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Optimal Allocation and Effectiveness of Midcourse Interceptors in a Layered Defense

C. T. Cunningham

April 19, 1989

Lawrence Livermore National Laboratory

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ABSTRACT

Adaptive preferential employment of interceptors in midcourse ballistic missile defense is considered. The defense discriminates decoys, with such discrimination characterized by a K-factor, and determines optimal intercepts and salvo structure in shoot-look-shoot scenarios. The attacker's strategy to determine proper allocation of warheads to targets of varying value in the presence of a defense is also described. Representative results are presented for the effectiveness of the preferential midcourse defense by itself and in conjunction with a random-subtractive boost/deployment phase defense tier. Quality of discrimination is by far the strongest determinant of performance; the ability to perform a shoot-look-shoot is also important. Inventory requirements for midcourse and boost-phase defenses are determined for missions in which target value saved is the goal, for representative defense parameters. Based on these results, the midcourse tier appears to be a necessary component of a cost-effective defense.

I. Introduction

Presently we are engaged in a joint study with the Phase One Engineering Team (POET) and the National Test Facility (NTF) to determine the effectiveness of a Phase One strategic defense as a function of the force mix of space-based and ground-based interceptors. An important part of LLNL's contribution will be to relate results from the NTF regarding warheads killed by the defense in a strategic attack to the value of ground installations which is saved by the presence of the defense.

To perform this calculation we have decided to adopt the strategy used by Chrzanowski, Duffy and Abey in similar studies. (Reference 1,2) Briefly, this methodology treats the allocation of attacking and defending resources to a variety of target classes as a two-person game and determines a min/max solution for the target value remaining after the attack. It was necessary to extend the formal models developed by Chrzanowski (Reference 1) in order to consider interceptor allocation when midcourse decoys are present and when a shoot-look-shoot (-look-shoot-...) strategy may be used, both quite important elements of the present study. Further details in the context of the study will be presented elsewhere.

This paper formally describes the problem faced by the defender in midcourse. He knows which clusters of RVs and associated decoys have penetrated the boost/deployment layer of the defense and can determine the ground targets toward which they are heading. A discrimination system provides him with information as to the most likely RV candidates in each cluster. He then must decide which objects in which clusters must be intercepted in order to maximize the defense performance, i.e., to maximize the value of ground installations surviving after the attack. We note that this construct does not necessarily apply to the proposal Phase One defense, for which the resolution and track accuracy of SSTS, the midcourse sensor system, is still under discussion and might not permit aimpoint prediction.

The defender is constrained by a limited number of interceptors. He can significantly reduce the number he needs by firing them in salvos, assessing in which clusters the RVs have been killed (a successfully intercepted RV should give a dramatic signature) and firing again (i.e., shoot-look-shoot-...). However, this adds another level of complexity to the defense's planning, since he must determine the salvo structure as well as the objects to be attacked.

II. Mathematical Formulation

Suppose the target set may be divided into classes of identical targets with N^T the number and V^T the individual value of targets in T. The defender finds that there are $N^T(n_p)$ targets in T for each of which exactly n_p RVs (and associated decoys) have penetrated into midcourse. If each target in T were allocated a total of n_{RV} RVs initially and the probabilities P_{p1} of each RV penetrating to midcourse were independent, then $N^T(n_p)$ would have a binomial distribution

$$N^T(n_p) = N^T\, C^{n_p}_{n_{RV}}\, (P_{p1})^{n_p}\, (1 - P_{p1})^{\,n_{RV}-n_p} \qquad (1a)$$

$$C^i_n = n!/i!\,(n-i)! \qquad (1b)$$

The total value of targets surviving the attack is therefore

$$V = \sum_{T,n_p} N^T(n_p)\, V^T\, P^T_S(n_p) \qquad (2)$$

where $P_S{}^T(n_p)$ is the probability that a target in T attacked by n_p RVs will survive, assuming an optimal defense strategy. Similarly the number of interceptors used will be

$$I = \sum_{T,n_p} N^T(n_p)\, I^T(n_p) \qquad (3)$$

Where $I^T(n_p)$ is the number of interceptors used, on the average, for each target in T which is attacked by n_p RVs.

Now the total surviving value V is to be maximized for a constrained number of interceptors used I. This maximization is to be accomplished by selecting the appropriate strategy to be used for each subclass of targets (of class T and attacked by n_p). Let us suppose that we have a single parameter σ describing these strategies and that $Ps^T(n_p,\sigma)$ and $I^T(n_p,\sigma)$ are continuous functions of this parameter. If the strategy parameter σ were itself continuous, we would have that for all targets which were defended by any interceptors, the strategies must be such that

$$V^T P_s{}^{T*}(n_p,\sigma)_{,\sigma} / I^T(n_p,\sigma)_{,\sigma} = (dV/dI)^* \qquad (4)$$

where ",σ" denotes a partial derivative, Ps^{T*} is the convex hull of Ps^T, and $(dV/dI)^*$ is some constant. If (4) were not true, it would be possible to slightly change two of the strategies and increase V for constant I. In fact, we shall use a discrete, rather than a continuous, strategy parameter. In this case, the generalization of (4) is straightforward.

The convex hull f* of function f(x) is the upper bound of linear combinations of elements of f(x):

$$f^*(x) = \max_{x_0<x<x_1} [(x_1 - x)\, f(x_0) + (x - x_0)\, f(x_1)]/(x_1 - x_0) \qquad (5)$$

In (4) Ps^{T*} is understood as the hull of Ps^T over domain I^T; i.e., $Ps^T(I^T)$.

