

*Near-Term Boost-Phase
Defense Sensitivities*

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Gregory H. Canavan

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NEAR-TERM BOOST-PHASE DEFENSE SENSITIVITIES

by

Gregory H. Canavan

ABSTRACT

Boost-phase defenses are sensitive to offensive and defensive parameters. For distributed silos and mobile heavy missiles, about 25% of the weapons should penetrate the boost phase, which would require midcourse defenses. Concentration of heavy mobiles before launch would not impact that. Single-missile mobiles are less attractive targets and should penetrate near-term defenses, but second waves of fixed or compact mobile heavy missiles would be overwhelmed. For nominal costs and performance, combined defenses have adequate margin, but degraded space-based interceptor (SBI) performance or increased sensor costs would eliminate it. Discrimination could keep costs in balance while defending useful numbers of targets.

I. INTRODUCTION

This report discusses boost-phase defensive requirements in the near term and their sensitivities to offensive and defensive performance. The estimates are performed parametrically for strategic arms reduction talks (START)-limited missile forces in relatively compact basing. They indicate that deployable numbers of current defenses could significantly attrit silo and mobile heavy missiles and largely suppress submarine-based launches.

For current booster burn and deployment times, concentration before launch does not greatly improve mobile heavy-missile penetrativity.

Rough estimates indicate interceptor cost-effectiveness on the order of 6 to 10:1 in the near term for current cost and performance. Those values are relatively insensitive to uncertainties in performance for defensive combinations with many SBIs. These estimates are somewhat at variance with those of another recent study, but it apparently used slower SBIs and sensor-rich constellations. Discrimination could keep costs in balance while defending useful numbers of targets.

II. ANALYSIS

The analysis treats boost-phase SBI kills of heavy intercontinental ballistic missiles (ICBMs) and their multiple independently retargetable reentry vehicles (MIRVs), heavy mobile missiles, single-RV missiles, and submarine-launched ballistic missiles (SLBMs) in turn. It then aggregates the SBIs' performance against each into an estimate of their performance against their launch in combination. For all of the calculations below it is assumed that the SBI's execute only one engagement on each missiles or bus and that the probability of its success is 90%. Since for these assumptions the resulting RV kills are linear in the kill probability, they can be scaled directly to other assumed values.

The discussion primarily treats near-term SBIs' performance against START-limited missile forces. Performance against current forces is treated elsewhere,¹ as is cost-effectiveness against longer-term threat modernization.² The space-based elements treated could be made survivable without disproportionate increases in mass or cost.³ Air-breathing delivery vehicles are somewhat decoupled from initial missile exchanges; thus, they are treated separately.⁴ The emphasis is on determining sensitivity to offense and defense variations in the near term. Midcourse performance is reviewed briefly, and

the costs of combined boost-phase and midcourse constellations are estimated for sensors with varying abilities to discriminate.

A. Threat

The basic calculations assume START force levels. Although there are remaining uncertainties, Soviet strategic offensive forces are relatively well defined. The calculations below use 154 heavy silo-based SS-18 or follow-on missiles and 112 SS-24 rail-mobile SS-24s, each of which has 10 RVs, plus 344 road-mobile, single-RV SS-25s. That gives a total of 610 land-based missiles and 3004 RVs, all of which are assumed to be on line. The calculations also use 324 SLBMs with an average of 6 RVs per launcher for another 1896 RVs, 86% of which are on line.⁵

Fixed ICBMs are assumed to be deployed in the ≈ 1000 -km-diameter area in which current heavy missiles are deployed. That is smaller by a factor of 5-10 than the total current launch area. The deployments of mobile ICBMs and SLBMs are varied. Heavy missiles are assumed to have the roughly 300-s booster burn times and the 300-s deployment times of current SS-18s. SS-25s are taken to have 300-s burn and 30-s deployment times. Variations of SS-24 and SLBM parameters do not significantly impact the calculations below.

B. Distributed Heavy Missiles

Figure 1 shows the number of heavy-missile RVs destroyed in the boost phase under the assumption that the heavy mobile missiles are distributed over the whole 1000-km-diameter fixed-missile launch area for survivability. In these calculations the "nominal" SBIs are assumed to be singlets with 6-km/s axial-plus-divert velocity requiring ≈ 10 s for acceleration and a like delay for launch confirmation and approval.⁶ Their performance is similar to that of "brilliant pebbles, but they are referred to below as current SBIs to differentiate them from the multiplet SBIs of previous years, which had 4-5 km/s velocity and 30-60 s delay for separation.⁷ The impact of those differences is studied below.

The abscissa shows the number of SBIs in the constellation, which varies from 0 to 4000. The ordinate gives the number of RVs destroyed, as calculated by a geometric model⁸ of near-exact calculations of SBI trajectories⁹ and allocations¹⁰ from optimal SBI constellations.¹¹ For $K = 0$ SBIs, no boost-phase defenses, the top curve for the threat shows that all 2660 RVs from heavy missiles penetrate the boost phase, by definition. By 2000 SBIs only about 1300 penetrate, and by 4000 SBIs about 800 penetrate. The next curve down shows its complement, the number of RVs killed, which rises from 0 to ≈ 1800 RVs at 4000 SBIs. The shape of the curve is important; it shows that the number of kills per SBI rises rapidly for small values of K , but falls for large values of K as the added SBIs kill fewer RVs.

The lower curves show the boost and deployment components of the total kills. The bottom curve shows the kills during deployment. It peaks at about 700 kills at 2500 RVs and falls thereafter as more RVs are killed before or early in deployment. The last curve shows the kills during the boost phase, which is relatively straight, because it is linear in the number of SBIs for modest constellations.¹² Boost and deployment kills are roughly equal up to $K \approx 2000$ SBIs, after which boost grows at the expense of deployment. The total gives $\approx 1900/2660 \approx 70\%$ attrition in the boost phase.

A recent report released by the Defense Intelligence Agency (DIA)¹³ estimates somewhat lower values, but assumes the multiple, slow, and delayed-acting SBIs of earlier deployments.¹⁴ Figure 2 shows the threat and number of kills for SBIs with 4-km/s velocity and 50 s delays for confirmation, release, and activation. The threat falls linearly all the way from 2660 to ≈ 1200 RVs. Boost and deployment kills are decreased about evenly from those of Fig. 1, although the latter do not begin to saturate until almost 4000 SBIs. At 1500 SBIs about 600 RVs are killed versus the 1100 RVs for current SBIs. The difference between the two primarily reflects the differing fraction of the SBIs that are available. For the current distributed launch area, about 20% of current SBIs would be kinematically within

range of the launch; for the 1000-km heavy-missile launch area, about 13% of current SBIs would still be within range. For 4-km/s SBIs, only about half as many would be in range.¹⁵

The 600 RVs killed by 1500 early SBIs is in rough accord with DIA report, which gives a total of ≈ 800 RVs killed in the boost phase. For that comparison early-SBI estimates above are relevant because the DIA stated that "The only SDI architecture available to test the effectiveness of the three Soviet force postures. . . was a predecessor of 'brilliant pebbles'. . . which consisted of some 1500 orbital interceptors and some 1700 ground based interceptors."¹⁶ The DIA report corresponds to $\approx 800/2,660 \approx 30\%$ attrition of ICBMs in the boost phase. That is a factor of 2.3 lower than that for 4,000 current SBIs, so assumptions about both performance and constellation size are important. The DIA report also assumed a 20% withhold of ICBMs, which would reduce Fig. 2's 600 ICBM kills to ≈ 480 . However, the DIA's 800 RVs also includes SLBM kills, which are estimated below.

C. Mobile Heavy Missiles

Mobile missiles can disperse in order to enhance prelaunch survivability; they can also concentrate to enhance their penetration of boost-phase defenses. When mobile heavy missiles are distributed among heavy-missile silos, their survivability against preemption is enhanced greatly, but their ability to penetrate boost-phase defenses is not. Their precise location within the launch area at the time of launch is not critical to space-based defenses; only the area over which they are distributed is critical. Interspersed with the silos, mobiles just enter the analysis as more missiles, albeit expensive ones, which might as well be in silos. If distributed over a significantly larger area than the silos, the mobile's prelaunch survivability improves further, but their penetrativity falls because they become diluted and present less of a threat to a given boost-phase constellation.¹⁷

Mobile missiles only stress boost-phase defenses if they concentrate in a small area before launch. There are constraints

on their ability to concentrate. Unless it is much less than the silo launch area's 1000-km diameter it is unimportant, and if it is less than 200-300 km the concentration becomes susceptible to barrage attacks and fratricide. Nevertheless, the calculations below assume that the missiles can be concentrated at a point, ignoring the latter penalty.

When the heavy mobiles are concentrated at a point, the fraction of the SBIs to which they are accessible drops to about 10%, which is smaller than, but not greatly smaller than the 13% of current SBIs against silo launch areas 1000 km across. The reason the reduction is modest is that the mobile SS-24's boost and deployment times are comparable to those of the SS-18s, so the distances from which current SBIs can fly in are large compared with the current launch area, let alone one 1,000 km across or a point. The fraction of SBIs available scales on the sum of the launch-area radius and the distance from which SBIs can fly in. For large fly-in times, their sum, and the fraction of SBIs available, decreases little for current heavy mobiles. That changes for faster missiles, as shown in the next section.

The calculations displayed in Figs. 1 and 2 show the impact of distributing the mobiles over the whole heavy-missile silo launch area. Those below treat the opposite case in which they are launched from a point. The calculations were performed by shifting varying numbers of SBIs from a given constellations to the mobiles, allocating the rest to the fixed missiles, and calculating the total number of kills from both.

Figure 3 shows the result. The abscissa is the number of SBIs allocated to mobiles; the ordinate is the total number of RV kills from fixed and mobile heavy missiles. The top curve is for a constellation of 4000 SBIs; the middle one is for 3000; the bottom one for 2000. The first rises from ≈ 1400 , the number the SBIs would achieve if they strongly suppressed the silo-based missiles and ignored the mobiles, to a peak of about 2100 RVs at 2000 SBIs. That is in accord with the previous observation that silo and mobile missile absenteeism and performance are not greatly different and hence they should be treated about equally.

The middle curve for 3000 SBIs has a maximum of about 1800 RVs at about 1300 SBIs. There $1300/3000 \approx 40\%$ of the SBIs would be allocated to the mobiles, which is in rough accord with the mobiles' constituting about $112/(112+154) \approx 42\%$ of the total heavy missiles. For 2000 SBIs the peak is at 500 SBIs, or 25% of the constellation, reflecting the reduction of SBIs effectiveness against compact mobiles. Still, clustered mobile heavy missiles are not much more effective than silo-based heavy missiles when launched in conjunction with them, largely because of their long burn and deployment times.

It is interesting to examine the effectiveness of heavy mobiles when they are used as a strategic reserve. Figure 4 shows the number of RVs killed when the SS-24s are launched by themselves against various SBI constellations. The top curve is the total number of RVs destroyed; the next is those destroyed in boost; the bottom is those destroyed during deployment. The curve asymptotes to about 1000 RVs by 4000 SBIs, the most that could be achieved for single engagements because of the 90% kill probability assumed. By 1500 SBIs the RV kills have reached 75% of that. The implication is that against constellations of 2000-4000 nominal SBIs, a second wave of heavy mobile missiles would be overwhelmed, even if launched from even a compact area.

