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MISSILES, MIRVS, OR INFORMATION - A MODEL FOR COMPARATIVE ASSESSMENT

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20. Continued.

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It was found that a hierarchy exists among the three types of battle information: Attack Damage, Empty Silo and Warning. Conditions for the usefulness of information are shown to be more stringent and not identical to the conditions for an effective counterforce capability. For present forces, with only marginal CFPs, information will not alter the expected outcome of a rational exchange. Information becomes more useful when weapon accuracy, yield or MIRV numbers increase. For large CFPs, some types of information will completely reverse the outcome, thereby, offering a potential deterrence against counterforce attack.

It is further shown that improvements in missile quality cannot compensate for lack in missile quantity; corresponding improvements in silo quality (hardness or defense) are required. When submarine-based SLBMs are introduced, the model shows generally the same trends, although the pay-off for information and the sensitivity to changes in the force parameters are reduced.

MISSILES, MIRVs OR INFORMATION: A MODEL FOR COMPARATIVE ASSESSMENT *

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ABSTRACT

To maintain a strategy of realistic deterrence with a missile force which is by agreement limited and inferior in numbers, one must look for improvements elsewhere. Improved CEP, MIRVs, or the use of battle information are possible options. This paper presents a model and some of the results obtained in the evaluation of such dissimilar alternatives.

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It is further shown that improvements in missile quality cannot compensate for lack in missile quantity; corresponding improvements in silo quality (hardness or defense) are required. When submarine-based SLBMs are introduced, the model shows generally the same trends, although the pay-off for information and the sensitivity to changes in the force parameters are reduced.

INTRODUCTION

Over the last few years two major developments have focused interest on the utility of information in strategic warfare: (1) the achievement of relative force parity between the two major nuclear powers and (2) the agreements reached during the Strategic Arms Limitation Talks (SALT). Published data indicates that the USSR has achieved numerical superiority in the ICBM area and is in the process of catching up with the US in SLBMs. ICBM and SLBM numbers specified by the SALT agreements show inferior levels for the US. It is generally implied that quality and better force utilization can make up for this deficiency.

Our model was developed to help clarify these notions. In particular, the model was aimed at quantitative comparisons between possible force improvements from a counterforce point of view. A unifying concept was sought which could compare such dissimilar alternatives as acquisition of information systems and improvements to the missile force itself. The paper presents the way this was achieved and a sample of the most interesting conclusions.

In addition to freezing force levels, the SALT agreements all but eliminate Ballistic Missile Defense (BMD) as a factor in full scale nuclear war. Our model does not treat BMD explicitly. As will be mentioned later, the effects of BMD can be accounted for indirectly within the model through appropriate interpretation of input parameters.

Force improvements which are not covered by SALT, and are therefore permitted, fall into two categories. The first comprises such characteristics as yield, accuracy (CEP), and silo hardness which determine the kill probability of a warhead against a missile target. Some modest improvements over the present values seem possible in this category.

The second category of improvement comprises the different schemes where multiple warheads are

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delivered by a single missile. In particular, the current US-developed system of multiple independently targetable reentry vehicles (MIRVs) is of interest, as it introduces a leverage factor in counterforce missile warfare. This leverage has a double effect as a weapon and as a target. A single MIRVed missile can attack several silos and, if the opponent also has a MIRVed force, each warhead in turn can destroy several MIRVs in each silo. A rational counterforce missile exchange depends on the existence of such a favorable exchange ratio. MIRVing tends to increase the advantage of a first strike, but constitutes a liability to the side which rides out the attack.

OBJECTIVES FOR THE MODEL

The main objective for our model was a detailed understanding of the premium which a second strike force would put on the use of battle information and of the conditions under which this premium becomes available. In addition to Warning about an impending attack, we examined two other types of information which may be available for a counterforce response: Attack Damage Assessment and Empty Silo information. The first of the two is used to reprogram the surviving warheads so as to achieve the best coverage of the target set while the second is used to concentrate the force against the remaining non-empty silos. Aside from these "pure" cases, situations where more than one type of information is available are of interest. Empty Silo information can be combined with Attack Damage Assessment to more effectively reprogram the surviving warheads onto the remaining targets. Similarly, Empty Silo information can be used with Warning to better focus the counter strike.

Before getting deeper into the description of the model, it seems appropriate to briefly review its potential role among other strategic war models and to look at its limitations. The model concerns itself strictly with counterforce missile war. It can provide good insight into the influence of force characteristics and information over a much wider range of parameter variations than most other models. It fulfills well its prime objective to yield an understanding of basic relationships and trends but care must be exercised as with most analytic models, when conclusions are used for the explicit evaluation of particular system configurations or threat conditions.

Economy of size and running time were prime considerations. Rather than using complex simulation of time and scenario-dependent events, the model calculates the expected outcome of a simple two player, single move, zero sum game. Considerable and, we believe, partly new insight into the nature of counterforce missile warfare was gained through the process of setting-up and solving the analytic expressions which describe the interaction between forces and information.

Extensions of this work seem possible and deserve to be mentioned. In particular, an extension to more than one move, i.e., multiple salvos, the addition of strike assessment information, wave timing, non-uniform launch rates, and timely overlap between attack and response would seem to be of interest. All these extensions require the explicit tracking of time and a much more complex model. As the expected results would have to fall somewhere between the cases which have been already run and are reported here, the reader is left to judge the possible pay-off versus the additional expense.

DESCRIPTION OF THE MODEL

The model evaluates counterforce objectives of two opposing missile forces. Consistently throughout the model the side which makes the first move is labeled RED, the side which responds is labeled BLUE. Each force may contain two types of missiles: Silo-based ICBMs and submarine-based SLBMs. The silos of one side make up the set of targets for the other. Neither side can target SLBMs. Because of their relative vulnerability, ICBMs are exhausted first, before SLBMs are allocated. Target coverage is optimized in a routine which assigns the warheads with the highest kill potential against those targets which have the highest residual survival probability.

Forces for either side are characterized by two sets of three parameters: the number of missiles, the number of warheads per missile and the overall probability of success for an individual warhead against a silo. Independent values can be selected for SLBMs and ICBMs, RED and BLUE. The top of Table 1 shows the twelve parameters which are input to the model. In addition, the table lists two parameters which reflect the operational choice available to both sides.

MODEL INPUTS

(1) FORCE STRUCTURE PARAMETERS	RED	BLUE
NUMBER OF ICBMs	Mr1	Mb1
NUMBER OF MIRVs/ICBM	kr1	kb1
ICBM WARHEAD PROBABILITY OF KILL	pr1	pb1
NUMBER OF SLBMs	Mr2	Mb2
NUMBER OF MIRVs/SLBM	kr2	kb2
SLBM WARHEAD PROBABILITY OF KILL	pr2	pb2
(2) FORCE EMPLOYMENT PARAMETERS		
FRACTION OF FORCE TO BE USED	fr	fb

Table 1

The three pure and two combined types of information incorporated in the model have been mentioned above. They are input to the model in the form of a three digit binary number. Table 2 lists abbreviations and codes used.

MODEL INPUTS (CONT'D)

(3) TYPE OF INFORMATION AND USE	ABBR.	CODE
BLUE HAS NO INFO EXECUTES PREPLANNED OPTION	O	000
BLUE HAS EMPTY SILO INFO REPROGRAMS REMAINING TARGETS	E	001
BLUE HAS ATTACK DAMAGE INFO REPROGRAMS SURVIVING FORCE	A	010
BLUE HAS WARNING INFO LAUNCHES PRIOR TO ATTACK IMPACT	W	100
BLUE HAS ATTACK DAMAGE AND EMPTY SILO INFO REPROGRAMS FORCE AND TARGETS	A&E	011
BLUE HAS WARNING AND EMPTY SILO INFO LAUNCHES PRIOR TO IMPACT ON REMAINING TARGETS	W&E	101

Table 2

MEASURES OF OUTCOME

Many different measures characterize the result of a counterforce exchange: the sizes of the remaining forces, their difference, the number of warheads above a certain minimum to be reserved for countervalue, etc. are all of interest. We found that the ratio of the surviving forces is a most meaningful measure from a counterforce point of view. The ratio must, however, be normalized by its original, prehostility value so that it becomes independent of variations in force size. As Table 3 shows, this normalized force ratio can also be interpreted as a "change in force ratios" which results from the exchange. This measure has been used in most runs and for the optimization routines of the model.