Our strategy parameter will be denoted m_I, the maximum number of interceptors the defense is willing to use to defend a single target. One may show that for an optimal strategy each of the n_p penetrating RVs is to be allocated the same maximum number, so that m_I is a multiple of n_p:

$$m_I = n_I\, n_p \qquad (6)$$

Then

$$P_s{}^T(n_p,m_I) = (1 - P_s^{RV}(n_I)\, P_{k1}^T)^{n_p} \qquad (7)$$

where $Pk_1{}^T$ is the probability of target kill by a single RV which penetrates all layers of the defense and $Ps^{RV}(n_I)$ is the probability that an RV which penetrates to midcourse will survive (a maximum of) n_I interceptors. It is evident that the desired sequence of defense strategies minimizes P_S^{RV} for given n_I.

Each RV is associated with a number of decoys, the total number of objects being o*. These objects have been discriminated and rank-ordered with respect to the discriminant, and $P_{RV}(o)$ is the probability that the object of rank o is the RV; thus

$$P_s^{RV}(n_I) = \sum_o P_{RV}(o)\,(P_{s1}^{RV})^{m(o)} \qquad (8)$$

where P_{s1}^{RV} is the probability that the RV will survive a single interceptor directed at it and m(o) is the number of interceptors directed at object o. This equation may be rewritten as

$$P_s^{RV}(n_I) = 1 - \sum_{i=1}^{n_I} \Delta P_k^{RV}(i) \qquad (9a)$$

$$\Delta P_k(i) = P_{RV}[o(i)]\,(P_{s1}^{RV})^{m(i)-1}\,(1 - P_{s1}^{RV}) \qquad (9b)$$

where o(i) is the object which is targeted by the i^{th} interceptor and m(i) is the number of times that object has been targeted. These equations imply how to pick o(i): it should simply be the object for maximum $\Delta P_K(i)$.

The probability that the object of rank in a cluster of o* objects containing one RV is the RV itself may be written

$$P_{RV}(o) = \int [dP_{RV}(Z)]\, C_{o^*-1}^{o-1}\, [P_D(Z)]^{o-1}\, [1 - P_D(Z)]^{o^*-o} \qquad (10)$$

where $P_{RV}(Z)$ and $P_D(Z)$ are the cumulative probabilities that an RV and a decoy have discriminants less than standard variable Z. If the discriminants for each class of objects are normally distributed with unit variance (a common assumption for lack of a better one) then

$$P_{RV}(Z) = P_D(Z + K) = [\mathrm{erf}(Z/\sqrt{2}) + 1]/2 \qquad (11)$$

where the "K-factor" K is the ratio of the separation in means of the RV and decoy distributions to the (unit) standard error and erf(x) is the error function.

In practice, performing the integration (10) in the vicinity of $P_{RV}(Z) \sim 1$ proved tricky for large K. We found that an open-type Newton-Cotes method worked fairly well.

It is quite likely that the defense will have more than one opportunity to discriminate the decoys. Both the ground-launched Surveillance and Tracking Systems (an IR sensor) and the Ground-Based Radar have been proposed as components of the Phase One Strategic Defense System. Thus it is possible the defense may fire one (or several) salvos with data from one sensor system, re-discriminate with a second system and fire again.

Let $Ps^{RV*}(n_I{}^*)$ and $Ps^{RV\dagger}(n_I{}^\dagger)$ be the probabilities for the RV to survive intercepts using data from either two different sensor systems independently, as described above. Then if the systems are used jointly the cumulative probability of survival is

$$Ps^{RV}(n_I^* + n_I^\dagger) = Ps^{RV^*}(n_I^*)\, Ps^{RV\dagger}(n_I^\dagger) \qquad (12)$$

assuming that these probabilities are independent. It is quite possible, and is planned for Phase One, that the defense would want to use information from the first discrimination, and the (negative) outcomes of interceptor engagements together with the second discrimination results to plan his strategy. In the case the probabilities in equation (12) would not be independent. Such issues are outside the scope of this simple analysis.

Consider now the salvo structure of the intercepts and the average number of interceptors used $I^T(n_p,m_I)$. We have just described the way to pick a sequence of intercepts [o(i),m(i)] in such a way that RV probability of survival decreases as rapidly as possible along the sequence. For minimum interceptor usage, the first i_1 intercepts in the sequence should be made in the first salvo and RV kill assessed, then intercepts up to element i_2 should be made in the second salvo and kill assessed, etc., with remaining intercepts up to n_I made in the last salvo. If $P_s{}^{RV}(i)$ denotes the probability of RV survival through the i^{th} intercept and s the number of salvos, then the average number of interceptors used in protection of the target will be

$$I^T(n_p,m_I) = n_p \sum_s (i_s - i_{s-1})\, P_s^{RV}(i_{s-1}) \qquad (13)$$

There are n_p RVs to be attacked and the probability of launching salvo s against each of them is $P_s{}^{RV}(i_{s-1})$, i.e., the probability that the RV has not been observed to have been destroyed prior to salvo launch.

The total number of salvos exceeds the number of looks by one. However, since $i_s = n_I$ for the last salvo, the number of degrees of freedom in choice of salvo structure, i.e., the ways to pick $\{i_s\}$, subject to the above optimality condition, equals the number of looks n_{Look}. In practice, we used a hill-climbing technique in an n_{Look}-dimensional representation of $\{i_s\}$ to find a near-optimum.