As shown in Fig. 4, 2000 SBIs would kill about 850 mobile-missile RVs. From Fig. 3, 2000 SBIs would also kill $2100 - 850 = 1250$ SS-18 RVs. Thus, launched separately against a constellation of 2000 SBIs, the two would lose a total of $850 + 1250 = 2100$ RVs, which is a factor of $2100/1400 \approx 150\%$ higher than the 1400 RVs that would be lost if they were launched together. Launched together, about 1200 RVs would penetrate; launched separately, about 560 would penetrate, which represents over a factor-of-2 reduction in the penetrating attack. Using two equal waves is tantamount to discarding half the attacking missiles; unequal waves would discard even more. The offense's best strategy would appear to be to put all of missiles into one strike. Holding back 10-20% would simply waste that percentage.

If the strike had to be put into two parts for other reasons, however, putting 50% in each would minimize overall losses.

Overall, near-term boost-phase constellations of SBIs with current performance goals could significantly attrit simultaneous launches of heavy missiles. Reducing the launch area diameter by a factor of 4, and launch area by a factor of 16, from current conditions does not greatly degrade performance against widely-distributed threats from current heavy missiles. START-constrained forces could achieve $\approx 30\%$ penetrativity if simultaneously launched against near-term SBI constellations. For two equal waves penetration could drop to $\approx 15\%$; for unequal waves it would drop below 10%.

D. Single-Weapon Mobile Launchers

As noted above, absentee ratios for clustered current heavy-mobile launches are only a factor of $0.2/0.13 \approx 50\%$ higher than those for silos distributed over 1000 km because the burn and deployment times for each, which are comparable, dominate availability. Single-weapon mobile missiles' engagement times can be much shorter. For current boosters burn times would not be greatly reduced, but RV-deployment times could be. This section examines defense effectiveness against an SS-25-like mobile missile with a 300-s burn time that takes 30 s to deploy its single RV and decoys. The combined heavy-singlet threat is again treated by allocating varying fractions of the SBIs from a fixed constellation to singlets and computing the total kills.

Figure 5 shows the result if the singlets are simultaneously launched from a point within and with all of the heavy missiles. The abscissa is the number of SBIs allocated to the singlets; the ordinate is the total number of heavy and singlet RVs killed. The top curve is for 10000 SBIs; the middle for 6000 SBIs; and the bottom for 4000 SBIs. The top curve shows that if it was possible to deploy very large numbers of SBIs in the near term, perhaps a 5% increase in the number of RVs killed could be possible by diverting several thousand SBIs to singlets. That is because, as Fig. 1 shows, the heavy-missile RV kills start to

saturate at 2000 SBIs and asymptote by 4000. Thus, if 10000 SBIs are available, diverting a few thousand SBIs does not reduce the number of heavy RVs killed significantly; but it picks up a few of the singlets.

The middle curve shows that for 6000 SBIs the loss of heavy-missile RVs just offsets the gains from singlets out to about 2000 SBIs. The curve is flat out to there and falls thereafter. For a near-term 4000 SBI constellation, the curve falls for all numbers of SBIs diverted. If all 4000 SBIs were diverted to singlets, the total number of RVs killed would fall to just 100 singlets.

Figure 6 shows the impact of holding the singlets back as a strategic reserve. The abscissa is again the constellation size, extended here to 16000 SBIs. The ordinate is the number of singlet RVs killed. Few RVs are killed in deployment because it is so short. The number killed in boost increases linearly. It reaches the 100 RVs of Fig. 5 by 4000 SBIs; it reaches ≈ 320 by ≈ 14000 SBIs. By 4000 SBIs, where 100 RVs are killed, the penetrating threat is about 240 RVs, or 70%.

The greater penetration of the singlets is due to their greater absentee ratios. For defensive constellations optimized for the first silo launches, their absentee ratio is $\approx 3\%$, which is a factor of 3 below that of the heavy missiles. However, their 10-fold fewer RVs largely compromises that advantage. If launched later as a reserve at a 2000 SBI constellation, singlets would only produce $50/1300 \approx 4\%$ as many penetrating RVs as heavy missiles. Fast singlets get a free ride, but don't carry much.

Comparing mobile singlets and heavy missiles becomes almost a question of whether the attacker takes the RVs off or leaves them on and lets the defender destroy them during deployment. Still, singlet mobiles should provide a system with maximum mobility and hence prelaunch survivability for a limited retaliatory strike. The point discussed above still holds; boost-phase defenses are most effective against small launches. Thus, to avoid uncertainties about the effectiveness of near-term constellations against small strikes, the attacker could maximize

the number of penetrating RVs by launching all ICBMs at once and generating the retaliatory contributions from bombers, cruise missiles, or SLBMs depressed below boost-phase defenses. If that was done, the contribution from fast mobiles would be small.

E. Submarine-Launched Missiles

Submarines maximize dispersal area and hence prelaunch survivability, but dispersing a modest number of submarines over a very large area acts to the defense's advantage because each then becomes a point source of a small number of missiles, for which SBIs are well suited. Figure 7 shows the total, boost, and deployment kills for the SLBMs from a single boat on patrol as a function of SBI constellation size. If on the average each submarine has 16 SLBMs with 6 RVs each, each could launch a maximum of 96 RVs. For that, a constellation of 800 SBIs would kill about 86 RVs, the maximum RV kills possible for single 90% engagements. If only a portion of the SLBMs were launched, the fraction destroyed would be even higher. That has particular impact on their use as a reserve or in retaliation. Boost-phase defenses act disproportionately on single submarines.

Submarines in port or bastion fare better than those on patrol because the larger number of launches can partially saturate the SBIs. The calculations below assume that half of the ≈ 20 submarines are in each ocean; that of those, half are in port or bastion; and that each launches half of its missiles and withholds the rest. For 20 submarines there would be about $20/4 = 5$ submarines launching $0.5 \cdot 16 = 8$ SLBMs each or 40 SLBMs from one point in each ocean. The total number of RVs from each would be $40 \cdot 6 = 240$ RVs.

Figure 8 shows the kills for that case. The total number of kills from submarines in port or bastion accumulates much more slowly than those on patrol, but for a constellation of ≈ 2000 SBIs the number of kills from each ocean again climbs to $\approx 0.9 \cdot 240 \approx 216$. Even for 1000 SBIs the number killed is ≈ 200 , or about 83% of those launched. Constellations that are small by ICBM standards are adequate for SLBMs.

Figure 9 shows the total submarine RV kills, calculated by taking 10 times the kills per submarine on patrol plus twice the number of kills per ocean in port and bastion from Fig. 7, assuming that half of all SLBMs are held back in reserve.¹⁸ The top curve is the total number of kills; the second is the kills of RVs from submarines on patrol; the third is the kills from those in port. The bottom curve is the residual threat. The patrol kills accumulate most rapidly; they saturate by about 500 SBIs. Port kills saturate by about 1000 SBIs. By 1000 SBIs the total kills are over 800; by 2000 they reach the single engagement limit. By comparison, Fig. 1 shows that that constellation size would attrit ICBMs only about 50%.

These numbers are somewhat sensitive to SBI performance. Figure 10 shows the kills from early SBIs with 4-km/s velocity and longer delays. Relative to Fig. 9, the constellation size required to kill half of the RVs is roughly tripled--from 300 to 900 SBIs. The overall impact is to rescale the abscissa. As a result, by 2000 SBIs, about 200 RVs still penetrate; twice the number required by current SBIs.

For a constellation of 1500 slow SBIs, the total number killed would be about 650. The DIA report discussed above gives a total boost-phase kill of about 800 RVs. It does not break the total down into ICBM and SLBM RVs. Figure 2 gives 600 ICBM RV kills for their conditions, or 480 kills, corrected for a 20% inventory. That, plus the 650 SLBM RVs gives about 1100 RVs. The DIA's 800 boost-phase kills is about 25% lower. Such differences are well within the modeling errors, let alone the uncertainties in untested concepts.

Against current SBI constellations, launches of half the SLBMs are undersized. Most of the SLBMs are killed by constellations sized for ICBM launches. SLBMs could penetrate somewhat better if they were all were launched together, as shown in Fig. 11. The impact is not dramatic for small constellations; the 50% kill point shifts to 400 SBIs rather than the 250 of Fig. 9. Saturation is, however, delayed. At 1500 SBIs, about 400 RVs would penetrate rather than the ≈ 100 of Fig. 9. Thus, full

launches could allow submarines to maintain effectiveness against small SBI constellations.

SLBM penetration is sensitive to the SBI performance assumed. Figure 12 shows the RV kills for a full SLBM launch against slow SBIs. The total launch starts at about 1900 RVs. By about 1250 SBIs, about half of the RVs are destroyed, including a high fraction of those deployed from SLBMs launched by submarines on patrol. Kills from SLBMs launched from submarines in port or bastion mount more slowly. The total is about 1100 RVs at 1500 SBIs; and 1500 at 4000 SBIs, which leaves about 400 penetrating RVs. Thus, full SLBM launches against SBIs of modest performance could produce useful retaliatory strikes.

III. COMBINATIONS

Previous sections treated various components of the threat; this section estimates the requirements for meeting their launch in combination. Figure 13 shows the performance of current SBI constellations against simultaneous launches from which 80% of the ICBMs and 50% of the SLBMs from Soviet START forces are withheld. For small numbers of SBIs the top curve is the residual threat; the second curve is the total kills; the third is that for ICBM kills; and the bottom is that for SLBM RV kills. For nominal performance, 50% attrition is reached at about 1250 SBIs. By 4000 SBIs only about 700 RVs penetrate. Most are ICBMs, including the singlet SS-25s that are essentially ignored by the allocation of Fig. 5 for small constellations.

These results indicate that strategic defense's phase 1 goal for RV attrition could be met by a constellation of about 1500 current SBIs, although that would leave a midcourse threat of $\approx$ 1700 RVs. For 4000 SBIs the residual threat would drop to about 700 RVs even without midcourse or terminal defenses, which is about 1 RV per U.S. silo and only a fraction of an RV per military target.

Total attrition is sensitive to SBI performance. Figure 14 shows the kills for slow SBIs, for which the constellation for 50% attrition moves to about 2,500 SBIs, a shift of a factor of 2

from the curve above. A significant fraction of the heavy ICBM RVs penetrate, but SLBMs are still strongly suppressed. The SLBM kills may be underestimated. Since the submarines on patrol are strongly suppressed, the calculations of Figs 13-16 assume that the submarines on patrol congregate at a prearranged rendezvous area a few hundred kilometers across before launch, which gives them roughly the same penetrativity as that of the SLBMs in small port or bastion areas.

The results are also sensitive to the size of the launch. Figure 15 shows the number of RV kills for a full 5000 RV launch with no SLBM withhold against current SBI constellations. The 50% attrition point moves out to about 1500 SBIs from the 1250 of Fig. 13. About 1000 RVs penetrate even 4000 SBI constellations. ICBMs penetrate well, although SLBMs are still strongly suppressed by about 2000 SBIs.

The impacts of full launches and slow SBIs compound. Figure 16 shows the number of kills for full launches against slow SBIs. For this case the 50% attrition point moves slightly beyond 3000 SBIs, about three times the value for current SBIs and launches. ICBMs penetrate well; even SLBM RVs achieve some penetration up to 3000 to 4000 SBIs. Still, the performance of a 4000-SBI constellation exceeds phase 1 percentage goals. Thus, the performance achieved by slow SBIs against full launches is a indication of the performance margin inherent in current SBIs.

IV. MIDCOURSE

The boost-phase performance discussed above can bring large launches down to manageable levels in midcourse. The DIA report does not credit midcourse with much capability. Its 1700 ground-based interceptors (GBIs) are only credited with about 150 kills, which is equivalent to their effectiveness being diluted about 10-fold by roughly 10 credible decoys per midcourse RV. That actually represents only an intermediate level of decoys and discrimination. Heavy ICBMs could provide each of their RVs 30-40 decoys without serious penalty, while good discrimination

could reduce the number of objects to 1-2 decoys per RV, at some price.

