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CONSIDERATIONS IN MISSILE REDUCTIONS AND DE-ALERTING

Gregory H. Canavan

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Earlier analyses assumed that all survivable forces could withstand first strikes and retaliate. Only those on alert, at sea, or capable of launching under attack meet that assumption. The sensitivity of those results to non-alert forces is discussed. Reduced alert rates decrease stability indices, primarily by reducing second strikes. Survivable, mobile Russian ICBMs could increase both sides stability. Dealerting hastens expected reductions and raises the possibility of abuse. And the low-force goal of arms reductions has some poorly understood and awkward attributes.

Earlier analyses have assumed that all survivable forces could withstand first strikes and retaliate. In practice, only the fraction on alert, at sea, or capable of launching under attack meet that assumption. The sensitivity of those results to strategic force alert rate is discussed below. The analysis is performed within the exchange framework derived earlier, which contains the essential elements of current U.S. and Russian analyses. Exchanges between effective vulnerable and survivable missiles forces are studied with an aggregated, probabilistic model, which optimizes each sides' first and determines each sides' second strikes and costs by minimizing first strike costs. The model is extended here to treat varying alert rates and survivabilities of non-alert forces.

The report studies alert rates that are steady, decreasing, or increasing in time. It is shown that even current alert rates decrease stability indices by factors of two from those that would be calculated under the assumption that all SSBNs were on alert or could launch on warning in port, and that this reduction is primarily due to the reduction of second strikes at reduced alert rates. The low, current Russian alert rates would, if maintained, produce further two- to three-fold reductions in stability indices, which could reach very low levels. A shift to survivable mobile ICBMs would increase Russian and overall stability indices, in which case increased Russian alert rates would act to the benefit of the stability and security of both sides. The common feature of these results is that a unilateral advantage may appear to be a favorable military attribute of a given force configuration, but can be a detriment from the perspective of stability, which must be viewed from both sides.

EFFECTIVE FORCES, WEAPONS AND AVERAGING

The missiles and weapons used model those in the reduction in from SALT II and START II through START III, as tabulated in a recent Los Alamos report, plus two further reductions suggested by a recent National Academy of Sciences study. Exchanges are modeled through an aggregated, probabilistic two-sided exchange model. In Table I, the two sides' forces are labeled “unprime” and “prime” for nationality neutrality, although the unprime forces are those of the U.S. and the prime forces are those of Russia. The analysis predicts the first (F) and second (S) strikes unprime could deliver on prime with his M vulnerable missiles with m weapons per missile and N survivable missiles with n weapons per missile from his total force of \( W = mM + nN \) weapons in any given period.
Prime delivers first (F') and second (S') strikes from the M' vulnerable missiles with m' weapons per missile and N' survivable missiles with n' weapons per missile total force of \( W' = m'M' + n'N' \) weapons available at that time.

### Table I. Vulnerable and survivable missiles and weapons.

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<th>M</th>
<th>n</th>
<th>N</th>
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</table>

The forces shown are averages. The total number of weapons on each ICBM launcher is summed over all launcher types; the total number of ICBM launchers is summed; and their ratio gives \( m \), the average number of weapons per ICBM launcher, which is used as the average number of weapons on vulnerable missiles. A similar calculation determines the average number of weapons per survivable missile. This process is repeated with the objective forces for each of the three stages of START I and two of START II to determine the average forces in the next five periods given in Table I.

START III forces shown reflect a mid-range option with a significantly reduced number of single-weapon ICBMs and a total of 2484 weapons, 940 carried by aircraft. Aircraft-borne weapons are not counted below because aircraft are too slow to participate in first strikes and inadequately survivable to participate in second strikes under projected conditions. The two options labeled NAS 1 and 2 are two options suggested in the National Academy of Science Study to retain the core deterrent at low levels. The equations for the exchange model are given in Appendix A. Those used to convert the exchange results into strike costs and stability indices are given in Appendix B. Individual stability indices are taken to be the ratio of first and second strike costs; the composite index is the product of the individual indices.

