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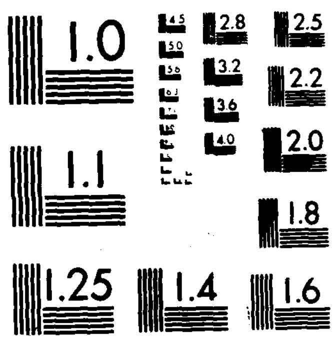

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SURVIVABILITY OF THE HARDENED MOBILE LAUNCHER WHEN ATTACKED BY A HYPOTHETICAL, RAPIDLY RETARGETABLE ICBM SYSTEM

THESIS

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THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Operations Research

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Abstract

This thesis evaluates the survivability of the hardened mobile launcher system (HML) against a hypothetical enemy ICBM system. The hypothetical system has two key capabilities: it can obtain near real-time intelligence information regarding the HML's location, and it can be retargeted in flight (as necessary) according to the intelligence information. Thus, the hypothetical ICBM threat systems can attack individual HMLs directly rather than rely on a "barrage attack" against HML bases.

Monte Carlo simulation is used to approach the problem. The model is an MBASIC computer program written and run on an Apple Macintosh computer. The model simulates the flight of the attacking ICBMs (there may be as few as one or as many as fourteen warheads directed at each HML) and the random dispersal tactics of a single HML. The model determines the locations of the detonations and the location of the HML at time of detonation. Based on these locations, probability of kill due to peak blast overpressure is calculated.

A key parameter in the model is "intelligence / retargeting cycle time" -- the amount of time required to obtain intelligence and retarget accordingly. This time is varied from one to thirty minutes. The model also allows variations in HML speed and hardness and threat system CEP. A subroutine for examining the effects of neutron fratricide on the attacking warheads is also included (although the effects were found to be negligible).

The main result of this thesis is that very small intelligence/retargeting cycle times are required for this to be an effective weapon system against the HML. Thus, with today's technology (or technology of the near future), the HML can be considered a very survivable system.

SURVIVABILITY OF THE HARDENED MOBILE LAUNCHER WHEN ATTACKED BY A HYPOTHETICAL, RAPIDLY RETARGETABLE ICBM SYSTEM

I. Introduction

Background

The Scowcroft Commission

In January of 1983, President Reagan established a blue ribbon commission to study possible modernization plans for the United States' strategic forces. The commission, formally called "The President's Commission on Strategic Forces," was chaired by retired Air Force Lieutenant General Brent Scowcroft and is therefore often referred to as "the Scowcroft Commission."

Members of the commission met for three months and, in April 1983, they published a report which addressed many strategic issues, both political and military, including deterrence, arms control, and the importance of our strategic forces in maintaining stability with the Soviet Union. The commission defined stability as, "the condition which exists when no strategic power believes it can significantly improve its situation by attacking first in a crisis or when it does not feel compelled to launch its strategic weapons in order to avoid losing them" [19, 29]. Thus, the commission emphatically recommended that "stability should be the primary objective both of the modernization of our strategic forces and of our arms control proposals" [19, 3].

With this objective (stability) in mind, the commission examined the state of our strategic forces. Their primary task was to make specific recommendations regarding strategic modernization programs, and, at the request of the President, emphasis was placed on studying the future of our ICBM forces. In this area, the commission recommended a three-pronged approach to modernization. First, they recommended deploying MX missiles in existing Minuteman silos to satisfy the immediate need for ICBM modernization. Next, they recommended working to increase strategic stability through arms control agreements. Finally, they recommended designing a new small ICBM (SICBM) capable of carrying only one warhead [19, 14].

The commission had two primary reasons for advocating the SICBM, both relating directly to the stated objective of promoting strategic stability between the US and the USSR. First, the commission stated that a small, one-warhead missile is a far less attractive target than a large missile with many MIRVs. Secondly, they believed that a small missile would permit greater flexibility in basing modes. Not only could such a missile be based in a silo, but it could also be housed in a mobile launching platform. The result would be greatly increased survivability. Additionally, if the mobile launcher was hardened against nuclear blast effects, its survivability would increase even further. The commission noted the effects these systems would have on the stability of our strategic relations with the Soviets:

> A more stable structure of ICBM deployments would exist if both sides moved toward more survivable methods of basing than is possible when there is primary dependence on large launchers and missiles. Thus from the point of view of enhancing such stability, the Commission believes that there is considerable merit in moving toward an ICBM force structure in which potential targets are of comparatively low value -- missiles containing only one warhead. A single-warhead ICBM, suitably based, inherently denies an attacker the opportunity to destroy more than one warhead with one attacking warhead. The need to have basing flexibility, and particularly the need to keep open the option for different types of mobile basing, also suggests a missile of small size. If force survivability can be additionally increased by arms control agreements which lead both sides toward more survivable modes of basing than is possible with large launchers and missiles, the increase in stability would be further enhanced [19, 14].

For these reasons, the commission strongly recommended the development of the SICBM and the hardened mobile launcher. Development of both systems began in 1983

Hardened Mobile Launcher (HML)

The increased survivability of a missile housed in a hardened, mobile launcher is due to the two inherent capabilities of the launcher that are reflected in its name -- hardness and mobility. Hardness can be defined as, "the degree to which the launchers successfully resist nuclear weapons effects" [23, 1]. The two effects that are of the greatest concern to the HML are static overpressure and dynamic pressure. Static overpressure is a dramatic increase in atmospheric pressure that could crush the HML. Dynamic pressure refers to the blast winds that could blow the HML over, preventing it from launching [23, 1].

"Mobility is the capability to evade attacking warheads by either stationing at a point unknown to the attacker at the time the attack is launched, or by changing locations during the flight of the attacking missiles. In either case, the attacker is shooting 'blind'" [23, 1].

Prior to beginning SICBM / HML system development in late 1983, and because of the uniqueness of the systems and the urgency of the program, the Air Force Systems Command established a Small Missile Independent Advisory group to recommend an acquisition strategy and management approach for the small missile program. The group convened in July 1983. Its chairman was retired Air Force General Bernard A. Shriever. The committee recognized the uniqueness of the HML and recommended that its development receive special emphasis. The committee also pointed out that there is a trade-off to be made between the hardness and the mobility of the HML system [21, 7]. This trade-off, they said, could be a major design difficulty, requiring special attention:

> The key problem for the hard mobile launcher is balanced hardness design and mobility. Blast hardness in excess of 25 PSI is probably required to provide survivability while restricted to operation on DoD land areas. The vehicle must be designed so it will not be overturned by lateral blasts, but weight must also be kept to a minimum to facilitate mobility and minimize cost [21, 8].

As recommended by the commission, the Ballistic Missile Office (BMO) at Norton AFB, California received overall weapon system responsibility, and a Small Missile System

Program Office was established to manage the program. Development began with four contractors working on proposals for the HML system. The four were: Boeing Aerospace, Martin Marietta, Bell Aerospace Textron, and General Dynamics Early in 1985, at the beginning of the pre-full-scale development phase of the program, the latter two contractors were eliminated from the competition; Boeing and Martin Marietta remain. [22, 19] Martin Marietta is designing their version of the HML in partnership with the Caterpillar Tractor Company. Their prototype was rolled out on 9 September 1985 [12, 80]. Boeing is developing their HML in partnership with Goodyear. Their prototype was rolled out on 25 September 1985 [18, 24].

At the present time, tests are being conducted on both systems to determine hardness and mobility characteristics. According to the proposed development schedule, the winning system will be selected in October 1986, and production will begin in 1988. Five hundred HMLs are expected to be fully deployed by 1992 [11, 24].

The HML method of basing for the SICBM is generally preferred; however, it is not the only method being considered. While the two prototype HMLs are being tested, the Air Force is also conducting tests on super hardened silos. "The results of hard silo tests are classified, but (LtCol James L.) Horton said that the test results have been very satisfactory, offering 'good survivability' for the missiles that come under attack" [8, 24]. LtCol Horton is a Systems Command project manager for the small ICBM [8, 24].

In late 1986, a basing mode for the SICBM will be selected. The options under consideration are: the HML, the super hardened silo, or a mix of the two. Between the two systems, the HML is generally preferred, and is, in fact, considered the current baseline. [8, 24] However, a strong argument can be made for a combination of the two systems. The Scowcroft commission's report stated, "We should keep in mind, however, that having several different modes of deployment may serve our objective of stability. The objective for the United States should be to have an overall program that will so confound, complicate, and frustrate the efforts of Soviet strategic war planners that, even in moments of stress, they could not believe that they could attack our ICBM forces effectively" [19, 15].

The HML vs. super hardened silo decision will be a difficult one. It will be based on test performances and on strategic considerations, such as the one stated above by the Scowcroft commission. Another consideration will be, as stated by Scowcroft, "the evolution of Soviet strategic programs" -- in other words, the nature of the threat [19, 15].

<u>The Threat</u>

In proposing mobile basing for the SICBM, the Scowcroft commission stated that, "mobile deployments of U. S. missiles would require the Soviets to try to barrage large areas using a number of warheads for each of our warheads at risk, to develop very sophisticated intelligence systems, or both" [19, 15]. The first alternative, a large barrage attack, has been carefully studied at the Ballistic Missile Office. Their studies indicate that with a properly dispersed HML force, the Soviets would have to launch a salvo of approximately fourteen one-megaton warheads per HML to inflict lethal damage to a sufficient percentage of the HMLs. With a planned force of 500 HMLs, this would require 7000 warheads be targeted against the HML force alone. Our planners are certain that this is an unreasonably high number, and their conclusion is that deploying mobile missiles is truly an effective deterrent against a Soviet attack.

However, the second alternative mentioned by the Scowcroft commission, the development of sophisticated intelligence systems, has not been examined as thoroughly as the first alternative. Current planning seems to assume that the only threat to the HML force is a huge barrage attack, and at the present time that is probably true. The "sophisticated intelligence systems" do not yet exist (to our knowledge). Moreover, no weapon system exists (again, to our knowledge) that is capable of exploiting that intelligence rapidly enough to counteract the effects of the HML's hardness and mobility. However, the SICBM / HML system is not scheduled to be fully deployed until 1992, and its expected lifetime extends well into the next century. Within that frame of reference, it is not difficult to hypothesize a weapon system, essentially based on today's technology, that will be able to locate and target individual HMLs with some degree of accuracy, thus eliminating the need for a barrage attack, and possibly reducing the number of warheads necessary to inflict extreme levels of damage on the HML force. This thesis examines the impact of such a system on HML survivability.

The hypothesized Soviet weapon system is an ICBM with three essential requirements:

1. A sophisticated intelligence / communications system that is capable of locating the HMLs and relaying that information to the ICBM in near real-time. In this case, "near real-time" means at some time during the flight of the ICBM. The envisioned system consists of intelligence gathering by reconnaissance satellite or HUMINT or some combination of methods. The intelligence information is then relayed by communications satellite to a command center, where it is processed and relayed in the form of new geographic target coordinates to the attacking ICBM system.
2. The re-entry vehicle (RV) must be capable of being remotely retargeted in flight. In other words, they must have the capability to update the geographic target coordinates based on information relayed from the ground. At least in principle, that capability exists today and is used to make course corrections in unmanned space vehicles.
3. The RV must have the capability to effect the maneuvers required of it when it receives new target information. Again, this capability essentially exists today in our maneuverable re-entry vehicle (MARV) technology [1, 5].

Given these three capabilities, it becomes possible to direct an attack against individual HMLs, rather than relying on the barrage attack concept. This drastically changes the nature of the encounter. In the case of the barrage attack, the number of attacking warheads necessary is determined, in part, by the characteristics of the HML (hardness and speed), but primarily by the size of the tract of land upon which the HMLs are free to travel. The larger the land area, the more warheads required to completely barrage it. Given the intelligence / retargeting capability described above, and thus an attack on individual HMLs, the number of warheads necessary to inflict high damage levels depends on how rapid the intelligence / retargeting cycle is and how often the HML position can be updated during the flight of the RV. If the cycle time is short, then the HML will not have time to travel very far between the RV's last location update and weapon detonation. In this case, the probability of damage to the HML will be relatively high and less warheads will have to be expended per HML to inflict a high damage level. However, if the intelligence / retargeting cycle time is long, the HML will have the ability to drive out from under the attack, decreasing its probability of damage, and requiring more warheads to be expended to inflict high damage levels over the entire HML force.

Problem Statement

Recognizing that: 1) a final decision is pending regarding the basing mode of the SICBM, and 2) whatever mode (or combination of modes) is selected will almost certainly be the baseline ICBM force well into the 21st century, it seems prudent for the decision makers to have information available to them regarding the entire range of threats that may face the SICBM / HML system during its lifetime. The range of threats is defined on one end by the existing threat. This is the most likely threat if an attack were to occur today -- it is known to exist, it is fairly well understood, and it can be studied in great detail. In the case of the HML, the existing threat is the Soviet ICBM force (probably

SS-18s) launched in a massive barrage attack against the entire HML field. This scenario has been exhaustively studied and the results are favorable to a properly dispersed and hardened HML force.

The other end of the threat range should be defined by the worst case scenario. The threat system hypothesized in the previous section of this report, while not currently in existence, is certainly within the realm of technological feasibility, especially when considered over the lifetime of the SICBM / HML system, and can be regarded as the worst case scenario. It defines the worst end of the feasible range of threats against the HML system. To have complete confidence in the HML system, its survivability with respect to this end of the threat range should also be studied. Therefore, the problem posed by this study is:

"How survivable would the HML force be against a weapon system with the capability to periodically determine an HML's location (in near real-time) and retarget accordingly, thus permitting an attack against individual HMLs, as opposed to the barrage attack concept?"

Objectives of this Study

In addressing the problem posed in the "Problem Statement" section of this chapter, this study has three primary objectives:

1. Develop a methodology to calculate the pre-launch survivability (PLS) of the HML force when attacked by the hypothesized threat.
2. Use this methodology to provide accurate information about the PLS of the current baseline HML force if attacked by the hypothesized threat system. The survivability of the HML force will be studied with regard to a wide range of threat capabilities. This will be accomplished by parametrically varying the intelligence

/ retargeting cycle time of the threat system and by varying the number of warheads directed at each HML.

3. Provide a flexible computer model capable of studying the PLS of the HML force with initial conditions other than those studied in this report; e.g., different speeds, hardness levels, or tactics of the HMLs, or different cycle times, numbers of warheads, weapon yield, or circular error probable (CEP) of the threat systems.

Methodology

The study uses a "Monte Carlo" simulation technique to determine the probable damage levels inflicted on the HML force during an attack by the hypothesized threat. A Monte Carlo simulation model is appropriate in this study since, according to The Military Applications of Modeling, a Monte Carlo simulation is called for when "the objective is to replicate a reasonably well understood process" [4, 14]. In this study, several such processes are modeled, including the random movement of the HML, the occurence of intelligence / retargeting updates for the attacking ICBMs, and the effects of the attacking ICBMs' CEP on aiming accuracy.

Again, according to The Military Applications of Modeling, any Monte Carlo simulation uses the following two phased approach:

> First, in the course of running the basic system model for a given set of initial conditions, the sequence of random events is obtained by sampling a random number generator, comparing the resulting number with a specific distribution, and using the corresponding value of the random event in the process being modeled. Ultimately, this process results in a final output value or set of values, as indicated by the measure of effectiveness.
>
> The second phase involves repeating the first phase many times over. Each repetition will result in a different final Measure of Effectiveness (MOE) value, since the random processes operate slightly differently each time. This produces an approximate distribution of the MOE as a random variable itself. This can then be used to characterize the MOE through conventional indicators such as expected value or probability of achieving a minimum specified level of the MOE [4, 30].

In this study, Phase 1 represents an attack on one HML by a given number of warheads. Initial conditions are the number of warheads, the intelligence / retargeting cycle time of the attacking weapon systems, the weapon yield and CEP, the speed of the HML, and the hardness level of the HML. The final output value of each run is the probability of kill (P_k) due to the encounter. (Probability of kill represents the probability that the attacking weapons damage the HML sufficiently to prevent it from successfully performing its mission.)

To complete Phase 2 of the *Monte Carlo* simulation process, the computer model is run many times using the same set of initial conditions. The resulting P_ks are averaged. This average P_k value represents the probable damage level that would be inflicted on the entire HML force if attacked by a threat with the capabilities described by the set of initial conditions. In other words, the average P_k represents the percentage of HMLs that would be incapacitated following an attack by the described threat.

The actual model used in this study is an MBASIC computer program, written and run on an Apple Macintosh computer. It is described in detail in Chapter 2 of this report. The program listing is in Appendix A. Briefly, the model does the following:

1. Determines the flight time of the attacking ICBM.
2. Based on the flight time and the intelligence / retargeting cycle time, the model determines the time when the attacking weapon receives its last valid intelligence update. The time of the last update is significant because the HML's location at this time becomes the weapon's designated ground zero (DGZ). (A *valid* update assumes the attacking system receives the new target location and has enough time remaining in its flight to effect a course correction to the new DGZ.)
3. Uses effective targeting patterns (based on the number of attacking warheads

directed at each HML) to determine aimpoints for each of the warheads. When the attacking weapon system consists of more than one warhead, the optimal targeting pattern is used to conduct a "mini-barrage" attack on an "area of uncertainty" around the HML. The area of uncertainty is a circle whose radius is determined by the amount of time the HML traveled unobserved between the attacking system's last update and detonation of the warheads.

4. Determines the location of the HML at the time of detonation.
5. Computes the effect of circular error probable on the locations of the detonations.
6. Measures static overpressure effects on the HML.
7. Computes HML P_k.

II. Overview of the Model

The basic purpose of the model is to examine the survivability of a single HML against the threat posed by one or more attacking warheads. In order to calculate some measure of survivability, three things must be known or determined:

1. Range from detonation to target.
2. Certain warhead characteristics (most notably, yield).
3. Target hardness.

Given a range and a weapon yield, the peak amount of overpressure experienced by the target can be computed. The peak overpressure level and target hardness can then be used to compute the probability of kill (P_k). (A kill occurs when the HML has been damaged sufficiently to prevent it from successfully completing its mission.)

The computer model is written in MBASIC for the Apple Macintosh computer. Each run of the model simulates an encounter between one HML and a specified number of attacking warheads. Viewing the model from a very broad perspective, it can be separated into three functional sections:

1. First, the model determines two critical times:
   a. the time from launch detection until the attacking warheads' last valid intelligence/retargeting update. This time is assigned the variable name TIME1.
   b. the time from the final update until weapon detonation. This is assigned the variable name TIME2.
2. Next, the model simulates random motion of the HML for periods of time equal to TIME1 and TIME2 to determine two important locations:
   a. The warheads' aimpoint. (Note: If only one warhead is directed toward each HML, the location of the HML after a period of time equal to TIME1

(the last valid update) will be the warhead's aimpoint or desired ground zero (DGZ). If multiple warheads are aimed at each HML, then the HML's position at TIME1 represents the center of a circular "area of uncertainty" which the attacking warheads must attempt to barrage as thoroughly as possible. In either case, the HML's position at TIME1 is a target reference point for the incoming warheads.)

b. The location of the HML at detonation.

3. Finally, the model uses the location of the target, the location of the bursts, and a model for approximating the effects of circular error probable (CEP) to determine the effective range from each burst to the HML. Based on these ranges, the damage due to static overpressure is computed, and from the results of these calculations, P_k is computed.

Detailed descriptions of the three model sections comprise the following three chapters of this report. The computer code for the model is included in Appendix A. A basic flowchart is in Appendix B.

Modeling Assumptions

1. The HML force is strategically dispersed at the time of the attack. It is assumed that as tension increases, the force is dispersed to its strategic dispersal levels to increase survivability. It is also assumed that this assures sufficient average separation between HMLs to ignore residual damage from neighboring attacks.
2. Cumulative damage effects on the HML are negligible. When each burst's effects are calculated, it is assumed the HML has not been weakened from previous bursts.
3. Predominant kill mechanism is peak overpressure.
4. HML can predict time of detonation and sets up exactly two minutes prior.
5. Intelligence information is "perfect." Likewise, retargeting is perfect.

III. Model Section 1: Determining HML Movement Times

As mentioned in the previous section, there are two critical HML locations during each encounter between the attacking warhead(s) and the HML. The first is the HML's location at the time of the warheads' last valid intelligence/retargeting update. This location is important because it will become the aiming reference point for the warheads. (Recall from the previous section, if only one warhead is attacking the HML, the HML's location at the last update becomes the warhead's desired ground zero (DGZ). If multiple warheads are attacking the HML, its position at the last update will be the center of the circular area of uncertainty which the warheads will barrage. Thus, in both cases, the HML's position when the last update occurs becomes an aiming reference point.)

Of course, the HML may continue moving after the last update. So it is necessary to determine the second critical HML location -- its position at the time of weapon detonation. Once this location and the aiming point of the attacking warheads are known, the distance from the HML to the bursts can be determined, and then the amount of overpressure damage can be calculated. Note that the two critical locations of the HML depend directly on elements of the attacking ICBM system's flight sequence (specifically, last update time and time of detonation). Therefore, to determine these two locations, the corresponding times must be determined. To do so, a time sequence of the attacking warhead must be modeled. Figure 1 is an illustration of this sequence. (See the flow chart in Appendix C.)