MEASURES OF OUTCOME

MEASURE	
SURVIVING FORCES SIZES	Sr, Sb
SURVIVING FORCE RATIO	Sr/Sb
NORMALIZED FORCE RATIO	$\frac{Sr/Mr}{Sb/Mb}$
"CHANGE IN FORCE RATIO"	$\frac{Sr/Sb}{Mr/Mb}$
RELATIVE FORCE DIFFERENCE	$\frac{Sr - Sb}{Sr + Sb}$
"CHANGE IN FORCE DIFFERENCE"	$\frac{Sr-Sb}{Sr+Sb} : \frac{Mr-Mb}{Mr+Mb}$

Table 3

Other measures such as the ratio of the surviving forces, their difference, normalized by the total number of remaining missiles, etc. are available as optional outputs and have been used to check the sensitivity of the results to the particular choice of measure.

RESULTS FROM THE MODEL

Up to this point we have considered the outcome of a single exchange. For a given force structure, results may drastically differ with the force fractions used on both sides. To obtain a quick overview for the entire field of possible force employment options, we used a tabular representation as shown on the left in Figure 1. The force fractions for RED and BLUE increase along the x and y-dimensions. The content of the table represents the z-dimension and is the value of the force ratio change. The origin corresponds to prehostility conditions; along the bottom, RED attacks and BLUE does not respond counterforce. The opposite is true along the left edge of the figure: RED has not attacked counterforce but BLUE launches. In the upper right corner, both forces have been fully exhausted.

In Figure 2 we have tabulated the expected outcome for the exchange of any force fractions between two equal, moderately MIRVed ICBM forces. Note that the z-function at the right margin, where RED has used all its missiles, is zero and inversely, at the top, tends toward infinity when BLUE has exhausted its arsenal. This is shown by the entry of 8888 in the computer print-out. Note also that z values below 1.0 represent a favorable outcome for BLUE. They are generally found on the right but also on the left side of the table. RED benefits where the entries are greater than 1.0, generally in the middle and upper portion of the table.

Figure 3 shows what happens when SLBMs are added to the ICBM forces. Generally, the same trends are observed, although the magnitude of the effects is reduced. This will be discussed in detail later on.

To obtain easy visual representation we devised a 3-D display format, as shown in Figure 4. Here x and y are again the RED and BLUE force fractions, but for the vertical dimension we used the logarithm of the z-function to obtain graphical symmetry between RED and BLUE. The plot is truncated on the top and bottom when the ratio exceeds 10 (or ± 10 db), as this represents an already lopsided result for any counterforce exchange. A neutral outcome (z = 1.0) would be found in the median plane of the "cube".

Depending on the size and characteristics of the forces, some interesting topological features can be observed. We note that valleys below the level of the origin are favorable to BLUE and hills above the origin are favorable to RED. BLUE has a choice of moving from the front towards the rear of the cube, while RED moves from the left to the right. In the far rear there is always "a RED wall" while on the extreme right we have "deep BLUE water".

MODEL OUTPUTS

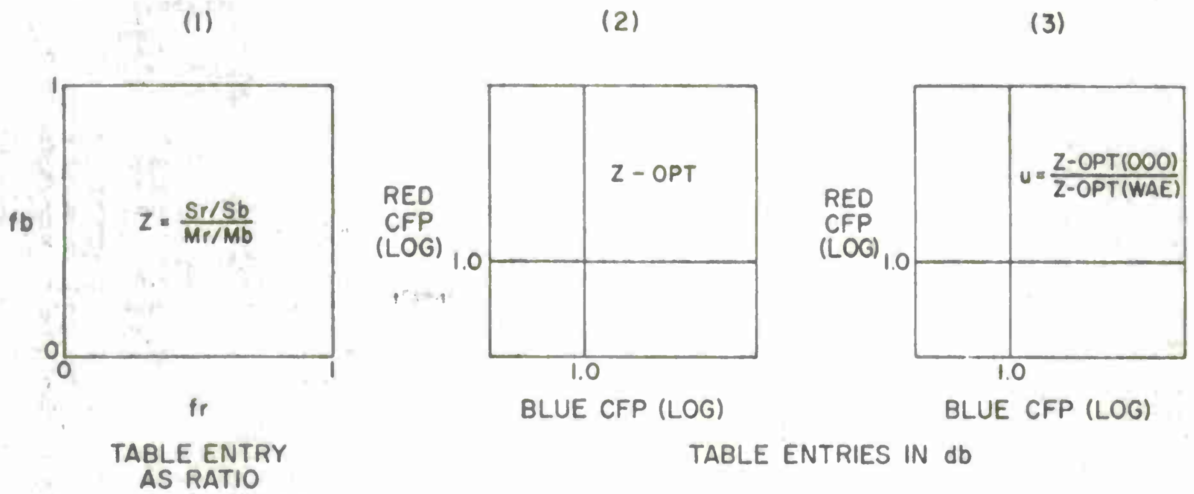


Figure 1

```
CASE  000:            RED:             BLUE:

MISSILES(SILO):       Mr1=  1000       Mb1=  1000
WHDS/MISSILE   :      kr1=   3.0       kb1=   3.0
PK(WHD/TGT)    :      pr1=   .50       pb1=   .50

MISSILES(SUBM):       Mr2=     0       Mb2=     0
WHDS/MISSILE   :      kr2=    .0       kb2=    .0
PK(WHD/TGT)    :      pr2=   .00       pb2=   .00
```

fb:	fr= .0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
1.0	8888	8888	8888	8888	8888	8888	8888	8888	8888	8888	1
.9	1.63	2.46	3.65	5.40	6.75	7.65	8.62	8.99	7.53	4.90	0
.8	1.00	1.45	2.08	2.98	3.64	4.07	4.53	4.67	3.89	2.51	0
.7	.79	1.12	1.55	2.17	2.61	2.88	3.16	3.23	2.67	1.72	0
.6	.75	1.00	1.34	1.80	2.12	2.30	2.49	2.52	2.07	1.32	0
.5	.75	.96	1.23	1.59	1.83	1.96	2.10	2.09	1.71	1.08	0
.4	.75	.93	1.15	1.45	1.64	1.74	1.83	1.81	1.47	.93	0
.3	.79	.93	1.12	1.37	1.52	1.58	1.65	1.61	1.30	.81	0
.2	.88	.99	1.13	1.33	1.44	1.48	1.52	1.47	1.18	.73	0
.1	.94	1.03	1.14	1.30	1.38	1.40	1.41	1.35	1.08	.67	0
.0	1.00	1.06	1.14	1.27	1.33	1.33	1.33	1.26	1.00	.62	0
fb:	fr= .0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Figure 2

CASE 000:	RED:		BLUE:	
MISSILES(SILO):	Mr1=	1000	Mb1=	1000
WHDS/MISSILE :	kr1=	3.0	kb1=	3.0
PK(WHD/TGT) :	pr1=	.50	pb1=	.50
MISSILES(SUBM):	Mr2=	500	Mb2=	500
WHDS/MISSILE :	kr2=	1.0	kb2=	1.0
PK(WHD/TGT) :	pr2=	.50	pb2=	.50

fb:	fr= .0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
1.0	8888	8888	8888	8888	8888	8888	8888	8888	8888	8888	1
.9	4.02	4.38	4.74	4.77	4.62	4.26	3.74	3.00	2.00	1.00	0
.8	2.04	2.24	2.45	2.47	2.38	2.18	1.89	1.50	1.00	.50	0
.7	1.38	1.53	1.69	1.70	1.64	1.49	1.28	1.00	.67	.33	0
.6	1.10	1.27	1.44	1.47	1.43	1.31	1.12	.88	.59	.29	0
.5	.96	1.14	1.32	1.37	1.35	1.25	1.08	.85	.57	.29	0
.4	.89	1.06	1.24	1.30	1.29	1.20	1.04	.82	.55	.23	0
.3	.87	1.03	1.19	1.25	1.24	1.15	1.00	.79	.53	.27	0
.2	.88	1.01	1.16	1.20	1.19	1.11	.97	.77	.52	.26	0
.1	.94	1.04	1.15	1.17	1.16	1.08	.93	.75	.50	.26	0
.0	1.00	1.06	1.14	1.15	1.13	1.04	.91	.72	.49	.25	0
fb:	fr= .0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0