**RESULTS FOR NOMINAL ALERT RATES**

Figures 1-4 show the weapon allocations, first and second strikes, costs, and stability indices in each period of the force reduction which are arrived at by numerically minimizing the first strike cost of Eq. (7), and the conjugate equation for prime, for the forces shown in Table I. Figure 1 shows each side’s allocation of weapons. The top curve is for the U.S. (unprime) forces, which are initially allocated about 55% to Russia’s vulnerable missiles due to their large number in SALT II. The allocation falls roughly linearly in time until period 7, after which it rises...
slowly. The bottom curve is the Russian allocation, which is initially about 50% smaller because of the fewer U.S. vulnerable missiles. From period 2 to 5 the two allocations decrease in parallel. In period 6 Russia’s excess missile warheads causes the curves to meet. The dominant singlet systems in period 7 and the symmetric, small forces in periods 8 and 9 cause the allocations to be equal at about 20%.

Figure 2 shows the first and second strikes. The top curve is the Russian first strike. It is initially large because of Russia’s additional weapons under SALT II and small allocation to the lesser number of U.S. vulnerable missiles, which leaves a large number of weapons allocated to value. The Russian first strike falls roughly linearly with the arms reductions. The second curve is the U.S. first strike, which is initially only 2/3rd as large, but partially offsets reductions in weapons by reducing allocations to missiles, as shown in Fig. 1. The third curve is U.S. second strike, which is roughly constant at about 1,500 weapons through period 5, and then falls with START II reduction in weapons per SLBM. The bottom curve is the Russian second strike, which is smaller and flatter through period 6 due to the lesser number of survivable Russian weapons. Although strikes are diminished by orders of magnitude by the end of the transition, they could still be significant, depending on the proximity of value to urban areas.

In comparing the curves of Fig. 2 to those of the corresponding figures in the previous report for $h = 0$, the first strikes are affected little, but the second strikes are reduced by factors of 2-3 by the nominal $h = h' = 0.6$ of this report, which reduces the number of alert weapons by factors of 2-3. The resulting overall strikes are similar, particularly in later periods, but in periods 1-5, Russian first strikes are significantly larger than U.S. and U.S. second strikes are about 50% larger than Russian.

Figure 3 shows the U.S. cost of damage to self and incomplete damage to other. Russia’s costs are similar. The top curve is the cost of damage to the U.S. when it strikes second, which is initially large because of the large Russian forces. The second curve is the cost of damage to the U.S. when it strikes first, which permits it to limit damage by the vulnerable Russian forces. The third curve is the cost to the U.S. for incomplete damage to Russia when striking second, which increases as its inventory of weapons is diminished. The bottom curve is the U.S. cost for incomplete damage to Russia when striking first, when it has much larger forces.

The costs for striking first are much smaller than those for striking second. Their ratio is about a factor of two for damage to self and a factor of two to five for damage to other. The costs for damage to self fall and those for damage to other rise sharply beyond period 5. They cross at about START III. The sum of the cost of damage to other and self is about constant for either first or second strikes. The costs for incomplete damage to other are about twice those for damage to self by NAS 2. In comparing these costs with those for $h = 0$ in Fig. 3 of the previous report it is clear that the main changes are the ~ 50% reduction in damage to self in striking first and the ~ two-fold increase in cost of incomplete damage to other in striking second.

Figure 4 shows the total first and second strike costs, which are the sum of the cost of damage to self and other of Fig. 3. First strike costs are 0.4-0.5 and second strike costs are ~ 0.7 for both sides in periods 1-8, in accord with the rough agreement of first and second strikes in Fig. 2. Thus, their ratio is roughly constant during that period. In comparing these costs with those for $h = 0$, the main changes are the two-fold reductions in the U.S. first strike costs produced by their strong suppression of Russian second strikes.

