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STABILITY OF MISSILE FORCES AND DEFENSES

Gregory H. Canavan

This note derives the exchange equation for mixes of missiles and defenses and discusses the impact on stability of varying their relative proportions. For fixed offenses increasing defenses decreases stability until first strikes fall to zero. The same is true of decreasing offenses for fixed defenses, although the decrease in indices is smaller. A judicious increase in defenses and decrease in offenses should effect that transition with minimum loss of stability.

This note derives the first and second strike levels, costs, and stability indices for exchanges between missile forces that include missile defenses. Exchange equations are derived in a form that permits the explicit optimization of those strikes. The costs of striking first or second are measured in terms of the physical damage inflicted. The main objectives of each side are to minimize the damage inflicted on oneself and to retain the ability to inflict damage on the other. The costs of damage to self and other are combined into costs for striking first and second, whose ratio is the overall stability metric. This note assumes that the offensive forces of each side are comparable in size and capability. The extension of forces and stability metrics to non symmetrical forces is derived in a companion paper.¹

For equal MIRVing of vulnerable and survivable forces, the exchange equations are a simple extension of those derived previously for mixes of vulnerable and survivable forces. For fixed missile numbers, increasing defenses first decreases strike sizes, costs, and stability due to the preferential erosion of second strikes by the defenses. For fixed numbers of defenses, decreasing the number of missiles decreases stability to the point where first strikes fall to zero. Making the defenses larger could effect that transition at a larger number of missiles. A judicious increase in defenses and decrease in offenses should effect that transition with minimum loss of stability during the transition.

Analysis. A previous note² derives the equations for exchanges between symmetric missiles forces in terms of the first, F, and second, S, strikes that either could deliver. For a force of M vulnerable missiles with m weapons each and N invulnerable missiles with n weapons each, of which a fraction f is directed at the opponent's missiles, given D random subtractive defenses that negate the missile before the deployment of warheads, the first strike on value targets is reduced to

$$F = (1 - f)(mM + nN)[1 - D/(M + N)], \quad (1)$$

where the number of weapons is $W = mM + nN$. The effect of such defenses is to reduce the number of both survivable and nonsurvivable offensive missiles by a factor of $1 - D/(M + N)$. If

there were $D = M + N$ defenses, the fraction would be zero, and neither sides' missiles would penetrate the defenses. The average number of weapons delivered on each vulnerable missile is

$$r = f(mM + nN)[1 - D/(M + N)]/M. \quad (2)$$

For r large, the average probability of survival is approximately³

$$Q \approx q^r, \quad (3)$$

where $q = 1 - p$, and p is the attacking missile's single shot probability of kill, which is taken to be the same for all missiles. The second strike is

$$S = (mMQ + nN)[1 - D/(MQ + N)], \quad (4)$$

all of which is delivered on value targets as missiles remaining at the end of the exchange are taken to have no value. Equation (4) again subtracts proportionally from the number of missiles launched in the second strike. While it is possible to solve Eqs. (1) - (4) for arbitrary parameters, a simple and relevant choice is $m = n$, i.e., equal degrees of deMIRVing on survivable and vulnerable missiles, which reduces Eq. (1) to

$$F = (1 - f)m(M + N)[1 - D/(M + N)] = (1 - f)m(M + N - D), \quad (5)$$

i.e., the number of escaping missiles times m weapons per missile times the fraction directed towards value. For this choice Eq. (2) reduces to

$$r = fm(M + N - D)/M, \quad (6)$$

and hence Eq. (4) to

$$S = m(MQ + N - D), \quad (7)$$

which is number of surviving missiles less the number of defenses times m weapons per missile.