III. Representative Results

In the previous section we introduced several variables which determine the interceptor engagement. Along with illustrative values, they are:

Table 1. Exemplary engagement parameters

Description	Value
RVs deployed for target	8
RVs in midcourse bound for target	4
Probability that target survives RV	0.3
Objects in discriminated cluster	100
K-factor for decoy discrimination	3
Probability that RV survives interceptor	0.1
Number of "looks"	2

Thus, we consider the attack of a hard target for which two RVs are needed for a high confidence kill. Four RVs have penetrated into midcourse, a comfortable excess. They are accompanied by a very large, although not unreasonable, number of decoys, but discrimination is good: $K = 3$ corresponds to only an 0.067 probability of equal false alarm and discrimination leakage (type 2 and type 1 errors). The interceptors are very reliable with a 90% SSP_K, and they may be utilized in up to three salvos: shoot-look-shoot-look-shoot. Thus, both offense and defense seem to be in fairly advantageous positions. In the Phase One system, it seems unlikely that three salvos will be possible with ERIS, the ground based interceptor. For three salvos, the space based interceptors might be used for the initial salvo, or some of the ground based interceptors might be forward based, or a terminal underlay might be added. In any case, the advantage gained by the third salvo is slight, as seen in Figure 1, to follow.

Figures 1-3 show results and some sensitivities for this attack. Figure 1 shows the variation of the target probability of survival $P_S{}^T$ with average number of interceptors used per target I^T for 0-2 looks. The ability to perform a shoot-look-shoot has a dramatic effect on the results, at least with regard to the numbers of interceptors required to ensure a high probability of target survival: for our example, it required 28 interceptors per target, on average, to ensure a 70% probability of survival if no looks could be taken. This number dropped to 13 interceptors for one look, and 11 interceptors for two looks. While the advantage for two vs. one look is not nearly as great as for one vs. no looks, for 90% target survival 19 interceptors are required with two looks and 28 with one look.

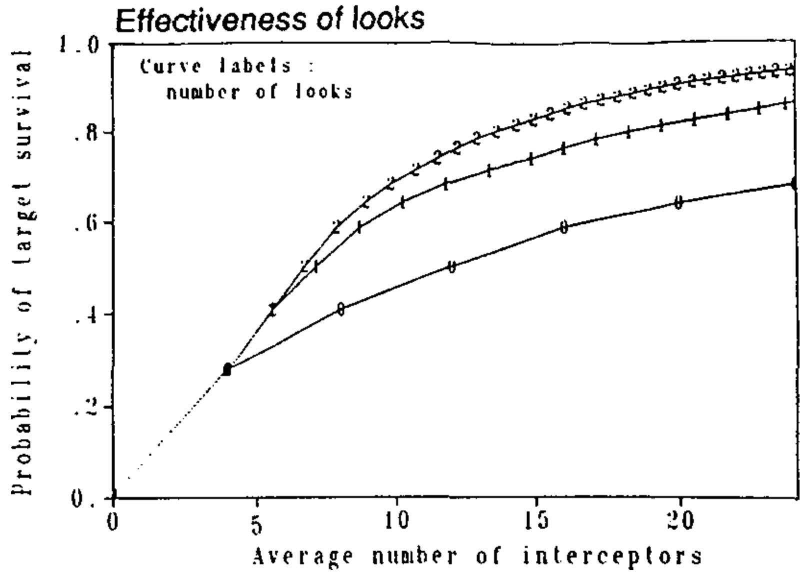

Figure 1. Curves of target survival vs. number of interceptors used differ by number of looks in a multiple shoot-look-shoot scheme. Other parameters as in Table 1.

Figure 2 presents target survival as a function of interceptor usage for different numbers of RVs penetrating into midcourse. While this plot holds few qualitative surprises, it shows that interceptor requirements do not scale linearly with numbers of RVs. A target survival of 70% requires 3.3 interceptors for 2 RVs, 11 interceptors for 4 RVs, and 20 interceptors for 6 RVs. (For a fixed number of interceptors per RV, the RV probability of arrival will be constant. Target probability of survival then scales non-linearly with n_p by equation 7.)

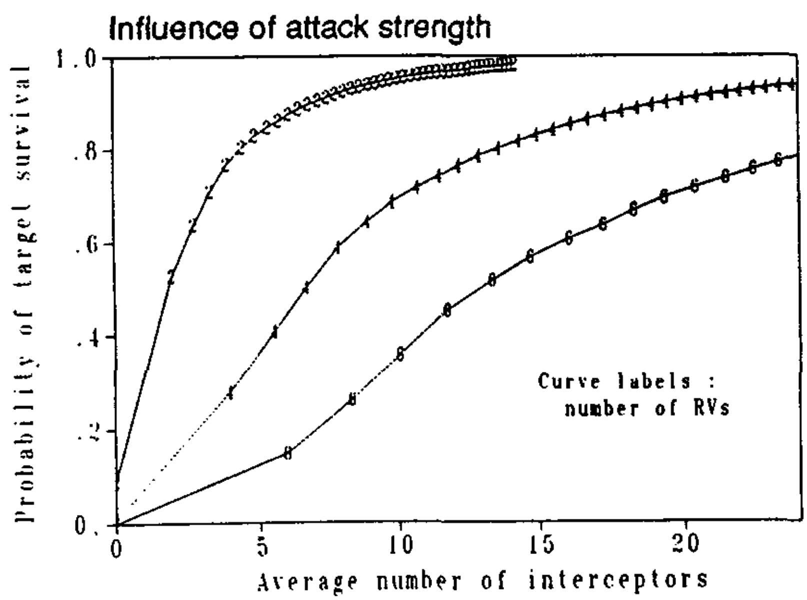

Figure 2. RVs per target is the variable illustrated. Other parameters as in Table 1.

