocket</td>
<td>310 pound Fragmentation</td>
<td>Command</td>
</tr>
</tbody>
</table>
The tactical air base complex to be defended from Soviet air attack consists of 103 planned and existing U. S. and NATO air fields: forty-seven located in Great Britain, twenty-nine in the 4th ATAF area, twenty-three in the 2nd ATAF area and three in Denmark. The 4th ATAF area covers roughly the northeast portion of France and the southwest portion of Germany, and the 2nd ATAF area borders on the 4th ATAF area and covers roughly the northwest portion of France and all of the low countries. Present indications are that U. S. fighter-bombers and light bombers equipped to deliver atomic bombs will be stationed at only eight bases; four in England and four in France. The remainder of the airfields are scheduled for U. S. defensive fighters and NATO aircraft.

At present the burden of Western Europe air defense falls almost entirely on U. S., NATO and British fighter forces. A few TAC bases are defended and are scheduled to be defended by anti-aircraft artillery, however, as is shown in Appendix A, the protection offered the bases by these guns is inadequate against low altitude bomber attacks and is nil against medium or high altitude bomber attacks. Furthermore, no significant improvement in base defense by the use of more or newer guns can be expected because of the inherent limitations of unguided weapons.\(^{(2)}\)

The present and planned fighter defense force for the reference time period has certain weaknesses and limitations which if exploited by the Soviets could degrade its effectiveness seriously. The outstanding deficiency of a fighter defense appears to be its inability to put up an effective defense against a surprise D-day mass bomber attack.\(^{(3)}\) To remedy this deficiency with fighters would require a large increase in fighters and men
to maintain a continuous peacetime alert at great expense and effort. Even with the fighter force in complete readiness, a Soviet mass attack will probably saturate the data handling capability of the fighter control center thus limiting the number of fighters that can be effectively vectored to targets. Vectoring problems also arise when bombers fly at low altitudes. Here the ground clutter on radar scopes obscures or hides the position of attacking bombers and makes interception difficult or impossible. The question is thus posed as to whether surface-to-air guided missiles would be of value in assisting fighters against surprise, low altitude or mass air attacks.

To treat the question of NIKE effectiveness and suitability for defense of Allied tactical bases, three general types of NIKE employment in Western Europe are studied and compared. They are point, barrier and area type deployments. Point NIKE deployment is the location of units at particular bases for local protection. Barrier deployment is the placing of missile units along a line which stands in the way of enemy air approaches to TAC bases. Finally, area deployment is the uniform spacing of NIKE units throughout a sector containing TAC bases. Since at most, few NIKE units could be spared for overseas defense in the period 1955 to 1958, the emphasis in the study is placed on the effectiveness of a small number of NIKE battalions.

The Soviet air threat consists of many types of aircraft and tactics. Under the heading of tactics are included such considerations as flight altitudes, approach routes, bombing techniques, countermeasures and attack timing and size. To provide a simplified basis for evaluation and comparison
of the three NIKE deployments, a particular type of Soviet air attack is
used primarily in the analysis. This attack assumes a high altitude mass
D-day strike by II-28 bombers, coordinated with a low altitude mass strike
by TU-4 bombers, against Western Europe. This strike is described more fully
in Section II, along with a discussion of alternate aircraft and tactics.

Probably the most difficult problems to be solved in planning the use
of defensive guided missile systems in Western Europe are connected with
fire direction. Under the heading of fire direction are included detection,
identification and designation of targets. Section III discusses how these
functions will probably be performed and discusses some of the difficulties
that might arise. In particular, the problem of identifying attacking
bombers and the problem of rapid data handling and transmission appear to
be quite troublesome.

To obtain an insight into NIKE capabilities and limitations and to
discover the problems arising from its employment in Western Europe, the
NIKE I system is described to some detail in Section IV. Some of the topics
covered are missile performance, unit organization, site requirements,
system operation and initial and operating costs.

In Section V, the defense potential of the NIKE I is expressed in terms
of expected inbound and round-trip attrition to attacking Soviet bombers
from only the NIKE defenses. The expected attritions inflicted by the
three types of NIKE deployment against the particular Soviet attack
described in Section II are compared primarily on the basis of the equivalent
of eight NIKE battalions used in each deployment. For point deployment, each
of the eight tactical bases scheduled to house atomic delivery units are
treated as defended by a NIKE battalion. For barrier deployment, a line of 32 NIKE batteries spaced 30 n. miles apart and extending from the Northern tip of Denmark to the Mediterranean coast of France is considered. For area deployment, three areas with 32 uniformly distributed NIKE batteries are examined. They are a 300 by 250 n. mile, a 150 by 250 n. mile and a 200 by 150 n. mile region covering bases, respectively, in the 2nd and 4th ATAF areas, in the 4th ATAF area and in England. The various NIKE deployments are also compared in Section V on the basis of more than eight NIKE battalions and for some variation in Soviet air tactics.

The results indicated by the attrition calculations are then discussed in Section VI in context with considerations of enemy threat uncertainty, fire direction, land acquisition, NIKE readiness, system costs and NIKE compatibility and effectiveness with other defense measures. Also treated in the discussion is the amount of protection offered to other than Tactical air installations in Western Europe by the various NIKE deployments. Although this last consideration is beyond the scope of the study, it merits some recognition because of the important part it will play in any decision to use NIKE for TAC defense.

To give a somewhat broader timewise perspective of the problem, Section VII departs from the reference time period and discusses defensive guided missiles and Soviet air threats to be expected after 1958.
II. SOVIET THREAT (1955-1958)

In the years 1955 to 1958, the Soviets are expected to have available between 50 and 200 nuclear bombs for use against West European targets. This means that from one atomic bomb per target for half the bases to two atomic bombs per target for all the bases might be allocated against Allied tactical air bases if the Soviets choose TAC as their sole target for nuclear weapons in Western Europe.

BOMB CARRIERS

To deliver atomic and H. E. bombs to West European targets, the Soviets are estimated to have ready around 1500 IL-28 and 250 TU-4 bombers, with another 500 IL-28's held in reserve.\(^1\) Table 2 gives the estimated total Soviet force available for offensive air action in the theater by 1955. The MIG-15, although present in large numbers, lacks the range and bomb carrying capacity to present a real threat to tactical air bases.

Capabilities of the IL-28, TU-4 and MIG-15 aircraft are listed in Table 3 and strafing ranges of the MIG-15 for various tactical conditions are presented in Table 4. The small combat radii of the IL-28 and MIG-15 aircraft at low altitudes are the result of poor jet engine efficiency at these altitudes.

During the time period 1955 to 1958, new Soviet bomb carriers will undoubtedly begin to appear, although probably not in any great numbers. A list of these possible new air weapons along with their estimated capabilities and operational dates are given in Table 5.
Table 2

FORCES AVAILABLE TO THE SOVIET UNION FOR AIR ATTACKS AGAINST WESTERN EUROPE IN MID-1955 (1)

<table>
<thead>
<tr>
<th>Type of Aircraft</th>
<th>Employed</th>
<th>Reserves and Replacements</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIG-15</td>
<td>1200 Ground Attack</td>
<td>840</td>
</tr>
<tr>
<td>IL-28</td>
<td>1500 Light Bombers</td>
<td>500</td>
</tr>
<tr>
<td>TU-4</td>
<td>250 Medium Bombers</td>
<td>---</td>
</tr>
<tr>
<td>IL-28</td>
<td>500 Reconnaissance</td>
<td>150</td>
</tr>
<tr>
<td>Aircraft</td>
<td>Type</td>
<td>Engine</td>
</tr>
<tr>
<td>----------</td>
<td>---------------</td>
<td>------------</td>
</tr>
<tr>
<td>IL-28</td>
<td>Light Bomber</td>
<td>Turbo-jet</td>
</tr>
<tr>
<td>TU-4</td>
<td>Medium Bomber</td>
<td>Piston</td>
</tr>
<tr>
<td>MIG-15</td>
<td>Fighter</td>
<td>Turbo-jet</td>
</tr>
<tr>
<td></td>
<td>(External Tanks)</td>
<td></td>
</tr>
</tbody>
</table>
Table 4

STRAFING RANGE OF MIG-15(1)

<table>
<thead>
<tr>
<th></th>
<th>Combat Radii with 5 min. Combat at Sea Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cruise at Optimum Alt. (25,000 Ft.)</td>
<td>79 n. mi.</td>
</tr>
<tr>
<td>Cruise at Sea Level</td>
<td>58 n. mi.</td>
</tr>
</tbody>
</table>
### Table 5

**POSSIBLE NEW SOVIET AIR THREATS IN THE PERIOD 1955 to 1958**

<table>
<thead>
<tr>
<th>Bomb Carrier</th>
<th>Spd.(Kn)/Alt.(Ft.)</th>
<th>High Alt. Range (n. mi.)</th>
<th>Low Speed (Kn)</th>
<th>Altitude Range (n. mi.)</th>
<th>Estimated Operational Date</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type 31</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turboprop Bomber</td>
<td>400/40,000</td>
<td>6600</td>
<td>-</td>
<td>-</td>
<td>1956</td>
</tr>
<tr>
<td>Subsonic Jet Bomber</td>
<td>475/45,000</td>
<td>3400</td>
<td>300</td>
<td>2740</td>
<td>1956</td>
</tr>
<tr>
<td>V-1 Type Missile</td>
<td>450/Low</td>
<td>250</td>
<td>-</td>
<td>-</td>
<td>1954</td>
</tr>
<tr>
<td>Turbojet Missile</td>
<td>520/Up to 40,000</td>
<td>500</td>
<td>-</td>
<td>-</td>
<td>1954</td>
</tr>
<tr>
<td>V-2 Type Missile</td>
<td>3000</td>
<td>300</td>
<td>-</td>
<td>-</td>
<td>1956</td>
</tr>
</tbody>
</table>
The Type 31 bomber is probably intended to replace the TU-4 bomber, but because of the greater Soviet need for this bomber on long range missions, it is unlikely to be used for attack against Western Europe. The new subsonic jet bomber may eventually replace the IL-28 bomber in Europe but because of its late operational date, it probably will not appear in significant numbers before 1958. This new jet bomber is not much faster than the IL-28 bomber, but its range is considerably longer. Hence, it is primarily a more dangerous low altitude threat.

The three guided missiles listed in Table 5 are not considered a real menace to tactical air bases because of either short range capability or poor guidance. Neither the V-1 or V-2 missile appears to have range sufficient to reach to any but the most forward bases and only then by being launched practically on the east-west border. In the case of the turbojet missile, poor guidance is expected to be the limiting factor. Another reason for rejecting guided missiles as a real menace to tactical air bases before 1958 is the probable reluctance of the Soviets to risk delivery by missiles of their limited A-bomb stockpile.

TACTICS

The tactics that the Soviets are assumed to employ in the delivery of bombs to targets influence to a large extent the estimated effectiveness of guided missile defense systems. Hence, to have assurance that the air attack model chosen for the study is not unjustifiably biased toward or against some types of defense systems, it is necessary to consider the range of likely and possible tactics available to the Soviets. The particular tactics the Soviets decide to employ will probably depend largely upon the
numbers and capabilities of available bomb carriers, the mission to be accomplished and the type of defenses to be encountered.

The various tactics controlled by the Soviets in an air attack on Allied air bases include the attack timing, size, composition, formations, routes, altitudes, countermeasures and bombing techniques. For each attack there is both a range of possible tactics and a narrower range of likely tactics. Attention is first focused on the range of possible tactics.

It is assumed that hostilities will be initiated by the Soviets, so that they will have the option of launching an initial surprise air attack. The only apparent disadvantage to the Soviets in employing a surprise attack is that they will have to restrict their build-up for war in order not to tip off the Allies to the impending attack. An initial surprise attack against Europe would, of course have to be timed to correspond to other surprise air attacks launched by the Soviets against other parts of the world.

The limits on the number of bombers and atomic weapons available to the Soviets have already been discussed previously in this section. The possible attack compositions with these bombers and atomic weapons are limited by the capabilities of the bombers. Thus a backdoor strike against England, for instance, must be composed of TU-4 bombers which have sufficient range capability, rather than IL-25 bombers which do not. Where bomber ranges permit, the attack may consist of bomber cells penetrating either independently or in groups to the targets. After penetration the groups would presumably break up into cells to bomb the various targets. The number of bombers and atomic weapons sent against each TAC target can
also be varied but not too widely because of the many air bases to be destroyed and the few bombs and aircraft available to do the job.

Bomber cells can either be tight or spread but are limited from being too tight by the danger of collision and from being too spread by the danger of losing contact between members. For a large number of bombers, the overall formation will have to be divided into cells to maintain proper coordination between adjacent planes and the cells will probably be distributed some distance in depth because of errors and lags in rendezvous times.

The routes that a Soviet air attack can take to Allied tactical air targets are restricted by the bomber ranges and the locations of staging bases. Nearest potential Soviet staging bases, as shown in Fig. 1, are located in East Germany some 200 n. miles from the closest and about 500 n. miles from the furthest Allied TAC base. Thus the IL-28 bomber with a 690 n. mile combat radius must follow nearly direct routes between its staging base and target on round-trip missions. On the other hand, the TU-4 bomber with a 2000 n. mile combat radius has a great deal of latitude in the choice of route to the target area.

The upper bounds on the flight altitudes of IL-28 and TU-4 bombers with bomb loads are given as 41,000 feet and 39,550 feet, respectively, in Table 3. Besides the lower bound on altitude imposed by terrain considerations, the IL-28 bomber is forced to fly at high altitudes on most round-trip missions because of the limited combat radius (345 n. miles) at low altitudes. Since the TU-4 bomber has about the same combat radius at low as at high altitudes, it may fly at low altitudes for a considerable distance provided the crew is trained to navigate at these altitudes.
Fig. 1 — Staging and target areas
Several possible countermeasures might be employed by the Soviets against the early warning radar network and missile defensive units. They appear to fall into the following categories:

(1) Radar jamming techniques such as electronic devices and chaff,
(2) Decoy aircraft or missiles,
(3) Attacks on defense units, and
(4) Certain types of formation flying.

Each of these countermeasures could be extremely bothersome to a guided missile air defense system and might well cause a serious degradation in its effectiveness. The use of radar jamming devices could confuse the missile tracking radars and the use of decoys might saturate and exhaust the defense. Successful air attacks on missile defense units might leave holes or gaps in a defense network which could be exploited to reduce bomber attrition. Sabotage is another method of putting defense missile units out of commission. Finally tight formation flying could make it difficult for a target tracking radar to distinguish the individual targets so that resulting miss distances might be large.

The bombing techniques with atomic bombs that might be feasible for the Soviets to perform during the time period 1955 to 1958 are conventional gravity drops at altitudes above 5000 feet, parachute drops from altitudes as low as 2000 feet and toss or rocket-assist toss bombing at any altitude. The minimum altitude at which parachute drops can be made depend upon the size and altitude of the atomic bomb burst, the speed of the bomber and the size of the parachute.\(^{(15)}\)
In toss bombing, the bomber approaches the target at high or low altitude on a radial course, zooms to an appropriate climb angle, and releases the bomb on a ballistic trajectory toward the target. Immediately after release, the bomber executes a turn at maximum load factor in order to maximize its distance from the bomb burst. The IL-28 bomber is able to toss a bomb about 12,000 feet and achieve about the same separation distance while the toss range and separation distances for the TU-4 bomber are of the order of 4,000 feet. The 12,000 foot-separation distance permits the use of bombs of medium yield at low altitudes, but the 4,000 foot distance would not permit escape from even small bombs at low altitudes. Thus only IL-28 bombers are considered for the low altitude bombing tactic.

With the addition of a relatively small rocket motor to a toss bomb, the toss range can be substantially increased thus extending the low altitude toss capability to the TU-4 bombers. It is not likely, however, that the Soviets will develop this tactic in the time period 1955 to 1958.

**ATTACK MODEL**

For the purpose of computing and comparing kill potentials of various NIKE deployments and defense levels, a particular type of Soviet attack is assumed in the study. This attack is a mass D-day surprise assault with 1125 IL-28's and 166 TU-4's directed exclusively against Allied tactical air installations in Western Europe. It is divided into four direct IL-28 bomber strikes from Eastern Europe and one backdoor TU-4 bomber strike from the north and around Norway. Figure 2 maps the approach routes and lists the number and type of aircraft for each of these strikes. Table 6 describes the area and number of targets in the area attacked as well as
Fig. 2 — Initial Soviet air attack
<table>
<thead>
<tr>
<th>Attack Route</th>
<th>Against</th>
<th>Number of Targets</th>
<th>Number of Bomber Cells</th>
<th>Total Number of bombers</th>
<th>Bomber</th>
<th>Altitude (Ft) Penetration</th>
<th>Bomb Drop (Ft)</th>
<th>Speed (Knots)</th>
<th>Number of Bombers Per Cell</th>
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<td>397</td>
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<td>1291</td>
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</table>

* 5,000 feet for A-bomb drop and low for H.E. bomb drop.
the size and composition of the bomber force used for each strike. Also shown in this Table are the penetration and bomb drop altitudes and the bomber speeds assumed for the strikes.

Each IL-28 bomber cell contains about 13 bombers and is assigned a target to bomb. The cells group together in streams to approach the target areas, one stream for each strike, and after penetration, the cells separate from the streams to attack their assigned targets. The length of each IL-28 bomber stream is taken as 133 n. miles corresponding to 20 minutes duration. To simplify the attack model, the strike against Denmark is deleted and the three remaining IL-28 streams are made equal in size. Thus IL-28 bomber strikes 1, 2 and 3 are each treated as consisting of 364 bombers divided into 28 cells of 13 planes. Another simplification made in the attack model for purposes of computation is to let the bombing altitude for the IL-28 bomber be 40,000 feet or the same as the penetration altitude. The bomb run is taken as a straight line course over the center of the target with the bomb released conventionally at a point about 5 n. miles out from the center.

Each TU-4 bomber cell contains about 9 bombers and flies alone to its target at about 500 feet altitude. In order to reach a 5,000 foot bombing altitude, the TU-4 cell begins to climb at 10 n. miles and levels off at 4 n. miles from the target as shown in Fig. 3. During the climb, the cell speed is reduced to 180 knots. After completing the climb, the TU-4 cell returns to its 250 knot speed and starts the bomb run. Bomb release point is about one nautical mile from the target's center after which the cell quickly turns around and dives to 500 feet on leaving the target. The 500 foot altitude mark is reached about 7 nautical miles from the target.
Fig. 3 — TU-4 bomb run
The Soviet tactics assumed for the attack model appear generally to be representaton ones. A mass surprise high altitude IL-28 bomber attack from the east coordinated with a low altitude TU-4 bomber attack from the north is about the best tactic available to the Soviets and should provide a good test of the effectiveness of various missile defense systems. The number of bombers considered in the attack is thought to be the maximum effort that the Soviets could put into a surprise attack against Western Europe in the time period.

The altitudes chosen for penetration and bombing in the case of TU-4 bombers appear both likely and optimum from the standpoint of the Soviets. However, the altitudes chosen for the penetration and bombing in the case of IL-28 bombers, although they appear most likely, may not be optimum against a strong defense. Here one-way low altitude missions might give the best payoff with respect to bombs on the target per bomber lost as is shown in Section V.

Special bombing techniques are not assumed because either they do not appear to gain much, or to be feasible in the time period before 1958. Countermeasures are not considered in the attack model because of the difficulty in assessing their effectiveness. However, because of the important role they will play against missile defenses, they are considered in the final comparison of the various NIKE deployments in Section VI.
III. FIRE DIRECTION

Fire direction is defined as the employment of fire power, the selection of targets and the distribution of fire. The functions of a fire direction system are to detect, identify and designate targets.

DETECTION

In Western Europe, the first detection of a surprise Soviet D-day air attack will probably be provided by either the full-time USAF or British early warning system. The other radar detection systems serving Western Europe only operate part time and the Reds will undoubtedly launch the attack when they are inoperative. Figures 4 and 5 show the radar coverage expected against a surprise attack by high altitude IL-28 and low altitude TU-4 bombers, respectively. The attack altitudes assumed are 40,000 feet for IL-28 bombers and 500 feet for TU-4 bombers.

In Table 7 the distributions of gross warning times to Allied Tactical air bases from the USAF and British early warning systems are given against the strikes shown in Fig. 2. Allowing 15 minutes for transmission of the warning to the bases gives the net warning time distributions in Table 8. Since the system net warning times are only a few minutes at some bases, the first warning of attack in these cases may come from local defense radars. Likewise, forward missile defense installations may receive first warning of air attack from their own search radars.

IDENTIFICATION

Tied in closely with detection is the problem of identification. A reliable, accurate and rapid means of identification is certainly necessary
Fig. 4 — High altitude IL-28 radar coverage
Fig. 5 — Low altitude TU-4 radar coverage
Table 7

ALLIED BASES, BY NUMBER, CLASSIFIED ACCORDING TO
GROSS WARNING TIMES FROM RADAR NETWORK

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Table 8

ALLIED BASES, BY NUMBER, CLASSIFIED ACCORDING TO NET WARNING TIMES FROM RADAR NETWORK

<table>
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if early warning is to be effective. Since identification is the responsibility of the Air Force, guided missile defense units may receive the necessary identification data along with the attack warning. However, when a missile defense unit picks up a flight of unknown aircraft on its search radar without previous Air Force warning or identification, it will have to make its own identification. Also where friendly aircraft are mixed with enemy aircraft, it will be difficult for a central control center to give an accurate and immediate identification for all aircraft within range of the many defense units. Thus it will be necessary to provide all missile defense units with means for identifying friendly and hostile aircraft.

If feasible, all possible sources of identification data should be utilized for each missile unit as well as by the Air Force. The identification problem, which is a difficult one in the zone-of-the-interior, is even more difficult in Europe where many nations are involved. Probably no single source of data will be sufficient by itself, but rather identification will depend on correlation of several data. Some of the known methods of identification that might be utilized are:

1. Electronic IFF
2. Military and civilian flight plans
3. Operational doctrine
4. Direct communication
5. Visual observation

Electronic IFF appears to be the most promising single method of identification because of the speed with which it works. The Mark 10 IFF which is supposed to be sufficient by itself will be installed on defense
radars sometime in the future but probably not in Europe before 1958. Thus until then, a guided missile defense system will have to rely on present electronic IFF equipment along with other supplementary identification procedures.

**TARGET DESIGNATION**

Because of the long range and high single shot kill probabilities of NIKE and other guided missile defense systems that might be employed in Europe, it would be desirable to have target designation performed by a centralized control center to insure the most economical and effective use of defense missiles. Such a centralized control center will require highly trained personnel who have at their immediate disposal all possible data on the air defense situation and automatic devices using electronic methods of computation.

In the time period 1955 to 1958, it is unlikely that centralized control centers in Western Europe will have the automatic devices capable of handling large raids. Even against small Soviet raids, such control centers would probably not be able to receive, process and transmit target position data rapidly or accurately enough to provide effective target designation for the missile defense units. Therefore it appears that in the reference time period, target designation will generally have to be performed by the individual missile units using mostly data obtained from their own search radars.
IV. NIKE I SYSTEM DESCRIPTION

PERFORMANCE

The NIKE I is a surface-to-air guided missile designed to intercept and destroy bombers with speeds up to 1100 knots, at ranges up to 25 nautical miles and at altitudes up to 60,000 feet. Its propulsion is furnished by a liquid fueled rocket which gives it a speed varying from Mach 2.5 to 1.2. The NIKE I carries a three section fragmentation warhead totaling 310 pounds and is guided to the target by a command guidance system. The warhead is detonated by a signal from the ground.