Figure 5 shows the component and overall stability indices for each period. The top curve is the Russian index, which starts at about 0.8 due to the limited incentive for preempting survivable U.S. forces, dips slightly in
START I, further in START II, and then increases to about 0.75 by period 9. The second curve is the U.S. index, which is roughly constant at about 0.6 through period 8 and then increases with the Russian index due to the symmetrical forces assumed then. The bottom curve is the composite index, their product, which drops from about 0.55 to 0.35 by START III and then increases with the elimination of MIRVed non-alert survivable missiles. The total change in the overall stability index over the transition is negative.

In comparison with the corresponding figure of the previous report for $h=0$, the stability indices for $h=0.6$ start at two-fold lower levels, drop for all but the last step in the transition, and do not recover to unity for even the smallest forces shown. These quantitative differences are sufficiently large to represent a qualitative difference; they present a significantly different and less encouraging picture of the variation of stability through the transition. The reason is the reduction of both sides’ second strikes in proportion to their alert fraction, which reduces first strike costs much more than second strike costs. That reduces the ratios used as their stability indices by a like amount. The previous note for $h=0$ produces comparable first and second strikes and hence high stability. Values between $h=0$ and the $h=0.6$ of Figs. 1-5 of this report produce intermediate second strikes and stability indices. Larger values of $h$ produce smaller second strikes and lower levels of stability.

The evaluation of the optimal allocation of the attack to missiles and value requires an auxiliary determination of the optimal fraction of the attack on missiles to be allocated to non-alert SSBNs in each period. That sub-optimization can be done analytically. It is discussed in a companion paper, and is included in the optimal allocations in Fig. 1. In the early periods the fraction allocated to non-alert forces is only a few percent of the attack because only a small fraction of the large number of first-strike weapons available is required to thoroughly suppress the vulnerable non-alert SSBNs. By START III the fraction has reached about 10% for both sides and is rising sharply. By the second NAS reduction to 300 weapons, 240 on SLBMs, the fraction is over 20%.

The contribution to the second strike from ICBMs typically amounts to a few tens of weapons, which is about 10% of the second strike. Thus, the role of vulnerable missiles is to absorb attacking weapons rather than to restrike. The contribution from non-alert SLBMs is limited to about one weapon, which shows that their unintended role is even more strongly as a sink of weapons. The net allocation typically differs from that for no weapons allocated to non-alert SSBNs only slightly, thus, the diversion of the modest number of weapons needed to thoroughly suppress the non-alert SSBNs does not significantly alter the previously derived weapon allocations.

SENSITIVITY TO REDUCED ALERT RATES

Since the trends observed above have obvious explanations in the predicted strikes and costs shown, the effect of quantitative variations in forces is obvious. There are, however, two secular variations that deserve particular discussion because they represent likely variations in Russian forces beyond START II. The first is the effect on stability of the continuation of the current low alert rates of Russian SSBNs. The second is the effect of the planned Russian shift to mobile ICBMs. The first would decrease Russian second strikes and stability. The second would increase them.

The above assumed ~60% of Russian SSBNs in port. The current fraction is ~ 90%, which represents a four-fold reduction of SLBMs and weapons at sea. The effect on strikes and costs are shown in Figs. 6-11. Figure 6
shows that it increases the US allocation to missiles by about 10% throughout in order to take advantage of the
greater opportunity for damage suppression. Figure 7 shows that this reduces the Russian second strike to only the
~10% SSBNs at sea, which only represent a few hundred weapons after the second phase of START I. Figure 8
shows that the impact on US costs is to reduce the cost to self of a US first strike by about a factor of three.
Comparing Figs. 9 and 3 shows that the impact on Russian costs is to significantly increase the cost of incomplete
damage to the US. Figure 10 shows that increases the Russian second strike cost about 20% and reduces the US first
strike cost after the first phase of START I about three-fold.

Comparing Figs. 11 and 5 indicates that stability as seen by the US decreases about a factor of three
because the cost of striking first is reduced by about that amount. That only decreases the Russian stability index by
10-20%. The US stability index decreases sharply from about 0.8 to 0.2 in phase two of START I and slowly
recovers to about 0.3 by NAS 1. The Russian index falls from 0.85 to 0.6 and then decreases gradually through
START II. It increases little in START III and NAS 1. The composite index falls from 0.7 to 0.1 and remains there
through NAS 1, the slight increases in the US index being offset by the decreases in the Russian index. The indices
increase only in NAS 2, as the numbers of weapons become inadequate for the number of value targets held at risk.