Figure 3 presents a similar plot for curves of different K-factor. The importance of discrimination when many decoys are present cannot be overemphasized: it is the strongest sensitivity in the problem. Although K = 3 corresponds to quite good discrimination, it represents the regime in which results are most sensitive to K-factor for our example with 100 decoys: K = 4 helps the interceptors remarkably, while for K = 2 the interceptors perform poorly, even with many tens of them per target and the opportunity for two looks.

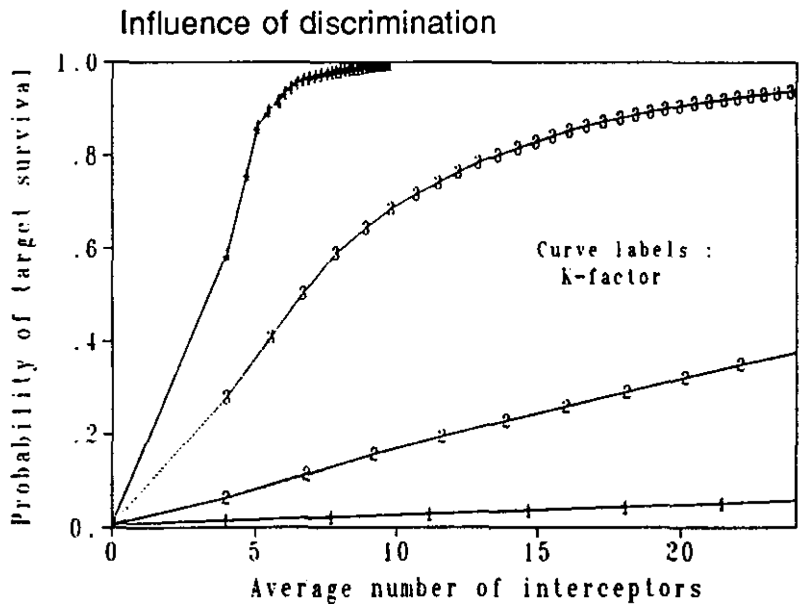

Figure 3. Probability of survival vs. interceptors used. Curves are labeled by K-factor.

IV. Attacker Allocation Strategy

In order to put these results in context, consider the attack of a large number of hard targets. The targets may either have similar values, as would be true for missile silos, or have a pronounced contrast in values, as would be true for political leadership or military targets. We must now take into account the probability that RVs are killed before reaching midcourse, i.e., by a boost-(and deployment) phase defense. The probability of a given number of RVs for a target penetrating boost defense is given by the binomial distribution of equation (1).

For the case of equal-target values, the attacker does best to allocate RVs evenly among targets. Results for this attack are shown in Figure 4. Here we assume the system parameters are still as in Table 1; in particular enough RVs are launched to get four per target into midcourse. The boost-phase defense kills either 50% of the RVs launched, or else none of them (for comparison). The midcourse defense takes either two looks during the battle, or else none.

Influence of boost phase leakage

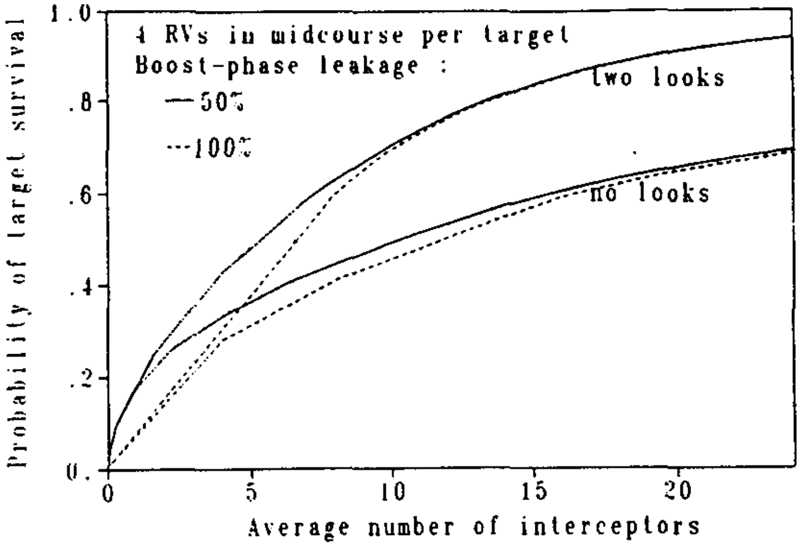

Figure 4. For 0 or 2 looks, leakage varies from 50-100%. Attack is sized to always give 4 RVs in midcourse per target.

When the defense is present the offense must launch twice as many RVs in order to get 4 RVs per target into midcourse. Whether or not there is any additonal benefit to the random-subtractive defense depends upon the level of defense required. If only a few interceptors per target on average are to be used, the presence of the random-subtractive defense may more than double their effectiveness. However, if a target probability of survival of 50% or greater is to be achieved and several interceptors per target are to be used, then the boost phase defense's "ability to break up structured attacks" matters little. The ability of the midcourse defense to look during the engagement is shown to be a very important parameter, as we have already seen.

