Errata

To: Recipients of OP-223-AF, Thinking About America's Defense

From: RAND Corporation Publications Department

Date: November 2008

Re: Corrected pages

Errors were identified within the originally published document. The errors have no effect on the inferences or conclusions in the report. The currently posted document has been corrected.

We apologize for any inconvenience.

1) Equations on the following pages have been amended for mathematical clarity or for dropped characters: pp. 33 (bottom), 57, 232–234.

2) The column headings of Tables 2.1 and 2.2 have been amended for clarity; these and other elements have also been amended to sync with related amended equations.

3) In Table 2.3, the units for "Bomber Takeoff Weight" have been amended to be "000s lbs."

4) The discussion in the first full paragraph of p. 210 was also clarified.

CRAF	civil reserve air fleet
DARPA	Defense Advanced Research Projects Agency
DDR&E	U.S. Department of Defense Office of Research and Engineering
DE	damage expectancy
DGZ	designated ground zero
DIA	Defense Intelligence Agency
DoD	U.S. Department of Defense
DPM	draft presidential memorandum
DSP	Defense Support Program
erdel	a dummy term of measurement indicating xxx
FSB	fraction surviving of bombers; fraction surviving Blue (in certain equations)
FSR	fraction surviving Red (in certain equations)
GAO	U.S. General Accounting Office (now known as the U.S. Government Accountability Office)
GEO	geosynchronous orbit
GPS	Global Positioning System
HTK	hard-target kill
ICBM	intercontinental ballistic missile
IDA	Institute for Defense Analyses
IDAGAM	IDA Ground-Air Model
IOC	initial operational capability
IR	infrared
JCS	Joint Chiefs of Staff
JDAM	Joint Direct Attack Munition

people familiar with the workings of the Air Staff from this period refer to General Kent as having been "the brain of the Air Force," it is not far-fetched.

In 1973, after General Ryan retired, General Kent was named director of the Weapon Systems Evaluation Group (WSEG). The head of WSEG was a three-star general who reported directly to both the Director of Defense Research and Engineering and the Chairman of the Joint Chiefs of Staff. Here, General Kent presided over assessments of the operational utility of many systems—Army, Navy, and Air Force. He was also instrumental in promoting the development of several theater-level combat models, including the Institute for Defense Analyses's (IDA's) Ground-Air Model (IDAGAM), which evolved into the TACWAR model. TACWAR was a blunt but fairly reliable instrument for assessing the outcome of combat in Central Europe, the Korean peninsula, and other theaters. During the 1980s and 1990s, TACWAR was DoD's most widely used campaign model (see Chapter Six). General Kent later came to regard TACWAR and other opaque, theater-level models as rather poor tools, both for estimating the outcomes of operational plans and for informing decisions about the relative merit of various investment options for modernizing operational capabilities. But at the time, sponsoring the development of theater-level campaign models seemed like a good idea.

General Kent retired from active duty in 1974 and became a consultant to Boeing, Northrop-Grumman, and other defense contractors. During these years, he played important roles in a number of programs that have figured prominently in modern U.S. military operations. For example, he helped broker the deal between Boeing and Northrop-Grumman to share development and production of the B-2 bomber. He also gained the support of Gen Robert Dixon, commander of the Air Force's Tactical Air Command, for development of the JSTARS aircraft (Chapter Five).

In 1982, RAND's president, Donald Rice, persuaded General Kent to join RAND as a senior research fellow. He essentially offered Glenn carte blanche to define and undertake research on issues that he felt were relevant to the Air Force and the broader national security community. During his early years at RAND, General Kent's efforts in the Soviet Union. Activities had been observed at some 40 separate sites around Tallinn. DIA was not certain how many interceptors had been deployed (or were to be deployed) at each site and was not all certain of the effectiveness of each interceptor, but it did give a range: between 20- and 80-percent effective—whatever that meant.

The planners in Omaha, in the presence of these tentative assessments by DIA, assumed (1) that 15 interceptors had been (or might be) deployed at each of the 40 suspected sites and (2) that each interceptor had around a 65-percent probability of kill (P_k) given a launch. In the presence of these assumptions, the planners had allocated five RVs per site, for a total of 200 weapons, to suppress the Soviet ABM system. It was the number 200 that bothered the OSD analysts. It seemed like overkill, especially in view of the uncertainty surrounding the complex. Accordingly, they had labeled the allocation "ridiculous."