Reducing SSBN alert rates has little effect on attack allocations; it primarily reduces the second strike of
the side with the lower alert rate. That reduces his opponent’s cost for striking first and his own for striking second,
which reduces both stability indices. The reductions in the first strike cost and index are greater because he sees a
reduced penalty for attacking. However, those reductions are also seen by the side with the lower alert rate, who sees
his opponent as less deterred from action, which is reflected in the reduced composite stability index. Thus, a
reduced alert rate on one side acts to the detriment of the stability and security of both sides.

SENSITIVITY TO INCREASED ALERT RATES

It is the stated Russian intent to shift towards mobile ICBMs. Although the US finds undersea deployment
the more survivable, there are arguments for sovereign ICBM basing, if sufficient position location uncertainty can
be maintained to produce survivability. A shift from SLBMs to mobile ICBMs can be studied with the above model
by varying alert rate, since making ICBMs mobile on land hand has much the same effect on survivability as hiding
them at sea. One distinction is that the non-alert rate for ICBMs can be very low, which has interesting and useful
properties. It is intended to eliminate heavy ICBMs by the end of START I. It is not known precisely how they
would be replaced by mobile ICBMs. The calculations below assume that non-alert rate decreases linearly from 0.6
at the end of START I to 0.1 by the end of NAS 2.

Figure 12 shows the resulting allocation. It resembles the baseline for 60% non-alert in Fig. 1 except that f
falls about 10% below f* in the latter periods because of the falling number of Russian missile targets for US
weapons. Figure 13 shows that the increasing alert rates increase the Russian second strike to roughly the level of
the Russian and US first strikes, which are about twice the level of the US second strike. Figure 14 shows that
increases the cost of incomplete damage to other in a US first strike to roughly that in a second strike, i.e. it largely
eliminates the possibility of damage limiting. Comparing Figs. 15 and 9 shows that reduces the cost of incomplete
damage to the US by about three-fold. Figure 16 shows that has little overall impact on second strike costs, but significantly increases US first strike costs.

Comparing Figs. 17, 11, and 5 shows that increasing alert rates by shifting to survivable mobile ICBMs would greatly increase the overall stability index from the low alert case and increase it significantly even from the nominal alert case. That is because the increase in the US index in period six and later due to the reduced number of vulnerable, attractive targets for preemption more than offsets the decrease in the Russian index in that interval, resulting in a progressive increase in the overall index all the way from START I to NAS 2, which results in an overall ~50% increase in stability.

Increasing alert rates primarily increases the Russian second strike, which increases the US cost for striking first and stability index. These increases in the US first strike cost and index are also seen by Russia, which perceives the US as more strongly deterred from attack, which is reflected in the increased composite stability index. Thus, increased alert acts to the benefit of the stability and security of both sides. Having a first strike advantage may appear favorable militarily, but it is generally a detriment from the perspective of stability.

IMPACT OF DEALERTING

It is reported that “more than 100 former or current heads of state and civilian leaders from around the world, including ex-presidents Jimmy Carter and Mikhail Gorbachev, have signed a statement that calls for removing nuclear weapons from alert status and other measures aimed at the eventual elimination of atomic arsenals...reflecting mounting support for the cause of nuclear abolition...” This section uses the above stability analysis to study the impact of dealerting on stability, finding that it could be negative. Dealerting is modeled by reducing the SSBN alert rates. The contributions from single-weapon ICBMs after START II are small, and it is assumed that they could be alerted more rapidly, so ICBMs are treated as fully alert.