If the targets are not of equivalent value, the attacker should not allocate RVs to them evenly. His optimal strategy is analogous to that of the defense, cf. equation (4). Specifically each RV assigned to any particular target must extract a value greater than some limit (-dV/dRV)*. In calculating this extraction, we shall assume that the offense knows the size of the midcourse interceptor inventory and therefore can evaluate (dV/dI)*, which determines the defense's strategy. Since the number of interceptors is constrained, a putative RV assignment will draw interceptors away from other targets, thus:

$$(-dV/dRV) = (\partial V^*/\partial RV) + (-dI/dRV)\,(dV/dI)^* \geq (-dV/dRV)^* \qquad (14)$$

where (-∂V*/∂RV) represents the damage to the specific target under attack, V* is the hull of target value V over RVs used, and (-dI/dRV) represents the depletion of the defender's inventory due to the assignment. Equivalently, the attacker's problem may be written as a linear program and solved by standard techniques. More formal details about sequential games of this sort will be presented shortly. (Reference 3).

Chrzanowski suggests that a good form for the value profile of non-silo targets has the value of the n^{th} target proportional to $1/\sqrt{n}$. With this value profile the average number of RVs and interceptors assigned to the various value classes are as shown in Figure 5 for an attack in which an average of eight RVs per target are launched initially and four RVs per target enter midcourse to be met by eight midcourse interceptors per target using two looks.

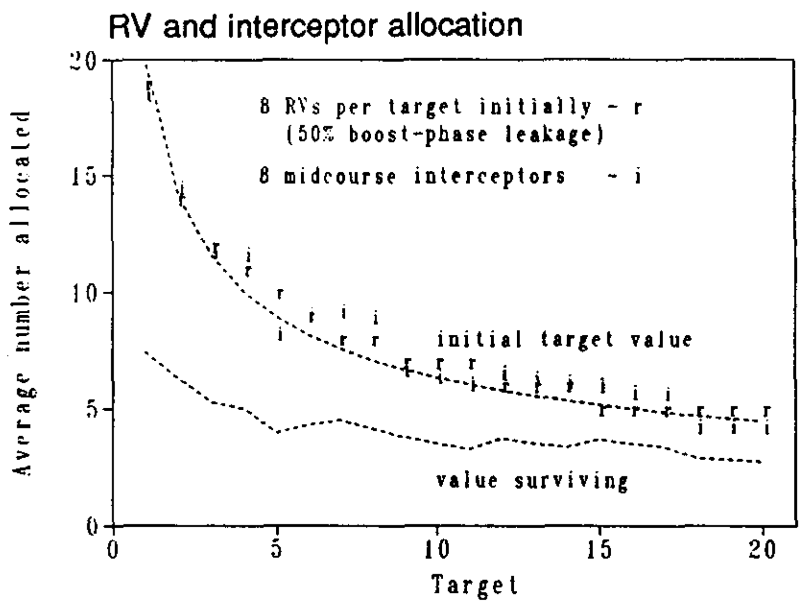

Figure 5. The r's give number of RVs initially deployed to each target; i's give average interceptor use for each target. Targets have a $1/\sqrt{n}$ value distribution. Value surviving after the attack is roughly constant. An average over all targets of 8 RVs and 8 interceptors per target is used.

The optimal assignments had both RVs and interceptors per target almost exactly proportional to target value. The only deviations from this simple rule were caused by the necessity that the number of RVs per target be a small integer (at least for all but one of the target classes). Chrzanowski suggests that by means of this strategy the offense keeps the value associated with each attacking RV nearly constant in order to deprive the defense of good preferential opportunities.

This assignment scheme tended to save the low value targets preferentially: as we remarked in Figure 2, the attacker is favored when large numbers of interceptors and RVs are assigned per target.

Similar results were obtained for the case in which a shoot-look-shoot strategy was not used. Again the numbers of RVs and interceptors used in each value class was nearly proportional to target value. Compared to the results of Figure 5 the value surviving was even less for the high value targets since the shoot-look-shoot scheme makes better use of large numbers of interceptors.

In Figure 6 we compare the fraction of value surviving for varying numbers of interceptors for the two value profiles. Since we have seen in Figure 2 that large numbers favor the attacker, it is not surprising to see that the fraction of value saved is lower in the case of a pronounced value contrast, in which offense and defense tend to load resources preferentially on a few targets. However, the overall effect of the strong value contrast, compared to uniform target value, is surprisingly minor. The figure also shows results for two looks or no looks taken by the midcourse defense. This has a stronger effect on the results than does the difference in value contrast .

Influence of value contrast

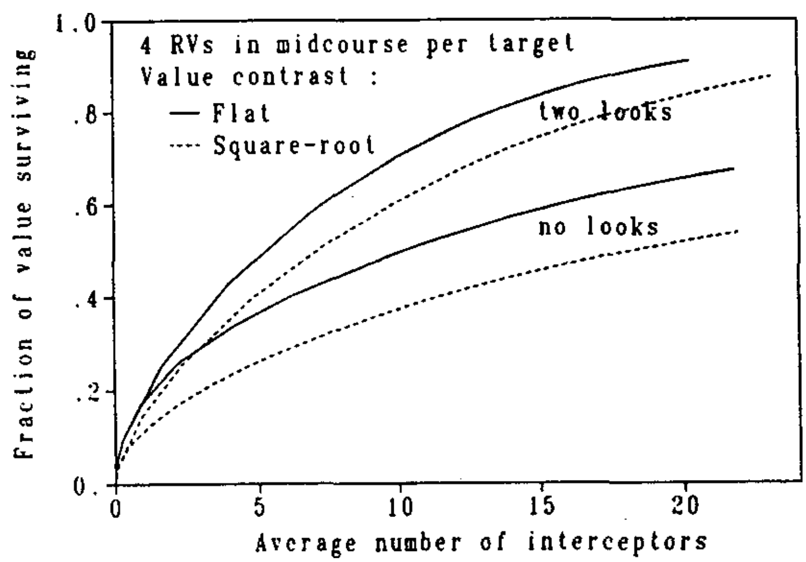

Figure 6. Curves give target survival weighted by target value for two looks or no looks in target sets in which the target value is either constant or varies as $1/\sqrt{n}$, with n the number of the target.