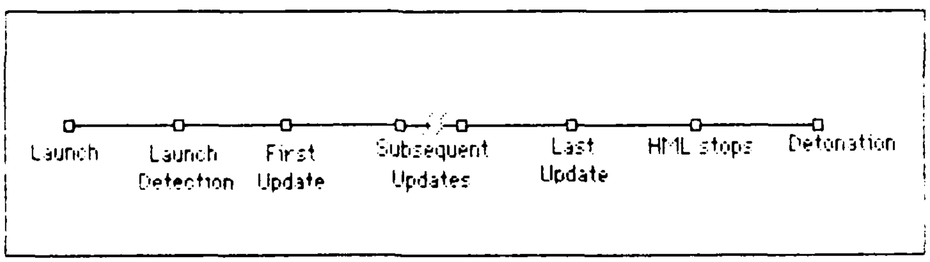

Figure 1: ICBM Flight Sequence

Before attempting to describe the mechanics of the computer program that models the warheads' flight time sequence, it will be helpful to explain some of the elements of the sequence. Those descriptions follow:

1. Launch of the ICBM is treated by the model as Time = 0.

2. The total flight time of the ICBM is the time from launch to detonation. In the computer program, this time period is represented by the variable FLTTIM (See Figure 2) The value of FLTTIM is drawn from a Uniform (26, 34) distribution. This distribution is based on a time of flight graph in <u>Long Range Ballistic Missiles</u> by Eric Burgess [6, 195]. According to the graph, the average time of flight of an ICBM is 30 minutes. (This corresponds to a distance of 5500 nautical miles.) The value of FLTTIM is modeled as a uniform random variable (with mean = 30 minutes) to account for variations in the locations of the ICBM launch sites and the targeted HML bases.

3. Launch detection time is the amount of time after launch required for friendly sensors to detect a hostile ICBM launch and to alert the HML force of an incoming attack. The model refers to this time as DETECT (See Figure 2). The value of DETECT can be easily changed in the computer program to reflect changing technology. However, in this study its value was held constant at 1.5 minutes. This value is based on an approximation used to evaluate bomber reaction times in a Brookings Institution study [20, 46].

4. A continually decreasing time-to-go is computed throughout each run of the model. This variable is called TTG (See Figure 3). It represents the amount of time remaining from the current time until detonation.

5. The intelligence/retargeting cycle time is the essence of this study. It represents a technological capability -- the amount of time required to complete one intelligence/retargeting cycle. (Cycle time is called CYCLE in

the computer program.) Because the cycle time is one of the critical parameters in this study, the structure of an intelligence/retargeting

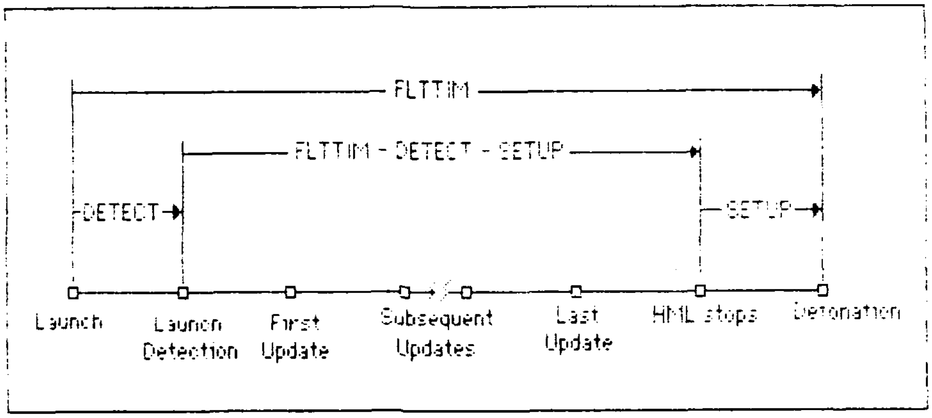

Figure 2 ICBM Flight Time, Launch Detection Time, and HML Set-up Time

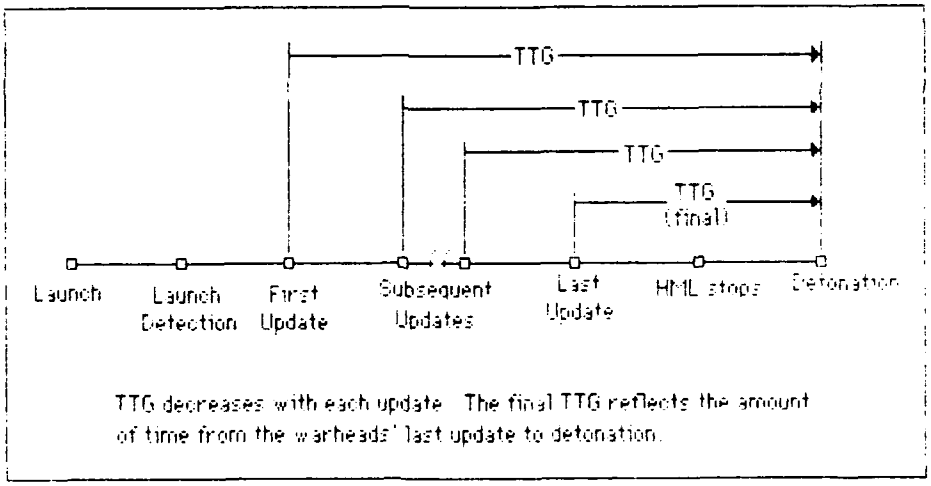

Figure 3 Time remaining to detonation (TTG)

cycle was studied and defined very carefully to ensure a close approximation to the probable structure of a corresponding "real-world" system. It is assumed that such a real-world system would be essentially a four-step process:

a. Obtain intelligence data regarding the location of the HML.

b. Process the data.

c. Relay the new location to the ICBM in flight.

d. Retarget -- change course to the new DGZ.

In the model, the cycle begins with the receipt of intelligence data. It is assumed that acquiring intelligence is a rapid procedure relative to the other steps in the process. Thus, it is further assumed that at the end of each cycle, the next batch of intelligence data has already been received, and the next cycle begins immediately.

As previously mentioned, the cycle time is treated as a technological capability, i.e., the cycle cannot be completed in less time than the current value of CYCLE. This implies that the last three steps in the process require any and all remaining time once the intelligence data has been received. This is an important consideration in understanding the model. At the beginning of each cycle, the model compares the cycle time with the time remaining until detonation. If the cycle time is less than the time to go (CYCLE < TTG), then there will be enough time to accomplish steps 2, 3, and 4 of the cycle process. In this case, the update is considered valid, and the warheads' aimpoint will be based on information obtained during this cycle. However, if the cycle time is greater than (or equal to) the time remaining until detonation (CYCLE >= TTG), there will not be enough time to complete retargeting of the warheads. The model will not consider this a valid update. The warheads' aimpoint will be based on the previous update.

6. The HML requires time to assume its fully hardened configuration. This period of time is called SETUP in the program. (See Figure 2). The value of SETUP can be easily changed to model technological variations. However, in this study, the value was held constant at two minutes. This is based on information received from the Ballistic Missile Office (BMO) [7].

An assumption was made regarding the location of the set-up period in the time sequence. SETUP always occurs precisely at the end of the sequence (in this study, it is always the last two minutes). This assumes that the HML has perfect information regarding the flight time of the attacking ICBMs. "Perfect" information rarely exists in the real world. However, ICBM flight times can be estimated with enough accuracy to make this a reasonable assumption. Additionally, it is assumed that enough of a "pad" is built into the two minute set-up time to compensate for any inaccuracy in estimation of the ICBM's flight time.

The model uses the above six elements to define the ICBM's flight time sequence. From the time sequence, the two critical times are determined. A step-by-step description of the first section of the model follows:

1. The model begins by selecting a value for FLTTIM, the ICBM's total time of flight. As previously mentioned, FLTTIM is drawn from a Uniform (26, 34) distribution.
2. Time to detonation is set equal to flight time (TTG = FLTTIM).
3. The time to the first intelligence/retargeting update is determined. This time is drawn from a Uniform (0, 5) distribution, simulating receipt of the first intelligence data early in the flight (within the first five minutes). The value selected is assigned to the variable UPDTIM. (Throughout the simulation, UPDTIM represents the time to the next update.)
4. The time to the first update is compared with the time remaining until detonation.
    a. If the time to detonation is greater than the time to the first update (TTG > UPDTIM), then a valid update occurs.
    b. If the time to detonation is less than (or equal to) the time to the first update (TTG <= UPDTIM), then no valid update occurs. Since UPDTIM, in

this case, represents the first update, TTG <= UPDTIM implies that the ICBM receives no intelligence updates during its entire flight. Thus its aimpoint is based on its best information prior to launch. To simulate this, set TIME1 = 0. (Recall that TIME1 is the time from launch detection to the last update.) TIME1 = 0 implies that the warheads' aimpoint will be the HML's location prior to its dispersal. Go to Step 9.

5. If a valid update occurred, the new time to detonation equals the current time to detonation minus the time to the update (TTG = TTG - UPDTIM).

6. After the first update, all subsequent update times are computed using the cycle time (CYCLE). So, to determine if there will be another valid update, compare cycle time with the current time to detonation.

   a. If the cycle time is less than the current time remaining to detonation (CYCLE < TTG), than a valid update occurs. (Otherwise, go to 6.b., below.)

      1) Set the time to the next update equal to the cycle time (UPDTIM = CYCLE).

      2) Return to Step 5. This loop is repeated until the cycle time is greater than (or equal to) the time remaining until detonation. This is how the final update time is determined.

   b. If the cycle time is greater than or equal to the time remaining until detonation (CYCLE >= TTG), then there is not enough time to complete the entire cycle, and a valid update does not occur. The previous update was the final valid update. The warheads' aimpoint will be the HML's location at that time.

7. Add the update time to the current time to go. (TTG = TTG + UPDTIM). This step is necessary because in Step 5, UPDTIM was subtracted from TTG. However, it was subsequently determined (in Step 6) that the cycle under consideration will not produce a valid update. Thus, a final TTG must be

computed based on the previous valid update (which is the final valid update). See Figure 3. By adding UPDTIM to TTG, the current TTG will reflect the time remaining from the final update until detonation.

8. Since the time of the final update has been identified, TIME1 (the time from launch detection to the final update) can be established. TIME1 will be the ICBM's total flight time minus the current time to detonation minus the launch detection time (TIME1 - FLTTIM - TTG - DETECT). See Figure 4.

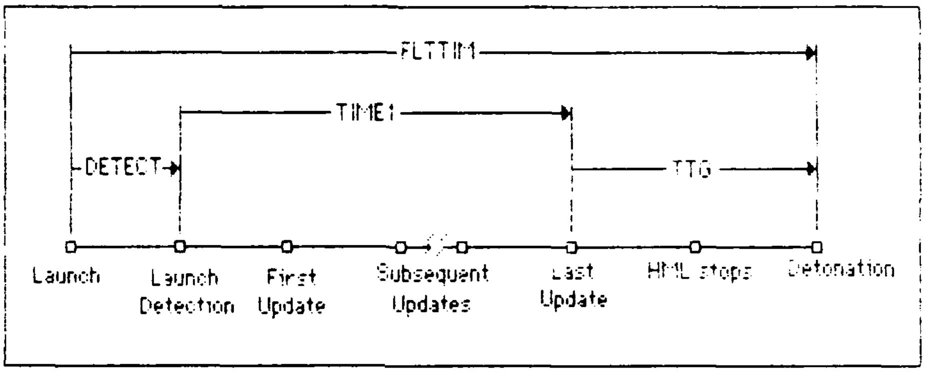

Figure 4. TIME1 = FLTTIM - DETECT - TTG

9. Once TIME1 has been determined, TIME2 follows directly. Recall that TIME2 is the amount of time the HML travels between the warheads' final update and detonation. Thus, TIME2 is equal to the current time remaining to detonation minus the amount of time required for the HML to assume the hardened configuration (TIME2 - TTG - SETUP). See Figure 5.

Note that it is possible for TIME2 to be a negative number. If the final update occurs during the period of time when the HML is setting up, TTG will be less than SETUP, and TIME2 will be less than zero. The model tests for this condition, and, in the event that TIME2 is negative, the model sets TIME2 - 0. This simply implies that the HML did not move between the warheads' final update and weapon detonation. See Figure 6.

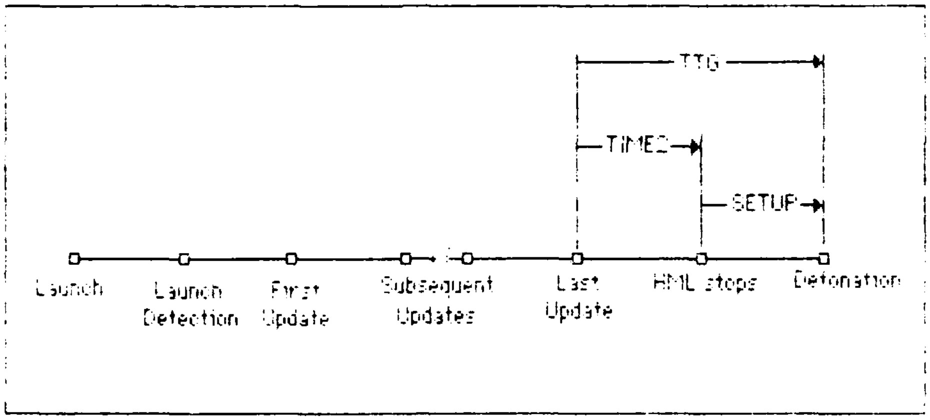

Figure 5. TIME2 = TTG - SETUP

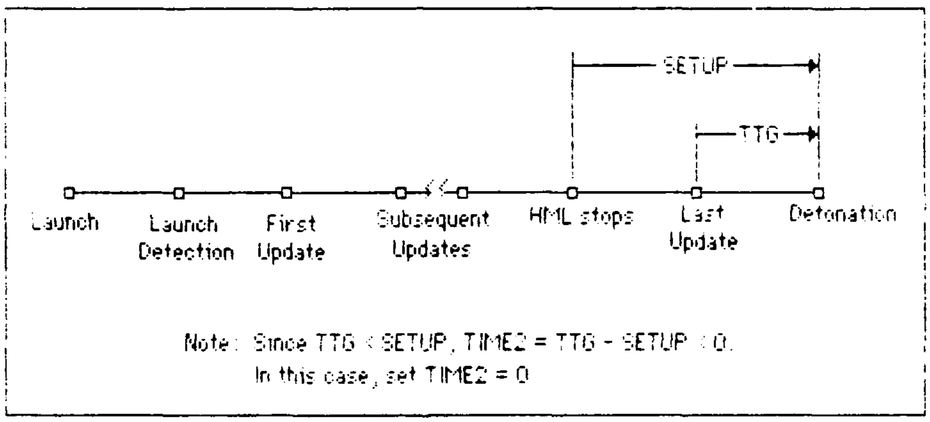

Figure 6: TIME2 < 0.

IV. Model Section 2: Determining HML Locations and ICBM Aimpoints

Overview

Section 2 of the model computes the location of the nuclear detonations and the location of the HML at the time of the detonations. It simulates a random dispersal of the HML and computes these critical locations relative to the HML's movement during its dispersal. The HML begins dispersing at launch detection and continues moving at random speeds and in random directions until the time when it must assume its hardened configuration to ride out the attack. During this random dispersal, the critical locations of the HML are computed based on the variables TIME1 and TIME2, which were calculated in the previous section of the model.

TIME1 is used to compute the location of the HML when the attacking warheads receive their last valid intelligence / retargeting update. Since this will be their best known information for the remainder of the flight, this location becomes an "aiming reference point." In cases when only one warhead is being directed toward each HML, the aiming reference point is the actual designated ground zero (DGZ) of the warhead. If more than one warhead is directed toward each HML, the aiming reference point is treated as the center of a circular "area of uncertainty" which the warheads must barrage as thoroughly as possible. The model determines the actual laydown pattern of the warheads to achieve maximum coverage of the area of uncertainty. The determination of the proper pattern is based on the number of attacking warheads and the radius of the circle (called the "radius of uncertainty," or R_U).

TIME2 is used to compute the actual position of the HML at detonation. It represents the amount of time the HML travels between the attacking warheads' last update and the time of detonation. To compute the HML's position at detonation, the model starts the HML at its position after TIME1, and then simulates random movement for a period of time equal to TIME2. The HML's position at the end of TIME2 is where it will stop and assume its hardened configuration to ride out the nuclear attack.

Section 2 of the model consists of five subroutines:

1. The main subroutine ties three of the other four subroutines together to determine the aimpoint locations and the HML's location at detonation (based on TIME1 and TIME2).
2. One of the subroutines called by the main subroutine simulates HML random movement for a given period of time.
3. Another subroutine randomly selects the HML's speed on each leg of its movement.
4. The main subroutine also calls a subroutine to determine an effective weapon laydown pattern in cases when multiple warheads are attacking the HML.
5. Section 2 of the model also uses a subroutine to compute a miss distance based on the attacking warheads' circular error probable (CEP).

Section 2 and its subroutines are described in detail below. The main subroutine is described after the random movement subroutine. This is because an understanding of how the program simulates random movement is essential in understanding the structure of the main subroutine.

A flowchart of this section of the model is included in Appendix D.

Random Movement of the HML

Although the simulated random dispersal of the HML is continuous from launch detection until it must stop to prepare for the attack, the dispersal is divided into two periods by the model. The first period starts at launch detection and lasts for an amount of time equal to TIME1. The location of the HML at the end of this period will be the aiming reference point for the attacking warheads. The second period starts at the end of the first period and lasts for an amount of time equal to TIME2. This period will end when the

HML must begin assuming its hardened configuration. Thus, the location of the HML at this time will be its location at the time of detonation.

The random movement of the HML is simulated using the same procedure during both periods. Random movement of the HML is simulated as follows:

1. The HML's current location is established. The coordinates of the current location are always represented in the model as (X0, Y0).
2. A "time to go" is established (called TTG in the computer program). TTG can represent one of two critical times. If the subroutine is currently computing the aiming reference point (actually the HML's location at the time of the last update), then TTG is initially set equal to TIME1. If the subroutine is computing the HML's location at the time of detonation, TTG is set equal to TIME2. (Throughout the subroutine, TTG will decrease until it reaches zero.)
3. A destination location is selected at random. This point is called (X1, Y1). The selection of the destination point is accomplished as follows:
   a. The HML's original position is initialized as (X0, Y0) = (0, 0). This is assumed to be the center of a circle within which the HML is able to move during the encounter. Its radius is calculated by multiplying the maximum speed of the HML by the flight time of the attacking ICBMs. Thus, there are no circumstances in which the HML could travel outside this circle during the encounter. In the model, the flight time is in minutes and is referred to as FLTTIM. The maximum speed of the HML is called MAXMPH and is in miles per hour, so it must be converted to miles per minute for this calculation. Thus, the formula for determining the radius of this circle is FLTTIM * MAXMPH / 60. (See Figure 7.)
   b. A distance is selected from a uniform distribution. The parameters of the distribution are zero and the radius of the circle. The variable name assigned to this distance is DIST.

c. An angle is randomly selected from a uniform distribution between zero and 2π radians. The angle represents the direction from point (0, 0) to the selected point and is referred to as DIR in the program.

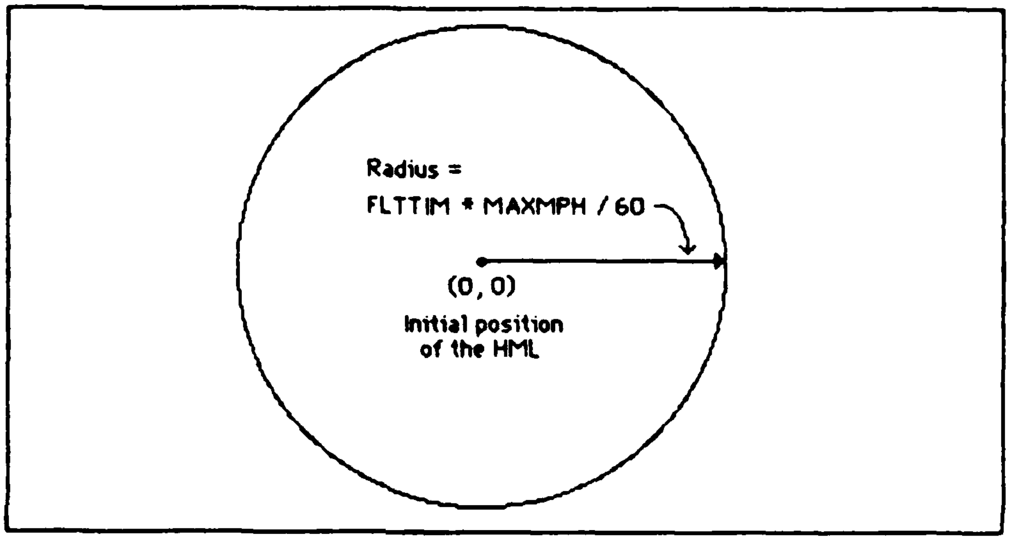

Figure 7: Circle Representing the Maximum Extent of the HML's Movement

d. The destination point's coordinates are computed using the following formulas (see Figure 8):

X1 = DIST * COS (DIR)

Y1 = DIST * SIN (DIR).

4. The HML's speed (MPH) is obtained from another subroutine. (It is described in detail later in this chapter.) A new speed is selected for each leg of the HML's movement.