The forces used approximate those after START II. They are symmetric, each side has 500 single weapon ICBMs and 336 SLBMs with five weapons each on 15 SSBNs. Dealerting and subsequent mobilization would have similar effects on both sides. Dealerting forces removes them from first and second strikes for as long as they are dealerted. If they are dealerted for periods long compared to the evaluation of first strike stability, dealerting has the same effect as permanent arms reductions: it subtracts them from first and second strikes. Thus, de-alerting is conceptually a way of implementing such reductions at an accelerated pace.

The calculations in Figs. 1-5 show that the effect of such reductions through current and planned START I-II reductions would decrease first strike stability indices about 35%. However, if one side could realert his strategic forces much faster than the other—or had hidden weapons, which serve much the same purpose—such rapid realerting would shift the balance from equal forces to one in which the side that realerted first had a significant advantage. Used in a first strike, those realerted forces could greatly reduce the damage the other could produce in retaliation. The result of that advantage is studied below in terms of its affect on the allocation of first strikes, the magnitudes of those strikes, strike costs, and first strike stability indices.

As unprime’s dealerting increases (i.e., his SLBM alert rate decreases), unprime’s allocation of his first strike to vulnerable prime missiles is constant, while prime’s allocation to vulnerable unprime missiles increases
from about 0.2 to 0.4 to limit damage against the larger number of unprime missiles made vulnerable by dealerting. Unprime's first strike does not change because his allocation does not change. But his second strike decreases monotonically as prime limits damage. Prime's first strike decreases slightly because of his increasing allocation to missiles, but his second strike does not change under unprime's optimal allocation.

Figure 18 shows the resulting first and second strike costs. Unprime's first strike costs are constant, but his second strike cost increase because of the progressive reduction of his second strike. Prime's second strike costs increase slightly because his increasing allocation to missiles reduces damage to unprime value, but his first strike costs decrease sharply because of his progressive reduction of unprime's second strike. Figure 19 shows the resulting stability indices for each side. For low dealert rates, the top curve is the stability index for prime, which decreases from about 0.85 at 0.15 to 0.25 at 0.95 (5% SSBN alert). The drop is due to sharp reduction in prime first strike cost at high dealert, which reduces unprime's second strike. The second curve is unprime's index, which falls from about 0.7 to 0.55. The compound product thus falls from about 0.6 to 0.1. The current nominal alert rate of 0.4 (dealert = 0.6) gives a compound index of 0.4, so the reduction to an alert rate of 5% would give a reduction by a factor of $\frac{0.4}{0.1} = 4$.

Dealerting strategic forces has been posited as a stabilizing step towards abolition. START reductions will reduce stability indices by about a factor of two. Dealerting would hasten those reductions. It would also raise the possibility that one side could re-alert faster than the other. If so, the remobilized forces could be used to damage limit, which would reduce the re-alerter's first strike cost and stability index. The impact of complete demobilization of SSBNs would be an order of magnitude reduction in the overall stability index, to the residual level set by alert ICBMs. Generally, it would appear preferable to maintain existing strategic forces at the highest level of alert possible to minimize this effect and to concentrate on decreasing their total number if it is desired to reduce the maximum impact of potential conflicts.

STABILITY AT LOW FORCE LEVELS

At low force levels—roughly beyond Period 6, or START II—the equations for the exchange and optimal allocation become linear. This has several interesting results, the principal one being that the number of survivable weapons cancels out, because the number delivered is the same in both first and second strikes. Thus, the differences between second and first strikes, and hence stability indices, depend only on the number of vulnerable missiles, the number of weapons per missile, their survival probability, and the first striker's relative damage preference. Thus, stability indices do not depend on survivable forces, although first and second strikes do.

In this limit the stability index factors into a product of the number of vulnerable missiles and the difference between the second and first strikes by vulnerable missiles. Figure 20 shows the number of weapons allocated to each vulnerable missiles ($r$), their survival probability ($Q$), the first ($f$) and second ($s$) strikes, and stability index $j = (1 - l/k)M = s - f$, normalized to the number of vulnerable missiles ($M$) with $m$ weapons per missile on each side (for kill probability $p = 0.8$ and $1/k = 1,000$ value targets at risk). The number of weapons allocated to each vulnerable missile increases as $r \sim \ln m$. $Q$ falls as $1/m$, so $s$ is constant. The first strike $f(m - r)$ increases almost as rapidly as $m$, so $j$ falls to large negative values by $m = 3$, indicating instability. Reducing $p$
decreases f and increases Q, so that j falls, though more slowly. Thus, decreasing the accuracy of vulnerable weapons increases stability for all m. More aggressive attackers increase preference for damage to other, which shifts weapons from counterforce to countervalue attacks. However, Q and s increase proportionally, so j remains much as seen in Fig. 20.

