S E C R E T

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Project RAND FC
RESEARCH MEMORANDUM

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STRATEGIC BOMBARDMENT CAMPAIGNS AND THE EFFECTS OF SOME ELECTRONIC COUNTERMEASURES

MARCH 1955

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## PREFACE

This is an abridged version of a research memorandum prepared in December of 1953. The abridgment consists merely in the omission of data concerning actual costs and fissile material requirements for the strategic bombing campaigns analyzed. The discussion, analytical methods, and conclusions remain unchanged, and are felt to have a certain value apart from the specific numbers on which they are based. The reader is reminded, however, that the study was conducted approximately a year and a half prior to the issuance of this abridged version; as a result no special significance should be attached to the aircraft types, etc., that are used for illustrative purposes.

Analyses are made of several strategic bombing campaigns against targets defended by an efficient defense system of medium strength, equipped with area weapon systems (interceptors) and local weapon systems (missiles). Attention is concentrated on the reduction of defense effectiveness by electronic countermeasures (ECM) and the resulting effects on size, structure and tactics of the forces required by the offense to achieve campaign objectives.

The basic purpose of the study is to describe the impact of the preferred countermeasures upon strategic bombardment force planning. It is hoped that this memorandum can provide guidance for ECM development and for integration of ECM into the family of USAF weapon systems.

Special acknowledgment is due E. S. Quade. Mr. Quade contributed greatly to the development of the analytical campaign models used in this study; in addition he supervised the computations and aided in interpretation. Acknowledgment is also due J. L. Hult, who contributed much to the over-all analysis.

A list of symbols used is included in fold-out pages at the end of the report, pp. 80 and 81.

## SUMMARY

Three strategic bombing campaigns for the purpose of destroying 80 out of 100 Russian targets are studied analytically to show the effect of ECM on campaign costs and to bring out the changes in force programming and strategy which will make the best use of ECM. The defense is assumed to consist of a fixed force of radar-directed manned interceptors spread over the area containing the targets, plus a local surface-to-air radar-directed missile battery at each target. Relationships between the investment cost in B-47B aircraft and the quantity of fissile material used in the total campaign are derived for variations in the number of targets attacked per strike. After consideration of a basic campaign series without ECM, the degrading effects of chaff and decoy countermeasures on the area and local defenses are estimated, and the effects of applying ECM are calculated for a series of strikes in which the original force size is the same as that required without ECM, and for a series of strikes in which the initial force size is reduced by an amount permitted by the ECM.

It is shown that by the use of ECM with the previously programmed force, the capability of the force to strike an additional series of defended targets is increased greatly for a small ECM cost, while in the last campaign the total cost of executing the fixed campaign requirement is reduced greatly for a relatively small expenditure on ECM. The ECM expenditures which seem reasonable as a result of this study are considerably greater than those now being made. The direct expenditures on ECM devices are far smaller than the total costs of applying the ECM contemplated in the campaigns, because the major part of ECM cost in a campaign is in the purchase and maintenance of the aircraft and aircrews needed to carry ECM devices into battle. Primary attention is given to high-confidence ECM such as chaff and decoy vehicles, although some consideration of countermeasures of opportunity is included.

## I. INTRODUCTION

From the first uses of electronic countermeasures by offensive airborne forces to interfere with the application of defensive weapons, a method has been needed to enable the offensive weapon system planner to evaluate the expected results of ECM activities. Evaluation is necessary for guiding ECM development projects and for integrating ECM effort into force planning.

In order to throw some light on the problem of evaluation, RAND has undertaken a study of strategic air bombardment campaigns including ECM activities on the part of the offensive forces. This report is one of a series(1)(2)(3) presenting results of the study.

The concepts used in the description of offensive and defensive forces and in the analysis of campaigns are drawn from the defense systems study(4)(5) and the Missiles Systems for Strategic Bombardment study(6)(7)(8)(9) conducted at RAND. Most use is made of the latter study, especially with regard to the analytical model used to obtain quantitative results. All numerical values and estimates used (except where noted) are drawn directly from that study.

The present memorandum is concerned, so far as the numerical values and examples referred to, only with the period 1956-1958. The context is a USAF strategic bombardment campaign of about two to three months' duration, using B-47B aircraft from overseas operating bases, with and without countermeasures. The campaign consists of a series of high-altitude strikes against 100 representative industrial targets within the USSR. Atomic weapons are used against the targets. The targets are located in 66 metropolitan areas having a fairly

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(1) References are listed at the end of the report, p. 82.

general geographic distribution. About 75 to 90 per cent of USSR steel, petroleum, aircraft engine, motor vehicle, combat vehicle, and synthetic ammonia production capacities are included. (See map, Fig. 5, p. 19.) The campaign objective is to destroy at least 80 of the 100 targets.

During the study of ECM in aerial warfare, it became clear that nearly all countermeasures of practical military interest could be divided conveniently into two broad categories. The first consists of countermeasures which rely for their effectiveness on more or less fundamental limitations of the defenses; these have been called "high-confidence countermeasures." The second group must rely for their effectiveness on taking advantage of some particular defensive weapon, circuit, or tactic; these have been named "countermeasures of opportunity."

High-confidence countermeasures (for example, small unmanned decoys*) are characterized generally by the fact that they can be expected to be effective threats over a relatively long period of time. The important property of such countermeasures to the offensive force planner is that the defense cannot exert a strong influence on the calculable success of the countermeasure. This is in contrast to the countermeasures of opportunity (e.g., burst chaff) which depend for their success upon the defense employing a specific circuit or system at a specific time. The offensive force planner cannot rely upon such countermeasures over a long period of time, since their effectiveness is a strong function of detailed defensive weapon characteristics.

Additional interesting properties appear to characterize these two

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*As an example of a decoy, consider an XQ-1- or XQ-2-like vehicle carrying repeaters or barrage jammers flying in a bomber strike with aircraft also carrying the same ECM equipments.

categories of countermeasures. Production costs of high-confidence ECM (at least for those found so far) are generally higher than for countermeasures of opportunity. Relative development costs would be difficult to determine without a considerably more extensive study than has been carried out so far, but it appears that the difference in cost between high-confidence countermeasures and countermeasures of opportunity is not great. With respect to possible reduction of defense effectiveness, the two ECM categories exhibit quite different characteristics. High-confidence countermeasures may be expected to reduce defense effectiveness by factors of 1/4 to 3/4, whereas the countermeasures of opportunity are capable in many instances (if the defense uses a susceptible circuit or weapon) of wholly negating a specific weapon. Thus the reduction of defense effectiveness can vary from almost none to total.

If the offense knows and can exploit the weakness of the defense, the effect of countermeasures of opportunity can be devastating. However, it is difficult to see how offensive force planners can recognize such opportunities years ahead and take the advantage into account in force design, procurement, and tactics.

To study the effect that various categories of ECM activity might have on strategic air campaigns, several types of campaigns, with different "payoff" functions, were analyzed.

Campaign I

Electronic countermeasures are introduced, but the tactics used by the offense force are identical to those which the analysis would prescribe if no electronic countermeasures were used. The over-all cost of the offense force is increased slightly but aircraft and crews are saved by the countermeasures. The payoff for ECM is to be found either in higher survival during the specified campaign or in the additional targets that may be attacked with the same force.

Campaign II

Electronic countermeasures are introduced, and the tactics of the offense are allowed to take into account the decreased defense kill potential expected. Since this implies that the offense is depending upon the success of ECM, only high-confidence countermeasures can be considered to apply, and their cost is included in total campaign costs. The cost of the ECM is not, however, allowed to influence the offensive tactics. The payoff for ECM activity in these circumstances is typically measured by the reduced force, and hence reduced costs, required to obtain the specified target damage. This saving can be related to the cost of the ECM effort, to establish the relative values of the various ECM techniques applicable.

Campaign III

This analysis considers the special case of using decoy countermeasures. Both the cost to the offense and the reduction of defense effectiveness are considered in determining the offensive tactics. The decoys lower the defense effectiveness by saturating either or both area and local defenses. The payoff for this form of ECM effort is found in the form of a smaller force and hence lower cost needed to achieve a specified target damage. In addition, since the offensive tactics are influenced by both reduction in defense effectiveness and by ECM costs, some indication of optimum aircraft expenditure and decoy expenditure is available.

## II. CONCEPT OF A STRATEGIC AIR CAMPAIGN

For the purposes of this report a strategic air campaign is conceived to be as follows:(6)(7)(8)

The job specified is the "confirmed"* destruction of a prescribed proportion of a set of targets or aiming points. The attack consists of utilizing B-47's to transport A-weapons from overseas operating bases through the enemy zone(s) of air defense to the bomb release points, releasing the bombs, and returning again through the defense zone(s) to base. The attacking force encounters area defenses, consisting of interceptor aircraft, throughout its flight in enemy defense zones at distances greater than 30 miles from targets. Within the 30-mile target areas, it encounters local defenses, consisting of ground-to-air missiles. (See pp. 17-19.)

It is assumed that the defender has no loopholes in warning and data-handling systems or in weapons systems. In addition, the composition of the defense forces is assumed to remain constant—that is, the maximum defense kill potential is fixed.** In the presence of ECM, however, the effectiveness of the defense weapons is a variable, as is discussed in following portions of this report.

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*I.e., at least one of the attacking aircraft for each target must have a high probability (greater than 90 per cent) of round-trip survival.

**In general, an increase in defense would require more ECM effort and cost, but the payoff per dollar spent for ECM also would increase. For decreases in defense level less ECM effort would be required. Both statements apply when the campaign objective is held fixed. The results obtained show that the defense potential must be decreased to about 5 to 10 per cent of the initial values used in the numerical analysis here before no cost saving by high-confidence (the more costly form of ECM) countermeasures is obtained.

Consider for the moment possible influences, other than the use of ECM, on attrition of the attacking force. Under the assumptions that the defense system is without loopholes and operates at a fixed maximum kill potential, only the offense can control attrition--by saturating the defense. All known weapon systems suffer from limitations with respect to killing airborne vehicles. Saturation tactics take advantage of these limitations, which are functions of quantity, space, and time.

These limitations are illustrated in the following sketches. Figure 1(a) shows the number of bombers killed by a unit of defense, at various fixed defense kill potentials, as the number of bombers changes. A unit of defense consists, for example, of the interceptors under the control of one OCI station, or the interceptors that can be brought into action over a given area. The same data can be expressed as the rate of bomber attrition. It then appears as in Fig. 1(b).

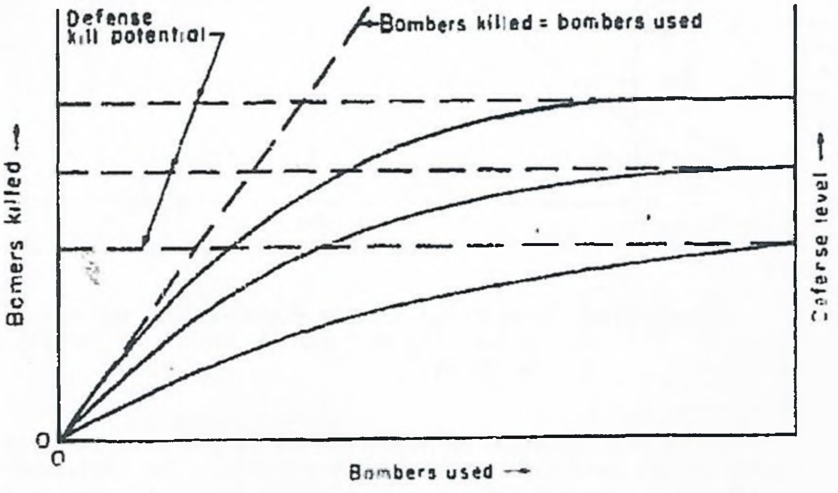

Figure 1(a). Variation in Bombers Killed with Bombers Used and with Defense Kill Potential

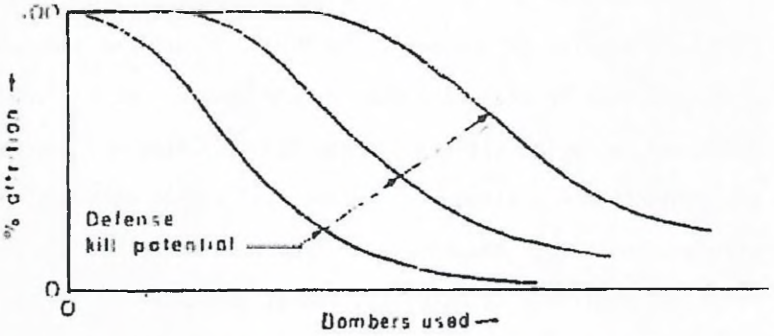

Figure 1(b). Variation in Bomber Attrition Rate with Bombers Used and with Defense Kill Potential

Figures 2(a) and 2(b) show the general way in which the quantities of area and local defenses excited vary with the number of targets attacked.

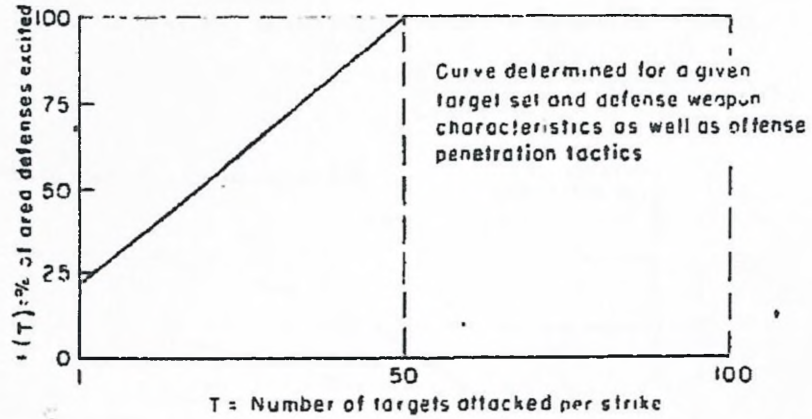

Figure 2(a). Percentage of Area (Interceptor) Defense Excited by the Offense Force vs. Number of Targets Attacked Per Strike*

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*The general relation between strike size and area defenses is also influenced by the detailed structure of the strike. The influence of the total length of the bomber formation in a single strike is seen in Fig. 3(a). The influence of the width of the formation is dependent on the increased number of interceptor and/or GCI stations that can be brought to bear against the raid. See Ref. 9 for a more detailed discussion.

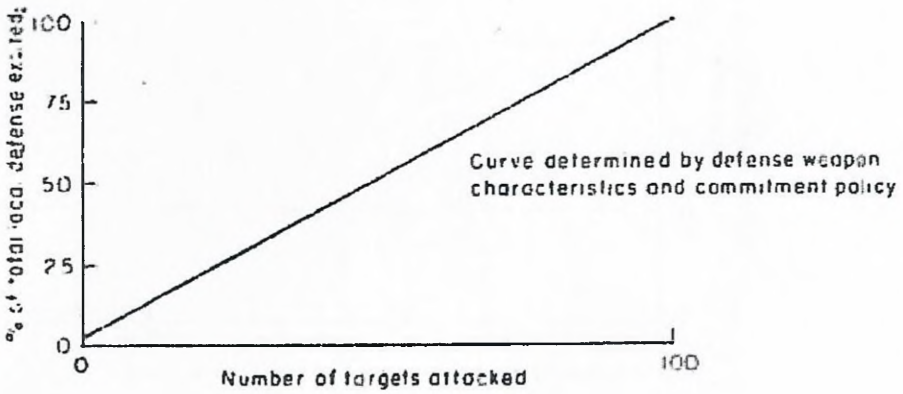

Figure 2(b). Percentage of Local Defenses (Missiles) Excited by the Attacker vs. Number of Targets Attacked

The values indicated on the sketches are typical. The data of Fig. 2(a) are simplified approximations to similar data used in the Missile Systems for Strategic Bombardment study;(6) while the data of Fig. 2(b) are identical to those used in the same study. The area defenses excited per strike* are a function of the targets chosen for attack, as well as a function of the area-defense (e.g., interceptor—GCI) weapons characteristics.

Figure 3(a) shows the fraction of area defense that can be brought to bear against attacking bombers as a function of the length of time during which those defenses must maintain interceptors ready for combat at altitude.

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*A strike is a single penetration of enemy defenses (by one or more vehicles).

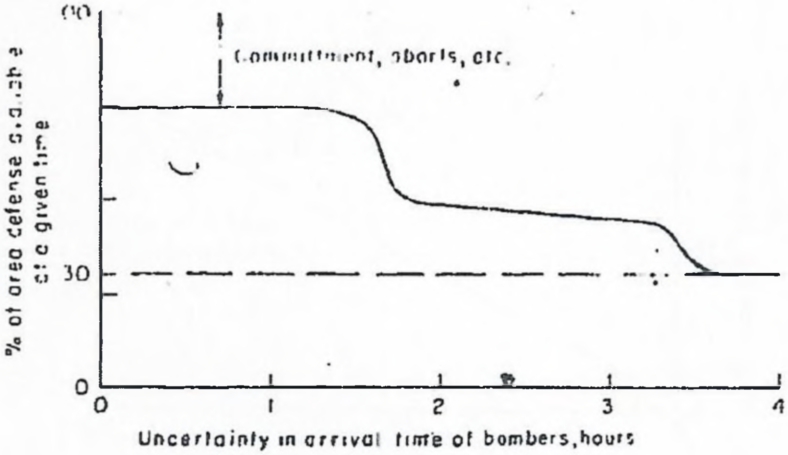

Figure 3(a). Per cent of Area Defense Available vs. Uncertainty in Attack Time

Figure 3(b) shows the relation taken in this study between the fraction of local defenses available and committed against an attacking cell of bombers and the separation, in time, between arrivals of bombers. This curve represents a so-called commitment or firing doctrine on the part of the local defenses as well as the influence of the local defense missile and guidance characteristics.(6)(10)

An examination of Figs. 3(a) and 3(b) will show that the successful exploitation of saturation requires different degrees of bomber density over the local (missile) defense and the area (interceptor) defense. This shows up most markedly in terms of bomber spacing along the penetration path. Whereas the re-cycle time of expected USSR area-defense units (to 1958) is estimated to be of the order of 1 1/2 hours (equivalent to a distance of about 600 nautical miles at bomber speed) the corresponding re-cycle time of local missile defense is very much smaller, of the order of 1 minute or say, 10 miles distance. Within these boundaries the offense must provide more than the number of bombers that the defense can attack successfully. Roughly speaking, the densities required against "good" defenses (in quantity and quality) correspond to spacings (*not* considering elevation spacing) of 5 to 20 miles in area-defense regions and 1 to 5 miles in local-defense regions.[*]

In this study no parameter measures directly the possible variation in local defense efficiency arising from uncertainty in arrival time or course of the attacking cell of bombers. The effect of ECM on the local defense with respect to these parameters must therefore be reflected by interpretation of the "local defense reduction factor" (see p. 38).