In truth, at first blush it does seem like overkill (allocating five weapons per site)—if the lethality of each weapon is such that one is all that is required to destroy all the interceptors at one site. But DIA had stated that the probability of intercept might be as high as 80 percent (or words to that effect). The Soviets would use the interceptors at the site in self-defense, and there would be only a 20-percent probability (at worst) of each U.S. RV penetrating, as long as the ABM system is operating. So, it makes some sense to put a sizable number of weapons onto the Tallinn ABM system to ensure that the complex is destroyed and that the U.S. RVs attacking other DGZs are not intercepted. The question remains: What is the optimum number of RVs to commit to attack this complex?

I began to consider ways to quantify the value of suppressing this defense. Starting from the simple case of a single RV against a single ABM site, we can calculate (on an expected-value basis) that the RV would cause one interceptor to be launched in self-defense and destroy 2.8 of the remaining Soviet interceptors: $0.2 \times (15 - 1) = 2.8$. (The 0.2 comes from $1 - 0.8$.) Thus, 11.2 Soviet interceptors would remain. If two RVs were allocated per site, 8.32 Soviet interceptors would remain: $0.8^2 \times (15 - 2) = 8.32$. So there is merit in allocating more than one RV per site. I saw that we should expand these calculations to determine the "optimum number of RVs per site." My measure of *optimum* in this proposed agreement, one side or the other might be able to achieve the capability for a robust second strike after incurring a first strike by the other, but it was not possible for both to do so.

I constructed a table that showed the number of missiles that side A must deploy, A_{req}, in the constrained area to ensure a second-strike capability, given that side B has deployed a certain number of missiles, B_{dep}. In the analysis, I assumed that each side would wish to assure itself that 300 missiles would survive a first strike by the other. The inputs were as follows:

1. the size of the constrained deployment area (the proposal had designated an area of 50 km by 50 km—2,500 km^2—for each side)
2. the lethal area of the weapon on each missile (which I calculated to be 3.5 km^2).

Thus, the fraction surviving, P_s, for side A can be taken as

$$P_s\left(A_{dep}\right) = \mathbf{e}^{-\left(\frac{B_{dep} \times 3.5}{2{,}500}\right)},$$

and for side B,

$$P_s\left(B_{dep}\right) = \mathbf{e}^{-\left(\frac{A_{dep} \times 3.5}{2{,}500}\right)}.$$

So, to achieve its objective of 300 missiles surviving a first strike by side B,

$$A_{req} = \frac{300}{P_s\left(A_{dep}\right)}.$$

Similarly,

$$B_{req} = \frac{300}{P_s\left(B_{dep}\right)}.$$

The results of these calculations on a range of force sizes for both sides are summarized in Table 2.1. The "Requires" columns of the table show the number of missiles that the indicated side must deploy to ensure that 300 missiles survive, as a function of the other side's deployment.

The results show that, for the conditions posited previously (the deployment area is constrained to 2,500 km^2, and the lethal area of each attacking missile is 3.5 km^2), no stable, symmetrical deployment is possible. That is, there is no deployment for which both countries are satisfied that 300 missiles will survive. Specifically, the number in the third column for each side is always larger than the number in the first column.

Enlarging the deployment area for both sides can help: Table 2.2 shows the results for side A when one assumes that the lethal area for each attacking missile is 3.5 km^2 and the deployment area is 3,000 km^2.

Given a total deployment area of 3,000 km^2, both A and B meet the requirement of 300 missiles surviving between deployments of more

Table 2.1
Total Missiles Required to Ensure that 300 Survive a First Strike, Smaller Deployment Area

For A to Ensure 300 Survivors			For B to Ensure 300 Survivors		
If B Deploys (no.)	Percentage of A Surviving[a]	A Requires (no.)	If A Deploys (no.)	Percentage of B Surviving[a]	B Requires (no.)
0	100.0	300	0	100.0	300
200	75.5	397	200	75.5	397
400	57.1	525	400	57.1	525
600	43.2	695	600	43.2	695
700	37.5	799	700	37.5	799
800	32.6	919	800	32.6	919

NOTE: The lethal area for each attacking missile is 3.5 km^2, and the deployment area is 2,500 km^2.