Figure 3

Most interesting is the behavior at the origin. If the surface slopes down to the right and up towards the rear, we obtain a very stable situation. Both parties stand to lose from a counterforce move. The opposite is true when the slopes are reversed. In this case both sides find an incentive in striking first. This is a "trigger-happy" situation which is held in check only by considerations outside the scope of our model. It seems clear, however, that small scale counterforce operations (small excursions from the origin) would hardly be feasible unless the slope is fairly flat at this point in both directions. This case is labeled INDIFFERENT on Figure 5 which illustrates a number of typical topologies. Of interest is also the PREVENTIVE case, where RED has an incentive to attack first in spite of the fact that it has an inferior force. In situations of this kind, RED stands to lose more when it waits until BLUE makes the first move. In an effort to get better insight into these relationships, we derived analytic expressions for the slope of the z-surface. An example for homogeneous forces without information is as follows:

DERIVATIVES OF THE z-FUNCTION

$$\frac{\partial z}{\partial x} = \frac{(1\text{-fb}).\,pr.\,kr.\,Mr/Mb - (1\text{-}pb.\,kb.\,(1\text{-fb}).\,Sb/Mr)}{(1\text{-fr}).\,(Sb/Mb)^2}$$

$$\frac{\partial z}{\partial y} = \frac{(1\text{-fb}).\,(1\text{-}pb.\,kb.\,Sb/Mr)}{(1\text{-fr})^2.\,(Sb/Mb)}$$

with x = fr, y = fb, and z = (Sr/Mr)/(Sb/Mb)

Using the proper expression for Sb these equations become rather involved and generally are not solvable in closed form. However, at the origin where Sb = Mb explicit solutions have been obtained. They lead to an unexpectedly simple result and the definition of two composite parameters which turned out to play a powerful role in describing the counterforce capabilities of the opposing missile forces. Appropriately, we called them the RED and BLUE COUNTER FORCE POTENTIAL (CFP). Their mathematical definition is shown below.

3-D PLOT

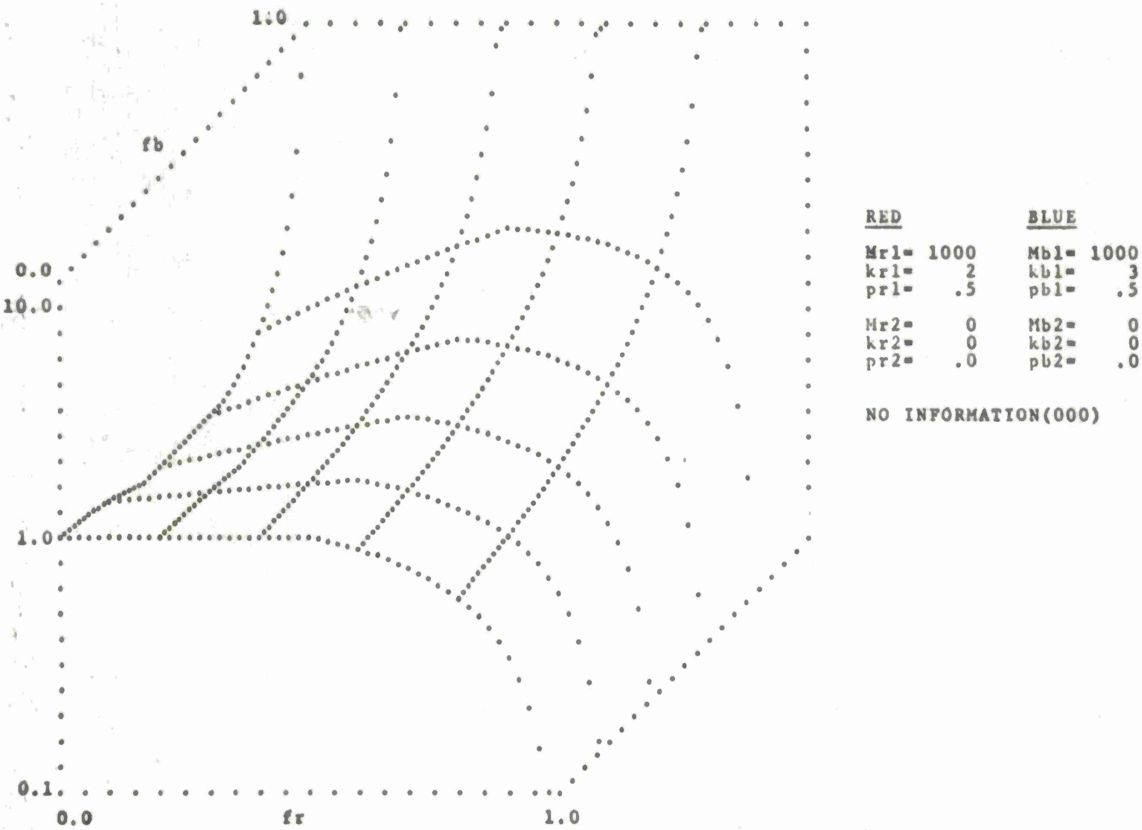


Figure 4

DEFINITION OF COUNTER FORCE POTENTIALS

$$\text{RED CFP} = \frac{Mr.kr.pr}{Mb}$$

$$\text{BLUE CFP} = \frac{Mb.kb.pb}{Mr}$$

STABILITY CRITERIA IN TERMS OF CFP

CONDITION	RED		BLUE
STABLE	CFP ≤ 1	and	CFP ≤ 1
INDIFFERENT	CFP = 1	and	CFP = 1
UNSTABLE	CFP ≥ 1	or	CFP ≥ 1

The power of the CFP concept reaches beyond the area of limited force operations near the origin of the z-plot. In fact, the two CFP numbers characterize the capability of the forces over the entire field of counter-force operations and do this independently of detailed force characteristics. We felt justified in giving it the following interpretation.

INTERPRETATION OF CFP

A missile force "has a counterforce potential" against an enemy missile force if, and only if, it contains more than one effective (ICBM) warhead for each enemy silo.

OPTIMUM ENCOUNTERS

In choosing force fractions for counterforce employment, both sides would want to maximize the resulting force ratio change in their favor. RED will choose his force fraction so as to maximize the z-function; BLUE tries to minimize it. RED must take into account that BLUE can make his choice after RED has made his commitment. In each case, assuming that both sides have knowledge about the forces involved, an optimum, mutually enforceable strategy evolves. The outcome represents a MIN/MAX solution for the game and a saddle point on the 3-D graphs. Figure 6 shows such a case.