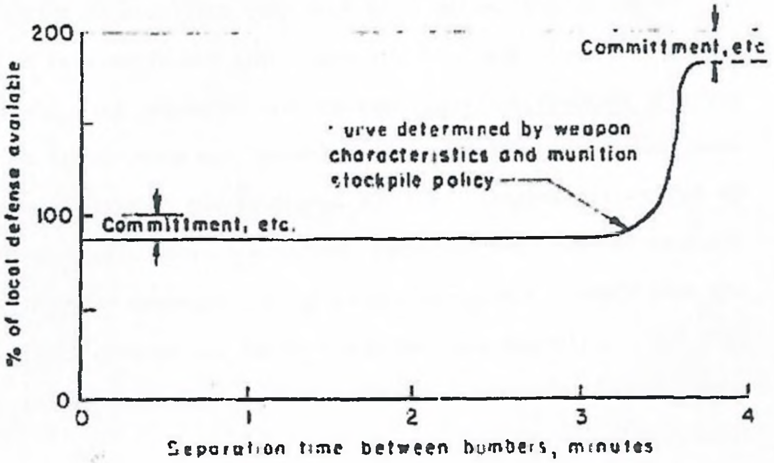

Figure 3(b). Per cent of Local Defense Available vs. Separation Time Between Bombers

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[*] See Ref. 9 for further details on strike requirements generated by these considerations.

Figures 1 through 3 are meant to be illustrative only. A given analysis must specify the values in detail.

The offense has an almost unlimited number of possible strike patterns to choose from in carrying out the total campaign. At one extreme all targets can be attacked simultaneously, once only, for which case all the local defenses and all the area defenses can be brought to bear, but just once. This type of strike minimizes over-all losses to the offense. At the other extreme each target can be attacked by an individual strike with a separation between strikes of several hours or days, in which case all local defenses will eventually be encountered,* and some fraction of the area defenses will be seen as many times as there are targets.

In the latter tactic it is obviously desirable to minimize the exposure of the bombers to the area defenses. This has given rise to the so-called <u>corridor penetration tactic</u> through area defenses, in which attacking bombers enter and proceed into the area defenses in a corridor of a width determined by defense characteristics. The length of the formation is determined by the area-defense re-cycle time. Multiple targets attacked in a single strike are also chosen to minimize exposure. The corridor concept is ideally valid only for a uniformly deployed area defense and becomes less useful as the area-defense deployment becomes bunched for whatever reasons, or if loopholes exist.

The general way in which the numerical strength of the area defense changes with corridor width is shown in Fig. 3(c).

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*Neglecting overlap of the local defenses, for the moment, for simplicity in description.

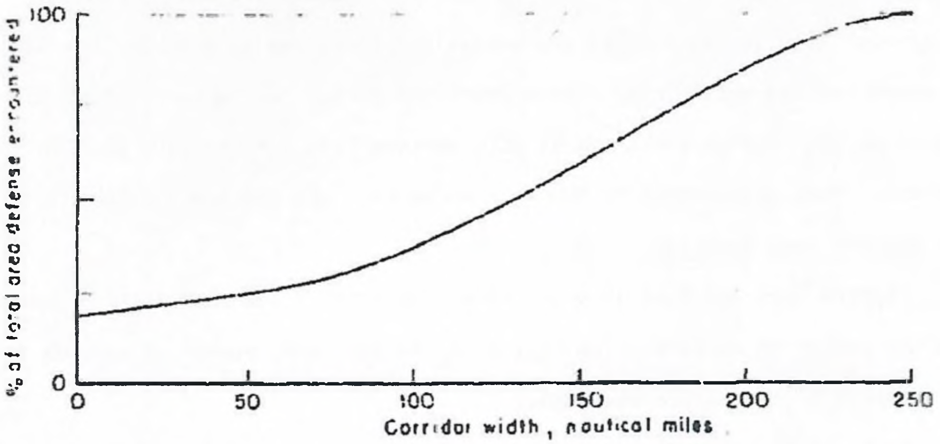

Figure 3(c). Effect of the Penetrating Formation Width

In general, the character of area defenses is such that the extreme multi-strike strategy causes the offensive to encounter up to twenty times as much area defense as the single strike strategy. On the other hand, only about twice as much local defense will be encountered because of local-defense overlap. The multi-strike strategy is usually characterized by efforts to reduce attrition rate rather than total losses. That is, by means of this strategy losses per strike can be reduced (via saturation of portions of the defense), but many strikes are required and hence over-all losses are not reduced.

In order to form some judgment concerning the relative worth of different offense weapons and/or tactics and strategies, it is necessary to represent the costs of the various campaigns considered. These have been termed "system costs." For the campaigns examined here, the system cost is the dollar cost of the total force required to carry out the campaign from stockpile items.

System cost includes strike aircraft, reserve aircraft, total logistic support, base construction and manning, base support,[*] crew training, and so on, totaled for a four-year period of readiness for all components. In general this is the cost to the entire Air Force, as opposed to just SAC, of procuring and maintaining over a four-year period the force required in the campaign. System costs change with various attack strategies and ECM factors. When dollar cost is the only criterion, the optimum solution is the *minimum cost campaign*.

Figures 4(a) and 4(b) show the relations between the more important costs and the number of strikes. (In Fig. 4, $T_o$ is the total number of targets to be attacked in the entire campaign.)

It is clear now how the campaign analysis proceeds insofar as cost criteria are concerned. Aircraft costs, i.e., losses, which are a function of defense effectiveness (and hence ECM) and number of targets attacked per strike (or total number of strikes in the campaign) are balanced against support costs, which tend to be inverse functions of total force size, number of strikes, and campaign time restrictions. For any specified strike size a "best" combination of targets attacked, aircraft per target, bomb size and number per target[**] (all of which influence defense effectiveness) can be computed to minimize the dollar costs. A spectrum of strikes is then examined, and from all such cases a best or minimum cost strategy can be obtained.

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[*] Active defense of strike bases is not included, although the base costs, etc., are based on a dispersal-to-squadron level to reflect some degree of cost of protection.

[**] Bomb size and number will not be specifically optimized in these ECM campaigns. In general a bomb big enough to do the required damage is considered available, with the assumed circular probable error (CEP), and enough must be transported through the defense to produce the required expectation of bomb drops. See Refs. 6 and 5 for further discussion of bomb optimization.

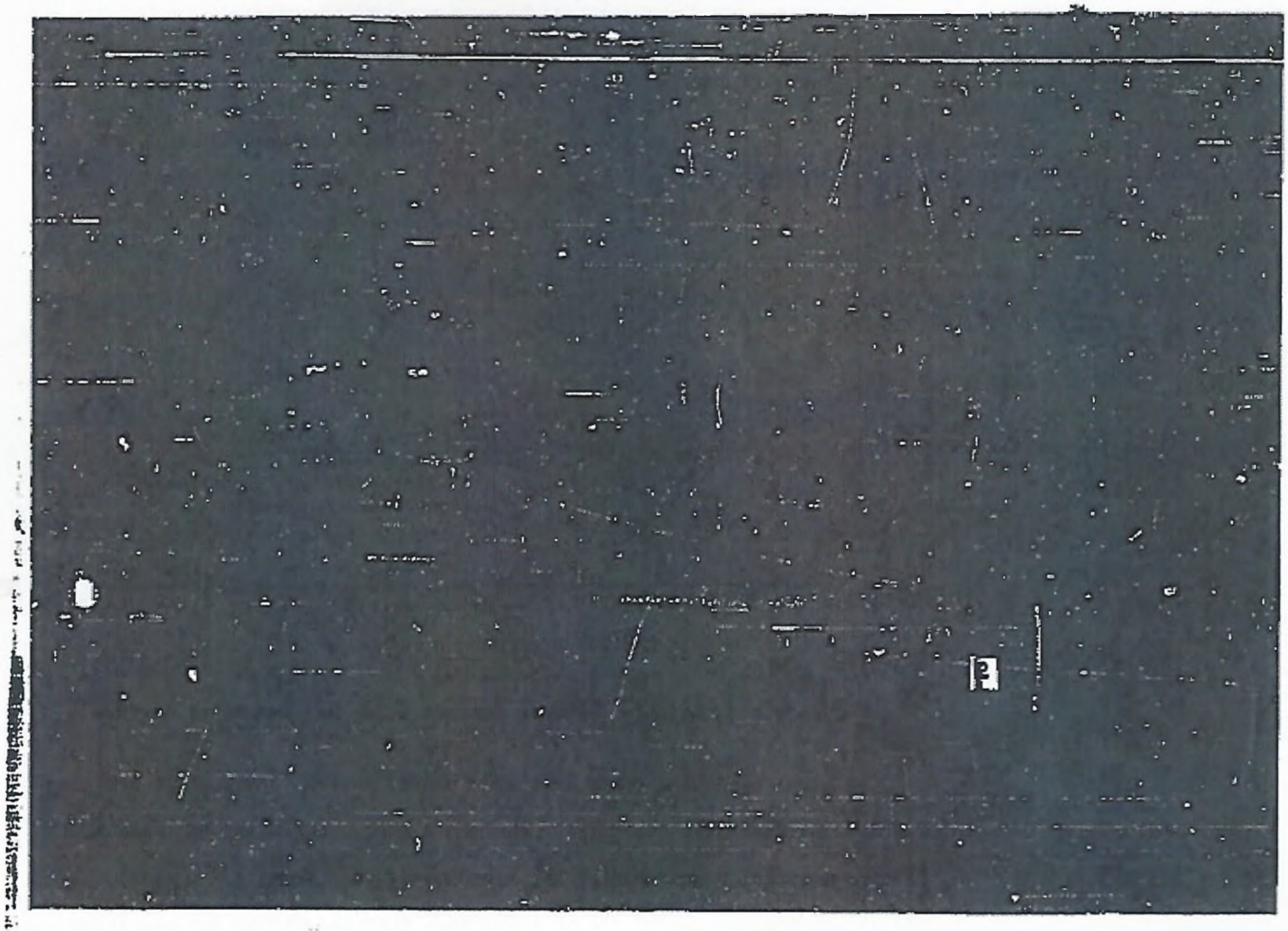

Figure 4(a). Relation between Aircraft Costs and Number of Strikes

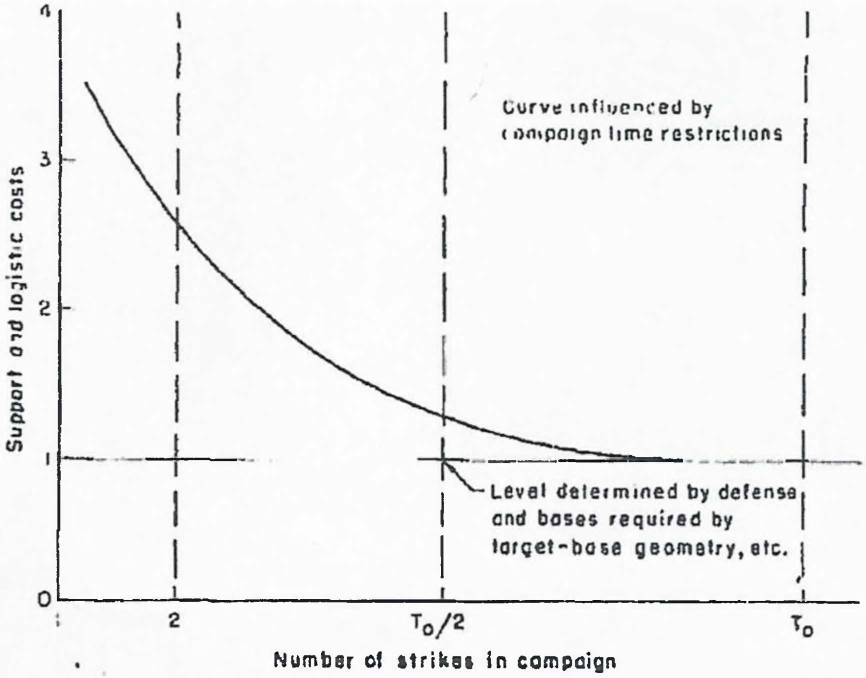

**Figure 4(b). Relation between Support Costs and Number of Strikes**

Besides the dollar costs discussed above, several other costs are also involved in strategic campaigns. Among the more interesting of these are fissile material requirements, air crew losses, and total force size. In the study referred to,(6) all of these were included within the campaigns and "best" combinations were determined. In the ECM campaigns reported here, fissile material requirements are not optimized or minimized for three reasons: the analytical work is unduly complicated without adding insight into the questions concerning effectiveness of ECM; and the results of previous studies(6)(7)(8) are available to show that results are fairly insensitive over wide variations of fissile material restrictions.

Therefore, the campaigns reported here merely indicate the relative amount of fissile material required for strike restrictions (e.g., aircraft survival per target) that have been shown previously to be nearly best with respect to this material.

## III. CAMPAIGN ENVIRONMENT

### A. THE DEFENSE

The 100 targets chosen for the initial campaign are shown in Fig. 5, p. 19. The estimated defense consists of:

1) An aircraft control and warning net providing complete coverage of the area brought under attack and capable of detecting and tracking all the aircraft employed by the offense forces.

2) An inventory of 3000 improved MIG-15 interceptors with afterburners assigned to defend against strategic bombardment. Each interceptor is capable of a single attack against an aircraft. However, attack routes are so chosen, and the interceptors are so distributed, that a maximum of 2200 are excited by attacks against the targets chosen.(6) The interceptors are assumed to have all-weather capability* and are deployed to provide uniform coverage of the area under attack. The performance assumed is equivalent to saying that one-half the interceptors on a base are able to reach (not necessarily attack and kill) the bomber stream out to ranges of 150 miles laterally from the base.

3) An inventory of 200 local-defense guided missile installations (Wasserfall surface-to-air missiles) distributed equally among the targets attacked. The Wasserfall missile has operational and rate-of-fire characteristics essentially the same as those of the Nike missile.

The defensive interceptor force is assumed to be capable of utilizing broadcast as well as close GCI control conditions. This assumption is

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*It is felt that very little difference insofar as basic ECM conclusions are concerned results from changes to day-only interceptors.

important only in that the saturation level of the interceptor defense is computed as that due to interceptor quantity limitations and not to GCI controller limitation and that, in the presence of some forms of ECM, the interceptor forces can use broadcast control without an extra lowered effectiveness due to inadequate training.

Interceptors are not allowed within 30 miles of a target. The acquisition of airborne targets by the missile guidance system is provided for by a local surveillance or acquisition radar. The acquisition and control capabilities of the local-defense units are such that, although little time is consumed in the process, effective programming of missile fire over the incoming aircraft is impossible. Hence the distribution of defensive fire against the aircraft within an attacking cell is considered to be random.

Random distribution is also utilized in the area defenses as a result of broadcast control conditions.[*]

The following list of numerical factors is used in computing area interceptor defense potential:

a) Over-all probability that a committed interceptor kills a bomber,[**]
$P_{AK} \cong 1/10$

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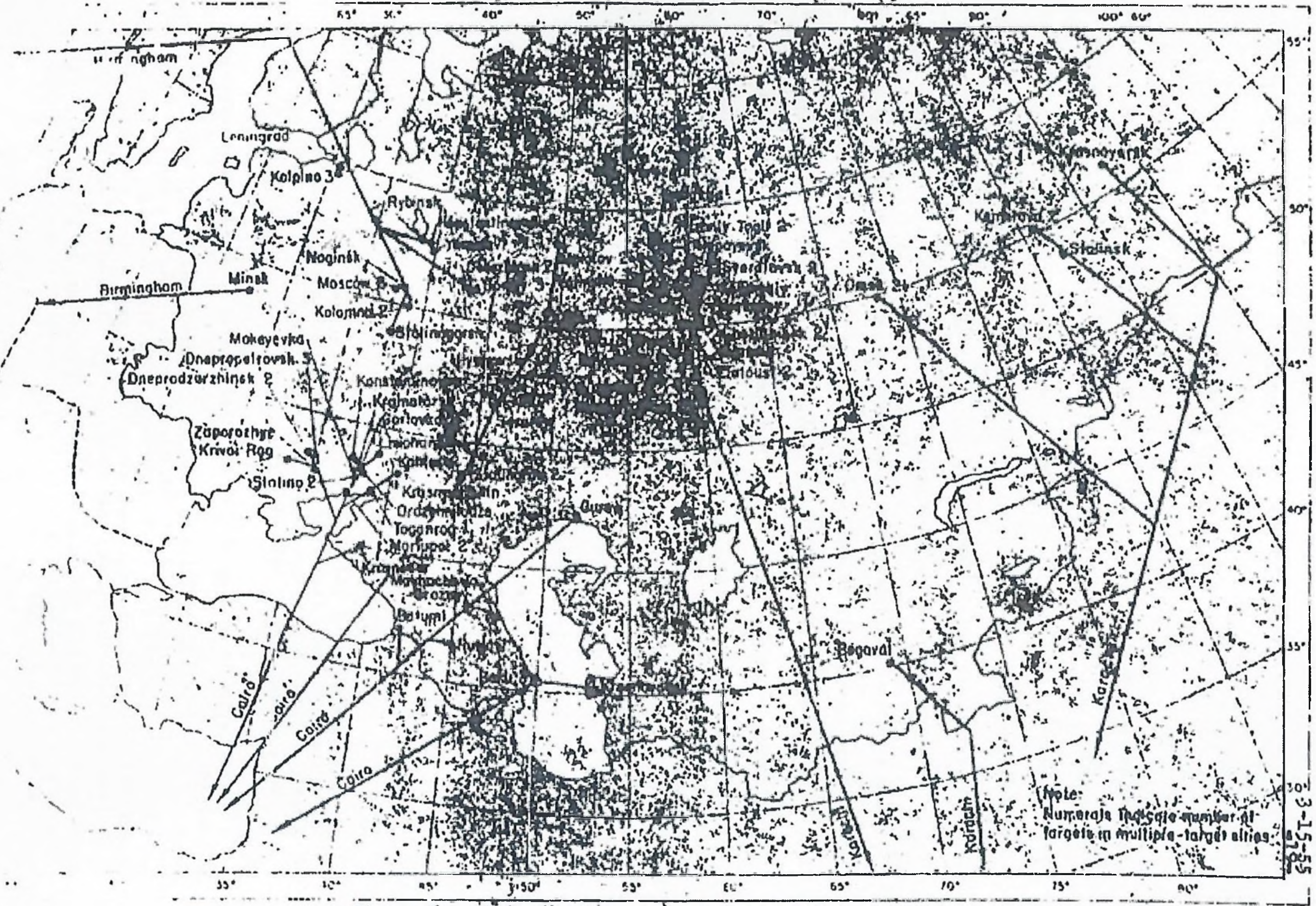
[*] Using close-control and hence uniform fire distribution as working assumptions would make little difference in the conclusions of the study since the effective interceptor-bomber ratio will turn out to be about one or less for conditions of interest.

[**] This factor is made up of the product of several conditional probabilities such as:

Over-all probability of non-abort (and non-gross error), 1/2
Probability that a non-aborting interceptor detects a bomber, ~8/10
Probability that a detecting interceptor kills a bomber, 1/4

Any other values on the conditional probabilities (each in turn made up of various sequential operations) that result in $P_{AK} \cong 1/10$ will leave the campaign analysis unchanged. A reduction of defense effectiveness by ECM may be on one or more of these conditional probabilities, and then it is the resultant proportional effect on $P_{AK}$ that counts.