The NIKE command guidance system consists essentially of two tracking radars and a computer. Initially, the target is picked up by the NIKE acquisition radar which gives continuous surveillance of all targets within radar range. An IL-28 bomber cell at high altitude should be acquired between about 45 and 85 n. miles and a TU-4 bomber cell at low altitude (500 feet) should be acquired between about 42 and 67 n. miles from the radar depending upon the cell size and length. At the proper range the target is transferred to the target tracking radar.

Prior to launching, the missile tracking radar locks on to the missile beacon and the computer originates and sends launch data and orders to the launcher. After launching, both the missile and target tracking radars feed information to the computer which resolves the data into steering commands and sends these commands to the missile by way of the missile tracking beam. This system is only capable of engaging one target at a time because the missile tracking radar is tied up during the whole missile flight which may vary in time from about 20 to 100 seconds depending upon the interception range and altitude.
The NIKE missile is launched with the assistance of a solid rocket booster from a fixed light monorail launcher pointed 2 to 5 degrees from the vertical. As a result of this fixed near vertical launching, a dead zone is described about the launcher by the maximum maneuver capability of the missile within which no target can be intercepted. This zone is about 7 n. miles in radius at the base and rises to about 25,000 feet at its peak. Another zone in which the NIKE cannot intercept targets is the space within 15 mils of the horizon around the target tracking radar. The reason for this restriction is that the excessive ground clutter introduced into the radar pointed at an angle less than 15 mils off the horizon prevents accurate determination of the target elevation. Figure 6 illustrates the two dead zones and the time of flight profiles for the NIKE.

**ORGANIZATION**

The standard zone-of-the-interior NIKE organization is a battalion consisting of 440 men and broken down into one headquarter's battery and four launching batteries.\(^{(8)}\)\(^{(9)}\) This organization includes no medical detachment and assumes that a certain amount of support either military or commercial is available and little if any mobility of the battalion is required.

The headquarters battery assembles, services and supplies missiles for the launching batteries. It consists of 92 men (17 officers and 75 enlisted men) and includes facilities for assembly and testing of 16 missiles per 8-hour shift. Storage facilities are available for 32 ready service and 32 inert missiles. Distances between the assembly area and the launching batteries of the battalion should not exceed 10 miles to insure reasonably prompt delivery of missiles.
Fig. 6 — Nike I time of flight
Each launching battery consists of 37 men (7 officers and 30 enlisted men) and is divided into a control area and a launcher area. The control area includes an acquisition radar, a target tracking radar, a missile tracking radar, a radar control trailer and a battery control trailer housing the computer. The launcher area is composed of four launching sections with eight enlisted men and four launchers to a section. Four ready missiles are scheduled for each launcher making a total of 64 ready missiles for each launching battery. Figure 7 presents a schematic of the NIKE launching battery.

Since the deployments of NIKE to be considered do not require the location of units anywhere near the front lines, the standard ZI type organization is assumed for this study. That is, the NIKE battalion will have little mobility and must receive some support and all its medical service from either outside military or commercial sources. A few changes, however, will be introduced into the battalion organization for the different deployment patterns.

For point type deployment, the number of launchers per section is reduced to 3 and the number of sections per battery to 3 because in this case there appears to be no need for long sustained fire. For the barrier and area types of deployment, a missile assembly area is provided each of the launching batteries so that instead of one assembly area there are four to a battalion. This is necessary because the batteries in most instances will be separated by more than 10 miles and will be required to provide a high sustained rate of fire. It is estimated that about a 10 per cent increase in battalion personnel will be required to man the additional assembly areas.
Fig. 7 — Nike I battery
SITE REQUIREMENTS

The total area required for the standard above ground NIKE battalion site is approximately 676 acres or 1.1 square miles. The missile assembly area needs about 200 acres and each launching battery takes up about 126 acres. In turn, the launching battery is divided into a control area covering 8 acres and a launcher area covering 118 acres. Figures 8, 9 and 10 show the layouts for the battalion assembly area, the battery control area and the battery launcher area respectively.

Certain requirements are placed on the selection and preparation of these sites. For the control area, the tracking and acquisition radars must have no mask above one degree of elevation throughout the field of fire. Also the missile tracking radar must have a clear line of sight to all launchers in the battery. The launcher area must be located so that the launchers lie between 1000 and 6000 yards from the control area. In addition, the launcher area should be adjacent to an area about two miles in diameter which can be used for booster disposal. Revetments and 500 feet spacings are required between launching sections.

For the three launcher section and three section battery considered for point type deployment, the size of the launcher area required is about 103 acres. This is only a small reduction in size from the standard launcher area of 119 acres and as is shown in Fig. 11, there is no significant difference in layout.

In the case of barrier and area type deployments, the three assembly areas added to the standard above ground NIKE battalion bring the total area required by the battalion to around 1276 acres or 2 square miles.
Fig. 8—Nike I missile battalion assembly area

- Hq btry housing, admin, and motor pool
- No housing inside this line
- Missile assembly
- Inert storage
- Missile booster joining area
- Booster storage
- Live storage
- Fence
- 310 ft
- 1275 ft
- 500 ft

Farming, roads, etc permitted

(200 acres)
Fig. 9 - Nike I battery control area

Total area - 6 to 8 acres
Fig. 10 — Full strength Nike I launching area
Fig. II - Reduced strength Nike I launching area

Area inside of fence
25.2 acres

Total area - 103.3 acres

Security fence

Launcher

Section control

Generator bldg

Control trailer

Acid fueling

Property line

Barracks

Fig. 11 - Reduced strength Nike I launching area
Each launching battery with an attached assembly area takes up about one-half square mile.

Since Western Europe is fairly densely populated, consideration should be given to decreasing the amount of land needed for each NIKE site. Where sites are intended to be permanent, underground missile storage magazines similar to those being built in the zone-of-the-interior and illustrated in Fig. 12 might be used. The layout for such a launching area is given in Fig. 13. Underground missile storage permits a reduction in the number of launchers and a decrease in the safety distances so that only about 43 acres are needed for the launcher area.

To eliminate the large area required for booster disposal, methods are being investigated whereby the booster can be retarded, consumed by burning or chemical action, or fragmented during the falling period. The most promising method appears to be the development of a ceramic booster case with primacord wrapping which would produce small, nonlethal fragments within a small time interval. The weight penalty of 11 per cent on the booster is not severe but the ceramic booster is not adaptable to existing units.

Because of the large tract required for a launcher area even with underground missile storage, it is doubtful that a NIKE battery can be emplaced within the limits of a TAC air base without interfering with the operation of the base. Thus new land would probably have to be obtained for NIKE sites unless the air bases could be converted primarily to launching sites.

OPERATION

The assembly and testing of missiles is performed by the assembly and
Fig. 12 — Nike I underground missile storage magazine
Fig. 13—Nike I permanent launching area
The missile with booster rocket attached (less booster fins) is then delivered to the launching site where it loaded onto a missile rack adjacent to the launcher. Under a proposed logistics plan, the NIKE missile will be fueled (less propellant starting mixture) and pressurized prior to delivery at the launching site.

All launchers of one battery should be oriented in azimuth so as to make use of a common booster disposal area. A 5° vertical adjustment of the launcher allows the center of the disposal area to be shifted one to two miles from the launcher. Each launcher is initially loaded and erected for firing and has a ready supply of three missiles on its ready-rack. After a missile has been fired, the launcher is depressed to a horizontal position and the empty launching rail is removed. Another flat plate launching rail with a missile-booster-rocket combination already attached is then fastened to the erecting rail of the launcher. After the electrical connections are made, the loaded launcher is elevated to the firing position.

The estimated total reloading time is slightly less than 5 minutes for continuous firing utilizing ready rounds on the rack at the launcher. This time is divided into about 2 1/2 minutes needed to reload the launcher and 2 1/4 minutes for the firing sequence. Each section reloads while the other sections are firing, so that a battery having four sections with four launchers to a section would be expected to have a maximum sustained rate of fire of one missile every 30 seconds for about 25 minutes. This allows for one defective missile in every four and for 5 seconds after operation of the firing key in which to launch a missile before it is rejected as faulty.
The switching or dead time between the burst of one missile and the launch of the second missile is about 11 seconds. This is the time required for the missile tracking radar to slew to a new missile. The time of flight of the missile to the target is between 20 and 100 seconds, so that the rate at which the standard battery can launch missiles is as good or better than the rate at which the tracking radars can handle them.

In the case of point type deployment, it appears that a long high-rate of sustained fire may be unnecessary and that three sections of three launchers each may be sufficient for the battery so emplaced. The argument in favor of fewer launchers per battery for point defense is based on the assumption that the enemy will send small single-cell raids against all TAC targets rather than large strung-out raids against only a few select targets. Since the average missile flight time against an incoming bomber cell should be about a minute, each launcher section should have time to reload while the other two sections are firing. Also, against bombers traveling over 250 knots, the battery will have less than 6 minutes to shoot at a cell before it reaches the target. Thus nine missiles fired at the rate of one a minute should be adequate even allowing for 2 or 3 aborts.

**WARNING TIME**

The warning time from the standpoint of a NIKE battery is the time interval between notification of attack and the moment when a missile must be launched to intercept the target at maximum range. Notification of attack may either come from the radar network or from the NIKE battery's own search radar depending upon the battery's location with respect to the attack route and the radar network.
For instance, forward NIKE units such as found in a barrier type deployment would at best receive only a few minutes warning of an IL-28 high altitude surprise attack from the radar network and would thus obtain first warning from their own radars. Also, certain peripheral NIKE units of an area type deployment would probably receive first warning of a high altitude IL-28 or a low altitude TU-4 attack from their own radars.

On the other hand, some interior units might receive as much as an hour's warning from the radar network of a surprise attack. Some idea of the distribution of warning times from the radar network to NIKE batteries stationed near TAC bases can be obtained from Table 8 by subtracting 5.4 minutes and 7.7 minutes, respectively, from the net warning times given for the IL-28 and TU-4 strikes. These time intervals must be subtracted from the warning times to allow for target interception by the missile at maximum range.

The NIKE search radar is estimated to have a detection range of 45 to 85 n. miles against a high altitude IL-28 attack and 42 to 67 n. miles against a low altitude TU-4 attack depending upon the size and type of bomber formation. Thus an IL-28 bomber cell should be detected from 6.75 to 12.7 minutes before it arrives over the battery and a TU-4 bomber cell should be detected from 9.05 to 15 minutes before it arrives over the battery. Taking off 5.4 and 7.7 minutes respectively, from the IL-28 and TU-4 cell detection times to allow for target interception at 25 n. miles leaves only 1.35 to 7.30 minutes warning of an IL-28 attack and only 2.4 to 8.4 minutes warning of a TU-4 attack.
The short warning times for forward and peripheral batteries furnished by the radar network or NIKE search radars are quite marginal in giving the batteries time to identify enemy aircraft and prepare for firing. At present, the time required for identification is estimated in Ref. 13 to be about 4 minutes. With installation of Mark 10 IFF sets on NIKE search radars, the time for identification may well be cut to a fraction of a minute. However, it appears unlikely that these sets will be available before 1958 so that no reduction in identification time can be expected in the reference time period.

After detection by the battery acquisition radar, the minimum time in which firing can commence is estimated by Ref. 13 to be 141 seconds. This is the time allotted for the tracking radar to lock on the target. Thus if precise identification is furnished by the radar network a minimum warning time of about 2 minutes is required for interception at maximum range. However, if identification must be made by the NIKE battery, then 4 or 6 minutes minimum warning time is required for maximum range interception depending upon whether identification and tracking radar lock-on are performed in parallel or in series.

**READINESS**

The actual warning time a battery will need to prepare for firing will depend upon its readiness or state of alertness. Under present AA doctrine all antiaircraft fire units tactically deployed in the United States will maintain one of the following conditions of readiness: all clear, standby, or battle stations. These conditions of readiness will normally be prescribed by an antiaircraft operations center and correspond to the four
alert statuses used by the Air Force in the following manner:

1. All clear corresponds to white alert.
2. Standby corresponds to both yellow and blue alert.
3. Battle stations corresponds to red alert.

Since no information could be found on proposed readiness states for NIKE units overseas, it is assumed that the same scheme will be employed in Europe as in the United States. The readiness states for the NIKE battery in the Zone-of-the-Interior are described in some detail in Ref. 14 and are summarized briefly as follows. Under all clear, the command post and communications are manned by a minimum operating crew. The acquisition radar is on search as required and personnel needed for full operation of the system are within calling distance. Under standby, all power is turned on and all electric and electronic equipment are warmed up. All communications and electronic equipment are fully manned and all launcher missiles are at least partially prepared for firing with one missile being warmed up. Upon notification of battle stations, all personnel man their posts, the missile tracking radar is slewed to the first missile to be launched and the remaining 7 missiles in the first two sections to fire are warmed up.

The time required for a NIKE battery to go from one state of readiness to another or into complete firing readiness can be specified by standing operating procedures with certain minimum time limitations. The minimum time required for the battery to go from battle stations to complete firing readiness is estimated at between 0 and 2 minutes depending upon whether or not the time is considered for the tracking radar to lock on the target.
The minimum time required to change from standby to battle stations is estimated at about 2 to 3 minutes to allow for warming up the remaining 7 missiles in the first two sections to fire. To go from all clear to standby is estimated to require a minimum of between 5 to 10 minutes.

Therefore it appears that NIKE batteries near the edge of the area covered by the radar network should be kept on battle stations or standby readiness whereas batteries more centrally located could probably be kept on all clear with standard operating procedures tailored to bring them into battle stations in time to fire at maximum range.

For those batteries required to remain on continuous standby alert, additional equipment and manpower may be required. However, from a cursory look at the battery requirements for continuous alert, it appears that the battery organization assumed in the study might be sufficient for this task with little or no augmentation.

**COST**

The estimated costs for various types of overseas above ground NIKE battalions are given in Table 9. For point type deployment, both a full and reduced strength battalion are priced. The full strength battalion is the standard ZI type with one assembly area and four launching batteries each with four launching sections. The reduced strength battalion is the same except that each launching battery has only three reduced launching sections. For barrier and area types of deployment, the augmented full strength battalion having one assembly area per battery is priced. In the Table, the cost is broken down into initial investment and annual operating costs. A more detailed description and breakdown of costs is presented in Appendix B.
Table 9

COST OF ABOVE GROUND NICE UNITS OVERSEAS

(Costs in Millions of Dollars)

<table>
<thead>
<tr>
<th></th>
<th>Local Deployment</th>
<th>Barrier or Area Deployment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Full Strength</td>
</tr>
<tr>
<td></td>
<td>Battalion</td>
<td>Batteries</td>
</tr>
<tr>
<td></td>
<td>Full Strength</td>
<td>Separate Batteries</td>
</tr>
<tr>
<td></td>
<td>Reduced Strength</td>
<td></td>
</tr>
<tr>
<td><strong>Initial Investment</strong></td>
<td>29.87</td>
<td>8.67</td>
</tr>
<tr>
<td><strong>Annual Operating Cost</strong></td>
<td>8.44</td>
<td>7.51</td>
</tr>
<tr>
<td></td>
<td>9.80</td>
<td></td>
</tr>
</tbody>
</table>
V. NIKE I DEFENSE POTENTIAL

INTRODUCTION

The purpose of this section is to estimate and compare the defense potential of various NIKE deployments treated as the sole defense of Allied tactical air installations against a particular Soviet air attack. Section VI will evaluate the problems of air defense augmentation resulting from the integration of the various NIKE deployments with other defense measures against all forms of air attack.

The numerical measure of defense potential employed in this study is the expected number of bomber kills inflicted by the defense. This will also be referred to as the expected bomber attrition.

The conditions that determine the expected bomber attrition fall into three categories: those controlled by the Soviets, those controlled by the defense and those that are not controlled by either side. The Soviets control bomber tactics and the defense controls deployment of missile units, state of alertness and firing doctrine. Conditions not controlled directly by either side include the weather, equipment malfunctioning and human errors.

For each set of controlled conditions, a kill potential can be calculated for a defense unit or system by assigning various probabilities to chance and uncontrollable conditions. Kill potential is defined as the expected number of killing hits that the defense scores on an enemy raid and represents the maximum number of planes that the defense can expect to kill out of a raid. With good fire direction, a guided missile defense might expect to inflict a bomber attrition approaching the kill potential but, of course, no greater than the number of bombers in the raid.
Where missile firing is not directed by a control center above the battery level and where bomber targets are chosen at random for each shot, then the expected number of bomber kills should approach as a lower limit.

\[ E = n \left( 1 - e^{-K_p/n} \right) \]  

(1)

where

- \( E \) = expected number of bomber kills,
- \( n \) = number of bombers in the formation or raid, and
- \( K_p \) = kill potential

This equation assumes that killed bombers remain in formation during the time of fire so that overkills result. Since, in practice, most killed bombers will probably fall out of formation within a few minutes, Eq. 1 gives too low an estimate of expected bomber kills particularly where the formation is under fire for a long period of time. Thus the actual expected bomber attrition should lie between the expected bomber kills given in Eq. 1 and the kill potential but never greater than \( n \).

Two types of kills scored by the defense against enemy aircraft are considered in this study. They are inbound kills where the bombers are destroyed before reaching their target and round-trip kills where the bombers are destroyed before reaching their home bases. From the standpoint of protecting air bases, the inbound kills are of primary importance. Round-trip kills are more important for their effect on reconnaissance and future raids by the enemy.

**MISSILE LETHALITY**

The lethality of a missile is expressed in terms of single shot kill probability. From data given in References 5 and 11 the single shot kill
probability for the NIKE is plotted in Fig. 14 against horizontal range.
Since the NIKE is command guided and fuzed, the standard deviation of miss
distance increases with range and thus the kill probability of the missile
decreases with range. The kill probability against the IL-28 is taken as
somewhat less than against the TU-4 because the IL-28 is a faster and smaller
bomber thus tending to increase the miss distance.

In Fig. 14, both NIKE missile and overall system are considered to be
working perfectly and all kills are assumed to cause fairly fast destruction
of the aircraft. The lingering type of kill is not treated because it does
not appear to occur often for NIKE and would complicate the calculation of
inbound kills.

**MISSILE AND SYSTEM RELIABILITY**

The reliability of the missile after leaving the launcher is taken as
0.90. In addition a factor of 0.75 is applied to the single shot kill
probability of the missile to take into account combat as well as normal
degradation on the whole system. Thus, in calculating kill potential, each
single shot kill probability is multiplied by a combined reliability factor
of 0.675. This factor, however, does not take into consideration such
degradations as might result from the lack of proper warning or alert, or
because of enemy countermeasures. On the basis of NIKE firings conducted
at White Sands, this estimate of missile and system reliability appears to
be attainable but only with well trained crews.

**FIRING DOCTRINE**

For computation of kill potential and expected attrition, the following
firing doctrine is assumed for NIKE batteries. Since no control above the
Fig. 14 — Nike single shot kill probability against either TU-4 or IL-28 bomber.
battery level as to particular target designation is anticipated, the batteries are treated as selecting their own targets. The general rule assumed for target selection is that each battery fires at the bomber cell which requires the least missile flight time. If another cell comes within closer interception range, then the battery's fire is transferred to it. Individual bomber targets within the engaged cell are considered to be selected at random.

**LAUNCHER-RADAR SEPARATION**

To give the battery as many shots against low altitude attacks as possible with available equipment, the target tracking radar is assumed to be placed the maximum 6000 yards in front of the launcher section in the expected direction of enemy attack. This allows the battery more inbound firing time along paths from the expected direction of attack. Since inbound shots require less flight time than corresponding outbound shots, the greater the proportion of firing time devoted to inbound firing the greater will be the total number of shots fired at a cell.

**GEOGRAPHICAL LOCATION**

Although the effectiveness data on NIKE are presented so that they are as independent as possible of the particular unit locations, certain specific targets or areas are assumed to be defended by NIKE in the defense model to inject a certain amount of realism into the study. Also there are military, political, geographical and other considerations which impose restrictions on the location of NIKE units that should be noted in the analysis.

For point or local defense of Allied tactical air bases, emplacement of units at the highest priority targets appears in order. However, the
allocation of defense units will still involve a compromise between the desire to defend a large number of targets and the desire to provide adequate defenses for those targets that are defended. In the case of eight battalions of NIKE assigned to point defense, a possible compromise might be to locate one battalion at each of the six atomic fighter-bomber and two atomic light bomber bases. This arrangement is illustrated in Fig. 15 where four of the bases are located in England and four in France.

For a NIKE barrier type defense in Western Europe, the battery locations should lie somewhere between the majority of air bases to be protected and the iron curtain. It would be an advantage from the standpoint of defending more bases and causing less interference with friendly aircraft to place the barrier as far forward as possible. However, the further forward the NIKE units are located, the more exposed they become to Soviet fighter and ground attack. In addition, the units close to the iron curtain will receive little if any notification of attack from the USAF warning net. The distribution of NIKE units along the barrier and the length and path of the barrier are other decisions which affect battery placement.

For eight battalions (32 batteries) of NIKE allotted to barrier defense, the batteries are assumed in the defense model to be spaced uniformly 30 n. miles apart along a line extending from the northern tip of Denmark to the Mediterranean coast of France and following the path of the Rhine River through Germany. This deployment is shown in Fig. 16 along with the maximum combat radii of IL-28 bombers flying at low altitudes through the barrier. A spread of maximum radii is given to take into consideration Soviet bombers launched from both forward and rear staging bases.
Fig. 15 — Point TAC base defense with Nike

Data and symbols
Defense uses 8 Nike battalions:
one battalion at each of 8 bases

Total defense cost
Initial-$203,200,000 Annual-$60,080,000

Nike battalion and maximum effective range circle
□ TAC fighter-bomber base
○ TAC light bomber base
Fig. 16 — Nike barrier defense

Data and symbols
Barrier uses 32 Nike batteries spaced 30 n mi apart

Barrier cost:
Initial: $277,440,000
Annual: $78,400,000

Nike battery and maximum effective range circle
A NIKE area type defense in Western Europe will have to be located in a region containing Allied Tactical air bases in order to offer protection to bases against air attacks from all directions. The three principal base areas in Western Europe are the 2nd ATAF area, the 4th ATAF area and England. Figure 17 shows the regions within these areas where most tactical air bases are situated and Fig. 18 illustrates an area deployment with eight battalions (32 batteries) of NIKE encompassing bases in both the 2nd and 4th ATAF areas.

Three NIKE defended areas are considered in the analysis. They are the 300 by 250 n. mile, 150 by 250 n. mile and 200 by 150 n. mile regions shown in Fig. 17 covering bases respectively in the 2nd and 4th ATAF areas, in the 4th ATAF area and in England. The spacings between batteries for the NIKE deployment shown in Fig. 18 are about 50 n. miles. For closer battery spacings, more than 32 batteries are required to cover the same area.