TYPICAL TOPOLOGICAL CASES

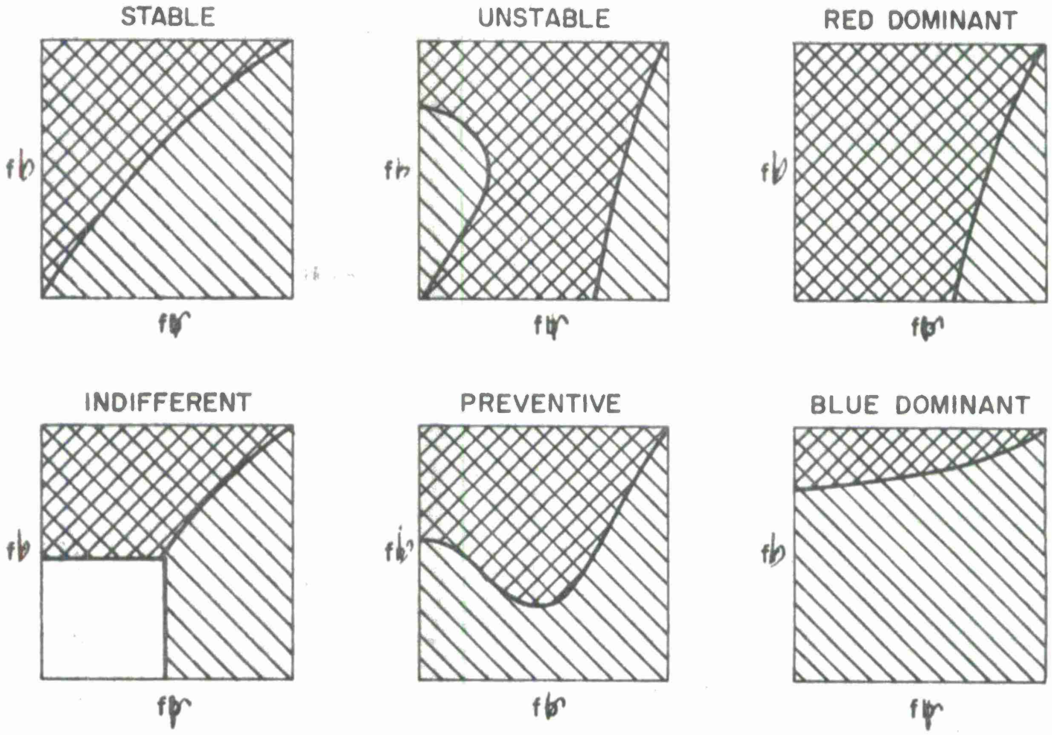


Figure 5

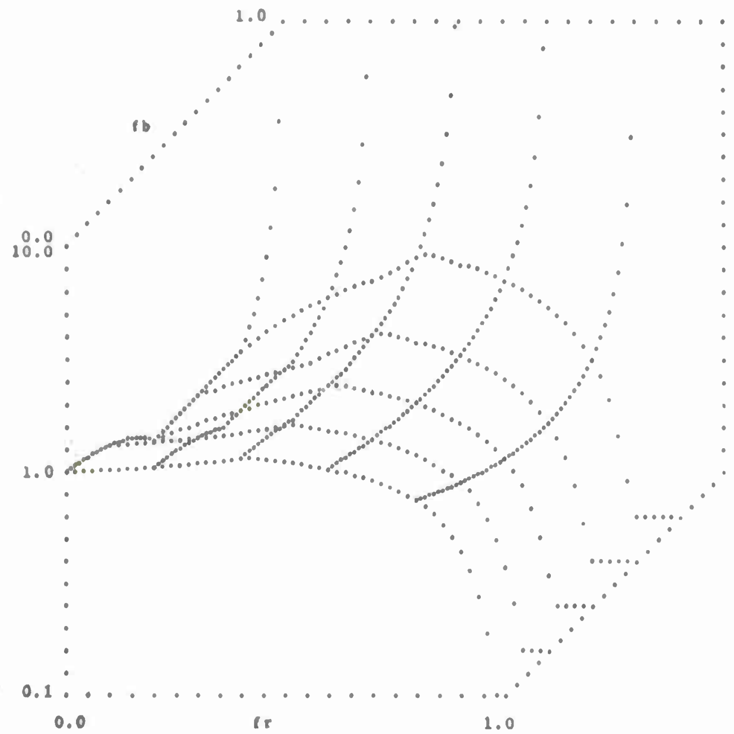
Calculation of the MIN/MAX solution would seem to be straight-forward. Let me point out, however, that it is not. Examination of all possible points with the desired fineness in x and y is prohibitive in time, even on a fast digital machine. Standard MIN/MAX routines fail because we are not dealing with a uniform analytical surface over the entire field. The need to assign only integer warheads against targets breaks the field into many individual subfields, each with its own analytic form. Shape and size of the subfields vary with force parameters as well as with information. We finally developed a reasonably fast search routine which was used to obtain accuracies in x and y down to 0.2% of the full force levels.

After a number of runs with different force structures, we were faced with a considerable stack of these xyz-tables and plots. It became apparent that a more compact form of display for all this data was needed. Fortunately, the previously mentioned concept of CFPs turned out to be of great help when we plotted the optimum outcome (z-function at the MIN/MAX point), z-OPT, against the BLUE and RED CFP. As it turned out, and not entirely unexpected, the lines where the CFPs are equal to one divide the plot into four distinct regions. The center of Figure 1 illustrates the configuration of these tables. Actual computer printouts for force levels as agreed to in SALT, with arbitrarily assumed MIRV numbers k and selected types of information, are shown in Figures 7 through 9. Note that the z-OPT values are in db and that the warhead success probability p has been used to vary the CFP over the full range of practical interest. An even wider range is covered in Figures 10 through 12, where the MIRV numbers k are used to vary the CFP, while p is held at 0.4.

Basic features of these CFP plots are rather independent of specific force compositions. As long as the CFPs are the same, it does not matter what values the individual parameters such as M, k, and p have. For small excursions from a given point, and to a linear approximation, these force parameters can be traded in accordance with their relationship in the CFP.

Figure 13 translates this fact into terminology which is familiar from ballistic missile improvement

3-D PLOT



RED

Mr1= 1200
kr1= 2
pr1= .50

Mr2= 0
kr2= 0
pr2= .00

BLUE

Mb1= 1000
kb1= 3
pb1= .67

Mb2= 0
kb2= 0
pb2= .00

EMPTY SILO INFORMATION(001)

Figure 6

CASE 000:	RED:		BLUE:	
MISSILES(SILO):	Mr1=	1700	Mb1=	1000
WHDS/MISSILE :	kr1=	2.5	kb1=	5.0
MISSILES(SUBM):	Mr2=	700	Mb2=	600
WHDS/MISSILE :	kr2=	2.5	kb2=	5.0

FORCE RATIO CHANGE AS RESULT OF OPTIMUM CF-EXCHANGE (RED:BLUE IN db)

pr:	cr:	cb= / pb=	.37 / .125	.46 / .157	.58 / .198	.74 / .250	.93 / .315	1.17 / .397	1.47 / .500	1.85 / .630	2.33 / .794
.794	3.38		2.201	2.201	2.201	2.201	2.201	2.201	2.201	2.201	2.201
.630	2.36		1.605	1.605	1.605	1.605	1.605	1.605	1.605	1.605	1.605
.500	1.88		.983	.983	.983	.983	.983	.983	.983	.983	.927
.397	1.49		.445	.445	.445	.445	.445	.445	.445	.438	.265
.315	1.18		.158	.158	.158	.158	.158	.158	.052	-.101	-.329
.250	.94		.000	.000	.000	.000	.000	-.074	-.320	-.560	-.851
.198	.75		.000	.000	.000	.000	.000	-.283	-.590	-.937	-1.290
.157	.59		.000	.000	.000	.000	.000	-.395	-.768	-1.209	-1.662
.125	.47		.000	.000	.000	.000	.000	-.395	-.862	-1.385	-1.965

Figure 7

CASE 011:	RED:		BLUE:	
MISSILES(SILO):	Mr1=	1700	Mb1=	1000
WHDS/MISSILE :	kr1=	2.5	kb1=	5.0
MISSILES(SUBM):	Mr2=	700	Mb2=	600
WHDS/MISSILE :	kr2=	2.5	kb2=	5.0

FORCE RATIO CHANGE AS RESULT OF OPTIMUM CF-EXCHANGE (RED:BLUE IN db)

pr:	cr:	cb= pb=	.37 .125	.46 .157	.58 .198	.74 .250	.93 .315	1.17 .397	1.47 .500	1.85 .630	2.33 .794
.794	3.38		2.201	2.201	2.201	2.201	2.201	2.201	2.198	2.117	2.011
.630	2.36		1.605	1.605	1.605	1.605	1.605	1.605	1.452	1.133	.697
.500	1.88		.983	.983	.983	.983	.983	.920	.584	.120	-.550
.397	1.49		.445	.445	.445	.445	.445	.241	.097	-.560	-1.232
.315	1.18		.158	.158	.158	.158	.145	-.155	-.565	-1.113	-1.778
.250	.94		.000	.000	.000	.000	.000	-.395	-.846	-1.518	-2.211
.198	.75		.000	.000	.000	.000	.000	-.395	-.888	-1.701	-2.480
.157	.59		.000	.000	.000	.000	.000	-.395	-.888	-1.701	-2.549
.125	.47		.000	.000	.000	.000	.000	-.395	-.888	-1.701	-2.549