[a] $P_S(A_{dep})$ and $P_S(B_{dep})$, respectively, rendered here as percentages.

Table 2.2
Total Missiles Required to Ensure that 300 Survive a First Strike, Larger Deployment Area

If B Deploys (no.)	Percentage of A Surviving	A Requires (no.)
0	100.0	300
200	79.2	397
400	62.7	478
600	49.7	604
700	44.2	679
800	39.3	763
900	35.0	857
1,000	31.1	963
1,200	24.7	1,217

NOTE: The lethal area for each attacking missile is 3.5 km^2, and the deployment area is 3,000 km^2.

than 600 and less than 1,200 missiles. In other words, A can achieve its goal of 300 missiles surviving without having to deploy more missiles than B has deployed. Beyond 1,200 missiles deployed by B, the situation is unstable. Each side, to meet the requirement, must deploy more and more missiles.

This analysis showed that not all approaches to constraining strategic nuclear forces were desirable from the standpoint of survivability and stability. I did not claim that the concept of an agreement whereby each side deploys mobile missiles in a designated area would not work. But—and this is the central point—the permitted deployment area must not be too small. One might prefer a small area from the standpoint of verification. But it cannot be too small, lest the survivability of the retaliatory force be compromised. Neither side will tolerate a position of inferiority, and such an agreement would not be negotiable.

I had read and reread the book *The Strategy of Conflict* by Dr. Schelling and took to heart the most insightful statements, one

Table 2.3
U.S. Strategic Forces, Mid-1983

Force	Number	Missile Throw-Weight (000s kg)		Actual or Estimated Weapons	SALT Weapons		Standard Weapon Stations	
		Per Missile	Total		Per Missile	Total	Per Missile	Total
Ballistic missiles								
ICBMs								
Titan II	45	3.8	171		1	45	7.6	342
Minuteman II	450	0.7	315		1	450	1.4	630
Minuteman III	550	1.0	550		3	1,650	3.0[a]	1,650
Total	1,045		1,036	2,100		2,145		2,622
SLBMs[a]								
C-3	304	1.5	456		14	4,256	14.0[b]	4,256
C-4	264	1.3	343		8	2,112	8.0[b]	2,112
Total	568		799	5,200		6,368		6,368
Total ballistic missiles	1,613		1,835	7,300		8,513		8,990

Table 2.3—Continued

Force	Number	Bomber Takeoff Gross Weight (000s lbs) Per Bomber	Total	Actual or Estimated Weapons	SALT Weapons Per Bomber	Total	Standard Weapon Stations Per Bomber	Total
Bombers (active)								
B-52G with ALCMs	104	488	49,752				19.5	2,028
B-52G	66	488	32,208				9.8	647
B-52H with ALCMs	95	488	46,400				19.5	1,853
FB-111A	60	115	6,900				2.3	138
Total active bombers	325		135,260	2,900				4,666
Retired B-52s[d]	308	488	150,300				9.8	3,018
Total bombers	633		285,560					

SOURCE: Adapted from Kent, DeValk, and Warner, 1984, pp. 30–31.

NOTE: The data in this table reflect the status of forces at the time the source document was published.

[a] The U.S. submarine force consisted of 31 Poseidon submarines, of which 19 were equipped with C-3s and 12 with C-4s, and three Trident submarines equipped with C-4s.

[b] The number of standard weapon stations declared or tested exceeded the value obtained by applying the missile throw-weight or bomber takeoff gross weight counting rules.