5. The distance and direction from the HML's current location to the destination are calculated. (Note that these are not the same calculations as in 3.b., c., and d. above. Those calculations selected a random point based on a distance and

direction from the HML's *initial* location (0, 0). The calculations currently under discussion measure the distance and direction from the HML's *current* location (X0, Y0) to the destination point which has already been selected.)

a. The distance, R, from the current location, (X0, Y0) to the destination location, (X1, Y1), is computed using the following:

$$X = X1 - X0$$

$$Y = Y1 - Y0$$

$$R = \sqrt{X^2 + Y^2}$$

b. Next, the direction (THETA) from (X0, Y0) to (X1, Y1) is computed. The formula used to compute THETA depends upon the quadrant in which the destination point is located (with respect to X0, Y0).

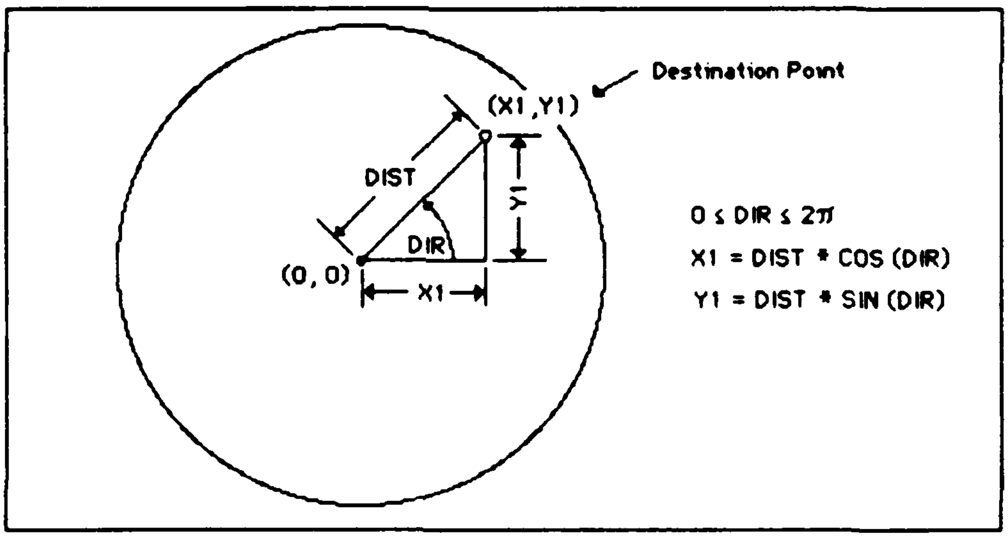

Figure 8: Random Movement -- Selection of the HML's Destination Point

6. Based on the distance (R), the HML's speed (MPH), and the time to go (TTG), the HML may or may not reach the destination point before it must stop and prepare to ride out the attack.

a. If the HML reaches the destination point (see Figure 9):

1) The amount of time required to travel from (X0, Y0) to (X1, Y1) is computed. This time is called MOVTIM.

2) The destination position becomes the current position. This is accomplished by setting (X0, Y0) = (X1, Y1).

3) A new destination (X1, Y1) is selected (as in item #3 above).

4) A new time to go is selected by the formula:

TTG = TTG - MOVTIM.

5) The procedure is repeated until a destination point is selected that time will not allow the HML to reach.

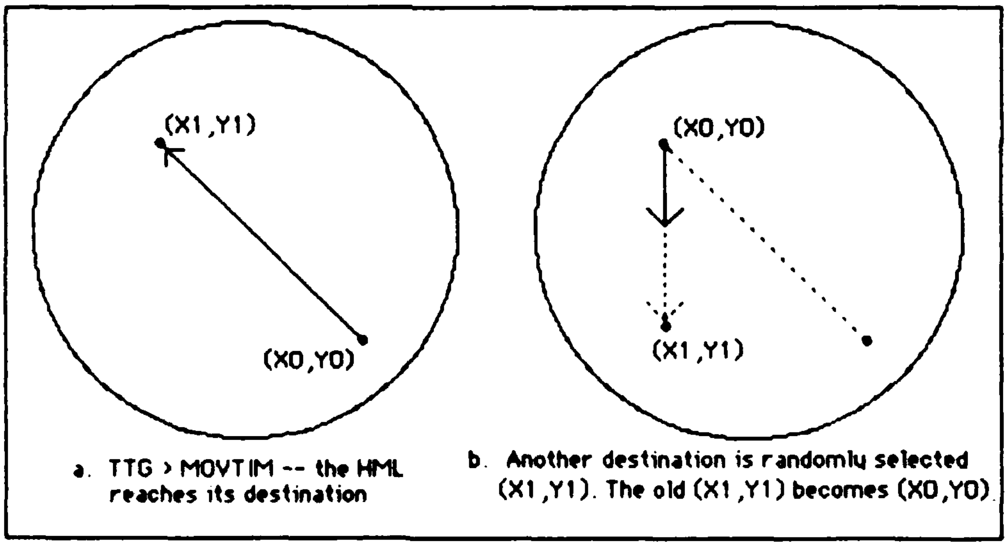

Figure 9: The HML reaches its Destination and Another is Selected

b. If the HML cannot reach the destination point before the time to go elapses, it will travel in the direction given by THETA (toward the destination point) for the remaining time. The distance it will travel is computed by multiplying the time remaining by the selected speed of the HML on that leg of its movement (see Figure 10).

c. Given this distance and the direction of travel (THETA), a point representing the end of the HML's random movement can be determined.

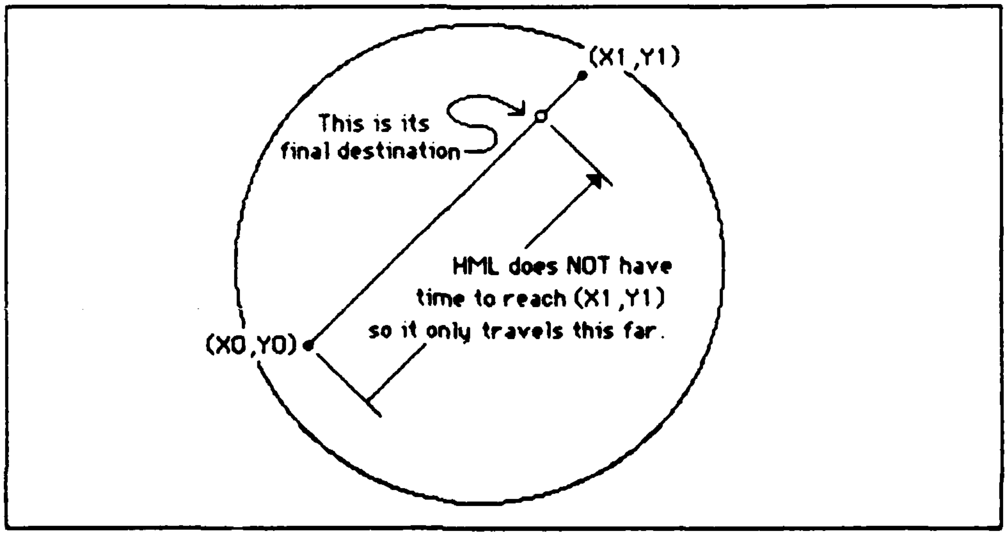

Figure 10: The HML Does NOT Reach its Destination.

Computing Burst Locations and the HML's Final Location

This is the main subroutine in Section 2 of the model. As previously stated, its description was saved until after the description of the random movement subroutine to facilitate a better understanding of the main subroutine.

The subroutine starts by setting the HML's initial position (X0, Y0) equal to (0,0). This assures that the HML starts at the origin.

The subroutine then checks to see if TIME1 = 0. Since TIME1 represents the time from launch detection until the attacking warheads' last update, TIME1 can only equal zero if no updates are obtained for the entire flight. (This should be a rare occurence and should only happen with very long cycle times.) If TIME1 = 0, then the warheads' best known location of the HML will be the origin (since it is assumed the HML's location is known at launch time). Thus, if TIME1 = 0, the warheads' aiming reference point is the origin. The coordinates of the aiming reference point are called (XRV, YRV) in the model. So, in this case (XRV,YRV) = (0,0).

If TIME1 is not zero (and this is generally the case), the time to go (TTG) is set equal to TIME1 and the random movement subroutine is called (see above). The subroutine simulates random movement of the HML for a period of time equal to TTG. Upon return from the subroutine, the aiming reference point coordinates are set equal to the coordinates of the HML's current location, or (XRV, YRV) = (X0, Y0).

Once the aiming reference point is determined, a subroutine is called to determine the optimal weapon laydown pattern for multiple warhead attacks. This subroutine is explained in detail later in this chapter. Thus, locations for all the bursts are established.

The subroutine's next task is to determine the location of the HML at the time of detonation. Its current location is (X0, Y0) = (XRV, YRV), which was just determined to be its position when the attacking warheads receive their last update. The HML will continue to move from this spot until it must stop to assume its hardened configuration. The length of time of this movement is represented by the variable TIME2 (the amount of time from the warheads' last update until the HML stops moving). So the time to go (TTG) is set equal to TIME2, and the random movement subroutine is called. The final location computed by the subroutine will be the HML's final position. This position is called (XHML, YHML).

Selecting the HML's Speed

The actual speed of the HML varies with the type of terrain it must traverse. Estimates provided by the Ballistic Missile Office indicated that it should be capable of traveling at speeds of 12 miles per hour over rough terrain and 38 miles per hour over smooth terrain or on roads. BMO also indicated that 30 miles per hour is a good approximation of the most likely speed over any terrain [7]. (As this report is being written, mobility tests are being conducted on full scale prototypes of the HML. Preliminary indications are that it will exceed expectations in both *off-road* and on-road speed capabilities [7]. However, this study focuses on the current estimates since conclusive results of the tests are not yet available. The model allows all three speeds, minimum, maximum, and average, to be easily changed for future use. A range of speed capabilities and their effects on survivability will be examined in the sensitivity analysis section of this report.)

Given the minimum, maximum, and most likely speeds, a triangular distribution was constructed for use in the model. This distribution is appropriate since, according to Banks and Carson, the triangular distribution is particularly useful "when assumptions are made about the minimum, maximum, and modal values of the random variable" [2,134].

In this subroutine, the minimum speed is represented by the variable MINMPH, the maximum speed is represented by MAXMPH, and the most likely speed is represented by *MLKMPH. Thus, the triangular distribution has the value of MINMPH as its minimum* value, MAXMPH as its maximum value, and MLKMPH as its modal value. The height of the triangular probability density function (PDF) at the modal value is given by the formula, Height = 2 / (MAXMPH - MINMPH). As previously mentioned, in the base case of this study, MAXMPH = 38, MINMPH = 12, and MLKMPH = 30. Therefore, the height of the PDF at the modal value of 30 is 2 / (38 - 12) = 0.0769. The distribution is illustrated in Figure 11.

The subroutine is relatively simple. It uses the cumulative distribution function (CDF) of the triangular distribution, which is determined by finding the definite integral of the PDF. As in all probability distributions, the value of the CDF ranges between zero and one. When the subroutine is called, a random number (called R12 in the subroutine) between zero and one is generated. This number represents a random sampling from the CDF. Using the value of R12, the corresponding random speed of the HML can be determined using the "Inverse Transform" technique [2, 299-300]. The random speed calculated will be the HML's average speed over that leg of its movement.

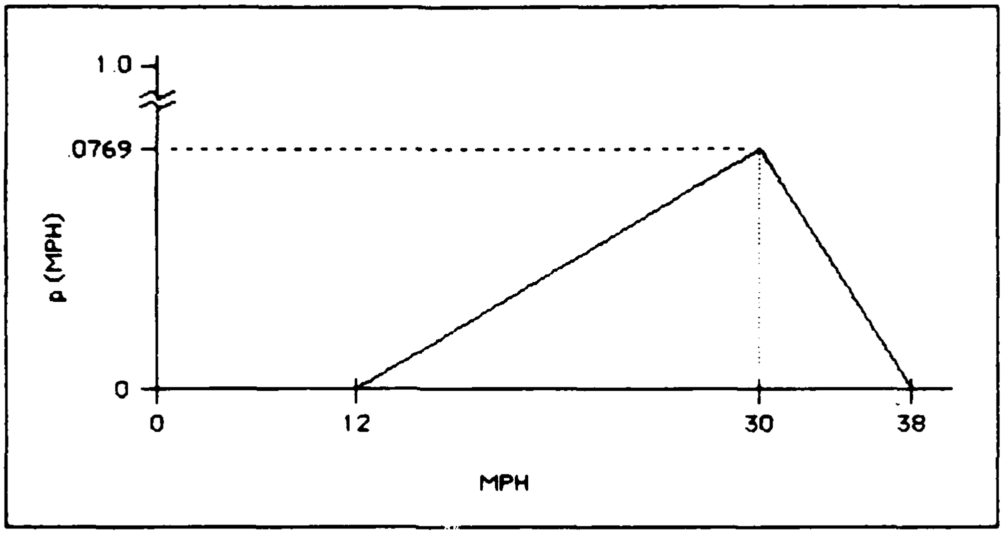

Figure 11: Triangular Distribution Used to Determine HML's Speed.

Determining Weapon Laydown Patterns

As mentioned previously, when only one warhead is attacking each HML, the aiming reference point is the warhead's DGZ. However, when multiple warheads are directed against each HML, the aiming reference point is the center of a circular "area of uncertainty." The HML is located somewhere within this circle, and the warheads must barrage this area as thoroughly as possible.

Once the aiming reference point for the warheads has been established (hence, the uncertainty circle has also been established), a subroutine is called to determine exactly where within the circle to aim each warhead. Thus, a weapon laydown pattern is established based on:

1. The number of attacking warheads. This value is examined parametrically by the model. In this study, attacks by one warhead per HML through fourteen warheads per HML are examined. (Fourteen was selected as the limiting value since preliminary studies indicate that a barrage attack would require roughly fourteen warheads per HML to achieve a .9 P_K on the entire HML force. This assumes a force of 500 HMLs which are

randomly dispersed on 16,000 square miles of land. It also assumes the attacking warheads are each approximately 1 megaton. Thus, if this thesis determines that more than fourteen warheads per HML are required to destroy 90% of the HML force, then the barrage approach can be considered the "dominant" approach. In other words, the obvious conclusion would be that the Soviets would never employ the dominated approach, so there is no need to study cases which target more than fourteen warheads against each HML.)

2. The weapon laydown pattern is also selected based on the relationship of the radius of the circle within which the HML must be located (called the radius of uncertainty, or R_U) to the lethal radius (R_L) of each warhead. R_U depends on the speed of the HML and the amount of time it travels without being observed. R_L depends on the weapon yield and its height of burst. (See Figure 12.)

The subroutine begins by determining the radius of uncertainty. This is the radius within which the attacking warheads "know" the HML must be located (based on their last intelligence update and their knowledge of the HML's speed capabilities) It is assumed that this radius (R_U) is determined prior to the ICBMs' launch using the intelligence/ retargeting cycle time as a basis for computing R_U. Cycle time is used based on the assumption that the shorter the cycle time capability, the greater the number of updates that will be obtained during the ICBMs' flight. This, in turn, implies that the HML will have less time to move (unobserved) between the warheads' last update and detonation. Therefore, a shorter cycle time implies a shorter radius of uncertainty.

To determine a formula for computing R_U, the model was temporarily modified to do nothing but generate random HML locations based on various cycle times. This modified model was run for each integral cycle time from one to thirty minutes. Two hundred repetitions of the model were run for each cycle time. The generated locations were

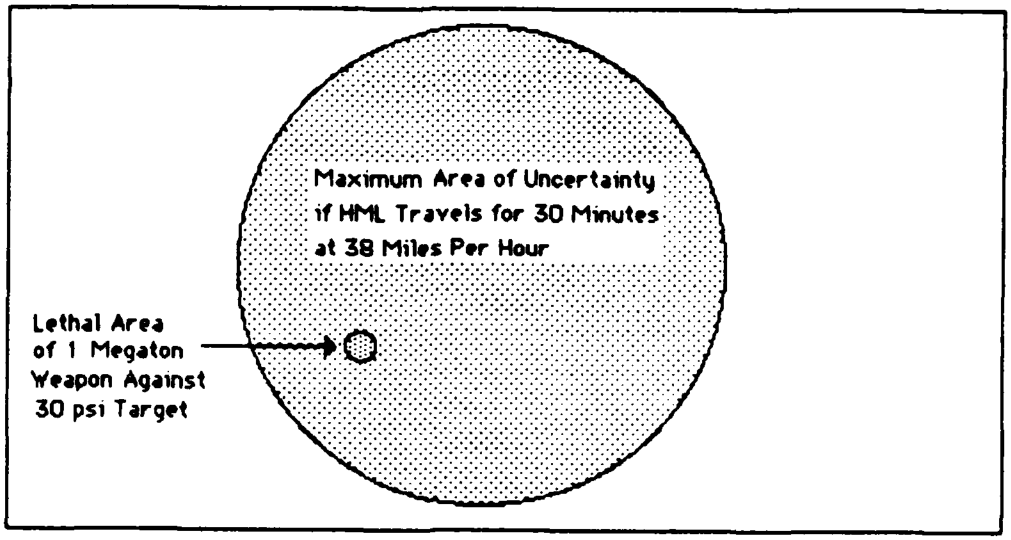

Figure 12: Maximum HML Area of Uncertainty vs. Lethal Radius of 1 Megaton Weapon.

then examined, and it was determined that in all cases, at least 98% of the generated locations fell with a radius equal to 85% of the product of the cycle time and the maximum speed of the HML. In the computer program, cycle time (in minutes) is represented by the variable CYCLE. The maximum speed of the HML is in miles per hour and is represented by the variable MAXMPH is divided by 60 to convert miles per hour to miles per minute.)

The subroutine then determines the value of the variable NUMRVS, which represents the number of re-entry vehicles (RVs) that are attacking each HML. Based on this number, the program flow is directed to the section of the subroutine which computes the weapon laydown pattern for that number of RVs. (The "weapon laydown pattern" will also be referred to as the "targeting pattern" throughout this discussion.) Examples of the targeting patterns will be described later in this section. First, however, is a general explanation of how the targeting patterns were designed.

Design of the targeting patterns is based on a comparison of the lethal radius of the weapons to the area of uncertainty which is being attacked. The objective in designing the targeting patterns is, of course, to blanket the maximum possible portion of the area of uncertainty with a lethal amount of overpressure from the explosion of the warheads. The larger the area covered by lethal overpressure, the smaller the probability of the HML surviving the attack. Since the area of uncertainty increases in direct proportion to the square of the warheads' intelligence/retargeting cycle time (see Figure 13), the ratio of lethal radius to radius of uncertainty (R_L/R_U) will also change with changing cycle times. The targeting patterns will change accordingly.

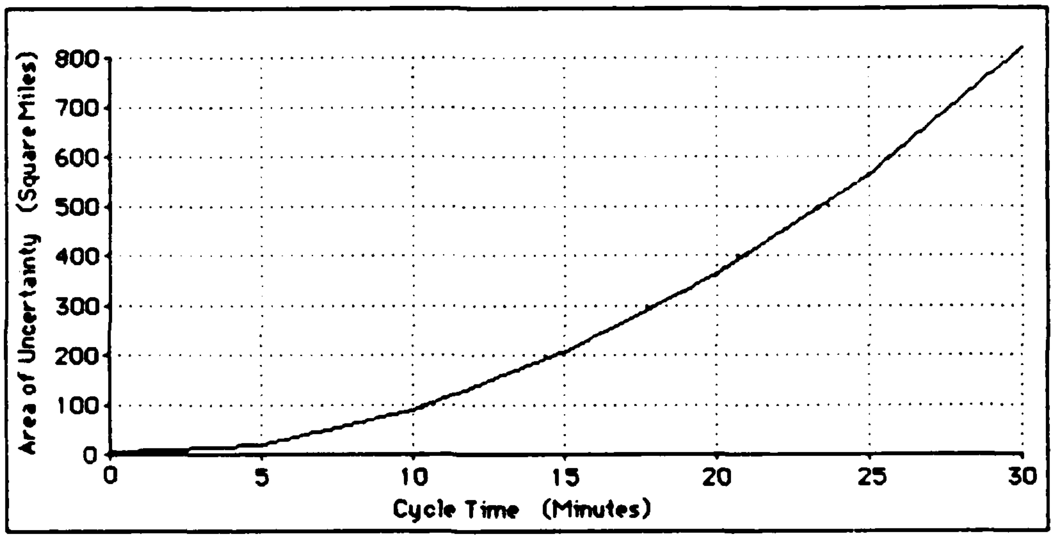

Figure 13: Cycle Time vs. Area of Uncertainty

To begin the design of the targeting patterns, it must first be recognized that for any number of warheads there are three basic cases to be examined:

1. Case 1: R_U is less than R_L. This is the trivial case. In this case, all warheads are aimed at the center of the uncertainty circle. (See Figure 14.)

2. Case 2: R_U is larger than R_L, but is still small enough that there is no possible way to lay down the weapons without having their lethal areas either overlap or extend outside the area of uncertainty. (See Figure 15.)