Figure 19 exhibits the number of batteries required and their cost for various spacings between batteries in the barrier and area type deployments. The expression used for converting battery spacings into number of batteries in an area type deployment is

\[ N = \left[ \frac{w - 50}{s} + 1 \right] \left[ \frac{2(L - 50)}{\sqrt{3} s} + 1 \right] \]  \hspace{1cm} (2)

where

- \( N \) = number of batteries,
- \( s \) = battery spacing in n. miles,
- \( L \) = length of defended area in n. miles, and
- \( w \) = width of defended area in n. miles
Fig. 17 — Approximate locations and coverages of Nike area deployments
Fig. 18—Nike area defense in one case

Data and symbols
Defense uses 32 Nike batteries spaced 50 n mi apart

Defense cost:
Initial: $277,440,000
Annual: $78,400,000

(x) Nike battery and maximum effective range circle
Fig. 19—Cost and number of batteries for various Nike deployments
DEFENSE POTENTIALS OF VARIOUS DEPLOYMENTS

The comparison of the defense potentials of the various NIKE deployments considered in this study is based primarily on eight NIKE battalions defending against the high altitude surprise attack by IL-28 bombers and the low altitude surprise attack by TU-4 bombers described in Section II. The particular deployments compared are a point type deployment with one battalion at each of eight tactical air bases (Fig. 15), a barrier type deployment with 32 batteries spaced 30 n. miles apart extending from Denmark to Southern France (Fig. 16) and three area type deployments with 32 batteries uniformly distributed over areas 300 by 250, 150 by 250 and 200 by 150 n. miles in the 2nd and 4th ATAF areas, the 4th ATAF area and England, respectively (Figs. 17 and 18).

In Table 10, the expected numbers of inbound and round-trip bomber kills inflicted on the IL-28 bomber attack by the various NIKE deployments are compared. The upper bounds are given by kill potential while the lower bounds on expected bomber kills are computed by Eq. 1. Defense costs and numbers of bombers exposed to each NIKE deployment are also listed in the table. In determining the kill potentials, sufficient early warning and identification for all batteries and no enemy countermeasures are assumed in the model. Also no assistance or hindrance is considered from other defense measures. The methods and assumptions in computing kill potential are discussed in Appendix C.

On the basis of bomber kills, the 150 by 250 and 150 by 200 n. mile area deployments rank first in both inbound and round-trip kills against the high altitude IL-28 bomber raid. The 300 by 250 n. mile area deployment inflicts the second largest inbound and round-trip attrition
<table>
<thead>
<tr>
<th>Deployment</th>
<th>No. of Planes Exposed to Defense</th>
<th>Cost (in millions of dollars)</th>
<th>Expected No. of Bomber Kills</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Initial</td>
<td>Annual</td>
</tr>
<tr>
<td>Point</td>
<td>One battalion at each of 8 bases</td>
<td>104</td>
<td>203.20</td>
</tr>
<tr>
<td>Barrier</td>
<td>32 batteries spaced 30 n. miles apart</td>
<td>1092</td>
<td>277.44</td>
</tr>
<tr>
<td>Area</td>
<td>300 by 250 n. miles (2nd and 4th ATAF Areas)</td>
<td>728</td>
<td>277.44</td>
</tr>
<tr>
<td>Area</td>
<td>150 by 250 n. miles (4th ATAF Area)</td>
<td>364</td>
<td>277.44</td>
</tr>
<tr>
<td>Area</td>
<td>150 by 200 n. miles (England)</td>
<td>364</td>
<td>277.44</td>
</tr>
</tbody>
</table>
and the barrier deployment inflicts the third largest inbound and round-trip attrition. Point type deployment comes in last in all categories. The outbound attrition inflicted by the barrier defense is much larger than the inbound attrition because the bomber cells are assumed to return through the barrier singly rather than in streams.

In Table 11, the expected numbers of bomber kills inflicted on the low altitude TU-4 bomber attack by the various NIKE deployments are compared. Since this raid is directed only against England and since it bypasses the Continent, the barrier and area defenses located on the Continent are not effective against it. Also only four of the eight point defended bases are assumed to be located in England, so that only the NIKE units at these bases are effective against the TU-4 attack. The area deployment in England is seen to inflict a higher attrition on the TU-4 bombers than the point deployment.

**COMPARISON OF DIFFERENT DEFENSE LEVELS**

To see how defense potential varies with the number of NIKE batteries, the expected attritions inflicted by the three area type deployments against the high altitude IL-28 bomber attack are plotted in Figs. 20, 21 and 22 as a function of number of batteries. Figures 20 and 21 give respectively the expected inbound and round-trip attritions inflicted by the larger and smaller area deployments on the Continent and Fig. 22 gives the expected inbound and round-trip attritions inflicted by the area deployment in England.

The problem arises with area deployment as to whether it would be better to cover a large area or a small area with a given number of batteries. From Fig. 20, it is seen that the smaller defended area causes
<table>
<thead>
<tr>
<th>Deployment</th>
<th>Description</th>
<th>No. of Planes Exposed to Defense</th>
<th>Expected No. of Bomber Kills Inbound</th>
<th>Expected No. of Bomber Kills Round Trip</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td></td>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
</tr>
<tr>
<td><strong>Point</strong></td>
<td>One battalion at each of 4 bases in England</td>
<td>36</td>
<td>13.0</td>
<td>15.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>19.4</td>
<td>23.4</td>
</tr>
<tr>
<td><strong>Area</strong></td>
<td>150 by 200 n. miles (England)</td>
<td>166</td>
<td>42.8</td>
<td>49.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>73.5</td>
<td>83.8</td>
</tr>
</tbody>
</table>
56 cells of 13 bombers penetrate 2nd and 4th ATAF defended area
28 cells of 13 bombers penetrate 4th ATAF defended area
30,000 ft. altitude

Fig. 20 — Expected inbound bomber kills by continental Nike area defenses against mass IL-28 bomber attack
Fig. 21 — Expected round-trip bomber kills by continental Nike area defenses against mass IL-28 bomber attack.
Fig. 22 — Expected bomber kills by Nike defense in England against mass IL-28 bomber attack
more inbound attrition if the number of batteries is less than 37 while the larger defended area causes more inbound attrition if the number is greater than 108. In Fig. 21, the corresponding cross over points for round-trip attrition are 22 and 47 batteries. Thus on the basis of expected bomber kills against the IL-28 attack considered, the smaller defended area is preferred with less than 22 batteries while the larger defended area is preferred with more than 108 batteries. Between 22 and 108 batteries, the preferred defended area will probably depend upon the quality of the fire control, the ability to recognize kills and the relative merits of inbound versus round-trip kills. Good fire control, quick kills and the desire for inbound kills all favor the smaller defended area while poor fire control, slow kills and stress on round-trip kills favor the larger defended area.

To get an idea of the degree of protection offered the tactical air bases within the two NIKE defended areas on the Continent the percentage of penetrating IL-28 bombers expected to be killed inbound is plotted against the number of NIKE batteries in the defended areas. These curves given in Fig. 23 are averaged between the upper and lower attrition bounds and show that for less than 53 batteries, the smaller defended area is expected to kill more than twice the fraction of bombers entering its territory than does the larger defended area. Above 53 batteries, the smaller defended area no longer maintains a better than two-to-one advantage over the larger defended area because the expected number of bomber kills approaches the number of bombers penetrating the smaller defended area.

**ALTITUDE COMPARISON**

Since the IL-28 bomber doesn't have sufficient range for two-way low altitude missions to most tactical air base targets, the Soviets will
Fig. 23 — Effectiveness of Nike as an area defense weapon against mass IL-28 bomber attack
probably not resort to low altitude missions unless the attrition at high altitudes is large and the inbound attrition at low altitudes is small.

To compare the NIKE defense potentials against the IL-28 bomber attack at high and low altitudes, the expected inbound attritions inflicted by the various deployments against this attack are plotted as a function of altitude in Fig. 24. Each type deployment is assumed to have eight NIKE battalions (32 batteries) and the area deployment in the 4th ATAF area is chosen to represent its type in the figure. The small expected attrition at low altitudes relative to that at high altitudes is the result of the NIKE radar's inability to track below 15 miles off the horizon. Although the area type defense potential drops off more sharply at low altitudes than does the barrier and point type defense potential, it still maintains its superiority over them for altitudes above 500 feet.

A comparison between the expected inbound attrition inflicted by the 300 by 250 and 150 by 250 n. mile NIKE area defenses against the mass IL-28 bomber attack at 500, 1000 and 2000 foot altitudes is shown in Figs. 25 and 26 as a function of the number of NIKE batteries. It is to be noted that the smaller defended area loses its edge over the larger defended area at altitudes 1000 feet or less for a small as well as a large number of NIKE batteries. However, neither area defense appears significantly better than the other at these altitudes and there appears to be little hope of causing a high attrition against very low altitude bombers with any reasonable number of NIKE batteries.

Figure 27 compares the expected inbound bomber kills by the two area deployments on the Continent as a function of bomber altitude. Two defense levels, 32 and 64 batteries, are considered against the mass IL-28 bomber
Fig. 24 — Comparison of Nike deployments on basis of bomber attrition against mass IL-28 attack
Fig. 25 — Expected inbound bomber kills by Nike continental area defenses against mass low altitude IL-28 attack
56 cells of 13 bombers penetrate 2nd and 4th ATAF defended area
28 cells of 13 bombers penetrate 4th ATAF defended area
2000 ft. altitude

Defended 2nd and 4th
ATAF area
(300 X 250 n mi)

Defended 4th ATAF area
(150 X 250 n mi)

Number of penetrating bombers

Range of uncertainty

Fig. 26 — Expected inbound bomber kills by Nike continental area defenses against mass medium altitude IL-28 attack
Fig. 27—Expected inbound bomber kills by Nike continental area defenses against mass IL-28 attack at various altitudes.
attack in the figure. It appears that for 32 NIKE batteries the smaller defended area has the edge because of the greater attrition inflicted at high altitudes. For 64 NIKE batteries, there doesn't appear to be a clear cut choice from the standpoint of inbound attrition.

**DISCUSSION**

It is evident that on the basis of attrition expected against Soviet air attacks by just NIKE defenses, the area type deployment is superior to both the barrier and point type deployments. This indicates that if NIKE were used as sole air defense in Western Europe, the area type deployment would offer the greatest protection to the Allied tactical air forces although a few air bases might receive greater protection from a point type defense and more air bases might receive some protection from a barrier type defense.

With eight NIKE battalions, an inbound attrition of about 50 per cent should under ideal conditions be inflicted by a NIKE area defense in the 4th ATAF area against a mass high altitude IL-28 bomber penetration. If the same number of units are spread out over an area encompassing bases in both the 2nd and 4th ATAF areas, then an inbound attrition of about 15 per cent should be expected against penetrating high altitude IL-28 bombers.

For a NIKE area defense in England with 8 battalions, an inbound attrition of about 50 per cent could be expected against a high altitude IL-28 bomber strike and an inbound attrition of about 25 per cent could be expected against a low altitude TU-4 bomber strike.
In order to get about 90 per cent inbound attrition against a large high altitude bomber force attacking air bases in the 4th ATAF area, 37 NIKE battalions (148 batteries) at an estimated initial cost of one and a quarter billion dollars would be required. Using this same number of NIKE units over the larger area in defense of TAC bases in both the 2nd and 4th ATAF areas, an inbound attrition of about 76 per cent would be expected against an even larger IL-28 bomber force at high altitudes. The round-trip attrition in either case would approach near annihilation of the enemy force.

At altitudes below 2000 feet, if the Russians choose mass one-way IL-28 bomber strikes, the number of NIKE battalions needed to inflict a high level of inbound attrition on the attacking force would be prohibitive. However, it appears that the Russians will be reluctant to send any great number of bombers in at low altitude since this tactic dictates one-way missions so that a smaller defense potential at low than at high altitudes may suffice.

The NIKE area type defense would be a good deal more effective against a high altitude TU-4 bomber attack than against a high altitude IL-28 bomber attack because the TU-4 is much slower than the IL-28. However, since the TU-4 doesn't sacrifice range at low altitudes as does the IL-28, it is considered as a more likely and thus a more serious low altitude threat than the IL-28. In the case considered in this study in which the TU-4 bomber cells are assumed to come in at 500 feet and then climb to 5000 feet to bomb, it appears possible with a reasonable number of NIKE units to inflict a high inbound attrition against this particular type of attack by hitting the bombers hard when they climb to bomb. But, if the Soviets can bomb without climbing to altitude, then high inbound attritions against the TU-4 bombers will not be feasible even with a large number of NIKE battalions.
VI. NIKE I EFFECTIVENESS IN EUROPEAN MILITARY ENVIRONMENT

In Section V, NIKE guided missile units are treated as the sole air defense for tactical air bases against essentially only one type of Soviet air attack. This section, on the other hand, treats some broader considerations relevant to the use of the various NIKE type deployments in augmenting present defense measures in Western Europe. The topics to be discussed and their order of presentation are as follows:

(1) Enemy threat uncertainty
(2) Fire direction considerations
(3) NIKE system considerations
(4) NIKE compatibility and effectiveness with other defense measures
(5) NIKE defense contribution to other than tactical air targets.

ENEMY THREAT UNCERTAINTY

In Section II, the various possible Soviet air threats against tactical air bases during the time period 1955 to 1958 are discussed to some extent. Also, the particular Soviet attack used for calculation of attritions in Section V is described and is shown to be a reasonable model for the study. The question to be considered now is how do the various NIKE deployments compare when considered against other possible Soviet air attacks.

As pointed out in Section II, the various tactical choices open to the Soviets with regard to the air attack are:

(1) timing
(2) size
(3) composition
Out of this list, the only changes in tactics which appear to favor one NIKE deployment more than another are in the attack composition, altitudes and countermeasures.

In the attack composition, a change in the method that bomber cells penetrate to target areas appears to affect the relative standings of the different NIKE deployments. If, for instance, the IL-28 bomber cells approach the target areas individually instead of in three streams, then the NIKE barrier type defense might inflict up to four times as many inbound bomber kills against the separate cell attack as against the three stream attack. On the other hand, no change should occur in the expected attritions inflicted by the area and point type deployments because the streams are assumed to break up into cells on entering the target areas anyway. The reason that the NIKE barrier is able to inflict so many more inbound bomber kills against the separated cells than against the stream attack is that more batteries can be brought to bear on the attack as the cells are spread out laterally.

Changes in attack altitude can have an appreciable effect upon the expected bomber attritions inflicted by the various NIKE deployments as is shown in Fig. 24, where their expected inbound attritions against IL-28 bomber attack fall off rapidly at low altitudes. However, the IL-23 bomber
sacrifices range proportional to the time spent at low altitude, so that it may fly only for a short time at low altitude and still perform round trip missions. Hence, from this standpoint some deployments are more effective than others against low altitude attack.

Figure 16 shows the spread for maximum IL-28 bomber radius where the NIKE barrier is flown both ways. The spread is to allow for the dispersal of Soviet staging bases. Hence, it appears that from an average staging base, IL-28 bombers should be able to fly low through the barrier and still be able to hit most Allied tactical air bases on two-way missions. Similarly, IL-28 bombers should be able to fly low through local NIKE defenses and still be able to hit most point defended targets on two-way missions. However, this tactic requires a low altitude method of bomb delivery which may not be practical with atomic bombs.

Against a NIKE area type defense, IL-28 bombers don't appear able to fly low through the defended area and hit more than a few forward and peripheral bases on two-way missions.

Figure 24 shows what the barrier deployment inflicts some inbound attrition on the IL-28 bomber attack down to as low as 360 feet altitude. However, this is not the case if the Soviets know where the NIKE batteries are located because of the poor battery coverage at low altitudes. In Table 12, the gaps resulting between batteries because of reduced NIKE range at low altitudes are given for four battery spacings and three bomber altitudes. With battery spacings of 30 n. miles considered for 32 NIKE
### Table 12

NIKE BARRIER GAPS AT LOW ALTITUDES

<table>
<thead>
<tr>
<th>Battery Spacing</th>
<th>500 ft.</th>
<th>1000 ft.</th>
<th>2000 ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 n. mi.</td>
<td>39 n. mi.</td>
<td>28 n. mi.</td>
<td>7 n. mi.</td>
</tr>
<tr>
<td>40 n. mi.</td>
<td>29 n. mi.</td>
<td>18 n. mi.</td>
<td>0 n. mi.</td>
</tr>
<tr>
<td>30 n. mi.</td>
<td>19 n. mi.</td>
<td>8 n. mi.</td>
<td>0 n. mi.</td>
</tr>
<tr>
<td>20 n. mi.</td>
<td>9 n. mi.</td>
<td>0 n. mi.</td>
<td>0 n. mi.</td>
</tr>
</tbody>
</table>
batteries, the gaps in the barrier are 19 n. miles wide at 500 feet altitude and 3 n. miles at 1,000 feet altitude.

Of the countermeasures considered in Section II, the following three appear to affect the various NIKE deployments in significantly different degrees:

1. Radar jamming techniques such as electronic devices and chaff,
2. Decoy aircraft or missiles, and
3. Attacks on defense units.

NIKE radar countermeasure tests at White Sands\(^{(10)}\) indicate that because of the manual override on the NIKE tracking radar, the degradation in tracking accuracy caused by radar jamming techniques is a function of the skill of the NIKE radar operator. In any case, radar countermeasures appear to present a source of serious degradation.

Decoys used along with a bomber attack would have the effect of saturating the handling and firing capabilities of NIKE defense units, making the job of identification more difficult and exhausting the ammunition available to batteries.

Air attacks and sabotage against NIKE units are to be expected. It may even be that the Soviets would allocate atomic weapons for use against key batteries. Since the elements of the NIKE system are above ground and not too widely dispersed, they would constitute a good target for an A-bomb.

A NIKE battery is particularly vulnerable to low altitude attack because of its two dead zones: the 15 mil radar restriction off the horizon
and the 7 n. mile radius circle about the launcher in which no interceptions can be made. Guns deployed around batteries might decrease this danger somewhat but they are expensive and not too effective. A low altitude strafing or bombing attack would probably find that the control trailers are the most vulnerable links in the NIKE system.

Sabotage can take many forms and requires particular vigilance and cooperation with local authorities where the NIKE batteries are located on foreign soil. Batteries operating as independent units as in a barrier or area type deployment may require outside assistance in case of enemy parachute troop or local partisan attack. However, each battery should be prepared to handle less severe cases of sabotage such as sniping and infiltration into the battery area by individuals.

NIKE point defenses would be quite vulnerable to radar and decoy countermeasures because of the short times they have to fire at attacking bomber cells. In these short intervals of time, the Soviets could concentrate radar jamming and decoys so as to cause a maximum of confusion. On the other hand, NIKE point defenses are not particularly vulnerable to aerial attacks on defense units because of the mutual battery protection and duplication afforded by the four batteries at each target.

The barrier type deployment appears to be quite exposed to enemy countermeasures. Because of its short distance from enemy territory and the indispensableness of each battery, countermeasures can be brought to bear on the barrier easily and effectively. Only a few batteries need to be confused or put out of commission to make the barrier useless. The closeness of the barrier to Soviet bases may mean that some batteries might even be exposed to low altitude MIG-15 attack.
Although not invulnerable to countermeasures, the area type deployment appears to be in a less exposed position than point or barrier types because of the depth and overlapping of batteries. This means that the attacking bombers must sustain and coordinate radar and decoy countermeasures over a long time and large area to make them completely effective. Also the depth and overlapping of batteries provide mutual battery defense and no key battery targets to Soviet attacks.

FIRE DIRECTION CONSIDERATIONS

As is pointed out in Section III, fire direction includes target detection, identification and designation. Against a mass raid, identification and designation procedures will very likely have to be performed on the battery level because of the inability of a control center to handle large raids in the time period 1955 to 1958. In addition, some forward NIKE batteries may have to provide their own detection of an enemy attack. Thus the effectiveness of each battery depends to a large extent upon its ability to detect and identify hostile bombers and to direct fire in an intelligent manner.

From the standpoint of fire direction, point type deployment appears to create fewer problems than the other NIKE types of deployment. Since the point defended bases are well within the radar network, the attack warning should normally be received by the units at the bases in sufficient time for them to prepare for firing without starting from a high state of alert. Identification of hostile bombers is easier with a point deployment than with a barrier or an area deployment because of the smaller areas to be surveyed and the smaller amount of friendly aircraft traffic over these areas.
Centralized fire control might even be established over the four batteries at a defended base and all but essential friendly aircraft traffic might be excluded from the immediate air space around the base.

In the barrier type deployment, batteries are located relatively close to the Iron Curtain and in some cases outside the USAF radar network coverage so that only short or delayed warning times can be expected by the batteries from either the USAF radar network or NIKE search radars. Thus, even where the batteries are ready to fire, the lack of sufficient warning time may prevent them from opening fire the instant attacking aircraft come within range.

The time required for identification of hostile aircraft may be an even more important cause than short warning times in holding up fire by batteries in the barrier. Since the barrier is reached so quickly by attacking aircraft after crossing the Iron Curtain (between 10 and 25 minutes for the IL-28 bomber strikes shown in Fig. 2), there is little chance that any identification let alone warning of the attack would be received by the batteries from outside sources. Thus each battery will most likely have to identify friendly and hostile aircraft itself.

The normal identification time required by a battery is estimated at 4 minutes in Ref. 13. Based on this identification time, it is shown in Section IV that as much as five minutes delay might occur in opening fire against IL-28 bombers after coming within firing range. Hence, since total firing time of a battery against an IL-28 bomber cell is at best about seven and one-half minutes, additional delay in identification could mean that the battery
might miss firing at the cell altogether. This, of course, wouldn't be so bad in a stream attack, because all it would mean is that perhaps the first cell could slip through the barrier without being engaged. However, in air attacks against the barrier itself the results might be quite devastating to the defense, and in individual enemy bomber cell crossings the effectiveness of the barrier could be considerably degraded.

Since the batteries in an area type deployment are distributed in depth as well as in breadth, the warning times received will vary between forward and rear batteries. Hence the alert status of each battery will have to be tailored to fit its position in the defended area. The forward batteries in the area defenses considered for the Continent will be plagued with all the early warning and identification problems that face the batteries in the barrier deployment except that their operation is not so crucial to the defense. That is, if a bomber cell if able to slip by a forward battery in the area type deployment, it usually must face other batteries before reaching its target.

The area type deployment as a whole will probably have more identification troubles than the barrier type deployment because of the two dimensional nature of the defense and the heavy air traffic expected in any of the regions considered for NIKE employment. Whereas the barrier defense need only worry about planes approaching essentially from one direction, the area defense must consider flights from all directions. Also a flight through the area defense will normally have to be identified by many batteries instead of by just a few as in the case of the barrier defense. Some method of relaying flight information from battery to battery might help solve the identification problem for the NIKE area type deployment.
NIKE SYSTEM CONSIDERATIONS

An important consideration faced initially if the NIKE is to be employed in Western Europe is the acquisition of sufficient land for missile sites. As shown in Section IV, an above-ground battalion site requires about nine-tenths square mile of land when used in a point type deployment and about two square miles of land when used in a barrier or area type deployment. In addition, the launcher area of each battery should be adjacent to an area about two miles in diameter which can be used for booster disposal. Since a NIKE battalion has four batteries, it thus requires four booster disposal areas totaling about 12.6 square miles.

Because Western Europe is fairly densely populated, the difficulty in finding and acquiring the necessary land for even eight NIKE battalion (or 32 battery) sites may be enormous. The point type deployment requires the least land and hence should be the easiest of the three types of deployment for which to obtain land. However, the battery sites for point deployment must be near the base being defended (probably within five miles of the base) thereby limiting the region within which land can be selected. Also the areas around tactical air bases are usually built up more than the average areas in Western Europe making it particularly difficult to find uninhabited land for booster disposal.

