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Interaction of Strategic Defenses with Crisis Stability

Part II. Applications

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Interaction of Strategic Defenses with Crisis Stability

Part II. Applications

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INTERACTION OF STRATEGIC DEFENSES WITH CRISIS STABILITY

Part II. Applications

by

Gregory H. Canavan

ABSTRACT

Stability indices produce a picture of the transition from offensive to defensive deterrence. Now, fixed intercontinental ballistic missiles (ICBMs) act as a sink; submarine launched ballistic missiles (SLBMs) carry the brunt of retaliation; and aircraft add little. START would shift towards aircraft. Moderate defenses could suppress SLBMs, but would not protect a significant number of ICBMs. Retaliation would shift to aircraft, if protected and penetrating. Combined boost- and midcourse defenses increase stability. Reductions of heavy ICBMs or launch on warning would have little impact. Unilateral defenses change crisis indices little, but reduce delivery.

I. INTRODUCTION

A companion paper, "Interaction of Strategic Defenses with Crisis Stability--Part I. Framework and Analysis," derives the equations that determine the crisis stability indices of offense-defense configurations and uses them to discuss the impact of various Strategic Defense Initiative (SDI) Phase I-related strategic defenses on the stability of offensive force mixes governed by the Strategic Arms Reductions Talks (START). This note applies that methodology to a set of related issues involving optimal boost-phase and midcourse defense mixes, reductions of heavy intercontinental ballistic missiles (ICBMs), unilateral deployments of defenses, one-sided reductions of offenses in conjunction with defensive deployments, and the impact of aircraft alert and penetration rates on stability indices. It first reviews the model and the results of the earlier analysis.

The stability index calculations of the earlier report lead to a simple picture of the impact of the introduction of defensive forces. From the perspective of stability, in the current deterrent configuration fixed ICBMs largely act as a sink for reentry vehicles (RV); submarine launched ballistic missiles (SLBMs) carry the bulk of the retaliation; and bombers and cruise missiles add a bit to it. START would only shift that picture quantitatively; not qualitatively. Even moderate defenses would make a much larger shift. They would protect some ICBMs, though not enough to penetrate the other's defenses, strongly suppress SLBMs, and shift the bulk of retaliation to protected, penetrating bombers or cruise missiles.

Mutual reductions of heavy ICBMs would, in the absence of defenses, have little impact on stability. With defenses, the reductions appear to be unnecessary. Thus, it appears preferable from both stability and cost considerations to defend existing missiles in place. Contrary to popular opinion, unilateral defensive deployments do not appear to be destabilizing. They leave crisis indices essentially unchanged, but significantly reduce the number of weapons delivered. One-sided reductions of offensive forces in conjunction with the deployment of defenses increases stability.

Stability indices are sensitive to bomber alert rates, even more to bomber penetration. If defenses made RVs scarce, that could reduce bomber penetration, which would apparently be destabilizing, although that result in part reflects sensitivity to the target sets used. The prelaunch survivability and penetrativity of air-breathing vehicles are the most sensitive elements of the model.

II. INTERACTION AND STABILITY MODELS

The discussion is based on exchange models[1] and stability indices[2] derived[3] and discussed earlier.[4] The exchange model used is a two-sided, sequential, deterministic description of U.S.-Soviet exchanges, which parameterizes each sides' offensive and defensive force levels and effectiveness. The model calculates the costs of each side striking first or second and uses their ratio as an indicator of the pressures they could feel to show restraint in a crisis. The costs considered are those for the physical damage inflicted or denied; dollar costs are only a surrogate.

Boost-phase defenses are treated as nonpreferential, i.e., random and subtractive in their removal of missiles and weapons. They are modelled on current space-based interceptors (SBIs). Midcourse interceptors are treated as preferential and of long range, i.e. as having the characteristics of current ground-based interceptors (GBIs). Treating them as adaptive would increase performance slightly, but would not be consistent with near-term sensors and control nets.[5]

SLBMs are assumed invulnerable before launch, but are attrited thereafter by the available fraction of boost-phase defenses and the full set of midcourse defenses. Once airborne, aircraft are assumed invulnerable to boost and midcourse defenses. Their prelaunch survivability is calculated explicitly as a function of defense size and disposition. Penetrativity is generally treated parametrically; the loss of defense suppression at high levels of defenses is treated explicitly.

On the basis of the earlier calculations, the studies below deploy combinations of SBIs and GBIs at each level of deployment unless otherwise noted. The GBIs are adjusted to give about as many GBIs as SBIs in the engagement. Bombers and cruise missiles, at times referred to collectively as aircraft, have common baseline alert and penetration rates, which are varied.

Missile attacks can be concentrated on missiles, aircraft, or value targets; so can defenses. The sensitivity studies of the companion paper indicate, however, that attacks and defenses that divide their assets about equally between the three target sets perform well and have little residual sensitivity under START. Aircraft, which arrive well after the missiles and aircraft are launched, primarily attack value, which is taken here to be embodied largely in each sides' projection forces, i.e., its means of maintaining or extending power, in accord with current U.S. and Soviet doctrine.[6]

The principal components of the analysis are the two sides' first and second strikes, costs, and indices of stability. The strikes are calculated from aggregated models of boost and midcourse defenses that have been compared with other exchange analyses.[7] In the model one side strikes first, followed by the other's restrike. The order is then reversed and the damage to each calculated for both orders. Each sides' costs include both those for imperfect strikes on the other's value and those for imperfect limiting of damage to self.[8] The two sides' individual stability indices are taken to be the ratios of their first and second strike costs for each alternative. They are then combined into a composite index, which is the product of the two sides' ratios.[9] The conversion of the results into costs and stability indices are discussed in the appendix to this paper.

If the U.S.'s cost for striking first is denoted C_1 and the cost for its waiting, being struck, and then retaliating are denoted by C_2, the ratio of those costs, C_1/C_2, gives a measure of the relative penalty for striking first. Thus, it is a reasonable measure of how likely we are to wait, and hence how crisis-stable the situation is seen to be from the U.S. perspective.

In the discussion below, primes are used to denote Soviet parameters, while unprimed quantities correspond to those of the U.S., which simplifies derivations and avoids having to label one side or the other as the putative aggressor in exchanges that needn't happen if properly prepared for. Thus, the crisis index from the Soviet perspective is C_1'/C_2'. An index incorporating both sides' assessment is $Q \equiv (C_1/C_2)(C_1'/C_2')$. By this measure, and most others, current retaliatory deterrence is quite stable. The primary issue addressed here is the extent to which these stability indices are shifted by varying numbers of boost or midcourse defenses.

Because the two sides' strikes and costs are similar for the broadly symmetrical START-level forces, it is possible to see how the index varies by examining only the first term. For crisis stability it is obviously desirable to have C_1 large and C_2 small. The former requires that first strikes, R_1, be small and second strikes, R_2, be large. **Figure 1 shows** C_1, C_2, and C_1/C_2 as a function of the size of the first strike R_1 for R_2 = 1,000 and 2,000 weapons. At the left, where $R_1 \to 0$, the lowest two curves are the costs of the U.S. striking second with R_2 = 1,000 or 2,000 weapons. For either, the costs of striking first start small and rise rapidly with little spread. The middle two curves are the costs of the U.S. striking first. They decrease slowly with R_1 and are more sensitive to R_2. The top two curves show the U.S.'s stability index C_1/C_2, which for R_1 small is large indicating a significant penalty for striking first and a corresponding disincentive for doing so.

These relationships can be inverted to give the curves in Fig. 2, which shows the combinations of R_1 and R_2 that give constant values of the index C_1/C_2. For small indices the curves are essentially straight lines with $R_2 \approx R_1$. For larger C_1/C_2 the curves bend up more sharply. For $C_1/C_2 > 1.5$ the curves become almost vertical for $R_1 > 1,200$. Thus, for high values of the index it is necessary to achieve $R_1 \approx 1,000$ and $R_2 > 2,000$-3,000. Without defenses such combinations are unlikely and the index is typically near unity. With defenses, highly stable configurations can be achieved.

III. COMPANION ANALYSIS

Part I presents detailed calculations of two-sided strategic interactions and interprets them in terms of accepted stability criteria. They are only summarized briefly here. Costs are based on damage to self and the other. The objective is to prevent the former and inflict the latter. The index does not determine whether or not either side would strike; perhaps neither would. That depends heavily on psychological and unpredictable factors. The index does at least reduce complicated exchange calculations into a single index consistent with U.S. and Soviet analyses of correlations of forces.

The exchanges are calculated with analytic models developed over the last few years,[10] which are reasonably calibrated.[11] They predict that for moderate boost-phase layers, ICBMs play little role even in first strikes--too few are defended to penetrate boost-phase defenses. Heavy ICBMs play little role against large defenses; fast mobile singlets penetrate freely but provide too few weapons to alter stability calculations. For fundamental reasons, SLBMs are attrited more than ICBMs even when clustered before launch; their impact is diminished by even initial boost-phase defenses. The negation of SLBMs' retaliatory role by modest defenses is an obvious but little-remarked aspect of the analysis. Even with a large fraction of ICBMs surviving the first strike, only a few RVs penetrate to retaliate. For large defenses the contribution from ICBMs and SLBMs is an order of magnitude less than that expected from aircraft, and the main role of defenses is to increase the survivability of value targets and aircraft, which would deliver most of the restrike.

Without defenses, bomber restrikes are critically dependent on alert rates; with defenses that sensitivity is weakened. Thus, defending aircraft is a key role for promoting stability, and one that boost and midcourse defenses should be able to execute as well as they could the protection of missile silos. Combined boost and midcourse defenses give increased stability because midcourse defenses can preferentially increase the number of surviving aircraft. That increases the ratio of second to first strikes, and of first to second strike costs, making the stability indices of combined defenses much greater than those for boost only.

In this analysis, boost-phase defenses alone appear destabilizing, and midcourse defenses appear largely neutral, but combined boost and midcourse defenses significantly increase stability indices. The fundamental difference between the three combinations is the preferential impact of midcourse defenses, particularly in conjunction with adequate boost-phase attrition, in enhancing the contributions from bombers and cruise missiles. This midcourse contribution is a major departure from earlier calculations, which omitted midcourse defences.[12]

Significant sensitivities remain in the analyses. Decoys could reduce composite stability indices, and saturating the midcourse defenses with decoys would collapse the combined stability curve back onto that for boost phase only. Attack and defense interactions indicate modest penalties for nonoptimal allocations of defenses. Sensitivity to the target sets used is greater. If force levels were reduced without reducing the target sets, stability indices would degrade because strikes on value were reduced, even though fewer weapons would fall on either country. Overall, the model provides a robust and properly sensitive indicator of stability. Thus, one can have some confidence in applying it to the more detailed issues below.

IV. IMPACT OF INTERCEPTOR MIXES ON CRISIS STABILITY

The section above discussed crisis-stability indices for START forces for a range of SDI Phase I-like defenses. This section examines the sensitivity of those results to varying mixes of space-based defenders and midcourse interceptors.

A. Analysis

Figure 3 shows the number of unprime RVs penetrating prime's boost phase layer for various numbers of GBIs. To penetrate, unprime RVs must both survive the prime RVs that penetrate unprime's defenses and penetrate prime's boost-phase defenses.

The two boost-phase defenses are assumed equal; the number of SBIs in each, K, is used as the abscissa. The curves are for various numbers of midcourse interceptors (I). The top is for I = 2,000; the next for 1,000; the third for 500; the last is for 0. It is flat along the abscissa because without a preferential layer, essentially no missiles are protected. The curves increase with I at any K because the fraction of the missiles protected preferentially scales as approximately I/R, where R is the number of penetrating prime RVs. The number of penetrating missiles increases with I, but varies less with K. At greater K, more missiles survive to launch, but fewer penetrate the boost-phase defenses, there is little or no net gain.

Figure 4 shows the number of SLBMs penetrating the boost phase. It scales as a negative exponential of K/N, where N is the number of SLBMs launched. The number of SLBM RVs delivered is about 3,200 at K = 0, but falls to about 500 at K = 2,000, and to ≈ 100 at K = 4,000. Comparing Figs. 3 and 4 shows that below ≈ 2,000 SBIs the penetrating missile restrike is largely from SLBMs; above that it is largely ICBM RVs, although they are relatively few in number.

Figure 5 shows the number of delivered RVs, i.e., the sum of the ICBM and SLBM RVs of Figs. 3 and 4, filtered by prime's midcourse defenses that actually reach targets. They are a monotonically decreasing function of I for K small, where 2,000 GBIs decreases the number of penetrating RVs by ≈ 1,000 RVs. For K > 2,000 SBIs the sensitivity to I is reduced, and the number of retaliatory RVs is reduced to a few hundred. Fig. 6 shows the number of penetrating prime RVs, i.e., the surviving, penetrating prime ICBM and SLBM RVs filtered by unprime's terminal defenses. Comparison with Fig. 5 shows that prime and unprime missile restrikes are generally symmetrical for START forces. Prime's penetrating RVs are also monotonic in I, although their fall is faster because prime's force contains more ICBMs, which are suppressed. For I > 500, prime has essentially no penetrating RVs for more than about 1,500 SBIs.

Figure 7 shows unprime's first strike on value targets. For I = 2,000 they are a monotonically decreasing function of I out to K ≈ 1,500, where defenses take the striking RVs down to 0. The residual is then the level set by the surviving, penetrating aircraft. The curves for smaller I reach that level at progressively higher values of K. Figure 8 shows unprime's second strike. The curves are clustered and relatively insensitive to I for K < 1,000, where increasing I decreases the second strike, as expected. Beyond K ≈ 1,000 the strikes are a monotonically increasing function of I, since the additional midcourse defenses protect more aircraft, whose penetration is not impacted by the additional midcourse defenses. The curve for I = 0 continues to fall monotonically throughout, but those for I > 500 are relatively independent of K above 1,000 SBIs, and cluster around 2,000 weapons.

Figure 9 shows the number of bomber weapons delivered in retaliation, which is a monotonically increasing function of K and I. The top curve saturates at ≈ 3,000 SBIs, where about 90% of the aircraft have been defended. The flat bottom curve just reflects the aircraft on alert. The higher curves reflect the strong impact of midcourse defenses on aircraft survivability. None survive without midcourse defenses; a few leaking RVs are adequate to destroy them all. As I increases, so does the number of bomber weapons at each K. The overall increase can be about a factor of four. Moreover, at high levels of defense the fraction surviving would be large independent of the baseline alert rate.

Comparing Figs. 5 and 9 shows that over the interval from 0 to 2,000 SBIs where the restriking RVs fall from about 3,000 to 500 the bomber weapons increase from about 700 to 2,000. This complementarity causes their combined restrike to vary much less than the missile or bomber components. However, it also means that the bulk of retaliation shifts from missiles to aircraft quite strongly at modest levels of boost- and midcourse defenses. The connection between aircraft and defenses is strong but not particularly subtle: when the defenses negate all the missiles, there is nothing left but aircraft.

Figure 10 shows the composite stability index as a function of K for these values of I. The bottom curve is for zero midcourse. It falls monotonically, indicating progressive degradation of crisis stability. The next curve is for I = 500. It dips slightly to roughly unity at K = 1,000 and then climbs steadily to 2.5 at K = 4,000. The next curve is for I = 1,000. It is roughly constant at about 1.3 up to 1,000 SBIs and then increases more strongly, saturating at about 3.3. The top curve is for I = 2,000. It increases from the outset, rising sharply to ≈ 3 by K = 1,000 and then slowly approaching a value of about 3.7. At each K the index is a monotonically increasing function of I, though those for small I are not necessarily monotonically increasing functions of K.

B. Stability Indices

The variation of the stability indices with I is worth exploring further. From Fig. 7, R_1 falls monotonically with both K and I. From Fig. 8, below K ≈ 500, R_2 is maximized for I = 0, i.e. essentially no defenses and fairly high strike levels. There, increasing I decreases both R_1 and R_2. Thus, at low levels of defense the restrike part of the criteria indicates that defenses should not be deployed. The stabilizing reduction of first strikes is, however, a larger effect. Above K ≈ 500, increasing I decreases R_1 and increases R_2, both of which are stabilizing. The bottom curve for I = 0 continues downward, reflecting the fact that boost-phase defenses cannot defend retaliatory assets effectively. The behavior of the curves is complicated at small K, but at large K R_1 and R_2 both tend towards limits, $R_1 \approx 1{,}000$ and $R_2 \approx 2{,}000$, both of which are set by aircraft.

Since $k \approx 1/2{,}000$, and $k' \approx 1/3{,}000$,[13] i.e., the reciprocals of the number of value targets, and the two sides' strikes are comparable, $k \cdot R_2' \approx 1$, $k'R_1 \approx 1/3$, and $C_1 \approx 0.63 + 0.24 \approx 0.87$, where the terms are for damage limiting and value. The first is slightly saturated; the second unsaturated. From the perspective of increasing C_1 it is useful to operate at large K and I, where

R_1 is smallest and R_2 largest, i.e., to move toward strong defenses. The requirements for minimizing the restrike cost are that R_1 be small and R_2 large. Since $k \cdot R_1' \approx 1/2$, and $k'R_2 \approx 2/3$, $C_2 \approx 0.4 + 0.2 \approx 0.6$, so that neither exponential is small. R_2 is relatively independent of $K > 1{,}000$ and $I > 1{,}000$. There is relatively little freedom to shift C_1 and C_2. It is interesting, however, that these asymptotic parameters give $C_1/C_2 \approx 0.87/0.6 \approx 1.5$, which is relatively high. So is the composite $\approx 1.5^2 \approx 2.3$, which is over twice the current value without defenses in Fig. 10. Thus, the asymptotic conditions do produce stable, attractive configurations.

The composite indices of Fig. 10 contain some interesting structure. For small K, all of the curves cluster, reflecting the competing effects on C_1 from R_1 and R_2 in Figs. 5 and 6. Midcourse interceptors are not effective at increasing stability against START-level threats without boost-phase defenses. Conversely, the bottom curve shows that boost-phase defenses without midcourse layers degrades stability. The intermediate curves show that at moderate numbers of SBIs, increasing GBIs can be more effective than SBIs in increasing stability indices.

While there are detailed differences in the trajectories, the top two for 1,000-2,000 GBIs saturate at 3.3-3.5 by about 4,000 SBIs, exhibiting the asymptotic limits discussed above. Since GBIs cost roughly twice as much as SBIs, that leads, fortuitously, to a rough balance of costs between the boost and midcourse layers. These curves are calculated without decoys. If D decoys per RV were used to dilute the midcourse defenses, for each curve the total number of interceptors deployed would have to be increased by a factor of $1 + D$ to offset them. For $D > 2$ the dominant costs would shift to the midcourse interceptors.

C. Observations

Figures 3, 4, and 5 show that there a few restriking RVs for more than a thousand SBIs and GBIs. That means that the aircraft carry bulk of the restrike, as shown in Fig. 9, which means that they determine stability characteristics. Figures 7 and 8 show that first and second strikes fall monotonically with K, and that first strikes fall monotonically with I, but that second strikes fall with I for K small and increase strongly with I for K large, leading to the dips in the indices. Stability indices increase monotonically with I, essentially following the curves for the weapons from penetrating aircraft. They do not, however, increase monotonically with K. The variations of the survivors, penetrators, strikes, and indices are complex. Thus, in looking for appropriate mixes of SBIs and GBIs, the stability index, which incorporates damage to self as well as damage inflicted, would appear a useful guide.

According to that criteria, configurations with SBIs only should not be deployed. Indeed, to avoid any dip in stability, it might be best to deploy a thousand or more effective GBIs before deploying any SBIs. From the perspective of stability, neither boost nor midcourse defenses are effective by themselves. The primary goal is to reach the first and second strikes' asymptotic limits as quickly as possible. The secondary goal is to decrease the weapons delivered. From Figs. 7 and 8 the reductions would be a factor of three in first strike weapons and a factor of two in second strike while increasing stability.

V. CRISIS STABILITY DURING PARALLEL HEAVY ICBM BUILD DOWNS

This section discusses the variation of crisis stability during a build down from the START mix of ICBMs, SLBMs, and aircraft to a force of singlet ICBMs. Aircraft are not altered below, although the build down does impact their prelaunch survivability. SLBMs are unchanged except were noted.

A. Analysis

The transition from a force of multiple RV heavy missiles to a force of largely single RV missiles is treated below. It is assumed that all RVs removed from heavy missiles are placed on mobile singlet missiles, it having been shown previously that placing the RVs on heavy mobiles or immobile singlets would not improve stability. The singlets are assumed to be fast enough to elude most of the boost-phase space based interceptors (SBIs). Thus, they are non-targetable by offensive RVs and insensitive to boost-phase defenses. They are, however, still subject to attrition during midcourse. Terminal interceptors are ignored. They would not alter the analysis.[14]

Figure 11 shows the unprime, i.e., U.S., first strike. Prime's is similar. The top line is for no defenses, and shows that as the U.S. heavy missiles drop from 800 to about 120, and the fast singlet mobiles increase from 0 to ≈ 1,200, the first strike for purely offensive configurations changes little, remaining at 2,800 RVs on value. The middle curve is for 2,000 SBIs and 0 ground-based interceptors (GBIs). It increases slightly as the number of heavy missiles decreases, but remains about a factor of two below the offense curve. The bottom curve for 2,000 SBIs and 1,000 GBIs is flat at about 1,000 RVs.