Costs and stability index. These physical magnitudes of first and second strikes are converted into costs of striking first and second through exponential approximations to the fraction of the value targets destroyed by first and second strike,⁴ which retains the structure of the full exchange while making the calculations simple to explore. The cost of striking first, taken to be the weighted average of damage to self and of incomplete damage to the other fall is⁵

$$C_1 = (1 - e^{-kS} + Le^{-kF})/(1 + L), \quad (8)$$

where L is a constant that represents the attacker's relative preference of inflicting damage on the other and preventing damage to self.⁶ The normalized second strike cost is

$$C_2 = (1 - e^{-kF} + Le^{-kS})/(1 + L), \quad (9)$$

which uses the same constant L used above.⁷ indices.⁸ The ratio C_1/C_2 is used below as a stability index.⁹

$$I = C_1/C_2 = (1 - e^{-kS} + Le^{-kF})/(1 - e^{-kF} + Le^{-kS}) \quad (10)$$

Results. The above equations constitute a closed model that can be solved to predict the variation of C_1 , C_2 , and I with the principal model parameters M , m , N , n , p , L , and f . Figure 1 shows the first and second strikes for $M = N = 450$ missiles and $m = n = 3$ RV/missile with kill probability $p = 0.6$ as a function of the number of defenses D . The second strike falls linearly to

zero as D increases, reaching zero at about $D = 500$. F is about 200 weapons above it in that region. It then holds at about 400 weapons until $D = 900$, above which no missile penetrate.

The reason for the plateau in Fig. 1 at $D = 450$ to 700 is shown in Fig. 2. For $D = 0$, the optimization is as before. From $D = 0$ to $D = 500$, f doubles, which increases the attack on missiles to limit damage. At about $D = 450$, where the second strike falls to zero, it is no longer necessary to do so, and the attack saturates at about $f = 0.7$. For larger values of D , the defenses take care of damage limiting, and the attack shifts back to missiles.

Figure 3 shows the resulting costs C_1 and C_2 and index I . C_1 and C_2 are about 0.6 at $D = 0$. They fall together until $D = 450$, where the gap between them is about 1.5, which produces an index $I = C_1/C_2 \approx 0.67$. For larger D , C_1 saturates because $S = 0$, and C_2 saturates because both damage to self and other are unchanging. By $D = 900$, both C_1 and C_2 approach $L/(1 + L) = 1/3$, because $S = F = 0$, so there is no damage to self but none of the desired damage to other.

At $D = M + N$, no missiles penetrate, no damage is done to either side, and hence it makes no difference in which order the two sides strike, so the stability index rises again to unity from the minimum of 0.45. This behavior of I with D has been the source of some confusion, with some concentrating on the favorable stability characteristics of the large D configuration and some on the factor of two loss in stability during the transition.

The impact of defenses during deep reductions is also of interest. Figure 4 shows F and S as a function of $M = N$ for $m = n = 3$ and $D = 200$. As M falls, F and S fall for the same reasons as in Fig. 1; the defenses simply remove them subtractively. F and S reach zero at 100 and 150, respectively. Figure 5 shows f , C_1 , C_2 , and I . The allocation of the attack to missiles starts at about 0.4, increases to 0.6, and then drops sharply for the same reasons discussed in Fig. 2. The costs decline in parallel and then converge where $F = 0$. The role of increasing defenses for fixed offenses is almost the same as the role of fixed defenses for decreasing offenses. However, the decrease in the stability index is not as great before the recovery to unity for fixed defenses as it was for fixed offenses in Fig. 3. Note that the index jumps to unity at the value of D for which F falls to zero. Larger defenses would effect this transition at larger numbers of missiles with less intermediate decline.

Summary and conclusions. This note derives the first and second strike levels, costs, and stability indices for exchanges between missile forces that include missile defenses. For equal MIRVing of vulnerable and survivable forces, the exchange equations are a simple extension of those derived previously for mixes of vulnerable and survivable forces. For fixed missile numbers, increasing defenses first decreases strike sizes, costs, and stability due to the preferential erosion of second strikes by the defenses. For fixed numbers of defenses, decreasing the number of missiles decreases stability to the point where first strikes fall to zero. Making the defenses larger could effect that transition at a larger number of missiles. A judicious increase in

defenses and decrease in offenses should effect that transition with minimum loss of stability during the transition.

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F & S vs SBI

Fig. 1. First and second strikes versus defenses.

Fig. 2. Allocation versus defenses.

Fig. 3. Costs and index versus defenses.

F & S vs M

Fig. 4. First and second strikes versus number of vulnerable (and survivable) missiles.

indices vs M

Fig. 5. Allocation, costs, and index versus number of vulnerable (and survivable) missiles.