The nominal case shown in Fig. 13 leaves a midcourse threat of about 1000 RVs, which in the absence of decoys would require about 1000 interceptors. For 10 decoys per RV it would no longer be possible to destroy every RV, but 1500 preferential GBIs could protect about $1500/10 \cdot 1000 \approx 15\%$ of ≈ 2000 military targets. That would be about 300 targets, including perhaps 150 missiles. That would be marginal, but would at least provide some organized force for retaliation.

Much higher levels of decoys or lower levels of interceptors and survival would have only token impact. If, however, the defense could discriminate 90% of the objects, leaving ≈ 1000 decoys and 1000 RVs, it could afford to intercept them all effectively since that would only double the number of midcourse interceptors needed.

V. COSTS

It is possible to give rough estimates for the boost-phase SBI and midcourse interceptor costs for the deployments discussed above. Current estimates for SBIs are \$1-1.5M apiece, although life-cycle costs could double these initial investment costs.¹⁹ A reasonable average figure for 2000-4000 SBIs might be $\approx \$2M$ each, exclusive of control and warning sensor costs. Controls are potentially modest for SBIs, which can be largely autonomous. External sensors are undefined, potentially expensive, and somewhat controversial, but their costs are additive to those of the SBIs, so sensor costs do not impact overall tradeoffs between boost and midcourse. They only shift the total costs of the optimal mix. Life-cycle costs of $\approx \$2M$ have been cited for GBIs.²⁰ They are also dependent on somewhat undefined sensors, but they are deployed on the ground, and hence should be less expensive, and their costs of less concern.

Figure 17 shows the costs for boost-phase and midcourse deployments to protect 30% of 2000 military targets from a simultaneous launch of the ICBMs. ICBMs are illustrative of the

full attack, particularly since Fig. 9 shows that very few SLBM RVs would penetrate any but the smallest SBI constellations shown. The calculations assume that each RV entering midcourse is accompanied by 50 decoys. That is not a kinematic limit that is typical of offensive optima against such defenses.²¹ The bottom curve is for 100% discrimination, i.e. no credible decoys. All objects still have to be observed. The second curve up is for 75% discrimination; the next is for 50% discrimination; and the top curve is for no discrimination.

For complete discrimination, the cost curve is essentially flat because all costs are for interceptors of one kind or the other and the cost of boost and midcourse interceptors are similar. For predominantly boost-phase defenses, the SBIs are compromised by 10-fold absenteeism. For predominantly midcourse defenses, the GBIs are compromised by the \$0.1M per object discrimination cost assumed, which for 50 decoys per RV again amounts to about a 10-fold degradation.

For predominantly boost-phase constellations, the curves for 50-75% discrimination are only about 50% higher than that for complete discrimination. That is because most decoys have been killed in the boost phase and don't have to be screened in midcourse. That makes midcourse volume and costs much less sensitive to the level of discrimination.

The second curve up on Fig. 17 is for 75% discrimination; the next is for 50% discrimination; and the top curve is for no discrimination. All of the iso-contours show the same trends. They are relatively flat for largely boost-phase defenses, but increase significantly for largely midcourse defenses. For small numbers of SBIs, those curves all turn up sharply because the lack of discrimination forces investment in large numbers of SBIs to intercept all the decoys to kill enough RVs. For predominantly midcourse defenses the costs for 75% discrimination are about 3 times greater than those for full discrimination. The costs for 50% discrimination are a factor of 4 higher; the costs for no discrimination are off scale.

The top curve for no discrimination shows about \$25B for interceptors and sensors at 4000 SBIs and 5 times that number for 1000 SBIs. Thus, good discrimination could serve as a substitute for SBIs if inadequate numbers could be made available in the near term. It is likely that oversized SBI constellations would instead be used to destroy RVs and decoys before deployment to eliminate uncertainties about midcourse decoys and discrimination.²² That could be achieved with 2000-4000 SBIs against START forces. If heavy-missile forces were at the $\approx$ 1000-fast-missile level in midterm, overall defensive deployments would then be split roughly half and half between boost and midcourse interceptors.

Combined defense costs are \$10-20B for constellations consisting largely of SBIs. Those constellations would essentially negate large attacks. Thus, their costs should be compared to the cost of the attack, which is roughly \$200M per heavy missiles times about 210 heavy missiles or about \$40B. That results in a cost effectiveness of $\approx$ \$40B:\$10-20B $\approx$ 2-4:1 in favor of the defense.

Figure 18 shows how those costs shift for full launches against slow SBIs with longer delays. The shape of the bottom curve for complete discrimination changes little; it is just shifted up about 50% for all SBI constellation sizes. The next curve up for 75% discrimination is essentially straight, which is a significant departure from the corresponding curve for current SBIs in Fig. 17. By 4000 SBIs, its value is doubled; the increase is only 20% at no SBIs. The curves for 50% and poor discrimination increase about a factor of 2 at large numbers of SBIs; they increase very little for small numbers of SBIs.

For the top curve and few SBIs the costs approach \$100B, the cost estimated for the combined defenses in the DIA report. The agreement is, however, only apparent. The DIA report's midcourse interceptors had to intercept about 10 undiscriminated decoys per RV, e.g. 80% discrimination of 50 decoys per RV. For the DIA's 1500 slow SBIs and this 20% discrimination, Fig. 18 gives a cost of about \$30B. Figure 18 is, however, calculated for 30% target

survival, while the DIA's report corresponds to only 10% survival. The costs of constellations with few SBIs scale directly with the fraction of targets surviving, so for the DIA's 10% survival, the \$30B would be decreased by a factor of 3 to about \$10B, which is less than the DIA's \$ 100B estimate by about an order of magnitude. The reasons are discussed below.

For the values cited, the DIA report does not indicate that defenses would be effective. Its 1500 SBI and 1700 GBIs, which would cost an average of about \$100B/3000 interceptor $\approx$ \$30M per interceptor, are estimated to kill about 1000 RVs. The report estimates that heavy missiles have investment costs of about \$150M in silos and \$200M on rails. SLBM procurement costs are $\approx$ \$120M per launcher, but are roughly doubled to ICBM costs if the cost of the submarine is amortized over its missiles.²³ In the estimates above, life-cycle costs for offensive forces were estimated by doubling investment costs, which is also discussed in the DIA report.²⁴ The important point is that the report makes the assumption that all systems "cost the same in U.S. dollars" for "equivalent weapon system performance," i.e., to give no "free lunch" for cheap Soviet conscripted or military labor.²⁵

For the DIA's average cost per heavy missile RV of $\approx$ \$200M/10 RVs $\approx$ \$20M/RV, the cost to the Soviet Union of the $\approx$ 1,000 RVs destroyed is about \$20B. Thus, the cost-effectiveness of the DIA's \$100B defense is about \$100B:\$20B $\approx$ 5:1 adverse to the defense. Put another way, each interceptor costs about \$30M; each RV costs about \$ 20M. It takes an average of 3 interceptors per RV killed, or $3 \cdot \$30M \approx \$100M$, so the exchange is about \$100M:\$20M $\approx$ 5:1 adverse on each transaction, which aggregates to 5:1 adverse overall.

That contrasts with Fig. 17, which shows that predominantly boost-phase defenses with near-term discrimination should cost \$10-20B and hence be cost effective by about a factor of 2. The discrepancy between 2 for and 5 adverse is a factor of 10. A factor of 2 can be found in the differing SBI performance used, which impacts the number of RVs penetrating boost a like factor.

The other factor of 5 would appear to be in costing the interceptors, auxiliary sensors, and controls.

Costing the SBIs for nominal parameters can be illustrated simply. The absentee ratio for heavy missiles is about 10%. Thus, for ≈ 220 heavy missiles, about 2,000 SBIs are needed for single engagements of the missile or bus--or about 4,000 SBIs to kill most missiles in boost. At a cost of \$2M per SBI, the latter number gives about \$8B. Doubling that for midcourse interceptors and discrimination would give a total defensive hardware cost of about \$16B.

For a 220 heavy missiles launched against 4000 current SBIs, Fig. 2 gives about 2000 RVs destroyed, and hence a boost-phase cost exchange of $2000 \cdot \$20M : \$16B \approx 2.5:1$, about 12 times the DIA's value. Part of the discrepancy is the 2-fold higher number of RVs killed; the other factor of 6 is in the interceptors' cost. This accounting for interceptor and discrimination costs implies that the residual $\$100 - 15B = \$85B$ in the DIA estimate is in sensors and controls. Sensor- and control-rich constellations have been studied in the past, but with largely autonomous SBIs, it is not clear that large supporting sensor suites are needed.

Thus, the difference appears to lie in the costing external adjuncts that no longer appear essential. For nominal costs and performance, combined defenses appear to have adequate margin. The discussion above does, however, indicate that degrading SBI performance or doubling sensor or control costs could cut that margin in half and that doing both could eliminate it. The discussion treated only partial threat modernization. The missiles' spacing and deployment times could be reduced further to reduce the missiles boost and to reduce SBI availability even more. Nominal interceptors and sensors should, however, maintain defense effectiveness, although the SBIs' margin integrated over their whole period of deployment would be smaller.²⁶

VI. SUMMARY AND CONCLUSIONS

This report has discussed near-term boost-phase defenses and their sensitivities to offensive and defensive parameters. It

primarily addressed SBI performance against START-limited missile forces in relatively compact basings. For distributed silo and mobile-heavy missiles, about 800 RVs should penetrate the boost phase, which would require midcourse defenses, though not large ones. For heavy mobiles with current boost and deployment times, concentration before launch does not impact that value greatly. Single-RV mobile missiles are less attractive targets. They should penetrate near-term defenses, but their 10-fold fewer RVs offsets their 3-fold greater absenteeism, so that they wouldn't produce many penetrating RVs. Earlier, slow SBIs could double the size of boost-phase constellations.

Against near-term constellations, smaller second waves of fixed or compact mobile heavy missiles would be overwhelmed. The offense's best strategy would be to put all of its missiles into one strike, but if the strike had to be put into two parts, putting 50% in each would minimize losses. Holding back 10-20% of the missiles would essentially waste them. Near-term boost-phase constellations of SBIs with current performance goals could significantly attrit simultaneous launches of heavy missiles, although START-constrained forces could achieve $\approx 30\%$ penetration in near-simultaneous launches.

Dispersing submarines over large areas maximizes their prelaunch survivability but reduces SLBM penetration, so it acts to the defense's advantage. Constellations of 500-1,000 SBIs would suppress SLBMs launched from submarines on patrol; constellations about twice that large could suppress launches from port or bastions. Concentration before launch could improve penetrativity. Full launches against slow SBIs could achieve greater, but marginal penetrations.

When the elements of the threat are treated in concert, the bulk of the RVs killed come from heavy ICBMs. Singlets contribute in proportion to their numbers; SLBMs contribute little, although their penetrating RVs increase for full, concentrated launches against slow SBIs. Midcourse interceptor and sensor performance is critical if large numbers of SBIs cannot be deployed in the near term. Achievable discrimination

can keep midcourse costs in balance while defending useful numbers of targets. Rough estimates indicate interceptor cost-effectiveness on the order of 2-4:1 in the near term for currently estimated costs and performance. For SBI-rich combinations, costs are relatively insensitive to uncertainties in discrimination. These estimates are somewhat at variance with earlier studies, which used early SBIs and sensor-rich defensive constellations, which are not necessarily needed with largely autonomous SBIs.