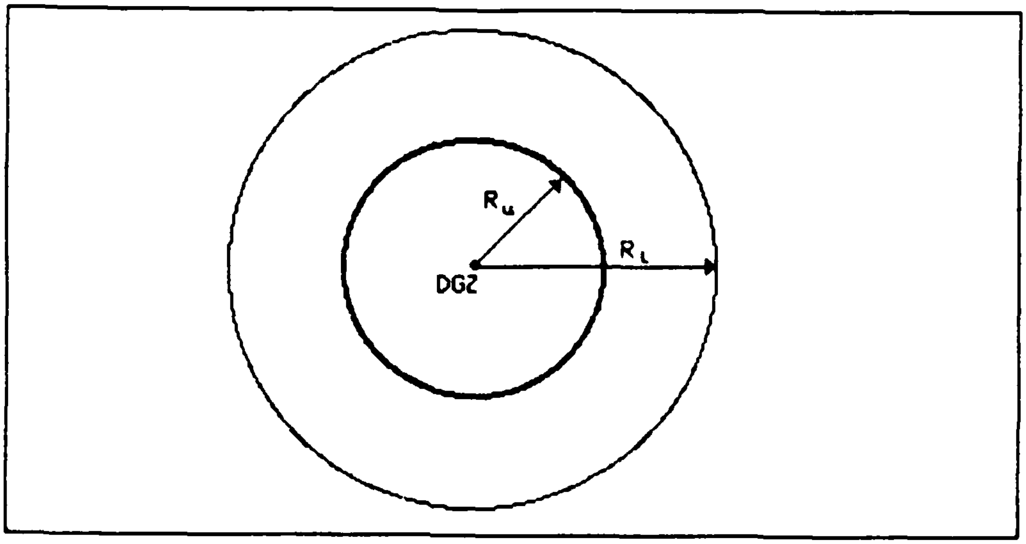

Figure 14 : Case 1 Occurs When $R_u < R_L$ and All Warheads are Aimed at the Center.

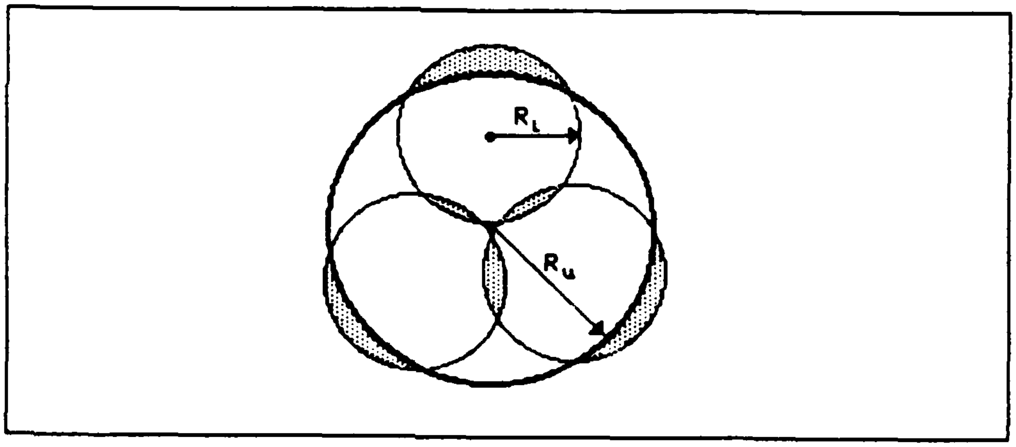

Figure 15 : Case 2 Occurs When $R_u > R_L$ with Overlapping Lethal Areas.

3. Case 3: R_U is larger than R_L, and the targeting pattern can be arranged so that none of the warheads' lethal circles overlap nor extend outside the area of uncertainty. (See Figure 16.)

As previously mentioned, Case 1 is trivial. All weapons will be aimed at the center of the uncertainty circle. Since the lethal radius of each of the warheads is greater than the

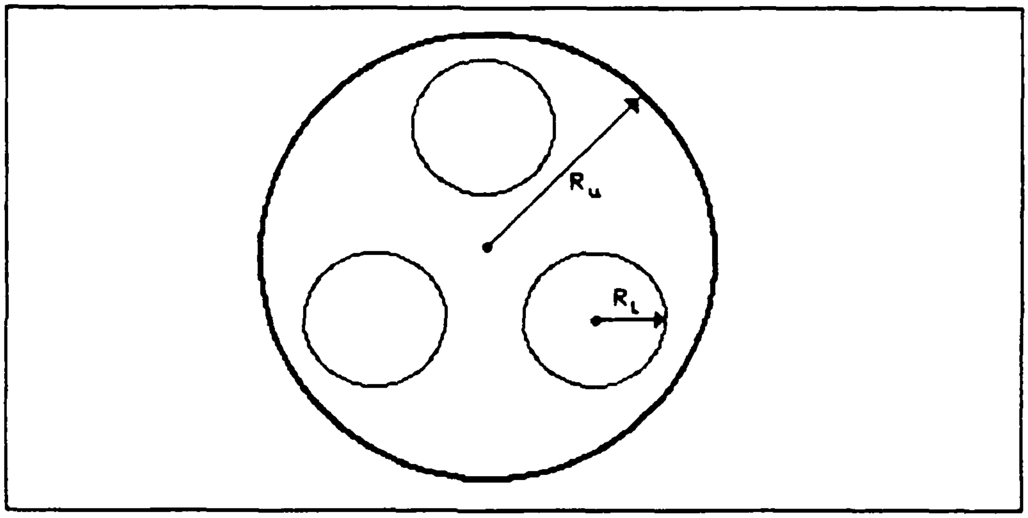

Figure 16 : Case 3 Occurs When $R_u >> R_L$ and There is NO Overlap of the Lethal Areas.

radius of uncertainty, a direct hit of any of the warheads at the DGZ will insure that the HML receives a lethal amount of overpressure.

As previously mentioned, Case 1 is trivial. All weapons will be aimed at the center of the uncertainty circle. Since the lethal radius of each of the warheads is greater than the radius of uncertainty, a direct hit by any of the warheads at the DGZ will insure that the HML receives a lethal amount of overpressure.

Case 3, while not exactly trivial, does present a relatively simple targeting problem (at least conceptually). Since R_U is sufficiently larger than R_L that there need be no overlap between the warheads' lethal areas, and none of the lethal areas need extend outside of the uncertainty circle, any targeting pattern that meets these two criteria (no overlap, no extension outside the uncertainty circle) is an effective pattern.

Case 2, however, is not as simple. Since some overlap or extension outside the uncertainty circle is required in this case, the pattern must be designed to minimize these. The pattern must also minimize "open areas," or areas within the uncertainty circle which are not covered with lethal overpressure (see Figure 15).

Since the targeting pattern is more critical for Case 2, the basic targeting pattern is designed around Case 2. First, however, a method must be devised to determine when Case 2 applies. This method will be based on the relationship between R_L and R_U, as R_U increases in size (with increasing cycle times).

It has already been established that when R_U is less than R_L, Case 1 applies. As R_U increases, it eventually becomes greater than R_L, and Case 2 applies. Thus, the lower limit of Case 2 occurs when $R_U = R_L$. As R_U continues to increase, the relationship between R_U and RL eventually reaches the point where no overlap is necessary and Case 3 applies. The relationship that marks the transition from Case 2 to Case 3 must be determined. In doing so, a basic targeting pattern will be established.

Establishing the basic targeting pattern is a process based on common sense and trial and error. First, it must be recognized that the objective of the targeting pattern is to maximize the efficiency with which the area of uncertainty can be attacked. This is accomplished by maximizing the ratio of the lethal area of the warheads (A_L) to the uncertainty area (A_U) that is being attacked. (Note that A_L is equal to the lethal area of the individual warheads multiplied by the number of warheads.) In order words, the most efficient targeting pattern is the one that creates the largest value of the ratio A_L/A_U. This implies a pattern with the warheads' lethal area circles packed together in the densest arrangement possible with a minimal amount of lethal area wasted due to overlap.

This is where the common sense / trial and error procedure begins. First, (for a given number of warheads) common sense is used to select any possible laydown patterns that might reasonably be expected to produce optimal results. Figure 17 illustrates four possible examples for the four warhead case. To select the most efficient, the smallest possible uncertainty circle is drawn around each of the possibilities. In each case, A_L is equal to four multiplied by the individual lethal areas (which are all assumed to be equal).

So the four *total* lethal areas are also equal. Thus, to determine the greatest value of the ratio A_L/A_U, the pattern which permits the smallest value of A_U must be selected. The areas, A_U, are, of course, determined by the formula, $A_U = \pi R_U^2$, so the circle with the smallest radius, R_U, will determine the targeting pattern.

Using elements of both geometry and trigonometry, the radii can be compared and the circle with the smallest radius selected. Hence, the targeting pattern is determined. In the example case (four warheads), it is pattern "b" (Figure 17).

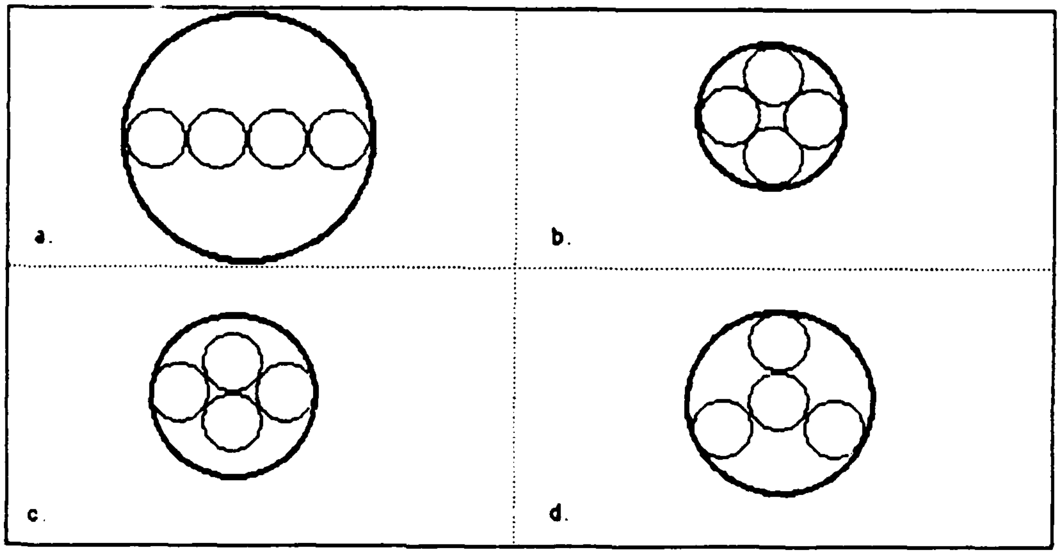

Figure 17: Four Possible Laydown Patterns for Four Warheads.

This procedure has also determined the relationship between R_L and R_U that delimits Case 2 from Case 3. In the example, when R_U is less than $(1 + \sqrt{2}) * R_L$, Case 2 applies, i.e., there will be some overlap among the lethal areas. When R_U is greater than $(1 + \sqrt{2}) * R_L$, Case 3 applies, i.e., there will be no overlap.

Targeting patterns across the range of possible relationshipts between R_L and R_U are still not completely determined. It is apparent that for Case 1, $R_U < R_L$, all weapons will be aimed at the center of the uncertainty circle. For Case 3, $R_U > (1 + \sqrt{2}) * R_L$ (in the four warhead example), the targeting pattern is not critical as long as the lethal areas are not allowed to overlap. However, when the relationship between R_L and R_U is such that $R_L \leq R_U \leq (1 + \sqrt{2}) * R_L$, Case 2 applies and the exact targeting pattern is critical.

However, the pattern may change within the limits of Case 2. In the four warhead example, Case 2 can be further divided into Cases 2a and 2b (see Figure 18). Case 2a applies when $R_L \leq R_U \leq 2 * R_L$. In this case, the weapons are targeted in the same basic arrangement with their aimpoints exactly one lethal radius from the center of the uncertainty circle. Note that there is (unavoidably) both overlap and portions of the lethal circles extending outside of the uncertainty circle.

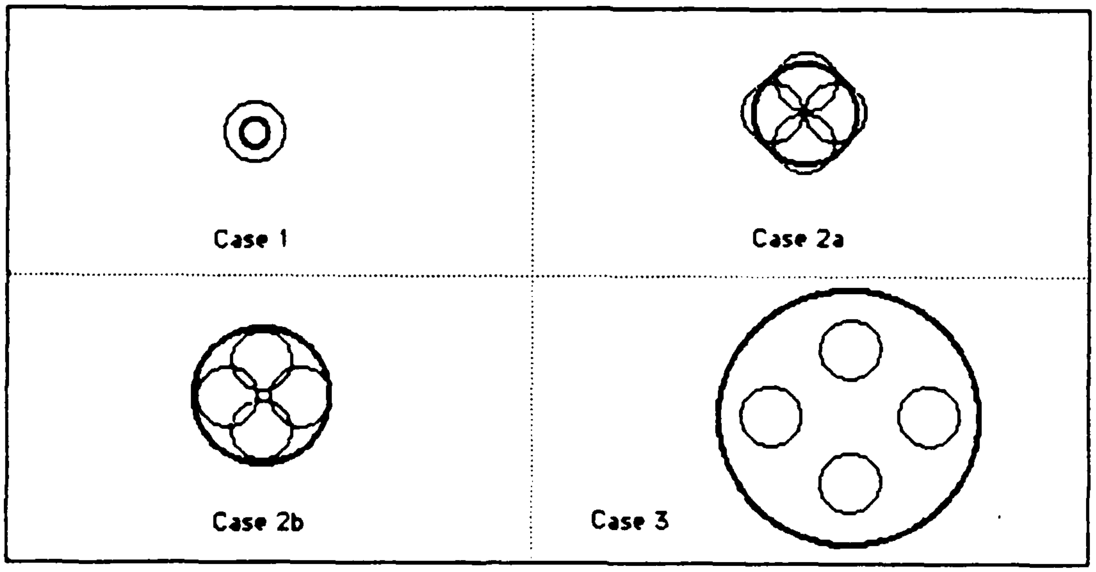

Figure 18: Range of Optimal Targeting Patterns for Four Warheads.

As R_U increases with increasing cycle times, it will eventually become as large as $2 * R_L$. When it increases beyond this size, there is no longer any extension beyond the edge of the uncertainty circle. However, the lethal circles must be rearranged to fill in (as much as possible) any open areas around the circumference of the uncertainty circle. This will, however, create a smaller open area in the center of the uncertainty circle.

Thus, in Case 2b, when $2 * R_L \leq R_U \leq (1 + \sqrt{2}) * R_L$ (still considering the four warhead example), the warheads are targeted in essentially the same arrangement, however their aimpoints will now be located a distance equal to $R_U - R_L$ from the center of the uncertainty circle. This will minimize the uncovered area near the circumference of the circle.

Cases 1, 2a, 2b, and 3 completely span the set of possible relationships between R_L and R_U. Likewise, in the four warhead example, the targeting patterns designed for the various cases comprise the entire set of targeting patterns for the four warhead case. In cases of other than four warheads, a similar trial and error procedure was used to determine the targeting patterns. Examples of these patterns for cases of two, five, ten, and fourteen warheads per HML are illustrated in Appendix F. (The one warhead case is not included, since it is the trivial case, i.e., no pattern is necessary -- the warhead is always aimed at the best known location of the HML.)

Calculating Miss Distance Based on Circular Error Probable (CEP)

Although each warhead is targeted for a specific aimpoint, the chances of it detonating precisely at that location are very slim -- theoretically zero. Rather, there is a finite probability that it may detonate at any given distance from the aimpoint. Atmospheric perturbations (most notably wind) combined with idiosyncracies in the ICBM's guidance and control systems can cause the re-entry vehicle (RV) to deviate from its intended trajectory and consequently miss its aimpoint.

A circular normal distribution was chosen to model warhead aiming errors [5, A-24]. The formula for the circular normal probability density function is given in Equation 4.1.

$$f(r) = \left[2\ln(2) \, r / CEP^2 \right] * e^{-(\ln(2)/CEP^2) * r^2} \qquad [\text{Eq } 4.1]$$

With a circular normal distribution as a model, the probability of the warhead detonating within a given distance of the aimpoint is solely a function of the radial distance from the aimpoint; in other words, there is no angular dependence. In the real world, range errors (those in the direction of the warhead's flight) are generally greater than deflection errors (those perpendicular to the direction of flight). The primary reason for assuming a circular normal aiming error is that it greatly simplifies the mathematics involved, yet it gives reasonably accurate results. [5, A-24]

The shape of this distribution (see Figure 19) shows that the probability of detonating at a given radius from the aimpoint first rises from zero to a maximum, then decays toward zero again at very great distances from the aimpoint. Intuitively, the shape of this curve appears to make good sense. One would expect it to be relatively unlikely for the warhead to detonate (in general) either very close to or very far from the aimpoint. Instead, it would seem more probable that the warhead would detonate over a range of distances, somewhere between the two extremes.

If Equation 4.1 is integrated from zero to any value, r, corresponding to a radius from the aimpoint, the result will be the cumulative probability of the warhead detonating anywhere within that radius. The function, f(r), resulting from that integration is referred to as the cumulative distribution function (CDF). The CDF for the circular normal function is given in Equation 4.2.

$$F(r) = 1 - e^{-(\ln(2)/CEP^2) * r^2} \qquad [\text{Eq } 4.2]$$

The circular error probable (CEP) of the weapon is defined as the radius, r, at which the CDF takes on the value .5. This is equivalent to saying that if a large number of warheads is fired at the aimpoint, fifty percent of them should detonate inside a circle of radius = CEP, centered on the aimpoint. As the value of r increases from zero to infinity, the CDF (reflecting the cumulative probability) increases from zero to one. For any value between zero and one, there corresponds a unique radius for which Equation 4.2 holds true. This can be treated as a miss distance -- the distance by which the warhead misses its intended aimpoint.

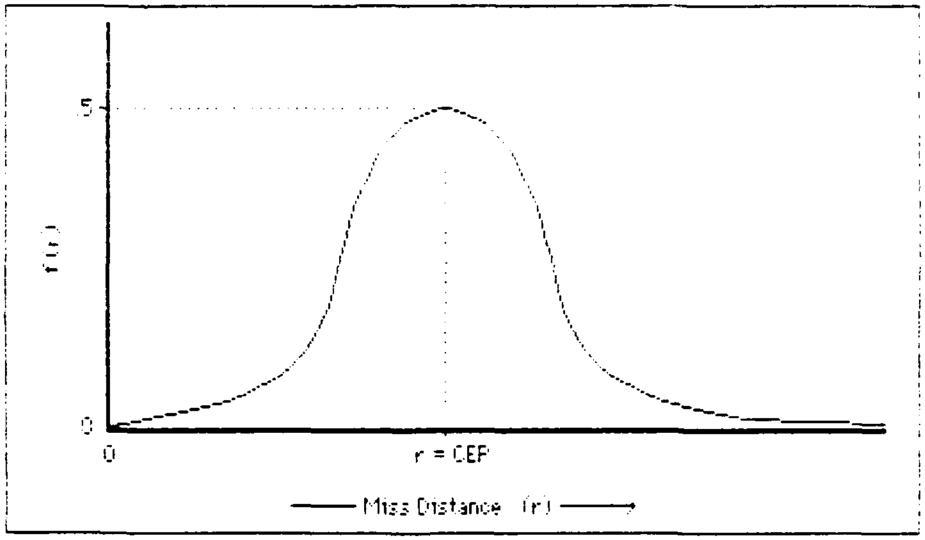

Figure 19. Circular Normal Probability Density Function (pdf).

The procedure for generating random miss distances in the model first involves drawing a random number between zero and one. This number represents a cumulative probability value. Then, Equation 4.2 is solved for r, and the result is Equation 4.3.

$$R = \sqrt{(CEP^2 / \ln(2)) \ln\left(\frac{1}{1-r}\right)} \qquad [Eq\ 4.3]$$

The value equation 4.3 takes on is consequently a randomly selected miss distance based on a circular normal distribution. Once a random miss distance is calculated, it is possible to choose the actual location of the detonation relative to the warhead's aimpoint. Since the circular normal distribution is independent of direction, a random direction between 0 and 2π radians is selected. The simulated location of the detonation will be the point in the randomly selected direction at a distance equal to the calculated random miss distance. Having the point of detonation and the actual location of the HML at the time of detonation, damage due to overpressure can be calculated.

V Model Section 3: Damage Calculations

Overview

The primary measure of effectiveness in this study is probability of kill (P_K), or, more specifically, the probability of killing an HML with a given number of attacking ICBMs. Probability of kill calculations are accomplished as follows:

1. The location of each of the bursts and the location of the HML at the time of detonation were calculated in the previous section of the model.
2. Using these locations, the model measures the distance between the HML and each of the bursts. This is accomplished in a subroutine called "Ground.695," which was provided as course material for AFIT course NE.695, "Nuclear Survivability of Systems" [17]. The next section of this chapter is a detailed description of that subroutine.
3. Given these distances, the amount of overpressure incident on the HML from each burst is computed. (This is also accomplished in "Ground.695." See the next section of this chapter.)
4. The probability the HML is destroyed by each burst (P_K) is calculated. This is accomplished in a subroutine called "Damage.695." This subroutine was also provided as course material for NE.695 [17]. The subroutine is described in detail later in this chapter.
5. The probability the HML survives each burst ($P_{S\ individual}$) is calculated using the formula, $P_{S\ individual} = 1 - P_{K\ individual}$.
6. The product of the individual probabilities of survival is calculated to determine an overall P_S, (denoted $P_{S\ overall}$) -- the probability that the HML survives all the

bursts, or $P_{S\ overall}$ = (the product of all the $P_{S\ individuals}$)

7. The cumulative P_K from all the bursts is computed using the formula,

$$P_{K\ overall} = 1 - P_{S\ overall}$$

As previously mentioned, most of the calculations necessary to compute $P_{K\ individual}$ are performed in subroutines "Ground.695" and "Damage.695." Descriptions of those subroutines follow:

Calculating the Incident Overpressure

Given the location of each burst and the location of the HML at the time of detonation (which were computed in the previous section of the model), the program calls a subroutine called "Ground.695." (This subroutine was provided as course material for use in AFIT course NE.695. [17]) Ground.695 calculates the peak overpressure experienced by the HML (from each burst).