Note:
Numerals indicate number of targets in multiple-target cities

Figure 5. Strike pattern against industrial targets from overseas bases

b) Interceptor availability = 2/3

c) Probability that an interceptor is available (not damaged and/or killed during inbound air battle) for outbound air battle = 6/10

d) The fraction (f(T)) of the total interceptor bases (on which are located a total of 2200 available interceptors) that are excited by an attack varies linearly from 1/5 for attacks against one target (an average penetration) to one for an attack against 50 targets, and is constant thereafter.*

e) On the average, one-half the available interceptors on a base are committed against an incoming raid for all raids that come within 150 miles of the base, as indicated by the diagram below.

[redacted]

f) The sequence of small-scale air battles that may occur is replaced by two separate equivalent massive air battles, one during the inbound penetration by the offense and one on the outbound course. The bombers killed in the first are deleted from consideration in

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*This particular f(T) function is of course an approximation. In the course of analysis different shapes of the f(T) curve were considered, but very little difference was observed as a result.

the latter. This equivalence is reasonable for saturation conditions (those analyzed), but cannot be used for conditions less than saturation.

The number of attacking bombers killed is then found by the relation

$$B'_K \cong (\tfrac{2}{3})\ (\tfrac{1}{2})\ .\ f(T)\ .\ P_{AK}\ .\ 2200 \qquad \text{inbound air battle}$$

$$B''_K \cong (\tfrac{2}{3})\ (\tfrac{6}{10})\ (\tfrac{1}{2})\ f(T)\ .\ P_{AK}\ .\ 2200 \qquad \text{outbound air battle}$$

and, $B_K$ per strike = $B'_K + B''_K$

These equations are linear approximations to the more accurate relations;*

$$B_K = B\left[1 - (1 - \text{probability a bomber is killed x probability a given bomber is attacked})^{(\text{number of effective interceptor passes})}\right]$$

$$= B\left[1 - e^{\frac{-\,(\text{probability of kill})\ (\text{number effective passes})}{B}}\right]$$

$$= B\left[1 - e^{\frac{-\,(\frac{2}{3})\ (\frac{1}{2})\ f(T)\ .\ P_{AK}\ .\ 2200}{B}}\right] \qquad \text{inbound}$$

$\cong (\tfrac{2}{3})\ (\tfrac{1}{2})\ f(T)\ .\ P_{AK}\ .\ 2200$ . where B = total number of bombers.

The above numerical quantities are equivalent to the statement that

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[*] The initial relation itself is an approximation to the correct law-of-air-battle under random assignment broadcast control conditions. (i.e., probability of attack on any given bomber = $\frac{1}{\text{number of bombers}}$ .)

under saturation conditions, the total area-defense kill potential on any single strike is about 110 bombers.[*] The fraction $f(T)$ is the proportion of this area kill potential any single strike that attacks $T$ targets (via corridor penetration) will see.[**] These quantities also define saturation for defense not interfered with by ECM; i.e., attrition per strike is a decreasing hyperbolic function of the number of bombers present when the number of bombers is roughly equal to or greater than $110f(T)$.

The following numerical quantities are used in computing local (missile) defense potential:

a) Local defense guidance units are spread equally over the 100 targets attacked; i.e., number of guidance units per target $(k) = 2$.

b) Average single-shot kill probability,

$$\overline{P_k}, = 6/10$$

c) Average over-all committed missile reliability, $R'$, $= 1/2$

d) Average total number of missiles that can be launched against a single incoming bomber $\overline{m}$, $= 2\ 1/2$

e) Minimum average time required to acquire and smooth data from a new aircraft target $\cong 30$ sec

f) Average flight time ground-to-target (at 40,000 ft, M.7 to M.9) = one minute.

g) Number of missiles that can be flown per guidance unit at any one time = 1

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[*] about 70 inbound, and about 40 outbound.

[**] Since the total number of strikes is about $\frac{T_o}{T}$, the accumulated area-defense kill potential is thus about $110 \cdot f(T) \cdot \frac{T_o}{T}$.

h) Maximum range for the first missile-aircraft interception (inferring an acquisition radar range of about 30 miles or more) = 20 nautical miles

i) Taking into account the random fire doctrine, the probability an attacking aircraft is killed by local defenses on the approach to bomb release line, $P_{Lk}$, is

$$P_{Lk} = 1 - e^{-\frac{(k)\,(\bar{n})\,(\bar{P_k})\,(R')}{M'}}$$

where $M'$ is number of bombers entering the local defenses in 1 1/2 minutes or less.

The corresponding kill probability per target for round-trip aircraft is:

$$P'_{Lk} = 1 - e^{-\frac{2(k)\,(\bar{n})\,(R')\,(\bar{P_k})}{M'}}$$

Substituting the numerical values used into these expressions gives:*

$$P_{Lk} \cong 1 - e^{-\frac{1.5}{M'}}, \text{ and}$$

$$P'_{Lk} \cong 1 - e^{-\frac{3}{M'}}.$$

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*These expressions imply that the inbound and outbound kill probabilities are equal ($= 1 - e^{-\frac{1.5}{M'}}$). Since $P_{\text{Round Trip}} = P_{in} + P_{out} - P_{in} \times P_{out}$

$P'_{Lk} = 2P_{Lk} - P^2_{Lk} = P_{Lk}\,(2 - P_{Lk}) = (1 - e^{-a})(1 + e^{-a}) = 1 - e^{-2a}$ where $a = \frac{1.5}{M'}$.

The number of aircraft killed is taken in each case as

$$M'_{k_i} = M' \cdot P_{Lk} \text{, and}$$

$$M'_{k_r} = M' \cdot P'_{Lk}$$

Again, the preceding relations are equivalent to saying that, for aircraft arriving in about a one minute time interval over the local defense, the kill potential of the local defense is about 1.5 inbound aircraft, or a total of about 3 inbound and outbound aircraft per target.

Again, the linear approximation to these formulas was used.

## B. THE OFFENSE

The bombardment aircraft considered, B-47B medium bombers,* are taken to have an unrefueled radius capability at Mach 0.74 cruise (Mach 0.84 in local defenses) of 1750 nautical miles with a 10,000 lb payload. With a single refueling by a KC-97 tanker the radius capability is considered to be 2550 nautical miles.

This force strikes from bases in the United Kingdom, Eastern Mediterranean area, North Arabian Sea area, and Far East. These locations,** insofar as the numerical analysis is concerned, are significant only as they affect costs. A multiplying factor on support and maintenance costs determined for ZI

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*181,500 lb T.O. gross weight.

**Each area listed has one or more actual bases as the strike strategy demands. The required number of bases is a function of base capacity and the number of aircraft sortied on a single strike.

conditions is used to represent the added cost incurred by overseas shipment, overseas pay, decreased labor efficiency, and so on. A further increase in costs is caused by the need for aerial refueling on strikes against some targets from some of the bases. About 33 per cent of the total B-47 force requires refueling. Refueling cost (i.e., the cost of KC-97's and required support) has been apportioned over the entire force by increasing the support cost for each strike bomber by the pro-rata amount.

Since a campaign, in this study consists of a series of strikes of equal size, replacements for losses must be provided from "replacement units" after each strike, with the exception of the last. This concept of a replacement unit arose in the course of the Missile Systems for Strategic Bombardment study(6) which included a <u>minimum</u> cost criterion and which considered an all-aircraft (B-47) bombing system as a means of calibrating, so to speak, the missile bombing systems. That study showed, as does the present one, that a series of strikes against the target system was to be preferred, <u>on the cost basis used</u>, so that the question arose as to the logistic and support considerations to be applied to those replacement aircraft required on strikes subsequent to the first. It is apparent that it would be cheaper to "store" these aircraft somehow in a "warehouse" rather than in a combat operational unit. This was done in the analyses, and the "warehouse" is the "Air Force Replacement Unit" described below.

The function of the Air Force Replacement Units is to provide aircraft and aircrew replacements to operating units during the campaign. These replacement units are Air Force wings in the ZI with an inflated complement of aircraft and air crews plus an augmentation of personnel, facilities, and equipment to support an activity level sufficient to maintain air crew proficiency.

This activity level is taken to be 50 hours per month per crew. The unit equipment inventory is taken to be 90 aircraft per medium bombardment wing. Economies are achieved by reducing manpower and facility requirements of these essentially doubled-up wings (doubled in terms of aircraft and crews only) below the level that could be achieved by assigning two normal wings to a single base. The former scheme is designed to provide replacement aircraft and air crews only to the operational units, while the latter would permit the replacement of an entire wing.

The distribution of aircraft between operational and replacement bases is dependent upon, among other factors, their relative unit costs, including a pro-rata share of all command, support, and operating costs, and is a parameter in the study. There exists, then, a "best" distribution of aircraft, yielding a least cost campaign, between operating and replacement bases.

The campaign consists of a sequence of strikes of equal size, each against the same number of point targets (i.e., strike size = MT, where M = cell size sortied against each T targets). It is required that 80 of 100 targets be destroyed, on an expected value basis. Although more than one bomb could be carried to the target and actually dropped, the damage to the target is computed as only that due to the expected yield of a single bomb.* The effect of multiple bombs per target is felt only as an increased expectation of delivery of a bomb and not in increased target damage.

The following numerical quantities are used in computing campaign costs:

a) A bomber wing consists of 45 B-47's.

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*This criterion implies something about bomb KT equivalent by use of target overpressure requirements together with a given bombing circular probable error (CEP). A range of bombs having yields of 100 KT to 1000 KT was considered available, which satisfied the damage criteria with a 6000 ft CEP assumption. The average target required a bomb lethal radius of 8000 ft at 12 psi overpressure.

b) The utilization rate of a wing is 2/3; i.e., 30 B-47's are available for a strike.

c) The several reliability factors concerned were estimated as follows:

  1. The probability that a sortied bomber does not abort prior to penetrating the area defenses, $R_1 = .84$.

  2. The probability that a bombing system does not malfunction, $R_2$, = .95.

d) Effects of ECM on campaign costs are computed on the basis of the following assumptions:

  1. The defensive ground control and warning system cannot differentiate between bombers and decoys, and interceptors cannot differentiate prior to making at least one complete attack. For simplicity, the kill probability against a decoy is considered to be identical with that against a bomber.*

  2. Both area-defense decoys and area chaff-sowing vehicles are launched into the penetration corridor from outside** the defensive warning cover by use of transports (C-124, C-132, etc.). Each transport carries and launches 10 unmanned decoy or chaff vehicles. In the campaigns employing these countermeasures the transports and necessary support and logistics are attached to the bomber wings in squadron units of 12 aircraft each. The estimated costs for such ECM squadrons are scaled from the estimated costs of a KC-97 tanker wing and adjusted for the ECM equipment required.

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*There are arguments that the decoy may be either more or less vulnerable than a bomber and no clear-cut answer to this problem is yet available.

**Hence a requirement of about 1200 nautical miles range for these vehicles.

## IV. ECM TECHNIQUES AND DEFENSE DEGRADATIONS

In a systems analysis such as this, before it is possible to discuss the effects of countermeasures, it is necessary to develop some logical relation between a given countermeasure technique and its quantitative effect upon the defense. The countermeasures of greatest interest are those that have been called "high confidence"; these are exemplified by the mass application of chaff from small unmanned vehicles within the bomber's penetration corridor, the mass application of barrage jammers in a similar fashion, and the mass application of area and/or local decoys utilizing various echoing means.* Beside these more important examples it is pertinent to explore the possible effects of some of the so-called countermeasures of opportunity, such as burst chaff, forward firing chaff rockets, radar or infrared blinkers ("artificial glint"), decoy infrared sources, and so on. The present report does not discuss all of these but rather attempts to point out the basic principles and to discuss certain examples.

### A. THE MASS APPLICATION OF CHAFF

As the offense acquires high-speed high-altitude bombers as carriers of atomic weapons in a strategic bombardment air war, highly efficient air defense systems become necessary. In order to alert, organize, and control the air defense system it appear that radar surveillance and control systems

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*Passively by means of tuned elements, corner reflectors, chaff trails, etc., or actively by echoing or obscuring means with barrage repeaters, barrage jammers, etc., plus active bombing radar simulators if necessary. For more detailed descriptions of and requirements on these and other preferred ECM methods, see references 1, 2, 3, 11.

are required and that no alternative technique will be used unless it is forced onto the defense system. At the present date no alternative techniques are available or planned.

Surveillance and control radar suffers from limitations in its ability to discriminate against interfering noise and clutter signals. The purpose of the radar system is to alert the defense, to direct the area-defense weapons system, and to assign airborne targets to the local-defense weapons. If the radar system is confused by noise or clutter from ECM, its effectiveness is reduced. Therein lies the quantitative payoff for such ECM effort. It is important to note that insofar as interceptor (area) defenses are concerned, they are essentially under command guidance by the ground surveillance system, so that with respect to the employment of defense weapons the search radars and the ground-to-air communication link are essentially in series. Consequently it is relatively immaterial whether the offensive forces confuses the search or GCI radars or confuses the communication link in the interceptor defense area; in either case the interceptors cannot be programmed accurately onto the bomber force. The offense can choose at its convenience which of these two parts of the system to jam. It is shown in references 1, 2, 3, and 11 that the radars represent the most profitable point of attack.

A promising technique is open to the offense in this regard. At present, and continuing until about 1958 or 1960, radars are expected to be vulnerable to severe confusion by the mass application of chaff at high altitudes as a consequence of the fact that chaff echoes in the high wind speeds aloft produce correlated echoes* with a high average velocity. No present moving

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*I.e., discrimination between chaff noise and target echo by integration techniques is inapplicable for the defense.

target indicator (MTI) technique can be relied on for rejection. The defense, to overcome this form of ECM, must bring new and different search and GCI radars into operation. The long time required to do this effectively, 8 to 10 years, gives this simple form of ECM its high-confidence character. Eventually high-power, high-resolution surveillance radars with relatively sophisticated moving target indicator (or doppler) techniques will be required.*

In this study the area defenses are such that corridor penetration tactics are preferred by the offense. Further, the sizes of the bomber strikes (without ECM) are such that the defense effectiveness is limited by the number of interceptors available. In addition, each interceptor has the capability, once successfully airborne, of detecting (probability about 8/10) and attacking (probability about 2/3) a bomber if the interceptor passes, on the average, within about 3 miles of the bomber.** The high density of bombers available results in essential certainty that each interceptor will detect a bomber. When ECM are used, these conditions do not prevail. Under the conditions postulated for the mass application of chaff by unmanned vehicles noted in references 1, 2, 3 and 11, the air surveillance system cannot know accurately <u>when</u> the bombers pass over, or where they are--if at all--within the large area of confusion generated by the offense. This forces the area defense to make two tactical decisions. First, some sort of interceptor sweep operation will be necessary, and second, such a tactic may have to be carried out for a

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*As a corollary to this it would be expected that such radars would use relatively low frequencies, say between 500 and 1000 Mc as opposed to present practice of 1200-3000 Mc.

**These values assume for the Soviet Union defense either fighter-borne AI radar similar to the APG-33 or visual sighting (without contrails).

relatively long time--say, from one to six hours. The effect of the first decision is to allow the offense to position bombers within the corridor of confusion during penetration so as to minimize the probability of detection and attack by forcing the interceptors to a more or less random search. Since the interceptor's search efficiency is a direct function of its acquisition range, it is apparent that the effective density of the bombers should be decreased; i.e., they should fly large distances apart. For example, the results of campaign calculations to follow show that whereas about 150 bombers are desirable per corridor per strike without this ECM, the same degree of success can be obtained with only about 50 bombers with mass chaff. The initial 150 bombers are distributed* in an area, say, 100 mi x 600 mi long, or at an effective spacing of about 4 miles between aircraft, viewed from the interceptor sweeping through the stream (roughly crosswise, due to interceptor attack performance and/or fuel limitations). With ECM, only about 50 bombers need be in the same area, so that, under cover of the mass chaff screen, the effective bomber spacing becomes nearly 12 miles. From the viewpoint of interceptor defense this would mean a "vectoring error" up to 5-6 miles, which can drastically reduce the probability of detection. It should be noted that the increase in effective spacing can also come about through grouping aircraft in twos or threes, depending upon the amount of chaff dropped.

A complete analytical solution of this sort of intercept problem has never been accomplished. However, sufficient experience with attempted solutions on similar problems shows that so far as the present study is

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*Distributed because any bunching up of bombers not under the cover of the mass chaff calls for a close control tactic on the part of the defense against groups of bombers--a very effective defense tactic.

concerned, the answer is dependent on an especially uncertain set of parameters such as Soviet AI radar power, antenna stabilization methods, data indicator technique, etc. Estimates of the effect of such drastically increased bomber spacings have been made from studies of U.S. radars such as the APG-33, SCR-720, etc.(12) These indicate that the probability of detection and attack will decrease by about a factor of two for the increase in effective spacing discussed above.

In addition to the reduction in the individual interceptor's detection efficiency just stated, a further reduction in effectiveness occurs because during continuous air patrol the interceptor is at altitude and available for combat only a fraction of its total airborne time. This is in contrast to the case where full information is available to the defense concerning the time and place of the bomber threat. For the MIG-15 type interceptor used in this study, the average total cycle time for an interceptor (take-off, climb, search, return, refuel and re-arm) is about 2 hours. Since the entire bomber stream can pass through the search area of an interceptor base in 1 hour or less it is apparent that only about half the interceptors will be in position and searching when the bomber stream is present.

The effect of the second tactical decision mentioned previously—to carry out interceptor sweep operations over a period of several hours—is to force continued re-use of interceptors, thereby progressively decreasing the number actually available due to maintenance difficulties. This effect has not been allowed in this study unless the mass chaff is made to persist by means of renewed sowings for 4-6 hours.

In summary, the effect of the area of confusion due to mass chaff is to force a defense interceptor tactic of more or less continuous air patrol. This results in a reduction in defense effectiveness for three reasons:

1) Because of poor timing, only about half the interceptors can be at the right place at the right time.
2) Because of increased bomber spacing unknown to the defense, detection efficiency is decreased by approximately half.
3) Because of continued maintenance, the number of interceptors available decreases with time.

References 1, 2, 3 and 11 show that the preferred way for creating the high-altitude chaff corridor is to use about one small unmanned vehicle, having a range of about 1200 nautical miles at Mach 0.9, per mile of desired corridor width, launched outside the area-defense perimeter. In this study vehicles similar to the XQ-2 drone are considered air launched from C-124 aircraft, at a rate of about 10 per C-124 per hour.

For one to two hours of effectiveness a single sowing appears sufficient. Since the corridor widths considered are of the order of 100 miles, about 100 sowing vehicles are necessary. Ten C-124's loaded with ten XQ-2's each can launch this number. In other words, approximately one squadron of C-124's is needed per corridor per one to two hours of confusion.

## B. AERIAL DECOYS

Aerial decoys are vehicles designed to simulate the aerodynamic and detection characteristics of possible bombers without possessing their actual threat capability. They are considerably cheaper than bombers, so that they can be used to generate an apparent threat at low cost. The most important type to be considered in this study are called "free decoys," that is, decoys which have no external mechanical or information links for guidance purposes. A distinction is made in this analysis between so-called area decoys and local decoys, which stems partly from the conceptual structure of the defenses and partly from examination of the development, use, and logistic problems associated with free decoys. This distinction is in many ways convenient, but it is not necessarily mutually exclusive under all conditions. Area decoys are vehicles launched *outside the defended perimeter* that are independent of each other and of bombardment aircraft. For air-launched area decoys, air ranges of about 1200 nautical miles are necessary. A vehicle resembling the XQ-2 target drone is representative. In general, the defense is unable to make any association among area decoys or between area decoys and bombers.