In the barrier type deployment, the NIKE batteries are suppose to be evenly spaced along a line. Since too wide departures from the battery's theoretical position may leave gaps or weak spots in the barrier, the region in which each battery can be located is fairly limited.
The area type deployment is the least restrictive of the three types of deployment as to the location of batteries. As long as no clear path is opened through the defended area, considerable latitude should be available in placing NIKE batteries without changing the area deployment's effectiveness.

The area required for the launcher area can be brought down to 43 acres in either the standard or reduced NIKE battery by using underground missile storage. This would result in only about 0.6 square miles of land being required for a battalion site in point type deployment and only about 1.6 square miles of land being required for four battery sites in barrier or area type deployment. The disadvantage to underground missile storage facilities is that they cost considerably more than above ground facilities and thus should only be used in permanent launching areas.

In barrier and area type deployments, it is possible that some reduction in the amount of land required can be obtained by merging the assembly areas with the launcher areas. Also, if adjacent batteries are close enough together, they might be able to share a common assembly area and even possibly a common booster disposal area. It is certainly a good possibility that batteries in point defense of a target could share a common booster disposal area. Although methods are being investigated to eliminate the need for booster disposal areas by retarding or destroying the boosters during their falling periods, it is likely booster disposal areas will be necessary for at least a few more years.

The stationing of NIKE batteries on or adjacent to airfields might help cut down on the amount of land required for battery sites and booster disposal areas. However, such sites might interfere with air operations on
the airfields and vice-versa unless the airfield is of a temporary or transient nature.

An important long term consideration for the NIKE system in Europe is that of keeping units in a high state of readiness to repel surprise air attacks. This consideration involves questions of training, morale, and equipment maintenance. Frequent air defense exercises and actual firing experience for personnel appear to be good methods for maintaining battery readiness.

In Section IV, the estimated minimum times required to go from one readiness state to another and into firing posture are given for the three readiness states: battle stations, standby and all clear. The usual state of readiness to be maintained by a particular NIKE battery will probably depend upon its position within the defense complex and upon the warning times it expects from the radar network or its own search radar. For batteries where detection of the attack is expected to be received first by their own radars or where the warning of attack received from the radar network is expected to be less than about 10 minutes, then a standby condition of readiness is recommended as the usual state of readiness for these batteries. Where the expected radar network warning times are greater than 10 minutes, the batteries probably can be kept in an all clear state of readiness until a warning is received.

Since the batteries are assumed to perform their own identification of aircraft coming within firing range, both identification and fire preparation must be squeezed into the time interval between the detection by the NIKE radar and the arrival of airplanes at maximum open fire range. The
warning time from the NIKE search radar of a high altitude IL-28 attack is estimated at between 1.35 to 7.30 minutes and the warning time of a low altitude TU-4 attack is estimated at between 2.4 to 8.4 minutes. Hence it is advisable to prepare for firing at the same time identification is taking place. Starting from standby readiness at the time of detection by the NIKE radar, the battery should have time to fully prepare for firing before identification is completed.

It appears that in the point type deployment the batteries may normally be kept on an all clear state of readiness if only high altitude attacks are expected. At the other extreme, all the batteries in the barrier would normally have to be kept in standby readiness. The area type deployment would probably require only the forward batteries to normally maintain standby readiness with the other batteries normally on all clear readiness. To defend against low altitude attack, most batteries in both point and area deployments would most likely have to be put on standby readiness.

Another system consideration is the relative cost of the various deployments. The reduced strength battalion used in point type defense is about 75 per cent as expensive as the full strength battalion (4 separate batteries) used in barrier or area type defense as is shown in Table 9. Thus for an equivalent cost, the point deployment in Table 10 should show an expected number of inbound bomber kills between 57 and 72. This puts it slightly ahead of the barrier deployment on the basis of inbound kills but still far behind the various area deployments.

NIKE COMPATIBILITY WITH OTHER DEFENSE MEASURES

Since NIKE alone cannot be expected to provide adequate air defense for all of Western Europe, any deployment of NIKE units should be judged
on the basis of its compatibility and effectiveness with the other defense measures likely to be employed. These other defense measures include both active and passive protection against air attack. The active defense weapon systems considered besides NIKE are fighters and anti-aircraft artillery while the passive defense measures for TAC bases might comprise dispersion, air evacuation and underground facilities.

The compatibility of NIKE with other defense measures is of particular importance in Western Europe because of the concentration of targets and defense weapons in a relatively small area. Of the three types of NIKE deployment considered in the study, no one type appears to fit in with all other defense measures without causing some problems. The two defense measures that NIKE will probably have the most trouble coordinating with are fighters and air evacuation.

To employ both fighters and NIKE in the same region without degrading the effectiveness of NIKE and without endangering the fighters will probably require faster and surer identification methods than are likely to be available before 1958. Hence it will probably be necessary to keep fighters at least outside of the range of NIKE missiles (25 n. miles) for their own safety. Furthermore, it might be desirable to keep fighters outside the NIKE search radar range which is about 50 n. miles to avoid any interference with NIKE identification of hostile bombers.

The areas from which fighters might be excluded in the case of NIKE point deployment with eight battalions are shown in Fig. 28. In this case, it is clear that the fighters would be severely restricted in their operation if required to stay outside NIKE radar range.
Fig. 28 — Nike radar coverage for point defense

Data and symbols

Defense uses 8 Nike battalions:
one battalion at each of 8 bases

- Nike battalion and maximum effective range circle
- TAC fighter-bomber base
- TAC light-bomber base
On the other hand, the NIKE barrier type deployment is located forward of the target areas and in fact forward of where fighters would likely be able to engage a surprise IL-28 bomber attack\(^{(3)}\), so that exclusion of fighters from the vicinity of the barrier should not affect the fighters in combating an initial inbound attack by IL-28 bombers. Such an exclusion would, however, prevent pursuit of Soviet bombers and other operations by fighters beyond the barrier.

There appear to be several possible ways by which friendly aircraft might cross the NIKE barrier without interference. One method might be to have friendly aircraft fly through the barrier at low altitudes and at locations where they cannot be tracked. Another method might be to have the barrier only concern itself with inbound aircraft so that friendly aircraft could cross in an outbound direction without requiring identification. These aircraft might be permitted to return through special fighter protected corridors.

The NIKE area type deployments considered in this study and illustrated in Fig. 17 cover large areas from which exclusion of fighters would be no simple matter. The larger area deployment considered for the Continent covers so much territory that if fighters were required to stay out of this area, they would add no real value to air defense on the Continent. Similarly the NIKE area deployment considered in England covers so much of the country that exclusion of fighters from this area would drastically reduce their contribution to the air defense of England. The smaller area deployment considered for the Continent and located in the 4th ATAF area,
while it might restrict fighter operations on the Continent to a large extent, would not eliminate their contribution to air defense as would the larger area deployment.

Air evacuation of Allied tactical air bases in the vicinity of NIKE guided missile units could confuse the identification of attacking bombers and expose friendly aircraft to missile fire. Thus, if possible, it would be desirable to evacuate bases and clear NIKE defended areas of friendly aircraft well before the arrival of Soviet bombers.

In the case of the barrier type deployment, few tactical air bases lie within the region of the barrier so that it should not be difficult to keep evacuated aircraft from interfering with NIKE units. However, in point and area type deployments, the NIKE units would be mixed in with the tactical air bases so that evacuation of bases and clearing the NIKE defended areas of friendly aircraft before the arrival of enemy bombers would not be an easy task particularly where the warning times are short. For point type defense, aircraft evacuating from the defended base shouldn't confuse the NIKE units protecting that base so much as aircraft from other bases coming within missile range. Aircraft leaving the base can be identified initially and followed out from the base whereas the aircraft coming within radar range from other bases must be treated as unknowns until identified.

Because of the large areas covered by NIKE point defense radars, it would be difficult for evacuating aircraft to avoid crossing these areas. In addition, the warning times of surprise attack are not sufficient to permit complete base evacuation at most bases before the arrival of enemy bombers. Thus unless forward base evacuation is curtailed somewhat, the NIKE units
at bases further back may have their radars saturated with friendly aircraft when the attacking bombers arrive within range.

For NIKE area type defense, the problem of evacuating friendly aircraft from bases without interfering with identification of hostile aircraft by batteries is similar to that for the point type defense except that the evacuated aircraft must generally fly further to get outside the NIKE defended area. It may be that only bases to the rear and near the edges of the NIKE area type defenses would have time to evacuate and clear the area before the arrival of a surprise IL-28 bomber attack. This means that the larger area deployment on the Continent would be less suitable in connection with air evacuation than the smaller area deployments.

NIKE EFFECTIVENESS WITH OTHER DEFENSE MEASURES

As brought out in the discussion so far, the NIKE contribution to the air defense of tactical air bases is as much a function of its compatibility with the other defense measures as its ability to kill enemy bombers. The three general types of NIKE deployment, point, barrier and area, are compared in Section V only on the basis of their ability to kill enemy bombers and so far in this Section only on their compatibility with other defense measures. Now these two considerations will be combined in an attempt to compare the contributions of the three types of NIKE deployment to European air defense.

NIKE AND FIGHTER COMBINED EFFECTIVENESS

To determine the potential contribution of NIKE to active air defense, the expected attritions inflicted by various combinations of NIKE with fighters against IL-28 and TU-4 bomber strikes are calculated and compared. Table 13 lists the estimated separate attritions expected against the mass
### Table 13

**Attritions Expected Against High Altitude IL-28 Attack by Separate Nike and Fighter Defenses**

<table>
<thead>
<tr>
<th>Defense</th>
<th>Inbound Attrition</th>
<th>Round-trip Attrition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Alert</td>
<td>Alert</td>
</tr>
<tr>
<td>Nike (8 Battalions)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>Barrier</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd and 4th ATAF</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td>4th ATAF</td>
<td>167</td>
<td></td>
</tr>
<tr>
<td>England</td>
<td>178</td>
<td></td>
</tr>
<tr>
<td>Fighters (Programmed for mid-1955)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>England and Continent</td>
<td>30</td>
<td>254</td>
</tr>
</tbody>
</table>
high altitude IL-28 bomber attack by the various deployments of eight NIKE battalions and by the programmed fighter defenses for mid-1955. The inbound and round-trip attritions expected to be inflicted by NIKE are obtained from Table 10 by taking the averages of the upper and lower bounds on expected bomber kills. The attritions expected to be inflicted by fighters are adapted from Ref. 3 and are given for both the no alert and military alert cases. Inbound attrition expected from fighters is estimated to be eight-tenths of the round-trip attrition.

Since the attritions calculated for NIKE assume that all NIKE units are fully effective against surprise air attack, they appear to correspond more closely to the fighter attritions calculated under military alert. In other words, each NIKE battery must be in a state of readiness at the time of the attack which permits it to intercept bombers at maximum range. This of course assumes that each NIKE unit receives sufficient warning and identification of the attack from either the USAF early warning network or its own acquisition radar to enable interception at maximum range under at least standby readiness. For the large formations considered for the IL-28 and TU-4 bomber strikes, the warning times and identification should be adequate to satisfy this condition.

One important difference appears to exist between fighters and NIKE in a state of military alert. While fighters cannot remain in this state of alert indefinitely without considerable additional expense and manpower over the presently programmed force, the assumed NIKE units should be able to do so with little or no additional expense or manpower. Hence the NIKE batteries are assumed to maintain the same condition of readiness under the
no alert as under the military alert state, so that the expected attritions will be considered the same under both alert states.

In Table 14, the expected attritions by combined NIKE and fighter defenses are given against the mass high altitude IL-28 bomber attack. For the NIKE area type deployments with fighters, two cases are considered in the table. In the first case, NIKE and fighter defenses are assumed to operate efficiently in the same area while in the second case, they are given separate areas to defend. The first case assumes an ideal situation where a fast and accurate method of identifying aircraft is available to all NIKE batteries. In this ideal situation, the combined attritions expected to be inflicted by NIKE and fighters are taken as the sum of their separately inflicted attritions.

In the second case, the fighters displaced by NIKE are assumed to double up with fighters in other areas. Table 15 shows how the attritions expected to be inflicted by fighters are affected by fighter redeployment. The fighters displaced in the 2nd and 4th ATAF are considered to be redeployed to England and to rear areas in France. Less than half of these fighters are assumed to be redeployed in England so that little fighter effectiveness is gained in England while much fighter effectiveness is lost on the Continent. Not all fighters from the 2nd and 4th ATAF are sent to England because of the need to protect the flanks and rear areas on the Continent.

Where NIKE only occupies the 4th ATAF area, the fighters in this area are assumed to be redeployed to the 2nd ATAF area. The loss in overall bomber attrition expected to be inflicted by fighters on the Continent resulting from this shift is caused by partial fighter saturation and over-killing of bombers in the 2nd ATAF area. In the case where NIKE displaces
Table 14

ATTRITIONS EXPECTED AGAINST HIGH ALTITUDE IL-28
ATTACK BY COMBINED NIKE AND FIGHTER DEFENSES

<table>
<thead>
<tr>
<th>Nike Deployment Used With Fighters*</th>
<th>Inbound Attrition</th>
<th>Round-trip Attrition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No Alert</td>
<td>Military Alert</td>
</tr>
<tr>
<td></td>
<td>No Alert</td>
<td>Military Alert</td>
</tr>
<tr>
<td>Point</td>
<td>79</td>
<td>303</td>
</tr>
<tr>
<td></td>
<td>131</td>
<td>412</td>
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<tr>
<td>Barrier</td>
<td>87</td>
<td>311</td>
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<tr>
<td></td>
<td>313</td>
<td>584</td>
</tr>
<tr>
<td>Area (Overlapping Fighters**)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd and 4th ATAF</td>
<td>129</td>
<td>353</td>
</tr>
<tr>
<td></td>
<td>320</td>
<td>601</td>
</tr>
<tr>
<td>4th ATAF</td>
<td>197</td>
<td>421</td>
</tr>
<tr>
<td></td>
<td>337</td>
<td>618</td>
</tr>
<tr>
<td>England</td>
<td>208</td>
<td>432</td>
</tr>
<tr>
<td></td>
<td>337</td>
<td>618</td>
</tr>
<tr>
<td>Area (Displacing Fighters)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd and 4th ATAF</td>
<td>115</td>
<td>201</td>
</tr>
<tr>
<td></td>
<td>303</td>
<td>411</td>
</tr>
<tr>
<td>4th ATAF</td>
<td>193</td>
<td>382</td>
</tr>
<tr>
<td></td>
<td>332</td>
<td>569</td>
</tr>
<tr>
<td>England</td>
<td>203</td>
<td>432</td>
</tr>
<tr>
<td></td>
<td>337</td>
<td>618</td>
</tr>
</tbody>
</table>

* 8 NIKE Battalions used with fighters programmed for mid-1955.

** Fast and accurate identification of hostile bombers assumed in this case.
<table>
<thead>
<tr>
<th>Defense Setup</th>
<th>England</th>
<th>2nd ATAF Area</th>
<th>4th ATAF Area</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Military</td>
<td>No</td>
<td>Military</td>
</tr>
<tr>
<td>Fighters Only</td>
<td>12</td>
<td>81</td>
<td>12.5</td>
<td>118.5</td>
</tr>
<tr>
<td>Nike Displaces</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fighters in 2nd and 4th ATAF Areas</td>
<td>20</td>
<td>128</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Nike Displaces</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fighters in 4th ATAF Area</td>
<td>12</td>
<td>81</td>
<td>20</td>
<td>188</td>
</tr>
<tr>
<td>Nike Displaces</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fighters in England</td>
<td>--</td>
<td>--</td>
<td>18.5</td>
<td>159</td>
</tr>
</tbody>
</table>
fighters in England, a redeployment of fighters to both the 2nd and 4th ATAF areas is considered. No fighter saturation of bombers and hence no loss in overall IL-28 bomber attrition caused by fighters in Europe is expected to result from this redeployment.

In Figs. 29 and 30, the per cent inbound and round-trip attritions expected against the mass high altitude IL-28 attack by the various combinations of eight NIKE battalions with programmed fighters are compared for both the no alert and military alert states. Because of the identification bottleneck anticipated in the 1955 to 1958 time period, only the case is considered in which NIKE and fighters are given separate areas to defend.

It appears from Figs. 29 and 30 that the highest expected IL-28 bomber attritions are caused by the combination of NIKE area deployment in England with fighters in the 2nd and 4th ATAF areas or by the combination of NIKE area deployment in the 4th ATAF area with fighters in England and the 2nd ATAF area. These combinations give expected inbound attritions from about 50 to 70 per cent higher and expected round-trip attritions from about 80 to 95 per cent higher than fighters alone give under military alert. Where the fighters are in a no alert state at the time of the attack, then the combined NIKE-fighter defenses are expected to inflict up to 7 times more inbound attrition and 9 times more round-trip attrition than fighters alone against the IL-28 attack. Hence eight NIKE battalions employed in the proper manner with fighters in Western Europe should augment air defense significantly particularly where fighters are caught in a no alert state.

To see how the addition of more NIKE battalions affects the relative standings of the various NIKE-fighter defense combinations, the per cent
Eight Nike battalions
Programmed fighters for mid-1955
Nike and fighters defend separate areas

Fig. 29—Inbound attritions expected against IL-28 bomber attack by combined Nike and fighter defenses
Eight Nike battalions
Programmed fighters for mid-1955
Nike and fighters defend separate areas

Fig. 30—Round-trip attritions expected against IL-28 bomber attack by combined Nike and fighter defenses
inbound and round-trip attritions expected against the IL-28 attack by sixteen NIKE battalions used with the programmed fighters are presented in Figs. 31 and 32. While the two smaller NIKE area deployments combined with fighters still cause the highest expected inbound bomber attritions in the military alert state, the larger NIKE area deployment with fighters causes the highest expected bomber attritions in the no alert state and the NIKE barrier deployment with fighters causes the highest expected round-trip bomber attrition in the military alert state. These combinations of 16 NIKE battalions with fighters give expected inbound attritions up to two times greater and expected round-trip attritions up to about three times greater than fighters alone give under military alert. Where the fighters are in a no alert state at the time of the attack, then these NIKE-fighter combinations are expected to inflict inbound attritions up to 12 times greater and round-trip attritions up to 18 times greater than fighters alone against the IL-28 attack.

In Figs. 33 and 34, the per cent attritions expected against the low altitude TU-4 bomber attack by the various NIKE-fighter combinations are shown. Figure 33 presents the per cent inbound attritions and Fig. 34 presents the per cent round-trip attritions. Since the TU-4 attack is assumed to be directed against England without crossing the Continent, only the NIKE and fighter defenses considered for England are effective against this attack.
Sixteen Nike battalions
Programmed fighters for mid-1955
Nike and fighters defend separate areas

Military alert
No alert

Fig. 31 - Inbound attritions expected against IL-28 bomber attack by combined Nike and fighter defenses
Sixteen Nike battalions
Programmed fighters for mid-1955
Nike and fighters defend separate areas

Military alert
No alert

Fig. 32 - Round-trip attritions expected against IL-28 bomber attack by combined Nike and fighter defenses
Fig. 33—Inbound attritions expected against TU-4 low altitude attack by Nike and fighter defenses
Military alert

No alert

Percent attrition to enemy bombers

Programmed fighters only (mid-1955)

Fighters + Nike point defense with four battalions in England

Nike area defense with eight battalions in England

Fig. 34—Round-trip attritions expected against TU-4 low altitude attack by Nike and fighter defenses
The NIKE area deployment in England with eight battalions appears to give a somewhat higher expected bomber attrition than the programmed fighters on military alert and a much higher expected bomber attrition than the programmed fighters on no alert status. The NIKE point defense makes a good showing because it is assumed to operate efficiently with fighters in England whereas the NIKE area defense is assumed to displace the fighters. It thus appears from Figs. 33 and 34, that, with eight battalions, the NIKE area deployment in England combined with fighters on the Continent is expected to cause a higher attrition to the low altitude TU-4 attack against England than fighters alone or any of the other NIKE-fighter combinations considered in Western Europe.

NIKE AND ANTIAIRCRAFT ARTILLERY COMBINED EFFECTIVENESS

In Appendix A, it is shown that 40 mm and cal. 0.50 antiaircraft guns are ineffective above 5000 ft. altitude so that these weapons stationed on or near air bases would offer no protection against enemy bombers at the bombing altitudes of 5000 ft. or higher assumed in this study. If, however, the guns are moved far enough away from the air bases, they could engage low altitude attacking bombers before they climb to bombing altitude. Thus in this manner, they might be able to discourage low altitude penetrations of NIKE defenses.

Since the guns would have to be placed on the order of 10 n. miles from the target in order to engage a bomber cell before it begins its climb to bomb (see Fig. 3, Section II), the sum of the gun ring circumferences about just eight air bases would amount to about 240 n. miles. Thus it appears that a barrier or area deployment of guns might be more efficient in Western Europe than ring defenses of air bases.
One possible deployment of guns which looks promising in connection with a NIKE area defense in the 4th ATAF area is illustrated in Fig. 35. Here the guns are assumed to be distributed more or less uniformly throughout a belt about 50 n. miles wide and 150 n. miles long. This gun belt is placed forward of most tactical air bases in the NIKE defended area and is intended to defend primarily against low altitude IL-28 bomber penetrations.

Figure 36 shows what inbound attritions can be expected against the mass IL-28 bomber attack at different altitudes by various numbers of U. S. Army AAA battalions dispersed within the belt. For comparison, the expected inbound attrition against the same attack by the NIKE area defense in the 4th ATAF area is given as a function of altitude. The AAA weapon battalions are assumed to have the same types and numbers of guns as the 39th battalion described in Appendix A. Table 16 shows how the kill potentials for the guns are calculated from the data in Appendix A. Since the 0.50 cal and 40 mm guns are optically fired, the assumed AAA battalions would not be effective against night air attacks.

From Fig. 36, it can be seen that 160 battalions of antiaircraft artillery would be required to inflict an inbound attrition at low altitudes as large as that inflicted by 8 battalions of NIKE at high altitudes against the IL-28 bomber attack. If each AAA battalion is assumed to cost on the order of the dual mount 40 mm battalion priced in Table 5 of Ref. 2, then the 160 AAA battalions would be somewhat more than five times as expensive initially as the 8 battalions of NIKE*. It may be, however, that the Soviets

* From Table 5 of Ref. 2, the initial cost of the dual mount 40 mm battalion is 9.1 million dollars and the annual cost is 5.0 million dollars. Hence the initial and annual costs of 160 AAA battalions would be 1,456 and 800 million dollars, respectively, compared to initial and annual costs for 8 NIKE battalions of 277 and 78 million dollars, respectively.
Fig. 35—Proposed location of antiaircraft gun belt.
Fig. 36—Inbound attrition expected against IL-28 bomber attack by gun belt and Nike in 4th ATAF area.

28 cells of 13 bombers penetrate defense.