Ground.695 begins by computing the "scaled" ground range from the HML to the burst and the "scaled" height of burst. Scaling is accomplished by applying established scaling relationships to the actual ground range and height of burst. (The scaling relationships are included in The Effects of Nuclear Weapons by Glasstone and Dolan. [9, 100-103]) Scaling these values allows data based on standardized values of height of burst and weapon yield to be transformed into data for any particular combination of actual height of burst and yield. Conversely, data from non-standardized cases can be scaled to the "reference case." (The standardized data is generally called the "reference case." The common nuclear effects reference case is the set of data that applies to a one kiloton detonation at sea level.) The net effect is that this set of standardized data can be used to study the effects of nuclear bursts of any size and at any altitude.

Peak overpressure can be computed in the reference case using a set of curves (often called the "knee curves" because of their shape), which are based on empirical data from nuclear weapon tests. The "knee curves" are from Glasstone and Dolan [9, 113].

Because of the irregular shape of the knee curves, it is impossible to represent them in closed mathematical form with a single equation. So they have been divided into several sections, and each section is described mathematically by a separate equation. Ground.695 uses these equations to approximate the knee curves. Once the scaled ground range and height of burst are computed, the appropriate equation is selected and the peak overpressure is calculated. This value is used in subroutine "Damage.695" to calculate the damage level inflicted on the HML.

Computing the Probability of Kill

Once the peak overpressure incident on the HML is known (see the previous section of this chapter), a subroutine called "Damage.695" is called to calculate the probability of kill based on this peak overpressure. (Damage.695 was provided as course material in AFIT course NE.695. [17])

Damage.695 uses a cumulative log normal damage function to calculate the probability of kill. The log normal function is used in situations where the logarithm of a random variable is believed to follow a normal distribution [3,160]. Physically, the log normal density function resembles that of the normal density function except it rises to its peak more rapidly and falls from it more gradually. The log normal is frequently used in reliability engineering to model failures [14, 189]. Accordingly, it is appropriate to use this distribution to model the "failure" of the HML as a result of being exposed to nuclear blast overpressures.

The cumulative distribution function (CDF) for the log normal is illustrated in Figure 20. As shown in the figure, two parameters are needed to completely specify a unique log normal distribution. These parameters can be determined by establishing any two points on the curve as reference points. The two points used in Damage.695 correspond to the "sure-safe" and "sure-kill" intensity levels (ISS and ISK). Sure-safe is defined as that intensity of peak overpressure that would result in only a 2% chance of killing the HML. Sure-kill is defined as that intensity level that would result in a 98% chance of killing the HML (again, refer to Figure 20).

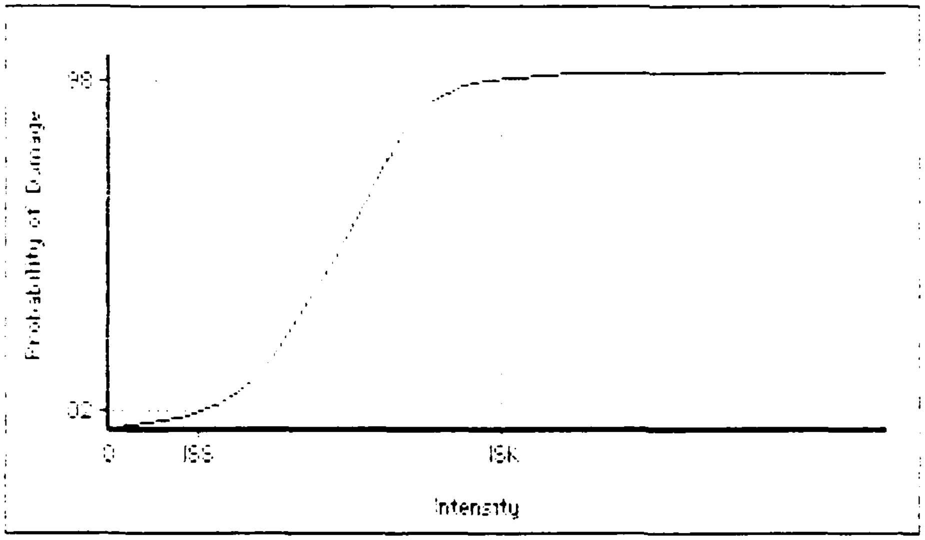

Figure 20. Cumulative Log Normal Damage Function.

The sure-safe and sure-kill levels are user inputs to the model. Their net effect is to determine the slope of the cumulative log normal damage function. The further they are apart, the more gradual the slope of the CDF will be, implying that there is a large range of overpressures over which the HML can survive. The closer they are together, the steeper the slope will be. In the limiting case, sure-safe equals sure-kill, and the damage function becomes a "cookie cutter." This means, quite simply, that if the HML experiences a peak overpressure less than the specified level, it will survive (probability of kill = 0); if it receives more overpressure than the specified amount, it will be destroyed (P_K = 1).

In general, the CDF of a probability distribution is determined by integrating the probability density function (pdf) over the appropriate range. However, the integral of the log normal pdf cannot be calculated in closed form. Rather than integrating by a numerical technique, a substitution is made which transforms the integral representing the cumulative log normal distribution function into one which is identical to the cumulative normal distribution function. This can be reasonably well approximated by a pair of closed form algebraic equations, thus eliminating the need to perform a difficult numerical integration. Damage.695 uses these equations to determine the probability of kill. The primary reason for using this approach is that it permits faster computer run times without sacrificing significant accuracy.

Damage.695 computes the $P_{K\ individual}$ of the HML resulting from each of the bursts. Upon return to the main program, the $P_{K\ individuals}$ are converted to $P_{S\ individuals}$ using the formula, $P_{S\ individual} = 1 - P_{K\ individual}$. The product of all the $P_{S\ individuals}$ is calculated to determine the $P_{S\ overall}$. Then the $P_{K\ overall}$ is calculated using the formula, $P_{K\ overall} = 1 - P_{S\ overall}$.

VI. Model Verification and Validation

Detailed verification and validation of the computer model began during model construction as essential parts of the modeling process. They continued after the model was complete, during the analysis of the model's outputs. Both verification and validation were performed using general guidance and several specific techniques from Discrete-Event System Simulation by Banks and Carson and Simulation Modeling and Analysis by Law and Kelton.

Verification

According to Banks and Carson, "Verification refers to the comparison of the conceptual model to the computer code that implements that conception. It asks the questions: Is the model implemented correctly in the computer code? Are the input parameters and logical structure of the model correctly represented in the code?" [2, 376] Several techniques are suggested in the two previously mentioned texts.

1. Both Banks & Carson and Law & Kelton suggest having more than one person check the computer code as an aid to verification "since the person who writes a particular subprogram may get into a mental rut and thus not be a good evaluator of its correctness" [15, 334]. (This is sometimes referred to as "egoless coding" [16, 184].) The authors of this thesis performed systematic checks of each other's coding throughout the model construction process. Thus every line of original computer code was checked by someone other than the programmer. Additionally, several subroutines in the model are derived from subroutines used in an Air Force Institute of Technology nuclear survivability course, NE 6.95. These subroutines have been verified by repeated use in that course.
2. In Banks and Carson, it is suggested that flow diagrams be made [2, 379] Detailed

flow diagrams were constructed and are included in Appendices B through E

3. It is suggested in Law and Kelton that the computer program be "debugged" in modules or subprograms [15, 334]. This procedure was carefully adhered to in the verification process of the model used in this thesis. The modules verified and the procedures used to verify them are as follows:

   a. The optimal height of burst subroutine was separated from the model and debugged as a module. This subroutine has as inputs the maximum speed of the HML and the intelligence retargeting cycle time currently under examination. It uses these to compute the maximum distance the HML can travel within one cycle, and based on this distance it computes an optimal height of burst. The subroutine is based on the peak overpressure "knee curves" from Glasstone and Dolan [9,113]. Several equations are used in the subroutine to algebraically approximate the knee curves, which are a set of continuous curves. To verify the accuracy of the subroutine, values of the input variables across the entire reasonable range were selected. These values were used to compute optimal height of burst both by hand using the knee curves in Glasstone and by running them through the subroutine. The results were then compared. In all trial cases, the differences were virtually negligible.

   b. The section of the model that computes HML movement times was removed from the model and tested as a separate module. (For a detailed description of the operation of this section of the model and for a definition of the variables used, see Chapter III of this report.) This section was tested by hand. It was run 100 times. Each time, the value of the variables TIME1, TIME2, FLTTIM, DETECT, and SETUP were displayed. They were then checked to insure that FLTTIM was equal to the sum of the other four variables. This proved true in all cases, so this module was considered verified.

c. The random movement subroutine was verified as a separate module. Given a length of time as an input, this subroutine simulates the random movement of the HML for that length of time. It is assumed that the HML moves in such a random fashion so that its location at the end of the time period is totally unpredictable. (Simulating the HML's dispersal tactics this way was suggested by the Ballistic Missile Office's Hardened Mobile Basing Branch [7]). A detailed explanation of the process used in this subroutine is included in Chapter V of this report. The desired outcome of the subroutine is a set of coordinates, (X,Y), representing a point that was selected totally at random from the set of all possible points, thus insuring that the HML's location will be totally unpredictable. Viewed another way, if the subroutine were run many times with the same input parameters, there would be no observable pattern in the output results. This is precisely the procedure used to verify the subroutine. It was run 100 times using an input time of thirty minutes (to approximate an ICBM's flight time), and the output points were plotted on a graph (see Figure 21). The distribution of the points on the graph was evaluated by inspection. No unusual groupings of points or other obvious patterns were noticed, so the distribution was considered sufficiently random, and the subroutine was considered verified. (The circle on the graph represents the limit of the HML's travel. It is calculated by multiplying the HML's maximum speed in miles per minute by 30 minutes. Thus, a further verifying check was to insure that all 100 points fell within the circle.)

d. The subroutine that calculates the HML's speed on a given leg of its movement was tested as a separate module. The subroutine selects speeds based on a triangular distribution with the HML's minimum and maximum speeds as the limiting ends of the distribution, and the most likely speed as

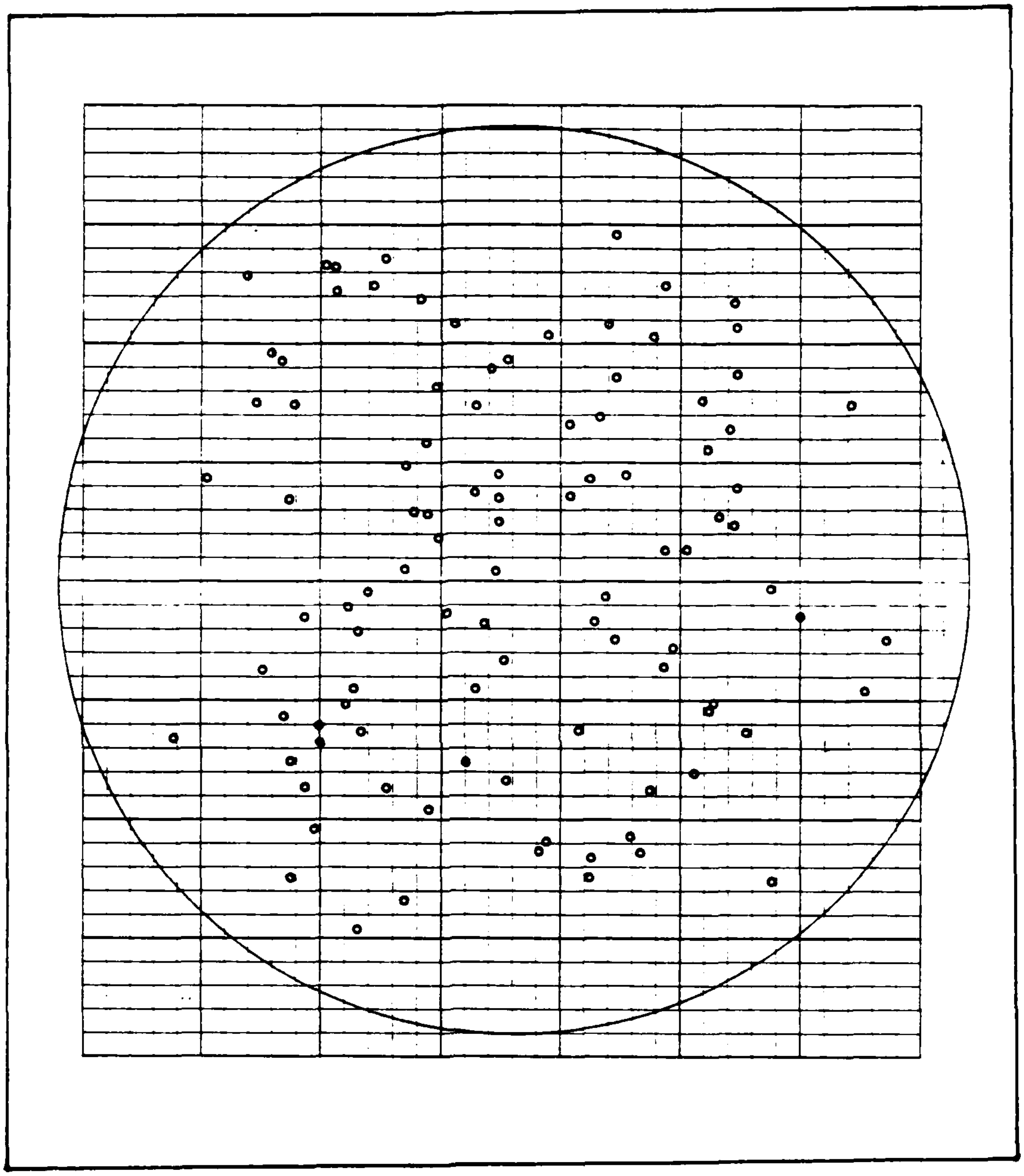

Figure 21: Verification of Random Movement Subroutine.

the modal value of the distribution. In the base case of the model, the minimum speed was set at 12 miles per hour, the maximum at 38 miles per hour, and the most likely speed was set at 30 miles per hour. Using these values, the subroutine was run 100 times, thus generating 100 random speeds. A frequency histogram was plotted and evaluated by inspection to insure that it was, in fact, roughly triangular in shape with its modal value near 30 miles per hour. The results appeared reasonably close to the desired distribution (see Figure 22), so this module was considered verified.

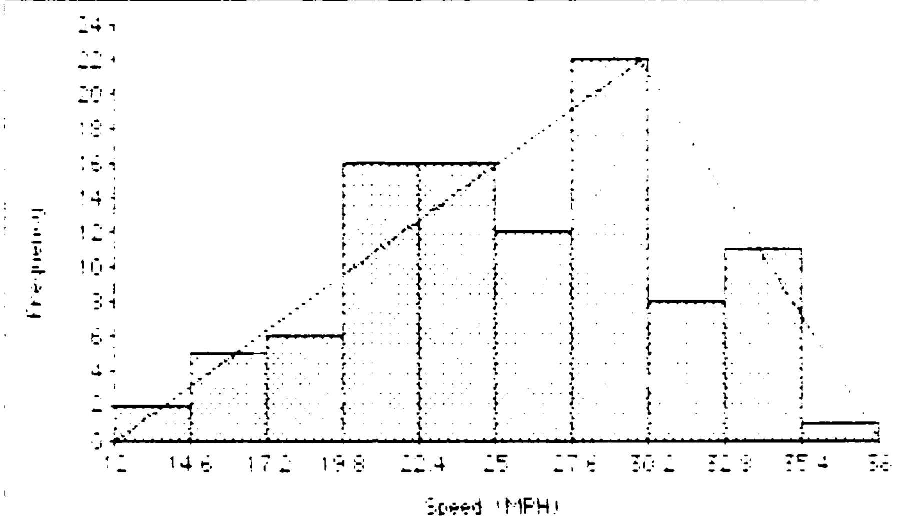

Figure 22. Frequency Histogram of HML Speed Distribution

e. The miss distance routine was verified as a separate module. This subroutine selects a miss distance for the incoming warheads based on the ICBM's circular error probable (CEP). The subroutine uses a circular normal distribution to compute the miss distance. Verification was accomplished in a manner similar to 3.d. above. The subroutine was run 100 times and a frequency histogram was constructed from the results. It was examined to insure the histogram approximated a normal distribution with a mean = CEP. Upon examination, the distribution was determined to be sufficiently accurate, so it was considered verified.

f. The warhead targeting subroutine was also checked as a separate module. This subroutine determines effective targeting patterns depending on the number of warheads aimed at each HML and also depending on the size of the region that must be attacked. This region is circular and represents an "area of uncertainty" within which the HML must be located. Since the HML's exact location within this region is unknown, the region must be barraged as thoroughly as possible by the attacking warheads. (This subroutine is examined in greater detail in Chapter IV of this report.) The subroutine was painstakingly checked by hand throughout the appropriate range of input parameters to insure its performance was as expected. The results were satisfactory, and the subroutine was considered verified.

g. As mentioned, the subroutines used to compute the damage levels inflicted on the HML were derived from subroutines used in AFIT course NE.695. Thus, they were considered to have been previously verified.

4. After the model has been divided into modules, and the modules have been individually verified, the model must be reassembled and verified as a unit to insure that the modules interact properly. A technique for verifying the entire model is suggested by Banks and Carson. "Closely examine the model output for reasonableness under a variety of settings of the input parameters" [2, 379]. This technique amounts to a form of "sensitivity analysis." This type of analysis was performed on the model using one further technique, this one suggested by Law and Kelton. "The model should, when possible, be run under simplifying assumptions for which the model's true characteristics are known or can easily be computed" [15, 335]. Using both of these guidelines, the entire model was examined. The procedure was as follows:

   a. All variables in the model whose values are normally determined through some random process were set equal to constant values. The value selected, if possible, represented the expected value of the variable (or a "most likely" value).

1) HML speed was set equal to 30 miles per hour.

2) The "sure-safe and "sure-kill" hardness levels of the HML were set to simulate the HML being hardened to 30 psi of overpressure.

3) ICBM flight time was set at 30 minutes.

4) Height of burst was set at 5200 feet.

5) CEP was set at 0 (thus miss distance was also set at 0).

6) Weapon yield was set at 1000 kilotons.

b. Each of theses variables was then varied through extreme values (one variable at a time, while the others were held constant at the indicated values), and the effect on the output of the model was observed for intelligence / retargeting cycle times of five, ten, and fifteen minutes. The results of these checks were:

1) The model was run with the HML's speed equal to 5 miles per hour and 100 miles per hour. A notable decrease in P_K was observed (as expected). It was therefore concluded that the model reacts properly to changes in HML speed.

2) The model was run using HML hardness levels of 1 psi and 100 psi. Again, a decrease in P_K was observed, indicating that the model reacts properly to variations in HML hardness.

3) The model was tested using ICBM flight times of 26 and 34 minutes. No significant variations in the model's outputs were observed.

4) Height of burst was varied through 1000 foot intervals from 0 to 10,000 feet. There were no obvious trends by which to verify the model's results. However, it was observed that the maximum P_K values "across the board" occurred for a height of burst of 5000 feet. This result was compared with values from the "knee curves" in

Glasstone and Dolan [9, 113]. It was seen that with a one megaton weapon, the 30 psi knee curve produces its maximum ground range with a height of burst (after scaling) of approximately 5200 feet. In other words, given a target that is hardened against 30 psi of overpressure and given a 1 megaton weapon, the lethal radius of that weapon against that target will be at a maximum when the weapon is detonated at an altitude of 5200 feet. (The lethal radius in this case is approximately 6400 feet, or about 1.2 miles.) Thus, the observation that P_K values in the test runs of the model were highest for a height of burst of 5000 feet is the expected result according to the knee curves. This result was regarded as sufficient to verify that the model reacts properly to the effects of changes in the height of burst.

5) CEP was varied from 0 to 1000 meters. The result, as expected, was a noticeable reduction in P_K. Thus, it was verified that the model reacts properly to changes in CEP.

6) Weapon yield was varied from 10 kilotons to 10,000 kilotons. As expected, there was a noticeable increase in P_K, and it was concluded that the model responds properly to changes in weapon yield.

The overall conclusion from these tests of the model's sensitivity is that the individual modules in the model work properly together.

5. One further suggestion in Banks and Carson to assist in verifying the model is to "make the computer code as self-documenting as possible" [2, 379]. The fully documented program is contained in Appendix A. Additional detailed descriptions of the model and definitions of the variables appear in Chapters II through V of this report.

5. Finally, in Computer Principles of Modeling and Simulation by Lewis and Smith, the authors state that, "since testing falls short of being exhaustive, we can never be sure that the program is truly correct" [16, 188]. However, they also suggest that common sense is a good "last resort" approach to the verification process, and that common sense should be used throughout the process of analyzing simulation output.

Validation

Validation of this particular model is a much more difficult undertaking than was verification. Validation of the model, according to Banks and Carson, "is the overall process of comparing the model and its behavior to the real system and its behavior" [2, 383]. Therein lies the difficulty, since the primary system being studied by this thesis, the HML, exists in prototype form only, and the threat system being studied is purely hypothetical. Thus, no "real-world" data exists, per se, for either system. However, validation can be accomplished to some degree by using the best available information to approximate the two systems and their interactions.