Local decoys are vehicles transported through the area defense by, and launched from, escort bombers.* They are considered to be free decoys of about 100 nautical miles air range.** Physically they can be described as liquid propellant rockets of about 10 ft length, 2 1/2 ft diameter, and 5 ft wing span. In this study each escort B-47 is considered to be able to transport and launch 10 such decoys, 4 carried internally and 6 externally. In general, the local defenses (missiles) are able to make an association between local decoys and a bombardment force.

For free decoys as described above to be effective as countermeasure devices, the first requirement is that they be *visible to the defensive surveillance and acquisition system*. It is important to note that they need not be perfectly visible to the defenses, but only *approximately* as visible as possible bombers. The reasons are apparent: the bombers themselves are

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*It may develop that a bomber can carry the bomb *and* decoys. This was not allowed in this study, however.

**This range requirement is the result of considering the acquisition range of local defenses as well as the juxtaposition of adjacent local-defense regions for the Soviet target system considered. It is felt to be representative. For those targets closest to the over-all defense perimeter a longer range decoy (say about 200 nautical miles) might prove useful.

neither perfectly visible nor do they reflect standard, calibrated echoes; and the defense weapon assignment system cannot take the chance--because of the tremendous attack potential that a single fission or fusion weapon in a single aircraft possesses--of assuming that any objects seen less frequently than others are not bomb carriers. A further fundamental point with respect to "visibility" of decoys is that they *do not necessarily have to appear the same as a particular bomber to the defense system*, although they must possess similar flight characteristics. The reasons are twofold: the decoys need appear only as *possible* bomb carriers and, more fundamentally, it is desirable that the bomb carrier and decoy appear equivalent, but neither necessarily has to look like a bombardment *aircraft*. This is one of the attributes of the offensive decoy-bomber system that produces the very high confidence estimate of decoy utility.

Some examples of methods valuable to the offensive decoy-bomber system are as follows: for interim use, decoys laying single chaff trails *as are* bombers; decoys using passive echoing means plus navigating radar radiations, *if bombers do*; decoys laying contrails *if bombers are*, etc. Eventually it is expected that active electronic repeaters, either as simple "echoers" or as noise-modulated barrage "echoers" employed on both bombers and decoys will force the defense to consider both types of vehicles as possible bombers, although the defense will never have a true radar echo from either.

To assess the payoff to the offense for using decoys it is necessary to establish whether the defense weapon system is or can be forced to be control-channel-, rate-of-fire-, or quantity-limited. It is apparent (e.g., see Fig. 1, p. 7) that if the defense is *not* limited in one or all of the above factors on any given strike, the use of decoys serves only to exercise the defenses, and so far as the offense force planners are concerned, decoys can then not be counted on to make such a limited strike more successful. Unless these limitations of the defense can be reached, i.e., unless the defenses can be saturated, the full potential of decoys to dilute the defense cannot be realized. In this connection it should be mentioned that saturation itself can best be obtained by use of proper decoys. All the above forms of defense limitations are used in this study. Either they appear in the form of a-priori judgments (e.g., GCI close-control capability for interceptors is considered to be limited even without ECM, and this limit is exceeded on all non-ECM strikes), or they are introduced by the force of countermeasures (e.g., mass chaff forcing interceptor sweeps or mass decoys forcing defense weapon dilution). For the area defenses the number and distribution of either bombers without ECM or bombers plus decoys always forces an interceptor-sweep type of broadcast control GCI conditions. In this event the area defenses suffers only an effective interceptor quantity limitation, so that the payoff in the area defenses from the use of decoys arises not because real bombers are not seen by the defense, but rather because some interceptors waste passes at decoys. Since the interceptors in this study have a capability for only one effective pass, the relation between the defense bomber kill potential with and without decoys[*] is particularly simple:

$$\frac{\text{Bomber kills with decoys}}{\text{Bomber kills (no decoys)}} \cong \frac{\text{number of bombers}}{\text{number of bombers plus decoys}} .$$

This relation applies only for the aforementioned conditions--namely, a large number of aircraft distributed in a strike corridor against a defense

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[*] The distribution of bombers or decoys plus bombers is considered to be the same, i.e., wide spacing between all vehicles with no special pattern visible to the defense.

with fixed kill potential. Further it is applicable only to the kill potential and does not attempt to include any surprise factors or defense reduction other than the use of decoys.

The same relation holds for local-defense decoys, launched prior to surveillance by the local-defense missile acquisition system. The missile system is considered to be control-limited[*] since the missile system is assumed to use command guidance and no change corresponding to broadcast control of missiles is allowed. If a semi-active homing-all-the-way type of guidance (together with some estimate of the number of "ready" Soviet missiles) were considered, the effect of decoys would necessarily be based instead on a quantity limitation—which could be made considerably more troublesome to the offense force. The control limitation postulated is similar to that expected for the Nike missile and is consistent with information obtainable on the Soviet Wasserfall missile to date. It should be mentioned that the semi-active guidance technique[**] is an economical way by which the kill potential of the defense can be raised. Any increase in kill potential will require more decoys to counter than shown here, but the value of such decoys will, by the same token, be greater.

The relative or absolute physical vulnerability of the decoys described could not be fully explored in this study. For this reason, such analysis as was made led to the belief that the decoys would not be significantly more vulnerable than B-47 aircraft to interceptor or missile fire. As a consequence this study considers that both forms of decoys have the same physical vulnerability to defense fire as a B-47. It is felt that a change in this relative

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[*] A fixed rate-of-fire limitation is also assumed: one launching per about 30 seconds per launcher which governs the radial extent of a cell of vehicles.

[**] It is known that the USSR is aware of the concept.

vulnerability by a factor larger than two would be necessary before any results need be re-examined.

## C. COUNTERMEASURES OF OPPORTUNITY

Most of the electronic countermeasure techniques considered heretofore by others fall into this category. Several fundamental questions immediately arise with respect to confident estimates of their value. Will the defense be vulnerable at all to the specific ECM in question? If so, does an alternate mode by which the defense may avoid the ECM exist? Is this mode available to the defense in action? To decide such questions, it is necessary to have firm estimates of specific defense-weapon types, operational doctrine, and proficiency. A further basic question also arises: If a specific ECM of this sort can be used and is successful, what is the effect in reducing the available kill potential? Here it is necessary to make a further detailed analysis of the characteristics of the defensive weapon system, its logical structure, and (most unfortunately) the "circuit" details of the specific weapon and system.

Examples of the above ideas are so numerous and well known as to require no detailed amplification. Whenever such specific cases can be detailed, however, the results of the present study can be applied. For example, the case of burst chaff or forward-firing chaff rockets is instructive. If the defense uses automatic or semi-automatic airborne radar fire-control equipment identical to that found in the U.S. F-86D, F-94C, etc., then it is possible to show analytically and experimentally that chaff properly ejected can cause a "break-lock" to occur in the tracking phase of a firing pass. This condition is not permanent insofar as the interceptor's equipment is concerned, and this technical loophole cannot be expected to be available to the offense in a continuing basis. While it does exist, however, a countermeasure of opportunity exists. In order to aid evaluation of the effect of such ECM, the results of some bombardment campaigns are displayed with a "defense reduction factor" as a parameter. On p. 53 the use of this parameter is outlined for an electronic countermeasure that can negate a certain number of firing passes by radar-controlled air or ground weapons. The countermeasure could be forward firing of chaff rockets; it might also be blinkers, towed decoys, swept jammers, etc., depending upon the specific defense technique considered. Further, the countermeasure may not negate a firing pass but only degrade it—for example, blinkers, towed decoys, or jamming against a large-warhead seeking missile. In this event an estimate must be made of the kill potential vs. miss distance and of miss distance vs ECM method in order to arrive at the degradation factor parameter. In general these sorts of estimates are difficult, insecure, and subject to sudden change, so that a preference for the "high confidence" countermeasure is held insofar as force planning is concerned.

The primary lesson learned from these ECM types is that several different complementary forms(1)(2)(3)(11) should be quickly available to bomber forces, easily substitutable on or in various aircraft, but that their payoff is too uncertain to be allowed to influence greatly the development planning of strategic air forces.

## V. OUTLINE AND DISCUSSION OF RESULTS

### A. NO ECM

As may be expected, the analysis of a bombing campaign can be very complex. In order to provide the reader with basic explanatory material the foregoing discussion of the analytical models has been included in this report. To further aid interpretation of the results of using ECM it is perhaps desirable to show some of the results obtained from campaigns of the sort considered here without the influence of ECM.

Figure 6 shows the limiting relation found between the over-all system cost and fissile material requirements. Three curves expressing this relation are given. The solid and dashed curves are computed, with and without a survival probability restriction, according to the analytical model used in R-260(6); the dotted curve is computed according to the simplified analytical model used in this report.

Each curve is an envelope curve bounding the region (above and to the right of the curve) where the variations in the available parameters--strike size, cell size, targets per strike, bomb size, bombs per cell, etc.--allow the prescribed damage to be inflicted and the region (below and to the left) where no combination of parameters achieves the required objective. The envelope curve represents a locus of points on various constant tactic curves (e.g., fixed strike size, fixed number of targets per strike, etc.) that minimize both dollar costs (exclusive of bomb costs) and fissile material requirements. It must be realized that in the region above and to the right of the curve a multitude of possible tactics (choices of strike size, cell size, etc.) will satisfy the conditions of the problem. The significance of the envelope curve is only that it represents the least costs inherent in the best tactics. Each point along the curve represents

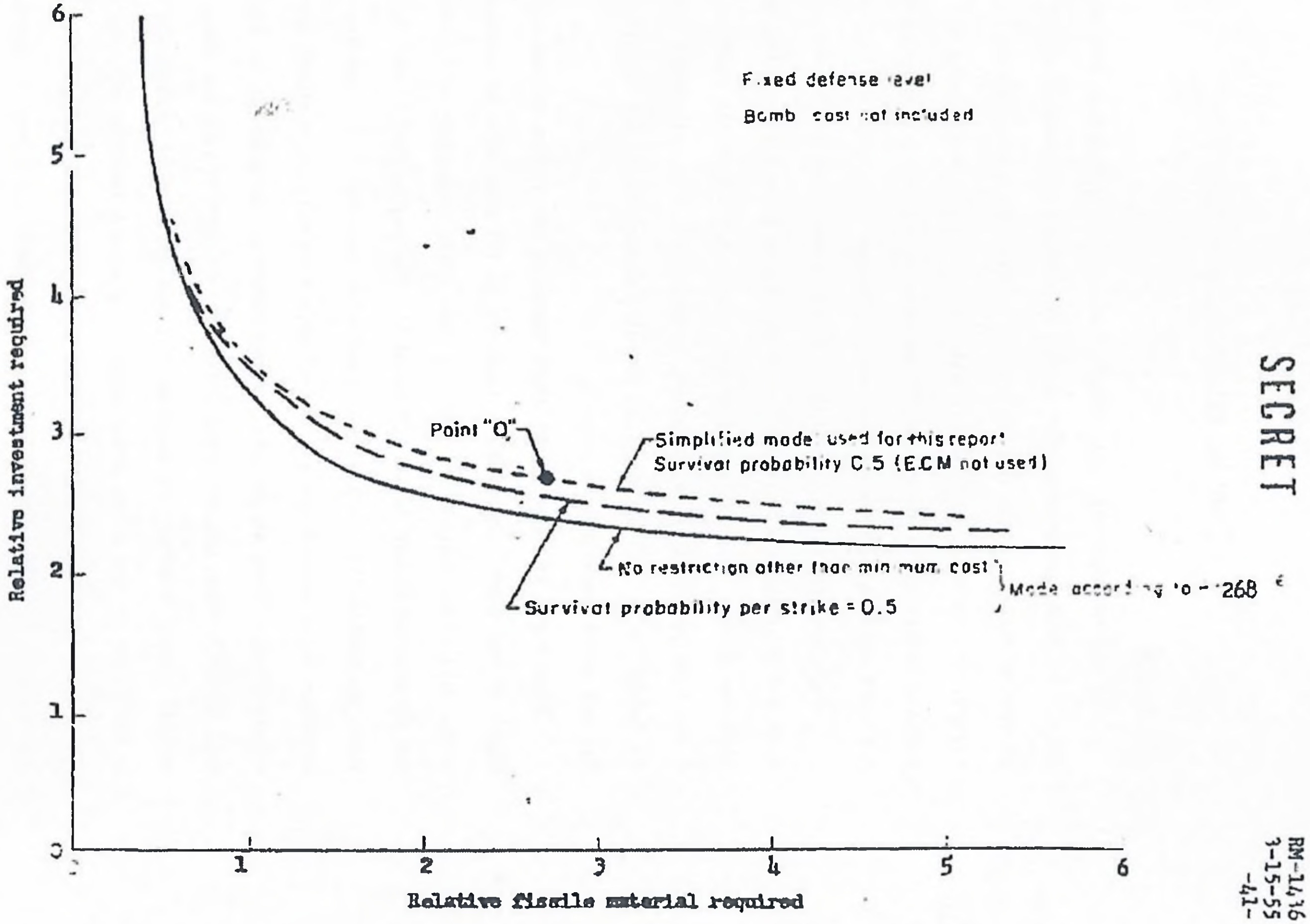

Fig. 6 — Minimum envelope curve of 4 year costs and fissile material requirements for fixed target damage capability, B-47B

a different, though best, choice of the campaign variables. Figure 7 shows how these variables change along the solid-line envelope curve of Fig. 6, marked "R268 model." It is interesting to note that relatively little variation does, in fact, take place. Possible variations in strike size, cell size, targets per strike, etc., could be overcome while holding strike size, losses (and hence costs), and fissile material requirements at a minimal level by the variations allowable in bomb yield and bombs carried per cell.*

In general, the results show that, when no value is to be assigned a striking force for any other job but that in question (bombing 100 targets), the least costly system buys just enough aircraft, bases, and support to do that job and no more, and should not have very many aircraft left over. If restrictions other than minimum cost are applied to the analysis, the increased costs for such restrictions can be shown. Figure 6 shows, for example, the cost difference between the least-cost strategies (solid line) and the strategies specifying that the round-trip survival expectation of each aircraft must be 0.5 or greater (dashed line-model used in R-268(6); dotted line-simplified model used in this report).

The difference between the dashed and dotted curves of Fig. 6 results only from the difference between the analytical models used; the dotted curve computed according to the simplified model used for ECM campaign analysis is based on a campaign in which ECM is not used. On the level of information represented by Fig. 6, the closeness of the three curves is felt to be well within the accuracy

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*This would not necessarily happen if bombs were included in the dollar cost to be minimized. However, the cost estimates actually made for fissile material used show that almost negligible affect would have been observed. The exchange curve would begin to bend upward at high fissile material values, however, rather than always decreasing as shown.

with which the numerical analysis can represent physical reality. The parameter variations found along the exchange curve computed from the simplified model are shown in Fig. 9 and may be compared with those in Fig. 7. In the simplified model somewhat more parametric variations are observed. Even so they are relatively minor, except for the variation observed before in bomb yield and bombs per cell.

The effect of one change between the analytical models used is significant, as can be seen by comparing Figs. 9 and 7. While the over-all strike size is about the same for the two cases, the resultant numerical values for cell size (M) and targets attacked per strike (T) are very nearly interchanged. This is a consequence of a difference in the form of the f(T) curve (see p. 7 ) used in the two models, and of the restriction to increase the survival probability to 0.5. In the simplified analytical model a simplified f(T) curve is used which introduces area defenses at a faster rate than in the original model. The effect of the change in the f(T) function, since the philosophy of minimal cost campaigning hold the strike size relatively stationary, is to call for a reduced number of targets attacked per strike and hence an increased total number of strikes to accomplish the end result. Requiring the increase in survival probability requires an increased cell size.

## B. ECM CAMPAIGN I

In Campaign I the *strategy of attack* is specified (cell size, strike size, etc.) on the basis of the results obtained by use of the simplified ECM analytical model, without consideration of ECM reduction of defense effectiveness. To illustrate the effect of ECM on the defense, the changes in survival probability per aircraft and/or targets destroyed are obtained

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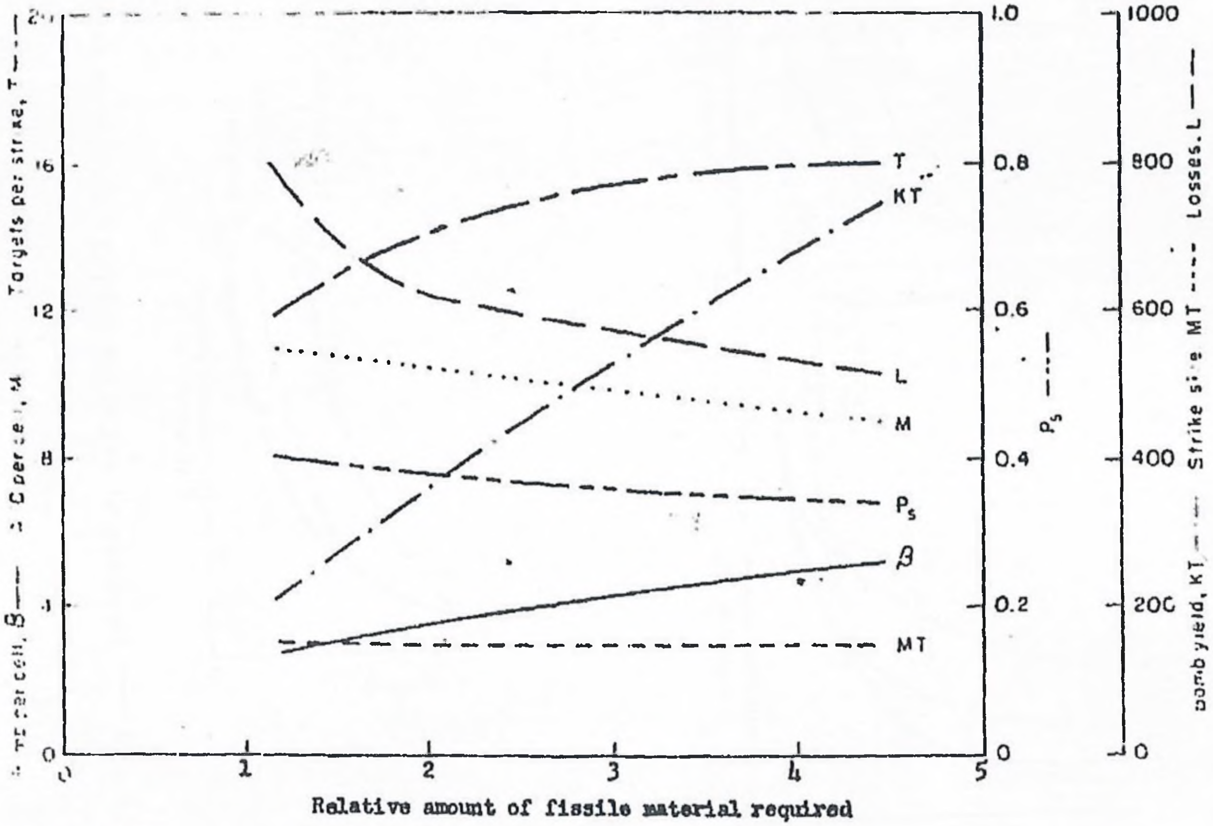