V. Inventory Requirements

We now consider the relative effectiveness of RV intercepts in midcourse vs. those in boost or deployment phases. Qualitatively, the midcourse interceptors may be deployed in an adaptive preferential manner to protect targets which are easy to defend and of high value, whereas earlier intercepts simply thin the attack. However, the midcourse tier is more vulnerable to decoys.

We determine the effectiveness of the space-based interceptor (SBI) tier in boost and deployment phases using an engagement simulation. Parameters for a representative engagement are given in Table 2.

Table 2. Representative parameters for SBI engagement analysis

Constellation		
	Altitude	500 km
	Inclination	80 deg
SBIs		
	Warning/start up delay	60 sec
	Axial velocity	6 km/sec
	Axial acceleration	20 g
	Minimum altitude during flight	100 km
	Range/viewing constraints	none
	Kill probability	0.9
	Salvo	2 max
Threat: SS-18 follow-on		
	Basing	SS-18 (all fields)
	Launch duration	Simultaneous
	Boost duration	240 sec
	Deployment duration	300 sec
	MIRV	15

Engagements of this sort are more fully described in Reference 4. The threat chosen here is one of the less stressing which might be considered in the late 1990s time frame since it relies on a highly MIRVed heavy liquid booster with only modest reductions in boost and deployment times in response to the defense.

The probability of RV kill in boost and deployment phases is plotted as a function of SBI inventory in Figure 7. We see that for each SBI deployed about one RV is killed up to an RV kill probability of about 0.7.*

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*This is better performance for the defense against this threat than was reported in Reference 4 in which about two deployed SBIs were needed for an RV kill. This difference arises primarily since that earlier analysis considered a partial launch from the 200 western-most SS-18 silos whereas this calculation assumes that the launch is spread proportionately over all SS-18 silo fields. In addition, the earlier results assumed threat launch at the worst moment for the defense, whereas these results represent time averages (a 10-20% effect). A performance of one RV kill per SBI deployed was seen in Reference 4 to be more characteristic of a threat based on the current SS-18 (than on an SS-18 follow-on).

Consider now the numbers of interceptors required to achieve a particular objective. In this case a specified fraction of targets or target value surviving after the attack. For a given ratio of SBIs to attacking RVs the probability of an RV penetrating the defense is found from Figure 7, then finding the number of midcourse interceptors needed to meet the objective is straightforward.

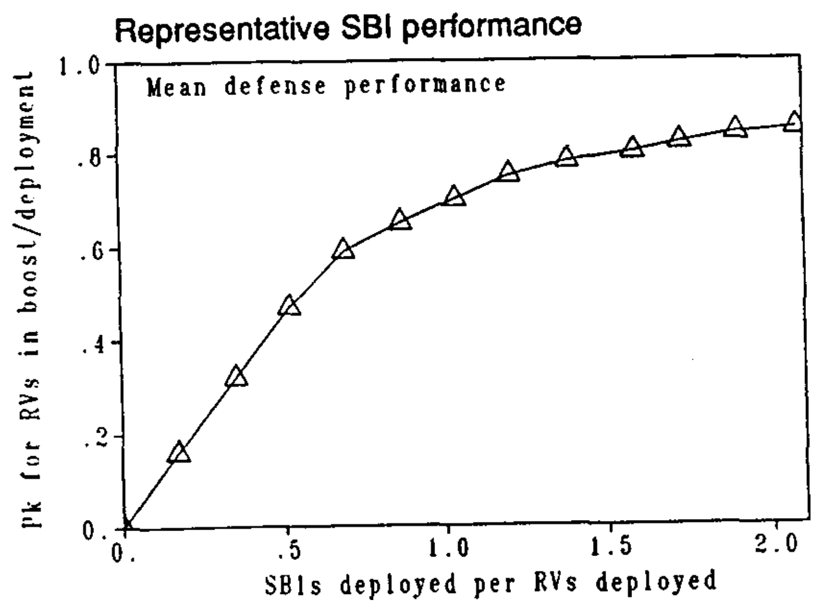

Figure 7. The figure gives the probability of RV kill in boost or deployment phases as a function of the ratio of SBIs deployed in the defense to RVs deployed in the threat. Parameters for threat and defense are given in Table 2.

In Figure 8 we plot the inventory levels needed for 50% survival of a set of targets of uniform value for two different attack levels and for the baseline system parameters of Table 1. If we assume that these targets are ICBM silos (as would be consistent with the rather low SSP_K assumed for an RV against them), that the two adversaries are treaty limited to about the same number of ICBM warheads, and that the primary targets for ICBM warheads are ICBM silos, then the number of RVs per target should be roughly the MIRV of the missiles. Thus eight RVs per target would correspond to the attack of a medium system like the MX (ten MIRV) while four RVs per target would correspond to a lighter system like Minuteman (three MIRV). An attack of eight RVs per target is baseline in Table 1 and will be used henceforward.