In Banks and Carson, a three-step validation process is suggested:

"1. Build a model that has high face validity.

2. Validate model assumptions.

3. Compare the model input-output transformations to corresponding input-output transformations for the real system" [2, 384-385]

Creating and maintaining a high face validity was a primary concern during model construction. The main time sequence upon which the model is based, is a simulation of the time of flight of the threat ICBM (see Figure 23). This sequence was actually modeled in greater detail than was strictly necessary, primarily to maintain the high face validity of the model. For example, in the sequence illustrated in Figure 23, the critical time can be identified as the time from the attacking warheads' last update until the time when the HML stops moving and begins assuming its hardened configuration. This is a critical time period, because it is during this time that the HML will be able to move without being observed by the incoming system. The further the HML can move during this time, the greater its probability of survival. Thus, it is conceivable that the entire problem could have been solved by parametrically examining this time interval alone. However, it was decided to model the entire flight sequence of the attacking ICBM, because the user of the model can easily visualize how this critical time period is determined and how it fits into the flight time sequence of the attacking ICBM. Standing on its own, the exact physical interpretation of this time period could be a source of confusion. Strictly speaking, then, the model may be slightly more complex than is necessary. However, the additional complexity increases the model's face value, and is thus beneficial in the long run.

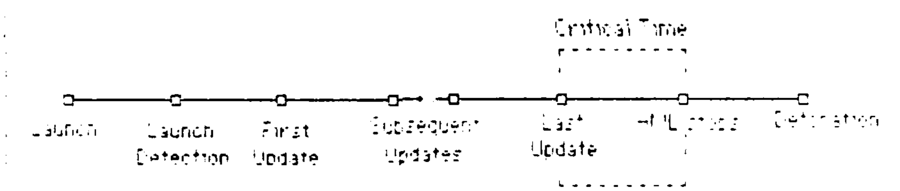

Figure [illegible]. ICBM Time Sequence Indicating Critical Time

The second step suggested by Banks and Carson is to validate model assumptions. This, again, is somewhat difficult to accomplish in this case, since model assumptions are based on one hypothetical system and one system that, to date, exists in prototype form only. However, in modeling these systems, every attempt was made to base assumptions on factors that could be justified by existing technology or by reasonable, documented projections of future technology. For example, the model allows the CEP of the threat system to assume any value. However, this study assumed the threat system to have a very low CEP (ten meters). This may seem unreasonably low. However, this assumption is based on projected AMARV technology and is taken directly from a 1982 AFIT Masters Degree thesis by Captain Paul Auclair. Thus, it is considered validated. All model assumptions are validated in a similar manner. The validation of each model assumption will not be discussed here. However, the source of each assumption is stated in this report when the assumption is made, hence the validity of each assumption can be examined.

The third suggestion in Banks and Carson, to compare model vs. real-world input-output transformations, is again difficult since real-world systems do not actually exist. "A necessary condition for the validation of input-output transformations is that some version of the system under study exists, so that system data under at least one set of input conditions can be collected to compare to model predictions" [2, 387]. This is a difficult condition to fulfill in this case. However, one method to circumvent this difficulty is suggested by an operating instruction (OI) issued by Headquarters Air Force, Center for Studies and Analyses. It is stated in this OI that in each study a preliminary analysis should be performed. There are several stated goals to this preliminary analysis, one of which is "to have a 'yardstick' against which to test the results of more in-depth analysis" [13, 8]. Thus, in the absence of real-world data, this preliminary analysis can provide a first order approximation of realistic data to compare to the output results of the model. This technique was used in this study. A preliminary estimate was made of the expected model results under various input conditions. The model was run and output was examined to insure that predicted trends were, in fact, being adhered to. While predicted results and actual results were not precisely the same in all cases, the predicted trends were as expected. Thus, the model's input-output transformations are considered to be valid.

The validation process of the model, using the three-step process suggested by Banks and Carson was completed as described. The validity of the model is therefore considered sufficient to instill confidence in its results.

VII. Base Case Analysis

Input Parameters for the Base Case Analysis

Where appropriate, the values of input parameters for the base case analysis were chosen to coincide with those used in a study conducted by the Ballistic Missile Office (BMO). This approach allows a comparison of the results of this thesis with the results of the BMO study. (It should be noted that the BMO study was quite preliminary and the results are by no means final [7]. However, they provide at least a good first order approximation for comparison purposes.) The next two sections of this chapter discuss various key input parameters and how the appropriate values were determined.

HML Characteristics

The HML's speed is modeled using a triangular probability distribution (for a more detailed description, refer to Chapter IV). A triangular distribution is characterized by three parameters, the maximum value, the minimum value, and the modal value. In the computer model, the triangular distribution's maximum value is set equal to the HML's maximum speed. This value represents the HML's speed on relatively smooth terrain. In the base case, this speed is 38 miles per hour. The distribution's minimum value is set equal to the HML's minimum speed. This represents the HML's speed over rough terrain. In the base case, it is 12 miles per hour. The value at the mode of the distribution is set equal to the HML's most likely speed over the range of terrains it will encounter during its dispersal. This speed is 30 miles per hour. (These speeds were suggested by BMO [7]).

In the base case, the HML is assumed to be hardened to withstand peak overpressures of up to 30 psi. This value was also suggested by BMO [7]. BMO also suggested using a "cookie cutter" approach to model HML hardness. This means, quite simply, that if the HML experiences a peak overpressure of less than 30 psi, it will survive ($P_K = 0$). If it receives 30 psi or more, it will be destroyed (P_K = 1)

The actual damage function used in the model is based on a log normal probability distribution, which is explicitly characterized by two parameters, the HML's sure-safe and sure-kill intensity levels. (This damage function is described in detail in Chapter V.) To reduce this damage function to the desired "cookie cutter" function, the sure-safe and sure-kill levels must be quite close together. In the base case, to model a cookie cutter damage function (centered around a 30 psi overpressure intensity level), sure-safe was set at 29.9 psi and sure-kill was set at 30.1 psi.

The HML requires a certain amount of time to be transformed from its mobile mode into its hardened configuration. It was assumed that the HML requires two minutes to accomplish this. This figure was suggested by BMO [7].

Launch detection time was assumed to be 1.5 minutes. This figure comes from a Brookings Institute study [20, 46]. Launch detection time is the amount of time required to alert the HML that an attack is underway.

Threat Characteristics

The yield of the attacking warheads in the base case analysis was one megaton (MT), again suggested by BMO [7]. This figure can be viewed as a very rough approximation of the capability of a Soviet SS-18 warhead.

The circular error probable (CEP) of an SS-18 is probably on the order of hundreds of meters. In this thesis, however, the threat weapon system was assumed to have a much smaller CEP. In fact, a CEP of ten meters was used. The decision to model a smaller CEP was based on projected advanced maneuverable re-entry vehicle (AMARV) technology. One type of AMARV, the "accuracy" AMARV, uses enhanced maneuverability to improve its accuracy, thus reducing CEP to near zero levels [1, 3]. Since the threat weapon system modeled in this study is hypothetical and based on potential technological advances, it was decided to include AMARV technology as one of the technological improvements.

A static height of burst of 5200 feet (approximately 1585 meters) was used in the base case of this study. This value was selected from the overpressure "knee curves" in Glasstone and Dolan [9, 113]. These curves indicate the optimal height of burst for any combination of ground range and incident overpressure. In this case, the object is to maximize the ground range over which a peak overpressure of 30 psi or greater can be achieved. This is accomplished by finding the point on the 30 psi curve that yields the greatest range, then determining the corresponding height of burst (after scaling). It was determined that the maximum ground range to achieve 30 psi with a one megaton weapon is 6400 feet (approximately 1.2 miles), corresponding with a 5200 foot height of burst.

Flight time of the ICBM was modeled as a uniform random variable between 26 and 34 minutes (thus, the mean is 30 minutes). This distribution approximates a range of values taken from a graph in Long Range Ballistic Missiles by Burgess [6, 195]. (Note that depressed trajectories were not considered.)

Analytical Approach

The purpose of this study is to determine the effectiveness of targeting individual HMLs as compared with the current baseline scenario, the barrage attack. As previously stated, the primary measure of effectiveness (MOE) is the probability of kill (P_K) of the HML when attacked by the hypothesized threat. Of particular interest is how the HML's P_K is effected by changes in the threat system's intelligence / retargeting capability. Since it is assumed that the threat system has the capability to locate the HML and retarget at regular intervals (cycles) during its flight, cycle times from one to thirty minutes (in one minute intervals) were examined. (Thirty minutes was selected as the upper limit since an ICBM's flight time is approximately thirty minutes. Thus, if the cycle time were longer than thirty minutes, the last update would necessarily be obtained prior to launch.)

BMO's study (again, note that this refers to a preliminary study, and the results are therefore quite approximate) indicated that given the proposed number of HMLs (500) and the proposed total land area of the HML bases (approximately 16,000 square miles), a barrage attack would require at least fourteen warheads per HML (approximately) to achieve a .9 P_K across the entire HML force [7]. That is precisely why the HML is considered a viable weapon system -- it is assumed that the Soviets will not be willing (or able) to expend that many warheads against such low value targets (recall, the SICBM will carry only one warhead). An interesting question, then, is whether the hypothetical threat system in this thesis is able to "out perform" the barrage attack, i.e., achieve a .9 P_K with an expenditure of less than fourteen warheads per HML. To examine this question, the number of attacking warheads (per HML) was varied from one to fourteen. Numbers greater than fourteen were not examined since the barrage attack is more effective and less expensive (since it requires no new technology) than these. Thus, for cases of more than fourteen warheads per HML, the barrage attack is clearly the dominant choice.

Results

The model was run for all combinations of cycle time and numbers of warheads. The results were then compiled and curves were plotted on a series of graphs. Each curve represents a given number of warheads. Each vertical axis represents the P_K, while the horizontal axis represents increasing cycle times. After examining the graphs, it was decided that presentation of the results would be better facilitated if four cases were selected to represent the entire set of results. This allows all four curves to be plotted on the same graph, making a direct comparison possible. (If all fourteen curves were plotted on the same graph, the results would be difficult to read and therefore quite confusing.) The one, five, ten, and fourteen warhead cases were selected to represent the entire set

These four curves adequately span the entire set, and the basic shapes of the curves are similar enough to allow easy interpolation of P_K values from the intermediate curves.

The results for the base case are illustrated in Figure 24.

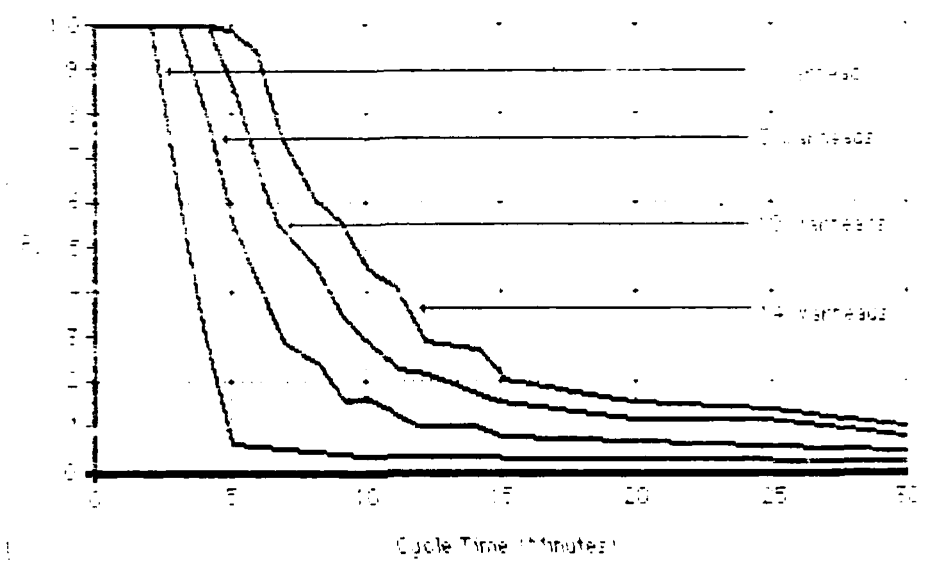

Figure 24: Base Case Results for 1, 5, 10, & 14 Warheads.

Observations

The basic shape of the curves in Figure 24 is as expected. For very short cycle times (less than two minutes), the P_K is approximately 1, regardless of the number of warheads. This is because the attacking warheads will obtain intelligence regarding the location of the HML frequently enough to prevent it from ever traveling outside the 30 psi lethal radius.

As cycle time increases beyond two minutes, the P_K falls off very rapidly. This is true regardless of the number of attacking warheads. The steep downward slope continues until the cycle time reaches approximately fifteen minutes, and then the curve begins to level off. However, P_K values are already quite low when this occurs. Even in the extreme case of fourteen warheads per HML, no better than a .2 P_K can be achieved with cycle times greater than fifteen minutes.

In all cases, for a given cycle time, the greater the number of attacking warheads, the greater the resulting P_K will be. There are, however, diminishing returns as the cycle time increases. At a five minute cycle time, for example, one warhead will produce a P_K of only .048, while fourteen warheads will yield a .99 P_K. For a ten minute cycle time, the P_K for one warhead drops by .038 to .01, while for fourteen warheads, it drops by .54 to a P_K of .45. This P_K for fourteen warheads is still clearly superior to that for one warhead (as expected), but the difference is not as large as it was for a five minute cycle time. Similar comparisons can be made for other combinations of warheads and cycle times, and the results are generally the same. Larger numbers of warheads will always produce greater P_Ks, but their marginal superiority decreases as the cycle time increases.

The study performed by BMO focused on the number of warheads (per HML) necessary to achieve a P_K of .9. In the base case of this study, to achieve a .9 P_K with one warhead, the cycle time must be approximately 2.3 minutes or less. By increasing the number of warheads to five, the range of cycle times that will achieve a .9 or greater P_K is expanded out to 3.5 minutes. For ten warheads it is further expanded to 4.7 minutes, and for the limiting case of fourteen warheads, a P_K of .9 or greater can be achieved with cycle times of 6.2 minutes or less.

The spacing of the one, five, ten, and fourteen warhead curves across the .9 P_K line indicates that there is a relatively constant rate of reduction in the number of required warheads as the cycle time is decreased. For every minute the cycle time is reduced below 6.2 minutes, the number of warheads required to achieve a .9 P_K is reduced by approximately 3.25.

A similar result is true for a P_K of .5. The cycle times required to achieve a .5 P_K extend from 3.2 minutes with one warhead to 9.6 minutes with fourteen warheads. Thus, for each minute the cycle time is reduced from 9.6 minutes, the number of warheads required to achieve a P_K of .5 decreases by approximately 2.

There are two primary conclusions to be drawn from the results of the base case. First and foremost, unless it is assumed that the Soviets can develop a system capable of cycle times less than approximately six minutes, this is not a viable attack scenario. If the threat system requires more than six minutes to complete an intelligence / retargeting cycle, it will require more than fourteen warheads per HML to achieve a P_K of .9. In this case, the barrage attack is a more cost efficient scenario.

Secondly, for cycle times less than ten minutes, P_K becomes very sensitive to even small changes in cycle time. This implies that if such a threat were developed, it would have to be extremely reliable. For example, if the threat consisted of one warhead with a cycle time of two minutes, the P_K would be .995 (refer to Table 1). If a problem developed during the flight of the ICBM resulting in a one minute increase in the effective cycle time, the expected P_K would drop dramatically to .554. The sensitivity of P_K to cycle time decreases slightly as the number of warheads increases. However, even the fourteen warhead case is quite sensitive, thereby requiring a highly reliable system to make this a feasible threat.

<u>Additional Observations</u>

Two interesting questions arise from a careful analysis of the base case results:

1. Why do the P_K curves drop off so steeply?

2 Why can a barrage attack achieve a P_K of .9 with an expenditure of (approximately) fourteen warheads per HML, yet in this study, which models a phenomenal improvement in technology, fourteen warheads will only produce a P_K of .9 or greater with cycle times less than approximately 6.2 minutes?

Quick, "back-of-the-envelope" calculations can provide answers to both questions.

The steep downward slope of the P_K curves is caused by the nature of the attack. From the point of view of the attacking warheads, there is some amount of uncertainty regarding the exact location of the HML at the time of detonation. This uncertainty is a result of the fact that the HML was still moving when the warheads received their last update. The distance the HML moved between the warheads' last update and detonation, of course, is proportional to the amount of time between the last update and when the HML stopped to assume its hardened configuration. This amount of time, in turn, is related to the warheads' cycle time. The longer the cycle time, the less updates the warheads will receive during the flight, hence, the longer the time between the last update and detonation.

Because of the uncertainty regarding the HML's location, the warheads are not actually attacking a point target. They are attacking a circular area of uncertainty which is centered on the HML's last known location. The radius of this circle is computed by the formula .85 * (maximum speed of the HML in miles per hour) * cycle time / 60. (For an explanation of this formula, refer to Chapter IV, in the section titled, "Determining Weapon Laydown Patterns.") In the base case, the maximum speed of the HML is 38 miles per hour, so this formula reduces to (0.538 * cycle time). The area of the circle is calculated by the formula $\pi * (0.538 * \text{cycle time})^2 = 0.909 * (\text{cycle time})^2$. The object of the attack is to barrage this area of uncertainty as thoroughly as possible. Thus all incoming warheads are detonated within this circle. This leads to a very rough "back-of-the-envelope" method for explaining the steep slope of the curves

Since each of the warheads has a lethal radius associated with it, a lethal area can be computed for each warhead. In the base case, a one megaton weapon has a lethal radius of approximately 1.2 miles against an HML hardened to 30 psi. Thus, the lethal area is found by the formula, $\pi * (1.2)^2$, or $1.44\,\pi$. The total lethal area is related to the lethal area of each warhead multiplied by the number of warheads. However, for small cycle times, this will overestimate the actual total lethal area, since there will be overlap of the individual lethal circles. Whether there is overlap or not, a rough estimate of the P_K can be made using the formula, (total lethal area) / (area of uncertainty), or, in equivalent form, (total lethal area) / (.909 * (cycle time)^2). So, as cycle time increases P_K decreases as the reciprocal of the square of the cycle time. Thus, the steep curve makes sense. Also, the eventual leveling off of the slope makes sense, since for very large cycle times, the value of P_K begins asymptotically approaching zero.

The answer to the second question of interest can be found by examining the focus of this study. Since this methodology is designed to analyze the results of an attack on a single HML, the effects of attacks on neighboring HMLs is ignored. Again, "back-of-the-envelope" calculations can provide a reasonable estimate of the magnitude of these neighboring effects.

If it is assumed that approximately 500 HMLs are to be dispersed over a land area of approximately 16,000 square miles, then, on the average, there will be one HML located on every 32 square miles of land area. In this thesis, the land area associated with each HML is the area of uncertainty which must be attacked by the incoming warheads. This area varies with cycle time (using the formula given above). This area can be quite a bit larger than 32 square miles. For example, when the cycle time is 30 minutes, the area of uncertainty is approximately 819 square miles. If it is assumed that the HMLs are uniformly distributed over the 16,000 square mile land area, and there is one HML on every 32 square miles of land, then the expected number of HMLs on 819 square miles is approximately 25.6. Using this number and the base case results for the fourteen warhead case, a rough estimate of the effect of neighboring attacks can be calculated and compared with the barrage attack results.

In the fourteen warhead case, the P_K for a cycle time of 30 minutes was .08. Another way of viewing this is that the probability of survival (P_S) of a single HML is equal to $(1 - P_K)$, or .92. To evaluate the effects of neighboring attacks on each HML, assume that 25.6 HMLs are located in each uncertainty circle, and therefore each HML will be subjected to overpressure effects from 25.6 neighboring attacks. Thus, the total P_S for each HML will be the product of the individual P_Ss from each of the 25.6 attacks, or $(.92)^{25.6} = .12$. Then, the overall $P_K = 1 - P_S = .88$. This is very close to the .9 P_K result of a barrage attack. When similar calculations are performed for other cycle times (within the fourteen warhead case), the results in every case are quite close to $P_K = .9$.

A variation of this method can be used to further validate the results of this study. First, note that the discrepancy between the results of this study and the barrage attack results occur when the cycle time is large enough to create an area of uncertainty greater than 32 square miles. When this condition exists, the study overlooks the effects of neighboring attacks, and the corresponding P_K is lower than the barrage attack P_K of .9. When the area of uncertainty is less than 32 square miles, there is no need to account for neighboring attacks, and the results of this study need no adjustment. Thus, if an area of uncertainty equal to 32 square miles is considered, and the cycle time required to establish this area is calculated, one would expect the cycle time to correspond to the point where the fourteen warhead P_K curve from this study crosses the horizontal .9 P_K line on the graph (corresponding to the P_K of a barrage attack).

Calculating backwards from 32 square miles, the radius of uncertainty is determined to be 3.19 miles. Using the formula, Radius = (.85) * (cycle time) * (38 / 60), the cycle time is determined to be approximately 5.9 minutes. Considering the rough nature of the calculations, this is very close to the value obtained from the graph, which is approximately 6.2 minutes.

More detailed analysis of these two additional questions are among the recommended areas for further research (see Chapter IX).

VIII. Variations to the Base Case

To determine the robustness of the results of this study (and to examine some very likely system improvements), several variations of the base case were studied. The variations fell into two general categories: variations in the HML's characteristics and variations regarding the threat system.

Variations in the HML's Characteristics

The two unique characteristics that make the HML a very survivable system are, of course, its hardness and mobility. It is, therefore, important to determine how changes in these two characteristics effect system survivability. Thus, the HML's speed and hardness were varied (individually and simultaneously), and the effects on P_K were calculated.