Fig. 7—Variation of parameters on R-268 model least-cost of Fig. 6, no ECM, B-47 B

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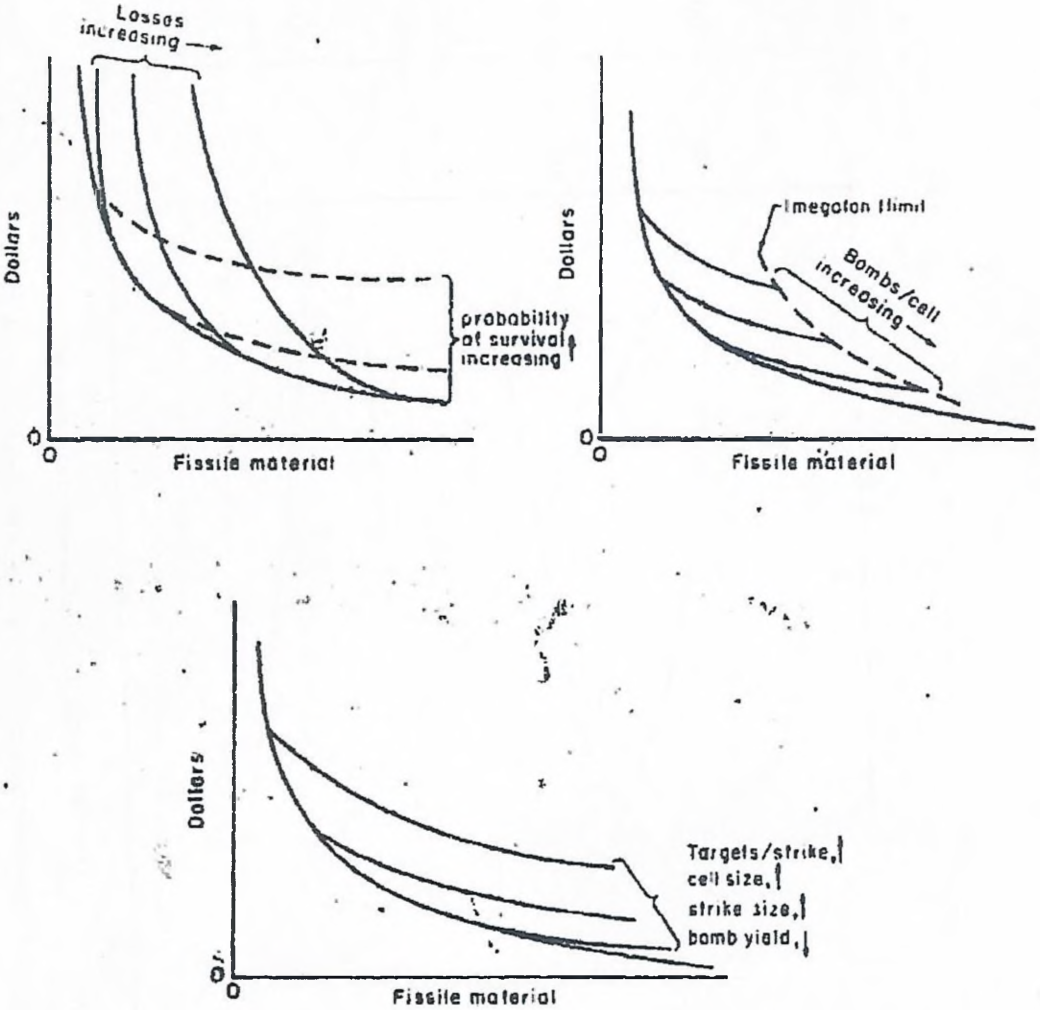

Fig. 8 — Sketches of exchange curves with various restrictions

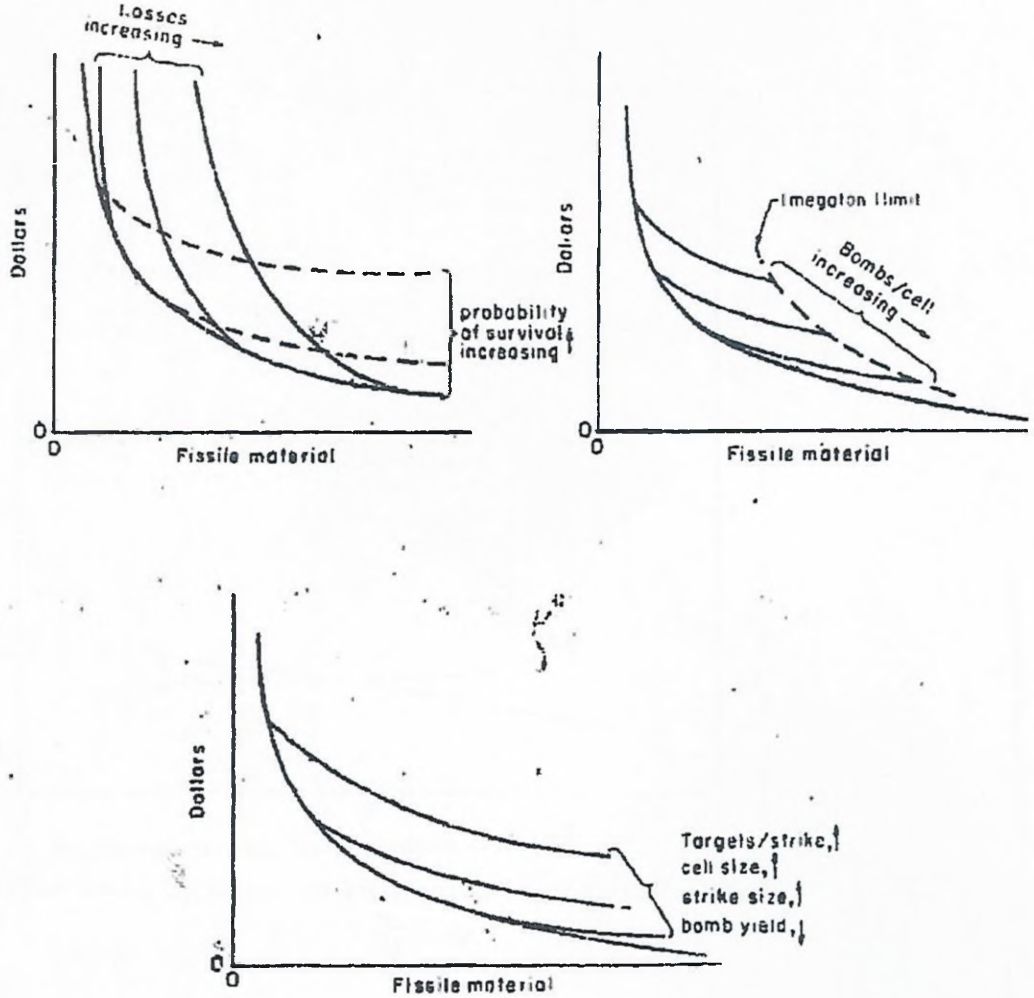

Fig. 8 — Sketches of exchange curves with various restrictions

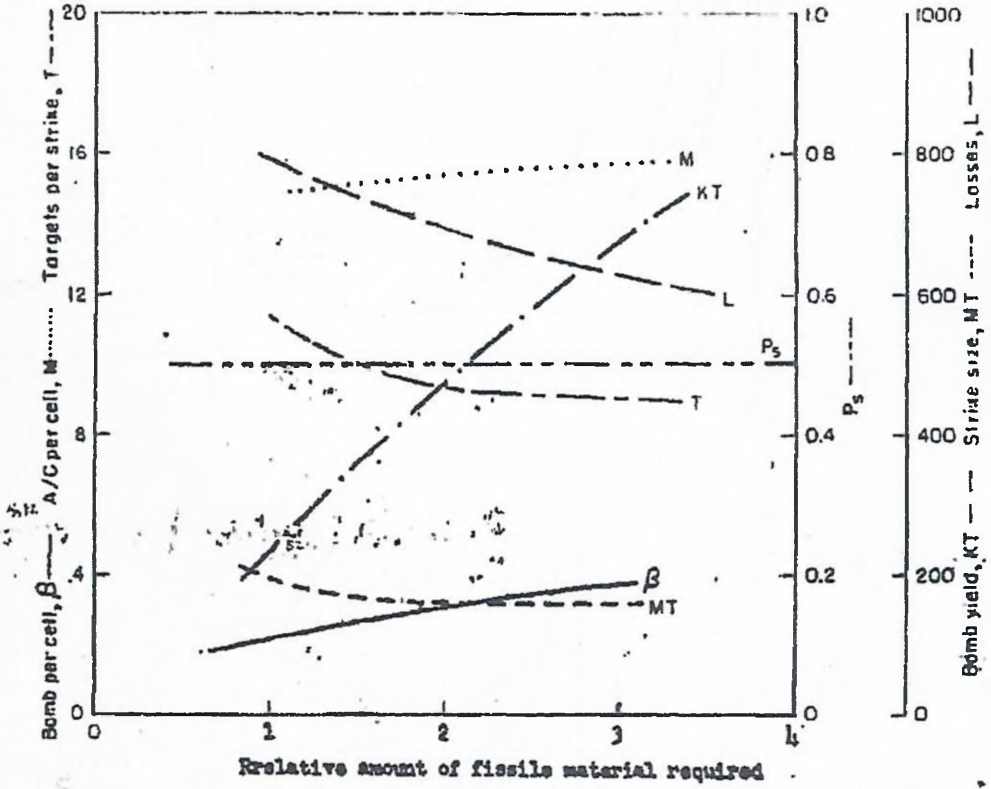

Fig. 9—Variation of parameters on simplified model envelope of Fig.6, no ECM, B-47 B.

for a single set of campaign variables which represent a single *point* on the family of preferred points along the exchange curve of Fig. 6. The point "0" is chosen as being representative. Figures 10 and 11 show the results of this analysis. The conditions without use of ECM are shown by the point X on these figures. Throughout these campaigns the tactical variables are held constant, hence the curves of Figs. 10 and 11 apply only to the single point "0" of the original family of campaigns. The value of the tactical variables can be found from Fig. 9.

The computation leading to Fig. 11 considers that the extra aircraft saved (by the increased survival experienced) for the several degrees of defense degradation shown continue the campaign to additional targets[*] (beyond the initial 100) until the same number of aircraft have been consumed.[**]

An examination of the figures shows several interesting points. The results of reducing either area *or* local defense effectiveness (not both) show that, in this campaign the value of offensive ECM against the area defenses will be appreciated more rapidly. This is due to the minimal cost concept, wherein it is advantageous to enter the area defenses several times. In short, from a *cost* point of view it is better to lose aircraft than provide large base and sortie capacities which are amortized over only a few periods of use.

Section IV-A discusses the use of *mass area chaff* to reduce area defense effectiveness. It is shown there that the employment of one squadron of

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[*] Each additional target was defended by the same local defense as a target of the first 100.

[**] Continuing until the same campaign *cost* had been reached gave very nearly (though not exactly) the same results.

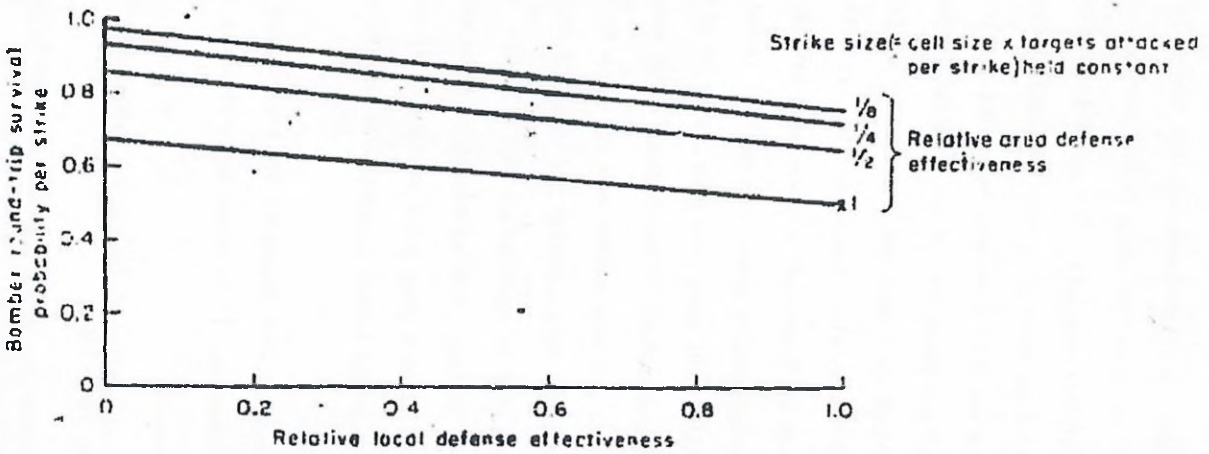
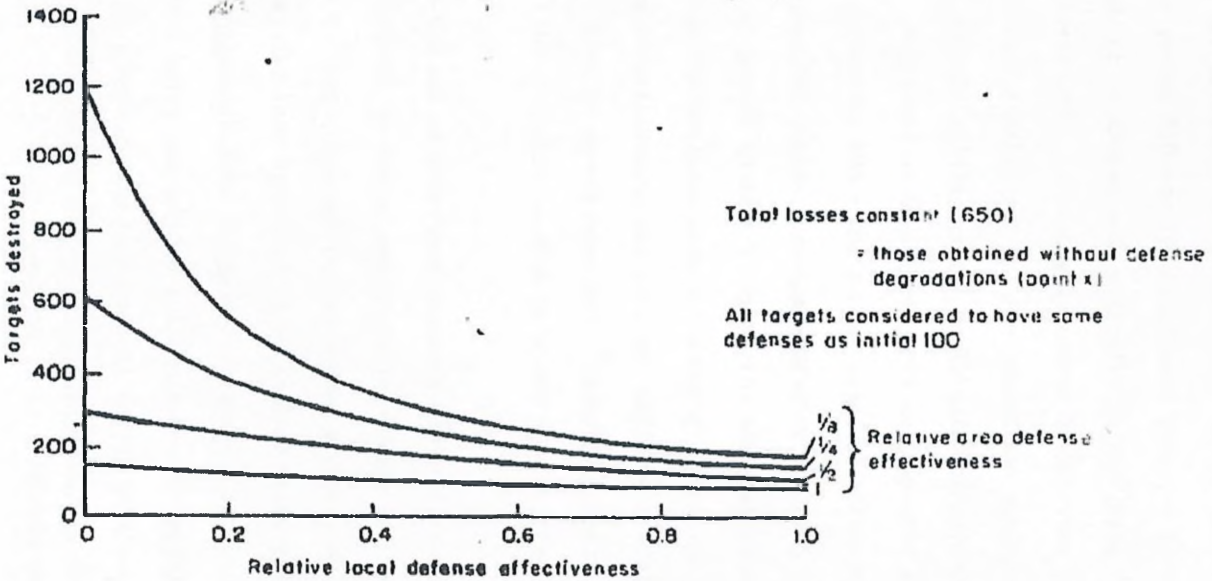


Fig 10—Aircraft survival probability vs defense effectiveness. ECM used, but not ECM strike tactics.



Total losses constant (650)

= those obtained without defense degradations (point x)

All targets considered to have same defenses as initial 100

Fig. 11 —Targets destroyed vs defense effectiveness. ECM used, but not ECM strike tactics.

C-124 aircraft per strike, each C-124 launching 10 XQ-2-type vehicles loaded with 300-600 lbs of chaff apiece from outside the defenses, can be expected to produce about 1 to 2 hours of uncertainty in the GCI system's estimate of <u>when</u> the strike will pass, and an extensive uncertainty as to <u>where</u> the aircraft are within the corridor of confusion generated. The advantage of this degree of time uncertainty was judged nil for the offense, but the fact that during the entire penetration time of an average strike the GCI system is unable to direct the interception from the ground is important. Since the area of confusion generated is large (about 100 x 600 nautical miles), the best the defense can do is to undertake airborne search interceptor-sweep operation. The offense can take advantage of this by flying in groups of, say, 3 to 5 bombers during the penetration with considerable separation between the groups (about 20 miles) so that the probability of an interceptor finding a bomber is greatly reduced.* The consequence of this tactic and counter-tactic is a reduction in the area defense kill potential of about one-half.

If the mass area chaff could generate confusion in the GCI-fighter system lasting 4 to 6 hours, the time uncertainty can become of interest. While the confusion may exist for, say, a 5-hour period for any sector of area defense, the actual time during which bombers would be within that defense sector need be only 1/2 to 1 hour. As a result, it would be advisable—<u>against an otherwise unsurprised defense</u>—to pre-alert the defense and force a maintenance of airborne search, especially if the interceptors must try to accomplish the initial detection job by sweep operations, unless the additional warning permits evacuation or effective Civil Defense.

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*I.e., a penetration tactic made to order for a close control fighter-GCI defense tactic but just the tactic the defense cannot use in the presence of the mass confusion!

The analysis shows that a period of confusion of 4 to 6 hours, during which the bombers can pass through the defense at any time, forces the defense into a more or less continuous air patrol operation. The result is a considerable reduction in the number of interceptors that can be brought to bear for the correct time--when the bomber stream is present. A 4 to 6 hour continuous patrol requires increased maintenance and hence causes an increased abort rate; in addition, only a fraction of any one interceptor's total flight time can actually be spent in search at altitude.

If perfect information about the strike were available to the GCI system, all available interceptors could be brought to bear from any one field. But with the time uncertainty considered, it is felt that the continuous flying called for by this countermeasure would reduce the number of interceptors available by 1/2 to 1/4, and those actually flying would be searching in the supposed bomber stream at altitude only about 1/2 to 1/3 of the time.

In essence, then, an over-all reduction of area-defense effectiveness to a factor of, say, 1/2 x 1/3 x 1/3, or about 1/20, could be induced. In this study, however, the ~1/3 factor due to maintenance has already been included once, and no further change in this factor is allowed due to this ECM. The time uncertainty was thus allowed only to produce a reduction of 1/2, giving a total reduction to 1/4 initial effectiveness. The right-hand portion of Fig. 12, marked "2 squadrons of C-124's per strike," shows the results graphically. Two squadrons of XQ-2 launching aircraft were required, since it was felt that one squadron could not launch twice within about 2 hours.*

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*Only 10 aircraft of a 12-aircraft squadron are considered successfully sortied for a launching, and each of these carries 10 XQ-2-type vehicles as chaff sowers.

In addition to the effects on interceptor effectiveness caused by mass sowing of chaff, Fig. 12 shows the increased survival expected due to the use of decoys in the local defenses. These decoy vehicles are considered to be small, short-range (about 100 nautical miles), liquid fueled rockets[(2)] transported by escort B-47's, and appear to the defense as possible bombardment aircraft.