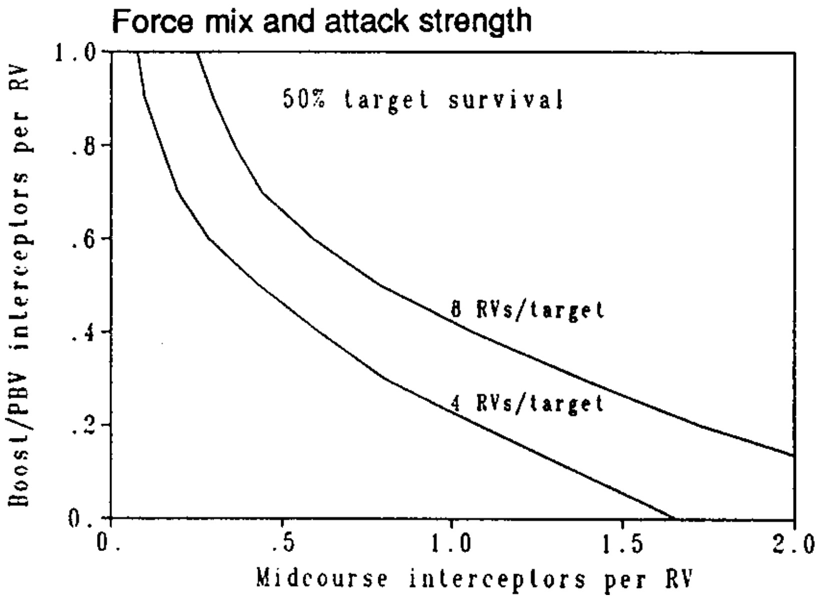

Figure 8. The curves give the tradeoff between boost phase and midcourse phase interceptors required for constant performance. Two attack strengths are considered.

We see that the number of interceptors needed does not scale linearly with the number of RVs in the attack, as was also noted in Figure 1. About 2.5-3 times as many interceptors are needed for the eight RV vs. the four RV attack. The curves of Figure 8 have a shape which will be characteristic of all the examples of this sort. They have relatively constant slopes when use of midcourse interceptors predominates but become progressively steeper as the boost phase interceptors become dominant. This is due to the fact that large numbers of adaptive preferential interceptors may be used efficiently whereas large numbers of random subtractive interceptors may not. This relatively constant slope for a high proportion of midcourse interceptors means that an all-midcourse system might be the most cost effective, as will be discussed. The all-midcourse requirement for the eight RV per target attack, not shown on the graph, is about 2.6 midcourse interceptors per RV, compared with about 1.7

interceptors per RV for the four RV attack. At least some midcourse capability appears desirable for cost-effectiveness: solely boost/PBV inventory requirements are 1.3 and 2.4 space-based interceptors per RV for the four RV and eight RV per target attacks, respectively.

Figure 9 gives similar results for different values of K-factor. As noted earlier, discrimination is the overwhelming determinant of system performance, particularly in these examples with 100 decoys per RV. With K = 4, less than one interceptor per RV is required in an all-midcourse system, while with K = 2 an all-midcourse system is clearly not desirable; it would require about 13 interceptors per RV! Nonetheless, even in this case the midcourse tier should not be eliminated: a good mix might be about one boost/PBV interceptor and one midcourse interceptor per RV.

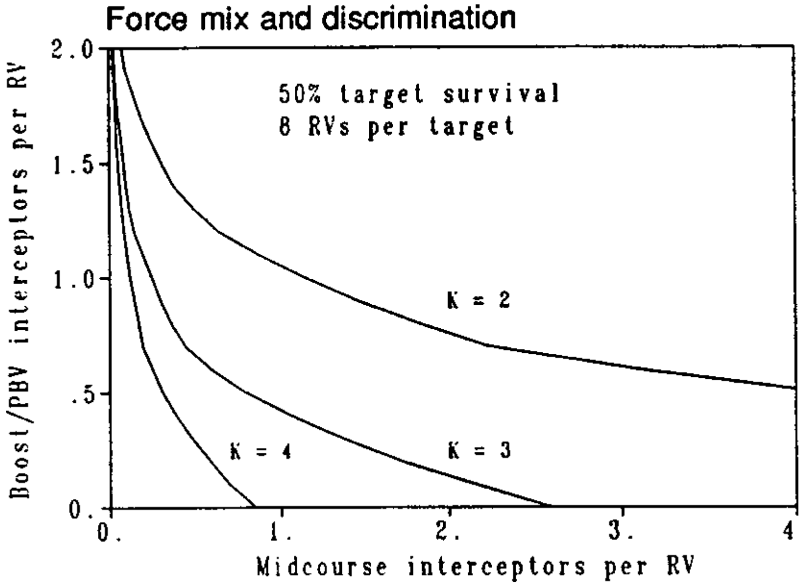

Figure 9. The boost/midcourse trade is parameterized by the K-factor of the discrimination system.

Another important parameter is the mission goal. The goal of 90%, as opposed to 50%, target survival about doubles inventory requirements, as is shown in Figure 10.