Figure 12 shows the second strike. The offensive curve is at 4,000-5,000 weapons, increasing with the shift to singlets. The curve for 2,000 SBIs and zero GBIs rises from 1,000 to about 2,500 weapons during the transition. The curve for 2,000 SBIs and 1,000 GBIs is flat at about 2,000 weapons. Figure 13 shows the aircraft contribution to the second strike. The offense and boost-phase only curves are flat, since neither contains other than alert aircraft. That for 2,000 SBIs plus 1,000 GBIs is about a factor of three higher at the beginning of the transition; about twice the offense and boost phase curves by 120 heavy missiles. It drops because the transition to singlets allows the penetration of more missiles, which suppress more aircraft.

Figure 14 shows the composite stability indices for four cases. At the left border the bottom curve is the stability index for the transition from heavy silo-based missiles to fast mobile singlets without defenses. The stability index increases from 1.2 to a little under 1.4, or about 10%, which is a rather modest increase, given the change of the missile force implied. The curve above it gives a rough bound on the impact of SLBMS. It was calculated assuming that SLBMs were eliminated at the same rate as heavy ICBMs. The SLBMs are discarded rather than being converted because singlet SLBMs would, because of the cost of submarines, cost about 10 times more per warhead than equally survivable mobile singlet ICBMs, which should also have better boost-phase penetration. The differential impact is quite small.

The third curve up is for the 2,000 SBI boost-phase-only defense. At 810 missiles it starts out about 20% below even the offensive curves, in accord with the earlier discussions of the fact that boost-phase only defenses are destabilizing. As the heavy missiles are eliminated, however, the boost-phase layer gives a larger increase in stability indices that from the offensive alterations. By 100 missiles the boost phase reaches about 1.6, which is a significant increase and about 10% above offense alone. The top curve is for 2,000 SBIs plus 1,000 GBIs. At 810 missiles it is about a factor of two higher than the other curves due to the lower first strikes and constant second strikes shown in Figs. 1 and 2. This factor of two separation is large compared to the estimated errors in the separate calculations.

B. Discussion

From these curves it would appear that a build down to singlets could have some useful products, but a large increase in stability does not appear to be one. A boost-phase defensive layer could exacerbate stability concerns in the early part of the transition, but a mix of Phase-I SBIs and GBIs could significantly stabilize it throughout. Dollar costs are not the prime consideration here, but it might be noted that the SBIs might cost about \$ 1 M/SBI x 2,000 SBIs ≈ \$ 2 B, and the GBIs a similar amount. Thus, for about \$ 10 B, including sensors, control, etc., defenses could stabilize a transition that would cost about \$ 100 M/missile x 1,000 missiles ≈ \$ 100 B.

C. Conclusions

It might be further noted that, to the extent that the performance estimates imbedded in the stability calculations are correct, it would be preferable from a stability standpoint to keep the current number of missiles, for which the index is about 2.3, rather than go to a lesser number, for which the index falls slightly. Providing defenses for current missiles rather than singlets would both provide higher indices and save the $ 90 B difference. Errors in analysis would have to amount to an order of magnitude to overcome that differential. With defenses, the mobility of the ICBMs matters little.

VI. LAUNCH ON WARNING/LAUNCH UNDER ATTACK

The previous section showed that a build down to mobile singlets, which is the reconfiguration of strategic offensive forces most often discussed for stability purposes, actually has little impact on crisis stability indices. If there is little gain from replacing heavy missiles with mobile singlets, the next step is to ask whether their vulnerability could be removed by changing to a policy of launching on warning or under attack. That option is discussed below.

A. Analysis

Launch on warning can be evaluated with the same model used for the calculations above. It allows for arbitrary allocations of the attack among missiles, aircraft, and value. The essence of launch on warning is to launch the missiles before the attack arrives. If that is known or thought to be unprime's policy, prime should logically not target unprime's missiles. Thus, launch on warning can be studied simply by allocating no missile RVs to missiles and dividing them instead between aircraft and value. Parenthetically, not targeting missiles would also be the logical policy if prime thought his missiles unable to kill unprime's missile silos. That comment probably applies primarily to U.S. doubts about the bulk of its missile force being able to destroy Soviet heavy missile silos. The analysis below thus also covers the impact of mutually invulnerable fixed missile silos.

Figure 15 gives a somewhat crowded summary of the strikes under this policy. The abscissa is the number of SBIs. For each K there are I midcourse interceptors. The ordinate is the number of weapons in the different components of unprime's restrike. At the left border the bottom curve is the number of unprime restrike heavy ICBM RVs penetrating prime's boost phase as a function of the mutual SBI deployments. The number is essentially zero below about 2,000 SBIs; it grows slowly to about 400 by 4,000 SBIs. The next curve up is the restrike bomber weapons, which show similar growth, although to much higher levels. The next is the number of restriking heavy ICBM RVs under launch on warning, which saves about 1,500 RVs for K = 0. The next pair of curves are the SLBM RVs and just below it the total number of RVs penetrating to target under the current U.S. policy of riding out the first strike. The top curve is the number of penetrating RVs under launch on warning.

B. Discussion

The variations are familiar, but there are a few new relationships. Under current policy ICBM RVs never play a significant role. They are totally suppressed for K small, where most of the restrike is by SLBMs; few penetrate midcourse defenses at K large; and there aren't enough to matter in between, where the burden of retaliation is shared by aircraft and SLBMs. The crossover between the two is at about 1,000 SBIs. Under launch on warning the same basic pattern results. The ICBMs are less than half those from SLBMs at small K and about 5%-10% those from aircraft at large K. In the middle, however, the contribution from the RVs saved by launching them on warning is significant. At 1,500 SBIs the SLBM RVs would be reduced to about 500 RVs and the aircraft would only be up to about 1,000. Thus, the ≈ 1,000 penetrating RVs from ICBMs could contribute. It means the difference between a retaliation of ≈ 2,000 RVs and one of about 1,500 under current policy.

Figure 16 shows the impact on stability. The lower curve is for current policy; the upper one for launch on warning. There is little difference at large K, largely because even launch on warning contributes little retaliation there. At 1,000-2,000 the difference is interesting. The additional retaliation essentially fills in the minimum in the current policy, which results from rapid drawdown of retaliatory assets by boost-phase defenses. The increase is 30%-40%. The result is a monotonic increase in stability throughout. There is, however, no improvement at $K = 0$ because SLBMs are adequate there, and dominant under either policy. Thus, launch on warning is apparently not useful for either zero or large defenses but makes an apparently useful but modest contribution at intermediate levels.

C. Observations

Launch on warning appears to improve stability indices in that it reduces the pressure on decision makers in crisis. It is, however, implemented through very fast acting, highly-automated machinery that could leave little or no time for human decision making. Thus, it decreases stability at the price of the possibility of accidental launch through machine error. Since unprime adopting such a policy would probably result in prime adopting it too, the effect of such an error could be the launching of both arsenals against the others' aircraft and value. The strikes on them would even be a bit stronger since no RVs would be wasted on silos. The result could be mutual annihilation without the need for human assistance.

The two types of stability shifts are not commensurate. The gain is through the lessening of pressure on decision makers; the loss through the introduction of a mechanical decision maker other than the national command authority. The latter is not accounted for in the current stability framework; it would be difficult to do so. It would appear, however, that the downside involved in automated launch on warning seems to outweight the transient, 20%-30% gain it might afford.

VII. UNILATERAL DEPLOYMENTS OF STRATEGIC DEFENSES

This section applies the crisis stability index formalism to unilateral deployments. Unilateral deployments are generally thought to be destabilizing, but they actually leave stability indices largely unchanged. They primarily reduce the number of weapons delivered, which is a positive step.

A. Analysis

Unilateral deployments can be accommodated by the model described earlier. They are studied here by varying unprime defenses while leaving prime offensive forces at START levels. Figure 17 shows the resulting components of prime's first strike as a function of the number of prime SBIs for I = K/4. The top curve is the number of ICBM RVs penetrating boost; the second is the total first strike; the third is penetrating SLBM RVs; and the fourth is the surviving weapons on aircraft. For no defenses the strike amounts to about 3,000 ICBM RVs, 2,000 SLBM RVs, and 700 bomber weapons for a total strike on value targets of about 2,600 weapons. By 2,000 SBIs the penetrating ICBM RVs have dropped to about 1,000, and the SLBM RVs to about 200. There and above the strike is composed largely of aircraft weapons, since few of the reduced number of RVs can penetrate the midcourse defenses. Above 2,500 SBIs prime's first strike is very nearly equal to the number of penetrating aircraft.

Figure 18 shows the components of prime's second strike. The top curve is prime's total second strike; the second is the number of RVs penetrating both boost and midcourse defenses; the third the number of SLBM RVs penetrating to targets; the fourth is the number of bomber weapons. The fifth is the number of single-RV mobile missiles, other ICBMs having been destroyed. For no SBIs the components and totals are much as before. By 2,000 SBIs the number of RVs penetrating both layers is only a few hundred, and the prime second strike is essentially equal to the number of prime bomber weapons. If prime does not deploy defenses, unprime's first strike is unattenuated. Unprime's second strike, not shown, is reduced by the number of nonalert aircraft and essentially all missiles. By 2,000-3,000 SBIs both are restored to their unattrited values.

Figure 19 shows the resulting costs. At 1,000 SBIs the top curve is the cost to prime for striking first, C1'; the second is his cost for striking second, C2'; the third is unprime's cost for striking second, C2; and the fourth his cost for striking first, C1. Roughly, C1' and C2' rise together until about 2,000 SBIs and then stabilize. Since C1' increases slightly more than C2', the overall effect is stabilizing. C1 and C2 fall together until about 2,000 SBIs and then stabilize as both first and second strikes become dominated by bomber weapons, which are not affected by further defense increases.

Figure 20 shows the resulting stability indices. At zero SBIs the top curve is the composite index; the second is prime's index; the third is unprime's index. Prime's climbs roughly monotonically from 1.12 to about 1.18, reflecting the slightly greater increase of C1' than C2' over the interval in Fig. 19. Unprime's index first drops from 1.04 to about 0.94, about 10%, and then rises to about 1. The composite index reflects this dip, but returns to about 1.17 by 2,000 SBIs.

B. Discussion

According to Fig. 20 the overall impact of the unilateral deployment of strategic defenses on stability indices is modest. That is apparently at variance with concerns that even imperfect defensive shields might be good enough to negate the other's second strike. The top two curves on Fig. 19 show that unprime's defenses do increase prime's costs for first and second strikes, and increase them in a ratio that increases his disincentive to strike first.

The bottom two curves, however, show that unprime's costs for striking first or second are reduced, but proportionally. Thus, prime sees no reduction in the relative costs of striking first and hence no incentive to take advantage of his "imperfect shield" in the context of this model. The first strike costs fall slightly faster for the forces assumed, which leads to the 10% dip in unprime's index in Fig. 20, but by Figs. 17 and 18, above 2,000 SBIs prime's missiles are largely negated and his second strike reduces to that by aircraft, so his strikes, costs, and indices are insensitive to further increases in unprime defenses, and the configuration is again quite stable.

C. Observations

First and second strike costs for both sides change, but proportionally, and each is proportional to the bomber weapons for large defenses. That means that while the defended side could reduce the cost of striking first by using an imperfect shield against the other's second strike, the overall cost of doing so would not be significantly less than that of defending against the other's first strike and then striking second. For that reason the composite indices of Fig. 4 vary much less than the order of magnitude changes in the components of the strikes and the factor of two changes in costs that go into it. Unilateral deployments of strategic defenses would thus appear to leave stability indices largely unchanged and primarily reduce the number of weapons delivered. The reductions could be significant.

VIII. REDUCTIONS OF OFFENSES WITH DEPLOYMENT OF DEFENSES

This section treats one-sided reductions of offensive forces in conjunction with the deployment of strategic defenses, which increase stability indices to an extent intermediate between increases for the mutual and unilateral deployments of defenses.

A. Analysis

Prime forces remain at START limits. Thus, prime first and second strikes remain as before; they are not impacted by the reductions of unprime offensive forces discussed here. Figure 21 shows the components of unprime's first strike under the assumption that unprime's missiles, submarines, and aircraft are all reduced by a factor of four from START limits. Intermediate reductions roughly interpolate between these curves and those of unilateral defenses discussed above.

The abscissa is the number of SBIs; the ordinate is the number of launchers or weapons. The bottom curve is the number of unprime missiles that survive prime's first strike. The second line is the number of RVs that restrike to targets, which is simply the number of surviving missiles times the number of RVs on each, since prime has no defenses. The third line is the number of surviving, penetrating bomber and aircraft weapons, which increases as the defenses improve due to the protection of their bases, which increases prelaunch survivability. The fourth line is the number of SLBM RVs, which are unattrited in the absence of prime defenses. The fifth line is the total number of penetrating RVs; the sixth is unprime's total second strike. All components increase gradually with defenses. For no defenses the restrike is about 1,200 weapons; by 2,000 SBIs is about 1,500 weapons; by 4,000 SBIs it asymptotes to about 1,700 weapons, about 75% of the 1/4 START or 9,000/4 = 2250 weapons deployed.

Figure 22 shows prime and unprime first and second strikes. As noted earlier, prime's strikes are essentially the same as those before unprime's offensive force reductions because those reductions do not impact his penetration or targeting for a given number of SBIs. Unprime's first strike is constant at the fraction of weapons allocated to value, which is not varied. Unprime's second strike increases gradually due to the greater survival of both aircraft and missiles, which has a significant stabilizing impact on indices. With one-sided defenses, retaliatory forces actually constitute a triad, whereas without them the land-based missiles are essentially RV sinks.

Figure 23 shows the costs. The contrast with Fig. 19 for unilateral deployments is instructive. Unprime's first and second strike costs fall much as for unilateral defenses, but stabilize at a higher level due to his reduced total offensive forces. Prime's first and second strike costs again increase roughly in parallel, but they start at much lower levels. Thus, the ratio of first to second strike costs increases about 50% rather than the $\approx$ 10% for unilateral defenses.

B. Discussion

Figure 24 shows the result. Unprime's average crisis stability index is little changed from that for additive defenses, but the offensive reductions smooth out the dip at 1,000-2,000 SBIs for unilateral defenses, eliminating even any transient degradation of stability. Prime's index again increases relatively slowly, but from a significantly increased base level. It starts from about 1.45 for no SBIs as opposed to about 1.12 for unilateral defenses. That results in about a $1.45/1.12 \approx 1.3$ increase in composite stability. That increases the ≈ 1.18 for unilateral defenses to the ≈ 1.5 average index seen in Fig. 24. That value is intermediate between those for the unilateral and mutual deployments discussed above. It is comparable to, but quantitatively more precise than, earlier studies of the qualitative impact of unilateral reductions.[15]

C. Observations

When offenses are reduced to compensate for the deployment of defenses, unprime's second strike increases gradually but significantly with defenses, asymptoting to about a quarter of the START total. Unprime's first and second strike costs vary much as for unilateral defenses, but stabilize at a higher level. Prime's costs increase in parallel, but start at a lower level, so the ratio of first to second strike costs increases. Unprime's average crisis stability index is smoothed by the deployment reductions, eliminating transient degradations.

For unilateral reductions of offensive forces in conjunction with the deployment of strategic defenses stability increases are intermediate between those for mutual and unilateral deployments. The increase in stability is largely due to the reduction in the defender's offensive forces, which reduces the other side's incentive to strike first in a crisis. The case discussed here of a factor of 4 reduction illustrates one stage in what should be a continuous progression. They show that it is appropriate to eliminate about 9,000 x 3/4 = 6,750 offensive weapons to compensate for the deployment of about 4,000 SBIs plus the complementary 1,000 GBIs, or that the offset is about 1.5-2 offensive weapons per SBI at START levels. That constitutes as firm and a more rational counting rule than those available for controlling offensive weapons.

IX. BOMBER ALERT AND PENETRATION RATES VS CRISIS STABILITY

Previous sections derived and discussed crisis stability indices for two-sided, unilateral, and one-sided deployments of strategic defenses. All ultimately depend critically on the weapons delivered by aircraft at high levels of defenses. This section discusses the sensitivity of those results to aircraft alert rates and penetrativity.

A. Alert Rates

For each strike it is assumed that the attacker strikes from an alert rate of 50%; the defender's alert rate is varied. Ideally, the attacker could alert all aircraft to achieve an effective alert rate near unity in order to maximize his aircraft survivability. Doing so could, however, alert the other side, allowing him to disperse his aircraft or increase their alert rate, which could deprive the attacker of the benefit of striking first. Thus, some lesser alert rate, possibly not much greater than the normal alert level, would be used instead for deception.

Figure 25 shows the components of unprime's second strike as functions of the bomber alert rate. The bottom three lines are for the number of ICBM and SLBM RVs that survive prime's first strike and penetrate his boost defenses; the bottom curve is the number of RVs that penetrate the midcourse defenses, which is small. The top curve is the second strike; the curve below it is the number of surviving, penetrating bomber weapons, which is its main component for these transitional conditions. The total second strike varies from about 1,800 weapons to 2,400 weapons as unprime prelaunch survivability improves. Survivability is significant even at a 10% alert rate because of the 2,000 SBIs, and 1,000 GBIs assumed.

Figure 26 shows that for these conditions prime's second strike is about 50% lower but comparable to unprime's throughout. Both sides' first strikes are independent of their alert rates. For these conditions the contributions from aircraft and RVs are comparable at an alert rate of about 30%. Figure 27 shows that both side's first strike costs rise about 10% and second strike costs fall about 10% over the range of alert rates shown. Figure 28 shows the corresponding ≈ 25% increases in the individual stability indices and 70% increase in the composite index. Increasing either's side's alert rate reduces the incentive for either side to preempt; increasing both improves overall indices even more.

Increasing alert rates improves stability indices, but it costs money. There are certain trends such as the faster warm-up and fly-out times of advanced bombers and cruise missile carriers that could improve their effective alert rates somewhat even without defenses, but there are other trends that could reduce them. SLBM RVs have shorter, faster trajectories than ICBMs, which reduce effective alert rates. Deployed closer to shore, they would reduce warning times to tens of minutes. On depressed trajectories, which could be used since great accuracy is not required, they could reduce warning times to minutes. Even alert aircraft might not be able to escape then. On such trajectories they would essentially underfly all of the boost-phase defenses as well. If so, that could essentially eliminate all unprotected bases. Without defenses, dispersal over many bases would be only a marginal improvement.

B. Penetration Rates

Penetration rates cause stability indices to vary more strongly. Figure 29 shows the variation of both sides' second strikes with penetration rates under the assumption that prime strikes from an alert rate of 50% and has a penetration rate of 50%, and unprime has an alert rate of 30% and the penetration rates shown on the abscissa. First strikes do not vary, but for fixed defenses, second strikes vary linearly with penetration.

They increase from 400-600 weapons, mostly RVs, at low penetrations to 2,400-3,300 aircraft weapons at high penetration.

Figure 30 shows the costs. First strike costs rise together; second strike costs fall together, unprime's being slightly higher in each case. Figure 31 shows that both side's stability indices are within a few percent except at very high penetration rates. The overall increase of each is about a factor of three. The composite rises more sharply, essentially as the square of the individual indices. Its total increase is about a factor of 10 over the range shown. It starts at a very low value for low penetration. The curves cross at about unity at a penetration rate of ≈ 1/3. The composite index exceeds 2 by a penetration rate of ≈ 2/3, but it is only about 0.5 at a penetration of 20%, a strong sensitivity.

Penetration is sensitive to the defenses assumed. For 4,000 SBIs and 2,000 GBIs, the intersection of the curves shifts to a penetration of about 25%, and the composite index reaches 2.5 by a penetration of 0.5. Conversely, for 1,000 SBIs and 500 GBIs, their intersection shifts out to 50%; the individual indices reach ≈ 1.2; and the composite only reaches ≈ 1.4 by 90% penetration. For small defenses, the curves become relatively flat; the aircraft contribution is only dominant above penetrations of ≈ 0.5.

C. Interactive Penetration

The previous section's parametric studies give a simple picture of the impact of bomber penetration rates; a full appreciation of the impact of the rates on crisis stability indices requires an analysis of the interaction between defenses and penetration rates.

Aircraft depend in part on defense suppression by ICBM and SLBM RVs for penetration. As defenses draw down those RVs, the fraction that can be spared for suppression decrease. If so, their penetration could fall. ICBM and SLBM RVs can both be used to suppress bomber defenses. For an exponential dependence of penetration on RVs committed,[16] for no defenses the penetration is about 63%, the nominal value used above. Figure 32 shows that with defenses penetration falls monotonically to about 0.23 by 2,000 SBIs and 0.17 by 4,000, which with Fig. 7 indicates indices below unity. Suppression is sharp out to about 2,000 SBIs; then penetration plateaus at ≈ 0.2 for unprime and 0.15 for prime.