Variations in HML Speed

The base case values of the HML's speed (ranging from 12 to 38 miles per hour) and its overpressure hardness (30 psi) were suggested by BMO [7]. Thus, the values in the base case are assumed to be nominal values for comparison purposes. However, personnel at BMO's Hardened Mobile Basing Branch indicated that full-scale prototypes of the HML are currently being tested for mobility, and preliminary indications are that the HML will be faster and more maneuverable over all types of terrain than was originally expected [7]. Early estimates are that the HML can achieve a speed of 15 miles per hour on rough terrain (as opposed to 12 in the base case). Over smooth terrain, or on hard surfaces, the HML can probably be expected to travel at speeds up to 60 miles per hour (vs. 38 mph in the base case). The most likely speed of the HML over all types of terrain has correspondingly increased from 30 to 35 miles per hour.

The model was run for this improved range of speeds and compared with the base case results. As a control, the effect of reducing the HML's speed capability was also examined. The reduced range of speeds used was: minimum speed - 9 miles per hour, maximimum speed - 33 miles per hour, and most likely speed (over all types of terrain) - 25 miles per hour. (These speed are each five miles per hour less than their base case counterparts.)

The model was run for the one, five, ten, and fourteen warhead cases. The results are shown in Figures 25, 26, 27, and 28 .

Examining the P_K values on the graphs, it is apparent that for a given number of warheads, P_K is only moderately sensitive to changes in the HML's speed. For example, in the five warhead case (see Figure 26), with the base case set of speeds, a .9 P_K can be achieved with a cycle time of approximately 3.5 minutes. If the HML's speeds are improved to the designated levels, a .9 P_K can still be achieved with only a one minute improvement in ICBM cycle time. (Actually, this only *appears* to be rather small. In reality, since this is a hypothetical system, there is no way of determining how costly a 29% improvement in cycle time capability from 3.5 minutes to 2.5 minutes might be. Thus, the effect of increased HML speed may be quite significant.)

As the number of warheads increases, the spread between the base case and the varied speed curves increases, but not drastically. For example, with fourteen warheads in the base case, a .9 P_K can be achieved with a 6.3 minute cycle time capability, while the improved HML speeds require a cycle time of 4.1 minutes or less, a 2.2 minute difference (35%) as opposed to 1 minute with 5 warheads.

Initially, this seems to imply that variations in the speed capabilities of the HML are relatively unimportant. However, if cycle time is held constant (implying, perhaps, that Soviet technology has reached its limit), the implied result is significantly different. For example, if it is assumed that the current Soviet state of the art allows a cycle time of five minutes, then a .9 P_K can be achieved with just over ten warheads (say, eleven). If the

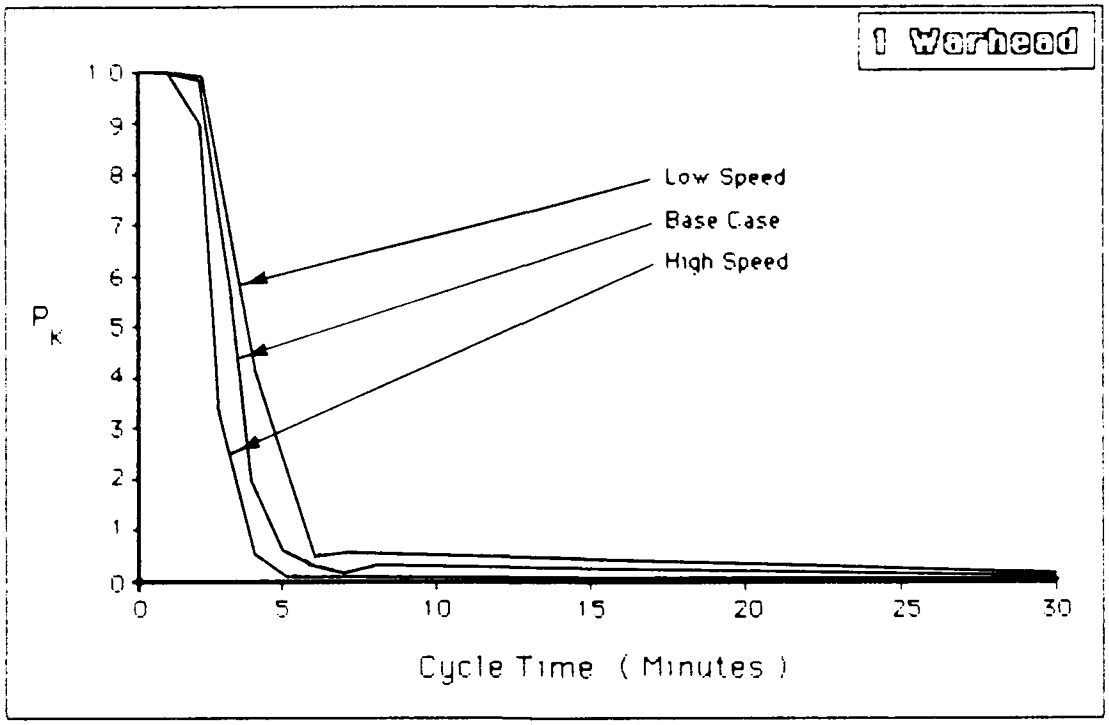

Figure 25 Variations in Speed for the 1 Warhead Case

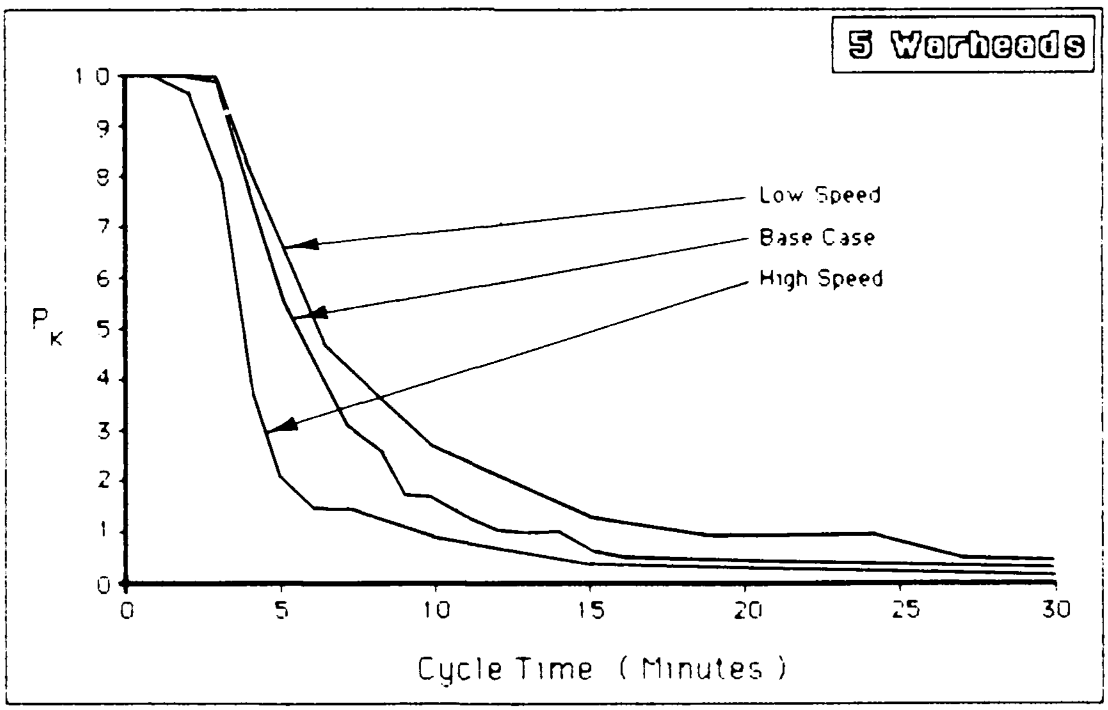

Figure 26 Variations in Speed for the 5 Warhead Case

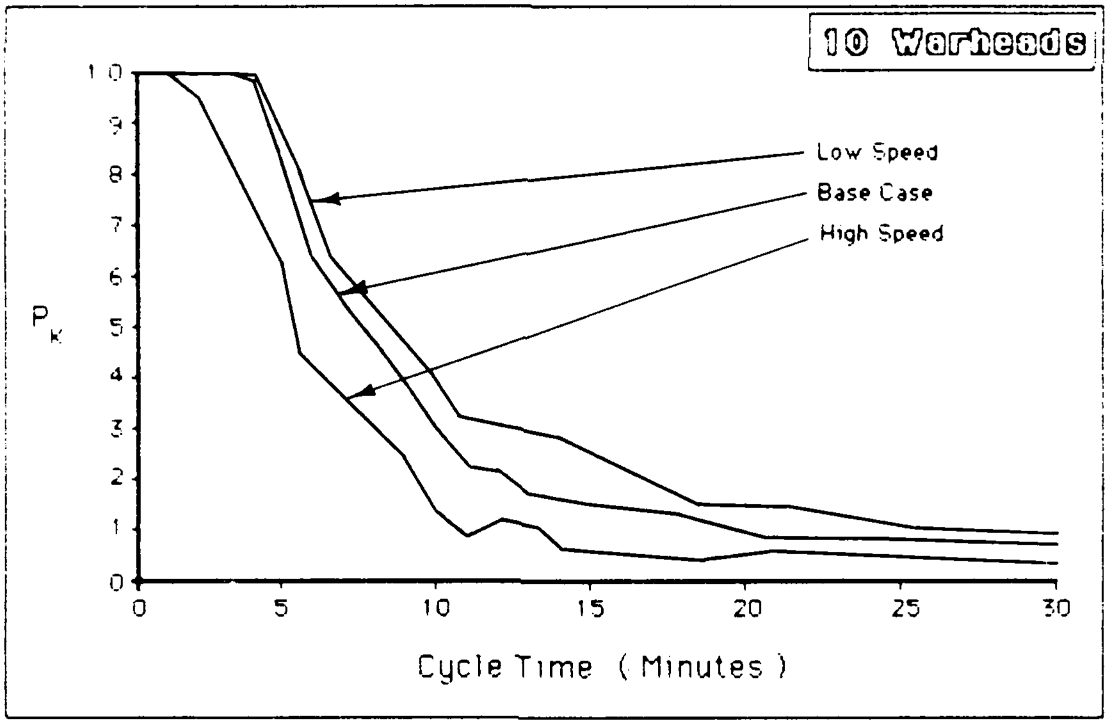

Figure 27 Variation in Speed for the 10 Warhead Case

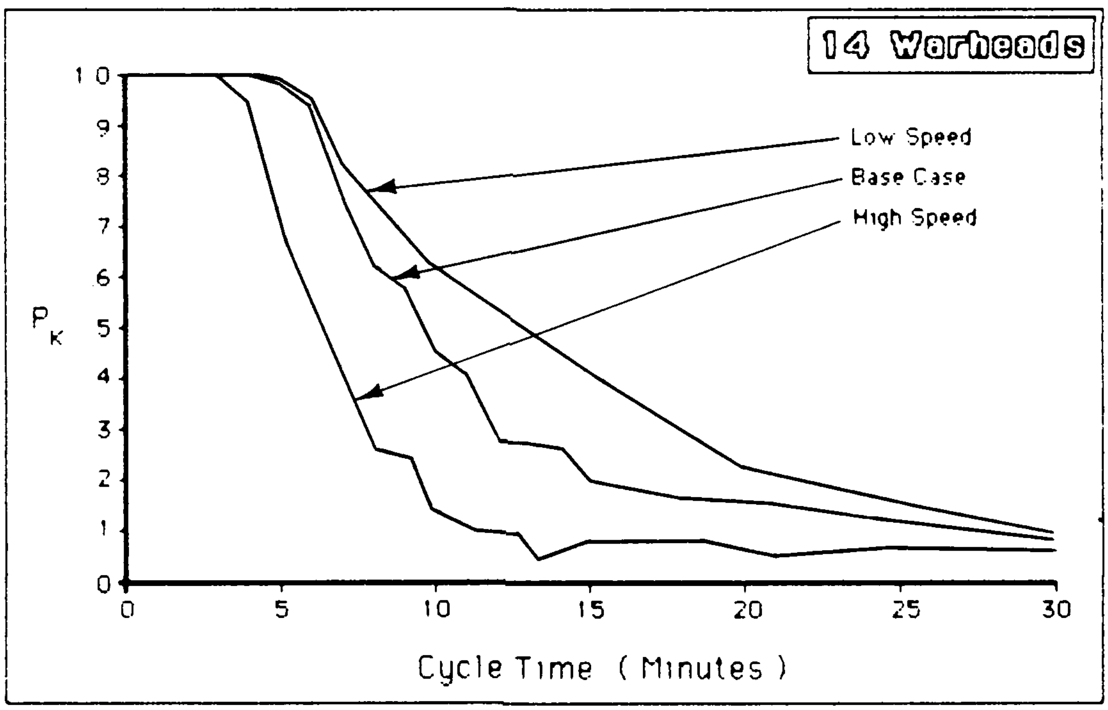

Figure 28 Variation in Speed for 14 Warhead Case

speed of the HML is increased and cycle time is held constant, the best P_K that can be achieved is .67, and that is with fourteen warheads.

The effect of increased HML speed can be seen easily from the graphs. However, the implications of these results depend largely on possible increases in Soviet technology.

Variations in HML Hardness

In the base case, the HML was assumed to be hardened against 30 psi of overpressure. This figure was provided by BMO. However, they also asserted that the HML could probably be hardened to approximately 50 psi at low cost and with very little detrimental effect to the speed and maneuverability characteristics of the system. Thus, it was suggested that sensitivity analysis be performed on the HML's hardness by examining the effects of increasing the hardness level to 50 psi [7].

Since system hardness is somewhat more difficult to estimate than characteristics such as speed (since speed is easily field testable, and hardness to nuclear effects is not), it was decided that a study of the effects of a reduction in hardness would also be of interest in order to bracket the sensitivity analysis around the base case. In this way, the appropriate information will be available if it is subsequently discovered that the HML's hardness levels are lower than predicted.

These changes in hardness were examined individually. (A detailed description of how hardness is modeled is included in Chapter V of this report. Note, however, that a "cookie cutter" approach is used in the variation studies, as it was in the 30 psi base case.) The model was run for both variations, keeping the values of all other variables, including speed, at their base case levels. The results are shown in Figures 29, 30, 31, and 32.

Interpretation of the results leads to virtually the same conclusions that were drawn when the HML's speed was varied. For a given number of warheads, P_K is only moderately sensitive to changes in the HML's hardness.