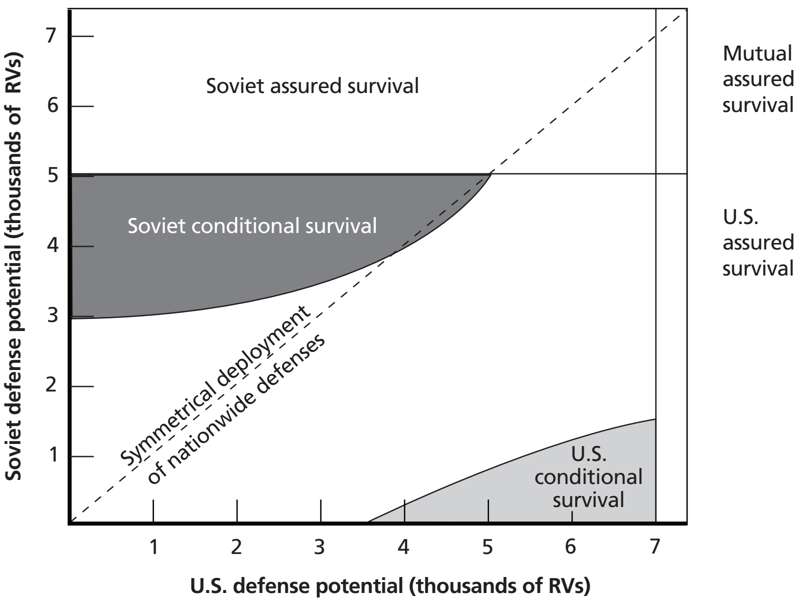
[c] These are SALT-accountable.

Force Summary	Total Number	Actual or Estimated Weapons	Standard Weapon Stations
Missiles and active bombers	1,938	10,200	13,656
Adding in retired bombers	2,246	10,200	16,674

Table 2.4
Soviet Strategic Forces, Mid-1983

Force	Number	Missile Throw-Weight (000s kg)		Actual or Estimated Weapons	SALT Weapons		Standard Weapon Stations	
		Per Missile	Total		Per Missile	Total	Per Missile	Total
ICBMs								
SS-11	550	0.9	495		1	550	1.8	990
SS-13	60	0.5	30		1	60	1.0	60
SS-17	150	2.7	405		4	600	6.7	1,005
SS-18	308	8.0	2,464		10	3,080	20.0	6,160
SS-19	330	3.6	1,188		6	1,980	9.0	2,970
Total	1,398		4,582	5,700		6,270		11,185
SLBMs[a]								
SS-N-6	384	0.7	269		1	384	1.4	538
SS-N-8	292	0.7	204		1	292	1.4	409
SS-N-18	224	1.0	224		7	1,568	7.0[b]	1,568
Total	900		697	1,800		2,244		2,515
Total ballistic missiles	2,298		5,279	7,500		8,514		13,700

Figure 2.5
Zones of U.S. and Soviet Conditional Survival in a Defense Domain



SOURCE: Kent and DeValk, 1986, p.15.
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assured survival that would avoid the danger zones of U.S. or Soviet conditional survival.

The work on the transition to assured survival led us to conclude that mutual assured destruction and mutual assured survival were the only two conditions that could offer both first-strike stability and arms race stability. We also concluded that it was possible to transition to mutual assured survival if both sides maintained their strategic defensive and offensive forces in highly survivable postures. The more survivable these postures, the smaller the U.S. and Soviet zones of conditional survival and the wider the path to mutual assured survival. On the other hand, increasing hard-target kill (HTK) capabilities while failing to improve survivability would tend to close this path.

We also noted that the comparatively large Soviet counterforce capability (as given in Table 2.6) meant that symmetrical deployment of intermediate levels of strategic BMD would erode the contribuother hand, the number of silos to deploy was such that the quantity $(1 - P_k)^n = 0.37$, where n is the number of Soviet RVs assigned to the attack on the Minuteman divided by the number of Minuteman silos deployed.

Thus, if the requirement is that 600 RVs are to survive, then we should deploy

$$600 \times 2.718 = 1{,}631 \text{ RVs}.$$

If the threat is 800 Soviet RVs with a P_k of 0.5 each, then deploy 552 silos, since

$$\frac{800}{552} = 1.45$$

and

$$0.5^{1.45} = 0.37 = \frac{1}{\mathbf{e}}.$$

I showed this math to Dr. Brown, and he announced the analysis was clever—maybe too clever. We would get different answers if we changed the requirement or the threat. That is so. But reasonable cuts at these two parameters provided a rationale for what we were planning, namely 550 silos and 1,650 RVs.