Since the campaign analysis, without ECM, shows that saturation tactics are desirable, the effect of these decoys is to provide this saturation at greatly reduced cost and logistic effort. That is, one escort B-47 can be made to appear, relatively simply, as (1 + n) B-47's to the local defenses. Since the campaign analysis used linear approximations to the attrition formulae, the relation between defense reduction factors and number of decoys is particularly straightforward.

The probability that a bomber is killed is proportional to the kill potential divided by the number of "bombers" available, or in symbols:

$$P(B_k) \sim \frac{K_a P_a}{M'} \sim \frac{K_a P_a}{M}$$

where M' is the cell size reduced by area attrition from the sortied cell size, M. Now if there are $\beta$ bombs sortied with each cell of M bombers, the number of bombers available as decoy carriers is $(M-\beta)$. If they, in turn, can carry n decoys apiece the new apparent cell size is

$$M' = M + (M-\beta)n.$$

Since the fraction of bombers killed is proportional to the apparent cell size, the relative reduction in defense effectiveness can be found by

$$\frac{B'_k}{B_k} \propto \frac{M}{M'} = \frac{M}{M + n\,(M - \beta)}$$

$$= \frac{1}{1 + n\,(1 - \beta/M)} \quad .$$

The point on the envelope curve of Fig. 6 chosen for examination has $M \cong 15$, and $\beta \cong 3$ (see Fig. 9). Hence the above expression gives, in tabular form

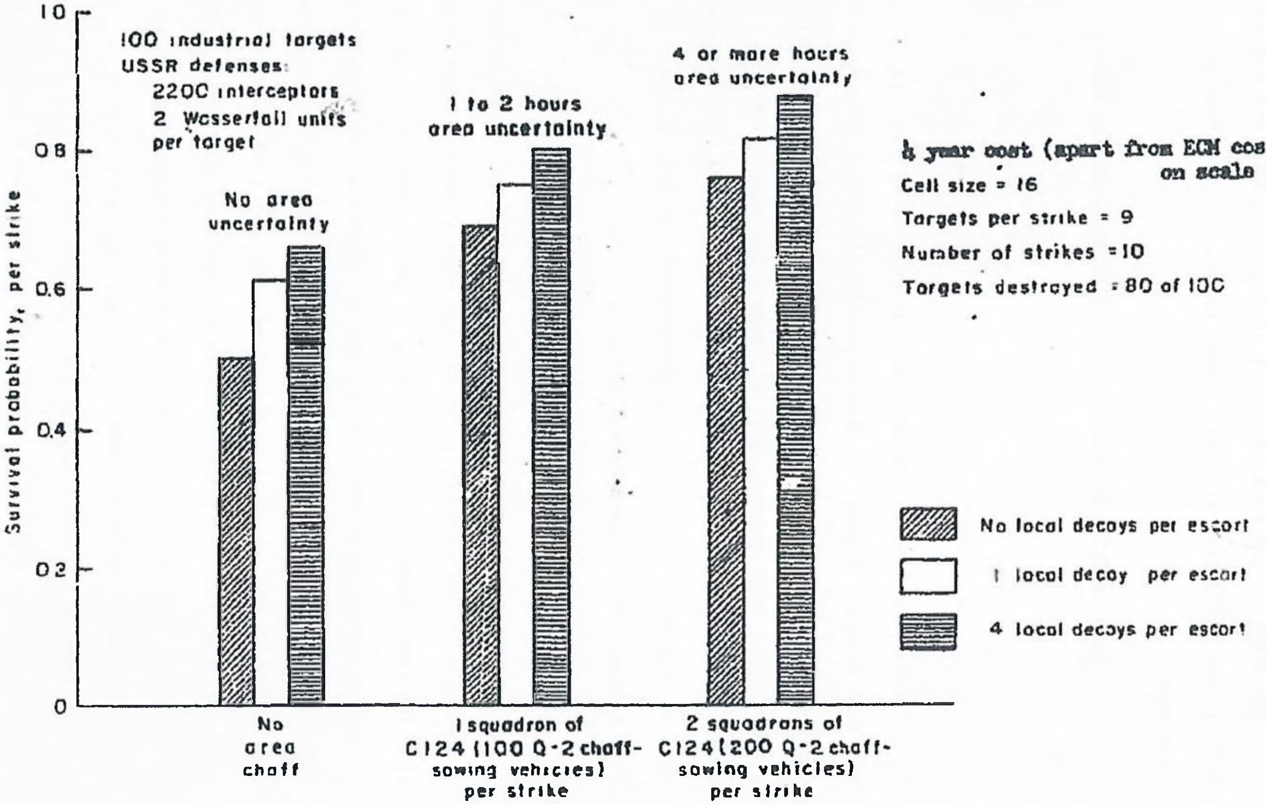
| Local Decoys per Escort | Defense Reduction Factor |
|---|---|
| 0 | 1 |
| 1 | 5/9 ⟶ 1/2 |
| 4 | 5/21 ⟶ 1/4 |

These reduction factors were used in Fig. 11 in plotting the effects of local decoys. Figure 12b also shows the <u>additional</u> defended targets that could be attacked if the B-47's saved by ECM, because of the higher survival expectations, were re-used until the same total number are lost as were lost in the initial, non-ECM, campaign against 100 targets. It is apparent that even a relatively small amount of ECM activity of this sort can be worth from 1 to 4 times the entire original striking force.

## C. CAMPAIGN II

Rather than take advantage of ECM by adding cost to the original campaign, observing a higher aircraft survival, and then attacking additional targets with the extra bombers made available, it was desired to see if, when the defense reductions expected are allowed to influence the campaign tactics, the campaign cost for damaging 80 targets would be significantly reduced. The results of the previous campaign indicate that such would be the case, at least until such low defense levels are expected that a large fraction of the total cost is represented by the bombing requirements (i.e., the cost of transportation of bombs) and not by survival requirements.

The results of this analysis are exhibited in Figs. 13 and 14. Defense reduction to less than 1/4 x 1/4 is not shown for two reasons: a defense



½ year cost (apart from ECM costs) = ~2.75, on scale of Fig. 6

Cell size = 16

Targets per strike = 9

Number of strikes = 10

Targets destroyed = 80 of 100

Fig. 12 a — Illustative ECM payoff in SAC campaign without using ECM strategy

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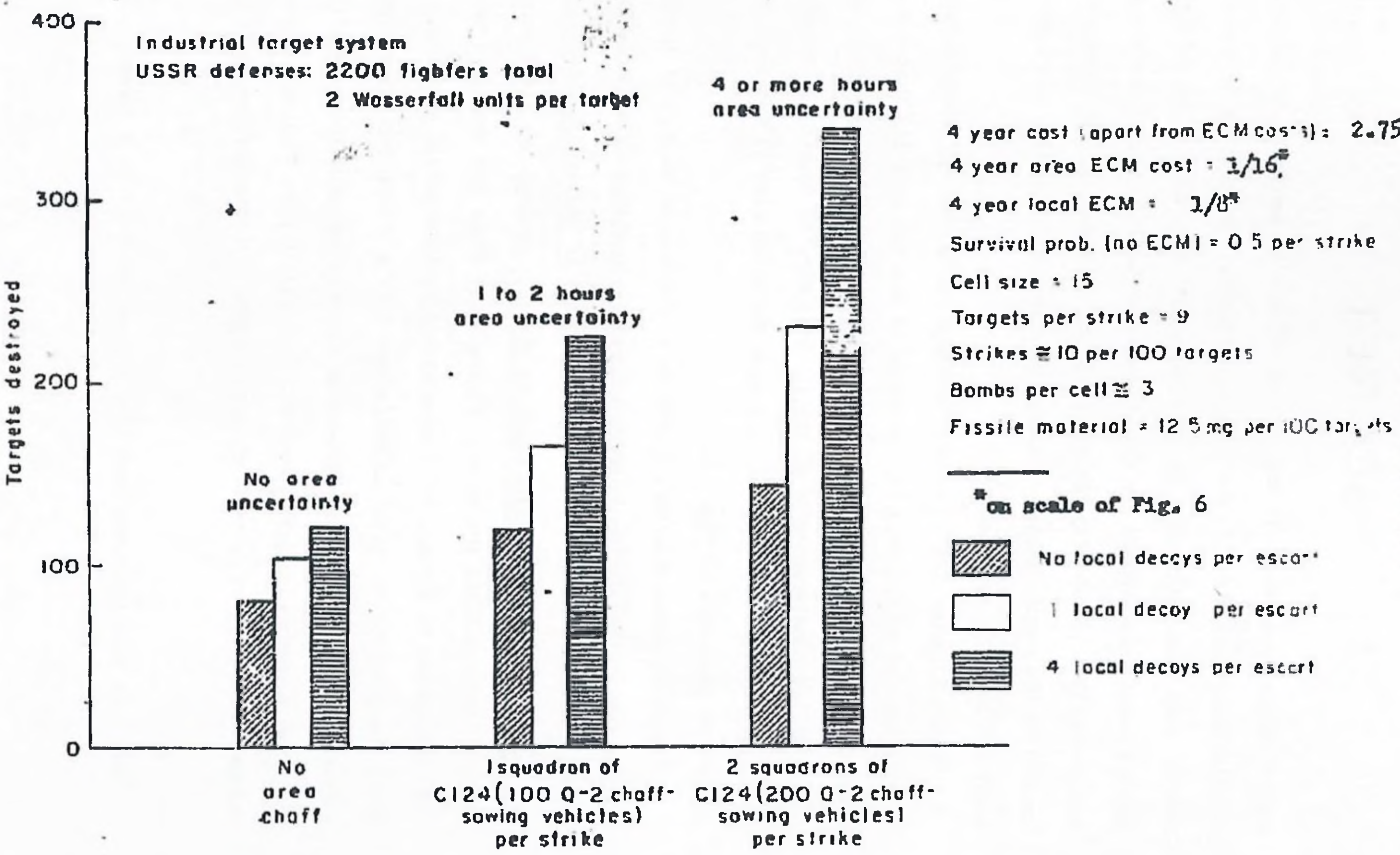

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Fig. 12 b — Illustative ECM payoff in SAC campaign without using ECM strategy effectiveness less than 1/16 the initial defense is hardly worth notice, and the analytical model is not felt to be proper for such low defenses even if they were realistic. At about a reduction to 1/10th the initial defense level, the problem for the offense changes from one of providing enough survival probability for the necessary bomb carriers to tactics bounded by the requirement that enough bombers are sortied to carry at least two bombs in each cell.[*]

Figure 13 shows the investment exchange curve with different reduction factors applied to the defense. Examples of the ECM activity that can cause the reductions plotted are those just discussed. Other forms of ECM, especially the so-called countermeasures of opportunity, may, of course, be considered to apply to campaigns I or II. In this case the added cost is too small to be plotted on the scale of Fig. 13.

Figure 13 shows that very little total difference in cost is involved whether the strike tactics do or do not reflect anticipated ECM effectiveness (up to factors of about 1/10 but not over that) if additional defended targets are available that the offense needs to attack. Against any fixed number of targets Campaign II is preferred. Figure 14(a) shows how the force per strike (MT) and number of strikes (N) varies with fissile material expended. Figure 14(b) demonstrates the previous conjecture that a search for the minimal cost solution will result in more strikes as the area defenses are reduced. At any fixed area-defense level, however, the results show that as the local-defense effectiveness is reduced, more targets are attacked per strike, so

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[*] Not less than two bombs were ever allowed to start to a target.

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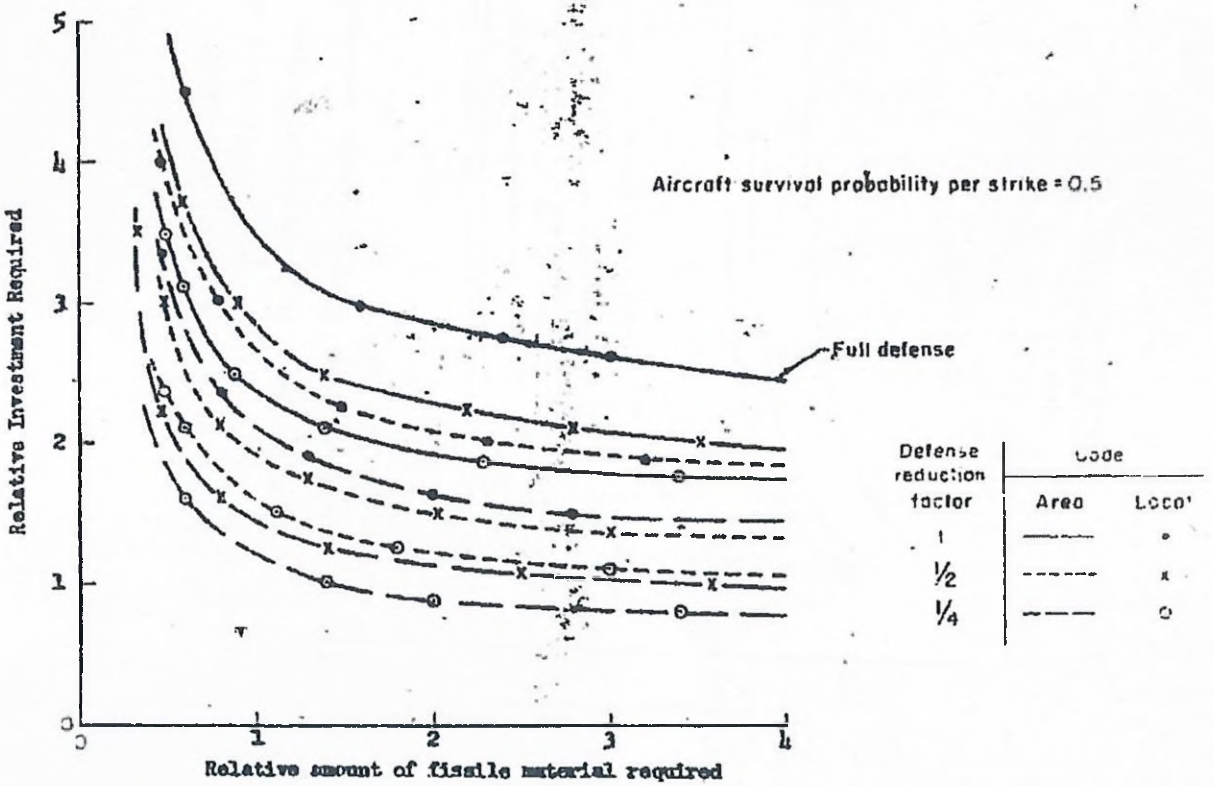

Fig. 13 —— Resource exchange curve (including ECM tactics) for B-47 B at various relative defense levels

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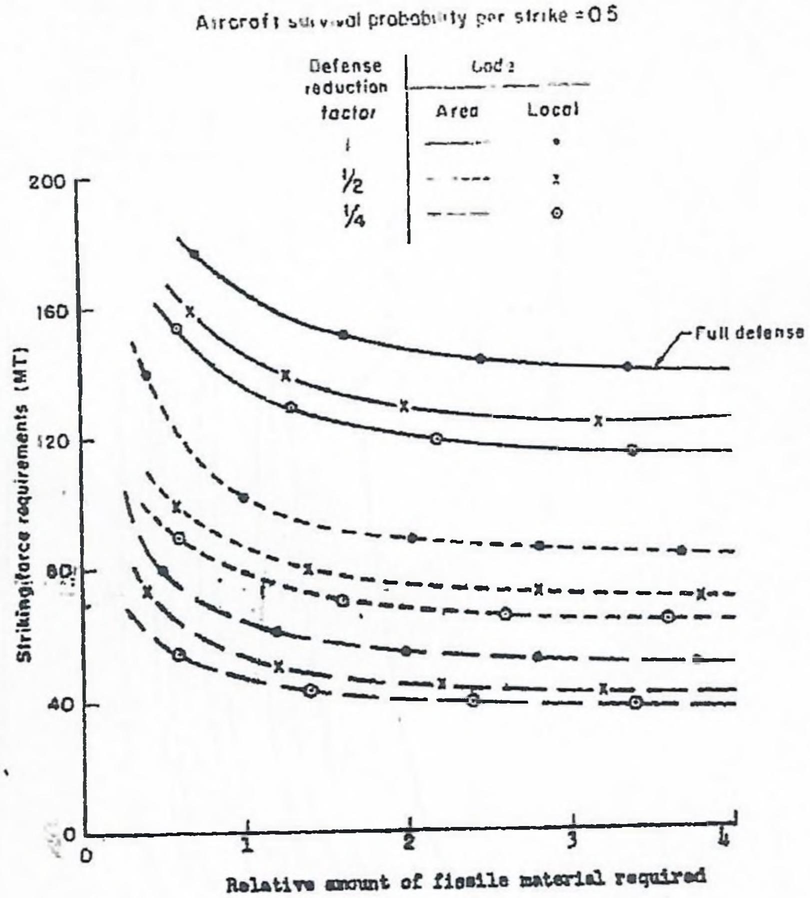

Fig. 14 a — Strike size along exchange curve for B-47 B at various relative defense levels

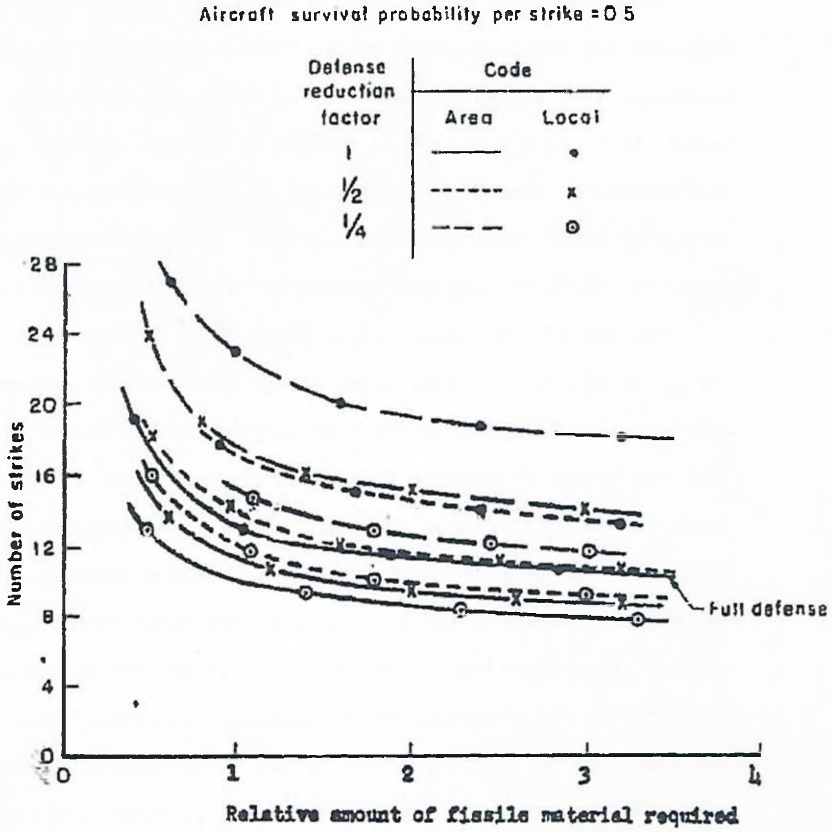

Fig. 14 b — Number of strikes along exchange curve for B-47 at various relative defense levels that the total number of strikes is reduced. This is a consequence of two factors: the survival probability per aircraft is fixed (at 0.5), and there is no large decrease in cost for a sortie capability of less than one or two wings.