Thus, the analysis here tends to support the conclusions of the DIA report cited, although its own analysis does not appear to do so. For nominal costs and performance, combined defenses appear to have adequate margin, but degrading SBI performance or increasing sensors costs could eliminate it. Discrimination could keep costs in balance in defending useful numbers of targets. Defenses should perform poorly against singlets missiles, well against heavy missiles, and better against SLBMs. They should be cost-effective in the near term; they arguably would remain effective in the long term on the basis of the trends discussed.

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Fig. 1 Heavy missile RVs destroyed

$m_0=10, V=6, M=270, S=350, T_b=300, T_e=2, p=.9$

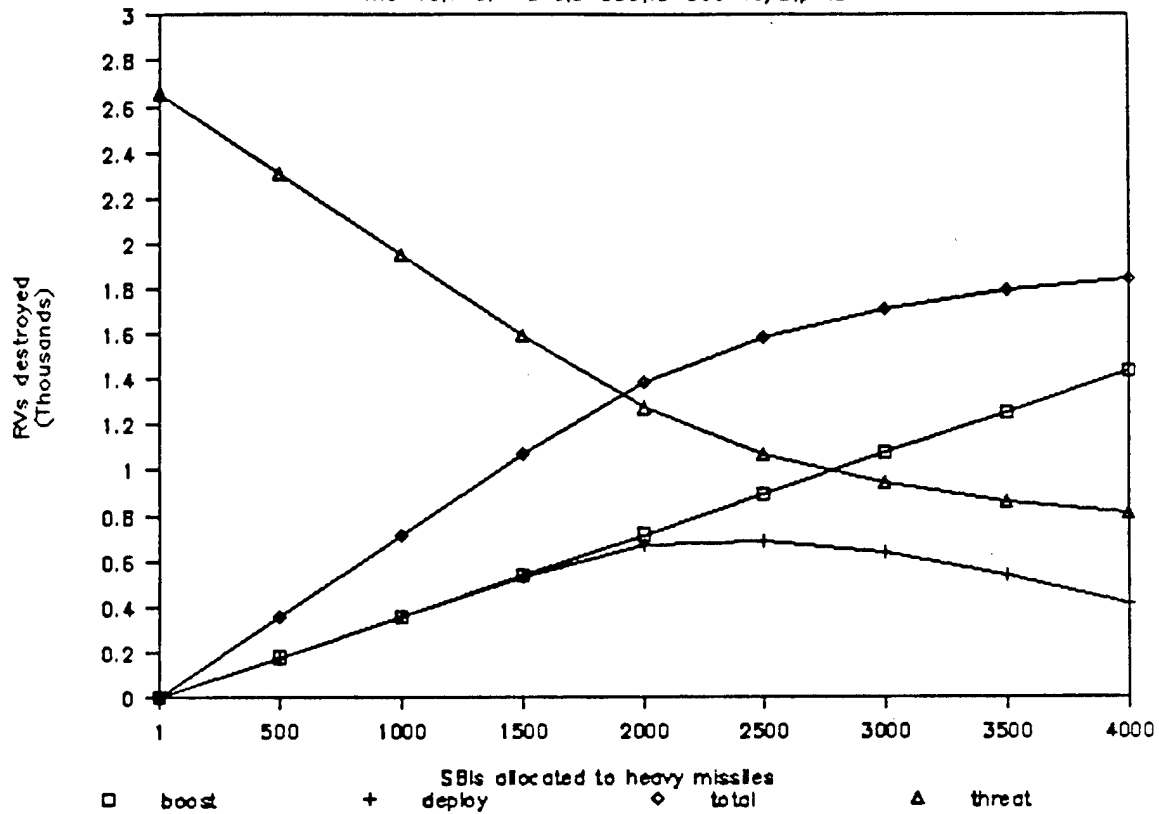


Fig. 2 Heavy RVs destroyed by slow SBIs

$m_0=10, V=4, M=270, S=350, T_b=250, T_e=2, p=.9$

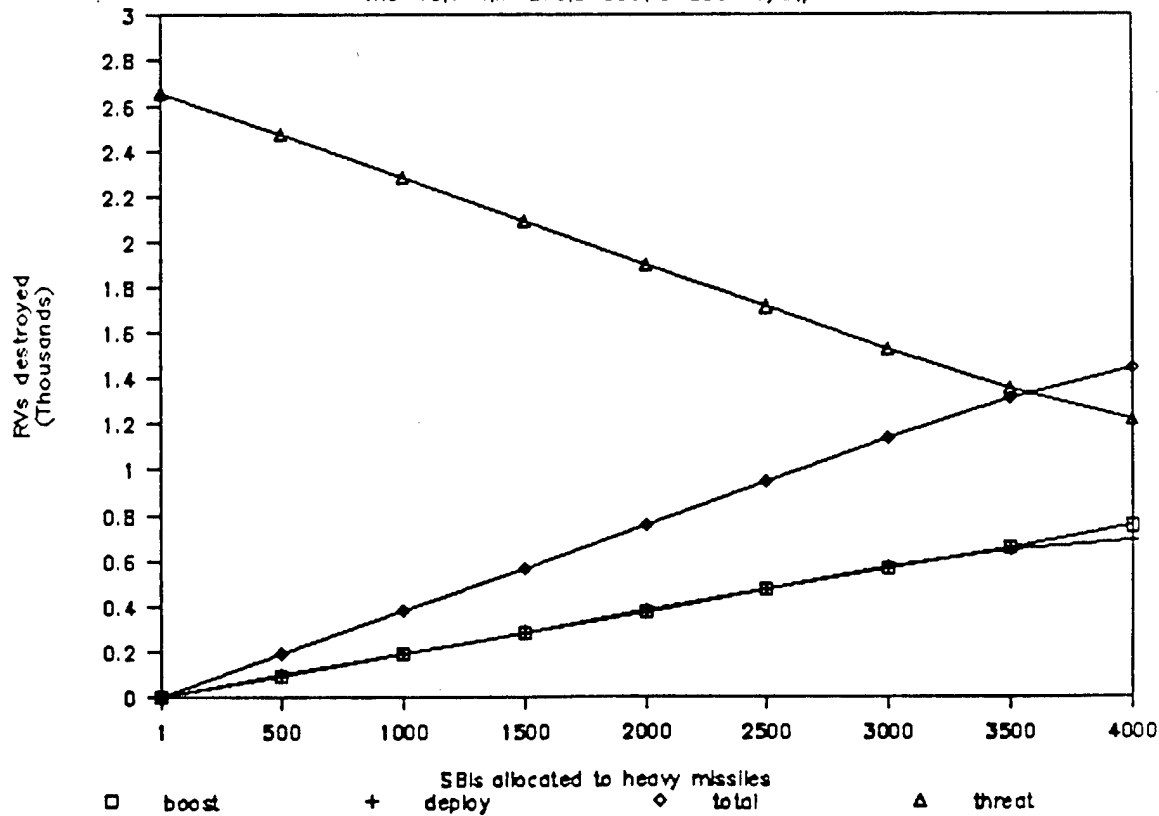


Fig. 3 Heavy mobile RVs vs current SBIs

$m_0=10, V=6, M=154, M_0=112, T_b=300=T_e/2, p=.9$

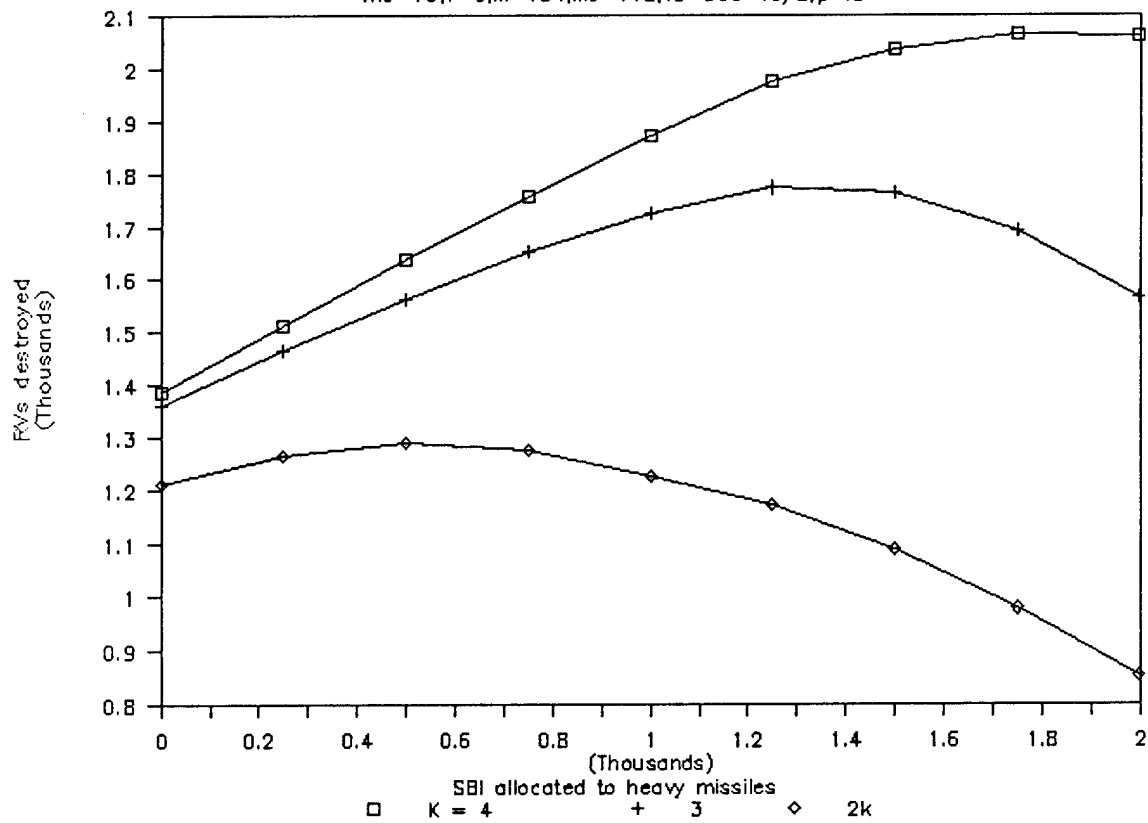


Fig. 4 Mobile heavy point RVs destroyed

$m_0=10, V=6, M_0=112, T_b=300=T_e/2, p=.9$

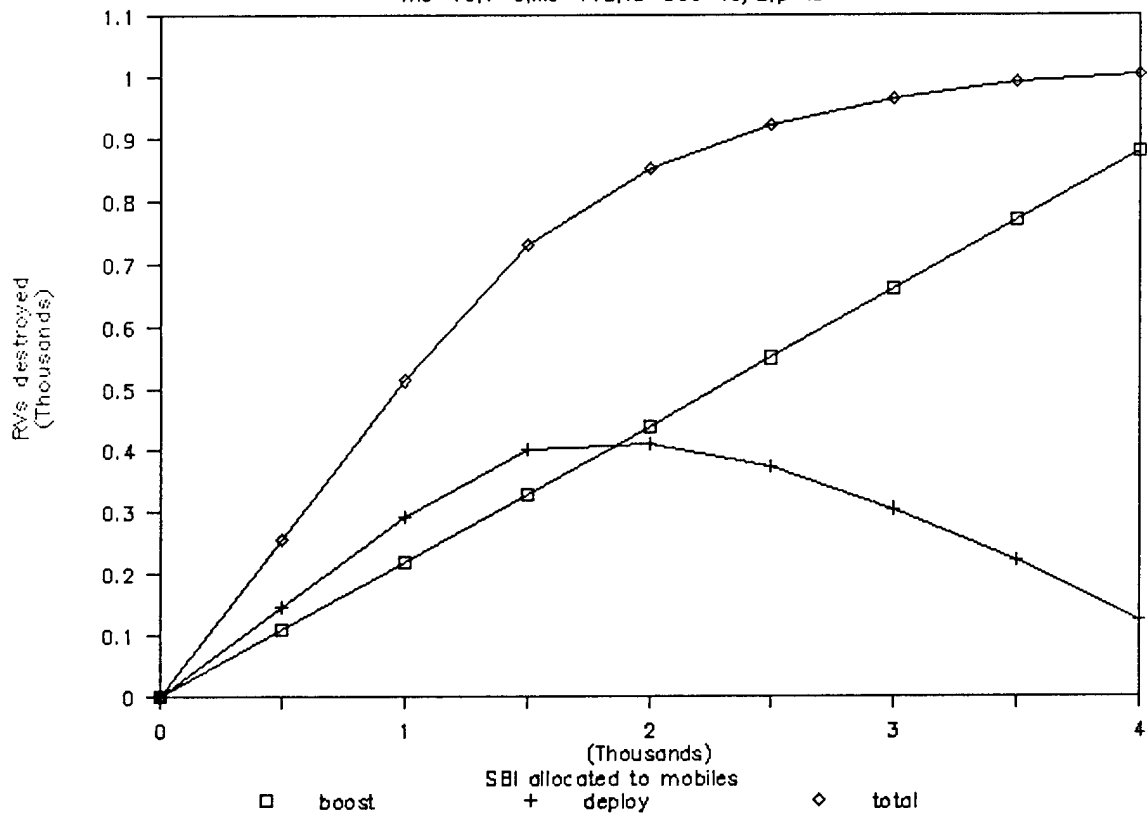