Figure 8

CASE 100:	RED:		BLUE:	
MISSILES(SILO):	Mr1=	1700	Mb1=	1000
WHDS/MISSILE :	kr1=	2.5	kb1=	5.0
MISSILES(SUBM):	Mr2=	700	Mb2=	600
WHDS/MISSILE :	kr2=	2.5	kb2=	5.0

FORCE RATIO CHANGE AS RESULT OF OPTIMUM CF-EXCHANGE (RED:BLUE IN db)

pr:	cr:	cb= pb=	.37 .125	.46 .157	.58 .198	.74 .250	.93 .315	1.17 .397	1.47 .500	1.85 .630	2.33 .794
.794	3.38		2.188	2.103	1.855	1.501	1.045	.508	-.092	-.645	-1.024
.630	2.36		1.578	1.501	1.386	1.216	..810	.366	-.209	-.752	-1.079
.500	1.88		.983	.983	.941	.795	.573	.124	-.424	-.931	-1.215
.397	1.49		.445	.445	.445	.445	.261	-.061	-.645	-1.158	-1.439
.315	1.18		.158	.158	.158	.158	.035	-.269	-.788	-1.355	-1.811
.250	.94		.000	.000	.000	.000	.000	-.395	-.888	-1.524	-2.147
.198	.75		.000	.000	.000	.000	.000	-.395	-.888	-1.656	-2.388
.157	.59		.000	.000	.000	.000	.000	-.395	-.888	-1.701	-2.534
.125	.47		.000	.000	.000	.000	.000	-.395	-.888	-1.701	-2.549

Figure 9

CASE 000:	RED:	BLUE:
MISSILES(SILO):	Mr1= 1700	Mb1= 1000
PK/WARHEAD :	pr1= .400	pb1= .400
MISSILES(SUBM):	Mr2= 700	Mb2= 600
PK/WARHEAD :	pr2= .400	pb2= .400

FORCE RATIO CHANGE AS RESULT OF OPTIMUM CF·EXCH (RED:BLUE IN db)

kr:	cr:	cb= / kb=	.29 / 1.25	.59 / 2.50	1.18 / 5.00	2.35 / 10.00	4.71 / 20.00	9.41 / 40.00	18.82 / 80.00
80.00	54.40		3.983	3.983	3.983	3.983	3.951	3.919	3.886
40.00	24.00		3.762	3.762	3.762	3.762	3.699	3.632	3.562
20.00	12.00		3.376	3.376	3.376	3.376	3.246	3.098	[illegible]
10.00	6.00		2.715	2.715	2.715	2.715	2.443	2.127	1.798
5.00	3.00		1.675	1.675	1.675	1.654	1.199	[illegible]	.029
2.50	1.50		.458	.458	.458	.342	[illegible]	-.887	[illegible]
1.25	.75		.000	.000	-.279	-.830	[illegible]	[illegible]	-2.658

Figure 10

CASE 011:	RED:	BLUE:
MISSILES(SILO):	Mr1= 1700	Mb1= 1000
PK/WARHEAD :	pr1= .400	pb1= .400
MISSILES(SUBM):	Mr2= 700	Mb2= 600
PK/WARHEAD :	pr2= .400	pb2= .400

FORCE RATIO CHANGE AS RESULT OF OPTIMUM CF·EXCH (RED:BLUE IN db)

kr:	cr:	cb= / kb=	.29 / 1.25	.59 / 2.50	1.18 / 5.00	2.35 / 10.00	4.71 / 20.00	9.41 / 40.00	18.82 / 80.00
80.00	54.40		3.983	3.983	3.983	3.980	3.947	3.914	3.881
40.00	24.00		3.762	3.762	3.762	3.751	3.682	3.611	3.539
20.00	12.00		3.376	3.376	3.376	3.331	3.175	3.017	[illegible]
10.00	6.00		2.715	2.715	2.715	2.535	2.148	[illegible]	1.221
5.00	3.00		1.675	1.675	1.675	1.044	[illegible]	[illegible]	-1.025
2.50	1.50		.458	.458	.253	[illegible]	[illegible]	-1.821	-1.860
1.25	.75		.000	.000	-.408	[illegible]	[illegible]	[illegible]	-3.047

Figure 11

CASE 100:	RED:		BLUE:	
MISSILES(SILO):	Nr1=	1700	Nb1=	1000
PK/WARHEAD :	pr1=	.400	pb1=	.400
MISSILES(SUBM):	Nr2=	700	Nb2=	600
PK/WARHEAD :	pr2=	.400	pb2=	.400

FORCE RATIO CHANGE AS RESULT OF OPTIMUM CF•EXCH (RED:BLUE IN db)

kr:	cr:	cb= kb=	.29 1.25	.59 2.50	1.18 5.00	2.35 10.00	4.71 20.00	9.41 40.00	18.82 80.00
80.00	54.40		3.169	2.247	.737	-.600	-1.065	-1.090	-1.090
40.00	24.00		3.111	2.224	.756	-.598	-1.067	-1.090	-1.090
20.00	12.00		2.932	2.038	.709	-.632	-1.070	-1.090	-1.090
10.00	6.00		2.576	1.859	.617	-.681	-1.078	-1.091	-1.091
5.00	3.00		1.675	1.397	.372	-.815	-1.121	-1.158	-1.173
2.50	1.50		.458	.458	.073	-1.179	-1.594	-1.727	-1.798
1.25	.75		.000	.000	.408	-1.758	-2.519	-2.784	-2.911

Figure 12

EFFECT OF FORCE STRUCTURE CHANGES

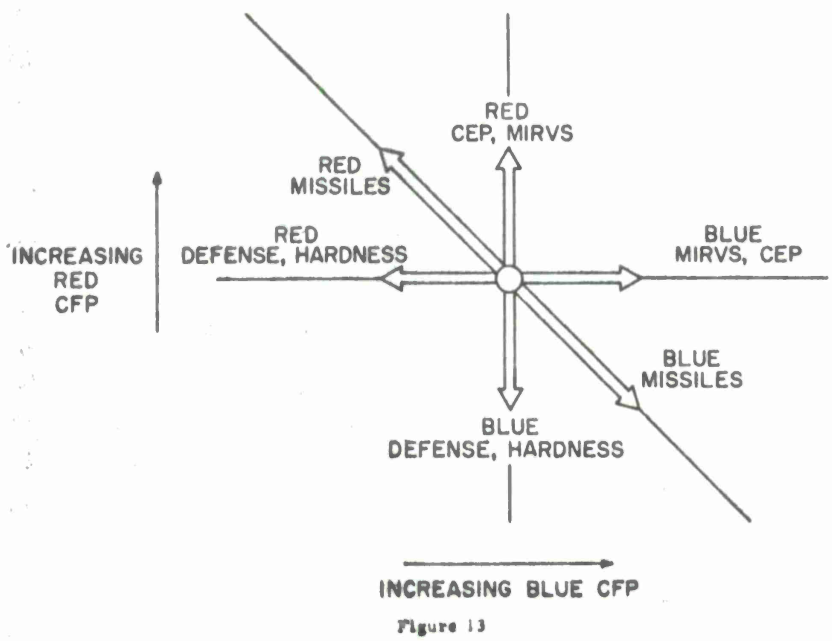


Figure 13

concepts. Factors which increase k (MIRVs) and p (CEP) for BLUE, work toward the right; the same factors for RED drive the game upwards. The addition of silo defense by BLUE tends to reduce the success probability p for RED and hence, moves the point down on the plot. Note that similar moves by RED and BLUE in k and p do not compensate for each other. Mutual MIRVing, for example, may maintain some form of balance but will move both sides towards more unstable territory in the upper right.

The case is different for the force size parameter M. Here, corresponding changes will cancel. A one sided force increase, however, has a dual effect and cannot be compensated for by either MIRVing or defense alone. To a first order approximation, a 10% numerical advantage on one side would require a 10% higher MIRV ratio and a 10% higher silo survivability as compensation on the other side.