Figure 33 shows what that means in terms of bomber restrike weapons: they are almost constant. Restrikes are the product of aircraft survival and penetration probabilities. As defenses increase, so do surviving aircraft. Not missiles. SLBMs fall monotonically; penetration falls faster, and the number of restrike aircraft falls. At 1,000-1,5000 SBIs, restrike hits a minimum. Then, as the number of survivors saturates and the penetration rates hit their plateaus, the restrikes hit maxima. Then as penetration falls further, the restrike falls again.

It is an interesting interaction, but it shouldn't obscure the main point: RV depletion could clamp aircraft restrikes at a few hundred weapons rather than the few thousand predicted by calculations with high, fixed penetration rates. Figure 34 shows unprime and prime's total second strikes. For no defenses they are at about 3,000 and 4,000 weapons, mostly SLBM RVs since the ICBMs are strongly suppressed. By about 2,000 SBIs they fall to about 1,000 and 500, respectively, as boost-phase defenses strongly suppress the SLBMs as well. Above that the dominant contribution to both strikes and restrikes is from aircraft, which are by Fig. 33 relatively constant and small, as are the totals in Fig. 34.

Figure 35 shows the strike costs. All start in the range 0.9-1.0 and then fall almost monotonically. Both sides' first strike costs fall by about a factor of two because of the much more effective damage limiting possible with interactive penetration. Second strike costs fall by 10%-20%. The result is shown in Fig. 36, in which the individual indices fall about 30%, and the composite index about a factor of two, which tends to support the common assumption that air defenses degrade stability.

The composite stability index can be interpreted as the complement of the probability of exchange for a given offense-defense configuration.[17] The consequence of such exchanges is roughly the delivery of the second strikes of Fig. 10. The product of the two gives the expected loss for any defenses. From Fig. 36 the probability of exchange increases from 0 to about 0.5 by ≈ 1,000 SBIs. Thus, the expected losses plateau at about 15% of the possible losses without defenses. They then fall further as restrikes fall with more defenses.

Part of the apparent degradation of stability is due to the reduced sizes of the strikes. In Fig. 34 the first strike costs fall because of improving damage limitation. As noted earlier,[18] as the sizes of strikes decrease for a given target set, the stability indices decrease due just to scaling. If the target sets were reduced in proportion to the sizes of the strikes, the apparent degradation of stability would be eliminated. These estimates assume that the fraction of the surviving RVs allocated to defense suppression is kept constant as defenses increase and RV inventories fall. It can be argued that for strong attrition, fewer RVs could be diverted to bomber defense suppression; it can also be argued that all should be diverted. Given the modest contribution from RVs to the strike for large defenses, it would appear that assisting bomber penetration could be the most effective allocation of the RVs. Even with all allocated to that task, however, there would still be a drop in penetration.

A short summary of the studies of prescribed and interactive penetration is that prescribed penetration gives adequate retaliation and stability that increases with defenses, and interactive penetration gives marginal retaliation and stability that degrades rapidly with defenses. The distinction is largely in the preferential and progressive attrition by defenses of the RVs needed for interactive penetration. The distinction is physical, fundamental, and critical. Defenses would have an untoward effect if applied with aircraft that relied on defense suppression for penetration.

The distinction also lies along aircraft penetration technologies. Bombers such as B-52s have competent but modest onboard defense suppression. Thus, they are critically dependent on defense suppression by RVs; they are the prototypical interactive penetration carriers. Bombers such as B-1s have advanced and extended onboard defense suppression, which should in the long term make them capable of detecting and degrading defenses enough to avoid them. They are intermediate. B-2s, which may be detectable, but should remain nontargetable to known fire control radars, are essentially independent of RV-aided defense suppression. They should have essentially prescribed, and potentially quite high penetrativity.

Cruise missiles don't follow quite the same categorization. Current cruise missiles are inert but small. They should be able to penetrate suppressed defenses but not unsuppressed defenses. Thus, they are essentially interactive penetrators and hence would lose out to large defenses. Stealthy cruise missiles could penetrate about as well overall as B-2s. They should have prescribed and potentially high penetrativity. Thus, the fundamental distinction would appear to be along the lines of stealth. Aircraft that didn't have it would appear to be degraded by defenses; those that did would appear to be enhanced by them. The distinction is, however, somewhat artificial now. It can only be made precise when the final trades between active suppression, passive stealth, and active stealth are in. Enough is known today, however, to indicate that the approximate divisions above are useful.

These penetration arguments distinguish between nonstealth aircraft and cruise missiles and stealthy ones, but not between stealthy aircraft and cruise missiles. For efficiency and arms control counting rules it is conventional to package many cruise missiles per carrier and release them not that far offshore. In the present RV-rich environment that has modest operational penalties, but with strong defenses, when the stealthy aircraft are expected to penetrate on their own wits, the larger and more visible cruise missile carriers could be inviting targets to capable and unsuppressed forward-based air defenses with already developed look-down, shoot-down technologies. That could push release points back to ranges where the cruise missiles' advantages were less pronounced. The distinction between stealthy bombers and cruise missiles would thus appear to hinge less on penetration during ingress than on survivability once inside and on flexibility in addressing important parts of the target set once there.

D. Sensitivity to Target Sets

The large discrepancy between the stability characteristics of prescribed and interactive penetration is bothersome, but much can apparently be accommodated by proper choices of aircraft, suppression, and signature reduction. Part of the apparent degradation of stability is, however, due not to the technical characteristics of the carriers but to the sizes of the strikes. It must ultimately be met whether new defenses against stealth are developed or simply if overall strategic forces are reduced. If strikes were reduced relative to target sets, stability would apparently be reduced; if target sets were reduced in proportion to the strikes, the apparent degradation of stability would be eliminated. As noted in Part I, decreasing aggregate first and second strikes apparently degrades stability even if the number of weapons delivered goes to zero.

From the form of the exchange model it follows that if unprime strikes first, soundly, and from good defenses, R_1 is large and R_2' small. Then, from the form of the equations for the two sides' first and second strike costs, it follows that the first strike costs $C_1 \rightarrow k \cdot R_2'$ and the second strike costs $C_2 \rightarrow 1 + L$, whos ratio, the individual stability index, is $C_1/C_2 \approx k \cdot R_2'/(1+L)$. For the small R_2s encountered when defenses are large, missile contributions are negligible, and aircraft restrikes are marginal, stability indices decrease simply because the R_2s are small relative to the $\approx 1/k$ target sets held at risk.

Note that this result doesn't depend on the details of the targeting strategy or cost metric used. Deleting the value-suppression function, i.e., $L \to 0$, would only be a few percent change. Eliminating damage limiting and going only against value would reduce unprime's index to $C_1/C_2 \to e^{-k'(R1-R2)}$, which for $R_1 >> R_2$ is small, and for $R_1 \to R_2 \to 0$ gives $C_1/C_2 \to 1$, assured destruction. All show sensitivity to small R. The problem is that for small R the ratio of the costs for striking first to those for striking second, kR_2 appear small, which would seem to provide an incentive for striking first in a crisis. This apparent pressure is not confined to this model; it appears in modified form for other cost metrics. It rests on little more than an intuitive notion of relative risks and the monotonic increase of damage functions.

There seem to be two solutions: increase R or increase k. The former means increasing offensive forces. That would amount to letting crisis stability overrule the apparent arms control stability of the cost-effective forces used. The latter would mean reducing the number of targets held at risk, $\approx 1/k$. That is a more reasonable option, since it would mean progressively taking projection forces out of the strategic target set as strategic resources fell.

That reduction could mean reassigning projection forces to nonstrategic assets or it could mean negotiating them away. The two approaches are logically equivalent from the perspective of strategic stability, but have quite different implications. Strategic defenses have been suspected of making Europe safe for a conventional World War III. Decoupling strategic targeting from projection forces would implement that. At some point such a decoupling is automatic. If strategic defenses eliminate strategic offenses there simply is nothing to which to couple. This implementation would, however, be a bit harsher and earlier than expected. It would have to start with the initial defenses.

The other approach has more promise in the long term but more problems in the near, because it would couple conventional arms reductions talks to strategic arms reduction talks and make both an essential part of the strategic defense deployment policies of both countries. Bureaucratically it could be a nightmare, but there are two offsetting advantages. It would recognize the goal of reducing offensive forces as a significant motivation for deploying strategic defenses, as reflected in their targeting already, and recognize the goal of minimizing expenditures on strategic defenses as a motivation for reducing projection forces, which might otherwise be maintained as a bit of an attractive nuisance to strategic offenses.

E. Observations

This section has discussed the sensitivity of the stability indices calculated in earlier notes to the alert and penetration rates of air-breathing launchers. Total second strikes vary about a factor of two as defenses improve prelaunch survivability. Contributions from aircraft and RVs are comparable at alert rates of ≈ 30%. Both side's first strike costs rise and their second strike costs fall as penetration improves. That leads to ≈ 70% increases in stability indices. Increasing either side's alert rate reduces the incentive for either side to preempt; increasing both rates improves overall indices significantly.

Penetration rates impact stability indices more strongly. Second strikes increase roughly proportionally with penetration. First strike costs rise; second strike costs fall. Composite indices rise sharply. They are sensitive to defenses. As defenses draw down RVs, the number that can be spared for suppression decreases. Suppression of penetration can thus be strong; it plateaus at 15%-20% for moderate defenses, producing an almost constant number of bomber restrike weapons. The interaction clamps the number of penetrators in a fairly narrow band, in sharp contrast with the strong growth of second strikes for fixed penetration. Composite stability indices fall by about a factor of two, which tends to support the common assumption that air defenses degrade stability. Expected losses plateau.

F. Conclusions

Crisis stability indices are sensitive to bomber, cruise missile, and carrier alert and penetration rates. Second strikes vary by factors of two as defenses improve prelaunch survivability; so do stability indices. The sensitivity to penetration rates is higher; composite indices vary by an order of magnitude. When the reduction of penetration due to strong suppression of ICBMs and SLBMs by defenses is taken into account, penetration could fall to levels factors of two to three lower than commonly assumed. That could adversely impact stability by about a factor of two, although reductions in the target set could partially offset it. Overall, the sensitivities of stability indices to air-breathing vehicle alert and penetration rates is larger than that to other variables and interacts to the detriment of defenses.

X. CONCLUSIONS

The stability index calculations discussed above lead to a simple picture of the transition from offensive to defensive forces. The current offensive picture is simple: Fixed ICBMs largely act as a RV sink; SLBMs carry the brunt of the retaliatory forces; bombers and cruise missiles add insult to injury. START would shift that picture slightly towards air-breathing vehicles. Moderate defenses would strongly suppress SLBMs. They would protect some ICBMs, but not enough to penetrate significantly. The brunt of retaliation would shift to aircraft, if numerous, protected, and penetrating. Boost-phase-only defenses would be destabilizing because they would suppress SLBMs but not protect aircraft. Combined boost- and midcourse defenses could protect more and stability would increase.

Two-sided reductions of heavy ICBMs have little impact on stability if unaccompanied by defenses. With defenses they are unnecessary; it appears preferable to defend current missiles in place. Launch on warning has a small positive impact on human decision making--at the risk of introducing accidental machine decision making of unbounded downside risk.

Contrary to popular opinion, unilateral deployments of defense are not destabilizing. They essentially leave crisis indices unchanged, while significantly reducing the number of weapons delivered. One-sided reductions of offensive forces to offset deployments of defenses produce stability indices intermediate between those for unilateral and mutual deployments.

Stability indices are sensitive to the treatment of aircraft alert and penetration rates. Interactive reduction of defense suppression could reduce penetration to levels at which stability indices were marginal. Stability at such levels in part reflects sensitivity to the target sets used. In part that is cost-model dependent; in part it reflects a real coupling between RV availability and the size of the projection force target set to be held at risk. That could require the alteration of targeting objectives or the negotiated reduction of the actual target set.

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APPENDIX: STRIKE, COST, AND STABILITY INDICES

The cost function used to interpret the calculations is[19]

$$C_1 = D(R_2') + L\cdot[1 - D'(R_1)], \tag{1}$$

where D is unprime's damage function and D' is prime's. The value that is damaged is taken here to be embodied largely in projection forces. Equation (1) states that the cost to unprime of striking first is the damage done to him by prime's incompletely suppressed second strike, R_2', plus the portion of the desired damage unprime is not able to inflict on prime by his first strike, R_1. The parameter L reflects the relative importance given to these two functions. For exponential approximations to the cost functions that gives

$$C_1 = 1 - \exp(-k\cdot R_2') + L\cdot\exp(-k'R_1). \tag{2}$$

as unprime's cost for striking first. Conversely, if unprime waits, and prime strikes first, the cost to unprime for striking in retaliation is

$$C_2 = 1 - \exp(-k\cdot R_1') + L\cdot\exp(-k'R_2). \tag{3}$$

A useful crisis stability index for unprime is C_1/C_2. The equations for C_1' and C_2' follow by conjugation, i.e., by replacing primed and unprimed symbols. The overall index is

$$Q \equiv (C_1/C_2)(C_1'/C_2'). \tag{4}$$

Since the two sides' strikes and costs are similar for START, it is sufficient to examine only the first term. For crisis stability C_1 must be large relative to C_2. By Eq. (1) the former requires R_1 small and R_2' large. The latter requires R_1' small and R_2 large. Since for typical conditions $R_1 \approx R_1'$ and $R_2 \approx R_2'$, the practical condition is that R_1 be small and R_2 large. For comparable strikes and the current $k' \approx k$, Eq. (1) can be divided by Eq. (2) and the result solved with the general solution for quadratic equations for R_2 as a function of R_1 as shown in Fig. 2.

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Fig.1 Costs and stability indices