Campaigns I and II and Figs. 5 through 14 that pertain to them are included for the convenience of the reader so that the effects of any defense reduction that can be estimated may be found with respect to the changes in costs, tactics, and so on. An example of the use of these campaigns to interpret the effects of mass chaff application on area defenses and nominal numbers of decoys on local defenses has been given. An additional example showing the possible effect of some countermeasures-of-opportunity is discussed below.

For the case of forward-fired chaff,(2)(3) suppose that a bomber can carry, at no cost for alteration, enough chaff rockets to negate, say, four firing passes from radar-controlled weapons, either ground or airborne, and that the bomber is expected to have an average number of eight such engagements in the area defenses and four in the local defenses. The question might arise as to whether the bomber could most advantageously expend this chaff against the area defenses, against the local defenses, or apportion it somehow between the two. Campaigns I and II can aid in approaching the answer. According to the conditions of the problem, the bomber has a choice of reducing the area defenses to 1/2 or reducing the local defenses nearly to zero, or to reduce both somewhere in between—for example, reducing the area defenses to 3/4 and the local defenses to 1/2. Campaign II (see Fig. 13) shows that the least costly campaign to damage a fixed number of targets is that in which the effort is not wholly used against the area defenses. That is, the bomber should save some chaff as he traverses the interceptor defenses if he expects missile defenses of nominal lethality near the target.[*] This result is based on the supposition that the campaign costing can be done in actuality as it was done in the analysis—namely, that use is made of the replacement unit concept, etc. If this is not in fact the case, then the cost of sortieing a greater number of aircraft per strike has already been amortized and hence cannot fairly penalize <u>this</u> raid, so that the area defenses can be saturated while the bombers attack a greater number of targets than considered in the analysis. It then becomes even more evident that a larger fraction of the chaff should be saved for the local defenses.

## D. CAMPAIGN XII

Since the concept of decoys represented a relatively expensive as well as one of the best high-confidence forms of electronic countermeasures, it was desired to make a special analysis of campaigns using decoys. There are several questions of immediate interest. What quantity of decoys (both area and local types) seem to be required? What are the relative values of area and local types? Do campaign tactics change significantly if decoys are employed? Is there a region of decreasing payoff for decoys and, if so, where? What fraction of total campaign cost should be expended in decoy effort? Is there some optimum ratio of costs and, if so, how sensitive is such a ratio to defense level? With the above questions in mind the campaign results shown in Figs. 15 through 18 are informative.

Figure 15 shows the investment exchange curve for a campaign using decoys. It is apparent that the addition of a nominal number of decoys can make a

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[*] This discussion is merely introductory, and serves only to show how system or campaign thinking may influence detailed operational plans.

radical change in either the system costs or fissile material requirements, or both. In the region on the exchange curves between the 2 and 3 relative units of fissile material requirements the investment cost (for 80 targets damaged) can be reduced by factors of the order of two with fairly small numbers of decoys. For example, Figs. 15 and 17 indicate that a cell consisting of about 5 bombers, about 3 of them carrying bombs, and about 2 carrying about 18 decoys in all, plus about 5 area decoys (say half of a transport aircraft load) sortied against each target to be destroyed, represents the sort of attack that results in a cost saving by a factor of two. The number of targets attacked on each strike is about 15, giving something like 7 strikes in the entire campaign, each of about 75 aircraft carrying 45 bombs, 270 local decoys and sortied together with, say, one squadron of C-124's launching 75 area decoys. This represents about 2 1/2 medium bomber wings committed per strike as compared to about 5 1/2 wings without decoy augmentation. Of course, it is just this decreased logistic and operational effort that produces the reduced campaign cost.

Figure 16 shows perhaps a more interesting result. Here the least campaign cost is plotted against, effectively, the number of local defense decoys used, with the number of area decoys used as a parameter. In this chart the amount of fissile material required is not allowed to influence the tactics, and consequently each point along the lines plotted on the chart represents a different fissile material requirement as well as different cell sizes, targets attacked per strike, decoy quantities, etc.

Had the chart been drawn for a constant fissile material consumption within the region of interest, essentially the same results as shown would have been obtained. It is interesting to note, from Fig. 16, that

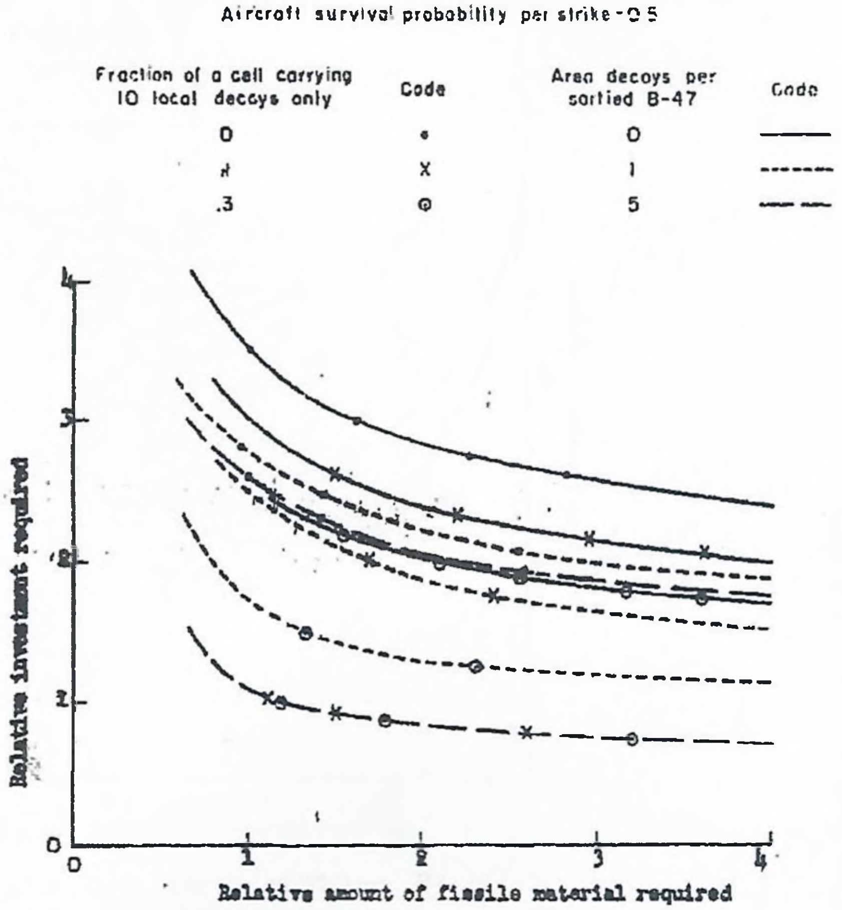

Fig. 15 — Exchange curve, B-47's with ECM decoys

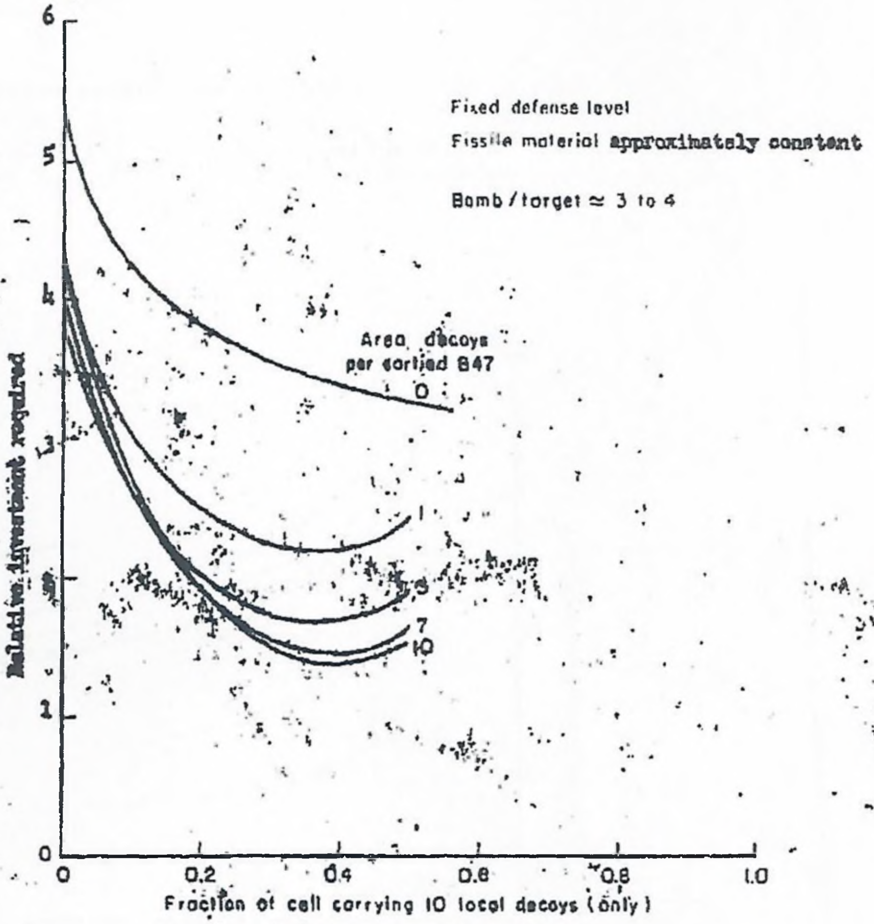

Fig. 16. —Campaign cost (including ECM) vs number of decoys used

decoy countermeasures, at the estimated costs, are sufficiently expensive--largely due to the cost of their transportation by C-124's for area decoys and by B-47's for the local decoys--that in an effort to oversaturate the defenses the expense can become more than the gain. Thus it is apparent that, taking the initial defense level used here, more than, say, 7 to 10 area decoys per B-47 and more than 1/3 to 1/2 the cell carrying 10 local decoys each produces no decrease in over-all costs. In fact, as decoys are further increased they begin to cost more than they buy. Had the initial level of defense been higher than that used here, this region of reduced payoff would have occurred at a larger number of decoys than that shown in Fig. 16. For a lesser defense level, fewer decoys would be needed to approach the region of reduced payoff.

The tactics called for by the campaign analysis (over the region of variation in the numbers of area and local decoys shown in Fig. 16) do change as a function of the numbers of decoys. Figure 17 shows the variation obtained in cell size, targets attacked per strike, bombs per cell, and strike size.

It is apparent that, as defense effectiveness is reduced by decoys, the cost advantage results largely from reducing the strike size. The curves of cell size, Fig. 17(a), targets attacked per strike, Fig. 17(b), and strike size, Fig. 17(d) indicate, however, that a rather drastic change in tactics occurs for all cases using area decoys somewhere between using up to 1/8 of the cell as local-decoy transports and more than about 1/4 of the cell as local-decoy transports. In this region, as local decoys are introduced, the targets attacked per strike changes rapidly from an increase to a decrease as local decoys are increased, until a low value, relatively independent of local decoys, is reached, while the strike size stops decreasing and remained

Aircraft survival probability per strike = 0.5

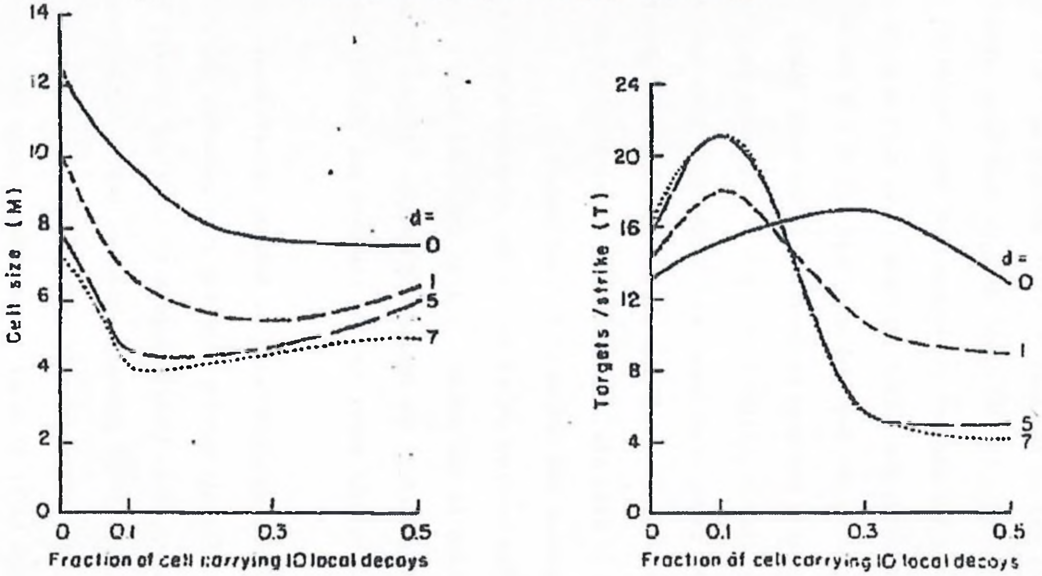

Fig 17 (a)

Fig. 17 (b)

Strike parameters along exchange curve vs fraction of cell carrying local decoys

Aircraft survival probability per strike = 0.5

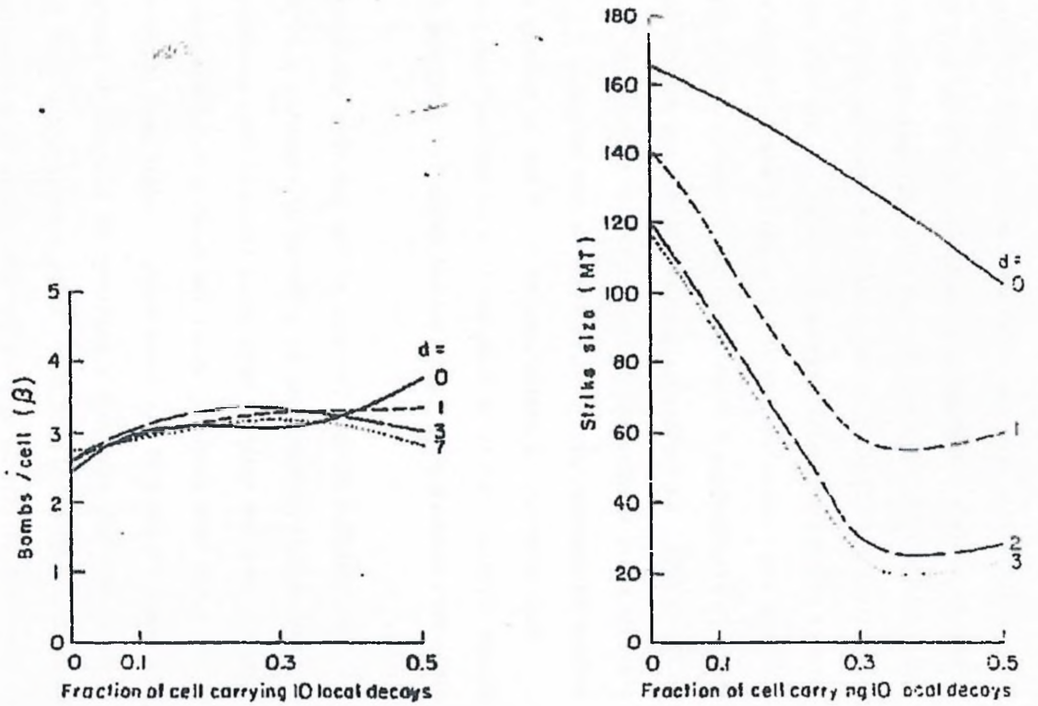

Fig. 17 (c)

Fig. 17 (d)

Strike parameters along exchange curve vs fraction of cell carrying local decoys relatively constant.

This indicates the change in tactics induced by the change in the problem's restrictions from one which required aircraft and decoys in sufficient number to satisfy the survival restriction to one which requires sufficient non-decoy carrying aircraft for the bomb carrying requirements. As defense effectiveness is reduced by using escort bombers as decoy carriers, fewer bombers are sortied until eventually almost all aircraft sortied are decoy carriers and bombers must be added to carry bombs. Essentially, this results in establishing a floor under the allowable strike size, as illustrated in Fig. 17(d). As further defense reductions are sought, bombers are again added to carry decoys, and their cost begins to outweigh their worth as defense saturators, even with 10 local decoys apiece.

This situation is reminiscent of World War II bombing strikes wherein enough airplanes had to be bomb carriers so that defense saturation requirements were automatically fulfilled and hence low attrition rates were observed.

The question of what fraction of the campaign cost should be expended on decoy countermeasures can be answered by examination of Fig. 18. It is apparent that the analysis here would indicate that something like 5 percent of the total cost should be spent for decoy countermeasures. Although this is a small fraction of the total cost, it would save billions of dollars. It does, however, represent a considerable increase in expenditure over that heretofore associated with ECM. It is interesting to note further from Fig. 18 that this fractional expense for ECM decoys is not very sensitive to defense level over at least a 2 to 1 range. A further point of interest is that the countermeasures themselves, even considering the most expensive types, do not accurately represent the actual cost of ECM in campaigns. The most important cost is incurred in transporting the ECM.

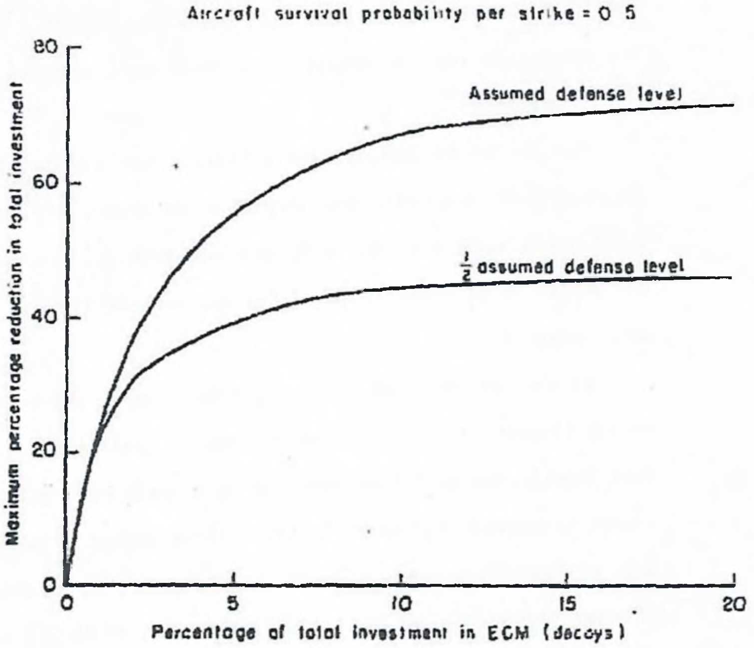

Fig. 18 — Percentage savings vs percentage investment in decoy ECM

## Appendix I

## THE ANALYTICAL MODEL

This appendix describes the campaign models used in the present study. The basic data, rules, and parameters are identical with those used in the Missiles Systems for Strategic Bombardment study,(6)(8) but the criterion for comparison and the attrition formulas were modified in order to simplify the computation.*

For the present study, the criterion used is the minimum dollar investment required to provide and support a SAC capability for making T' target visits with sufficient force to maintain both (a) the survival probability per strike to at least 1-r, and (b) the bomb-delivery capability per target** to at least $\mu$.