Fig. 5 Singlet mobile RVs destroyed

$m_0=1, V=6, M=270, S=350, T_b=300=Te/2, p=.9$

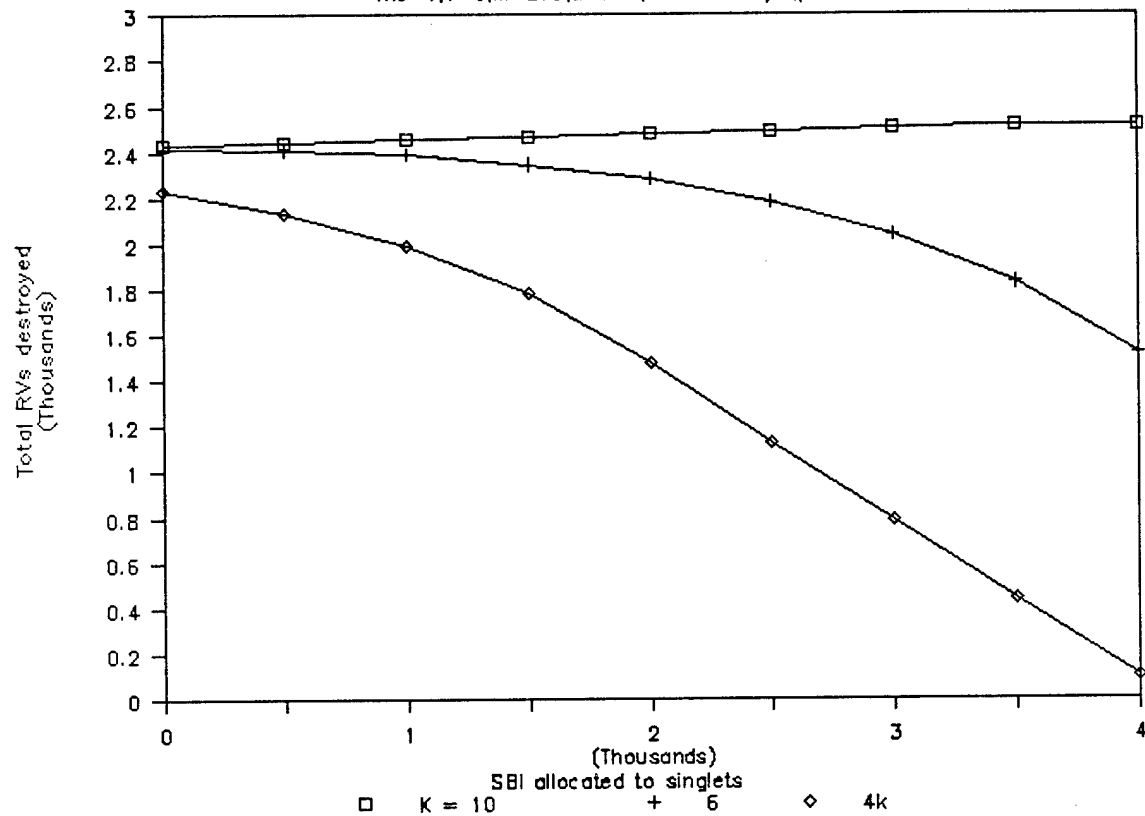


Fig. 6 Solo point singlet RVs destroyed

$m_0=10, V=6, M=270, S=350, T_b=300=Te/2, p=.9$

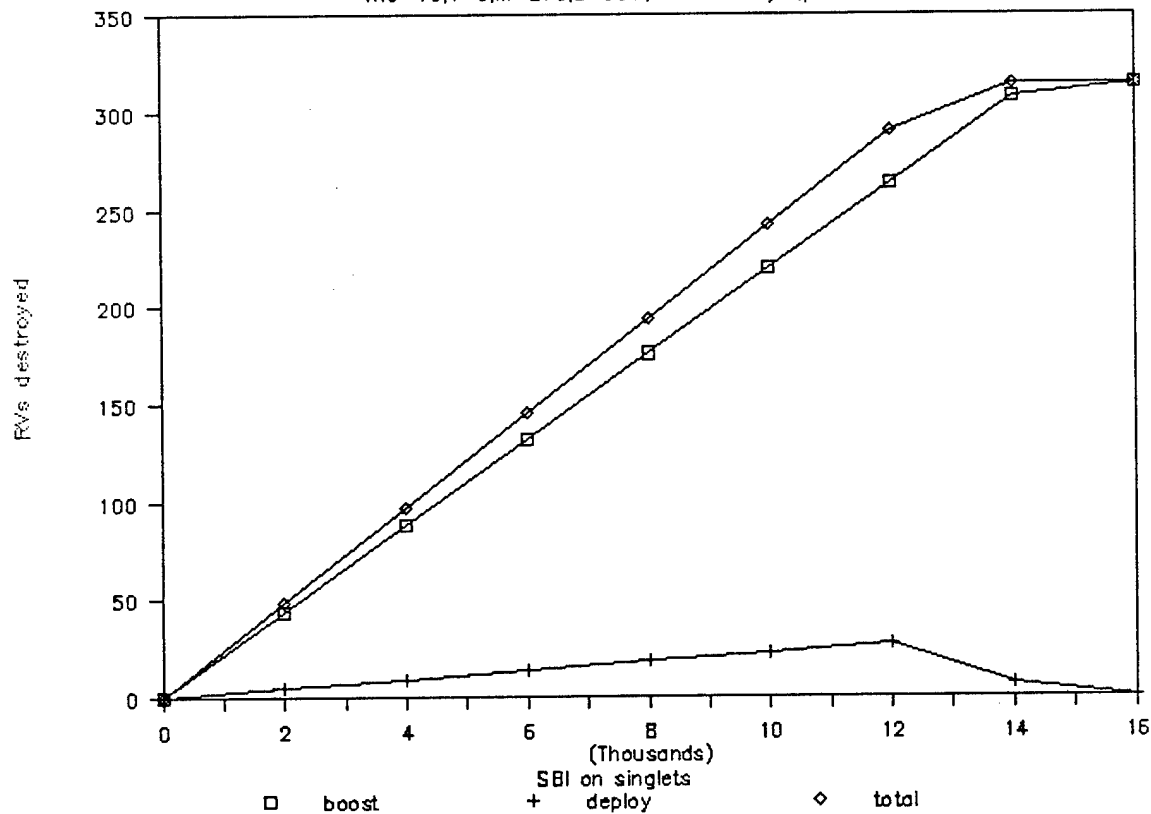


Fig. 7 Patrol SLBM RVs destroyed

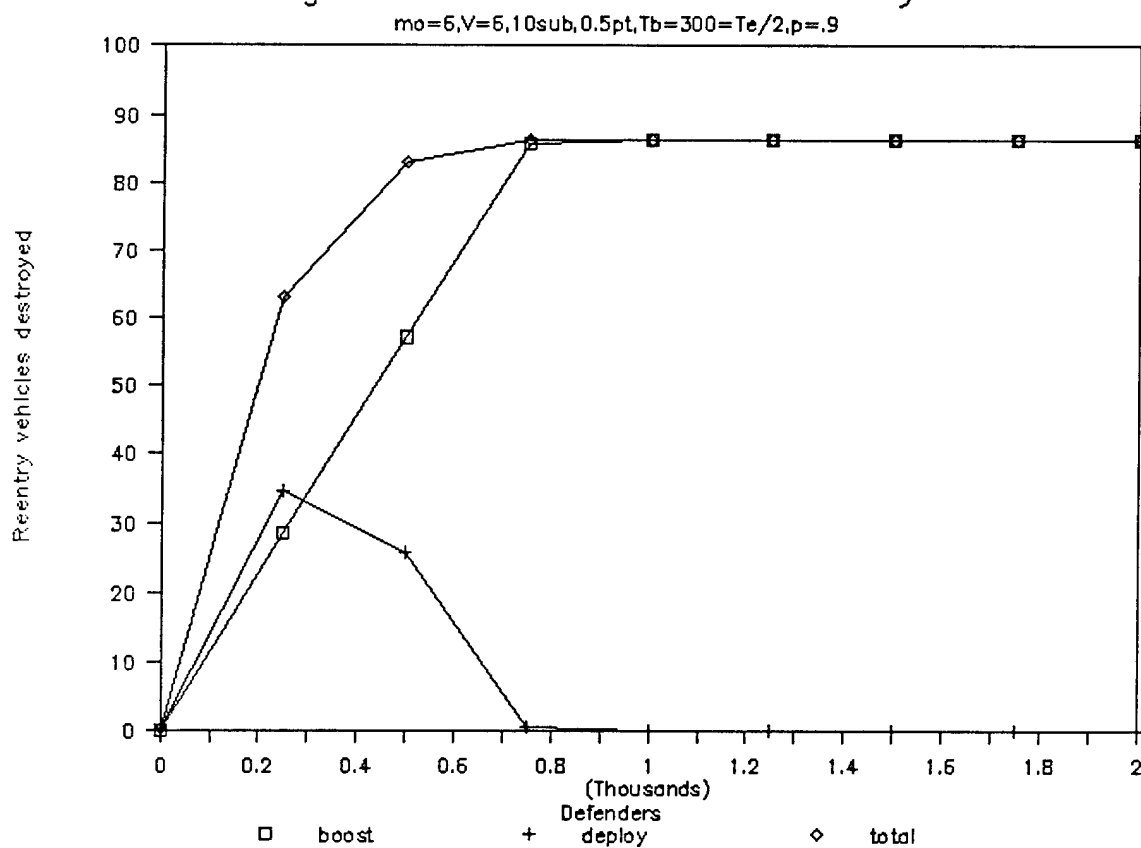


Fig. 8 Port SLBM RVs destroyed vs SBIs

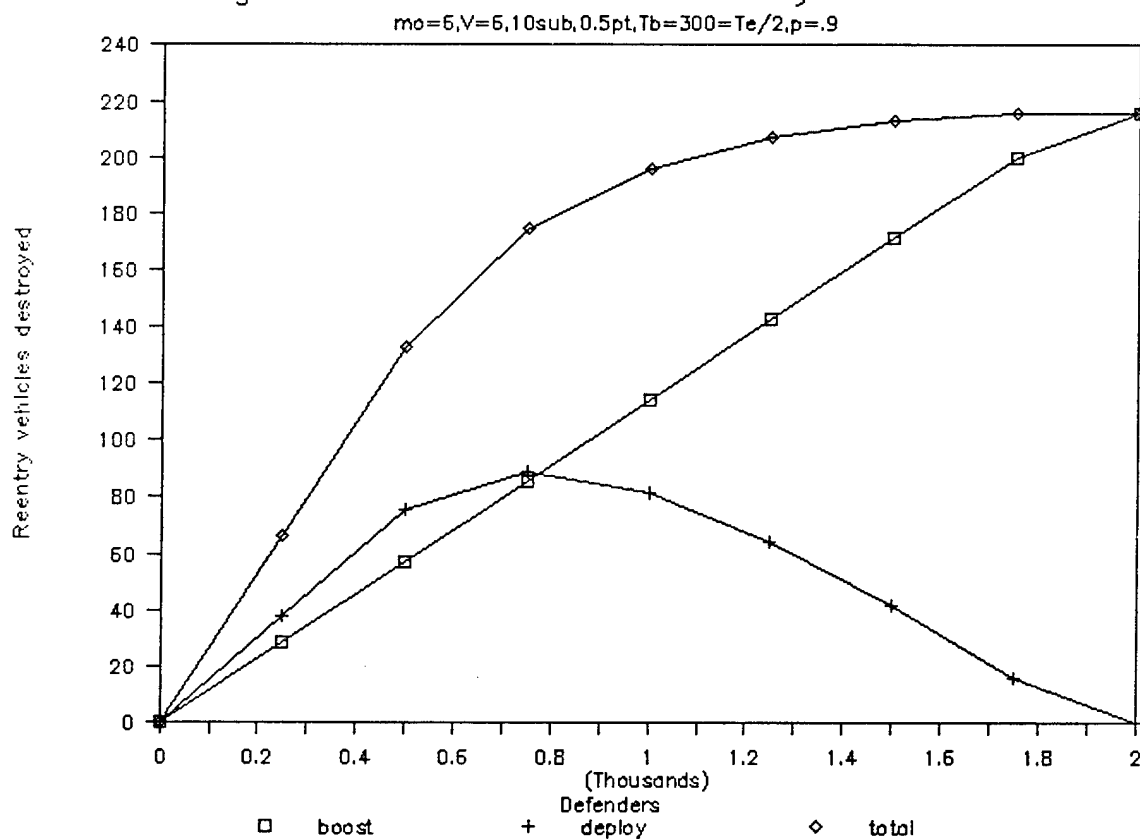


Fig. 9 Total SLBM RVs destroyed vs SBIs

$m_0=6, V=6, 10\text{sub}, 0.5\text{pt}, T_b=300=Te/2, p=.9$

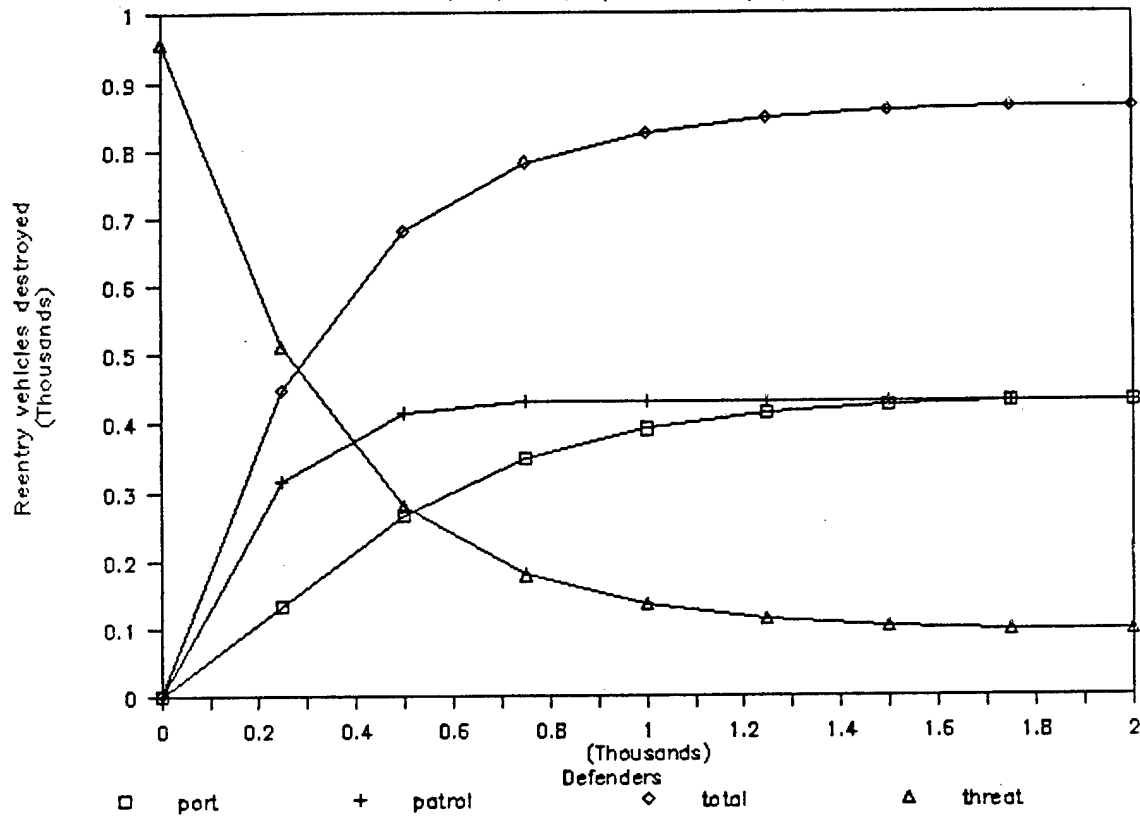