- Nike area deployment with 8 battalions (150x250 n mi)
- 160 antiaircraft artillery battalions along 150x50 n mi belt
- 8 AAA battalions
- 32 AAA battalions

Range of uncertainty.
Table 16

CALCULATION OF KILL POTENTIALS FOR ANTIAIRCRAFT ARTILLERY AGAINST IL-28 BOMBERS

<table>
<thead>
<tr>
<th>Alt. in ft.</th>
<th>Lethal Length Per Weapon Unit*</th>
<th>Degraded Inbound Lethal Length Per Weapon Unit**</th>
<th>Kill Potential Per Weapon on 150 n. mi. line</th>
<th>Kill Potential/AAA Battalion on 150 n. mi. Line Against Single Bomber Cell***</th>
<th>Kill Potential/AAA Battalion on 150 n. mi. Line Against 28 Bomber Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1440 ft.</td>
<td>205 ft.</td>
<td>1200 ft.</td>
<td>256 ft.</td>
<td>0.00133</td>
</tr>
<tr>
<td>500</td>
<td>1224</td>
<td>191</td>
<td>1020</td>
<td>239</td>
<td>0.00113</td>
</tr>
<tr>
<td>1000</td>
<td>1008</td>
<td>177</td>
<td>840</td>
<td>221</td>
<td>0.00093</td>
</tr>
<tr>
<td>2000</td>
<td>768</td>
<td>124</td>
<td>640</td>
<td>155</td>
<td>0.00071</td>
</tr>
<tr>
<td>3000</td>
<td>0</td>
<td>77</td>
<td>0</td>
<td>96</td>
<td>0</td>
</tr>
<tr>
<td>5000</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* These lethal length values are taken from Table 22 in Appendix A.

** Combat degradation factor is taken as 1/6 for the quad. cal. 0.50 mount and 1/2 for the single 40 mm gun. The lethal lengths are also multiplied by a delayed kill factor of 5 for the quad. cal. 0.50 mount and by a delayed kill factor of 2 1/2 for the single 40 mm gun.

*** AAA battalion assumed to have 32 quad. cal. 0.50 mounts and 32 single 40 mm guns.
will be unwilling to use as many IL-28 bombers on low altitude one-way missions as they would be willing to use on high altitude round-trip missions so that the defense level with guns may not have to be as large as the defense level with NIKE.

**NIKE AND PASSIVE DEFENSE COMBINED EFFECTIVENESS**

Where compatible, the NIKE area type deployment appears to make an effective combination with the passive defense measures of dispersion and evacuation of tactical aircraft. Both passive measures would require the Soviets to spread thin their attacking bomber force and thus to make it more vulnerable to NIKE area defense. In addition, the Soviets might have to launch repeated air attacks and reconnaissance missions thus reducing the number of bombs and bombers available for the initial attack.

Dispersal not only causes greater exposure of the attacking force to the defense by creating more targets but also increases the survival probability of each target and thus the percentage survival of the overall Allied tactical force to a fixed attacking force. This latter effect is illustrated in the following simple example. Suppose the attacking force consists of 100 bombers with 20 atomic bombs directed at either of two target complexes defended by NIKE. The first complex has 10 targets and the second has 20 targets. The attacker is assumed to divide his force of bombers and bombs evenly among the targets in either complex so that 20 planes and 2 bombs are sent to each target in the first complex and 10 planes and 1 bomb are sent to each target in the second complex. In either case, the NIKE area defense is assumed to kill fifty bombers before they reach their target. Hence, on the average, ten bombers carrying atomic bombs would be killed by
the NIKE defense. In the first complex 75 per cent of the bases would expect to be hit by atomic bombs assuming no bomber aborts and good bombing accuracy, whereas in the second complex only 50 per cent of the bases would expect to be hit.

If fighters are excluded from areas defended by NIKE, then atomic fighter-bombers and light bombers might take over the fighter bases in these areas permitting a wider dispersion and quicker evacuation of atomic units.

In fact, the atomic fighter bombers and light bombers might be moved from the fighter protected areas to the NIKE protected areas to make room for fighters displaced from the NIKE areas.

The NIKE point type deployment because of the few bases it protects, doesn't appear to make a very effective combination with the passive defense measures of dispersion and evacuation of tactical aircraft. It certainly doesn't give the broad defense coverage and high attritions necessary to benefit from and support the passive defense measures, and once the point defended bases are destroyed, the NIKE units at these bases are usually of little value in defending other targets.

Although the NIKE barrier type deployment is the most compatible of the three types of deployment with the air evacuation of bases, it doesn't appear to make as effective a combination with passive defense measures as the area type deployment. This is primarily because the barrier type deployment can be too easily circumvented by being underflown at low altitude or having holes punched in it.

NIKE DEFENSE CONTRIBUTION TO OTHER THAN TACTICAL AIR TARGETS

Although this study is only concerned with defense of allied tactical air bases in Western Europe, the amount of additional air protection that NIKE offers to other targets in Western Europe will certainly influence the choice of deployment as well as the priority for its use in the theater. Hence the various NIKE deployments are looked at briefly to see how they compare on the basis of their defense contributions to other than tactical air bases.
The more important targets in Western Europe besides tactical air bases should fall into one of the following categories:

1. Cities, ports and industries
2. Communications, transportation facilities and bridges
3. Supply depots
4. SAC air bases
5. Troop and armor concentrations

Because of the concentration of these targets within a relatively small area in Western Europe, any deployment of NIKE would probably give protection to some of these targets.

Of the three types of deployment, the point type appears to offer protection to the fewest targets because of the small area it covers. The barrier deployment while ostensibly offering direct protection to a large area of Western Europe, actually causes such a small inbound attrition and can be circumvented in so many ways that the amount of additional protection offered to targets located behind it is small.

The area type deployment appears to be the best of the three types of deployment from the standpoint of giving additional protection to all types of targets. It not only increases the protection to targets within the NIKE defended area but it enables fighters to be used in other areas to bolster their air defenses.

**DISCUSSION**

This section has attempted to answer the following three questions:

1. What are the problems connected with the employment of NIKE in Western Europe?
2. What is the best method of deploying NIKE for air defense of Allied tactical air forces?

3. How much can NIKE be expected to augment air defense in Western Europe?

In answer to the first question, the two biggest problems appear to be the identification of attacking bombers and the acquisition of land for NIKE sites. Since no fast and accurate method of identifying friendly aircraft from enemy aircraft now exists or is expected to exist before 1958, coordination between NIKE units and friendly aircraft will be hampered and special precautions which reduce the effectiveness of the overall air defense will probably have to be taken. For example, NIKE units and fighters may have to be given separate areas to defend and air evacuation of bases may have to be curtailed somewhat in NIKE defended areas.

Because of the relatively crowded conditions in Western Europe and the large amount of land required for each NIKE battery site and booster disposal area, the acquisition of land for 32 or more batteries may be a very difficult task. One possible way of relieving this situation would be to use underground missile storage thus decreasing the amount of land required for launching sites.

The best method of deploying NIKE for air defense of Allied tactical air forces appears to be in some form of area deployment depending upon the number of battalions available. The area type deployment should be less sensitive to enemy bomber tactics and should give more protection to tactical air bases and other targets in Western Europe than a point or barrier type of deployment. For eight battalions of NIKE, either the area deployment
considered in England or in the 4th ATAF area appears to offer the best air defense arrangement with fighters. The NIKE deployment in England has a slight edge because of the additional protection offered against a low altitude TU-4 attack. For more than eight NIKE battalions, a larger area deployment seems to be indicated as the best air defense arrangement with fighters.

As to how much NIKE can be expected to augment air defense in Western Europe, the bomber attritions calculated for NIKE against the type of Soviet attack assumed in this study seem to indicate that NIKE can make a significant contribution at a relatively small cost. With eight NIKE battalions, the defense potential of present Western European air defenses could be bolstered by at least 70 per cent against a mass high altitude IL-28 bomber attack and at least 45 per cent against a low altitude TU-4 bomber attack. The cost of eight NIKE battalions to obtain this increased defense effectiveness is estimated at about a quarter of a billion dollars initially and 78 million dollars for annual upkeep.

Even with the large expected increase in Western European air defense potential by the addition of eight NIKE battalions, the level of attrition against mass Soviet air attacks would still fall far short of that necessary to insure in itself that a large part of the Allied Tactical Air Forces would survive atomic devastation. Against a mass high altitude IL-28 bomber attack, the best NIKE-fighter combination is expected to inflict only a 40 per cent inbound attrition.

Doubling the number of NIKE units to sixteen battalions still gives only an expected inbound attrition of 50 per cent by the defense against the
mass high altitude IL-28 bomber attack. Against low altitude IL-28 and Tu-4 bomber strikes, the percentage expected attrition is even smaller. Therefore, even with a sizeable number of NIKE battalions combined with programmed fighters, the air defense by itself cannot guarantee a high probability of Allied tactical air force survival to Soviet atomic attack.
VII. LATER THREATS AND DEFENSE MISSILE SYSTEMS

In this section, the Soviet air threats and U. S. defensive guided missiles expected in the time period 1958 to 1962 are compared with present air threats and defensive missiles.

THREAT

The principal bomb carriers in the period 1958 to 1962 should be those shown in Table 5. Although these Soviet aircraft and missiles are expected to become operational before 1958, they shouldn't be available in large numbers until after 1958. More advanced offensive weapons than these are expected to be developed during the 1958 to 1962 time period but probably won't be available to the Soviets in large numbers before 1962.

The higher speeds and longer ranges of the newer Soviet bombers will make air defense more difficult in several ways. Faster bombers mean that the warning and firing times for defensive guided missile units will be reduced. The longer bomber ranges mean that the Soviets will have more choice as to direction and altitude of attack.

In Table 5, it is noted that the V-1 and turbojet type missiles have speeds only slightly faster than the bomber aircraft listed which means that they should be about as vulnerable to the defense as the bombers. However, because of their small radar cross sections, it is doubtful that present radars could detect these missiles at altitudes above 30,000 feet if that high. The V-2 type missile has a very high speed and small radar cross section so that active defenses will probably be ineffective against it in the time period 1958 to 1962.
The most significant change in the Soviet air threat between the time period before 1958 and the time period after 1958 will likely occur in the number of nuclear weapons available to the Soviets for use against Western European targets. Sometime in the period 1958 to 1962, the Soviets should have an abundance of atomic weapons.

**DEFENSE MISSILES**

The defensive guided missile systems currently under development and scheduled to be operational in the time period 1958 to 1962 are shown in Table 17 with some of their estimated capabilities and characteristics. Whether or not any of these missiles will be available for the European theater in the time period will probably depend upon how soon they become operational and the priority for their use in Europe as against the priority for their use in the United States.

The NIKE B is planned at first to supplement the NIKE I and later to supplant it entirely. Thus the NIKE B missile is designed to operate with the present NIKE I system although some of the equipment will have to be modified or replaced.

The Talos represents a whole series of missile types for many purposes. The two types of interest for air defense of land targets in the time period under consideration are the Talos S and Talos D missiles. These missiles are identical except that the Talos S uses an interferometer seeker and the Talos D uses a CW doppler seeker for terminal guidance.

The Bomarc is a long range guided missile designed primarily for use with the Lincoln system in the United States. Before it could be employed effectively in Europe some system comparable to the Lincoln system would probably have to be established there.
<table>
<thead>
<tr>
<th>Missile</th>
<th>Speed</th>
<th>Range (Nautical Miles)</th>
<th>Maximum Effective Altitude (ft)</th>
<th>Guidance</th>
<th>Propulsion</th>
<th>Warhead</th>
<th>Fuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIKE B</td>
<td>Mach 3.5 to 1.7</td>
<td>50</td>
<td>80,000</td>
<td>Command</td>
<td>Liquid Rocket</td>
<td>1200 lb. Command or Fragment Cluster or Atomic V.T.</td>
<td></td>
</tr>
<tr>
<td>Talos S and D</td>
<td>2000 ft/sec</td>
<td>50</td>
<td>60,000</td>
<td>Command and Semiactive seeker</td>
<td>Ram Jet</td>
<td>420 lb. Rod or small Atomic V.T.</td>
<td></td>
</tr>
<tr>
<td>Bomarc</td>
<td>Mach 2.4</td>
<td>125</td>
<td>60,000</td>
<td>Command and Active Seeker</td>
<td>Ram Jet</td>
<td>300 lb. Fragment, Rod or Small Atomic V.T.</td>
<td></td>
</tr>
<tr>
<td>Hawk</td>
<td>Mach 1.9</td>
<td>13</td>
<td>50,000</td>
<td>Semiactive seeker</td>
<td>Solid Rocket</td>
<td>120 lb. Blast or Fragment V.T. or Seeker</td>
<td></td>
</tr>
</tbody>
</table>
The Hawk is being developed as a short range but highly mobile missile for use near the front lines to protect troops and armor. Being the last of the four missiles to enter the development stage it is unlikely that the Hawk will be operational before 1962.

The important differences between these newer guided missiles and the NIKE I lie primarily in the range, guidance, warhead and fuse characteristics. All but the Hawk have considerably longer ranges than the NIKE I and all but the NIKE B have some sort of seeker for terminal guidance. The Hawk is the only one of the newer missiles for which an atomic warhead version is not being considered.

Only one of the newer guided missiles appears to offer better low altitude coverage than the NIKE I before 1962 in Europe. This one is the Talos D and it is expected to be able to intercept bombers at low altitudes through the use of a CW doppler seeker.

From the brief description of the various defensive guided missiles under development, the Talos S and Talos D appear to be the most suitable of the newer missiles for deployment in Western Europe to protect Tactical air bases. The Talos S is included because the Talos D is a more advanced development and may not become operational as soon as the Talos S. These two missiles will be studied more closely to see how they compare with the NIKE I in defending Western Europe. All the data on the Talos S and D are extracted from Ref. 19.

TALOS SYSTEM DESCRIPTION

Figures 37 and 38 show respectively, the vertical and horizontal coverages for the Talos S and D missiles. The only significant difference between the coverage of the two missiles is in their low altitude limit. Whereas the Talos D
Fig. 37 — Vertical coverage diagram for Talos missiles
450 Kn target

Talos S

All altitudes above 8000

8000 ft

Dead zone

2000 ft

Fig. 38 — Talos horizontal coverage
can intercept aircraft right down to the deck, the Talos S is limited to
interceptions above 2° (35 mils) off the horizon. In this respect, the
NIKE I is superior to the Talos S because the NIKE I missile is able to
intercept aircraft down to 15 mils* off the horizon.

Figure 39 presents the Talos time of flight as a function of horizontal
range for two interception altitudes. The Talos missiles being somewhat
faster than the NIKE I missiles have a slightly shorter time of flight to
the same range.

The Talos land system defense unit is housed substantially in one
building and is designed around an automatic loader-launcher mechanism.
Included in the structure are the associated radar guidance units, computers
and tactical control. The basic components of a Talos defense unit for a
Dual Simplex mode of operation are:

1. Loader mechanism
2. Single trainable and elevatable launchers
2. Tracking and illuminating radars
2. Guidance transmitters
2. Computers and predictors
1. Set of missile test and checkout equipment
1. Set of missile handling equipment
1. Building with internal communication and other facilities

Under the Dual Simplex mode of operation, a salvo of two missiles is
guided to the homing phase all the way by information received from the
tracking radar. This means that the guidance transmitter and tracking radar
are tied up during the entire time of flight of the missiles. In the case

* More recent data indicates, however, that NIKE I may not be able to
intercept accurately below 32 mils off the horizon.
Fig. 39 — Talos time of flight versus range
of the Talos D the only additional requirement is the slaving of a CW illuminator to the tracking radar. With Dual Simplex operation as many as 4 missiles (2 salvos) may be in the air at one time to 2 separate targets.

Two factors affect the rate of fire of the Talos system. They are the launcher-loader cycle time and the guidance system 'tie-up' time. It is estimated that 30 seconds will be required between the time the last missile of one salvo is fired to the time the first missile of the next salvo is ready to fire so that if the launcher-loader cycle time were the only restriction on the firing rate, two salvos of two missiles each could be launched every minute. However, since there are only two tracking radars, the guidance system 'tie-up' time normally determines the rate of fire for the Talos defense unit. Each tracking radar is tied up during the entire missile salvo time of flight plus some time for acquisition of new targets and computer settling. For the Dual Simplex mode of operation, the estimated tracking radar tie-up times are given in Table 18. Since the Talos time of flight ranges between about 20 and 160 seconds, the total tie-up time is estimated to range between 42 and 199 seconds. Hence on the basis of the launcher-loader cycle and guidance system 'tie-up' time restrictions, the maximum rate of fire for a Talos unit should vary from about 0.6 to 2 missile salvos a minute. For comparison a NIKE I battery with half the range is estimated to have a maximum rate of fire also between 0.6 to 2 missiles a minute.

In Fig. 40, the Talos kill probability against the TU-4 type bomber is given as a function of the shooting error. The kill probability is for the rod type warhead and assumes the missile is 100 per cent operable. Since the Talos S and D employ a seeker for terminal guidance, the shooting error should
<table>
<thead>
<tr>
<th>Item</th>
<th>Time (Sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition and lock-on</td>
<td>10</td>
</tr>
<tr>
<td>Radar slew</td>
<td>3</td>
</tr>
<tr>
<td>Computer and launcher settling</td>
<td>4</td>
</tr>
<tr>
<td>Missile smoothing</td>
<td>$t_f^*$</td>
</tr>
<tr>
<td>Speed uncertainty</td>
<td>0.08 $t_f$</td>
</tr>
<tr>
<td>Wind uncertainty</td>
<td>0.04 $t_f$</td>
</tr>
<tr>
<td>Salvo interval allowance for computer</td>
<td>1</td>
</tr>
<tr>
<td>Approximation</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$20 + 1.12 T_f$</td>
</tr>
</tbody>
</table>

* Missile time of flight
Fig. 40 — Talos kill probability against TU-4 type bomber
be independent of range. The expected miss distance is thought to be between 10 and 30 feet so that the kill probability against the TU-4 type bomber should be greater than 0.98 for a 100 per cent operable missile.

From the experience with the Terrier missile, the midcourse guidance and fuzing operability of the Talos missile is taken as 80 per cent. The seeker operability is estimated at 90 per cent so that the overall missile reliability is estimated to be 72 per cent. If a 75 per cent combat degradation for the Talos system as a whole is applied to the kill probability of the missile, then the degraded single shot kill probability against the TU-4 bomber is about 0.53. In contrast, the NIKE I missile degraded kill probability against the TU-4 bomber is estimated to vary from 0.51 to 0.20 depending upon the interception range.

The organization and costing of the Talos System is based on a squadron of 4 sites. Table 19 lists the basic costing components for a Talos squadron. For deployment in the zone-of-the-interior, the initial cost of a Talos dual simplex squadron is estimated to be 43.7 million dollars and the annual cost is estimated to be 7.84 million dollars. These estimates are based upon a production level of 60 Talos squadrons or 240 talos sites. If Talos W missiles are to be used with Talos S or D missiles, then 0.36 million dollars must be added to the initial cost of the squadron to cover the cost for a range tracking unit in each guidance transmitter. The cost of overseas deployment of a Talos squadron will be somewhat greater but probably not more than 50 million dollars initially and 10 million dollars annually. For comparison, the NIKE battalion used in an area type deployment costs about 35 million dollars initially and about 10 million dollars annually.
### Table 19

**BASIC COSTING COMPONENTS OF TALOS SQUADRON**

<table>
<thead>
<tr>
<th>Item</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personnel</td>
<td>272</td>
</tr>
<tr>
<td>Radars</td>
<td>8</td>
</tr>
<tr>
<td>Guidance transmitters</td>
<td>8</td>
</tr>
<tr>
<td>Computers</td>
<td>8</td>
</tr>
<tr>
<td>Missile test equipment</td>
<td>4</td>
</tr>
<tr>
<td>System test equipment</td>
<td>4</td>
</tr>
<tr>
<td>Round house with launchers</td>
<td>4</td>
</tr>
<tr>
<td>Internal communications</td>
<td>4</td>
</tr>
<tr>
<td>Housing facilities</td>
<td>1</td>
</tr>
<tr>
<td>Missiles Stored</td>
<td>240</td>
</tr>
</tbody>
</table>
TAILOS EFFECTIVENESS RELATIVE TO NIKE I

In order to obtain some idea of the effectiveness of Talos against Soviet air attack, the Talos S and D systems are compared with NIKE I on the basis of the following effectiveness considerations:

1. Low altitude coverage
2. Range capability
3. Fire power
4. Salvo kill probabilities

From Figs. 37 and 38, it is seen that while the Talos D is expected to have good low altitude coverage, the Talos S is expected to have poor low altitude coverage. For the Talos D, interception of enemy bombers should be possible right down to the ground between 5 to 37 n. miles from the launching site which makes the Talos D just about as effective against low altitude bombers as against high altitude bombers. However, for the Talos S, interception of bombers below 1,000 feet altitude is not expected to be possible and only limited interception capability is expected between 1000 and 8000 feet altitude. Since the NIKE I is capable of intercepting enemy aircraft at altitudes as low as 360 feet with the proper placing of the tracking radars, it appears to have somewhat better low altitude coverage than the Talos S but not as good coverage as the Talos D.

The ranges of the Talos S and D missiles, as shown in Fig. 37, are a function of interception altitude. Thus at 18,000 to 60,000 feet altitude, both Talos missiles have a maximum range of 50 n. miles. However, at altitudes below 18,000 feet the range of the Talos D missile falls off linearly with altitude to 37 n. miles at zero altitude. The Talos S follows the same range
pattern as the Talos D down to 8,000 feet altitude (42.5 n. miles) at which point the beam width limitation takes over and determines range. The NIKE I, on the other hand, has a maximum interception range of 25 n. miles at altitudes between 2250 and 60,000 feet. Below 2250 feet altitude the beam width limitation determines missile range.

The firepower or maximum rate of fire of the Talos unit is estimated at from 0.6 to 2 missile salvos a minute depending upon interception range. Since there are two missiles per salvo, this means that from 1.2 to 4 missiles might be expended per minute and with the 60 missiles stockpiled at each launching site, a maximum rate of fire could be sustained for somewhere between 15 and 50 minutes. In comparison a NIKE I battery has a maximum rate of fire of from 0.6 to 2 missiles per minute depending upon interception range. On the basis of 64 ready missiles available to the NIKE battery, a maximum rate of fire could be sustained for somewhere between 25 and 83 minutes assuming 25 per cent of the missiles are defective and cannot be launched.

Since the Talos unit has twice the range and about the same average maximum salvo rate of fire as the NIKE I battery at altitudes above 18,000 feet, it should be able to fire twice the number of salvos against a bomber cell flying directly over the firing unit as a corresponding NIKE battery. Where the bomber cell flies by at some distance from the firing unit, the Talos unit should have an even greater proportionate fire power advantage over the NIKE I battery. However, against a saturation air attack by many bomber cells more firing will be done at minimum range than against a single cell attack so that the salvo rate of the Talos should approach the firing rate of the NIKE with increasing attack size and duration.
Since 0.53 is the degraded Talos single shot kill probability computed against the TU-4 type bomber, the salvo kill probability of two Talos missiles would be 0.72 against the TU-4 type bomber. In contrast, each NIKE I salvo of one missile is estimated to have a degraded kill probability against the TU-4 type bomber of 0.51 to 0.20 depending upon the interception range. Hence against a single TU-4 bomber cell flying directly over the firing site, the Talos unit should have on the average a salvo kill probability twice as great as that of a NIKE battery. The further the bomber cell's path lies from the firing site, the greater will be the average salvo kill probably advantage of the Talos unit over the NIKE I battery. Against a saturation air attack, however, the average salvo kill probability advantage of the Talos unit over the NIKE I battery will be less than against a single cell. This kill probability advantage decreases toward the ratio 1.4 at minimum range by increasing attack size and duration.