At the initial level of defense taken here, whenever the survival probability is maintained above some reasonable level (say, 0.5 as a minimum acceptable level), the cell size obtained in a least-cost campaign is always large enough to provide for carrying the optimum number of bombs.*** The introduction of countermeasures, however, may so weaken the defense that the problems of operation become not those of survival but of delivery of a sufficient weight of bombs. For this reason, restriction (b), as well as (a), was

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*The structural changes in the attrition model are detailed in Appendix I of RM-879(7); the criterion change is discussed in Part II of the same Research Memorandum.

**On an expected-value basis.

***Using the "restricted yield assumption" which allows the offense to drop only ~~one~~ effective bomb per target, although more than one may be available. This assumption has the effect of increasing the yield called for if fissile material is to be conserved over that which would be requested if effective multiple bomb drops on a single aiming point were to be considered.

introduced.

Various types and amounts of countermeasures equipment were employed in the campaigns considered. The cost is given by:

$$C = C_T + C_S MT + C_V R_1 MT(1-P_S)\ (N-1) + C_{CM} R_1 MTN. \qquad (1)$$

(Definitions and numerical values of the symbols used in this appendix are listed on p. 7[illegible], 7[illegible], and 7[illegible].)

For each countermeasures system (that is, for each given type and amount, used with a particular aircraft) cost, survival, and bomb delivery criteria were applied to determine the best choice of M and T. In other words, the minimum of C was determined subject to the restrictions

(a) $P_s \geq 1-r$

(b) $\beta P_B \geq \mu$

for a given $T' = MT$. Systems were then comparable on the basis of minimum cost for the same number of attacks.

Thus far, nothing has been said about the destruction obtained, or the amount of fissile material required to achieve it, with these T' attacks. However, in determining the minimum of C, the tactics or values of M and T which lead to the minimum are determined. By the following process, a comparison may be made on the basis of the same expenditure of fissile material.

On any strike, using $\beta$ bombs per cell each with coverage $P_H$, under the restricted-yield assumption (only one bomb dropped per target), the expected number of targets destroyed with confirmation is approximated by

$$D = T \left[ 1 - (1-P_B)^{\beta} \right] \cdot \left[ 1 - (1-R_1 P_S)^{M} \right] P_H \qquad (2)$$

On N strikes, the number confirmed destroyed is thus

$$ND = T'P_H P_R P_\beta \text{ where } P_\beta = 1 - (1-P_B)^\beta \text{ and } P_R = 1 - (1-R_1 P_S)^M$$

It is necessary to determine values of $\beta$ and $P_H$ for which the amount of fissile material required, namely,

$$F = R_1 \beta NTK = R_1 \beta T'K(P_H) \qquad (3)$$

is a minimum, subject to the condition that the number of targets destroyed is

$$\alpha T_o = T'P_H P_\beta P_R \qquad (4)$$

Here $\alpha T_o$ represents the number of targets in the system required to be destroyed.

Using (4) to eliminate $\beta$ from (3) and differentiating F with respect $P_H$, the values of $\beta$ and $P_H$ which yield minimum F, for T and MT as determined to give the minimum of (1), can be obtained. Cf. reference 8, RM-986, Section 5.

For the target system, overpressure (psi) requirements, and yield-kilogram relationships used, the approximation

$$P_H = \sqrt{\frac{2\alpha T}{P_R T'} + 0.25} - 0.5 \qquad (5)$$

is very close. $\beta$ then may be obtained from

$$\beta = \frac{\ln\left[1 - \frac{\alpha T}{P_H P_R T'}\right]}{\ln(1-P_B)} = \frac{\ln\left[\frac{1-P_H}{2}\right]}{\ln(1-P_B)} \qquad (6)$$

Before illustrating the comparison of various systems, consider the problem of determining the minimum cost under restrictions (a) and (b) (p. 71) and the associated tactics.

Let $m$ = fraction of the bomber cell consisting of planes which are not potential bomb carriers. Thus $(1-m)M$ is the maximum[*] number of possible bomb carriers, and $\beta \leq M(1-m)$.

For the case in which the solution of (6) exceeds $(1-m)M$, the number of bombs, $\beta$, is taken equal to $(1-m)M$. The coverage, $P_H$, is obtained from (4) since $P_\beta$ can be computed directly.

The survival probability restriction requires

$$\text{(a)} \quad P_S = 1 - \frac{\phi_i + \phi_o + \Lambda_o T}{R_1 MT} \geq 1-r$$

and the bomb-delivery restriction requires

$$\text{(b)} \quad (1-m)MR_1R_2 \left\{ 1 - \frac{\phi_i + \Lambda_i T}{R_1 MT} \right\} \geq \mu$$

The minimum of the cost equation is required (with MT set equal to T'),

$$C = C_T + \left[ C_S + \frac{C_{OM} R_1 T'}{T} \right] MT + C_V(\phi_i + \phi_o + \Lambda_o T) \left[ \left(\frac{T'}{T}\right) - 1 \right]$$

subject to both (a) and (b).

Since for each T, the value of C is decreasing with MT, the minimum cost will lie on the boundary of the region in the (MT,T) plane which contains the values of MT and T satisfying both (a) and (b). See Fig. 19.

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[*] The case m = 0 implies that all planes in the cell are potential bomb carriers. This is never the case when local-defense decoys are employed.

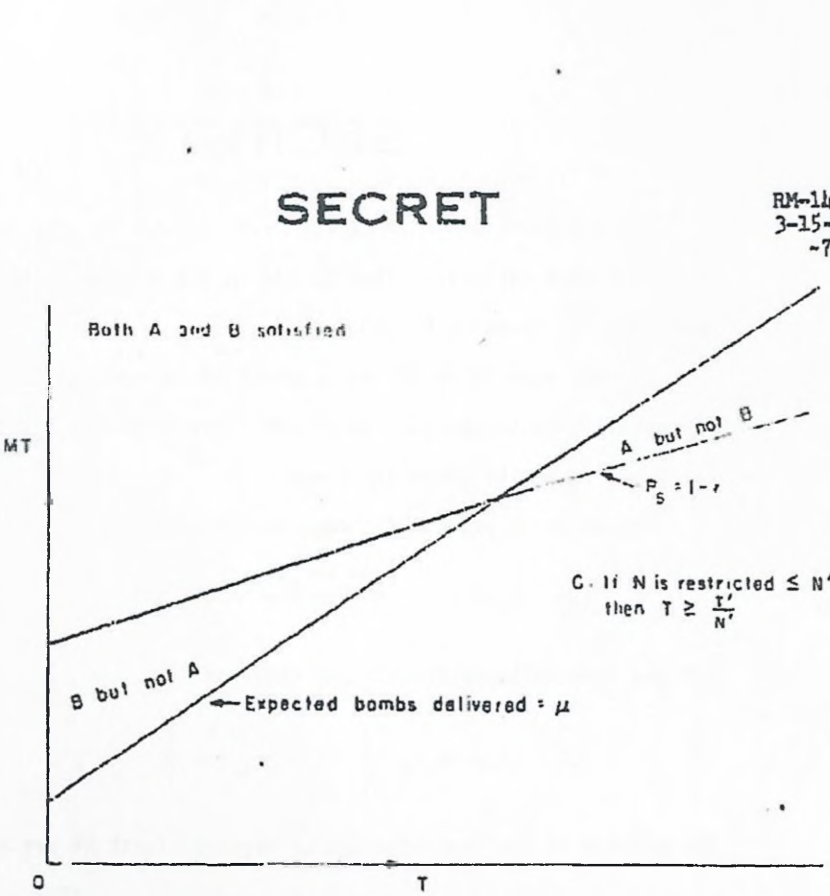

Figure 19. Boundary conditions on strike size as a function of targets per strike and various tactical restrictions

Using (a) with equality as the restriction, the minimum occurs at the solution of

$$MT = \frac{\phi_1+\phi_o+\Lambda_o T}{R_1 r}$$

$$T^2 = \frac{R_1(rC_V+C_{CM})\,(\phi_1+\phi_o)T'}{\Lambda_o(C_S-R_1 r C_V)}$$

Using (b) with the equal sign as the restriction, the minimum occurs at the solution of

$$T^2 = \frac{R_1 T' \left\{ C_V(\phi_1+\phi_o) + \phi_1 C_{CM} \right\}}{C_S \left\{ \Lambda_1 + \frac{\mu}{R_2(1-m)} - R_1 C_V \Lambda_o \right\}}$$

$$MT = \frac{1}{R_1} \left\{ \phi_i + \left[ \Lambda_i + \frac{\mu}{R_2(1-m)} \right] T \right\}$$

The procedure is to compute both points; if neither satisfies both conditions the point of intersection, P, is used; if each satisfies both conditions the one giving the lower value of C is used; if just one fails, the other is used.

Three types of computation were carried out. For Campaigns I and II, the costs of the countermeasures themselves were not considered as parameters in the determination of the tactics. For these cases, the coefficients in the cost equation were those for the B-47B (with $C_{CM} = 0$), and the presence of countermeasure served only to reduce the defense effectiveness. The total cost for the campaign was then found by adding the cost of the countermeasures required to attain the assumed reduction of the defense. For the case in which the countermeasures were decoys, however, the coefficients in the cost equation were functions of the number and the type of decoy.

For all cases, the aircraft considered was the B-47B, operating from overseas bases against the "industrial target system" and the "summer low defense" described in reference 6. This situation is characterized as follows:

$C_{CM}$ = Cost of the countermeasures expended per bomber sortie

$C_S$ = Sortie potential cost

$C_T$ = Theater support cost

$C_V$ = Vehicle replacement cost

$R_1$ = Probability that a bomber does not abort before entering area defenses = 0.84

$R_2$ = Probability that a bombing system does not abort = 0.95

$\Lambda_B$ = Local defense kill potential against aircraft up to bomb release = 1.5

$\Lambda_R$ = Local defense kill potential against round-trip aircraft = 3.0

$\Phi_i$ = Expected number of bombers killed, inbound, 100 targets under attack = 70

$\Phi_o$ = Expected number of bombers killed, outbound, 100 targets under attack = 40

Other symbols used above, included for ease of reference, are:

a and b = Constants referring to distribution of area defense

F = Total kilograms of fissile material expended

K = Number of kilograms of fissile material per bomb; ($K = K(P_H)$ for a given CEP and psi requirement)

M = Cell size

N = Number of strikes

$P_B$ = Probability a bomb is delivered $= R_1R_2 \left\{1 - \frac{\phi_i + \Lambda_i T}{R_1 MT}\right\}$

$P_H$ = Probability a target is destroyed by a dropped bomb

$P_S$ = Probability a plane survives a strike $= 1 - \frac{\phi_i + \phi_o + \Lambda_o T}{R_1 MT}$

T = Number of targets under attack per strike

T' = Total number of attacks on the campaign; T' = NT

$T_o$ = Total number of targets in the target system. Usually $T_o = 100$

$\alpha$ = Fraction of the target system required destroyed, = 0.8

$\beta$ = Number of bombs per cell

$\Lambda_i$ = Normalized inbound local kill potential

$\Lambda_o$ = Normalized outbound local kill potential

$\phi_i$ = Normalized inbound area kill potential

$\phi_o$ = Normalized outbound area kill potential

Unless otherwise stated $\mu = 2$ and $r = 0.5$.

For the first two computations a defense effectiveness reduction factor $f$ was introduced with the interceptor kill potentials $\Phi_i$ and $\Phi_o$, and one of $\ell$ with the missile kill potentials $\Lambda_B$ and $\Lambda_R$. The function used to indicate the fraction of the interceptor defense which entered the air battle was a linear form, $f(T) = a + bT$. This was taken to be:

$$f(T) = 0.2 + 0.016T \text{ for } T \leq 50$$

$$f(T) = 1 \text{ for } T > 50$$

Also, the local defense survival probability, $e^{-\frac{\Lambda}{M'}}$, was replaced by the linear approximation, $1 - \frac{\Lambda}{M'}$ where $M'$ is the cell size entering the local defense.

In the present model

$$\phi_i = a\,\Phi_i \,, \quad \phi_o = a\,\Phi_o$$

$$\Lambda_i = b\,\Phi_i + \Lambda_B \,, \quad \Lambda_o = b\,(\Phi_i + \Phi_o) + \Lambda_R$$

Inserting both the defense reduction factors and the numerical values,

$$\phi_i = 13.0\,f$$

$$\phi_i + \phi_o = 18.8f$$

$$\Lambda_o = 1.51f + 2.83\ell$$

$$\Lambda_i = 1.04f + 1.60\ell$$

In the first case, Campaign I, for $T' = 100$, and $m = 0$, the strategy for minimum cost was determined without considering ECM, that is, with $\ell = f = 1$. Also, the values of $\beta$ and $KT$ were next determined to require the minimum amount of fissile material to destroy 80 targets under the restricted-yield assumption with this minimum cost strategy. Then, using these values of $M$, $T$, $\beta$, and $KT$, the total number of targets that could be destroyed against a reduced defense ($f$, $\ell \neq 1$) was computed under the assumption that the campaign continued until the total losses for the campaign with the reduced defense were equal to those in the unreduced. The results appear in Figs. 9 and 10.

In Campaign II, by using various values of $T'$, curves of cost vs. F were drawn from the various $f$ and $\ell$ reductions. These appear in Fig. 13. As before, $r = 0.5$, $m = 0$, $\mu = 2$.

Next using the tactics of Campaign I, the campaign was assumed to go on killing targets until the total <u>cost</u> was equal to that required in the unreduced defense case. The results are not shown because, although more targets are destroyed when the strategy is adjusted to the defense, as is to be expected, the gain is insignificant.

For Campaign III, when decoys were considered as the countermeasure technique to reduce defense effectiveness, some additional factors are necessary.

Let

$d$ = number of area decoys employed per B-47B
$n_C$ = number of area decoys launched by a single C-124
$m$ = fraction of the B-47 cell consisting of decoy carriers
$\beta \leq (1-m)M$, maximum number of bombs per cell
$n_E$ = number of local decoys launched per escort B-47B

For all the computations, $n_C = 10$, and $n_E = 10$.

With the introduction of decoys the following modifications in the defense parameters take place:

$$\Phi_i \text{ becomes } \frac{\Phi_i}{1+d} \;;\quad \theta_i = \frac{a\Phi_i}{1+d} - \frac{13.0}{1+d}$$

$$\dot{\Phi}_o \text{ becomes } \frac{\dot{\Phi}_o}{1+d}\,;\quad \Lambda_o = \frac{a\dot{\Phi}_o}{1+d} = \frac{5.8}{1+d}$$

$$\Lambda_B \text{ becomes } \frac{B}{1+mn_E}\,;\quad \Lambda_i = \frac{b\dot{\Phi}_i}{1+d} + \frac{B}{1+mn_E} = \frac{1.04}{1+d} + \frac{1.60}{1+10m}$$

$$\hat{\Lambda}_R \text{ becomes } \frac{\hat{R}}{1+mn_E}\,;\quad \hat{\Lambda}_o = \frac{b(\bar{\Phi}_i+\bar{\Phi}_o)}{1+d} + \frac{\hat{B}}{1+mn_E} = \frac{1.51}{1+d} + \frac{2.83}{1+10m}$$

For the specific campaign computed, area-defense decoys are released outside the defenses from C-124's. These decoys are assumed to resemble bombers in every respect to the effective means of detection and destruction available to the defense; they furnish saturation both inbound and outbound. Local-defense decoys are carried by escort bombers and are released just outside the local defenses; they furnish saturation equivalent to that of escort bombers both inbound and outbound.

The coefficients in the cost equation (in millions of dollars) are modified as follows to include the cost of decoys and supporting equipment:

$C_T$ = theater cost of B-47B and KC-97 plus theater cost of C-124

$C_S$ = $C_S$ for the B-47 plus cost of modification to accommodate local decoys plus sortie costs of the C-124

$C_V$ = $C_V'$ for the B-47 plus modification cost

$C_{CM}$ = cost of the decoys used per B-47 employed

Campaigns were computed for various values of m and d and the minimum costs plotted against fissile material expended (see Fig. 15). In addition, the minimum campaign cost was obtained as a function of both m and d independent of fissile material expenditure and is shown in Fig. 16.

## LIST OF SYMBOLS

a and b = constants referring to distribution of area defense

$B$ = total number of bombers

$B_K$ = number of bombers killed

$C_{CM}$ = cost of ECM per bomber sortie

$C_S$ = sortie potential cost

$C_T$ = theater support cost

$C_V$ = vehicle replacement cost

$d$ = number of area decoys employed per bomber

$F$ = total kilograms of fissile material expended

$f$ = area defense effectiveness reduction factor

$f(T)$ = fraction of area defenses excited by a strike on T targets

$i$ = subscript, meaning "inbound"

$K$ = number of kilograms of fissile material per bomb

$k$ = number of local defense guidance units per target

$\ell$ = local defense effectiveness reduction factor

$M$ = number of bombers in a cell attacking one target

$M'$ = number of bombers in a cell entering local defenses (= M less bombers killed by area defenses)

$M'_{ki}$ = number of bombers in a cell killed by local defenses on approach to target

$M'_{kr}$ = number of bombers in a cell killed by local defenses on return from target

$m$ = fraction of bombers in a cell carrying decoys

$MT$ = total number of bombers in a strike on T targets

$N$ = number of strikes

$n_C$ = number of decoys per transport aircraft

$n_E$ = number of decoys per escort bomber

$\bar{n}$ = average total number of local defense missiles that can be launched against one bomber

## LIST OF SYMBOLS (Cont'd.)

$o$ = subscript, meaning "outbound"

$P_{AK}$ = probability that a committed interceptor attacks and kills a bomber

$P_B$ = probability a bomb is delivered

$P_H$ = probability a target is destroyed by a dropped bomb

$P_K$ = probability that a committed missile kills a bomber

$P_{LK}$ = probability that a bomber is killed by local defenses

$P_S$ = probability that a bomber survives a strike

$R_1$ = probability that a sortied bomber does not abort prior to entering area defenses

$R_2$ = probability that a bombing system does not malfunction

$r$ = probability of a bomber not surviving a strike

$T$ = number of targets in a strike

$T'$ = total number of attacks on a campaign = $MT$

$T_o$ = total number of targets in a campaign

$\alpha$ = fraction of target system required to be destroyed

$\beta$ = number of bombs per cell of M bombers

$\Lambda_B$ = local defense kill potential against aircraft up to bomb release

$\Lambda_R$ = local defense kill potential against round trip plane

$\Lambda_i$ = normalized inbound local kill potential

$\Lambda_o$ = normalized outbound local kill potential

$\mu$ = probability of delivering at least one bomb on target

$\Phi_i$ = expected number of bombers killed, inbound, 100 targets under attack

$\phi_i$ = normalized inbound area kill potential

$\Phi_o$ = expected number of bombers killed, outbound, 100 targets under attack

$\phi_o$ = normalized outbound area kill potential

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*Limited distribution.