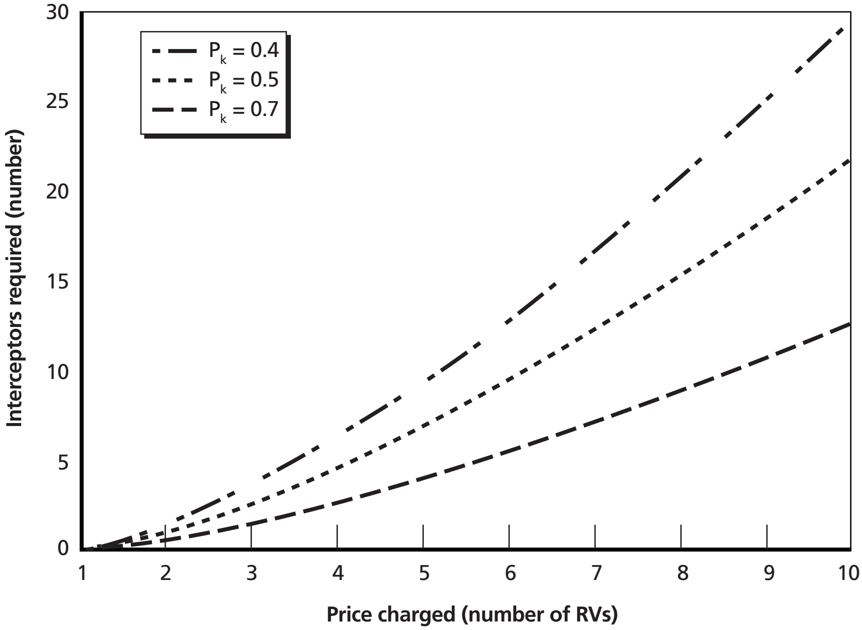
I recite this example to underline the idea that, if the analyst works hard enough, and long enough, and clearly enough, he or she will eventually arrive at a simple analytical solution to a complex problem.

Defining the Deployment of the Minuteman III

As stated in the prior section, the problem, in the barest of terms, is to deploy enough RVs on enough missiles, M_{dep}, so that a required number of RVs, Q, survive a stated Soviet attack on the Minuteman silos deployed—and do so at least cost.

With regard to cost, we know empirically that, if a single-RV missile costs one unit, a four-RV missile costs two units. In general, the unit cost per missile equals the square root of n, where n represents the

Figure 6.1
Interceptors Required Versus Price Charged for a Particular Target



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is exactly λ at the juncture of the lines of defended and undefended areas.

An example of such a plot is shown in Figure 6.2. The figure reflects calculations of worth destroyed as a function of the size of a Soviet attack for two cases: (1) no defense and (2) a defense that allocates interceptors according to the logic of Prim-Read. Both cases in this somewhat notional example assume a target set containing 1,600 DGZ areas and a total population of 200 million. The distribution of the total population among the 1,600 DGZ areas is assumed to obey a Pareto distribution with an exponent of one-half. That is,

$$W_{cum} = 200\left(\frac{n}{1{,}600}\right)^{\frac{1}{2}}$$

areas with 400 missiles. In the presence of a Prim-Read defense with $\lambda = 0.1$, the Soviets would need 1,000 missiles to inflict the same level of damage. Moreover, only defended areas would be targeted, since attacking these DGZs brings the highest "expected returns" for Soviet RVs and the attack is not large enough to expect to destroy the total worth in the defended areas (a population of 125 million). Undefended areas would be left alone unless the Soviet attacks involved more than 1,250 missiles.

It is worth noting that, while the defense significantly raises the price of achieving a specified level of damage, it is not an inexpensive proposition for the defender. For example, the third set contains five targets with a population of 5 million. The population of an average target within the set is 1 million. Since $\lambda = 0.1$, the defender should charge a price of 10 for the average target, which would require 21.8 interceptors for the average target. Thus, roughly 109 interceptors are required to defend the set of five targets if there are no decoys or if the radar can distinguish between RVs and decoys. If we assume, as before, that each Soviet missile in the attack carries one warhead and nine decoys and that the Nike-X radar cannot discriminate between RVs and decoys, roughly 1,090 interceptors would be required to defend the five DGZ areas in the set. Around 11,000 interceptors would be required to cover the 625 defended DGZ areas.