Combining the fire power and salvo kill probability considerations, it is now possible to say something about the relative kill potential of a Talos unit with respect to a NIKE battery against both saturation and non-saturation air attacks. In the non-saturation case at high altitude, the average maximum salvo rate of fire and average kill probability for the Talos unit were both estimated to be at least twice as great as those for a NIKE battery so that the Talos unit's kill potential should be at least four times as large as the NIKE battery's kill potential against the attack. In the saturation case at high altitude the average maximum salvo rate of fire and average salvo kill probabilities for the Talos unit were estimated to approach as a lower limit one and 1.4 times, respectively those for a NIKE battery so that the Talos
unit's kill potential should approach 1.4 times the NIKE battery's kill potential as the number of cells and duration of attack are increased. Hence, whereas both Talos systems appear to have a distinct kill potential advantage over the NIKE I against high altitude non-saturation air attacks, this advantage is not so pronounced against saturation attacks considering that a Talos unit costs about 1.4 times as much as a NIKE I unit initially.

At low altitudes, the relative kill potential advantage of the Talos D over the NIKE I should be greater. On the other hand, the relative kill potential advantage of the Talos S over the NIKE I should decrease with altitude and disappear at altitudes on the order of 2000 feet or less. Therefore, while the Talos D offers a substantial kill potential superiority over the NIKE I in most situations, the Talos S only offers a clear kill potential superiority over the NIKE I against non-saturation air attacks at high altitudes.

**TALOS EFFECTIVENESS IN EUROPEAN MILITARY ENVIRONMENT**

Because of its 50 n. mile range, the Talos would no doubt be deployed area wise to protect a large target complex rather than locally to protect just a few point targets. It appears that against a non-saturating high altitude air attack, less than one-fourth as many Talos units as NIKE I batteries will be required to have the same kill potential level over a given defended area. However, against a saturating high altitude air attack, almost as many Talos units as NIKE batteries may be required to have the same kill potential level over the given defended area. Since a mass saturation raid is the most likely type of air attack against Western Europe and high kill
potentials for small non-saturation air attacks have little value, the Talos doesn't appear to be a significantly more effective weapon than NIKE I for defense against high altitude air attack.

The same problems and considerations face the Talos that face the NIKE I in being integrated into the air defense of Western Europe. First there is the problem of working with friendly fighters and other active and passive defense measures. It may be that by the time Talos units are employed in Europe, methods will be available to obtain fast and accurate identification of friendly and hostile aircraft so that defensive guided missile units can operate in the same area with fighters. If this is not the case, Talos units and fighters will probably have to be given separate areas to defend as was suggested for a combination of NIKE and fighters.

With respect to the problem of detection, the Talos search and tracking radar has a reported range of well over 50 n. miles against most aircraft so that the chance of enemy aircraft slipping undetected through Talos defenses is less than for NIKE defenses. Also the increased radar range and interception range of Talos over NIKE allows more time for identification of hostile aircraft and preparation for fire.

For Talos units deployed in an area type manner, some form of central target assignment seems very desirable to permit defense fire to be spread evenly among attacking aircraft cells in a mass attack and to conserve on defense missiles in a small attack. The longer range and greater firepower of Talos over NIKE will probably mean that without good target assignment there will be more firing overlap between adjacent Talos units than NIKE batteries, thus leading to a greater potential waste of Talos than NIKE missiles.
From the standpoint of land acquisition for a missile launching site, the Talos unit requires much less land than a NIKE battery. Its longer range also gives it more flexibility than NIKE I as to site location so that uninhabited areas can more easily be found for booster disposal.

The Soviet threats that appear to affect the relative effectiveness comparison between Talos and NIKE I in the 1958 to 1962 time period are Soviet guided missiles, low altitude attacks and countermeasures. Against the V-1 and turbojet type missiles, the longer range Talos radars should be more effective than the NIKE radars in detecting and tracking the missiles. Against low altitude attacks the Talos D is definitely superior to the NIKE I.

A Soviet countermeasure which could be much more effective against Talos than NIKE I is the use of decoys. This countermeasure might strike at the Talos system in two ways. First the large area surveyed by the Talos radars means that the Talos defenses might be easily saturated with targets and second the use of Talos missiles in pairs might exhaust the ready missile supply quickly against decoys. Another Soviet countermeasure which might cause Talos more trouble than NIKE I is air attacks on the launching sites. Since a Talos unit is so compact, a direct hit by even an H. E. bomb on the site could knock it out. The Talos S unit is particularly vulnerable to enemy air attack because of its ineffectiveness against low flying aircraft.

A Soviet tactic which Talos W would be effective in countering would be tight formation flying. However, before Talos W can be employed in Western Europe objections to storing nuclear warheads on the Continent will have to be overcome.
DISCUSSION

From the very brief comparison of NIKE I with future defense missile systems, some tentative observations can be made about the advantages and disadvantages of the future systems compared with NIKE I. First it appears that no new guided missile system will reach the operational stage in significant numbers before 1960 so that NIKE I probably has a clear field until then if not later. Of the defense missile systems under development, only the Talos D is designed to provide effective low altitude coverage against Soviet air attack. This one factor alone makes the Talos D superior to the other systems considered because of the increasing Soviet capability to employ low altitude raids. At high altitudes against mass saturation bomber attacks, the Talos and other similar systems under development appear to have only a slight edge attrition wise over the NIKE I on a cost basis.

Some of the other advantages aside from attrition against Soviet bombers that the newer systems have over NIKE I are their longer detection and tracking ranges and smaller emplacement sites. The longer detection and tracking ranges would be particularly valuable against the faster Soviet bombers and harder to detect Soviet guided missiles expected to be available in large numbers in the 1958 to 1962 time period. The smaller emplacement sites would make the problem of land acquisition for missile sites less difficult.

A disadvantage to the new long range defensive missile systems is that they are probably more susceptible to the decoy countermeasure than NIKE I. The problem of identifying friendly and hostile aircraft may also be made more difficult by the greater range coverage of the newer defensive missile systems. By doubling the range of the missile system, four times as much area
is encompassed meaning that potentially four times as many targets must be handled.

At present there doesn't appear to be a direct method of defending against V-2 type ballistic missiles. However, employed in connection with mobility and dispersion of tactical air forces, defensive guided missiles with their ability to inflict high attritions against intruding aircraft could prevent effective air reconnaissance by the Soviets and thus indirectly protect against V-2 attack.
VIII. CONCLUSIONS

1. The three major problems connected with the employment of NIKE I or any other defensive guided missile system in Western Europe are:

   (1) Identification of friendly and hostile aircraft

   (2) Acquisition of land for missile sites

   (3) Protection against low altitude air attacks.

   The lack of an effective centralized fire control center and of rapid means of identifying aircraft will severely limit the ability of friendly fighters and defense missiles to work together in the same area. In addition the lack of effective control and rapid identification may require friendly air offense missions and air evacuation of bases to be limited in the missile defended area.

   Since missile sites require considerable land for launching and booster disposal areas and because Western Europe is relatively densely populated, the acquisition of land for very many sites may present a considerable problem.

   The NIKE I and other present defense missiles are relatively ineffective below 1000 feet altitude and completely ineffective below 400 feet so that some means of complimenting missile defenses at low altitudes would be very desirable.

2. The best method of deploying NIKE I for air defense of Allied tactical air forces appears to be in some form of uniform area deployment. This type of deployment generally inflicts higher bomber attritions and is less sensitive to enemy bomber tactics than a point or barrier type of deployment with a given number of NIKE units.
For eight NIKE battalions, the best deployment for air defense of TAC bases appears to be by batteries over an area of approximately 200 by 150 n. miles in England or over an area of approximately 150 by 250 n. miles in the 4th ATAF area on the Continent. Because of the identification problem, friendly fighters are displaced from the missile defended area. The fighters thus displaced are diverted to bolster fighter defenses in other areas.

For more than eight NIKE battalions, an increasing deployment area size with increasing number of battalions is indicated as optimum assuming that the fighter force is held constant.

3. The bomber attritions calculated for NIKE I against the type of Soviet attack assumed in this study seem to indicate that NIKE can be expected to make a significant contribution to the air defense of Western Europe at a relatively small cost. With eight NIKE battalions, the defense potential of present Western European air defenses could be bolstered by at least 70 per cent against a mass high altitude IL-28 bomber attack and by at least 45 per cent against a low altitude TU-4 bomber attack.

Even with the large expected increase in Western European air defense potential by the addition of eight NIKE battalions, the level of attrition against mass Soviet air strikes would still fall short of that necessary to insure in itself that a large part of the Allied tactical air forces would survive a surprise atomic attack. Against a mass high altitude IL-28 bomber attack, the best NIKE and fighter combination is expected to inflict only a 40 per cent inbound attrition.
In order to obtain a 70 per cent inbound attrition against a mass high altitude IL-28 bomber attack, it is estimated that on the order of 35 NIKE battalions would be required in Western Europe. The cost of such a defense, if the units could be spared from the defense of the United States, would be slightly over a billion dollars initially and 340 million dollars annually. Although this NIKE defense could cause on the order of 70 per cent or more attrition against high altitude bomber raids, it would be relatively ineffective against mass TU-4 and one-way IL-28 bomber raids below 1000 feet altitude.

4. From a brief look at Soviet air threats and U. S. defensive guided missiles expected in the time period 1958 to 1962, the following tentative conclusions are drawn:

- The air threat against Allied tactical bases will be increased considerably by the availability of more and larger atomic bombs to the Soviets. In addition the Soviets will have faster and longer range bombers and hard to detect guided missiles to deliver these bombs.

- No new defensive guided missile system is expected to reach operational stage in significant numbers before 1960.

- Of the new defensive guided missile systems under development, only Talos D at present is designed so as to afford effective low altitude coverage in Europe against bomber attack.

- Talos and other similar missile systems under development appear to have only a slight edge over NIKE I in Europe on the basis of expected bomber kills per dollar inflicted against mass high altitude raids.
Because of its longer detection, tracking and missile ranges, the Talos system is more effective than NIKE I against small targets such as V-1 and turbojet type guided missiles, however, for the same reason it is more susceptible to decoy countermeasures and therefore may have more difficulty in identifying hostile aircraft.
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APPENDIX A

ANTI-AIRCRAFT ARTILLERY EFFECTIVENESS IN AIR BASE DEFENSE

SUMMARY OF RESULTS

1. The 0.50 cal. and 40 mm. guns assumed for the defense of bases are not effective against:
   a. Aircraft attacks above 5000 feet altitude,
   b. Night or bad weather attacks, and
   c. Toss bombing attacks.

2. When guns can bear on attacking aircraft, defense effectiveness is sensitive to the state of alert. The number of batteries firing varies from one to four.

3. Under the maximum alert conditions against low (less than 500 feet altitude) level attack, the following attrition per base of a cell of 13 aircraft is expected.

<table>
<thead>
<tr>
<th>Type of Aircraft</th>
<th>Type of Attack</th>
<th>Inbound Kills</th>
<th>Round-Trip Kills</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL-28</td>
<td>Parachute Bombing or Strafing</td>
<td>0.14</td>
<td>2.21</td>
</tr>
<tr>
<td>TU-4</td>
<td>Parachute Bombing</td>
<td>1.05</td>
<td>9.07</td>
</tr>
<tr>
<td>MIG</td>
<td>Strafing</td>
<td>0.32</td>
<td>4.20</td>
</tr>
</tbody>
</table>
INTRODUCTION

It is assumed that in 1955 and 1956 there will be no change in the type of anti-aircraft defenses from what is now deployed or scheduled at TAC air bases. In England, only the TAC light bomber base at Sculthorpe is furnished with AAA by the U. S. Army. The other TAC installations at Bentwaters, Shephards Grove, and Wethersfield will be provided with AAA protection by British Forces after war mobilization is ordered.

The Sculthorpe base is at present defended by the 39th battalion of the 32nd AAA Brigade (Semi-Mobile) equipped with single 40 mm. and quad. cal. 0.50 mounts. The 39th battalion at full strength consists of four firing batteries and one and one-half smoke companies. Each firing battery has eight single 40 mm. guns and eight quad. cal. 0.50 mounts. The deployment of the guns and smoke generators is restricted to the base, thus somewhat reducing their effectiveness.

Some early warning information is available from Fighter Command filter centers and the U. S. Army's own radars. Each battalion has a plotting room, which attempts to diagnose the local air situation in order to pre-point the guns in the direction of enemy attack. Since the guns are visually aimed and fired, they have no nighttime effectiveness and thus are kept on readiness only one hour before dawn to one hour after sunset. Present SOP requires only one out of the four batteries to be on a 30 second alert, two batteries to be on 15 minute alert and one battery to be on one hour call.

Even in their present locations, the Smoke Companies are able to obscure completely the immediate base locations, depending on the wind velocity, in 10 to 15 minutes.
Since the guns are visually fired and are restricted to locations on the base, they would be rendered useless by the smoke cover.

The British Forces assigned to defend the fighter-bomber bases at Bentwaters, Shephards Grove, and Wethersfield are territorial units (roughly equivalent to our National Guard) equipped with 40 mm. guns. It is assumed that each of these units is about the size of an U. S. Army AA Battalion and that each is assigned thirty-two dual mount 40 mm. guns. The time required for these forces to be activated and put in place is from 3 to 14 days after mobilization day. Hence they will be of no use in case of a surprise attack.

Definite information is not available concerning AA defenses planned for TAC installations in France. It is assumed that the light-bomber base at Laon/Couvron will be defended by a battalion of AAA having the same organization, composition, and alert status as that of the 39th Battalion at Sculthorpe in England. It is assumed that each of the fighter-bomber bases at Chaumont, Phalsbourg, and Chennevieres-sur-Marne will be furnished with an AAA Battalion identical to the one at Laon/Couvron about two days after mobilization day.

**WEAPON AND TARGET CAPABILITIES**

Table 20 lists the relevant characteristics of the quad cal. 0.50 mount and single 40 mm. guns.
Since the guns are visually fired and have such short ranges, they are useful only against low altitude daytime attack. Therefore the only types of enemy attack that they can expect to defend against are strafing and parachute bombing.

The Soviet air threat for 1955 to TAC Bases consists of the TU-4 Bomber, the IL-28 Bomber, and the MIG Fighter. Both the TU-4 and IL-28 have sufficient range to attack all the eight TAC installations considered; the MIG at best will have sufficient range to attack only the installations at Chaumont, Phalsbourg and Chennevières-sur-Marne in France. Table 21 lists the aircraft able to attack the bases under consideration. The speeds assumed for the aircraft are as follows: 400 knots for the IL-28, 250 knots for the TU-4, and 450 knots for the MIG.

Of the three Soviet Aircraft considered, the IL-28 is the most versatile; the MIG is the least versatile. The IL-28 can strafe, drop parachute bombs, toss bombs, and bomb from high altitudes with either H. E. or Nuclear Bombs. The TU-4 can do all but strafe and toss bombs, while the MIG can only strafe.
Table 21

TAC INSTALLATION EXPOSURE TO ENEMY ATTACK

<table>
<thead>
<tr>
<th>Base</th>
<th>Exposed to Attack by</th>
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<tr>
<td></td>
<td>IL-28</td>
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<tr>
<td>England</td>
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<tr>
<td>Sculthorpe</td>
<td>x</td>
</tr>
<tr>
<td>Bentwaters</td>
<td>x</td>
</tr>
<tr>
<td>Shephard Grove</td>
<td>x</td>
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<tr>
<td>Wethersfield</td>
<td>x</td>
</tr>
<tr>
<td>France</td>
<td></td>
</tr>
<tr>
<td>Laon/Couvron</td>
<td>x</td>
</tr>
<tr>
<td>Chaumont</td>
<td>x</td>
</tr>
<tr>
<td>Phalsbourg</td>
<td>x</td>
</tr>
<tr>
<td>Chennevières-sur-Marne</td>
<td>x</td>
</tr>
</tbody>
</table>

ATTRITION CALCULATIONS

Two types of kill against the attacking aircraft are considered in judging the effectiveness of the anti-aircraft defenses at the TAC installations. The first type, called an inbound kill, results in the destruction of the airplane before it is able to attack the base. The second type, called a round-trip kill, prevents the airplane from reaching a home base. Thus against strafing and parachute bombing attacks, the guns can inflict inbound kills on the planes all the way up to the base, whereas against conventional or toss bombing attacks, the guns can inflict inbound kills, as defined, only up to the bomb release line.

The effectiveness of the anti-aircraft defenses is measured in terms of kill potential, which is defined as the number of planes that the defense would expect to kill out of a very large cell. For random fire against cells
having only a moderate or small number of aircraft, the following formula is used to find the expected number of aircraft killed.

\[ E = n (1 - e^{-\frac{K_p}{n}}) \]

where

- \( E \) = expected number of aircraft killed out of cell by random fire,
- \( n \) = number of aircraft in the cell,
- \( K_p \) = kill potential.

\[ \epsilon = \frac{K_p}{n}, \text{ and} \]

Kill potential estimates for the 0.50 cal. and 40 mm. guns are based on data from References 21 and 2, respectively, and an emplacement circle of one nautical mile radius. Since the data are not complete, they are modified where necessary to take account of type of target, altitude, combat degradation, and type of kill. Tables 22 and 23 outline the procedure and major modifications used in calculating degraded round-trip and inbound kill potentials for the guns.

The data taken from the references are either given in terms of lethal length per weapons or are converted into such a form. Lethal length is obtained by integrating under a curve of kill potential versus minimum horizontal weapon-to-target distance and is expressed in units of kill-potential feet. Thus to approximate the average kill potential for a weapon on a given emplacement circle, the lethal length is divided by the circumference of the circle. Since the data in the references refer to instantaneous kills inflicted on a bomber cell flying once through the circle of maximum gun range, the lethal lengths and average kill potentials derived from them have the same qualifications.
<table>
<thead>
<tr>
<th>Weapon</th>
<th>Target</th>
<th>Altitude (Ft.)</th>
<th>Lethal Length Per Weapon</th>
<th>Theoretical (Instantaneous) Kill Potential Per Weapon</th>
<th>Combat Degradation Factor</th>
<th>Round-Trip Potential</th>
<th>Degraded Round-Trip (Delayed) Kill Potential Per Weapon</th>
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<td>Dual 40 MM Gun (Equivalent to 2 Single 40 MM Guns)</td>
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<td>764</td>
<td>0.0200</td>
<td></td>
<td></td>
<td>0.075</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5000</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>MIG</td>
<td></td>
<td>100</td>
<td>700</td>
<td>0.0183</td>
<td>0.75</td>
<td>5</td>
<td>0.069</td>
</tr>
</tbody>
</table>
### Table 23

**Calculation of Inbound Kill Potentials**

<table>
<thead>
<tr>
<th>Weapon</th>
<th>Target</th>
<th>Type Attack</th>
<th>Altitude (Ft.)</th>
<th>Theoretical (Instantaneous) Kill Potential Per Weapon</th>
<th>Combat Degradation Factor</th>
<th>Inbound Factor</th>
<th>Degraded Inbound (Instantaneous) Kill Potential Per Weapon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single 0.50 Cal. Gun</td>
<td>IL-28</td>
<td>Strafing and Parachute Bombing</td>
<td>100</td>
<td>0.0096</td>
<td>1/6</td>
<td>0.5</td>
<td>0.0008</td>
</tr>
<tr>
<td></td>
<td>TU-4</td>
<td>Parachute Bombing</td>
<td>500</td>
<td>0.0444</td>
<td>1/6</td>
<td>0.5</td>
<td>0.0037</td>
</tr>
<tr>
<td>MIG</td>
<td></td>
<td>Strafing</td>
<td>100</td>
<td>0.0186</td>
<td>1/6</td>
<td>0.5</td>
<td>0.0016</td>
</tr>
<tr>
<td>Dual 40 MM Gun (Equivalent to 2 Single 40 MM Guns)</td>
<td>IL-28</td>
<td>Strafing and Parachute Bombing</td>
<td>100</td>
<td>0.0107</td>
<td>0.5</td>
<td>0.5</td>
<td>0.0027</td>
</tr>
<tr>
<td></td>
<td>TU-4</td>
<td>Parachute Bombing</td>
<td>500</td>
<td>0.1117</td>
<td>0.75</td>
<td>0.5</td>
<td>0.0419</td>
</tr>
<tr>
<td>MIG</td>
<td></td>
<td>Strafing</td>
<td>100</td>
<td>0.0183</td>
<td>0.75</td>
<td>0.5</td>
<td>0.0069</td>
</tr>
</tbody>
</table>
The undegraded lethal lengths for the dual 40 mm. gun against the TU-4, IL-28 and MIG aircraft in Table 22 are read directly out of Reference 2 with the MIG represented by the V-1. On the other hand, the undegraded lethal lengths for the 0.50 cal. gun in Table 22 are obtained indirectly from data in Figure 2 of Reference 21 where the degraded expected number of kills is plotted against minimum separation distance for only a TU-4 type target. Curves are given for target velocities of 150, 350 and 550 knots. The 12.7 mm. gun used in the figure is equivalent to the U. S. 0.50 cal. gun, but the expected number of kills, \( E \), is only approximately equal to kill potential, being converted by the relation

\[
K_p = 1 - e^{-E}
\]

for each plane engaged by the gun. Since it is assumed that a weapon will have time to engage only one plane out of the cell, and since the values of \( E \) are small even for a quad. 0.50 cal. gun mount, the \( E \) gives a fairly good approximation to \( K_p \) and, hence, may be considered its equivalent. The minimum separation distance (MSD) given in the figure is related to horizontal minimum separation distances for various target altitudes by the expression

\[
MSD = \sqrt{r^2 + h^2}
\]

where

- \( r \) = horizontal minimum separation distance, and
- \( h \) = target altitude.

In determining the expected kills, \( E \), for the 0.50 cal. gun against the TU-4 and IL-28 from Figure 2 of Reference 21, the IL-28 is assumed to have the same vulnerable area as the TU-4. Thus values of \( E \) against the IL-28 as well as against the TU-4 are found by direct interpolation between the curves in the figure, using a velocity of 400 knots for the IL-28 and 250 knots for the TU-4. The MIG's vulnerable area is assumed to be twice
and its velocity roughly equal that of the IL-28; so $E$ for the MIG is taken as twice the $E$ for the IL-28.

The resulting lethal lengths for the 0.50 cal. gun against the three types of aircraft cells at various altitudes are obtained by integrating the kill potential (i.e., $E$) curves with respect to horizontal minimum separation distance on both sides of the weapon. These degraded lethal lengths are multiplied by a factor of six to give the undegraded lethal lengths appearing in Table 22.

In order to obtain the theoretical kill potentials per weapon in Tables 22 and 23, the lethal lengths per weapon are divided by the circumference of the emplacement circle in feet. Defined in this way, the theoretical kill potentials approximate the true average undegraded kill potentials of a single emplaced weapon against an aircraft cell. They are not exact expressions, because the lethal lengths are calculated for the weapon emplaced on a straight line rather than on a circle. However, they appear to be reasonable approximations as long as the weapon's effective radius of fire is smaller than the emplacement radius.

Since the theoretical kill potentials are based on undegraded, instantaneous kills inflicted on an aircraft cell flying once inbound through the circle of maximum gun range, they are converted to degraded round-trip (or inbound) kill potentials by multiplication with combat degradation and round-trip (or inbound) factors.

The combat degradation factor of $1/6$ on the 0.50 cal. gun used in Reference 21 is reinstated in Tables 22 and 23. Combat degradations of 0.5, 0.75 and 0.75 are chosen for the 40 mm. gun against the IL-28, TU-4 and MIG aircraft, respectively, since it is generally agreed that optically aimed guns such as the 40 mm. are degraded less in combat than the manually aimed 0.50 cal. The degradation assigned to the 40 mm. gun firing at an
IL-28 is larger than the degradation for firing at the TU-4 or MIG because of the greater versatility of the IL-28.