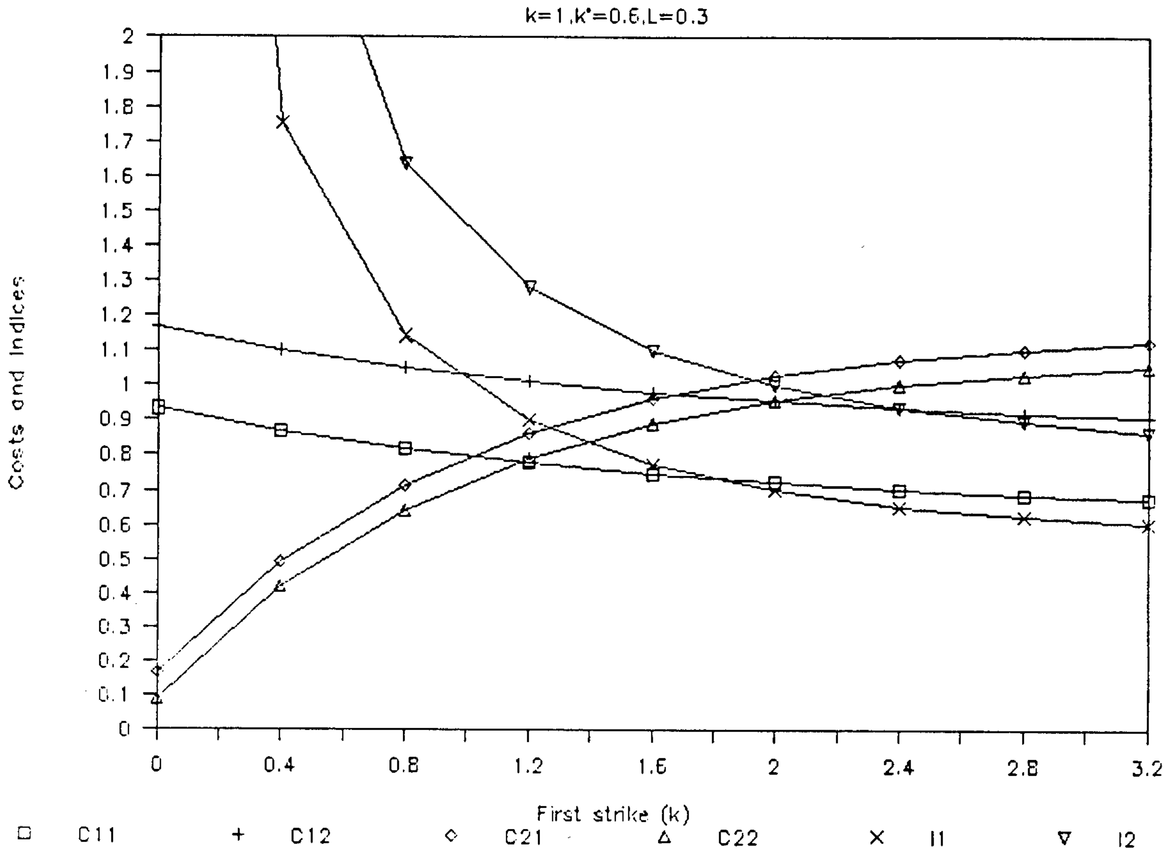


Fig. 2 Iso-stability contours

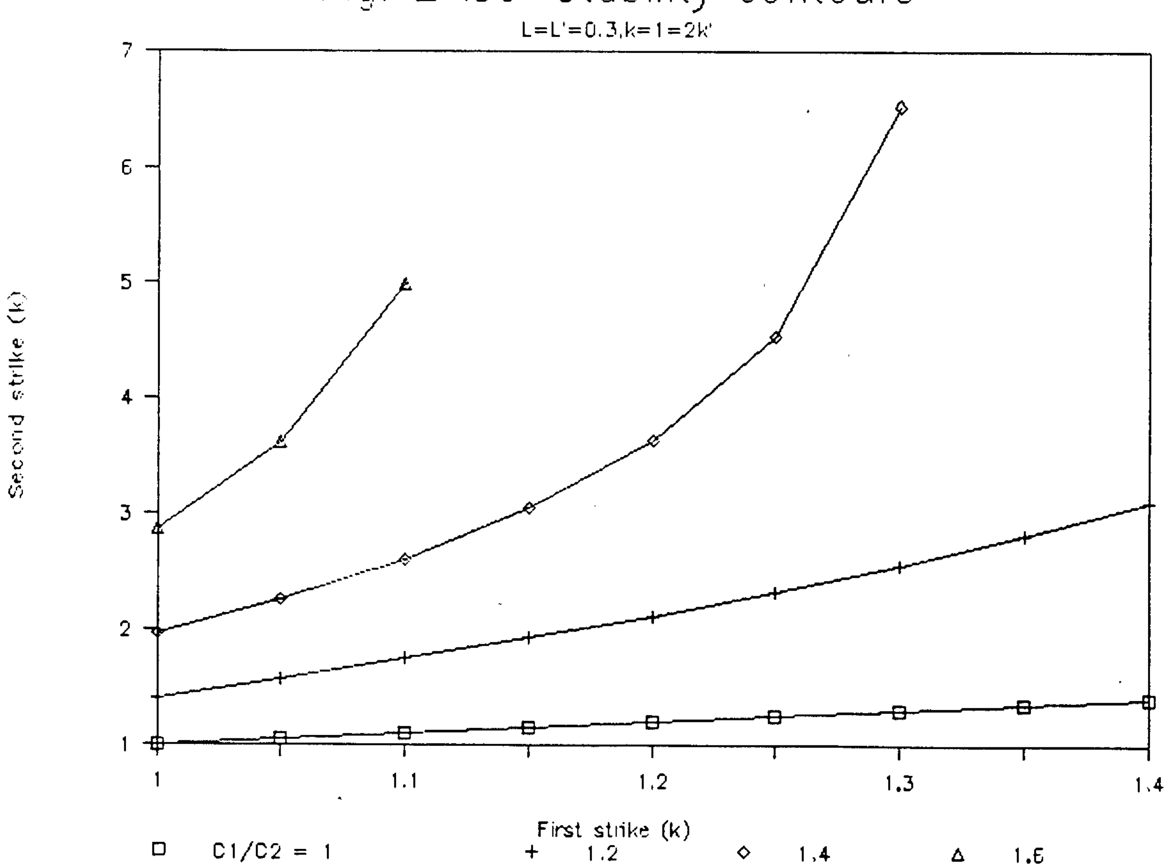


Fig. 3 Penetrating ICBM RVs

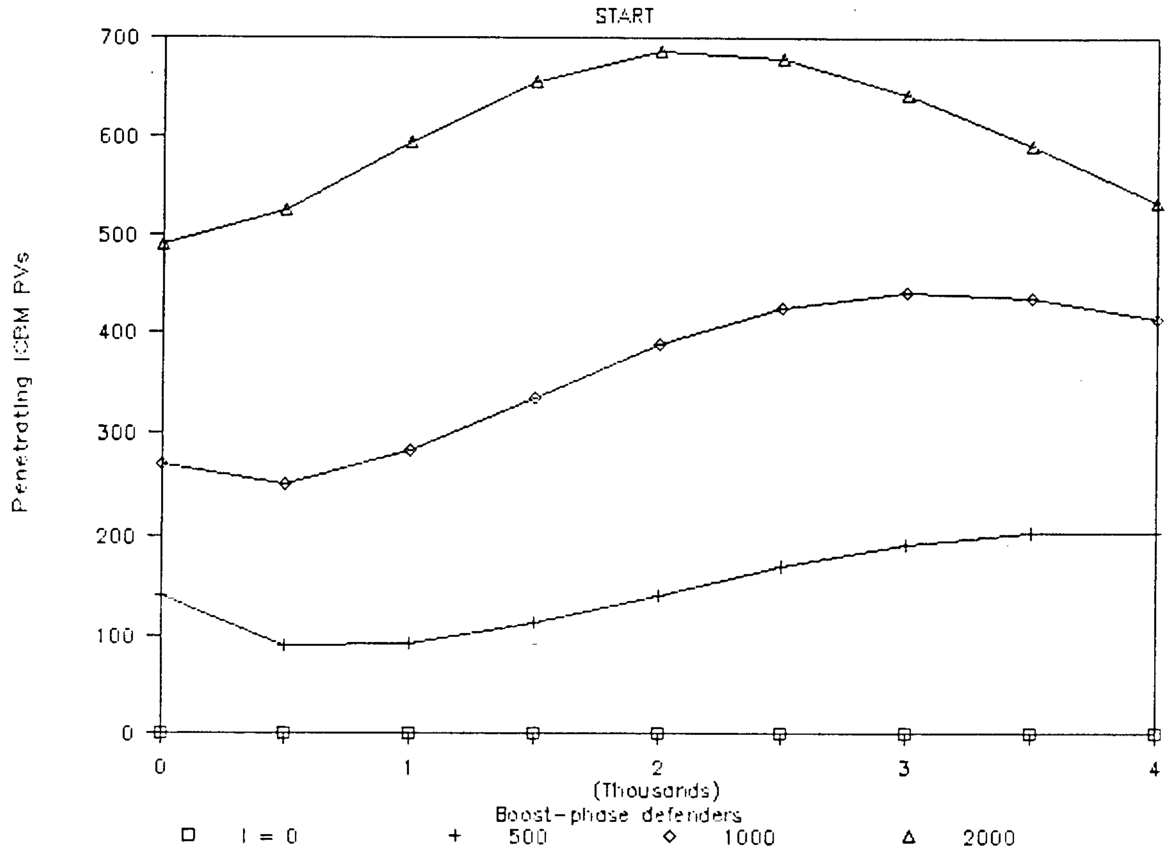


Fig. 4 Penetrating SLBM RVs

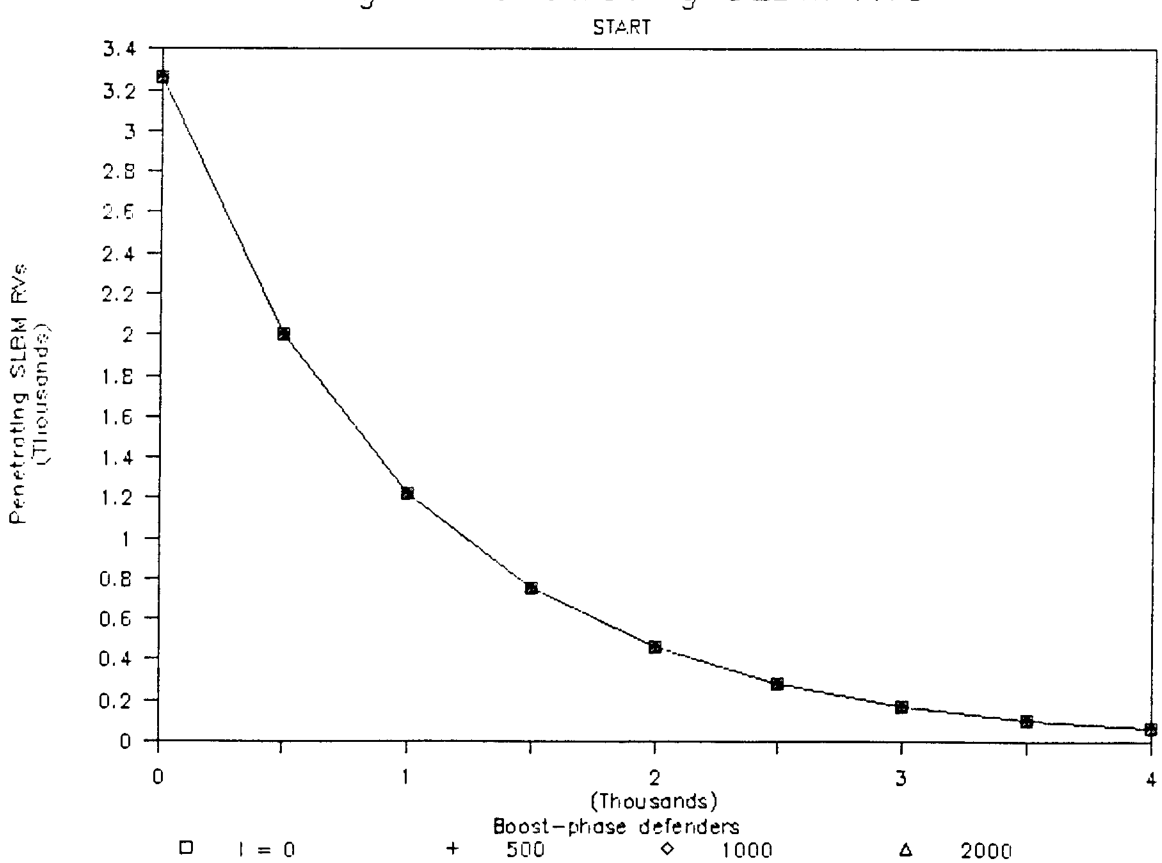


Fig. 5. Penetrating missile RVs

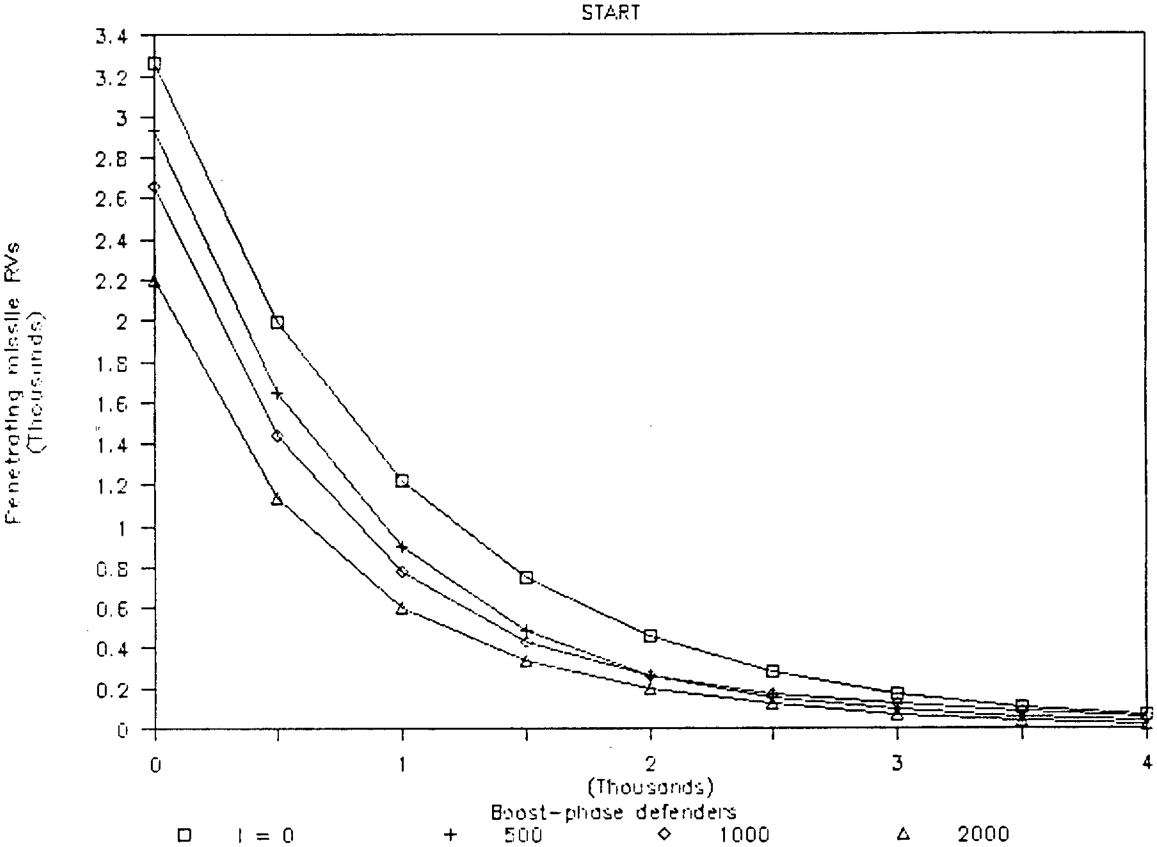


Fig. 6. Penetrating prime missile RVs

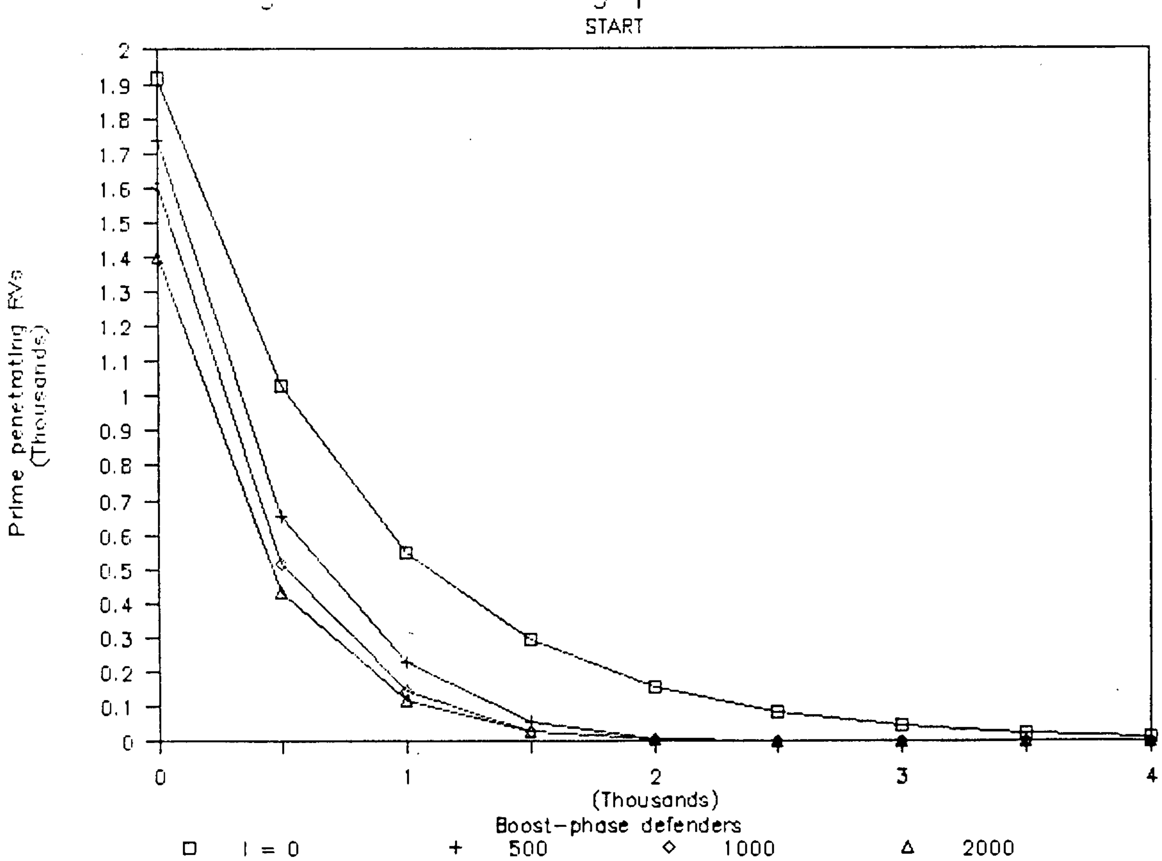


Fig. 7 First strike

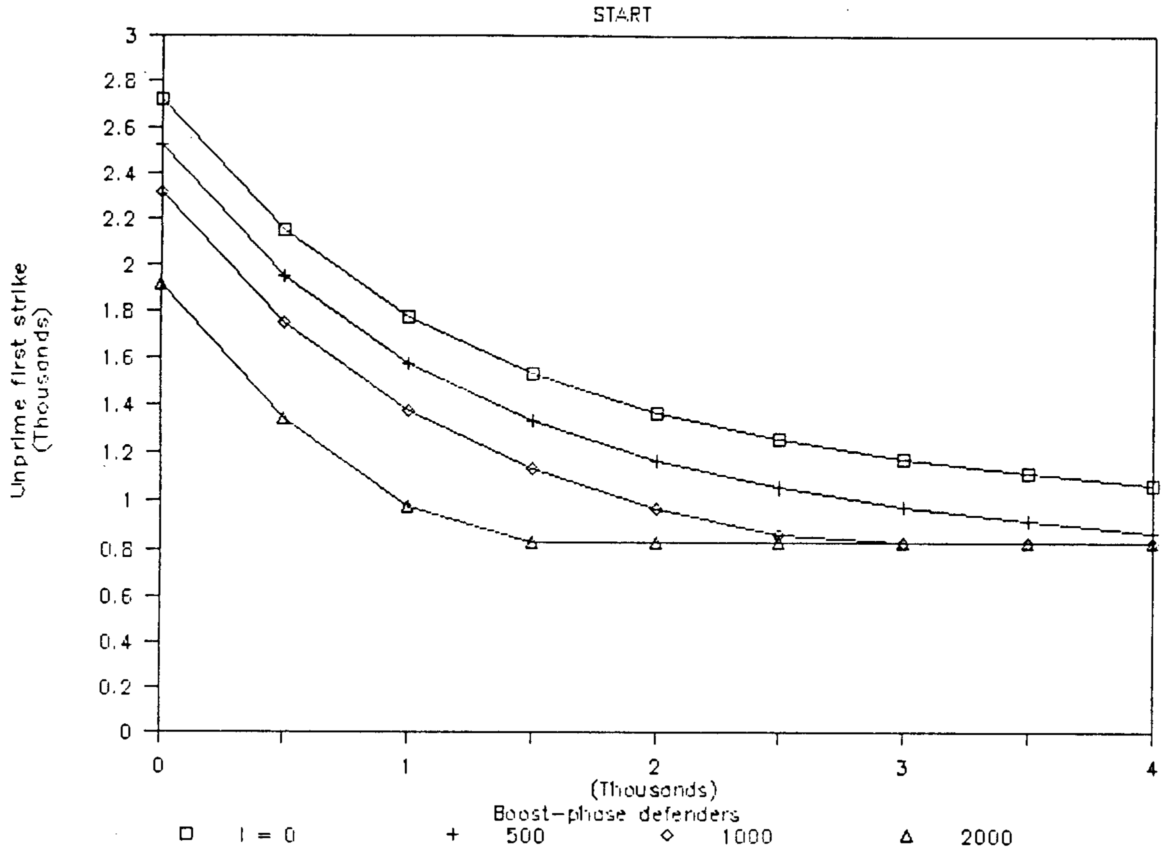


Fig. 8 Second strike

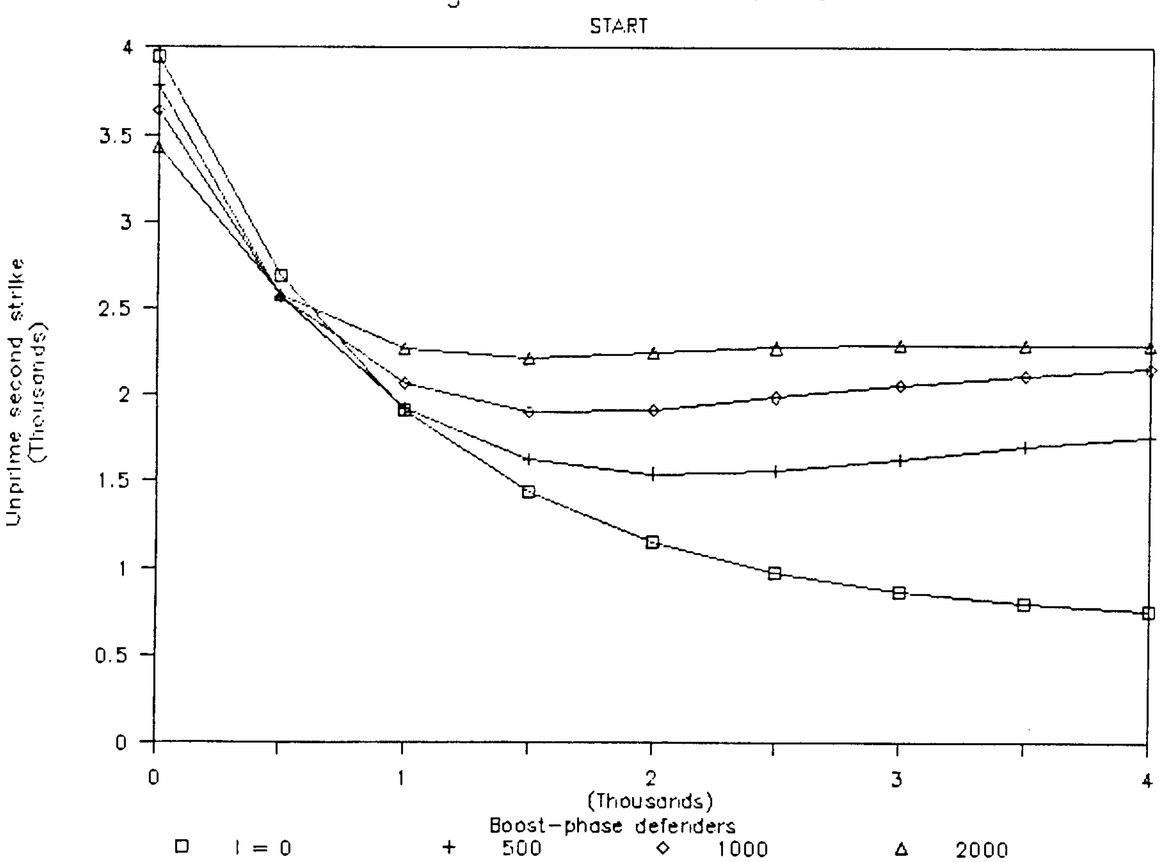


Fig. 9 Bomber weapons delivered