Dr. Brown was quite impressed. He directed that the Army use this construct. They accepted the construct, but it took the Army's contractor a while before he could get the computer to do his bidding. Accordingly, I spent a good deal of time doing "what-ifs" using a spreadsheet I had developed and a Friden calculator.

Doing "what-if" calculations on a target-by-target basis would have been extremely time consuming. After wrestling with the problem for a bit, I realized that I could reduce my workload substantially if I used a Pareto distribution with an exponent of one-half to represent the distribution of worth among U.S. targets. I could then take advantage of the properties of the distribution to define equal-value sets of targets. I placed the most valuable target in the first set, the next three most valuable targets in the second set, the next five most valuable targets in the third set, and so on. The total number of sets was equal to new guidance system for the Minuteman, but they did not approve a program for the new RV.

The above demonstrates that simple constructs can provide insight and reliably inform decisions about whether or not to proceed to implement some concept being proposed.

This episode was but one of a continuing battle between some members of the Air Staff and the ballistic missile program office. BMO continually sought funding to proceed with the development of a new RV for Minuteman, and I prevailed on the issue throughout my tenure in AFSA. However, subsequent to my departure from AFSA, a new Chief of Staff did grant approval to proceed with a new RV. The program was hardly a success—a large cost overrun occurred, and the resulting RV failed to meet its expected performance specification with respect to its yield.

The Trade-Off with "Soft" Area Targets

Now examine the trade-off between yield and numbers for the case of attacking "soft" area targets. Such targets include industrial infrastructure and unhardened military targets. In this case, the trade-off between numbers and yield is not so obvious. If the area occupied by the target is very large compared to the lethal area of one weapon, then the trade-off is the same: $ny^{2/3}$, where n is the number of RVs and y is the yield of each. But that is seldom the case; industrial facilities are generally built not in large, circular clusters but rather more on a line (e.g., along a river or railroad within a valley). If the facilities lie in a line whose width is less than the diameter of the lethal area of the weapon, then we can, by math, announce the trade-off: $ny^{1/3}$. The one-third term in the exponent results from the fact that some of the weapon's effects are expended outside of the target area. We have now bounded the problem: The exponent of y is somewhere between 0.33 and 0.67.

One might be tempted to take the arithmetic mean between these two values—0.5—but there would be a hue and cry about mathematical inelegance. So I devised a more complicated method for arriving at the answer. Specifically, I devised a chart with "Soviet value destroyed" on the ordinate and "number of weapons" on the abscissa and, for a family of curves, yields of 100, 200, 500, 1,000, and 2,000 kt. It took some effort to construct the lines, but finally we had the chart. Obviously, all lines (one line for each yield) started at zero and were concave downward—reflecting the fact that, as you went to more and more weapons on the abscissa, you were attacking targets of less and less value and thus for diminishing returns. Obviously, the 1-megaton lines rose more rapidly than the lines for lesser yields.

Now the trick: Draw a horizontal line from some place midway up the ordinate. This is a line of constant value destroyed. For example, we note that, for the line of 200 kt, it took 800 weapons to achieve this level of damage, and that, for the 1-megaton line, it took only 360 weapons. Now find the value of z so that $0.200^z \times 800$ is equal to $1^z \times 360$. The answer is $z = 0.5$. That is, when the exponent is 0.5, the square root of 0.200 × 800 = 358—close enough. Obviously, I took some other numbers and did not get the same value for z for all pairs. But the average value for the exponent was about 0.5—maybe a little less.

I now have stored in my mind that the exponent to use in determining the trade between numbers of weapons (n) and the yield of each (y) is $Y^{0.5}$ for the case of soft area targets. As we saw earlier, this relationship comes in handy in gaining insight into problems such as determining the number of RVs on the front end of the Minuteman III missile (see pp. 144–146).

Calculus of the Attrition of Agents in a Battle

Late in fall 2002, several RAND analysts participated in the Air Force's biennial war game, Global Engagement. Following the game, one of them, David Ochmanek, who had played on the Blue team during the game, approached me.