The round-trip factors are found in two steps. First, the theoretical kill potentials are doubled to include instantaneous kills inflicted on the aircraft cell as it flies outbound as well as inbound over the emplacement circle. In addition, the theoretical kill potentials are increased five times for the 0.50 cal. and two and one-half times for the 40 mm. gun to incorporate delayed kills as well as instantaneous kills. Thus, the resulting round-trip factors used in Table 22 are 10 and 5 for the 0.50 cal. and 40 mm. guns, respectively.

The inbound factors of one-half multiplied by the theoretical kill potentials in Table 23 for strafing and parachute bombing attacks assume that the enemy initiates his attack at about the emplacement circle. Thus only instantaneous kills inflicted by the weapon over half its circle of fire are effective in preventing the attack.

The degraded round-trip and inbound kill potentials derived in the tables are based on good visibility conditions during daytime. Against attacks at night or during bad weather, the 0.50 cal. and 40 mm. guns are ineffective because they are visually aimed.

The total round-trip or inbound kill potential for a ring of guns against an aircraft cell is found by summing the corresponding kill potentials of the guns emplaced on the ring.
In Table 24, the daytime kill potentials of the anti-aircraft defense at the Sculthorpe Base are given against strafing and parachute bombing attack by a cell of IL-28 Bombers and against parachute bombing attack by a cell of TU-4 Bombers. These kill potentials are presented for various warning times of a surprise attack.

Table 24

KILL POTENTIAL OF AAA DEFENSE AT SCULTHORPE TAC BASE

<table>
<thead>
<tr>
<th>Warning Time</th>
<th>Number of Batteries in Action</th>
<th>Strafing and Parachute Bombing Attack by IL-28 Cell</th>
<th>Parachute Bombing by TU-4 Cell at Low Altitudes (around 500 ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inbound Kill Potential</td>
<td>Round-Trip Kill Potential</td>
</tr>
<tr>
<td>30 sec - 15 min.</td>
<td>1</td>
<td>0.035</td>
<td>0.601</td>
</tr>
<tr>
<td>15 min - 1 hour</td>
<td>3</td>
<td>0.105</td>
<td>1.803</td>
</tr>
<tr>
<td>1 hour or more</td>
<td>4</td>
<td>0.140</td>
<td>2.404</td>
</tr>
</tbody>
</table>

The expected number of planes killed out of cells of 13 is given in Table 25.

Table 25

EFFECTIVENESS OF AAA DEFENSE AT SCULTHORPE TAC BASE AGAINST CELLS OF THIRTEEN BOMBERS

<table>
<thead>
<tr>
<th>Warning Time</th>
<th>Number of Batteries in Action</th>
<th>Strafing and Parachute Bombing Attack by Cell of 13 IL-28's</th>
<th>Parachute Bombing by Cell of 13 TU-4's at low Altitudes (around 500 ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Expected Inbound Kills</td>
<td>Expected Round-Trip Kills</td>
</tr>
<tr>
<td>30 sec - 15 min.</td>
<td>1</td>
<td>0.03</td>
<td>0.60</td>
</tr>
<tr>
<td>15 min - 1 hour</td>
<td>3</td>
<td>0.10</td>
<td>1.69</td>
</tr>
<tr>
<td>1 hour or more</td>
<td>4</td>
<td>0.14</td>
<td>2.21</td>
</tr>
</tbody>
</table>
The anti-aircraft defense considered does not have any inbound kill potential against conventional or toss bombing because the bomb release line is beyond the effective range of the 0.50 cal. and 40 mm. guns when restricted to an on-base deployment. However, if the effectiveness of the guns and crews is unimpaired by the enemy attack, the anti-aircraft defense will have a round-trip kill potential against conventional bombing at altitudes below 5000 ft. This is not the case with toss bombing since the bomber executes a sharp turn after releasing its bombs and thus does not come within range of the guns. Fig. 41 gives the daytime round-trip kill potential of the Sculthorpe Base AAA defense against conventional bombing by a cell of IL-28 Bombers or TU-4 Bombers. Only the kill potential for a warning time of one hour or more is shown. For other warning times, the kill potential can be found by multiplying the given value by the fraction of the total number of batteries which would be in action.

Fig. 42 gives the expected number of bombers in cells of thirteen killed by the defense. Here the expected number of bombers killed is given for the various warning times because it cannot be scaled linearly with the number of batteries in action as can be done with kill potential.

Since the Laon/Couvron light bomber base is assumed to have the same AAA defense as the Sculthorpe light bomber base, the data in Tables 24 and 25 and Figs. 41 and 42 are applicable to it as well. After mobilization day or D-day, it is assumed that TAC bases at Chaumont, Phalsbourg and Chennevières-sur-Marne will also be furnished with identical AAA defenses. It is to be expected, however, that after mobilization day, the defenses will be more rigidly alert than at present. Hence after D-day all the batteries will be considered on a 30 second alert, and the expected number of bomber kills calculated here for one-hour warning time will then
Fig. 41 — Daytime round-trip kill potential of AAA defense at Sculthorpe Base against conventional bombing attack

At least one hour's warning of attack

**TU-4 bomber cell**

**IL-28 bomber cell**

Probably parachute bombs used in this altitude range
Fig. 42—Daytime round-trip attrition by AAA defense at Sculthorpe Base against cells of thirteen bombers using conventional bombing.
apply to any warning time greater than possibly 30 seconds. Since these three bases may be exposed to strafing attack by MIG Fighters, Table 26 lists the inbound and round-trip kill potentials that the AAA defense at each of these bases would have against MIG attack.

<table>
<thead>
<tr>
<th>Type of Kill</th>
<th>Kill Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inbound</td>
<td>0.32</td>
</tr>
<tr>
<td>Round-Trip</td>
<td>5.10</td>
</tr>
</tbody>
</table>

For the fighter bomber bases at Bentwaters, Shephards Grove, and Wethersfield in England, the AAA defenses after mobilization or D-day will consist of British Territorial units equipped solely with 40 mm. guns. Assuming that each of the three bases will be assigned a unit having thirty-two dual mount 40 mm. guns equivalent to the U.S. 40 mm. guns, Table 27 gives the inbound and round-trip kill effectiveness for the AAA defense of any of these bases against low altitude attack by IL-28 and TU-4 Bombers. No night-time capability is given to this British AAA defense because the 40 mm. guns are optically fired.

In Fig. 43 the anti-aircraft effectiveness at any one of these British defended bases against conventional bombing is displayed as a function of altitude. Against conventional bombing, the AAA defenses are capable of inflicting only round-trip kills on the IL-28 and TU-4 Bombers because the bomb release line is beyond the effective range of the guns, which are presumed to be stationed on the base.
<table>
<thead>
<tr>
<th>Bomber</th>
<th>Type of Attack</th>
<th>Cell Size</th>
<th>Type of Kill</th>
<th>Kill Potential</th>
<th>Expected No. of Bombers Killed</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL-28</td>
<td>Strafing and Parachute Bombing</td>
<td>Very large</td>
<td>Inbound</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Very large</td>
<td>Round-trip</td>
<td>0.92</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Inbound</td>
<td>0.10</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Round-trip</td>
<td>0.92</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>TU-4</td>
<td>Parachute Bombing (500 ft Alt.)</td>
<td>Very large</td>
<td>Inbound</td>
<td>1.20</td>
<td>1.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Very large</td>
<td>Round-trip</td>
<td>12.30</td>
<td>12.30</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Inbound</td>
<td>1.20</td>
<td>1.12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Round-trip</td>
<td>12.30</td>
<td>7.96</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 43—Daytime round-trip attrition by AAA defense at any British defended base against conventional bombing attack

![Graph showing daytime round-trip attrition by AAA defense. The graph compares expected number of bombers killed against altitude in feet. The graph includes lines for TU-4 bomber cells of size 13 or more, IL-28 bomber cells of size 13 or more, and a dotted line for TU-4 bomber cells (large number planes).](image-url)
APPENDIX B

COST ESTIMATE OF ABOVEGROUND NIKE BATTALION

ZI AND OVERSEAS

R. W. Smith

The following estimates were based on data available to RAND in 1953. Many of these estimates would need to be modified to bring them up to date.

The NIKE system estimates shown in Tables 28 and 29 were developed as described in (20). Due to the lack of Army cost factors, the basic assumption was made that Air Force factors could be substituted. Army personnel have stated that this results in an overstatement of Army costs.

The cost of the NIKE missile of $30,000 each is from Army Progress Report 9-A, Procurement Schedule and Delivery, December 1953 (S), Office of Asst. Chief of Staff G-4, Department of the Army.

The number of personnel and launchers is from T/O&E 44-145, Antiaircraft Artillery Missile Battalion (tentative, 12 February 1953, Dept. of the Army.) As this T/O&E seems to be for a battalion located in the ZI, it is assumed that further augmentation is required for overseas operation and an increase of 10 per cent was used.

<table>
<thead>
<tr>
<th>Personnel</th>
<th>Full Strength</th>
<th>Reduced Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hq. and Hq. Battery(T/O&amp;E 44-146)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Officers</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Warrant Officers</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Enlisted Men</td>
<td>84</td>
<td>83</td>
</tr>
</tbody>
</table>
It is assumed that proficiency will be maintained by firing one NIKE per battery per year on the average. (Not fired on location.) In addition to this the 25 per cent of the personnel replaced each year will have had training including the firing of NIKEs.

The above referenced Army Progress Report 9-A gives the following cost of the special equipment:

<table>
<thead>
<tr>
<th>Cost per Battery</th>
<th>Cost per Battalion (4 Batteries)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guidance</td>
<td>$535,000</td>
</tr>
<tr>
<td>Special Equipment</td>
<td>405,000</td>
</tr>
<tr>
<td>Assembly area for battalion</td>
<td>500,000</td>
</tr>
<tr>
<td>Total per Battalion</td>
<td></td>
</tr>
</tbody>
</table>

At the suggestion of the Army Antiaircraft Command in Colorado Springs, this was doubled to include miscellaneous other special equipment.

The estimate of the cost of the facilities installations for the reduced battalion, $2,000,000, was also supplied by the Army Antiaircraft Command.

All other costs were based on Air Force factors as derived by RAND or obtained in Air Force publications. The back-up for these estimates is maintained in the Cost Analysis Section files.
The estimates of the overseas costs are made as described in the Appendix of Ref. 20. Overseas operation is about 15 per cent higher than Zone of the Interior operation.

The costs of the separate battery are based on the assumption that each battery will have its own assembly area and that manning will be increased 10 per cent for the less efficient operation including additional assembly and maintenance personnel.

Since there is some authority for the large items of cost there is some assurance that the battalion estimates are within 10 per cent of actual costs. This is, however, not true for the separate battery costs.

It will be noted that the separate battery system costs are estimated to be about 30 per cent of the battalion costs.
### Table 28

**ABOVEGROUND MINE BATTALION**

(Costs in Millions of Dollars)

<table>
<thead>
<tr>
<th></th>
<th>Full Strength</th>
<th>Reduced Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Battalion</td>
<td>Separate Battery</td>
</tr>
<tr>
<td><strong>Initial Investment</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equipment Facilities</td>
<td>2.50</td>
<td>0.75</td>
</tr>
<tr>
<td>Personnel Facilities</td>
<td>0.70</td>
<td>0.20</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nikes at Launchers</td>
<td>7.68</td>
<td>7.68</td>
</tr>
<tr>
<td>Special Equipment</td>
<td>9.00</td>
<td>9.00</td>
</tr>
<tr>
<td>Organizational Equip</td>
<td>0.66</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stocks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Stock Level</td>
<td>1.51</td>
<td>1.79</td>
</tr>
<tr>
<td>Spares - Major Equip</td>
<td>0.77</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation</td>
<td>0.22</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personnel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Training</td>
<td>1.92</td>
<td>2.11</td>
</tr>
<tr>
<td>Travel</td>
<td>0.10</td>
<td>1.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>25.06</td>
<td>29.87</td>
</tr>
</tbody>
</table>

(Costs in Millions of Dollars)
Table 29

ABOVEGROUND NIKE BATTALION

(Costs in Millions of Dollars)

<table>
<thead>
<tr>
<th></th>
<th>Full Strength</th>
<th>Reduced Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Battalion</td>
<td>Separate Battery</td>
</tr>
<tr>
<td></td>
<td>ZI   OS</td>
<td>ZI   OS</td>
</tr>
<tr>
<td><strong>Annual Operating</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spares</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installations</td>
<td>0.03 0.13</td>
<td>0.01 0.04</td>
</tr>
<tr>
<td>Major Equipment</td>
<td>0.77 0.77</td>
<td>0.19 0.19</td>
</tr>
<tr>
<td>Special Equipment</td>
<td>1.35 1.35</td>
<td>0.45 0.45</td>
</tr>
<tr>
<td>Organizational Equipment</td>
<td>0.04 0.04</td>
<td>0.01 0.01</td>
</tr>
<tr>
<td>Utilities, Instal. Services, etc.</td>
<td>0.13 0.13</td>
<td>0.04 0.04</td>
</tr>
<tr>
<td>Personnel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pay and Allowances</td>
<td>1.54 1.76</td>
<td>0.42 0.48</td>
</tr>
<tr>
<td>Travel</td>
<td>0.02 0.09</td>
<td>0.01 0.03</td>
</tr>
<tr>
<td>POL Miscellaneous</td>
<td>0.05 0.06</td>
<td>0.01 0.01</td>
</tr>
<tr>
<td>Indirect Services and Misc.</td>
<td>0.05 0.06</td>
<td>0.02 0.02</td>
</tr>
<tr>
<td>Support Intermediate Commands</td>
<td>0.07 0.78</td>
<td>0.20 0.22</td>
</tr>
<tr>
<td>Cost of NIKEs Fired for Proficiency</td>
<td>0.12 0.12</td>
<td>0.03 0.03</td>
</tr>
<tr>
<td>Transportation</td>
<td>0.26 0.52</td>
<td>0.09 0.18</td>
</tr>
<tr>
<td>Training of Replacement Personnel</td>
<td>0.48 0.52</td>
<td>0.13 0.14</td>
</tr>
<tr>
<td>Support Major Commands</td>
<td>1.84 2.11</td>
<td>0.54 0.61</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>7.38 8.44</td>
<td>2.15 2.45</td>
</tr>
</tbody>
</table>
APPENDIX C

METHODS OF COMPUTING NIKE KILL POTENTIALS

In this Appendix, the methods used for calculating kill potential and expected bomber kills are presented. Starting with graphs of kill probability and time of flight plotted against horizontal range in Figs. 14 and 44, the NIKE kill potentials are calculated as a function of horizontal minimum separation distance between launching battery and bomber cell. The results of these calculations are given in Figs. 45 and 46 for Il-28 and Tu-4 bomber cells, respectively, at various altitudes and constitute the basic data from which the kill potentials are determined for the different NIKE deployments and Soviet bomber tactics.

In calculating the NIKE kill potentials shown in Figs. 45 and 46, the relationship between the bomber cell's location at the time of missile launch and at the time of interception must be found to determine the number of shots fired and the kill probability for each shot. Figure 47 illustrates the geometry of this relationship and gives the equations with which to calculate it. Since \( t_f \) is given as a function of \( R_H \) by Fig. 44, \( D_L \) can be computed for various values of \( R_H \) given \( r \) and \( V_T \). Also, since \( p_k \) and \( t_f \) are functions of \( R_H \) through Figs. 14 and 44, \( p_k \) and \( t_f \) can be plotted directly against \( D_L \) as illustrated in Figs. 48 and 49.

The succession of bomber cell locations at times of missile launchings, \( D_L^{(k)} \), are found sequentially by the following equation:

\[
D_L^{(k)} = D_L^{(k-1)} - (t_f^{(k-1)} + 11) V_T
\]
Fig. 44 — Nike I time of flight

0-2000 ft. altitude

30,000 ft. altitude

Time in seconds

Horizontal range in nautical miles
Fig. 45 — Nike battery kill potential against IL–28 bomber cell
Fig. 46 — Nike battery kill potential against TU-4 bomber cell
Nike launching site

Missile launched

Point of interception

Missile time of flight to point of interception

Fig. 47—Geometry of single missile interception
Fig. 48 — $p_K$ vs $D_L$ for Nike missile shot at passing IL-28 bomber cell
Fig. 49 — $t_f$ vs $D_L$ for Nike missile shot at passing IL-28 bomber cell
where
\[ t_f^{(k-1)} = \text{Missile time of flight to point of interception on the (k-1)th shot in seconds, and} \]
\[ V_t = \text{Bomber cell velocity in n. miles per second.} \]

Equation 3 assumes that the NIKE battery is firing at maximum rate of fire and that 11 seconds elapse between interception time for one missile and launching time for the next missile.

At high altitudes, the maximum open and close fire \( D_L \)'s are determined by the maximum horizontal missile interception range, \( R_H^{(\text{max.})} = 25 \text{ n. miles} \).

Since \( D_L \), \( t_f \), and \( P_k \) are all found as a function of \( R_H \), their limiting values are automatically obtained by restricting the values of \( R_H \) to less than \( R_H^{(\text{max.})} \).

At low altitudes, the maximum open and close fire \( D_L \)'s are determined by the tracking radar restriction on interception range. This is illustrated in Fig. 50 where the NIKE radar site is located the maximum 3 nautical miles forward of the NIKE launching site in the expected direction of bomber approach. In addition, the figure shows that there is a minimum interception range circle at low altitudes inscribed about the launching site. These restrictions applied to the interception range are given by the following equations:

\[ R_H^{(1)} = \sqrt{r^2 + \left[ \sqrt{T_R^2 - r^2 + 3} \right]^2} \quad (4) \]

\[ R_H^{(k)} \geq R_H^{(\text{Min.})} = \text{function of altitude by Fig. 6} \quad (5) \]

\[ R_H^{(m)} \leq \sqrt{r^2 + \left[ \sqrt{T_R^2 - r^2 - 3} \right]^2} \quad (6) \]

where
\[ T_R = \left( \frac{1000}{15} \right) \left( \frac{h}{5000} \right) \leq 25 \text{ n. miles} \]
Fig. 50—Limits on interception range at low altitudes
<table>
<thead>
<tr>
<th>Altitude (in Feet)</th>
<th>Horizontal Minimum Separation Distance (in Nautical Miles)</th>
<th>Tracking Radar Restriction on Interception Range (in Nautical Miles)</th>
<th>Maximum Horizontal Interception Range (in Nautical Miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Open Fire</td>
</tr>
<tr>
<td>500</td>
<td>0</td>
<td>5.48</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>7.2</td>
<td>5.1</td>
</tr>
<tr>
<td>1000</td>
<td>0</td>
<td>10.96</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>13.7</td>
<td>8.4</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>12.5</td>
<td>10.1</td>
</tr>
<tr>
<td>2000</td>
<td>0</td>
<td>21.92</td>
<td>24.9</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>24.9</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>24.6</td>
<td>19.4</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>24.2</td>
<td>19.2</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>23.4</td>
<td>20.9</td>
</tr>
</tbody>
</table>
where

\[ K_F = \text{Kill potential} \]
\[ F = \text{Reliability factor} = 0.675 \]
\[ P_k = \text{Kill probability of } k^{th} \text{ shot, and} \]
\[ m = \text{Number of missiles fired against the bomber cell by} \]
the NIKE battery.

Figures 51 and 52 show the inbound and round-trip kill potentials as a function of altitude for the NIKE battery deployed in defense of a point target against an IL-28 and TU-4 bomber cell, respectively. For point defense of an airfield, the emplacement radius will probably be small so that the battery is treated as being placed at the center of the target. Thus the horizontal minimum separation distance is taken as zero and the round-trip kill potentials are found directly from Figs. 45 and 46. The inbound kill potentials include only kills up to the bomb release line and are computed separately.

Figures 53 and 54 present the one-way kill potential as a function of altitude for NIKE batteries deployed in a barrier type defense against single IL-28 and TU-4 cells. Kill potentials are given for various spacings between batteries and were found by summing the kill potential contributions of all batteries bearing on a cell flying through the barrier and by averaging these sums over all paths through the barrier.

In order to determine the kill potential of a NIKE barrier type deployment against a stream of IL-28 bomber cells, the kill potential of a single battery is first found against the stream as a function of minimum separation distance. Figure 55 shows the kill potential of a single battery against a
and where

\[ R_{H}^{(k)} = \text{Horizontal range in n. miles between launching site and point of interception on kth shot,} \]

\[ R_{H}^{(m)} = \text{Horizontal range in n. mile between launching site and point of interception on last shot,} \]

\[ r = \text{Minimum horizontal separation distance in n. miles between launching site and bomber cell path,} \]

\[ T_{R} = \text{Effective tracking range in n. miles, and} \]

\[ h = \text{Bomber cell altitude in feet.} \]

Maximum open and close horizontal interception ranges are listed in Table 30 for the various altitudes and horizontal minimum separation distances used in arriving at Figs. 45 and 46.

It should be noted that where the NIKE radar site is separated from the launching site, the kill probability is no longer a function of the horizontal range from the launching site but from the radar site. Since the bomber cell is assumed to come from the direction in which the radar site is set forward of the launching site, the kill probabilities for the separated sites can be read off a graph like Fig. 48 for combined sites by shifting the \( D_L \) axis to the left by the distance between sites.

The kill potentials against each bomber cell path by the NIKE battery site are just the sum of the single shot kill probabilities against the cell multiplied by the reliability factor or in equation form

\[ K_{P} = P \sum_{k = 1}^{m} P_{K}^{(k)} \quad (7) \]

where
Fig. 51—Kill potential of Nike battery protecting point target from IL-28 bomber cell
Fig. 52—Kill potential of Nike battery protecting point target from TU-4 bomber cell
Fig. 53—Kill potential of Nike barrier against cell of IL-28 bombers

50 n mi spacing between batteries
Fig. 54—Kill potential of Nike barrier against cell of TU-4 bombers
Fig. 55 — Nike battery kill potential against IL-28 bomber stream
stream of 28 IL-28 bomber cells stretching 133 n. miles in length. Except against the first and last cell of the stream, all shots by the battery under the assumed firing doctrine would be fired against the stream at near minimum separation range. Since the stream is 20 minutes in duration, the kill potential for the battery is equivalent to the kill potential for one full engagement of a cell plus the kill potential for 20 minutes of firing against cells at minimum range.

Suming the kill potentials of all batteries bearing on the IL-28 bomber stream and averaging over all paths through the barrier gives the kill potential for the barrier against the stream. In Fig. 56, the barrier kill potential against the stream is plotted as a function of bomber altitude for various battery spacings.

The kill potential of a NIKE area type defense is determined by treating the area deployment as a series of barrier deployments. Thus the kill potential of the area defense against a single cell or stream of cells is based on the number of barriers crossed equivalent to a given penetration of the defended area and is treated as proportional to the depth of penetration. The geometry of this situation is illustrated in Fig. 57 for batteries spaced 30 n. miles apart. Figures 58 and 59 give the kill potential of the NIKE area type defense as a function of attack altitude and normalized on the basis of every 100 n. miles flown by single IL-28 and TU-4 bomber cells through the defended area. Various spacings from 20 to 50 n. miles are considered between batteries in Figs. 58 and 59. Figure 60 gives the kill potential of the NIKE area type defense against the IL-28 bomber stream.
Stream includes 28 bomber cells

Stream length is 20 min or 133 n mi

20 n mi spacing between batteries

Fig. 56 — Kill potential of Nike barrier against stream of IL-28 bombers

Altitude in thousands of feet

Kill potential
Fig. 57—Geometry of Nike area deployment with batteries spaced 30 N. miles apart
Fig. 58—Kill potential of Nike area defense against cell of IL-28 bombers

50 n miles spacing between batteries

Kill potential of every 100 n mi through def
Fig. 59 — Kill potential of Nike area defense against cell of TU-4 bombers

Kill potential for every 100 n m i through defense
Stream includes 28 bomber cells
Stream length is 20 min or 133 n mi

Fig. 60—Kill potential of Nike area defense against stream of IL-28 bombers
In the case of a multiple cell penetration of a NIKE defended area, there might be more bomber cells than NIKE batteries within a region at a given time so that the batteries couldn't fully engage all cells. Thus, in this case, the NIKE area defense kill potential is not always simply the product of the number of penetrating cells by the area kill potential against an average penetrating cell. This is illustrated in the special case of a stream of penetrating cells where the batteries engaging the stream fire at most cells only a fraction of the time they are within battery range.