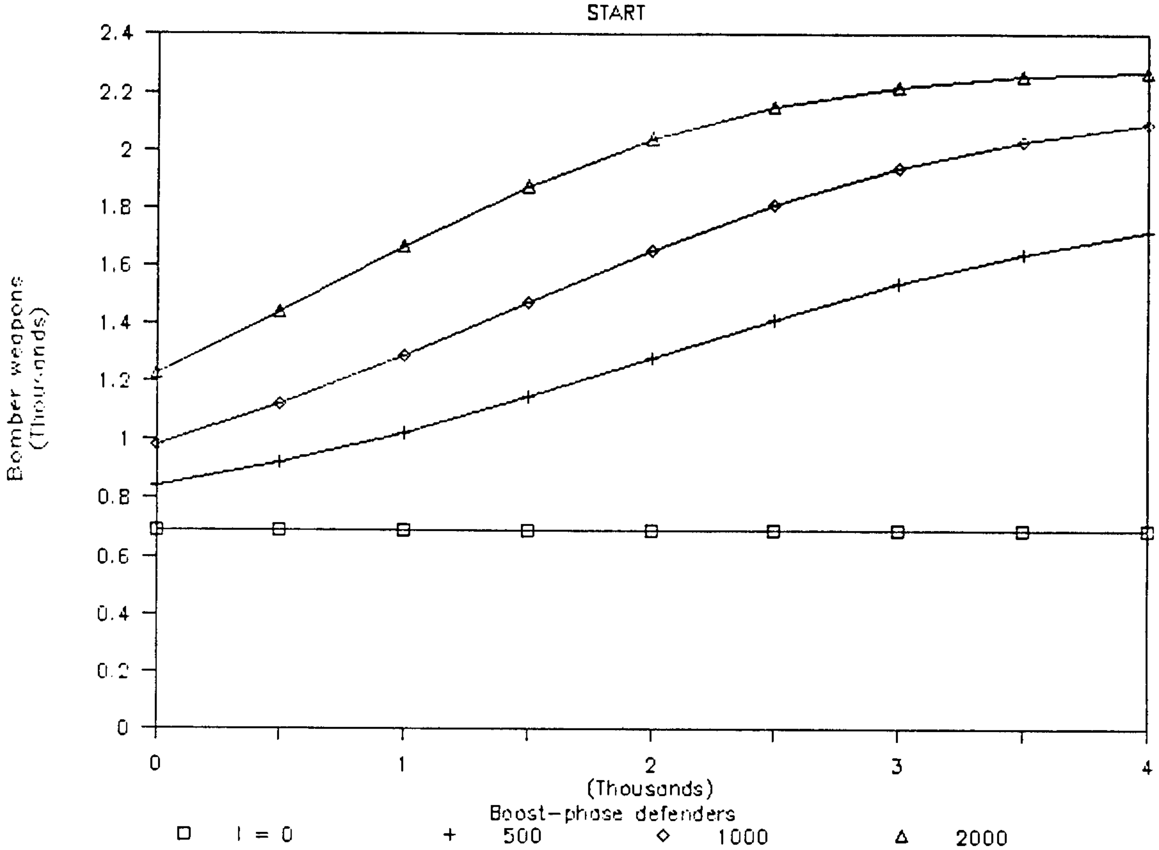


Fig. 10 Stability vs midcourse defenses

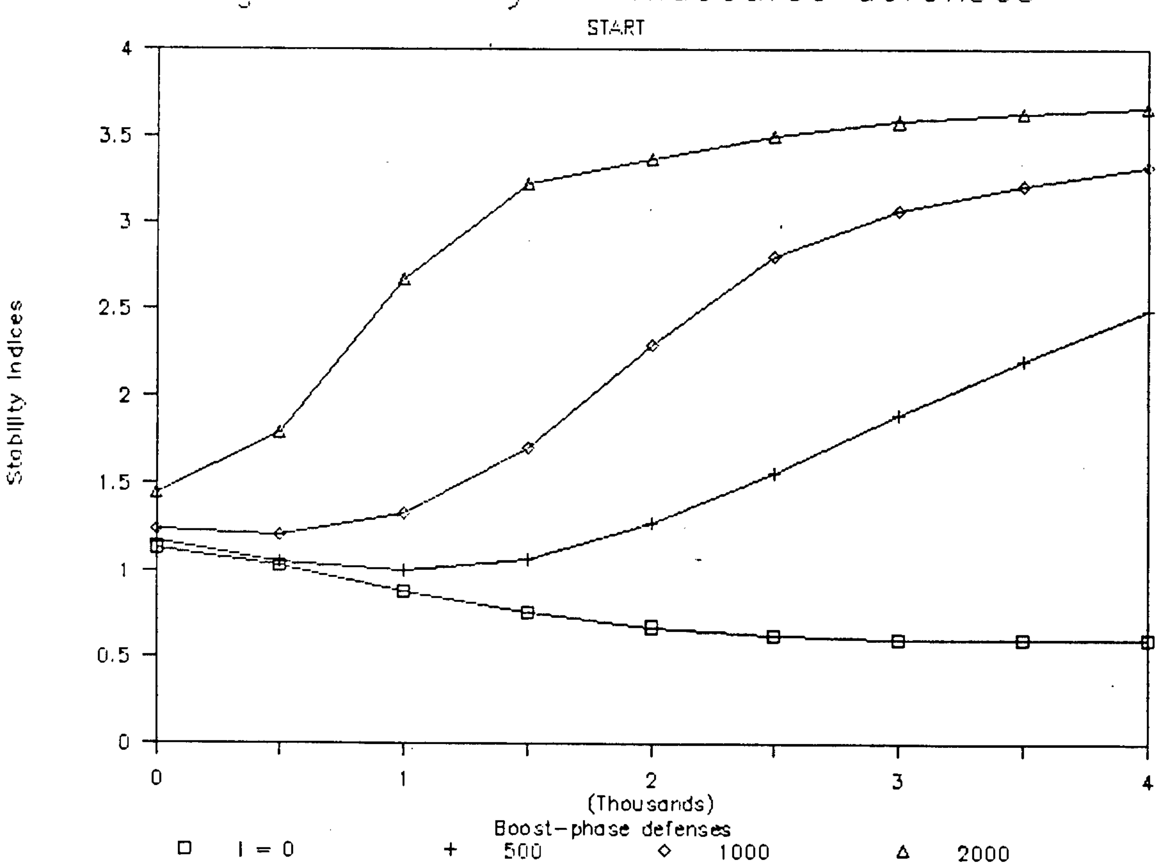


Fig. 11 First strike

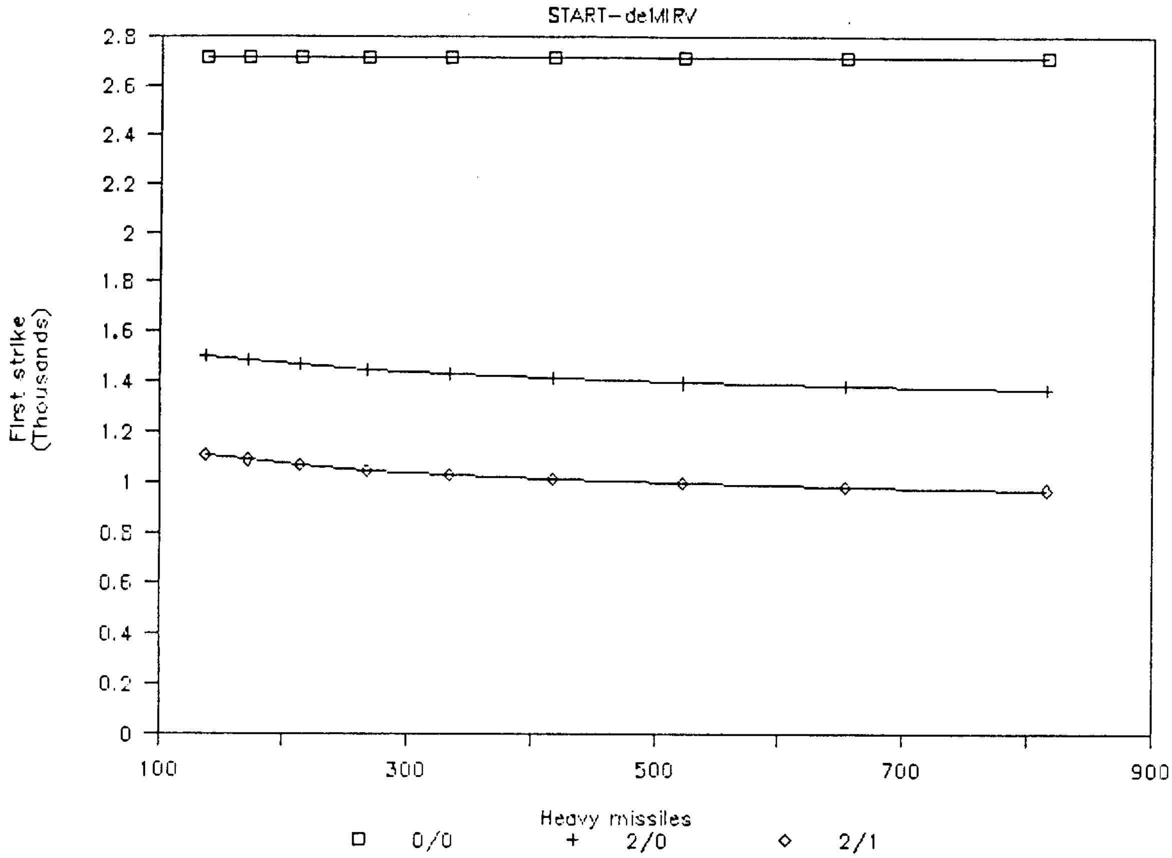


Fig. 12 Second strike

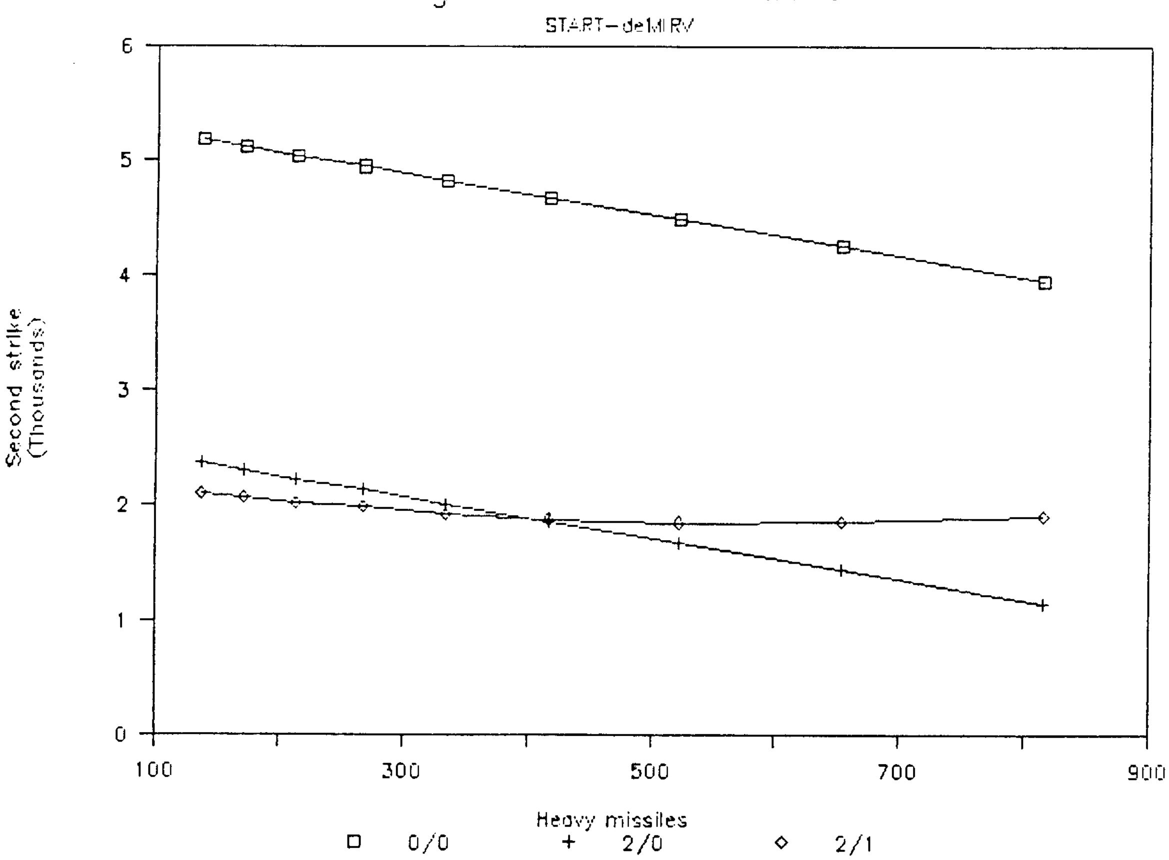


Fig. 13 Bomber second strike

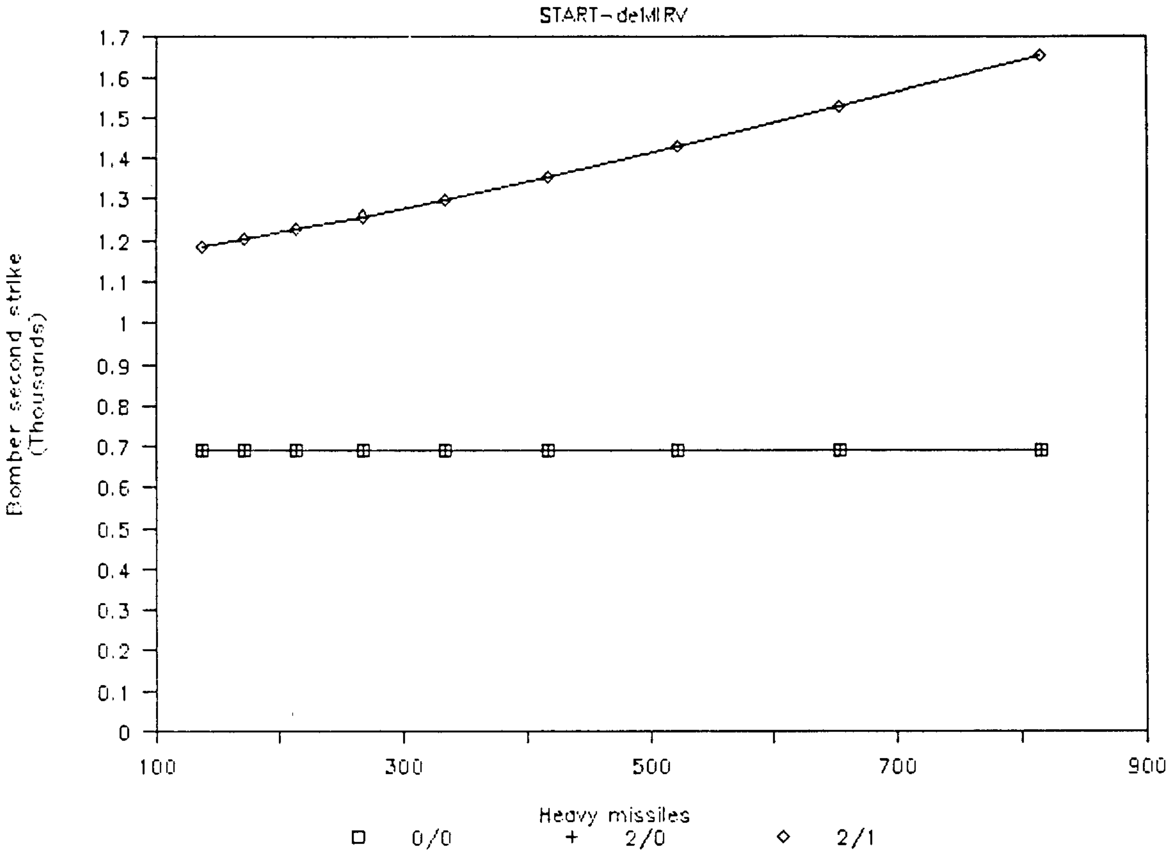


Fig. 14 Stability indices for de-MIRV

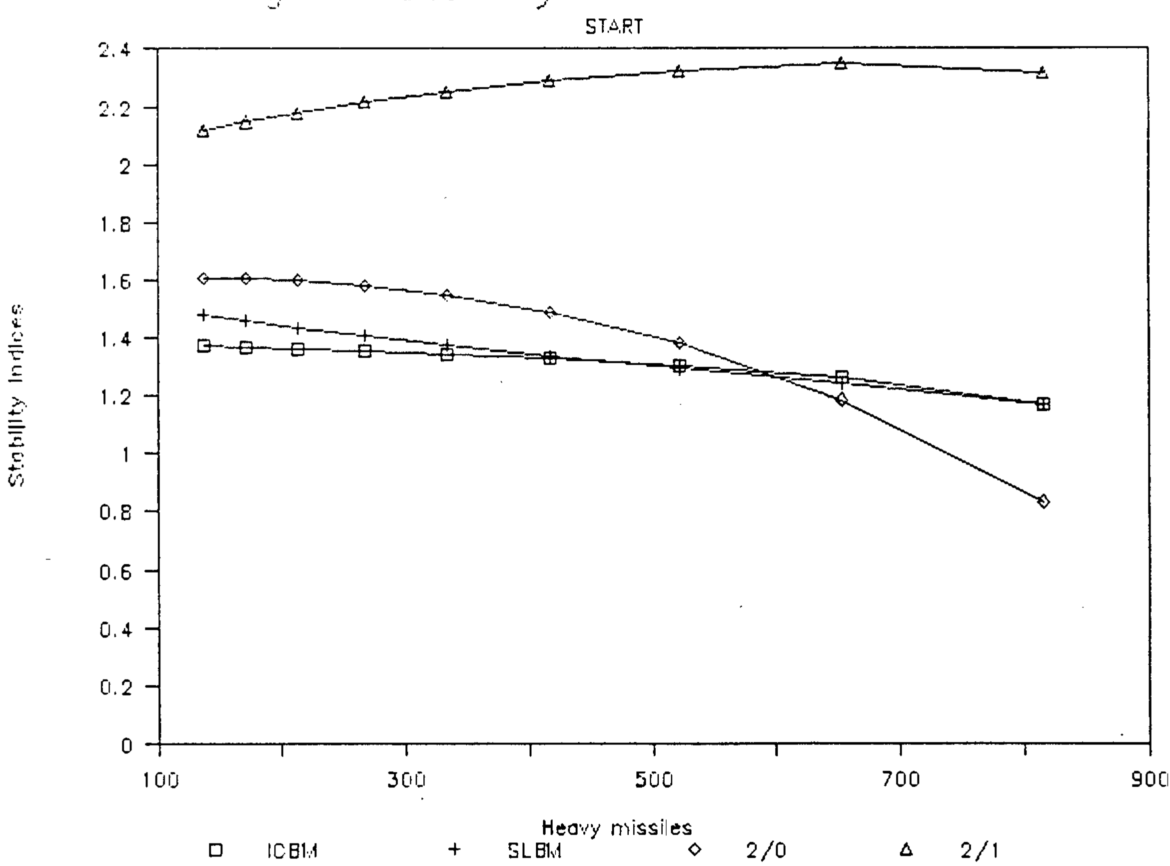


Fig. 15 Strikes for Launch on Warning

START;I=K/4

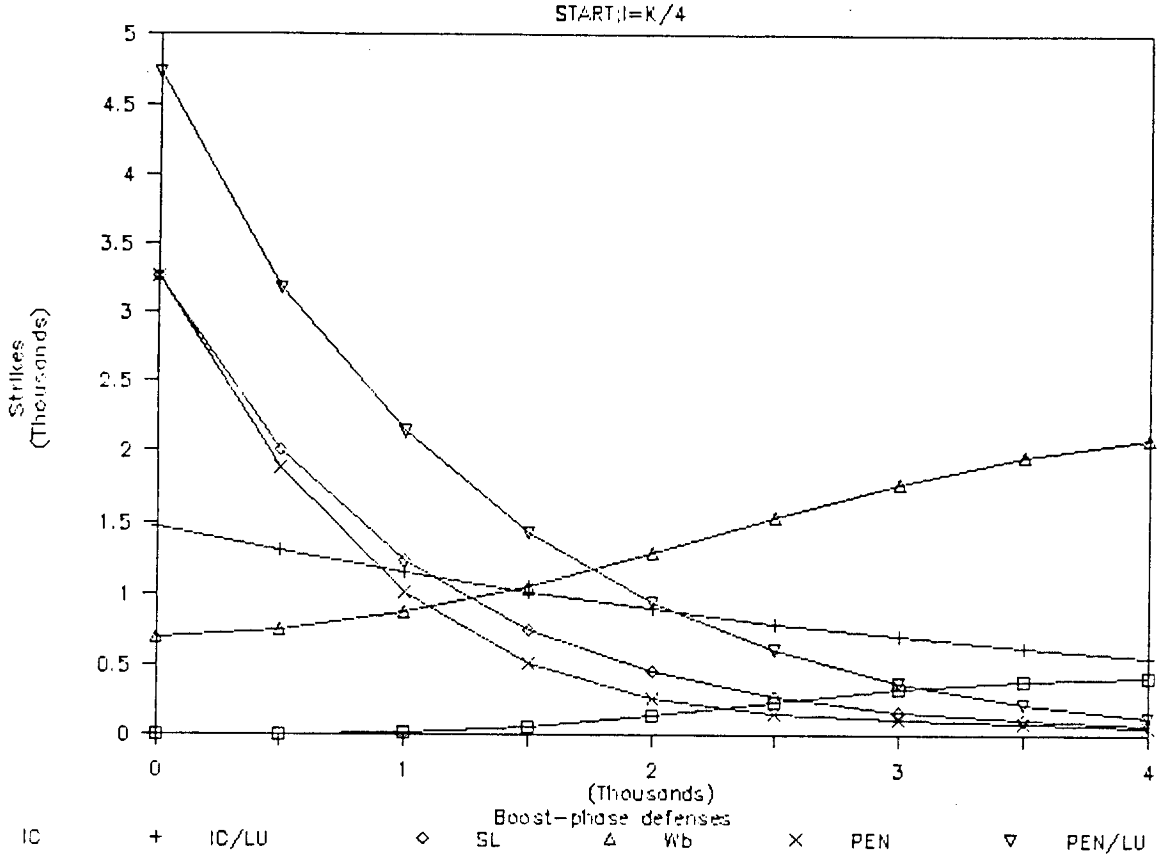


Fig. 16 Stability for Launch on Warning

START;I=K/4

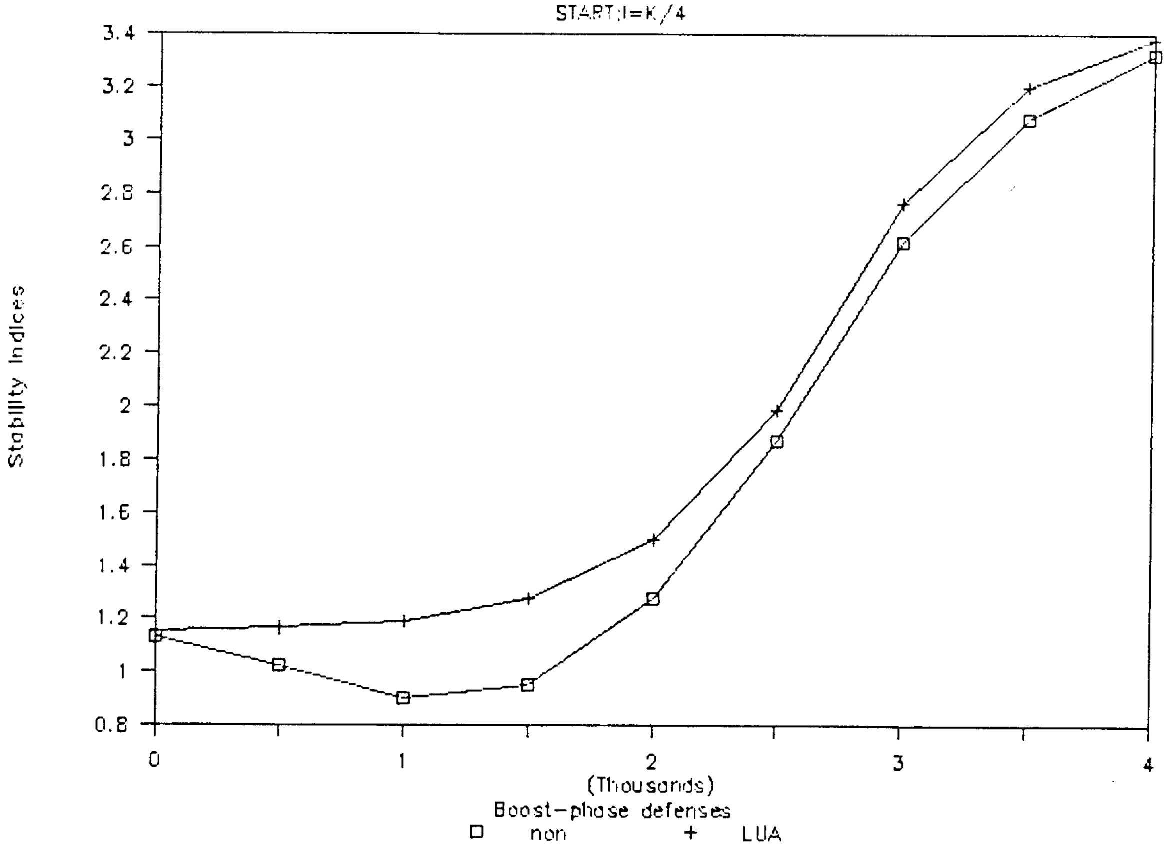