The current configuration involves many missiles and many weapons per missile, which are at the far right of Fig. 20. The most bothersome feature of the current configuration is the multiple weapons on vulnerable missiles. As missile forces decrease, the stability index falls with M. For any given M, as m decreases, the j decreases for all parameter variations shown. For nominal parameters the index reaches zero by m = 1. However, the index scales on kM, so if the number of targets decreases along with M—as has been the case in the last decade—the product and index no longer improve as forces.

There are two independent ways to achieve stability. The first is to reduce M to zero, which produces stability trivially with no missiles—but a strong sensitivity to hidden weapons or re-alerting. The second is to reduce j = s - f to zero, which can be accomplished by reducing m to unity for any M. A variant is suggested by the fact that s - f = 0 for m = 1.75 for p = 0.6. Thus, for moderately accurate missiles (or uncertain target locations), multiple weapon vulnerable missiles can be tolerated without stability loss. However, this result is sensitive to the value of p, which is not known with precision, particularly against mobile systems.

The above analysis also provides an alternative view of the change of stability indices as M or m are increased in the reconstitution of missile forces from low levels. The desired end point of most arms-control discussions is a configuration with a modest number of single weapon vulnerable missiles in a mix with many survivable weapon. Figure 20 shows this configuration would be stable. Increasing the number of vulnerable single-weapon missiles would not alter the stability index since ∆M(s - f) = ∆M(0) = 0. But increasing m decreases stability. By m = 2 the decrease ∆j ~ -0.5. For 200 vulnerable missiles, that would decrease the index by = kM∆j = 0.001 x 200 x (-0.5) = 0.1, which is significant, for an additional ~ 200 warheads.

For moderate forces, stability indices depend primarily on the number of vulnerable missiles and the number of weapons on them. The number of survivable weapons cancels out, and the stability index reduces to a bilinear product of the number of vulnerable missiles and the difference between second and first strikes by vulnerable weapons. That bilinear means stability can be gained by reducing the missiles to zero or by reducing the number of weapons per vulnerable missile to unity. The goal of most arms-control discussions—a few single-weapon vulnerable missiles in many survivable weapons—does not appear appropriate, given the above However, that configuration would be stable. Moreover, from it, increasing the number of vulnerable single-weapon missiles would not alter the stability index, although increasing the number of weapons per vulnerable missile would decrease stability for any number of vulnerable missiles. This suggests that at moderate forces, the issues of sensitivity to reconstitution and re-alerting are more sensitive than those of stability.

SUMMARY AND CONCLUSIONS

This paper uses the exchange model derived earlier and effective START missile forces to study sensitivity to SSBN alert rates. The model is extended to treat variable rates and optimal attacks on non-alert forces. Current
alert rates decrease stability indices by factors of two from those that would be calculated under the assumption that all SSBNs are alert or can launch on warning in port, primarily due to the ability to strongly suppress second strikes at low alert rates. Allocations to non-alert SSBNs are large only in the final periods. They do not significantly alter optimal allocations of weapons to missiles. Low current Russian SSBN alert rates would, if maintained, produce two-three-fold reductions of indices to very low levels.

A shift to land-mobile ICBMs with high alert rates would increase Russian and overall stability indices, if they could be kept survivable. Increasing alert rates increases Russian second strikes, which increases the US first strike cost and stability index and the composite stability index. Thus, an increased Russian alert rate would improve the stability and security of both sides. A first strike advantage might appear a favorable military attribute of a given force configuration, but it is a detriment from the perspective of stability, which must be viewed from both sides.