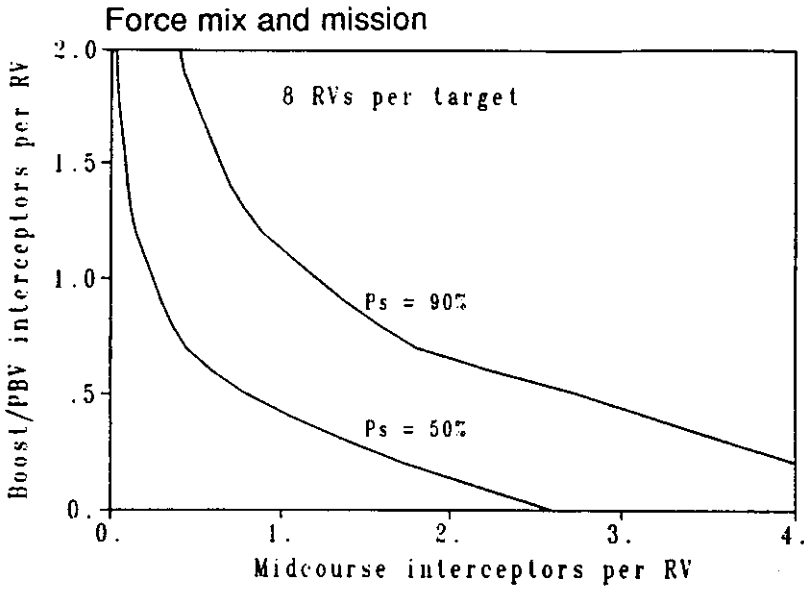

Figure 10. Two levels of desired target survival are considered.

The ability to use a shoot-look-shoot strategy is very important in order to make effective use of the midcourse interceptors as is shown in Figure 11. The number of interceptors required in an all-midcourse defense more than doubles from 2.6 per RV to 6.6 per RV if no looks may be taken.

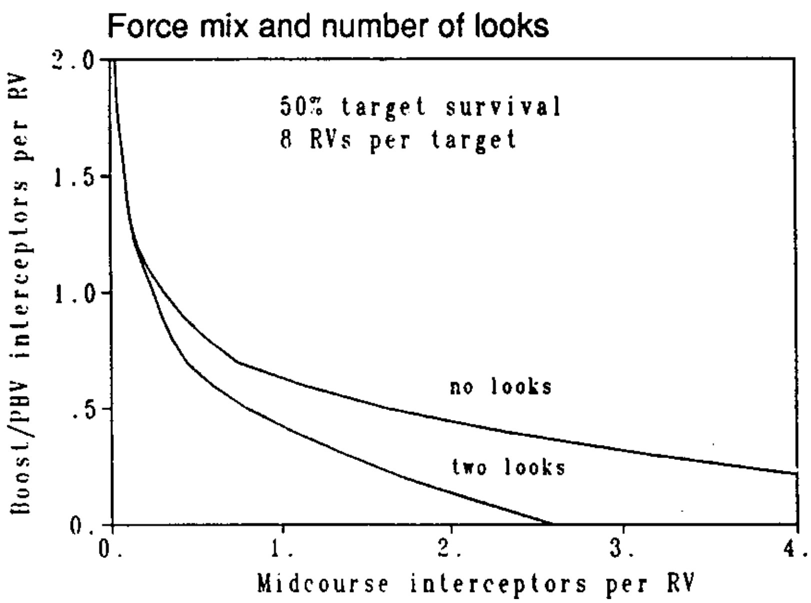

Figure 11. The shoot-look-shoot-look-shoot scheme reduces midcourse inventory requirement by a factor of two.

Inventory requirements are not very different to save 50% of the value in Chrzanowski's $1/\sqrt{n}$ scheme, compared to saving 50% of equal-value targets. About 14% more interceptors were required for the strong value contrast. (This said, we shall not show the figure.)

The above examples lead one to the conclusion that the defense architecture that meets mission requirements for targets saved or value saved at minimum cost is either composed of midcourse interceptors only (probably all ground-based interceptors GBI), or else has a mix of midcourse and boost/PBV-phase space-based interceptors (SBI). If a mix is used, there should not be so many space-based interceptors that they operate in a target-poor environment (which causes the notable inflection in Figure 7). This implies that at most about half the threat will be killed in boost or deployment phase. For the threat engagement considered here this corresponds to about one SBI deployed for every two RVs in the threat.

Whether a pure GBI architecture or a mixed GBI-SBI architecture will be more cost effective depends upon the relation of marginal SBI/GBI performance in the vicinity of the pure GBI solution. For our baseline system (50% mission, eight RV attack, K = 3) one SBI in boost or deployment replaces about four midcourse interceptors. Thus, if one SBI costs more than about four GBIs, the pure GBI solution is favored; if it costs less, a mixed solution is favored with about 50% RV kill prior to midcourse (about 0.5 SBIs deployed per RV).

We have seen that this result (the one-to-four rule) is relatively insensitive to value contrast, mission criterion, or attack level. It is very sensitive to decoys and discrimination. For 100 decoys per RV and K = 2 one SBI replaces about eight GBIs, with K = 4 two SBIs replace three GBIs. It is also very sensitive to SBI performance. We considered an example in which for each SBI deployed there was about one RV killed in a target rich environment. However, this is about the best performance which could be expected. We have shown elsewhere (Reference 4) that performance may be lower by a factor of two, even against not-particularly-responsive threats, requiring SBIs to be less than twice the cost of a GBI, etc.

Another striking conclusion to emerge from this study is the importance of a shoot-look-shoot strategy to midcourse interceptor performance. Since the ability to use such a strategy can reduce inventory requirements by more than a factor of two, significant penalties would be justified in GBI design in order to assure the ability to commit promptly and detect an RV hit.

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