It seems worth-while to reflect a moment on a historical perspective of missile force development between the US and USSR. Figure 14 shows this in terms of the CFPs of the two forces. Because we are here concerned with the United States using information in a second strike role, US forces have been labeled BLUE and USSR forces RED. The dominant position of the US at the time of the Cuban crisis can readily be seen. The increase in CFP for the USSR (up) and the decrease for the US (left) to the force levels agreed upon in SALT is largely the result of the Russian build-up in missile numbers. Other changes, such as SLBM levels, CEP, yield, etc., contribute, but to a lesser extent. Of particular interest is the position which may be reached through MIRVing which is permitted by SALT. A nominal average k of 2.5 has been used to illustrate this situation.

Figure 15 uses again a schematic representation to illustrate another general feature of the CFP/CFP plots. As before, the "cross hairs" represent the critical CFP values of 1.0. Curved lines represent 1 db (25%) contours for z-OPT (each line representing approximately 25% improvement); positive db-numbers indicate an advantage for RED, negative numbers an advantage for BLUE. Changes of 3 db or more, either way, reflect annihilation of ICBM targets. In the lower left corner, where neither side has a Counter Force Potential, we find again the "stable plateau".

The upper row of charts represents the data from Figures 10 through 12 and shows the case of most

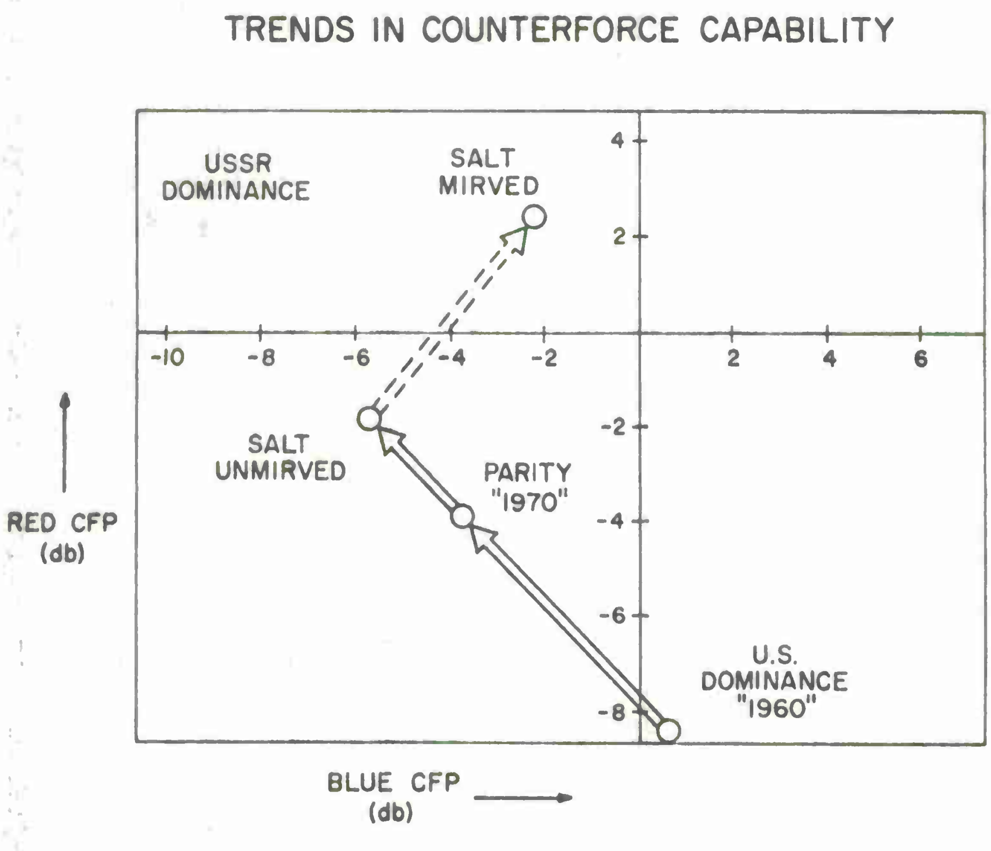


Figure 14

EFFECT OF SLBM/ICBM RATIO

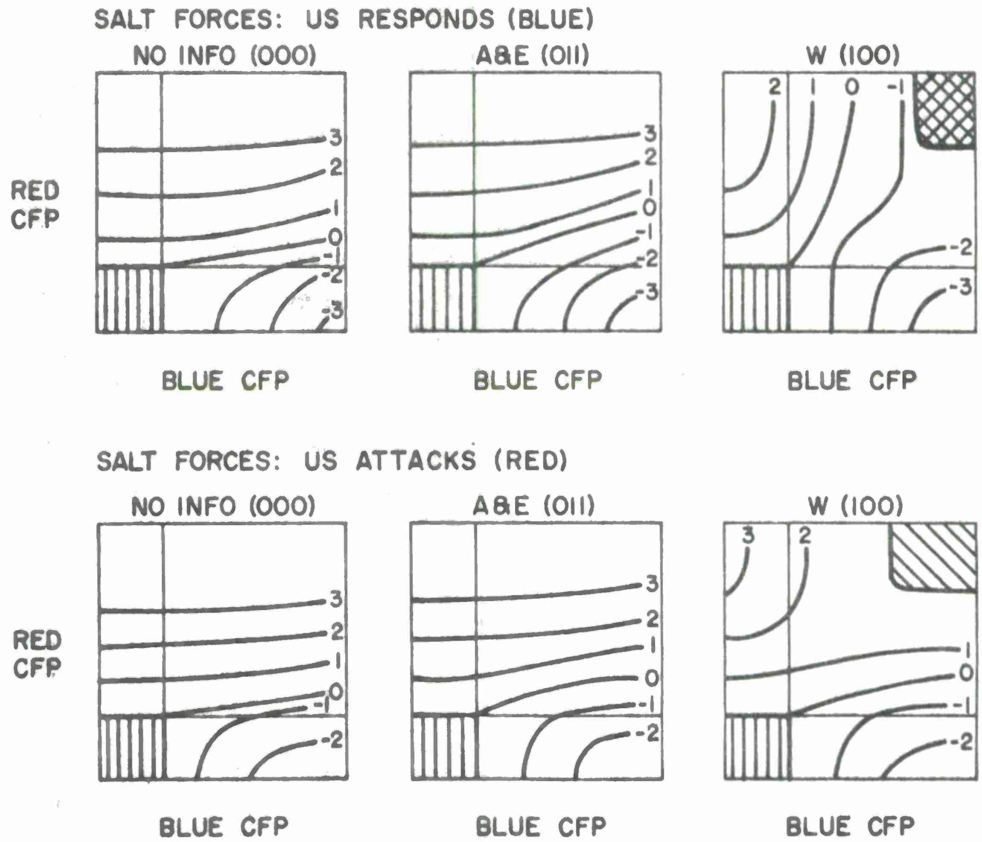


Figure 15

interest where the USSR attacks (RED) and the US responds (BLUE). In the lower row of charts the roles of the two forces are reversed, i.e., the US is RED and the USSR is BLUE. Positive z-OPT values are now favorable to the US and the USSR makes use of information.

Note that for all cases information is of use only within and closely around the upper right quadrant; combined attack damage and empty silo information is of only marginal use to either side; and even warning information will not be of much use to the USSR, except when both forces are heavily MIRVed (upper right corner).

An interesting feature, albeit of academic consequence, is the "plateau of mutual annihilation" which develops with warning in the upper right corner. Here both forces are reduced to their SLBM levels (which are invulnerable in the model). The plateau's "elevation" is essentially determined by the ratio of the SLBM versus the original ICBM and SLBM forces. For SALT forces, this ratio is favorable to the US, hence the plateau is negative (BLUE) in the top and positive (RED) in the bottom row of plots. The same effect influences the value of warning.

As can be seen by comparison of the 0 db lines from the upper plots, there is a significant wedge, generally around "force parity", where proper action by BLUE, in accordance with accurate information about the attack, can turn the expected outcome around from being favorable to RED towards being favorable to BLUE. In principle, and over a small region of CFPs this is true for any information, however, the effect is significant only for warning.

When we examine for a given force structure a set of such z-OPT plots for all types of information we find them generally in a certain order of utility. Each type of information listed in Table 4 is generally more and never less beneficial than the one below.