Fig. 10 SLBM RVs destroyed vs early SBIs

$m_0=6, V=4, 10\text{sub}, 0.5\text{pt}, T_b=300=Te/2, p=.9$

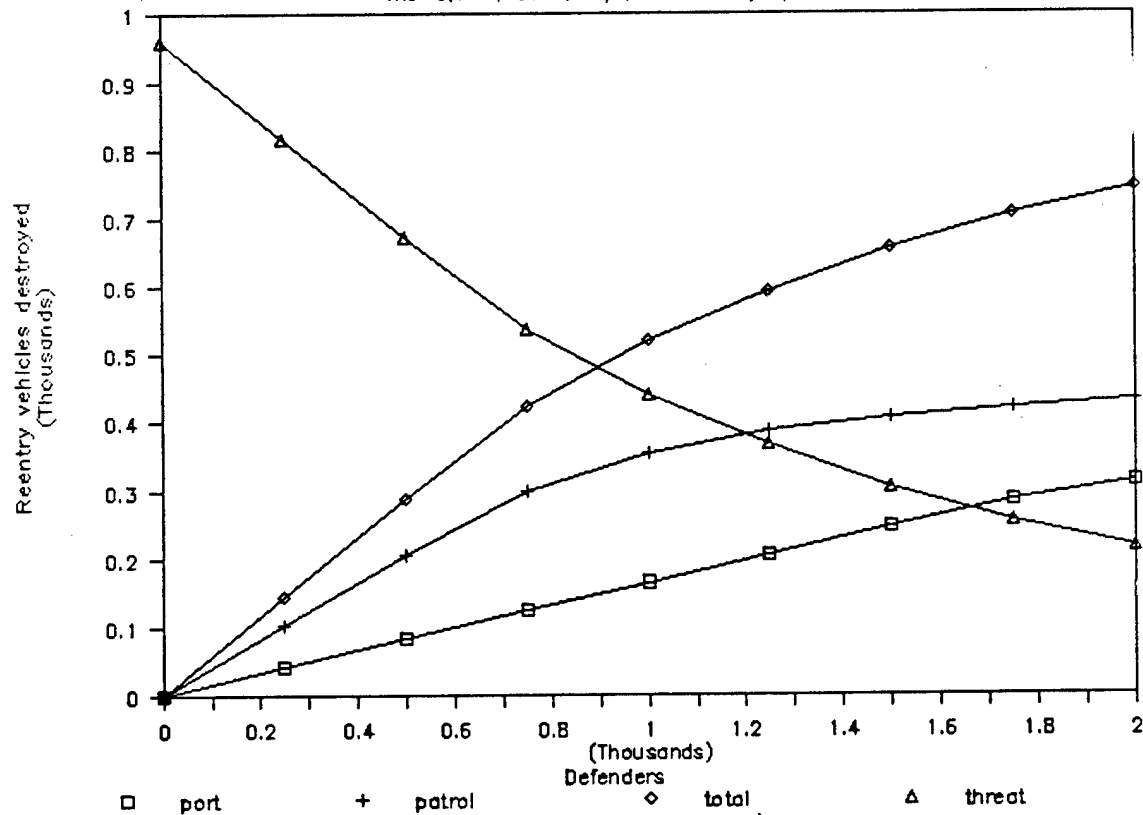


Fig. 11 SLBM RVs destroyed from total

$m_0=6, V=6, 10\text{sub}, 0.5\text{pt}, T_b=300=T_e/2, p=.9$

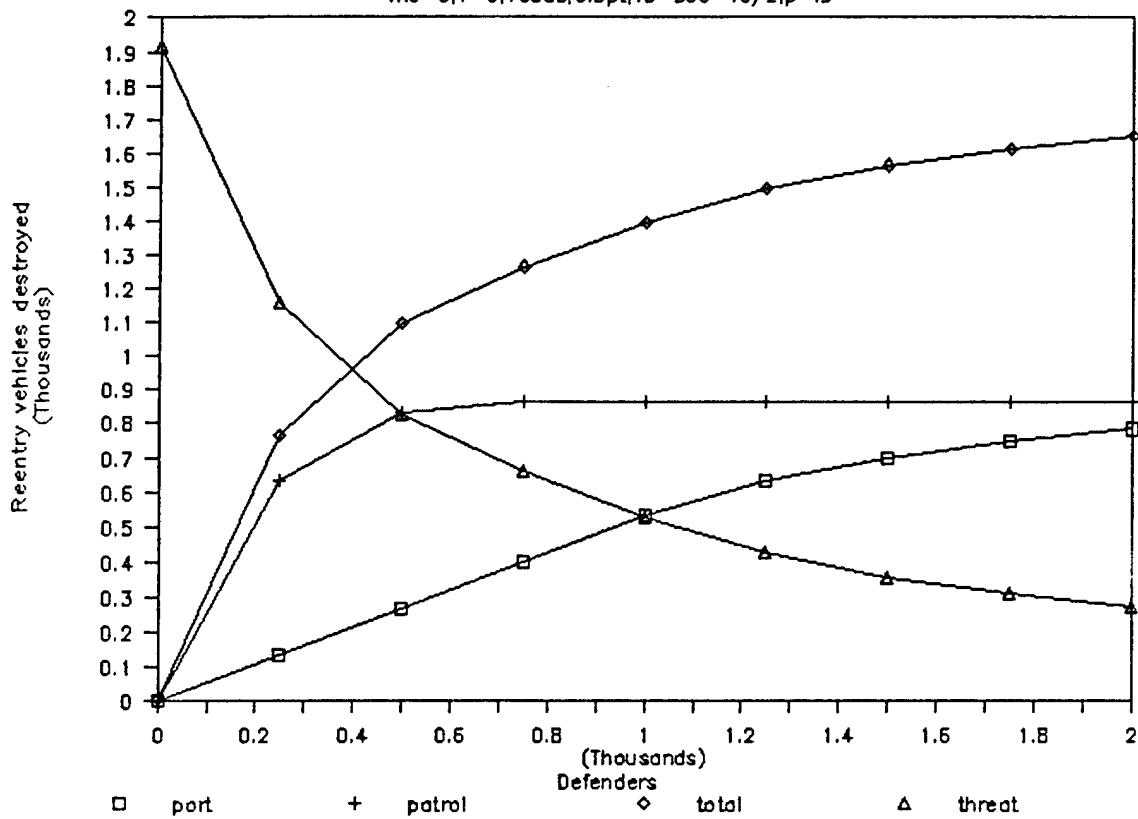


Fig. 12 All SLBM RVs vs early SBIs

$m_0=6, V=6, 10\text{sub}, 0.5\text{pt}, T_b=300=T_e/2, p=.9$

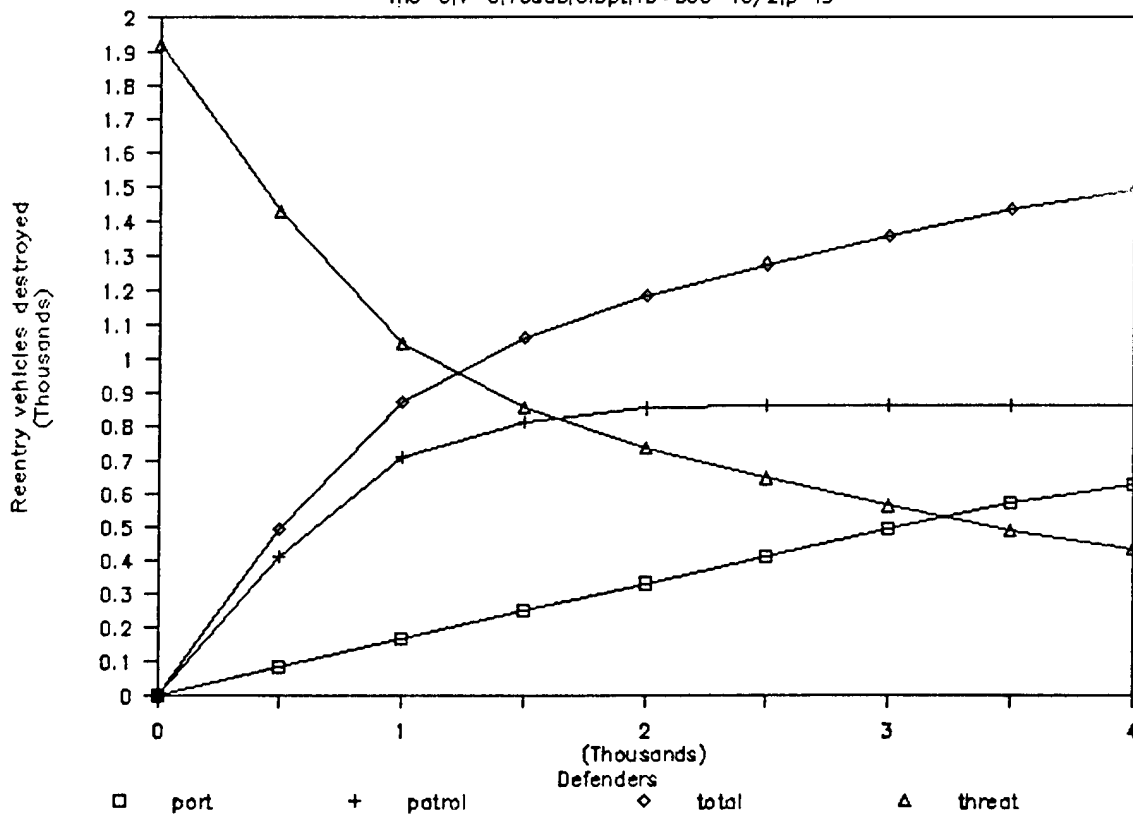


Fig. 13 Total RVs destroyed—nominal SBI

$m_0=10, V=6, T_b=300=T_e/2, p=.9$

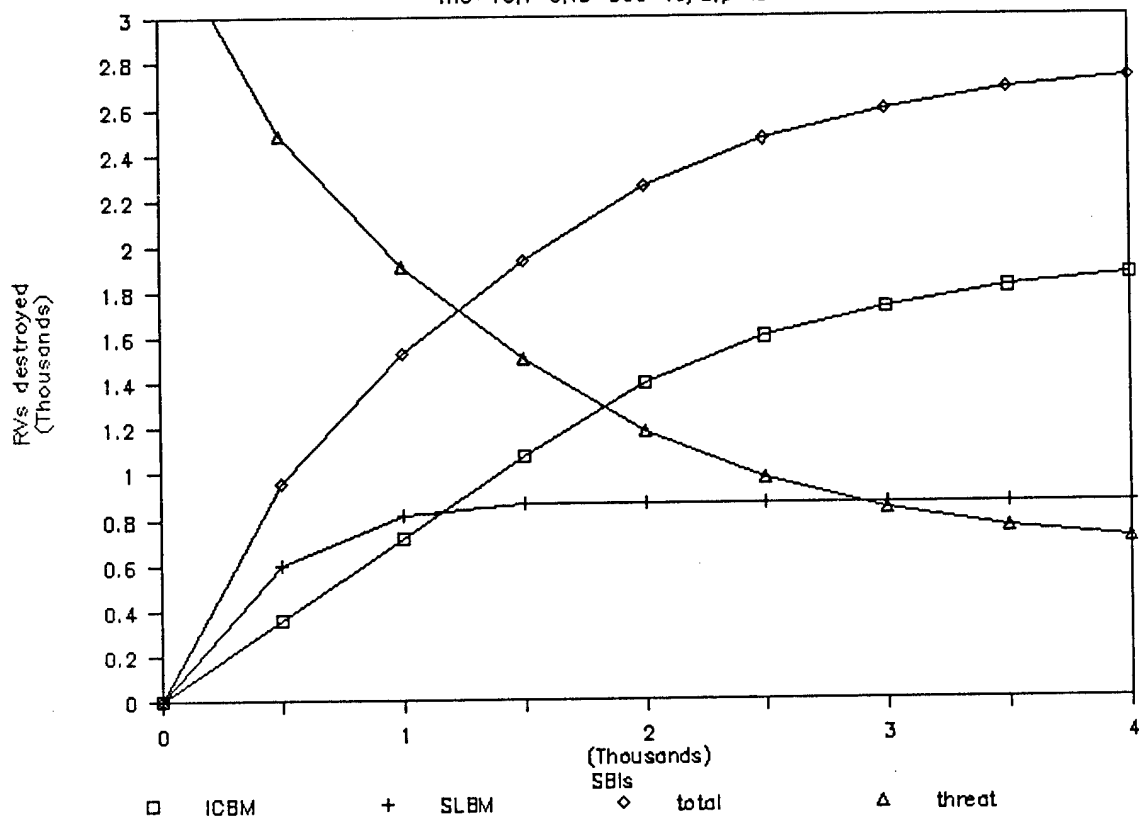


Fig. 14 Total RVs vs early SBI

$m_0=10, V=4, T_b=250=T_e/2, p=.9$