He said that, on the third day of the game, the players had been working through the scenario. Late in the afternoon, both the Blue and the Red teams were instructed to commit to a course of action. At this point in the game, it was clear that there would be a clash of forces. The Blue team had defined the types and numbers of forces it wanted

Basic Principles

Again, our objective was to estimate the outcome of a battle, which generally involves multiple types of Blue and Red agents, and to do so in a way that is rigorous, transparent, and quick. The approach I developed meets these requirements. It is based on a summing up of the outcomes of the types of engagements (agent-on-agent interactions) the battle is likely to comprise. The calculus defines the fraction surviving of each type of agent over time. The fraction surviving Red (FSR) is the fraction of Red agents of a particular type that remain after a time step (Δt) has elapsed[4]:

$$FSR = \exp\left(\frac{-\gamma B \Delta t}{R}\right),$$

where

B = the number of Blue agents at the beginning of the time step

R = the number of Red agents at the beginning of the time step

Δt = a small time step (e.g., one-tenth of an hour)

γ = the kill potential per hour of a particular type of Blue agent against a particular type of Red agent.

FSR can be simplified as

$$FSR = \exp\left(-\Omega_R \Delta t\right),$$

where Ω_R represents the weighted sum of all the kill potentials arrayed against the Red agents in question. In this way, the analyst can calculate the result for a large number of engagements by using this expression for the overall "stress" placed on a particular type of Red agent from all the Blue agents that are engaging that type. Calculating the fraction surviving Blue (FSB) is done in an analogous way. The γ term

4 It is important that the drawdown calculations be accomplished in small "bites" (that is, that Δt be of short duration) so that the average population of Red and Blue agents over the course of each time step be roughly equal to the population at the beginning of the time step.

in the equation above is, in this case, replaced by λ, which represents the kill potential per hour of a particular type of Red agent against the relevant type of Blue agent.

Obviously, the key to the validity of this approach is to have credible values for γ and λ. This is not simple but it is tractable. Values for these variables can be developed in any of five ways:

- using the judgment of operators and analysts informed by data from past engagements in actual conflicts
- performing analyses using inputs from physics, engineering, and mathematics
- conducting analyses using the outputs of such high-fidelity engagement-level simulators as TAC BRAWLER
- conducting field trials and analyzing their results
- some combination of the above approaches.

To illustrate this, we consider how an engagement-level simulator might be harnessed to derive kill potentials for two types of aircraft, one Red and one Blue. The analyst would be asked to set up a run of the simulator in which a modest number of Red and Blue platforms engage in "combat," say, four Su-27 and four F-22 fighters. The simulator is run until the *FSR* or the *FSB* reaches a predefined level. In this case, we will halt the simulation when the *FSR* equals 0.5, meaning that half the Red aircraft (i.e., two of them) have been "killed." At this point, we observe two other types of data from the simulator: the time (in "simulation time") at which this threshold is reached and the FSB—the fraction of Blue aircraft surviving.

Armed with these data, we can calculate γ and λ for this pair of agents:[5]

$$\gamma = \left(-\ln FSR\right)\left[\frac{R_0\left(1 + FSR\right)}{B_0\left(1 + FSB\right)\Delta t}\right]$$

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[5] Note that the terms (1 + *FSR*) and (1 + *FSB*) are inserted into the equations to capture the fact that the average population of *B* and *R* during the time step Δt is different from R_0 and B_0.

and

$$\lambda = \left(-\ln FSB\right)\left[\frac{B_0\left(1+FSB\right)}{R_0\left(1+FSR\right)\Delta t}\right].$$

The analyst then repeats the experiment many times (assuming a stochastic model) and calculates the median values of γ and λ accordingly. When this is done to the satisfaction of all concerned, the resulting values of γ and λ are stored in a catalog. The process is then repeated for each pairing of types of agents that could occur in a conflict. So, if Red operates Su-27s, Su-30s, F-9s, and F-10s and if Blue operates F15Cs, F-15Es, F-16 Block 50s, F-22s, and F/A-18E/Fs, we will need to run the simulator for all 20 possible pairings.