GENERAL HIERARCHY OF INFORMATION

(101)	Warning and Empty Silo
(100)	Warning
(011)	Attack Damage and Empty Silo
(001)	Empty Silo
(010)	Attack Damage
(000)	No Information

Table 4

This hierarchy holds true except for a limited range of situations where BLUE has a superior force and RED's CFP is close to 1.0. In this case Empty Silo information may be marginally more effective than Warning. The hierarchy seems to be very general indeed. It holds not only at the MIN/MAX point but for non-optimized encounters as well. None of the many z or z-OPT printouts which we made showed any exceptions than the one mentioned above.

A third output format, as shown on the right in Figure 1, has been used to examine in detail the benefits which BLUE can derive from the use of information. Table entries in the already familiar CFP frame now represent the ratio between the optimum outcome which BLUE can obtain without and with the use of information. Both outcomes are calculated independently as MIN/MAX solutions in the manner described for z-OPT. RED is assumed to know what type of information will be available to BLUE. BLUE's benefits can directly be read in decibels. For the reader who is not familiar with this convenient measure for ratios, Table 5 provides an approximate translation.

db	RATIO	db	RATIO
-9	.13	1	1.26
-8	.16	2	1.59
-7	.20	3	2.00
-6	.25	4	2.51
-5	.32	5	3.16
-4	.40	6	3.98
-3	.50	7	5.01
-2	.63	8	6.31
-1	.79	9	7.94
-0	1.00	10	10.00

Table 5

Figures 16 through 20 show detailed printouts of the benefits available from specific information. For each case the entries are calculated relative to the base case (000), where no information is available. SALT forces have been used; the overall warhead success probability has again been set to 0.4; and MIRV numbers are the driving variable for the CFPs. Contour lines have been drawn on these figures at 1 db (25%) intervals.

At this point it is worth-while to recall from Figure 14 that moderate MIRVing of SALT level forces moves the RED CFP slightly beyond 1.0, but leaves the BLUE CFP below that critical value. As Figures 16 through 20 plainly indicate, information is of little use to improve BLUE's counterforce position under these conditions. Larger MIRV numbers, such as k = 5 to 10, and/or significantly higher success probabilities, such as p = 0.8 or more, would be required to alter this conclusion. A word of caution is necessary. A mutual escalation of this kind, i.e., a diagonal move from the current position towards the upper right, will not make information more useful to BLUE except in the case of Warning. With CFPs around 4, both sides are rapidly approaching the point where a counterforce exchange will lead to the annihilation of ICBM forces. If BLUE has warning both will be annihilated. Without warning, BLUE's ICBM force would be eliminated before it could strike back and annihilate the remaining RED ICBMs.

To keep proper perspective, one must not lose sight of other limitations on a decision to launch on warning. It is also significant that the number of RED warheads detonating over BLUE would be large, and BLUE's retaliatory SLBM capability untouched, under any condition. Although such considerations belong to the broader realm of countervalue and retaliation, and transcend the scope of a counterforce model, they cannot be ignored when one draws final conclusions.

SUMMARY

The major results of the work which is discussed in this paper can be summarized in the following points:

(1) A simple model of counterforce missile warfare has been developed. Two opposing ICBM/SLBM forces are described by their basic properties: the number of missiles, the number of MIRVs per missile, and the overall probability of success for a warhead against a silo. Estimated outcomes of mutually enforceable, optimum encounters are derived over a wide range of variations in force characteristics. Results are compared when different combinations of warning, attack damage, and empty silo information are available. Expected force ratio changes, as well as benefits available from the use of information, can be directly read from the presented printouts for SALT level forces.

(2) The model operates on a small, desk-top computer with 2K 8-bit word memory. Other force levels and/or many special cases can be evaluated with little expense or time.

(3) General rules for the counterforce capabilities of two opposing missile forces as well as for the utility of information were found through use of the model. Analytic expressions used in the model lead to the definition of two simple parameters called COUNTER FORCE POTENTIALS (CFP) which govern the likely outcome of optimum exchanges between the two forces. The CFP of a missile force is defined as the ratio of the number of "effective" (ICBM) warheads to the number of targets (Silos) on the other side.

(4) General trends and behavior of counterforce exchanges can well be portrayed and analyzed in terms of the Counter Force Potentials. This reduces the

CASE 000/010 RED: BLUE:

MISSILES(SILO): Mr1= 1700 Mb1= 1000
PK/WARHEAD : pr1= .400 pb1= .400

MISSILES(SUBM): Mr2= 700 Mb2= 600
PK/WARHEAD : pr2= .400 pb2= .400

VALUE OF INFO IN AN OPTIMUM CF-EXCHANGE IN db

kr:	cr:	cb= .29 kb= 1.25	.59 2.50	1.18 5.00	2.35 10.00	4.71 20.00	9.41 40.00	18.82 80.00
80.00	54.40	.000	.000	.000	.000	.000	.000	.000
40.00	24.00	.000	.000	.000	.000	.001	.002	.002
20.00	12.00	.000	.000	.000	.000	.008	.011	.007
10.00	6.00	.000	.000	.000	.002	.036	.033	.042
5.00	3.00	.000	.000	.000	.000	.179	.170	.189
2.50	1.50	.000	.000	.000	.144	.136	.146	.086
1.25	.75	.000	.000	.001	.121	.114	.079	.047

Figure 16

CASE 000/001 RED: BLUE:

MISSILES(SILO): Mr1= 1700 Mb1= 1000
PK/WARHEAD : pr1= .400 pb1= .400

MISSILES(SUBM): Mr2= 700 Mb2= 600
PK/WARHEAD : pr2= .400 pb2= .400

VALUE OF INFO IN AN OPTIMUM CF-EXCHANGE IN db

kr:	cr:	cb= .29 kb= 1.25	.59 2.50	1.18 5.00	2.35 10.00	4.71 20.00	9.41 40.00	18.82 80.00
80.00	54.40	.000	.000	.000	.002	.004	.004	.005
40.00	24.00	.000	.000	.000	.010	.015	.019	.021
20.00	12.00	.000	.000	.000	.037	.066	.072	.086
10.00	6.00	.000	.000	.000	.144	.235	.313	.427
5.00	3.00	.000	.000	.000	.413	.813	1.031	1.055
2.50	1.50	.000	.000	.078	.742	1.056	.885	.526
1.25	.75	.000	.000	.129	.880	.903	.681	.389

Figure 17

CASE 000/011	RED:	BLUE:
MISSILES(SILO):	Mr1= 1700	Mb1= 1000
PK/WARHEAD :	pr1= .400	pb1= .400
MISSILES(SUBM):	Mr2= 700	Mb2= 600
PK/WARHEAD :	pr2= .400	pb2= .400

VALUE OF INFO IN AN OPTIMUM CF·EXCHANGE IN db

kr:	cr:	cb= / kb=	.29 / 1.25	.59 / 2.50	1.18 / 5.00	2.35 / 10.00	4.71 / 20.00	9.41 / 40.00	18.82 / 80.00
80.00	54.40		.000	.000	.000	.003	.005	.005	.006
40.00	24.00		.000	.000	.000	.011	.016	.021	.023
20.00	12.00		.000	.000	.000	.045	.071	.081	.100
10.00	6.00		.000	.000	.000	.160	.300	.403	.527
5.00	3.00		.000	.000	.000	.610	1.059	1.242	1.055
2.50	1.50		.000	.000	.205	.977	1.192	.934	.530
1.25	.75		.000	.000	.129	.970	1.018	.693	.389

Figure 18

CASE 000/100	RED:	BLUE:
MISSILES(SILO):	Mr1= 1700	Mb1= 1000
PK/WARHEAD :	pr1= .400	pb1= .400
MISSILES(SUBM):	Mr2= 700	Mb2= 600
PK/WARHEAD :	pr2= .400	pb2= .400