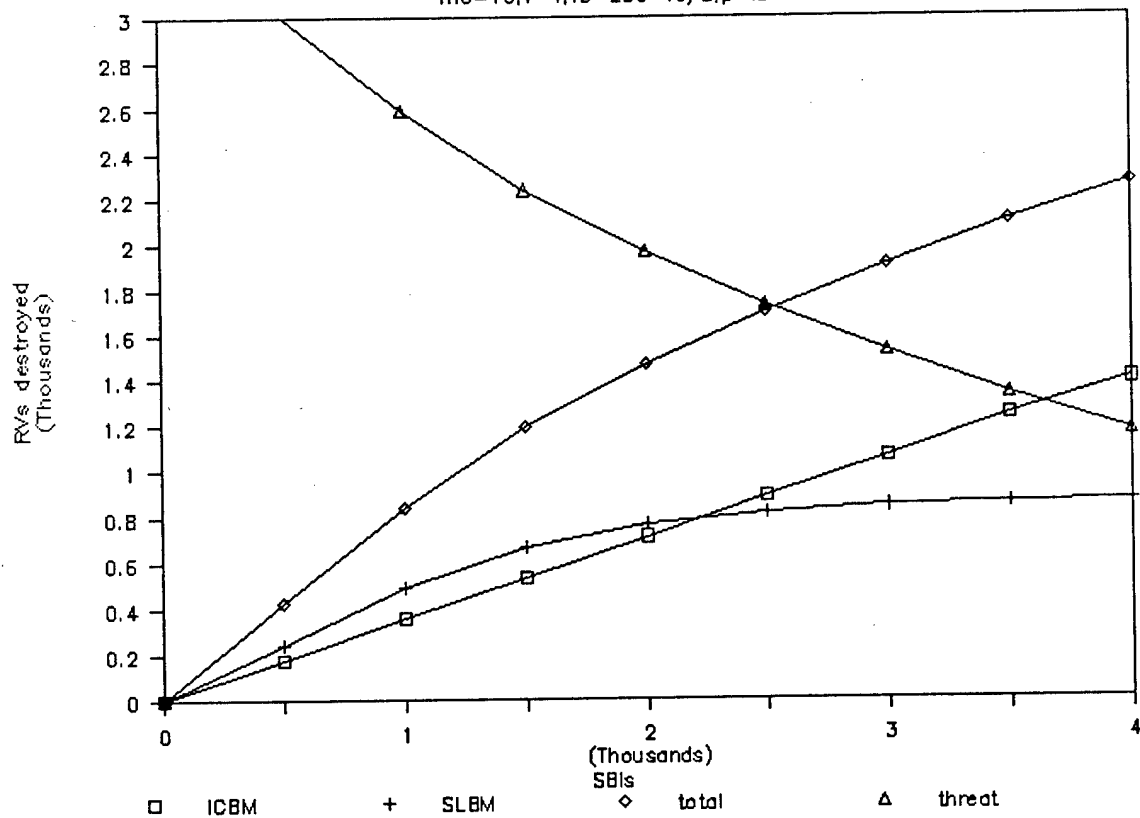


Fig. 15 Total RVs all vs early SBI

$m_0=10, V=4, T_b=250=T_e/2, p=.9$

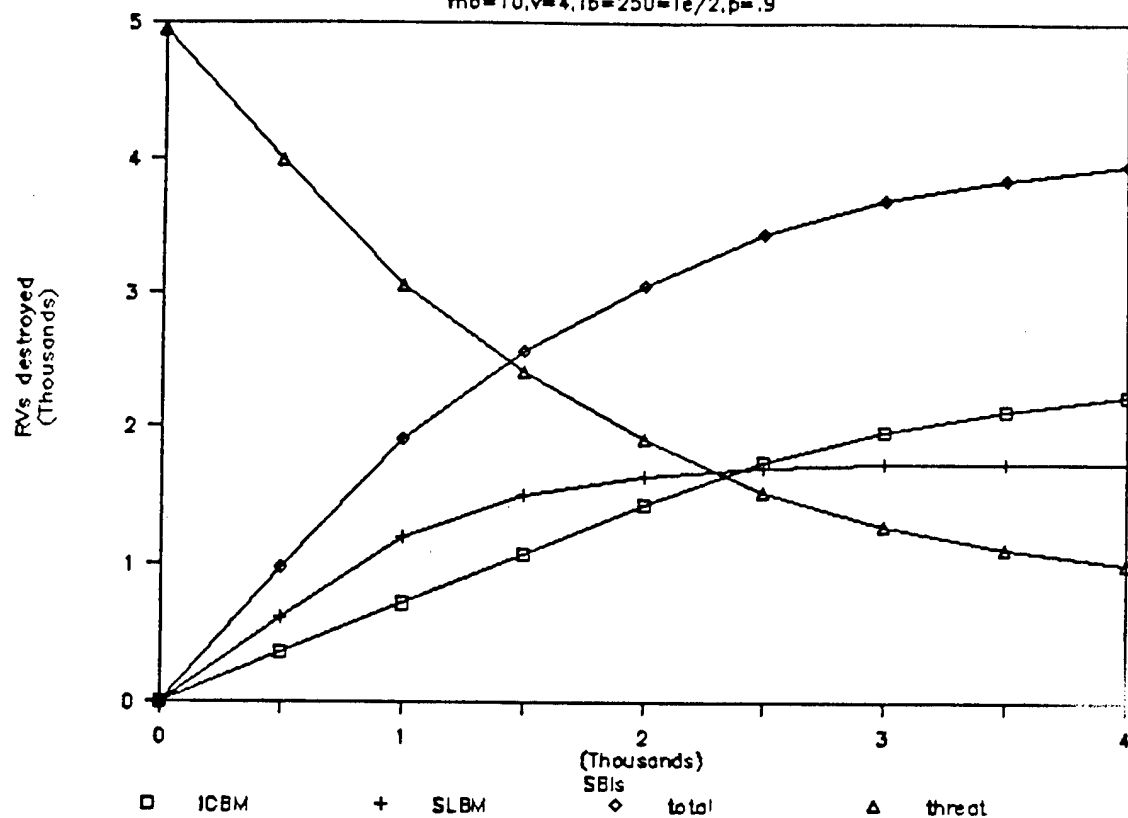


Fig. 16 Total RVs all vs early SBI

$m_0=10, V=4, T_b=250=T_e/2, p=.9$

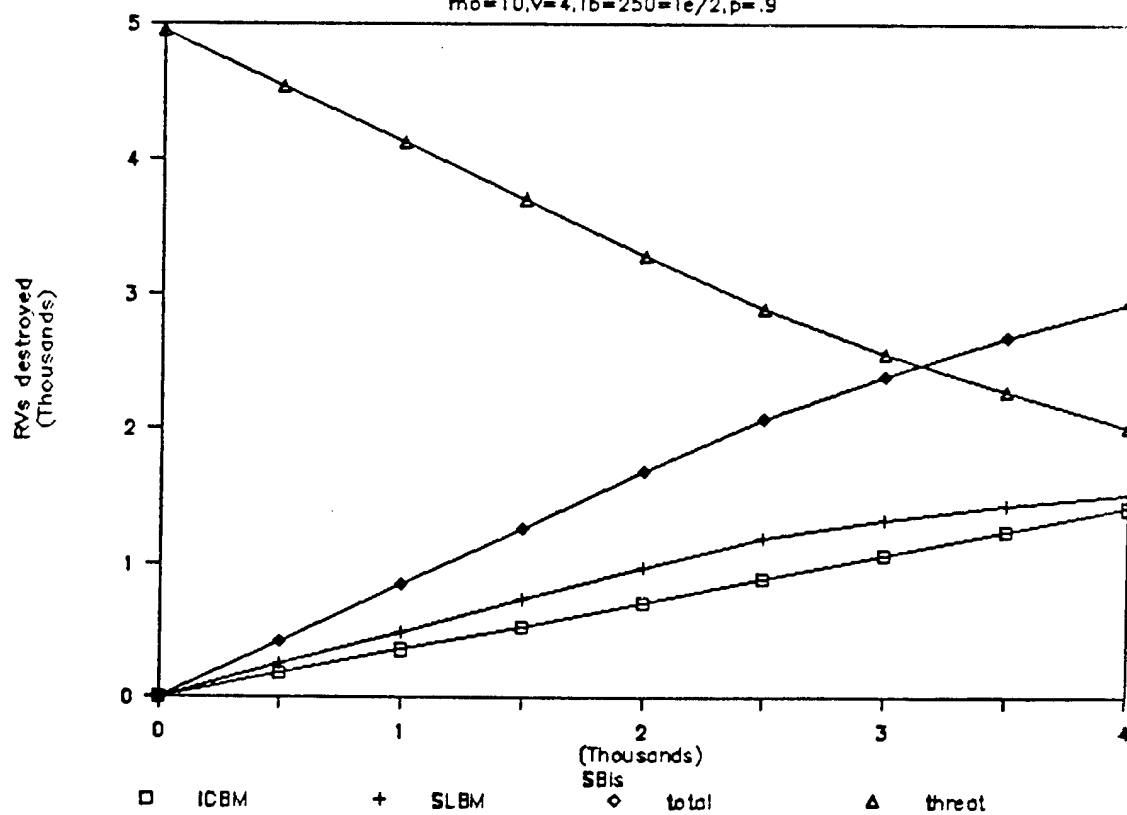


Fig. 17 Cost of defense vs number SBIs

$m_0=10, V=6, M=210, T_b=300s=Te/2, p=.9, D=50$

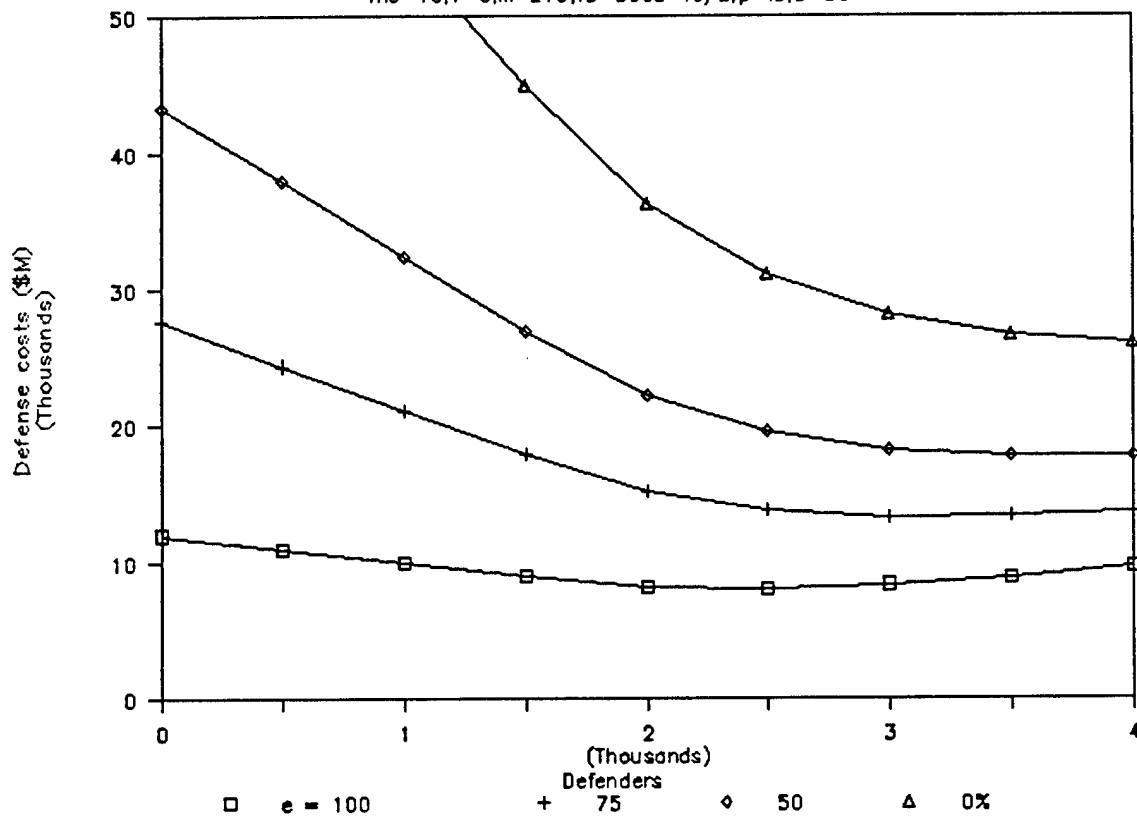
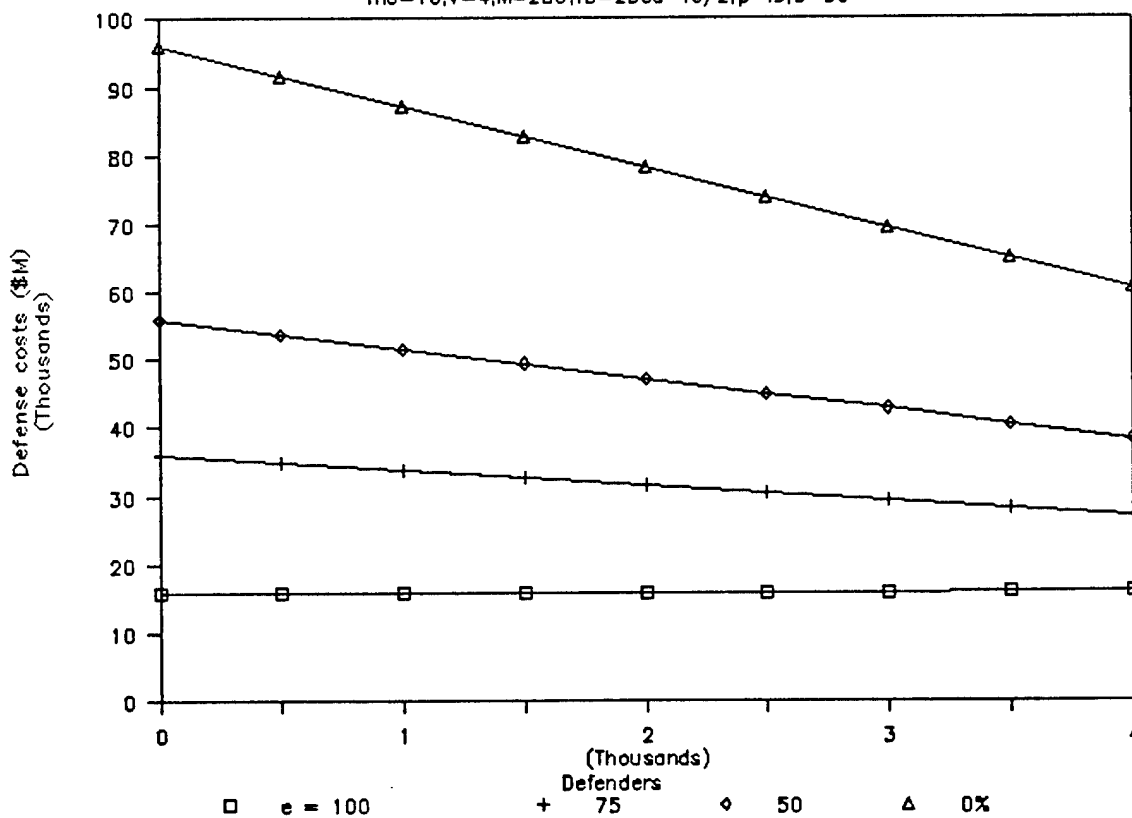


Fig. 18 Cost of defense v yearly SBIs

$m_0=10, V=4, M=280, T_b=250s=Te/2, p=.9, D=50$



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