To determine the round-trip kill potential against a multiple cell penetration of a defended area in the more general case where the cells are spread uniformly both laterally as well as in depth, the engaged cell density is multiplied by the kill potential rate per cell and integrated over the portion of the raid exposed to the defense from the time the raid enters to the time it leaves the defended area. This is expressed as

\[ K_P^{(\text{Rd. Trip})} = \int_0^A \int_{-V(v)}^V K_P(u, v) n_e(u, v) \, du \, dv \]  

(3)

where

- \( K_P^{(\text{Rd. Trip})} \) = Round-trip kill potential of NIKE area defense against multiple cell raid
- \( K_P(u, v) \) = Kill potential of NIKE area defense against single cell for each unit of distance flown through defended area at time \( t \) after penetration where \( v = V_T t \)
- \( n_e(u, v) \) = Engaged cell density at distance \( u \) into defended territory and at time \( t \) after penetration where \( v = V_T t \)
- \( V_T \) = Speed of cells in raid
- \( \dot{V} \) = Distance traveled by cells in the raid from the time the raid enters to the time the last cell leaves the NIKE defended area and
- \( V(v) \) = Spread from front to rear of raid within defended area.
Since the kill potential against a single cell is treated as proportional only to the distance traveled through the NIKE defended area without regard to the cell location within the defended area, the kill potential rate against a single cell, \( K_P(u, v) \), is constant, \( K_P \). Thus

\[
K_P(\text{Rd. Trip}) = \bar{K}_P \int_0^L \int_{V-V(v)}^V n_E(u, v) \, du \, dv. \tag{9}
\]

In order to determine \( n_E(u, v) \), certain assumptions are made about the location and distribution of targets within the defended area and the method of assigning bomber cells to targets. The targets are assumed to be distributed uniformly within the NIKE defended area except for a forward buffer zone \( L_B \) nautical miles in depth containing no targets. It is further assumed that the forward bomber cells bomb the deepest targets in the defended area and that the other bomber cells bomb the targets relative to their position in the raid going back to the rear bomber cells which bomb the closest targets. After bombing their targets, the cells are considered to turn around and proceed back through the defended area the same way they came. Hence during a portion of the attack there will be cells flying both inbound and outbound. Considering only the case where the depth \( L \) of the defended area is greater than the length \( L_s \) of the bomber raid or stream so that there is no overlapping of inbound and outbound portions of the raid, then

\[
n_E(u, v) = n_E^{(\text{Inb})}(u, v) + n_E^{(\text{Outb})}(u, v)
\]

and

\[
K_P(\text{Rd. Trip}) = \bar{K}_P \int_0^L \int_{V-V^*(v)}^V n_E^{(\text{Inb})}(u, v) \, du \, dv + \bar{K}_P \int_0^L \int_{V-V(v)}^V n_E^{(\text{Outb})}(u, v) \, du \, dv. \tag{10}
\]
On the basis of the assumed attack model, the engaged cell density is uniform at any instant over each of the inbound and outbound portions of the raid in NIKE defended territory. Thus

\[ n_E^{(\text{Inb})}(u, v) = \begin{cases} 
  n_E^{(\text{Inb})}(v) & \text{for } 0 \leq v \leq v^{(\text{Inb})} \\
  0 & \text{for } v > v^{(\text{Inb})}
\end{cases} \]

\[ n_E^{(\text{Outb})}(u, v) = \begin{cases} 
  n_E^{(\text{Outb})}(v) & \text{for } v' \leq v \leq v' + \chi \\
  0 & \text{for } v < v'
\end{cases} \]

where

\[ v^{(\text{Inb})} = \text{Distance flown by the cells from the time of raid penetration to the time the last bomb is dropped on target, and} \]

\[ v' = \text{Distance flown by the cells from the time of raid penetration to the time the first bomb is dropped on target,} \]

and

\[ K_P^{(\text{Rad. Trip})} = K_P^{(\text{Inb})} + K_P^{(\text{Outb})} \]

Therefore

\[ K_P^{(\text{Rad. Trip})} = K_P^{(\text{Inb})} + K_P^{(\text{Outb})} \]

where

\[ K_P^{(\text{Inb})} = K_P v^{(\text{Inb})} \frac{n_E^{(\text{Inb})}}{v^{(\text{Inb})}} \]

\[ \frac{n_E^{(\text{Inb})}}{v^{(\text{Inb})}} = \frac{1}{v^{(\text{Inb})}} \int_0^{v^{(\text{Inb})}} v^{*}(v) n_E^{(\text{Inb})}(v) \, dv \]

\[ K_P^{(\text{Outb})} = K_P v^{(\text{Outb})} \frac{n_E^{(\text{Outb})}}{v^{(\text{Outb})}} , \quad (v^{(\text{Outb})} = \hat{v} - v') \]
\[ \overline{n}_E^{\text{(Outb)}} = \frac{1}{V'(\text{Outb})} \int_{V'}^{V'} V'(v) \overline{n}_E^{\text{(Outb)}}(v) \, dv \]  

and where

\( K_p^{(\text{Rd Trip})} \) = Round-trip kill potential of NIKE area defense against multiple cell raid,

\( K_p^{(\text{Inb})} \) = Inbound kill potential of NIKE area defense against multiple cell raid,

\( K_p^{(\text{Outb})} \) = Outbound kill potential of NIKE area defense against multiple cell raid,

\( \overline{n}_E \) = Kill potential of NIKE area defense against single cell for each unit of distance flown through defended area,

\( \overline{n}_E^{\text{(Inb)}} \) = Average engaged number of inbound bomber cells,

\( \overline{n}_E^{\text{(Outb)}} \) = Average engaged number of outbound bomber cells,

\( v^{\text{(Inb)}} \) = Distance flown by the cells from the time of raid penetration to the time the last bomb is dropped on target,

\( v^{\text{(Outb)}} \) = Distance flown by the cells from the time the first bomb is dropped on target to the time the last cell leaves the defended area,

\( v \) = Distance flown by the cells from the time of raid penetration to the time the first bomb is dropped on target,

\( \hat{v} \) = Distance flown by cells in the raid from the time the raid enters to the time the last cell leaves the defended area,

\( V^*(v) \) = Spread from front to rear of inbound portion of raid within defended area,
Letting

\[ v' \] 

\[ n_E^{(\text{Inb})}(v) \] = Engaged inbound cell density at time \( t \) after penetration where \( v = V_T t \),

\[ n_E^{(\text{Outb})}(v) \] = Engaged outbound cell density at time \( t \) after penetration where \( v = V_T t \), and

\[ V_T \] = Speed of cells in raid.

Equations 14 and 16 become

\[ n_E^{*}(v) = v^*(v) n_E^{(\text{Inb})}(v) \]

\[ n'_E(v) = v'(v) n_E^{(\text{Outb})}(v), \]

where

\[ n_E^{*}(v) \] = Number of engaged inbound cells at time \( t \) after penetration where \( v = V_T t \), and

\[ n'_E(v) \] = Number of engaged outbound cells at time \( t \) after penetration where \( v = V_T t \).

At any instant, the number of engaged cells, \( n_E(v) \), equals the smaller of the number of bomber cells exposed to the defending MIKE batteries, \( n_R(v) \), or of the number of MIKE batteries able to bear on these cells, \( N_R(v) \).
Hence

\[ n_E^*(v) = \min \begin{cases} \frac{F_R}{R}(Inb) (v) \\ \frac{n_R}{R}(Inb) (v) \end{cases} \]

and

\[ n_E'(v) = \min \begin{cases} \frac{n_R}{R}(Outb) (v) \\ \frac{n_R}{R}(Outb) (v) \end{cases} \]

Tables 31 and 32 give the formulas for calculating the number of engaged inbound and outbound cells, respectively, at any instant. There are three different cases considered depending upon the size of \( L \) with respect to \( L_s \) and \( L_B \), and each inbound and outbound interval is divided into three segments with \( n_E(v) \) expressed as a continuous function in the segments.

Performing the integrations in Eqs. 17 and 18 gives the formulas for \( n_E(Inb) \) and \( n_E(Outb) \) shown in Table 33. Substituting these formulas into Eqs. 13 and 15, the inbound and round-trip kill potentials of a NIKE area defense against a multiple cell raid are given by

\[ K_p(Inb) = \begin{cases} \frac{1}{2} \left( \frac{L_s}{L} \right)^N \left( L + L_B \right)^N \frac{F_P}{P} \text{ for } n \geq \frac{L_s}{L} \end{cases} \]

(19)

\[ K_p(Outb) = \begin{cases} \frac{1}{2} \left( \frac{L + L_B}{L} \right) \left( 2L - L_s - 2L_B \right)^N \frac{F_P}{P} \text{ for } n \geq \left( \frac{2L - L_s - 2L_B}{L} \right)^N \end{cases} \]

(20)

where

\[ K_P \text{ (Inb)} = \text{Inbound kill potential of NIKE area defense against multiple cell raid}, \]

\[ K_P \text{ (Outb)} = \text{Outbound kill potential of NIKE area defense against multiple cell raid}, \]
### Table 31

**Formulas for the Number of Engaged Inbound Cells at Any Instant**

<table>
<thead>
<tr>
<th>Number of Engaged Inbound Cells, $n^*_R(v)$</th>
<th>For $n \geq \frac{L_s}{L} N, n_R(\text{Inb}) (v)$</th>
<th>For $n \leq \frac{L_s}{L} N, n_R(\text{Inb}) (v)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case</td>
<td>Range of $v$</td>
<td>For $n \geq \frac{L_s}{L} N, n_R(\text{Inb}) (v)$</td>
</tr>
<tr>
<td>$L \leq (L_s + 2L_B)$</td>
<td>$0 \leq v \leq L_s$</td>
<td>$\frac{V}{L} N$</td>
</tr>
<tr>
<td></td>
<td>$L_s \leq v \leq (L_s + L_B)$</td>
<td>$\frac{L_s}{L} N$</td>
</tr>
<tr>
<td></td>
<td>$(L_s + L_B) \leq v \leq L$</td>
<td>$\frac{L_s}{L} \left( \frac{L - v}{L - L_s - L_B} \right) N$</td>
</tr>
<tr>
<td></td>
<td>$(L_s + L_B) \leq L \leq (L_s + 2L_B)$</td>
<td>$0 \leq v \leq L_s$</td>
</tr>
<tr>
<td></td>
<td>$L_s \leq v \leq (L_s + L_B)$</td>
<td>$\frac{L_s}{L} N$</td>
</tr>
<tr>
<td></td>
<td>$(L_s + L_B) \leq v \leq L$</td>
<td>$\frac{L_s}{L} \left( \frac{L - v}{L - L_s - L_B} \right) N$</td>
</tr>
<tr>
<td>$L_s \leq L \leq (L_s + L_B)$</td>
<td>$0 \leq v \leq L_s$</td>
<td>$\frac{V}{L} N$</td>
</tr>
<tr>
<td></td>
<td>$L_s \leq v \leq L$</td>
<td>$\frac{L_s}{L} N$</td>
</tr>
<tr>
<td></td>
<td>$L \leq v \neq (L_s + L_B)$</td>
<td>$\frac{L_s}{L} \left( \frac{v - L_B - L_s}{L - L_s - L_B} \right) N$</td>
</tr>
</tbody>
</table>

$I_s$ = Depth of NIKE defended area.

$L_s$ = Length of bomber raid or stream.

$L_B$ = Depth of forward buffer zone in defended area containing no targets.
Table 31 (Cont.)

\[ v = \text{Distance flown by bomber cells from the time of raid penetration.} \]

\[ n = \text{Number of bomber cells in raid.} \]

\[ N = \text{Number of NIKE batteries in defended area.} \]

\[ N_R^{(Inb)} (v) = \text{Number of NIKE batteries able to bear on inbound cells at instant corresponding to } v. \]

\[ n_R^{(Inb)} (v) = \text{Number of inbound bomber cells exposed to defending NIKE batteries at instant corresponding to } v. \]
### Table 32
Formulas for the Number of Engaged Outbound Cells at Any Instant

<table>
<thead>
<tr>
<th>Case</th>
<th>Range of ( v )</th>
<th>Number of Engaged Outbound Cells, ( n_R^{(\text{out})}(v) )</th>
<th>Number of Engaged Outbound Cells, ( n_R^{(\text{out})}(v) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L \leq (L_a + 2L_B) )</td>
<td>((L_a + L_B) \leq v \leq (L_a + 2L_B))</td>
<td>( \frac{(2L - L_a - 2L_B)}{L} n )</td>
<td>( \frac{(v - L_a - L_B)(2L - L_a - 2L_B)}{L} n )</td>
</tr>
<tr>
<td>( L_a + 2L_B \leq v \leq L )</td>
<td>( (L_a + 3L_B) \leq v \leq L )</td>
<td>( \frac{v - L_a - L_B}{L} n )</td>
<td>( \frac{(2L - v)}{L} n )</td>
</tr>
<tr>
<td>( L \leq v \leq 2L )</td>
<td>((L_a + L_B) \leq v \leq (L_a + 2L_B))</td>
<td>( (v - L_a - L_B)(2L - L_a - 2L_B) )</td>
<td>( \frac{v - L_a - L_B}{L} n )</td>
</tr>
<tr>
<td>( L_a \leq L \leq (L_a + L_B) )</td>
<td>( L \leq v \leq (L_a + L_B))</td>
<td>( \frac{(2L - v)}{L} n )</td>
<td>( \frac{v - L_a}{L} n )</td>
</tr>
<tr>
<td>( L_a + 2L_B \leq v \leq 2L )</td>
<td>( (L_a + L_B) \leq v \leq (L_a + 2L_B))</td>
<td>( \frac{(v - L_a - L_B)}{L} n )</td>
<td>( \frac{(2L - v)}{L} n )</td>
</tr>
</tbody>
</table>

\( L \) = Depth of MKR defended area.
\( L_a = \) Length of bomber raid or stream.
\( L_B = \) Depth of forward buffer zone in defended area containing no targets.
\( v = \) Distance flown by bomber cells from the time of raid penetration.
\( n = \) Number of bomber cells in raid.
\( n_R = \) Number of MKR batteries in defended area.
Table 33
FORMULAS FOR THE AVERAGE ENGAGED NUMBER
OF INBOUND AND OUTBOUND BOMBER CELLS

Inbound

\[ L \geq (L_s + L_B), \quad v^{(\text{Inb})} = L \]

\[
\begin{align*}
\frac{n}{n}^{(\text{Inb})} &= \begin{cases} 
\frac{1}{2} \frac{L_s (L + L_B)}{L} \quad \text{N for } n \geq \frac{L_s}{L} \cdot N \\
\frac{1}{2} \frac{(L + L_B)}{L} \quad \text{n for } n \leq \frac{L_s}{L} \cdot N
\end{cases}
\end{align*}
\]

\[ L_s \leq L \leq (L_s + L_B), \quad v^{(\text{Inb})} = L_s + L_B \]

\[
\begin{align*}
\frac{n}{n}^{(\text{Inb})} &= \begin{cases} 
\frac{1}{2} \frac{L_s (L + L_B)}{L} \quad \text{N for } n \geq \frac{L_s}{L} \cdot N \\
\frac{1}{2} \frac{(L + L_B)}{L_s + L_B} \quad \text{n for } n \leq \frac{L_s}{L} \cdot N
\end{cases}
\end{align*}
\]

Outbound

\[ L \geq (L_s + L_B), \quad v^{(\text{Outb})} = (2L - L_s - L_B) \]

\[
\begin{align*}
\frac{n}{n}^{(\text{Outb})} &= \begin{cases} 
\frac{1}{2} \frac{(L + L_s) (2L - L_s - 2L_B)}{L (2L - L_s - L_B)} \quad \text{N for } n \geq \frac{2L - L_s - 2L_B}{L} \cdot N \\
\frac{1}{2} \frac{(L + L_s)}{2L - L_s - L_B} \quad \text{n for } n \leq \frac{2L - L_s - 2L_B}{L} \cdot N
\end{cases}
\end{align*}
\]

\[ L_s \leq L \leq (L_s + L_B), \quad v^{(\text{Outb})} = L \]

\[
\begin{align*}
\frac{n}{n}^{(\text{Outb})} &= \begin{cases} 
\frac{1}{2} \frac{(L + L_s) (2L - L_s - 2L_B)}{L} \quad \text{N for } n \geq \frac{2L - L_s - 2L_B}{L} \cdot N \\
\frac{1}{2} \frac{(L + L_s)}{L} \quad \text{n for } n \leq \frac{2L - L_s - 2L_B}{L} \cdot N
\end{cases}
\end{align*}
\]

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\( K_P (\text{Outb}) \) = Round-trip kill potential of NIKE area defense against multiple cell raid,

\( \overline{K}_P \) = Kill potential of NIKE area defense against single cell for each unit of distance flown through defended area,

\( L \) = Depth of NIKE defended area,

\( L_s \) = Length of bomber raid or stream,

\( L_B \) = Depth of forward buffer zone in defended area containing no targets,

\( n \) = Number of bomber cells in raid, and

\( N \) = Number of NIKE batteries in defended area.

To find the lower bound \( E_{\text{Inb}} \) on the expected number of inbound bomber kills by the NIKE area defense against a multiple cell raid, the following formula is applied

\[
E_{\text{Inb}} = \frac{n_B}{n_R} (\text{Inb}) \left( 1 - e^{-K_P (\text{Inb}) / \overline{N}_B (\text{Inb})} \right)
\]

where

\[
\frac{n_B}{n_R} (\text{Inb}) = 13 \frac{n_B}{n_R} (\text{Inb})
\]

and

\[
\frac{n_B}{n_R} (\text{Inb}) = \text{Average number of inbound bombers in range of NIKE batteries during inbound penetration of defended area.}
\]

\( K_P (\text{Inb}) \) = Inbound kill potential of NIKE area defense against multiple cell raid, and

\[
\frac{n_B}{n_R} (\text{Inb}) = \frac{n_E}{L} (\text{Inb}) \text{ for } n \leq \frac{L}{N}
\]

or the average number of inbound bomber cells in range of NIKE batteries during raid penetration of defended area.
Dropping out the bombers killed inbound gives the following expression for the lower bound \( E_{\text{Rd. Trip}} \) on the expected number of round-trip kills by the NIKE area defense against a multiple cell raid.

\[
E_{\text{Rd. Trip}} = E_{\text{Inb.}} + E_{\text{Outb.}}
\]

where

\[
E_{\text{Outb.}} = \bar{n}_B(\text{Outb}) - K_P(\text{Outb})/\bar{n}_R(\text{Outb}) (1 - e^{-K_P(\text{Outb})/\bar{n}_R(\text{Outb})})
\]

and

\[
\bar{n}_B(\text{Outb}) = \left( \frac{13n - E_{\text{Inb.}}}{n} \right) \bar{n}_R(\text{Outb})
\]

\[
E_{\text{Outb.}} = \text{Lower bound on the expected number of outbound bomber kills},
\]

\[
\bar{n}_B(\text{Outb}) = \text{Average number of outbound bombers in range of NIKE batteries during withdrawal from defended area},
\]

\[
K_P(\text{Outb}) = \text{Outbound kill potential of NIKE area defense against multiple cell raid},
\]

\[
\bar{n}_R(\text{Outb}) = \frac{\bar{n}_B(\text{Outb})}{n} \text{ for } n \leq \left( \frac{2L - L_b}{L} \right) N
\]

or the average number of outbound bomber cells in range of NIKE batteries during withdrawal from defended area, and

\[
n = \text{Number of bomber cells in raid}.
\]

Equations 19 through 22 are assumed to apply to the calculation of upper and lower bounds for the expected number of bomber kills by the three NIKE area defenses against the mass high altitude IL-28 raid. Although the raid approaches the proposed defended areas in three distinct cell streams, the streams are considered to break up and spread out on entering the areas thus approximating the condition of spread attack for the equations.
For medium (2000 ft.) and low (1000 ft. or less) IL-28 attack altitudes, these same equations are employed with only the following change at low altitude.

\[ n_E (\text{Inb}) = n (\text{Inb}) \quad \text{and} \quad n_E (\text{Outb}) = n (\text{Outb}) \]

so that at low altitude

\[ K_p (\text{Inb}) = K_p (\text{Outb}) = \left[ \frac{1}{2} (L + L_p) n \right] \overline{K}_p \]

This change in effect says that for low altitude attack, the limited NIKE range makes the chances of more than one cell in range at a time negligible. It should also be mentioned that the gaps in coverage are taken into account in determining the normalized NIKE area defense kill potential against a single cell, \( \overline{K}_p \).

The constants and parameters employed in Eqs. 19 through 22 to calculate limits on expected bomber kills by the three NIKE defended areas against the mass IL-28 raid are presented in Table 34. In Table 35, the calculated upper and lower bounds themselves are given for various altitudes.
### Table 3k

<table>
<thead>
<tr>
<th>Defended Area</th>
<th>L (n. mi.)</th>
<th>W (n. mi.)</th>
<th>L(_B) (n. mi.)</th>
<th>L(_s) (n. mi.)</th>
<th>n</th>
<th>S (n. mi.)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd and 4th ATAF Area</td>
<td>250</td>
<td>300</td>
<td>50</td>
<td>133</td>
<td>56</td>
<td>20</td>
<td>169</td>
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<td>34</td>
<td></td>
</tr>
<tr>
<td>4th ATAF Area</td>
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<td>50</td>
<td>133</td>
<td>23</td>
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<td>75</td>
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<td></td>
<td></td>
<td>50</td>
<td>13</td>
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</tbody>
</table>

L = Depth of NIKE defended area.

W = Width of defended area and formation of cells.

L\(_B\) = Depth of forward buffer zone in defended area containing no targets.

L\(_s\) = Length of bomber stream or formation of cells.

n = Number of bomber cells penetrating defended area.

S = Spacing between NIKE batteries.

\[ N = \left[ \frac{W - 50}{S} + 1 \right] \left[ \frac{L - 133}{S} + 1 \right] \text{ or number of batteries in defended area.} \]
<table>
<thead>
<tr>
<th>Battery Altitude (Feet)</th>
<th>2nd and 4th ATAF Area</th>
<th>4th ATAF Area</th>
<th>England</th>
</tr>
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<tbody>
<tr>
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<td>Round-Trip</td>
<td>Inbound</td>
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<td>Upper Bound</td>
<td>Lower Bound</td>
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<td>287</td>
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<td>122</td>
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<tr>
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<td>54</td>
<td>17</td>
<td>18</td>
</tr>
</tbody>
</table>

* Kill potential or upper bound on expected bomber kills not allowed to exceed the number of bombers exposed to the defense.