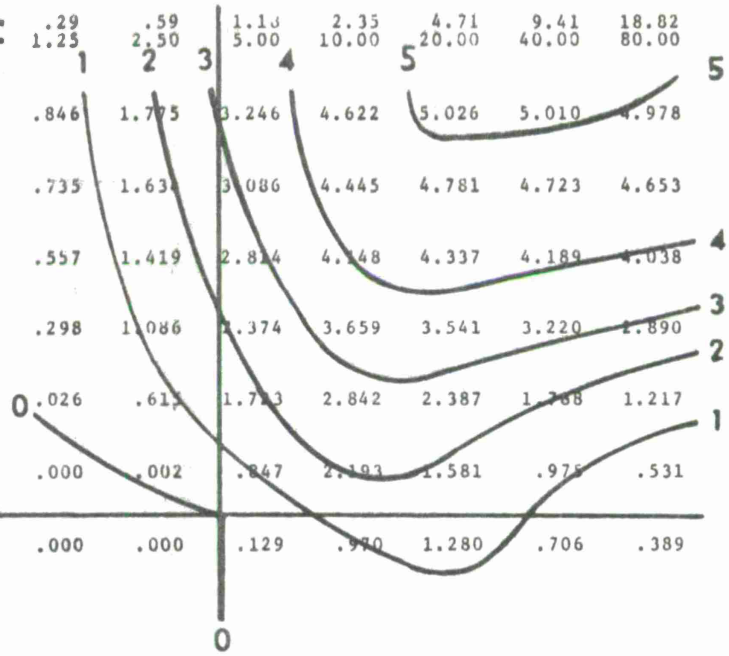
VALUE OF INFO IN AN OPTIMUM CF·EXCHANGE IN db

kr:	cr:	cb= / kb=	.29 / 1.25	.59 / 2.50	1.18 / 5.00	2.35 / 10.00	4.71 / 20.00	9.41 / 40.00	18.82 / 80.00
80.00	54.40		.81[illegible]	1.7[illegible]6	[illegible].206	4.584	5.018	5.010	4.[illegible]78
40.00	24.00		.671	1.568	3.006	4.373	4.767	4.723	4.653
20.00	12.00		.446	[illegible].290	2.608	4.[illegible]09	4.137	4.189	4.038
10.00	6.00		.143	.8[illegible]6	2.098	3.397	3.526	3.219	[illegible].890
5.00	3.00		.000	.278	1.303	2.470	2.321	1.[illegible]	1.203
2.50	1.50		.000	.000	.53[illegible]	1.522	1.313	.840	.466
1.25	.75		.000	.000	.129	.877	.752	.443	.253

Figure 19

CASE 000/101	RED:		BLUE:	
MISSILES(SILO):	Mr1=	1700	Nb1=	1000
PK/WARHEAD :	pr1=	.400	pb1=	.400
MISSILES(SUBM):	Nr2=	700	Nb2=	600
PK/WARHEAD :	pr2=	.400	pb2=	.400

VALUE OF INFO IN AN OPTIMUM CF-EXCHANGE IN db



kr:	cr:	cb= / kb=	.29 / 1.25	.59 / 2.50	1.18 / 5.00	2.35 / 10.00	4.71 / 20.00	9.41 / 40.00	18.82 / 80.00
80.00	54.40		.846	1.775	3.246	4.622	5.026	5.010	4.978
40.00	24.00		.735	1.634	3.086	4.445	4.781	4.723	4.653
20.00	12.00		.557	1.419	2.814	4.148	4.337	4.189	4.038
10.00	6.00		.298	1.086	2.374	3.659	3.541	3.220	2.890
5.00	3.00		.026	.613	1.713	2.842	2.387	1.788	1.217
2.50	1.50		.000	.002	.847	2.193	1.581	.975	.531
1.25	.75		.000	.000	.129	.970	1.280	.706	.389

Figure 20

number of parameters to be tracked from 12 to 2 and provides significant aid for qualitative visualization. For small deviations from a given force structure, force parameters such as missile numbers, MIRV numbers, and warhead success probability can be freely traded for both sides in accordance with their relationships in the respective CFPs.

(5) The usefulness of information for second strike counterforce objectives depends on the characteristics of both forces. The CFP concept is again helpful in describing this fact. Trends for the usefulness of information correlate with the CFPs of the forces and are largely independent of the force parameters which make up the CFP. Except for Warning, forces must have a COUNTER FORCE POTENTIAL before information becomes useful. If CFPs are less than 1.0, counterforce war is not an optimum choice and hence, information is of no value.

(6) A basic hierarchy of information types has been found. They are, in ascending order of effectiveness: No Information, Attack Damage, Empty Silo, Attack Damage and Empty Silo, Warning, and Warning and Empty Silo Information.

(7) For forces at the level agreed upon in SALT, information is of little use for counterforce purpose. Significantly increased CFPs, achieved through extensive MIRVing and/or large warhead success probabilities, tend to put a premium on launch on warning. However, considerations outside the scope of a simple counterforce model seem to take over at this point.

Discussion:

Missiles, MIRVs or Information: A Model for Comparative Assessments

W. A. Barbieri - The Rand Corporation

The paper presents a thorough analysis of a restricted problem. Highlights are that the problem is solved in terms of fundamental parameters, and that the authors present a mathematical analysis of stability in a systems context. The novel method of presentation of results (after one gets used to thinking in terms of db) is useful in surveying a wide range of parameters. The critique offered here is not concerned with the solution as presented but with the difficulty of transferring insight gained from this analysis to situations involving more complex force postures and interactions.

The system analyzed here consists of force characteristics and game rules. The results depend on specific assumptions about the form of both. If we change either the form of the force characteristics or the game rules, we have a different system that remains to be solved. For example, it is not clear how one would accommodate more realistic force postures containing mixtures of offensive missile weapons. The measure of outcome is (essentially) boosters, but if payloads vary from booster to booster, this outcome measure would not be adequate. Alternatively, one might consider the interaction of pure forces in an n move game. When the counterforce potential equals one, the offense possesses the capability to destroy a number of targets equal to the number possessed by the other side. In a multi-move game, there may be ways to operate the offense so as to achieve all of this potential. Now, it may be possible to chain a sequence of these two move games together to get the equivalent of a more elaborate n move game. The authors do not discuss this. On the other hand, knowledge of what is optimal for the simple game may not be sufficient to solve an n move game.

Missile duels can interact with targets other than missile silos and with bomber delivered weapons. These, in combination with postures considered in the paper suggest other systems that might be analyzed in regard to stability.

"Authors' Rebuttal to Discussant's Remarks of 'Missiles, MIRVs or Information: A Model for Comparative Assessments (U)'"

Otto A. Wech and Kathleen M. Kenny

Headquarters, Electronic Systems Division, U.S. Air Force

REBUTTAL

Bill Barbieri's concern about extending the conclusions from our restricted analysis to the complexities of the real world points out a problem which is common to most analyses. To help in this matter, we would like to offer some additional thoughts which occurred during our work.

The original homogeneous ICBM model most clearly exhibits the principal features of a counterforce exchange. It provides the best indication of what conditions must prevail for information to be of value. The introduction of "more realistic" mixed ICBM/SLBM forces does not alter the basic conclusions. It has a smoothing effect with less variability in the outcome, less sensitivity to parameter variation, and diminished achievable gains. This is, of course, a direct result of the irreducible bias provided by invulnerable SLBMs.

Although we have not developed mathematical proof, there is reason to believe that the same trend will prevail for the introduction of other mixes, i.e., bombers, mixed warheads, partial information, multiple salvos, etc. The "real world" behaves in a more complex but less drastic fashion than a simplistic model. "Real" gains from information are unlikely to exceed the ones shown by the model unless we consider such scenario-dependent details as defense roll-back, etc. or irrational, non-optimum decisions as basis for calculation.

For the multi-move game we developed analytic expressions which include time depent parameters such as launch rates, wave times, etc. A rather complicated system of equations results. In the limit, they resemble the classical wave equation. Their solution did not seem fruitful nor at hand. Without information, optimum outcome can be achieved in a single move. The same is true when warning is available. These two cases thereby set bounds except for non-optimum games and the shoot-look-shoot case with empty silo information. Reliance on this kind of target-dependent information for optimization, however, becomes problematic in protracted engagements because of the inherent delays between salvo arrivals due to the flight time of the missile. A sophisticated opponent must be allowed to take advantage of such delays as he does in our simple case with warning information. For positive Counter Force Potentials, where missile exchanges could be rational and weapons are plentiful, there is a premium on doing the job fast. We have not encountered situations in which benefits could be gained by either side through shoot-look-shoot strategies.