Dealerting strategic forces has been posited as a stabilizing step towards their abolition. START reductions will reduce stability indices by about a factor of two. Dealerting would hasten those reductions and raise the possibility that one side could re-alert faster than the other. If so, the remobilized forces could be used to damage limit, which would reduce first strike costs and hence stability indices. The impact of complete demobilization of SSBNs would be an order of magnitude reduction in the overall stability index, to the residual level set by ICBMs. Generally, it appears preferable to maintain existing strategic forces at the highest level of alert possible to minimize this degradation and to concentrate instead on decreasing their total number in order to reduce the likelihood of conflict.

The analysis above indicates that the goal of most arms-control discussions—a few single-weapon missiles in a larger number of survivable missiles—is stable, but of questionable relevance. While it would be insensitive to the addition of singlet missiles, its stability would degrade rapidly with re-alerting or reconstitution. Planned strategic reductions will reduce stability significantly, and dealerting forces would accelerate that reduction and reduce additional risks of abuse. And the region of moderate forces they lead to have complex stability properties that are not well understood, some of which appear unfortunate.
APPENDIX A. EXCHANGE EQUATIONS

Exchanges between equal missile missile forces can be modeled in terms of the first and second strikes each side could deliver. If unprime strikes first, and a fraction $f$ of his weapons is directed at prime’s vulnerable missiles, unprime’s first strike on value targets is

$$ F = (1 - f)(mM + nN). $$

The average number of weapons delivered on each of prime’s vulnerable missile is

$$ r = (1 - g)f(mM + nN)/M', $$

where $g$ is the fraction of the missile attack directed towards survivable but non-alert forces, e.g., submarines in port. For $r$ large, the approximate average probability of survival of a vulnerable missile is

$$ q' \approx q^i = e^{(1-g)fWlnq/M'}. $$

For $q' > 1 - q$ is the attacking missile’s single shot probability of kill. The corresponding average probability of survival of a non-alert survivable missile is

$$ v' \approx v^i = e^{gfWlnq/h'B'lnv}, $$

where $u = 1 - v$ is an attacking missile’s single shot probability of kill against a non-alert survivable missile, $B'$ is the number of SSBNs on which prime’s survivable missiles are deployed, and $h'$ is the fraction of prime survivable missiles off alert, e.g., in port.

The value $h' = 0$ would correspond to all missiles at sea, or capable of firing from port, which is the case treated earlier. $h' = 1$ corresponds to all SSBNs in port, in which case they would enter the analysis as essentially a few, highly-MIRVed, vulnerable missiles. The calculations below assume a nominal value of $h = h' = 0.6$, which correspond roughly to historical and projected conditions of about $40\%$ of SSBNs at sea. The ability to disperse somewhat on warning would produce values of $h$ and $h'$ between 0.6 and 0. Thus, decreasing alert through increasing $h$ conceptually changes potentially survivable missiles and weapons into vulnerable ones. With these expressions for vulnerable and non-alert missile survivability, prime’s second strike becomes

$$ S' = m'M'Q + h'n'N'V' + (1 - h')n'N', $$

which is delivered on value, as missiles remaining at the end of the exchange are taken to have no value. The corresponding equations for unprime’s second and prime’s first strikes can be derived either by repeating the logic from his perspective or by conjugating the above equations, i.e., interchanging primed and unprime symbols. This simplification of the exchange into one strike by each side emphasizes the deterrent role of the weapons over any possible role in extended engagements, in accord with recent strategic decisions.