Fig. 17 Prime 1st strikes—unilateral

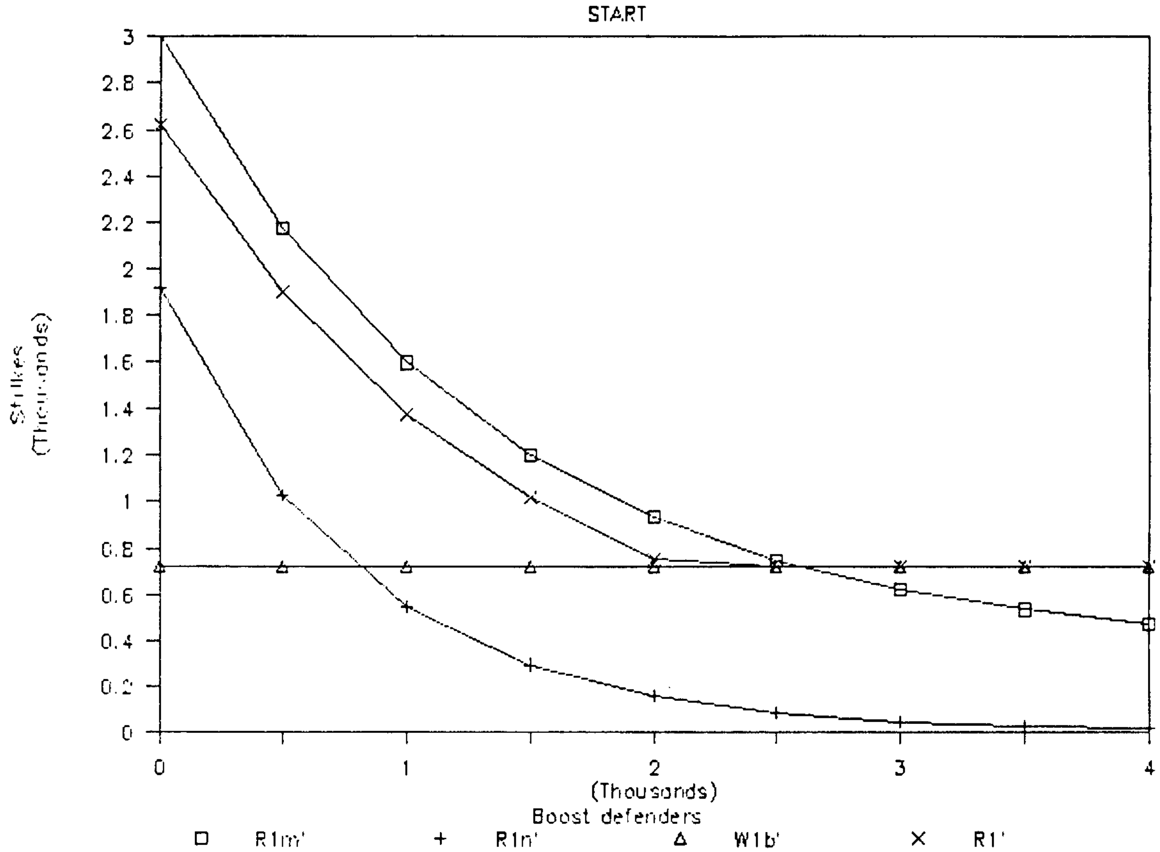


Fig. 18 Prime 2nd strike—unilateral

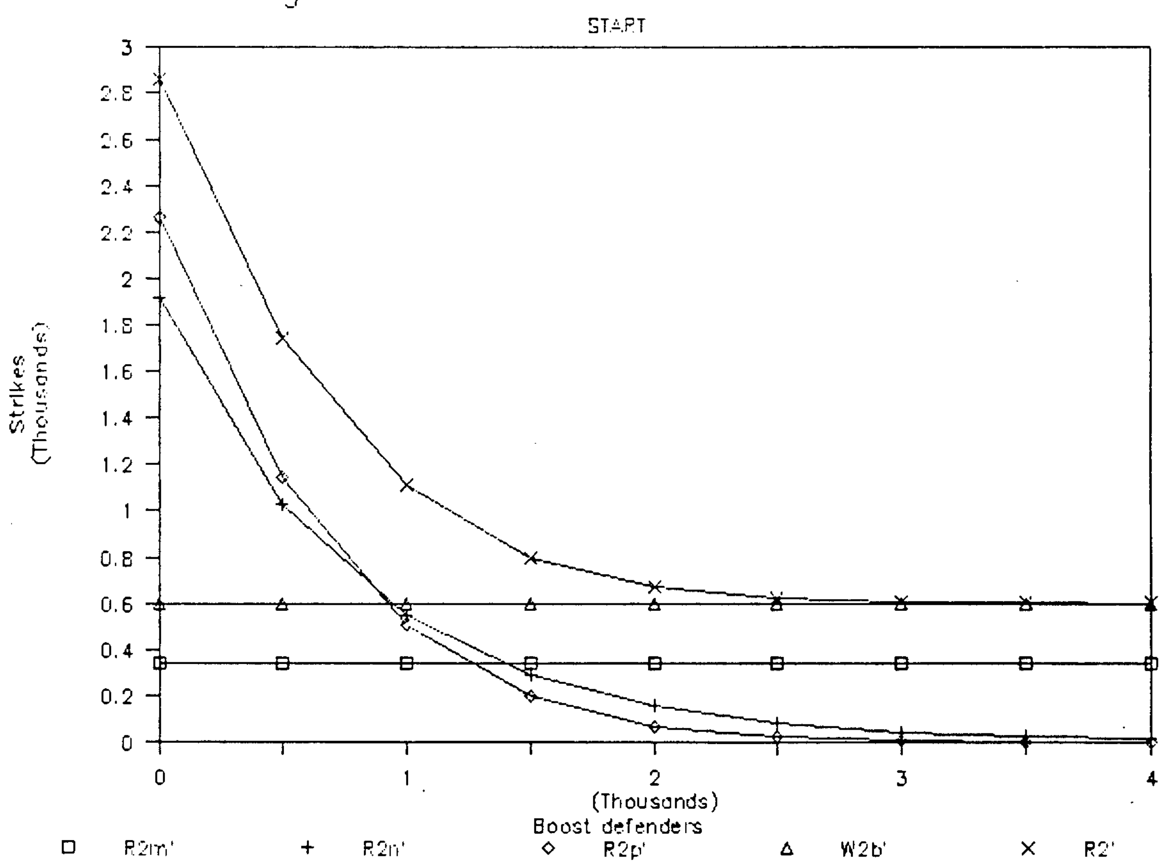


Fig. 19 Costs—unilateral

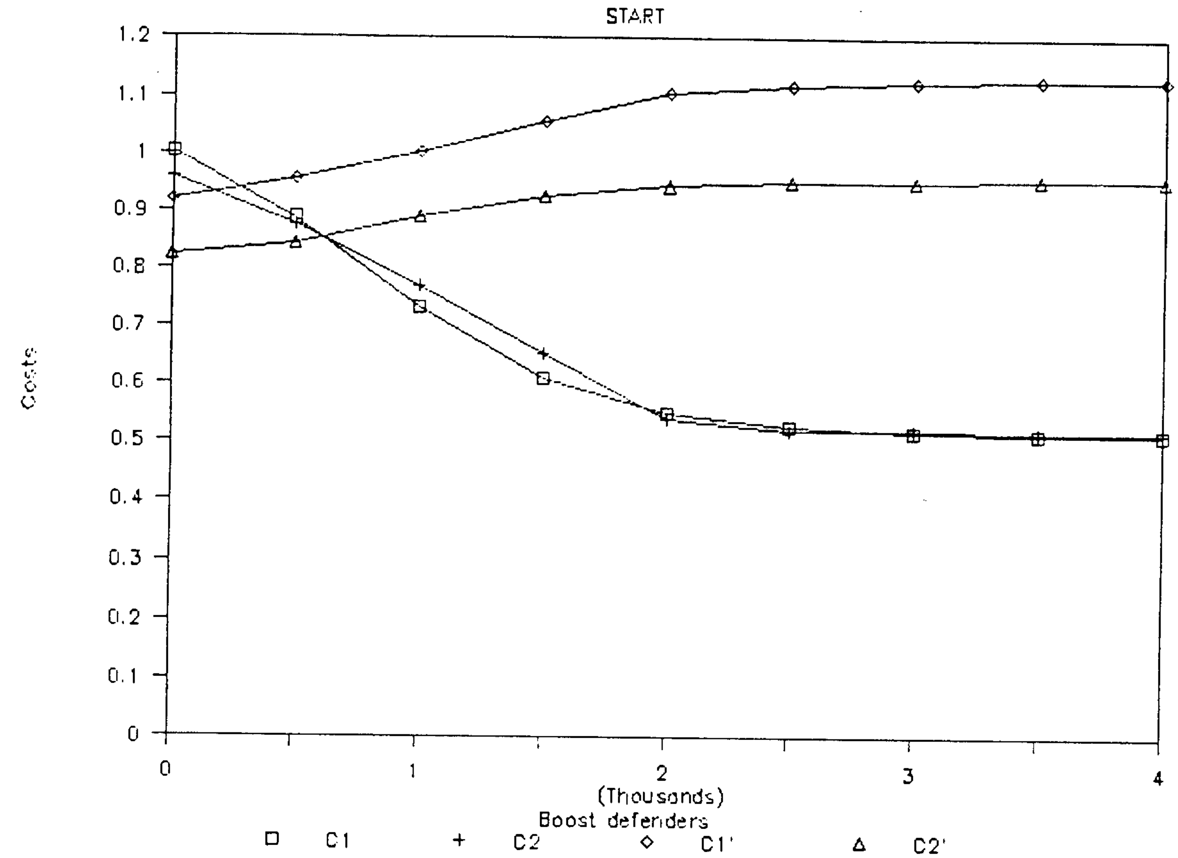


Fig. 20 Indices—unilateral defense

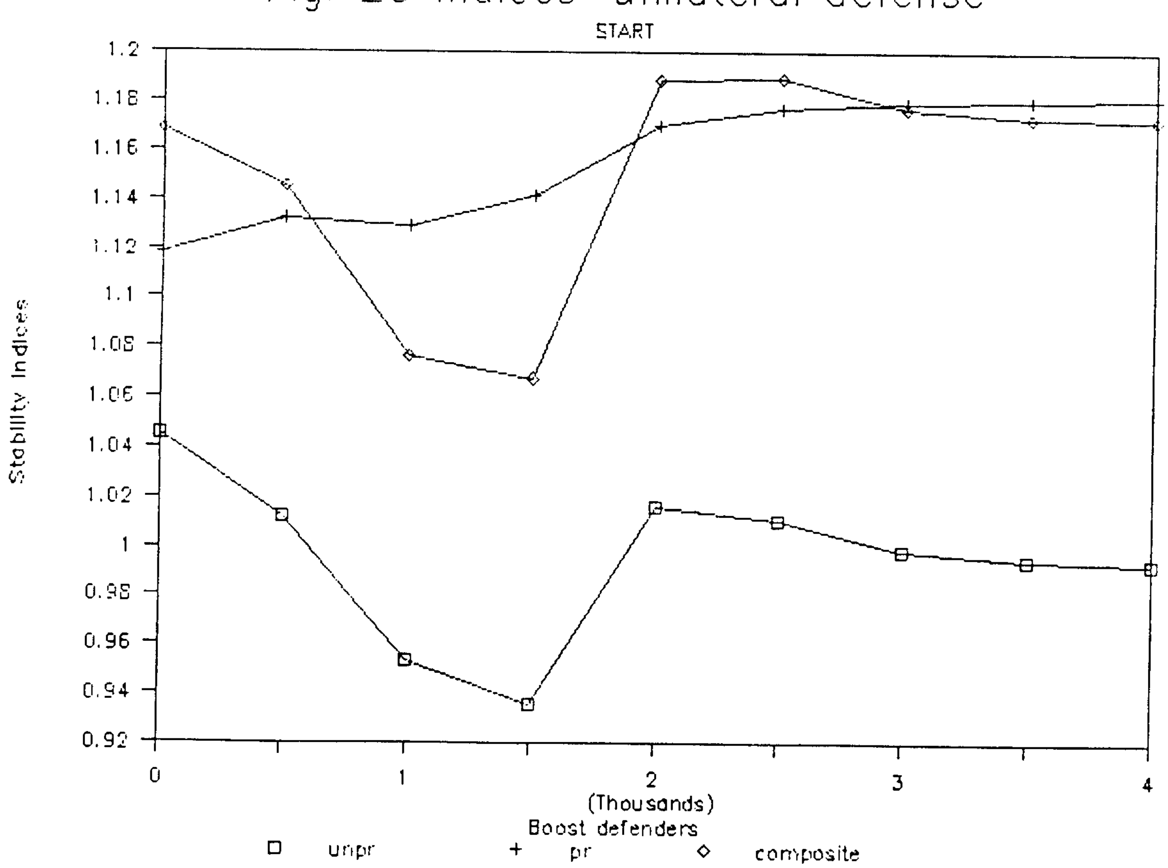


Fig. 21 Components of unprime strikes

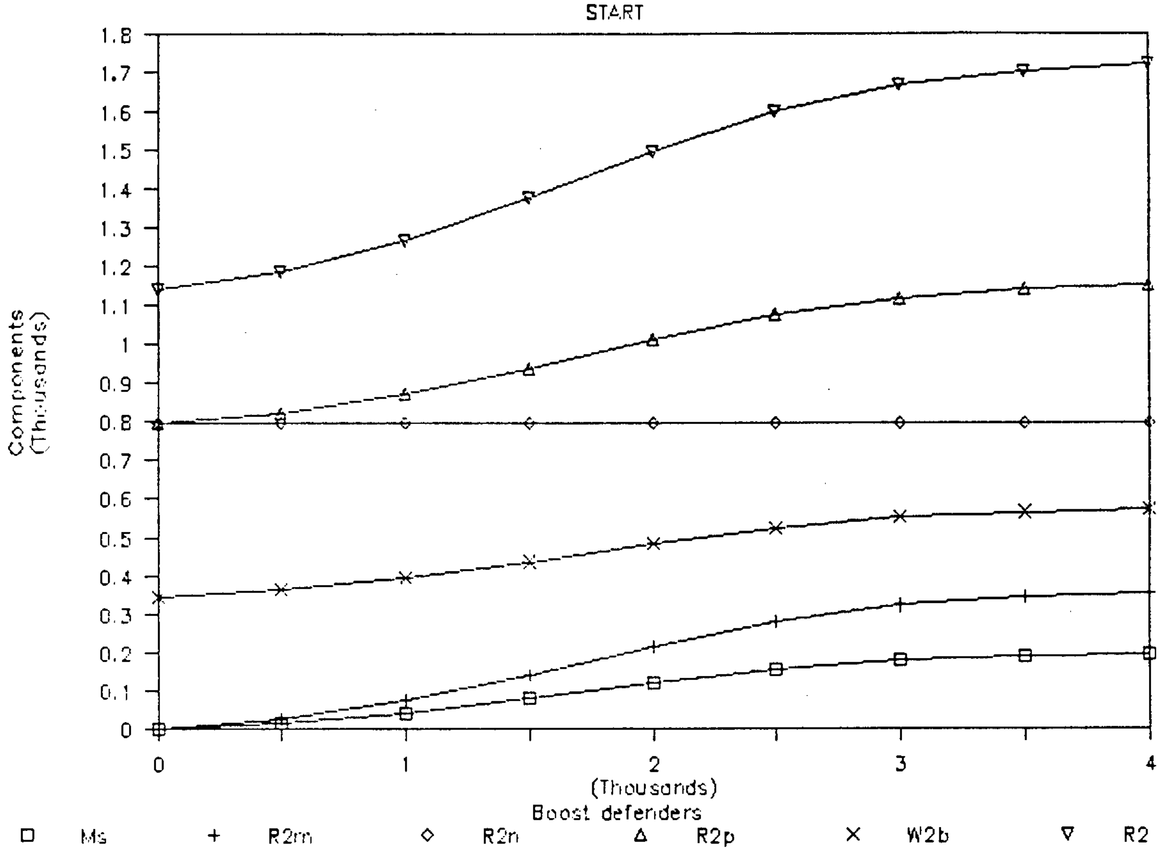


Fig. 22 Strikes—1 sided

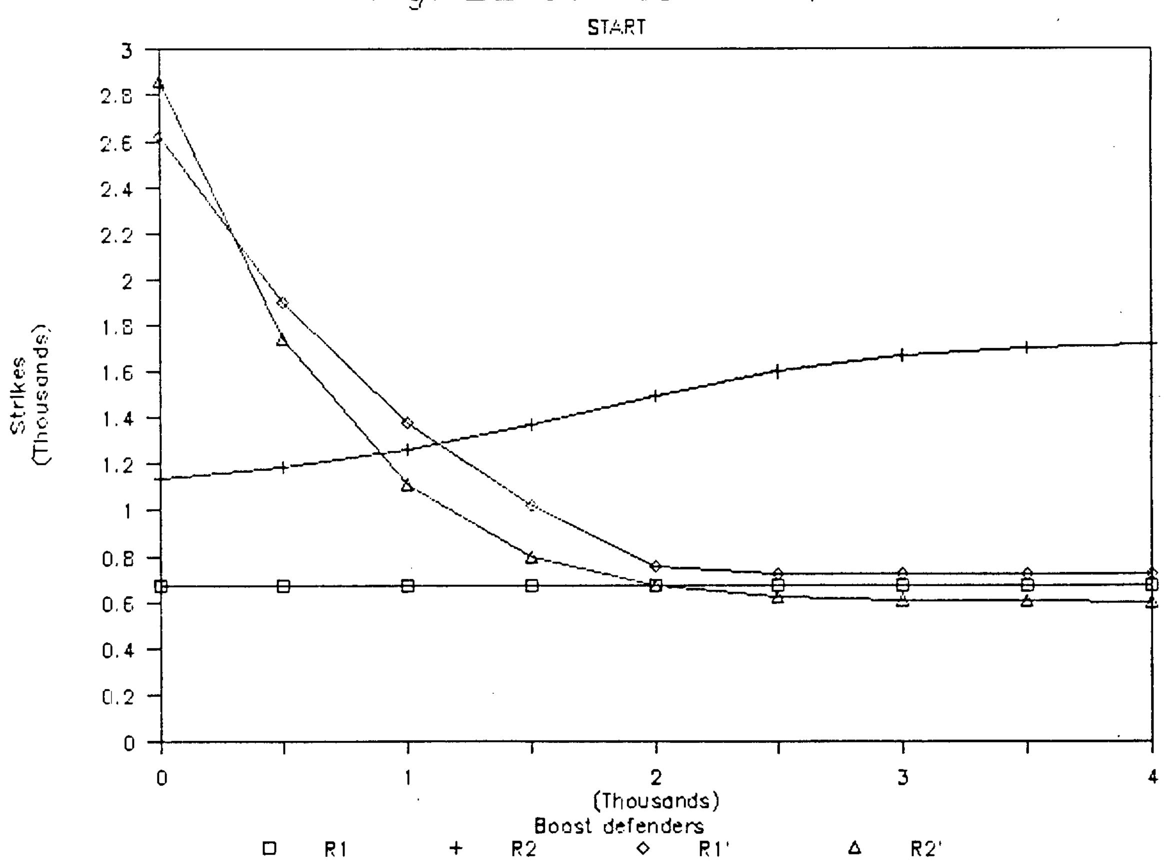


Fig. 23 Costs for 1 sided conversion

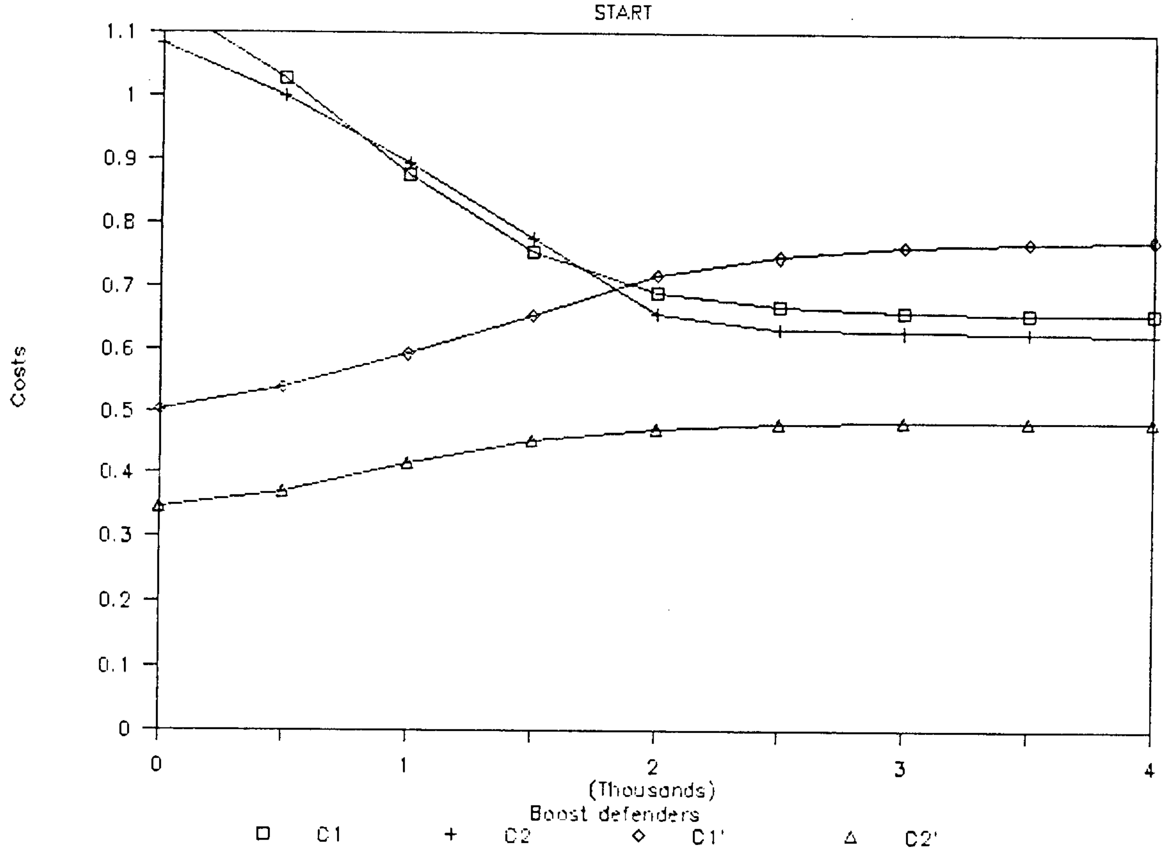


Fig. 24 Indices for 1-sided conversion