Scaling Up

Before we can assess a "real" potential conflict, however, we must go further. A war between the United States and China, for example, could be expected to result in large-scale battles. It might not be uncommon for, perhaps, 40 Blue agents of one type to engage 40 Red agents of another type. Yet our simulator can handle only small engagements, perhaps as large as four on four. Fortunately, the calculus can be scaled up to handle the larger battle. We do this by using the values for γ and λ that were derived as outlined above and plugging them into the equations for *FSR* and *FSB*, as shown below. Assume, for the purposes of illustration, that the median values from our simulator runs are $\gamma = 0.2669$ and $\lambda = 0.0347$. Assume also that B_0 and R_0 (the number of Blue and Red agents at the outset of the battle, when $t = 0$) are both equal to 40:

$$FSR = \exp\left(\frac{-0.2669 \times 40 \times 0.1}{40}\right) = 0.9737$$

and

$$FSB = \exp\left(\frac{-0.0347 \times 40 \times 0.1}{40}\right) = 0.9965.$$

Table 6.1
Tabular Data from 40-on-40 Example

Time Step	FSR	FSB
0.1	0.9737	0.9965
0.2	0.9474	0.9932
0.3	0.9213	0.9899
0.4	0.8953	0.9867
0.5	0.8693	0.9836
0.6	0.8434	0.9806
0.7	0.8177	0.9777
0.8	0.7920	0.9748
0.9	0.7664	0.9721
1.0	0.7409	0.9694
1.1	0.7155	0.9669
1.2	0.6901	0.9644
1.3	0.6649	0.9620
1.4	0.6397	0.9597
1.5	0.6146	0.9575
1.6	0.5895	0.9554
1.7	0.5646	0.9533
1.8	0.5397	0.9514
1.9	0.5149	0.9495
2.0	0.4902	0.9477

Note that, in Figure 6.4, Red forces are arrayed across the top and Blue forces are along the left-hand side.

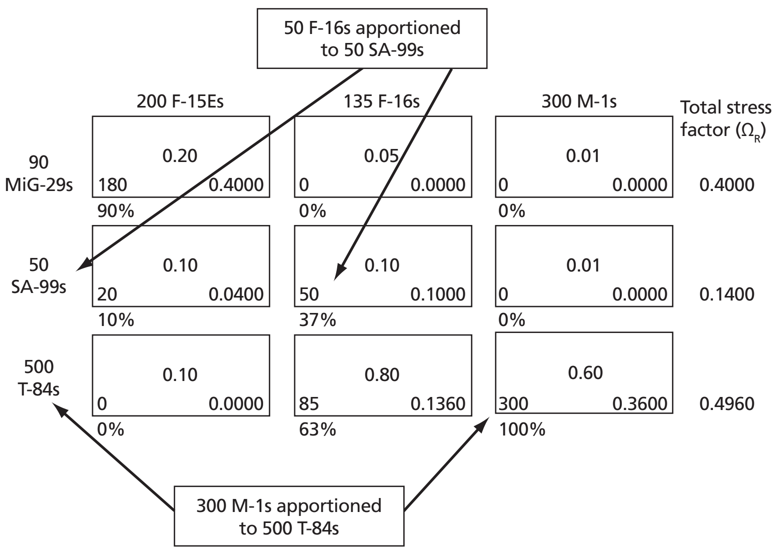
The number in the center of each box above represents λ—the kill potential per hour that the agent at the top of the column can inflict on the agent named at the far left-hand side of the row. So, in the upper left-hand box, we show that a MiG-29 is judged to be able to kill, on average, 0.15 F-15Es in 1 hour of combat. The number in the bottom right-hand corner of each box represents the stress factor, agents in the row. For example, Blue's F-15E force will face a total stress factor,

$$\Omega_B = 0.0675 + 0.0750 + 0.0000$$
$$= 0.1425.$$

The Blue commander prepares his OPLAN in a similar manner, as shown in Figure 6.5:

- He sends 180 F-15Es to engage the enemy's force of MiG-29s. The remaining 20 F-15Es are to engage the enemy's SA-99 SAMs.
- The F-16s are to try to avoid Red's MiG-29s. Instead, 50 of the F-16 sorties are to engage the SA-99s, and the remaining 85 are to engage Red's tanks.
- All 300 of Blue's M-1 tanks are to engage Red's tanks.

Figure 6.5
Blue Operational Plan



NOTE: Operational factors are notional.
RAND *OP223-6.5*