The fraction of the attack allocated to vulnerable missiles can be determined by an extension of this analysis. The attacker unprime seeks to minimize $S'$ by proper choice of $f$ and $g$. The latter can be accomplished by differentiating Eq. (5) with respect to $g$, equating the result to zero, and solving for the value of $g$ that minimizes $S'$, which is

$$ g_0 = [lnq/M' - ln(n'b'lnv/m'lnq) / fW] / (lnq/M' + lnv/h'B'). $$

With this relationship for $g_0$ as a function of force parameters, the solution for $f$ can be found by iteration, as discussed below. For $q = v$, i.e., equal survivabilities of vulnerable and non-alert missiles, $g_0$ simplifies to
\[ g_0 = \frac{1}{M'} - \ln(n'b'/m') / fWlnq / (1/M' + 1/h'B'), \quad (q = v) \] (A7)

in which the numerator contains a correction for the number of weapons per platform and the denominator contains only the number of missiles. If \( n'b' = m' \), e.g., single-missile, single-weapon SSBNs, the second term in the denominator vanishes and the allocation reduces to \( g_0 \sim 1 / (1 + M'/h'B') \). For \( M' = h'B' \), i.e., equal numbers of permanently and temporarily vulnerable missiles, \( g_0 \) would reduce to 1/2. In general \( n'b' >> m' \) and \( M' >> h'B' \), so the two terms in the numerator are comparable, the second term in the denominator is dominant, and \( g_0 \sim (h'B'/M') / fWlnq \), which varies as the ratio of vulnerable SSBNs to ICBMs and inversely as the size of the attack on them and its effectiveness.
APPENDIX B. COSTS AND STABILITY INDICES

First and second strike magnitudes are converted into first and second strike costs through exponential approximations to the fractions of military value targets destroyed. The cost of damage to self when unprime strikes first is

\[ C_{1s} = \frac{1 - e^{-kS'}}{(1 + L)}, \]  

where \( k = 1/1000 \) is the size of unprime target set prime wishes to hold at risk, and \( L \) is a weighting parameter that represents the attacker’s relative preference for inflicting damage on the other and preventing damage to self. The cost of incomplete damage to prime is

\[ C_{1o} = \frac{Le^{-kS'}}{(1 + L)}, \]  

where \( k' = 1/1000 \) is the inverse of the prime value unprime wishes to hold at risk. It is conventional to use their weighted sum as an approximate total cost for striking first

\[ C_1 = C_{1s} + C_{1o} = \frac{1 - e^{-kS'} + Le^{-kF'}}{(1 + L)}. \]  

Second strike costs are also composed of damage to self and other, which are approximated by

\[ C_{2s} = \frac{1 - e^{-kF'}}{(1 + L)}; \]  

\[ C_{2o} = \frac{Le^{-kS'}}{(1 + L)}; \]

so the total cost for unprime striking second is

\[ C_2 = C_{2s} + C_{2o} = \frac{1 - e^{-kF'} + Le^{-kS'}}{(1 + L)}. \]

It is conventional to use the ratio of first and second strike costs, \( I = C_1/C_2 \), as a stability index for unprime, and \( I' = C_1'/C_2' \) as an index for prime. When they are large, the two sides see no advantage to striking first. When they are small, there is an apparent incentive to attack first in a crisis. For unequal forces, their product is used as a compound index

\[ \text{Index} = I \times I' = (C_1/C_2)(C_1'/C_2'), \]

in which the smaller of the two indices determines overall stability.
References


Fig. 1. Allocations vs period
Fig. 2. First and second strikes vs period
Fig. 3. Costs of damage to self & other vs period
Fig. 4. C1 & C2 vs period

- C1
- C2
- C1'
- C2'
Fig. 6. Allocations vs period; reduced Russian SSBN alert
Fig. 7. First & second strikes vs period; reduced alert
Fig. 8. Costs of damage to self & other; reduced alert
Fig. 9. Russian cost self & other; reduced alert

![Graph showing cost progression over time for different scenarios.](image)
Fig. 10. C1 & C2 vs period; reduced alert
Fig. 11. Index vs period: reduced alert
Fig. 12. Allocations vs Period Increasing Russian Short
Fig. 14. US costs of damage to self & other; increasing alert
Fig. 16. C1 & C2 vs period; increasing alert
Fig. 17. indices vs period; increasing alert
Fig. 18. First and second strike costs vs dealer rate
Fig. 19. Stability indices vs dealer

19 l/h
Fig. 20. Indices vs weapons/vulnerable missile