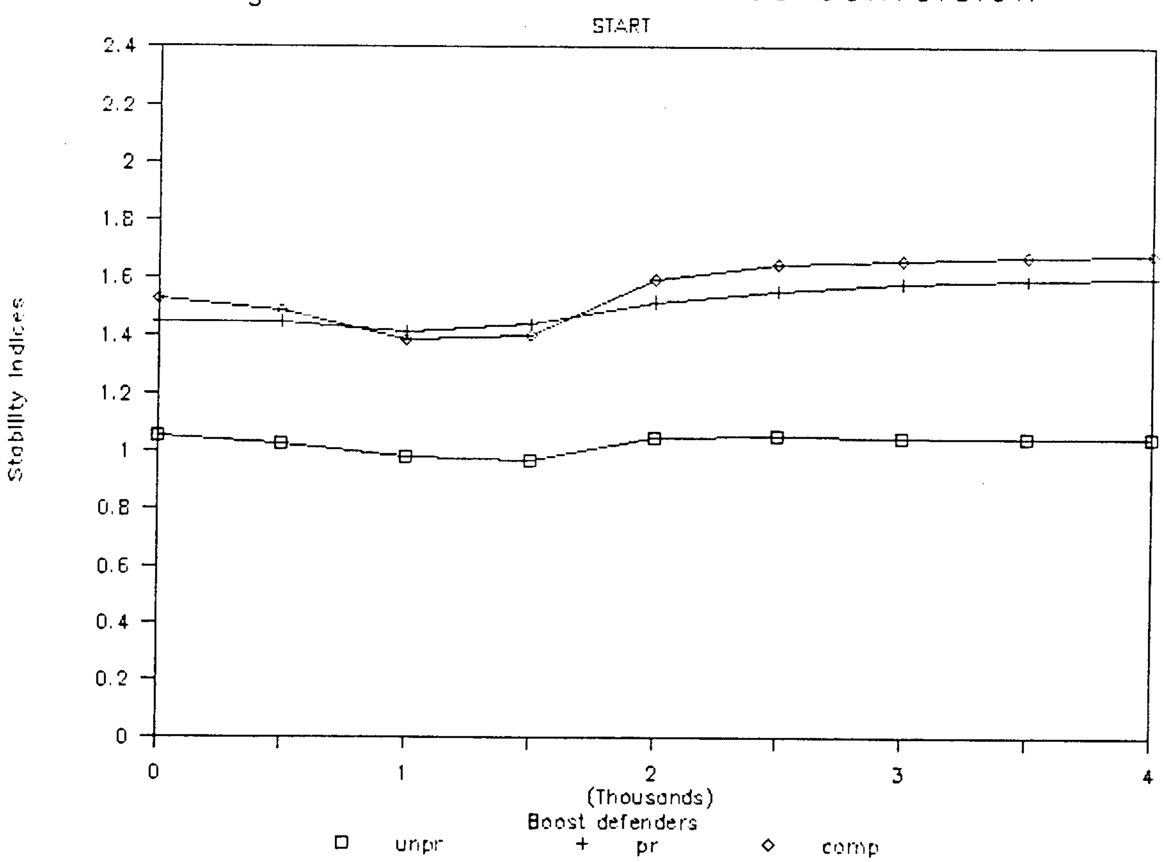


Fig. 25 Components of unprime strikes

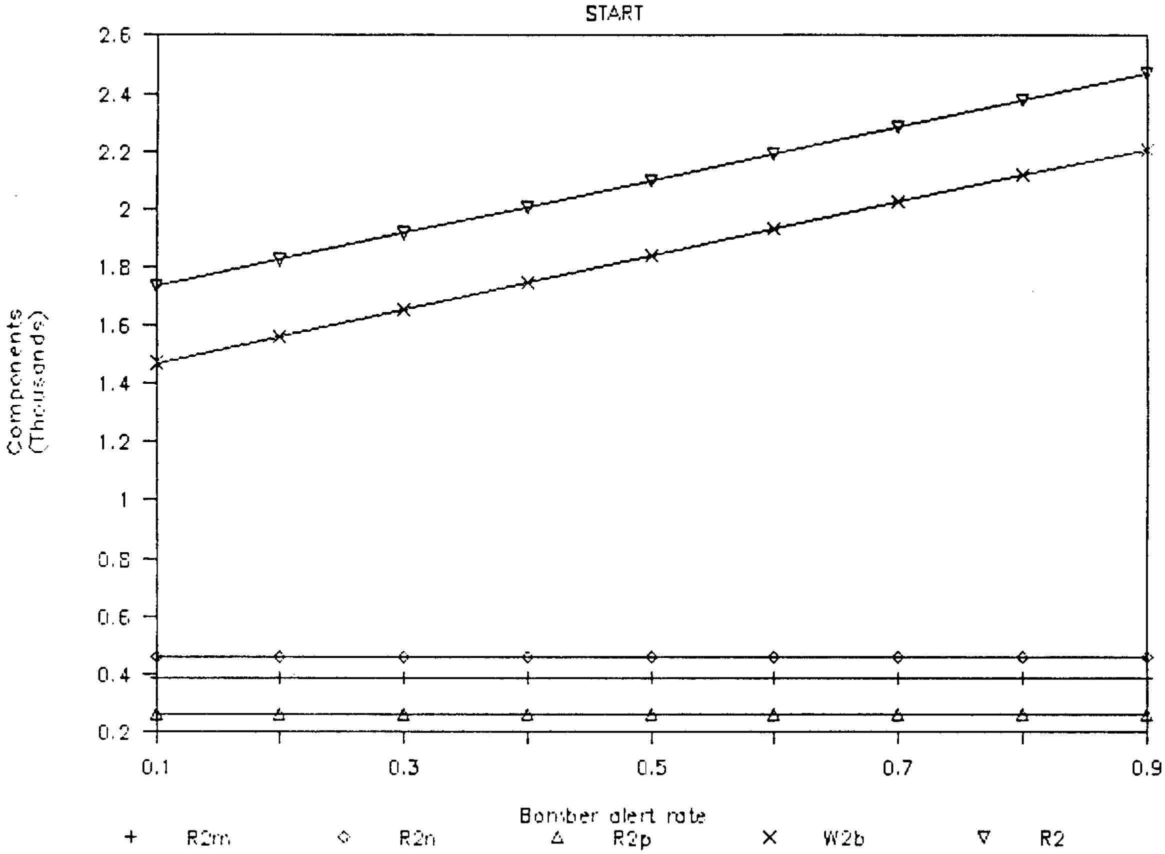


Fig. 26 Strikes

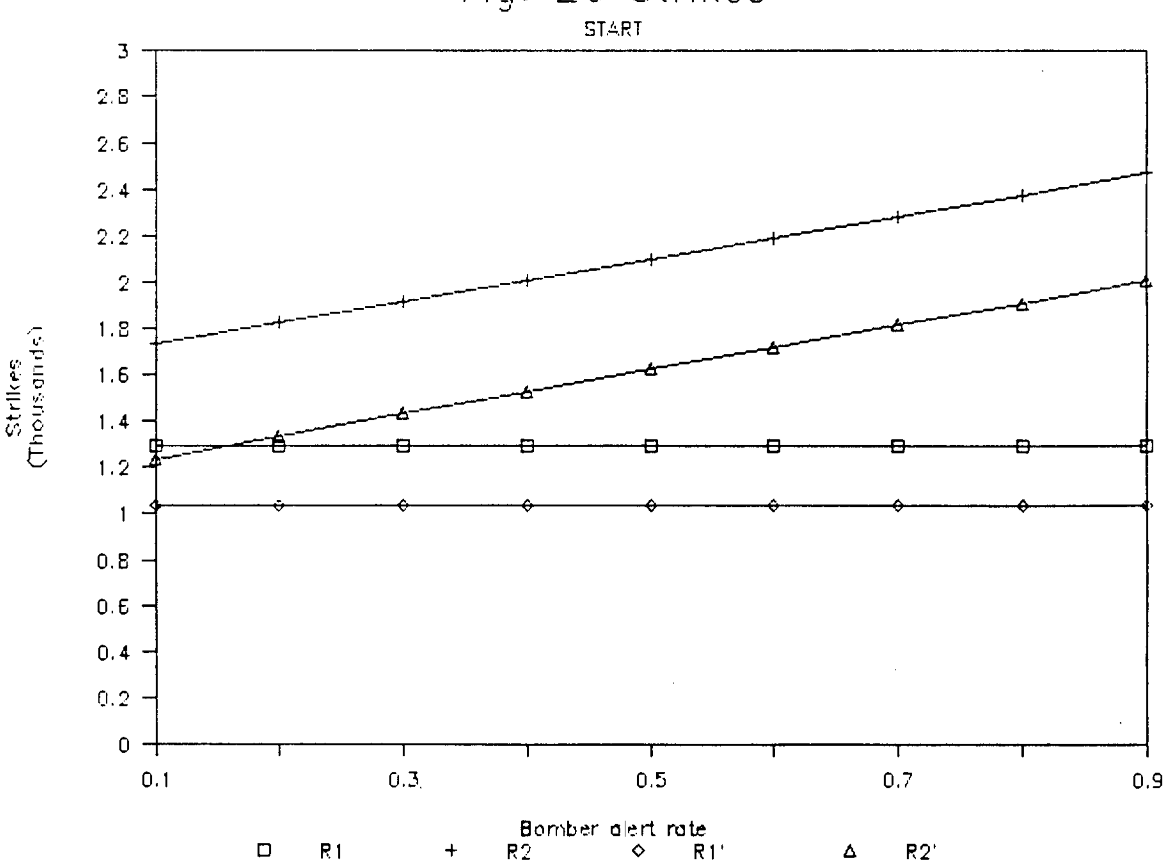


Fig. 27 Costs

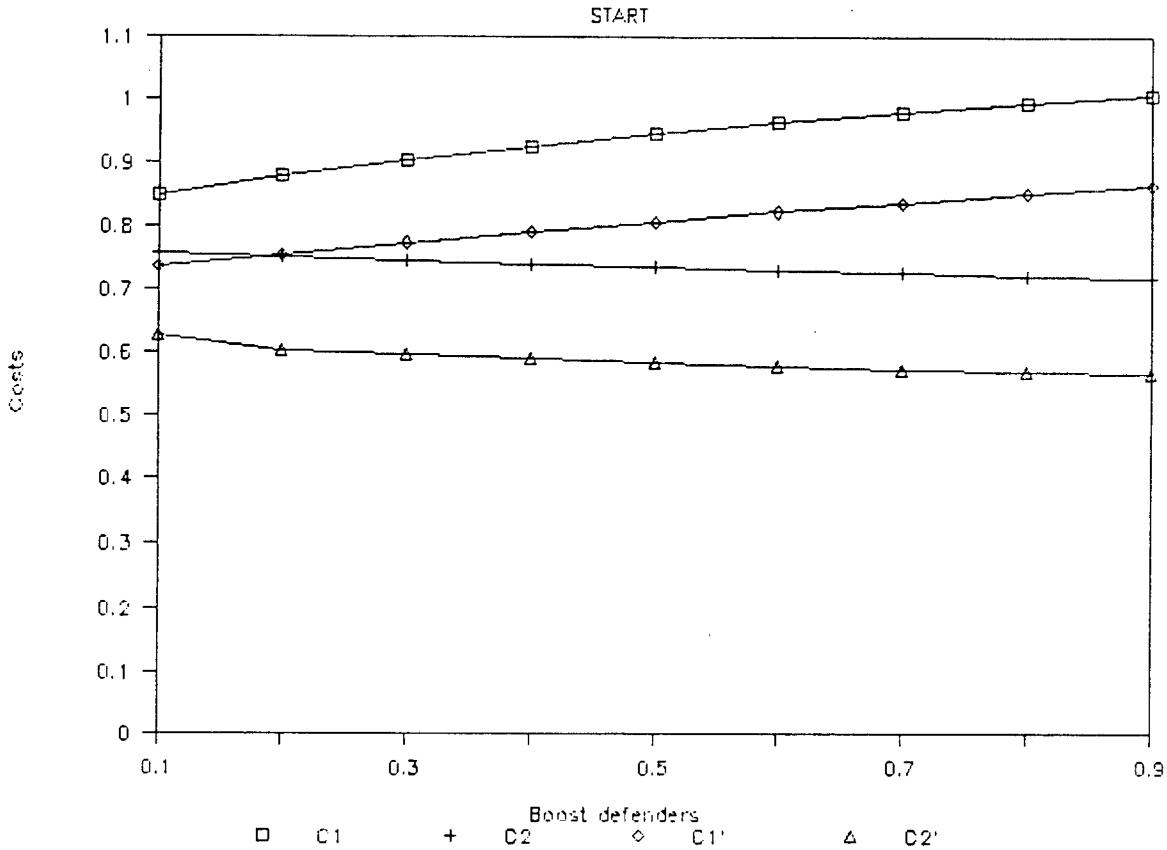


Fig. 28 Indices for one sided defense

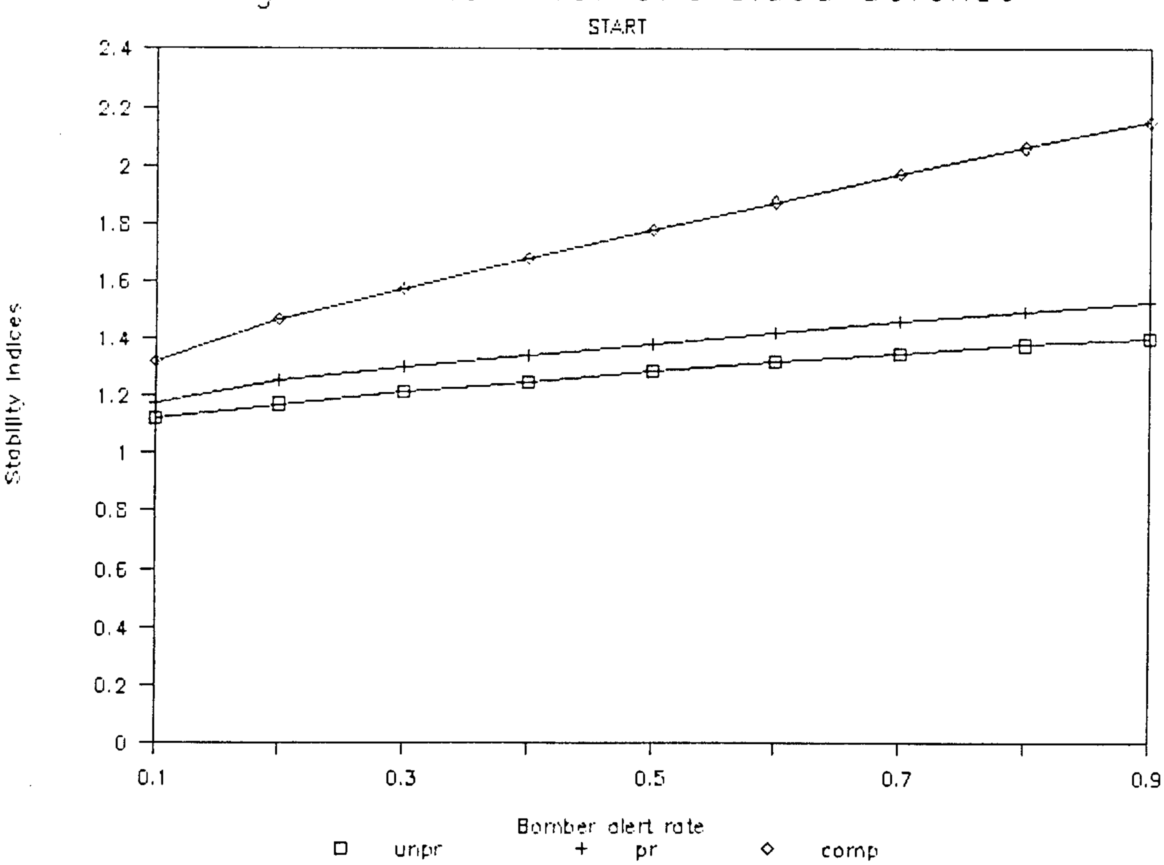


Fig. 29 Strikes

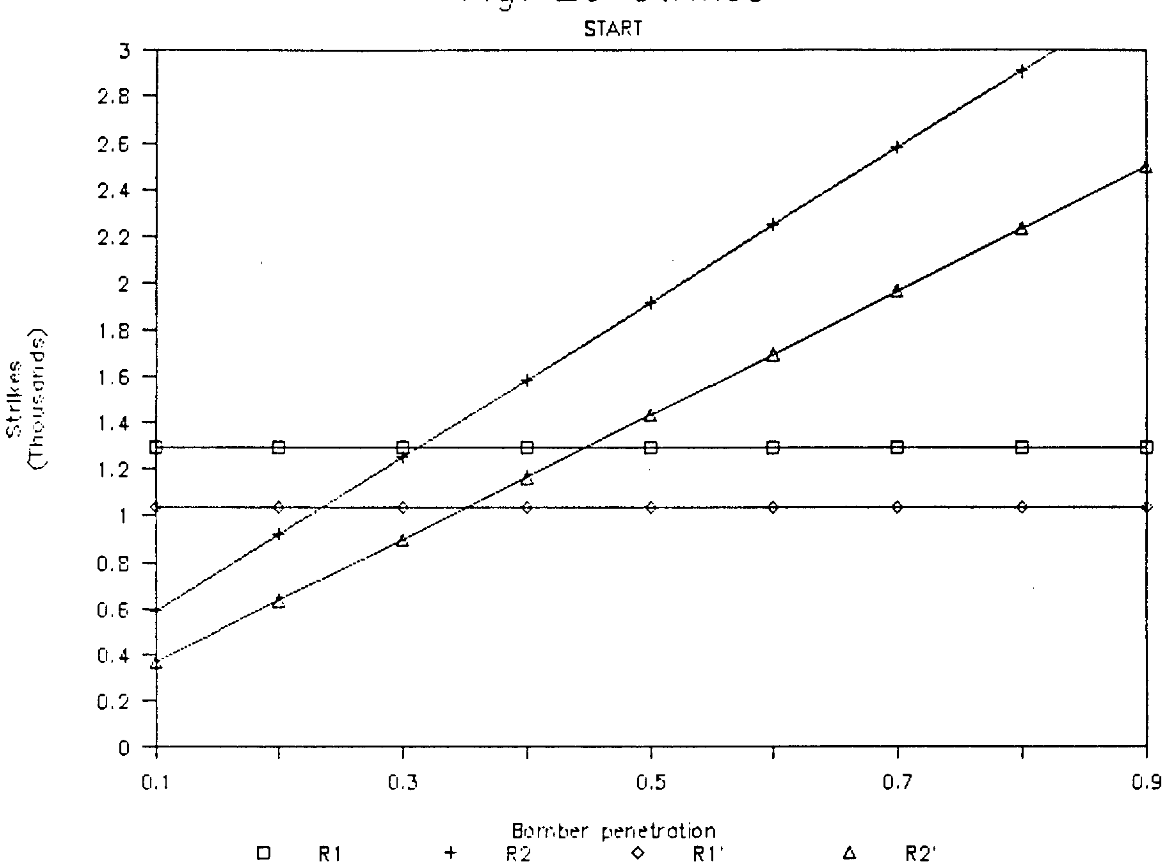


Fig. 30 Costs

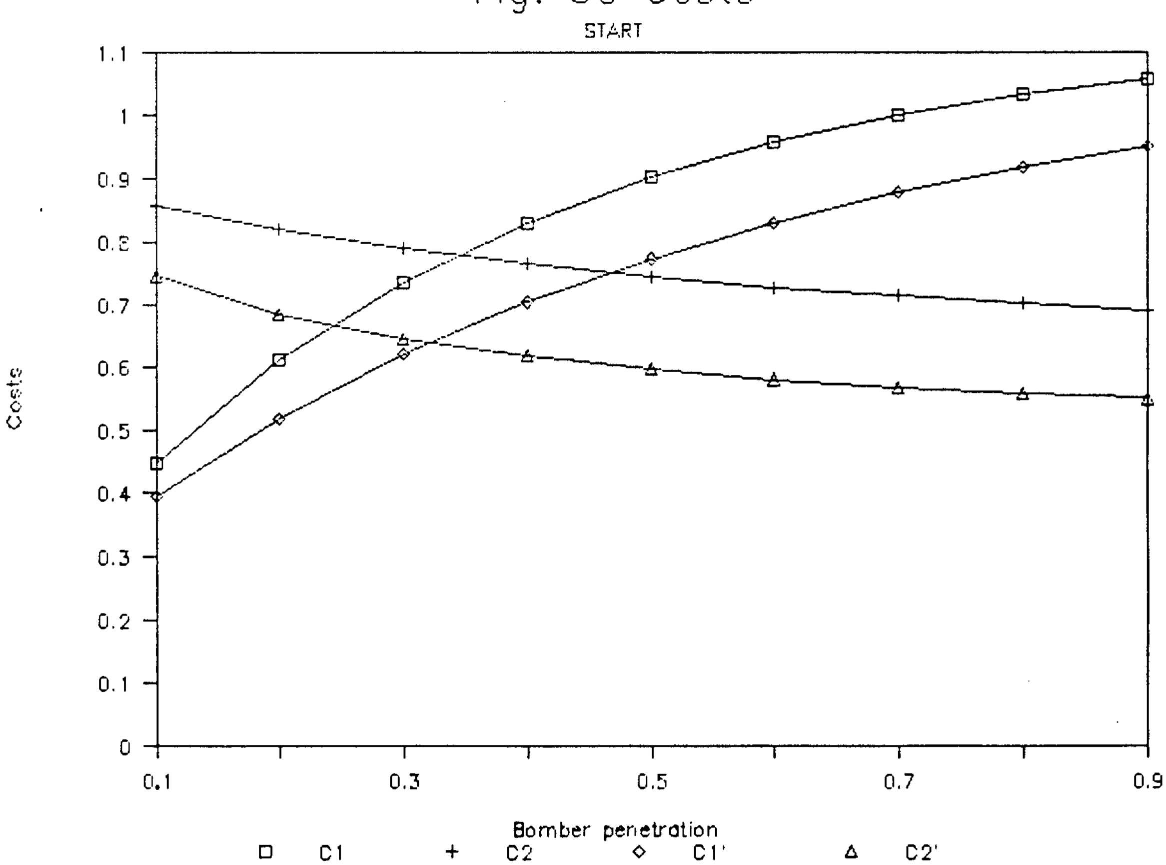


Fig. 31 Indices for one sided defense

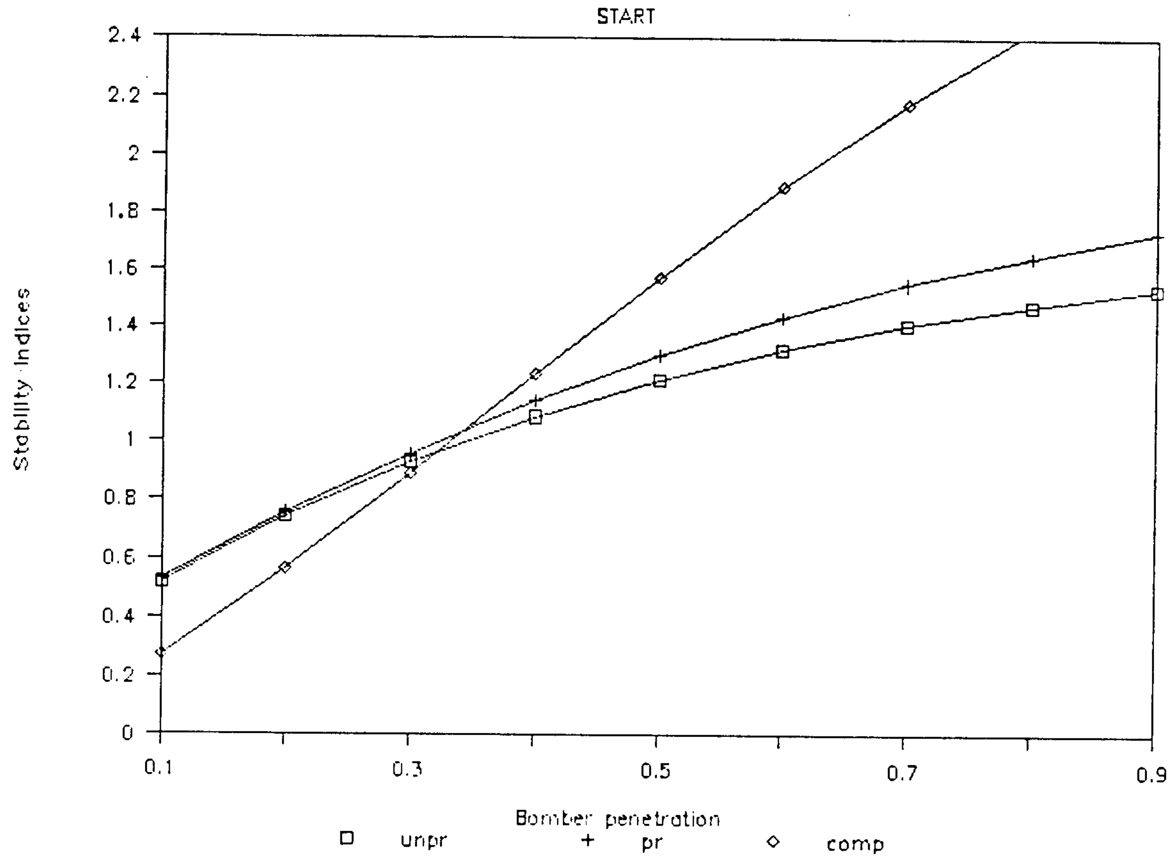
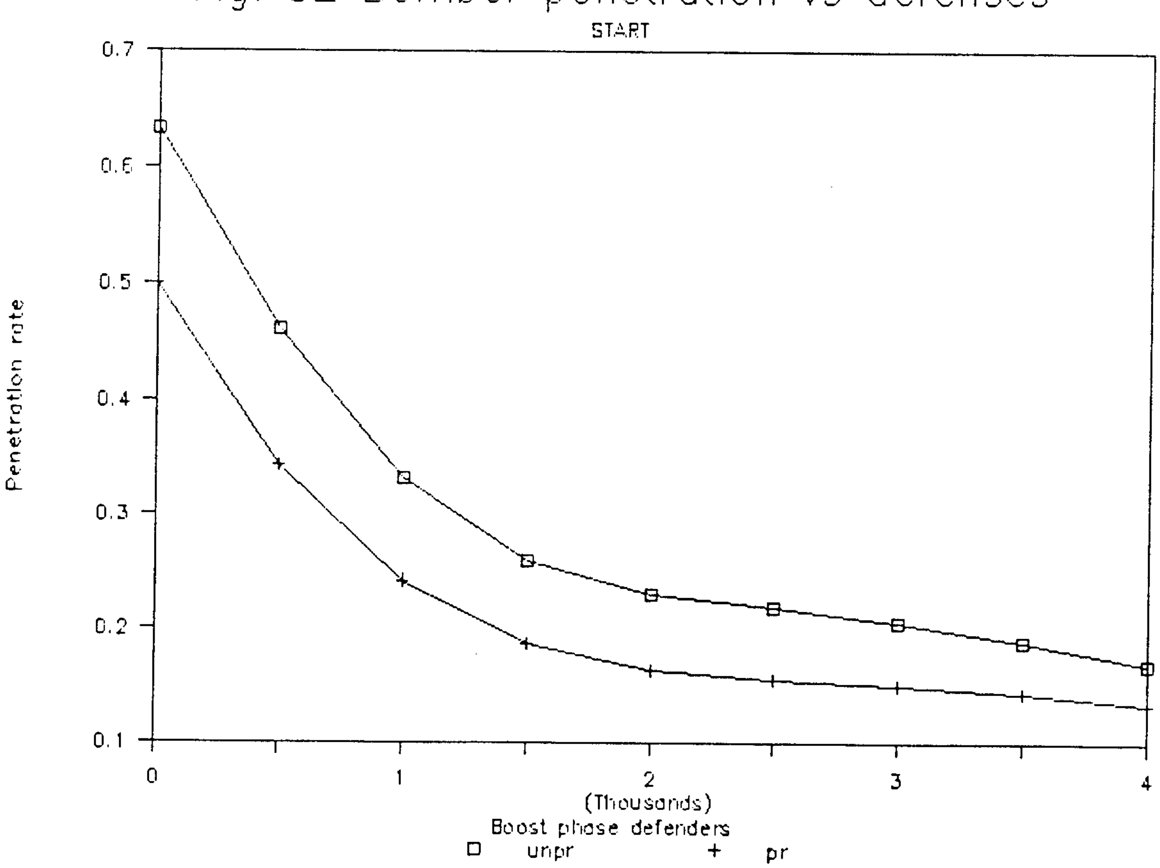


Fig. 32 Bomber penetration vs defenses



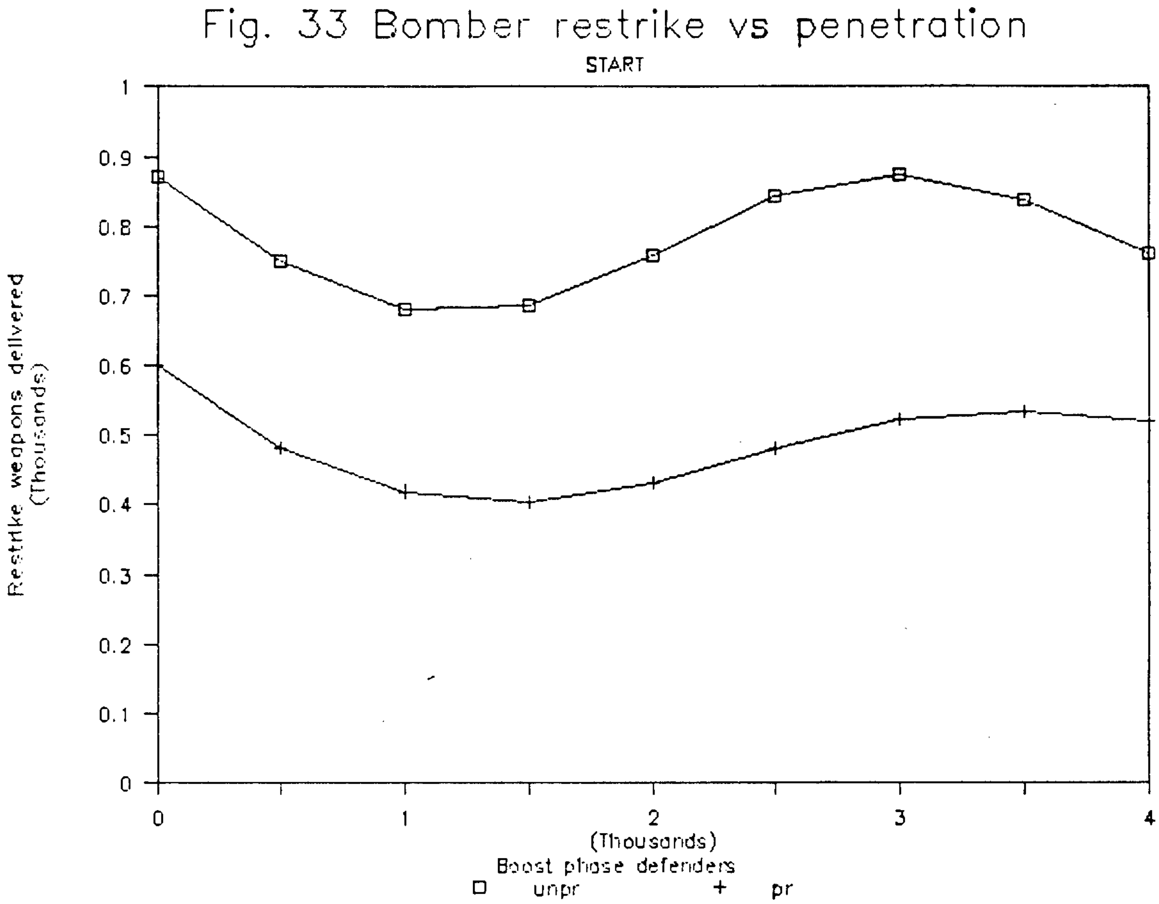


Fig. 33 Bomber restrike vs penetration
START
Restrike weapons delivered
(Thousands)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
(Thousands)
Boost phase defenders
unpr
pr

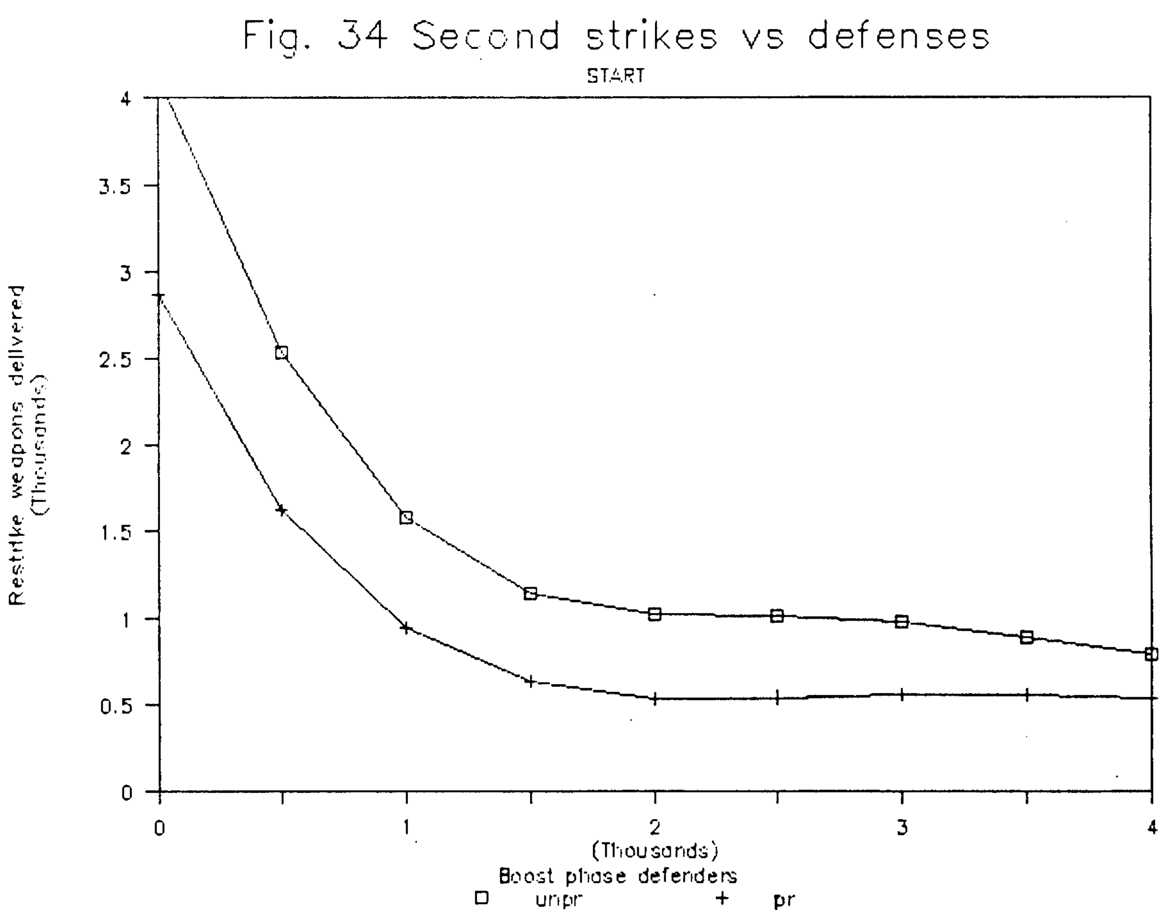


Fig. 34 Second strikes vs defenses
START
Restrike weapons delivered
(Thousands)
4
3.5
3
2.5
2
1.5
1
0.5
0
0
1
2
3
4
(Thousands)
Boost phase defenders
unpr
pr

Fig. 35 Strike costs vs defenses

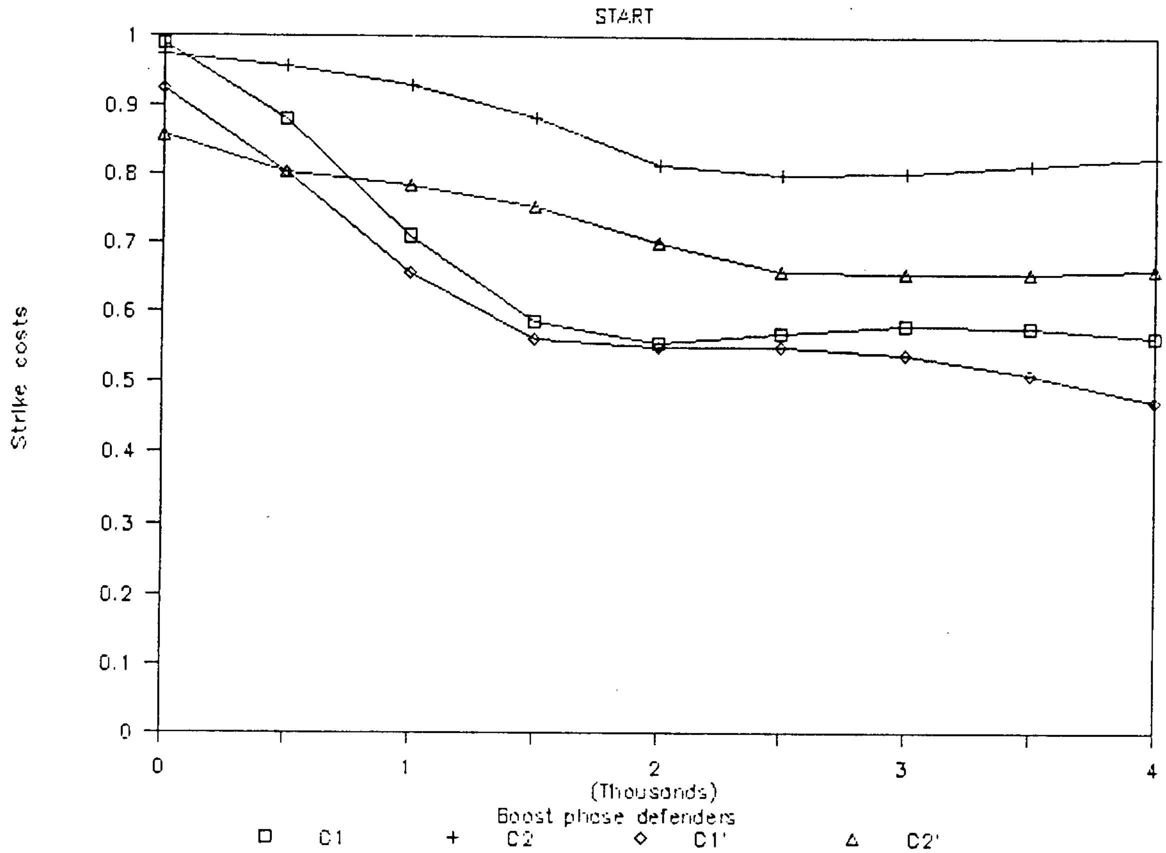


Fig. 36 Stability indices vs defenses