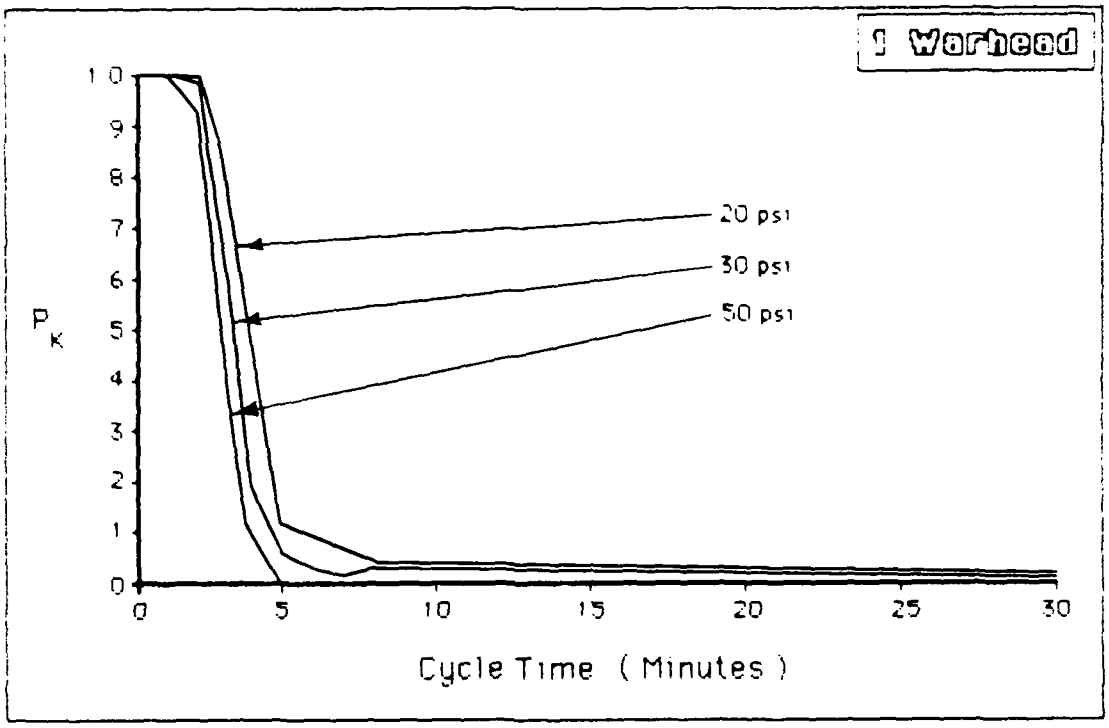

Figure 29 Variations in HML Hardness for the 1 Warhead Case

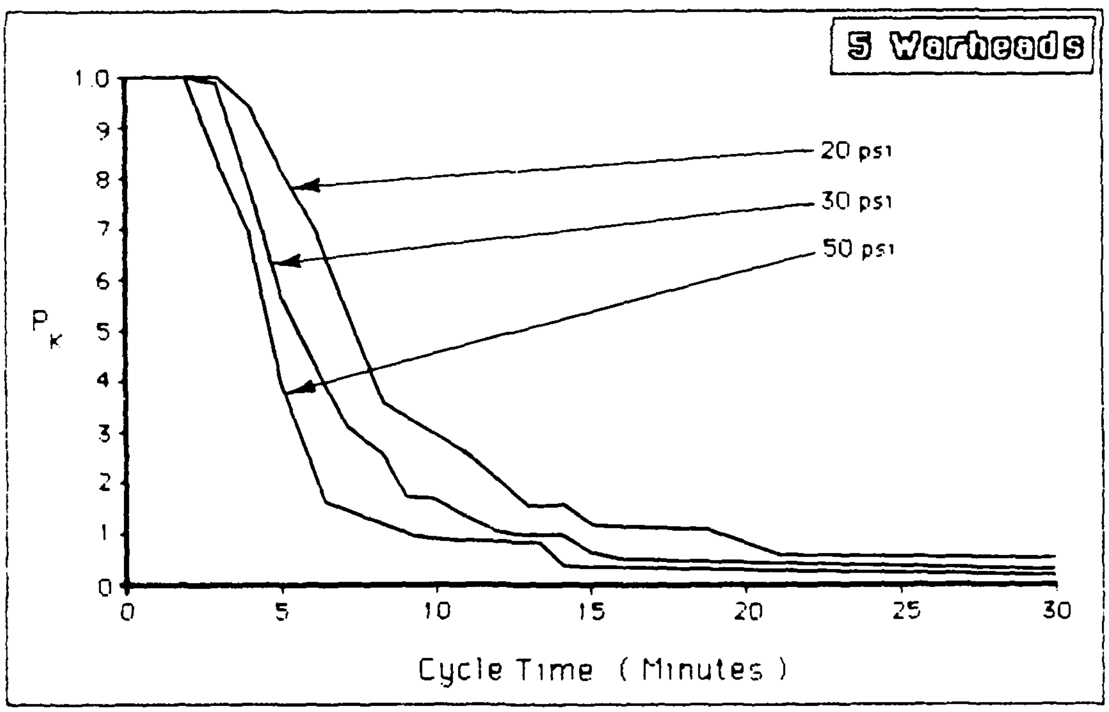

Figure 30 Variations in HML Hardness for the 5 Warhead Case

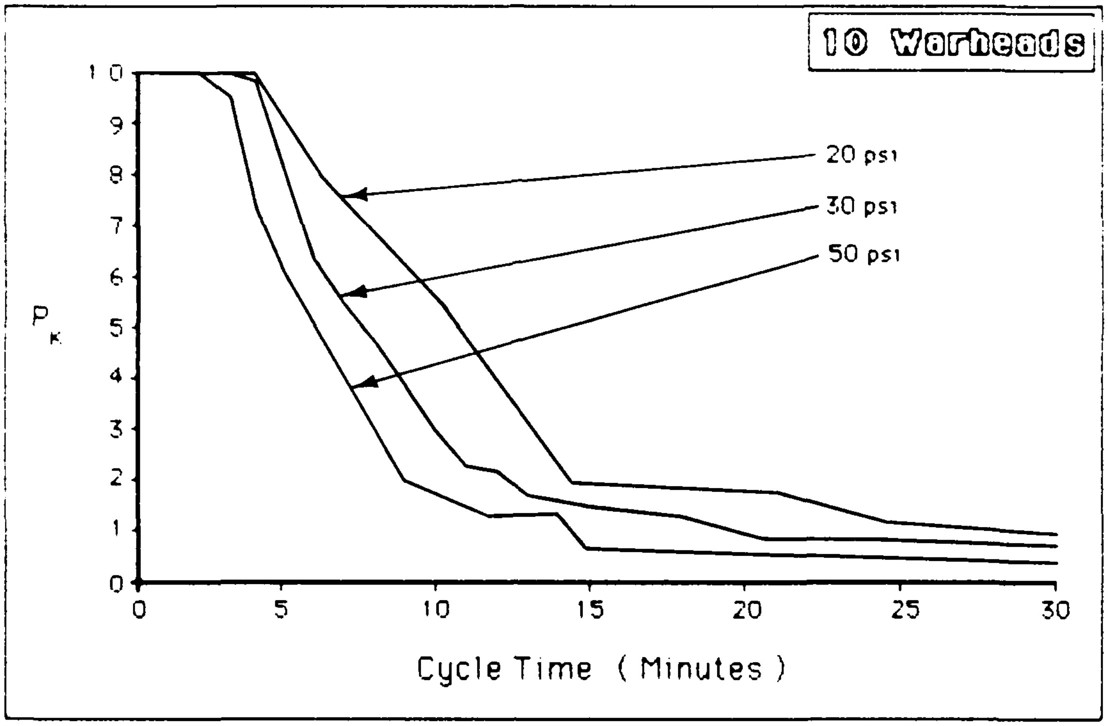

Figure 31 Variations in HML Hardness for the 10 Warhead Case

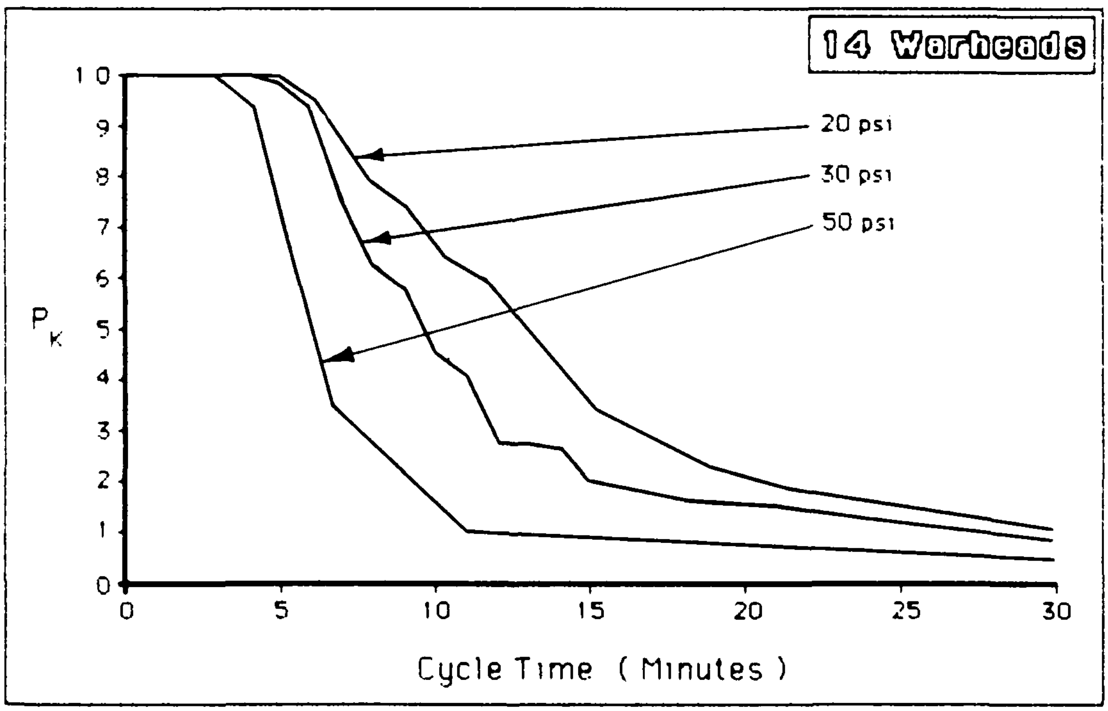

Figure 32 Variations in HML Hardness for the 14 Warhead Case

The curves illustrating the changes in hardness are remarkably similar to those for changing speed. At first glance, they are almost identical. Even under closer scrutiny, they are very similar. For example, in the five warhead case, it was shown previously that with an increase in speed, the cycle time required to achieve a .9 P_K decreases from 3.5 to 2.5 minutes (or 29%). This is also true when hardness is increased from 30 to 50 psi. The change in P_K is virtually identical. It was also shown previously that in the fourteen warhead case, as speed is increased, the cycle time required to achieve a .9 P_K, decreases from 6.3 to 4.1 minutes (or 35%). This is identical to the change in required cycle time when hardness is increased from 30 to 50 psi.

Reduction in hardness resulted in moderate increases in P_K. Again, the effect was large enough to be noticeable, yet it indicated only moderate HML sensitivity to changes in system hardness.

It appears that varying the HML's hardness has a similar degree of impact on P_K as varying its speed capability from the base case levels to the specified sensitivity analysis levels. It is therefore interesting to examine the effects of increasing both speed and hardness simultaneously.

Improvements in Both Speed and Hardness

The computer program was modified to simulate simultaneous increases in speed and hardness. It was then run, and the results are displayed in Figures 33, 34, 35, and 36. (Combinations involving decreased capabilities were not examined.)

The curves are basically the same shape as the curves generated when each parameter was varied individually. However, the decrease in P_K in all cases is greater than the decrease when speed and hardness were varied individually. This was, of course, expected. The relative amount of decrease is what is interesting in this analysis. Prior to running

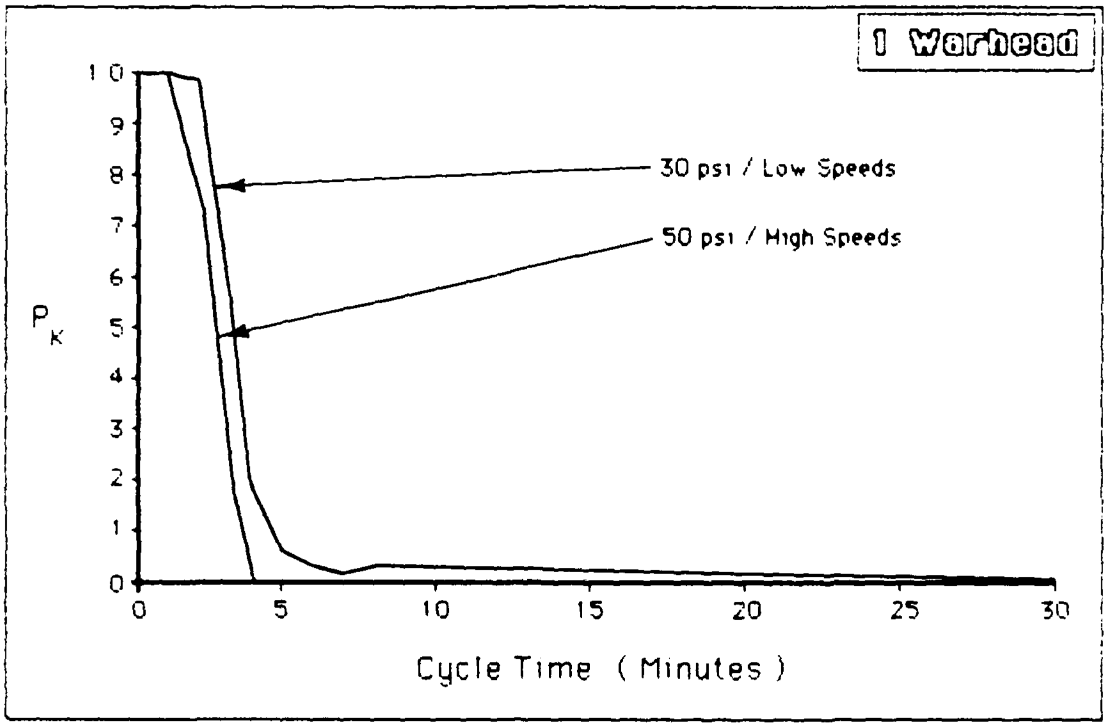

Figure 33 Increased Speed and Hardness for the 1 Warhead Case

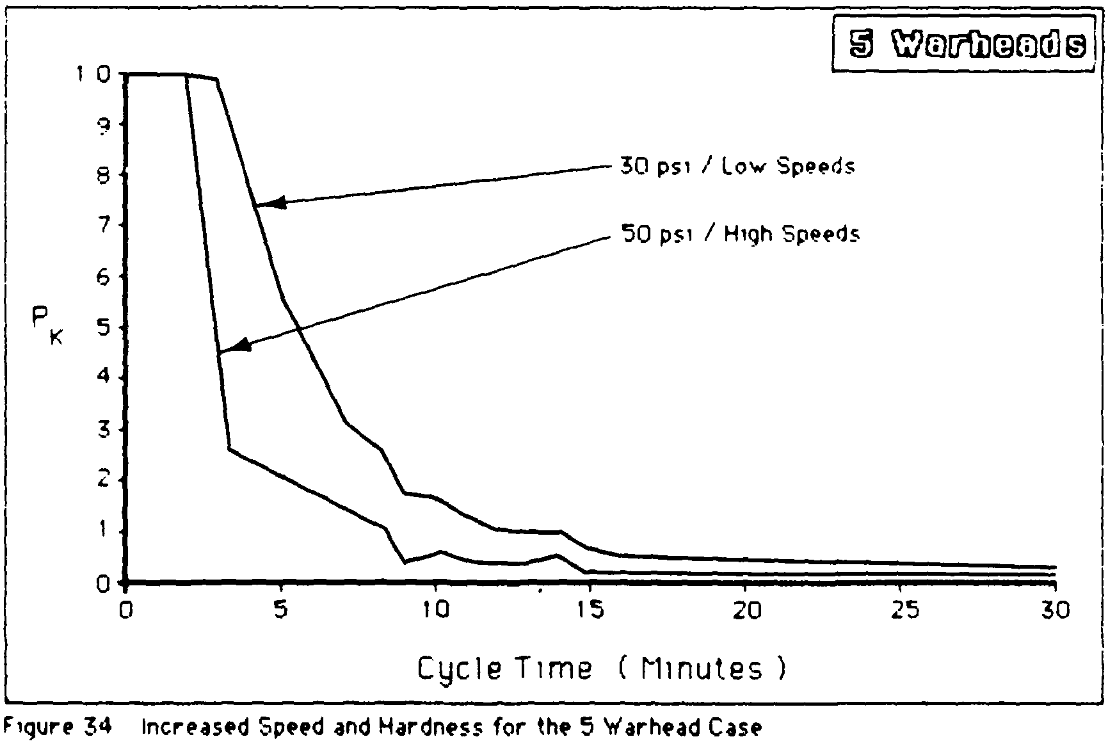

Figure 34 Increased Speed and Hardness for the 5 Warhead Case

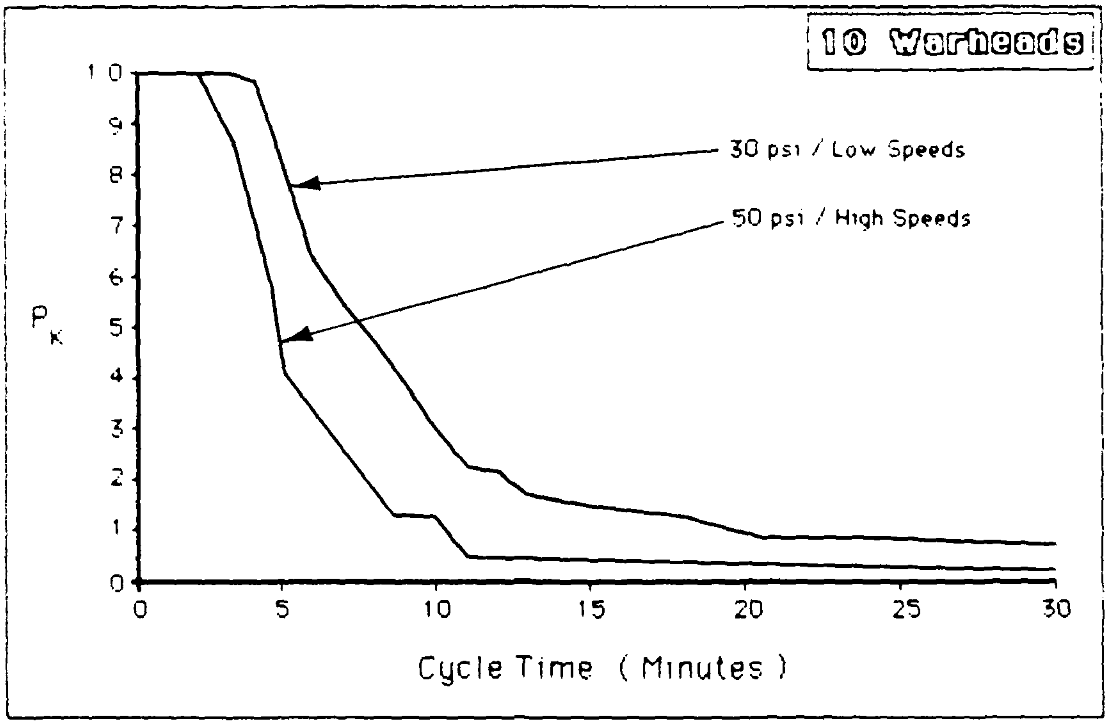

Figure 35 Increased Speed and Hardness for the 10 Warhead Case

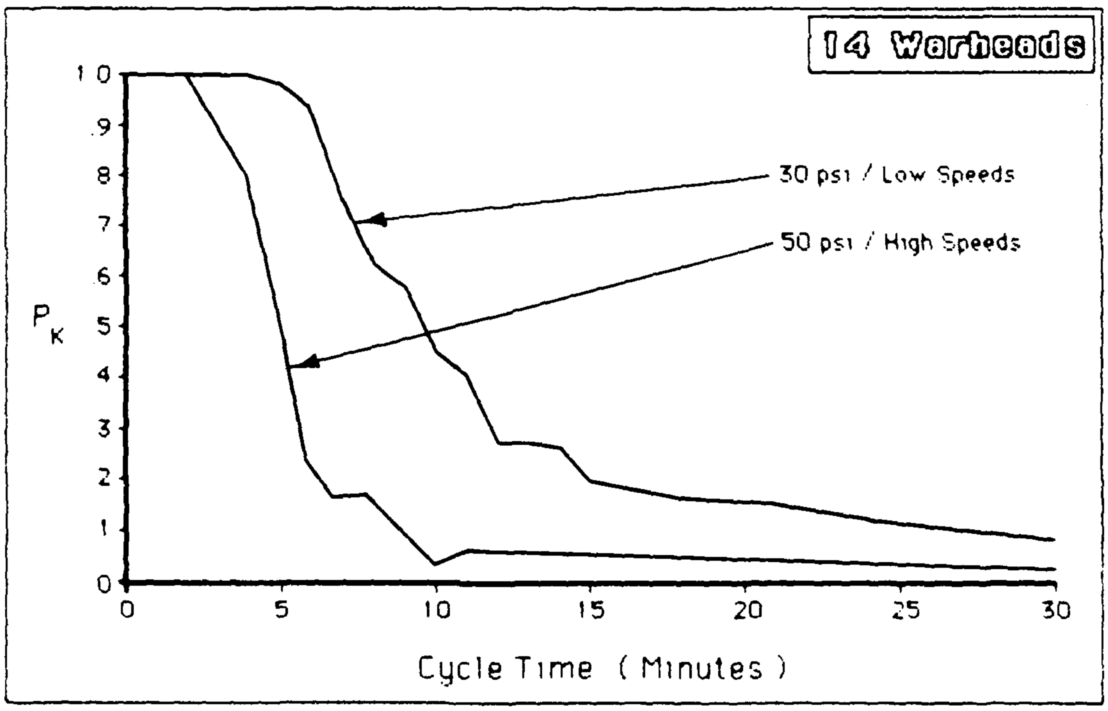

Figure 36 Increased Speed and Hardness for the 14 Warhead Case

the model, it could be imagined that the effect of varying both parameters would be roughly a the sum of the two individual effects or possibly some multiplicative combination of the individual effects. Upon examination of the results, it is apparent that neither expected result is precisely true, but the former is a closer approximation than the latter. The actual results indicate that the combined effect is slightly less than a simple sum of the individual effects. This can be illustrated by examining the same examples that were used in the previous sections.

For the five warhead case, individually increasing speed and hardness caused a one minute reduction (or a 29% reduction from the base case cycle time of 3.5 minutes) in the required cycle time to achieve a .9 P_K. When both parameters are varied, to achieve a P_K of .9, the cycle time must be 2.1 minutes or less, a reduction of 1.4 minutes (40%).

In the fourteen warhead case, individually increasing speed and hardness caused a 2.2 minute reduction (from 6.3 to 4.1 minutes, or 35%) in the required cycle time to achieve a .9 P_K. When both parameters are varied, to achieve a P_K of .9, the cycle time must be 3 minutes or less, a reduction of 3.3 minutes (or 52%).

While the results of the sensitivity analysis indicate that the HML is only moderately sensitive to changes in its speed and hardness capabilities, the overall implications of these results are not crystal clear. Neither individual improvements nor combined improvements produce radical reductions in P_K. In fact, the results can be countered by small improvements in Soviet cycle time capability (3.3 minutes in the worst case). Note that these improvements represent fairly large percentage changes (from 29% to 52%). Thus, they may be technologically difficult for the Soviets to achieve. As previously mentioned, since there is so little sensitivity to changes in HML speed and hardness, any decisions to make such improvements must be made in light of other factors, most notably, the Soviets ability to improve their cycle time capabilty and the cost of doing so.

Variations Regarding Threat System Performance

Two major variations regarding the threat system performance were examined. First, the effects of increasing the threat ICBM system's CEP was examined, and then the possible effects of fratricide among the detonating warheads was examined.

Effects of Increased Circular Error Probable (CEP)

One of the major assumptions in the base case was that the attacking warheads would be maneuverable re-entry vehicles (AMARVs). At least in theory, this could produce near zero CEPs and, thus, very small miss distances [1, 5]. To simulate this, a CEP value of ten meters was used in the base case. Since this is such an extremely low value, it was decided to examine the effect on P_K if the threat weapon system was assumed to have a CEP more closely approximating today's technology. Thus, the model was run using a CEP of 500 meters. The results are shown in Figures 37, 38, 39, and 40.

Essentially, this study indicates that CEP is not an important factor. The curves for 500 meter CEPs closely follow the base case curves. The major difference is a slight increase in the erratic nature of the curves when CEP is increased. This is due to the added measure of randomness in the Monte Carlo simulation The fact that CEP is of such small importance can be explained by the nature of circular error probable. A weapon system's CEP is a statistical method used to approximate its miss distance given a single shot. However, in a Monte Carlo simulation such as this, the effects of CEP are averaged over many shots. Since misses occur in all directions, when the effects of many shots are combined, the misses begin to offset each other, and the expected value approaches zero.

The conclusion to be drawn from the study of increased CEP is that the effect of CEP is not significant in a study such as this. That is not to say that the CEP of the attacking ICBM system will have no effect on the outcome of any given encounter. It will. However, since there will likely be 500 HMLs, the effects of the ICBM system's CEP will be effectively averaged over 500 cases, and the expected value of the miss distance will be nearly zero.

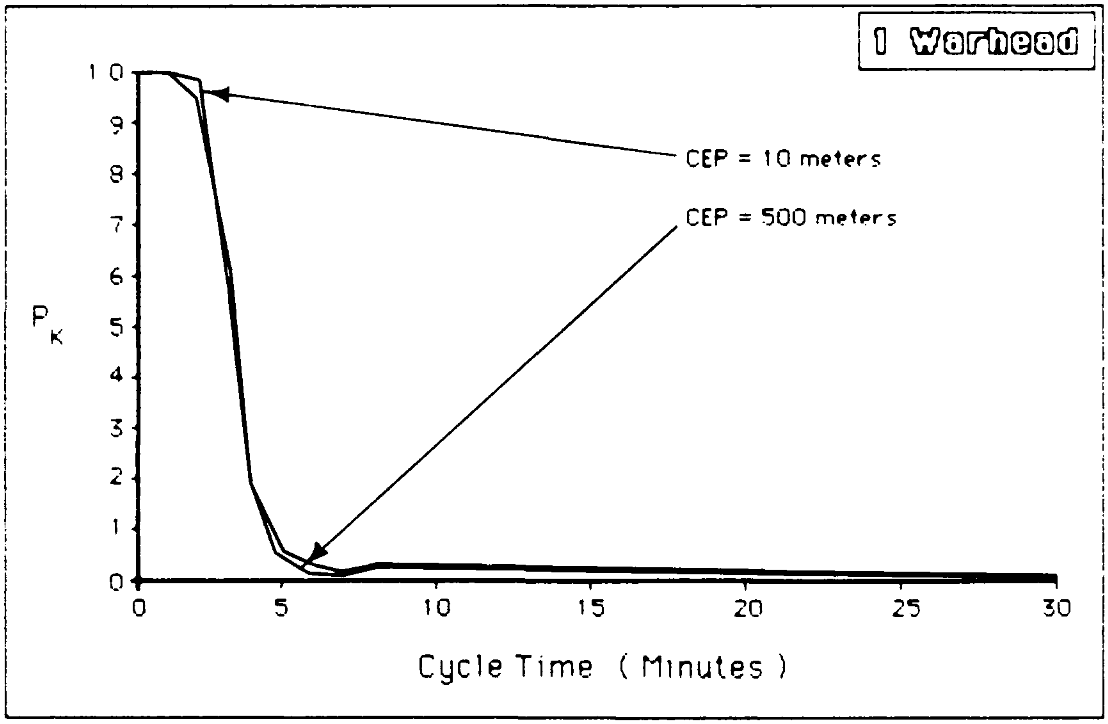

Figure 37 Increased CEP for the 1 Warhead Case

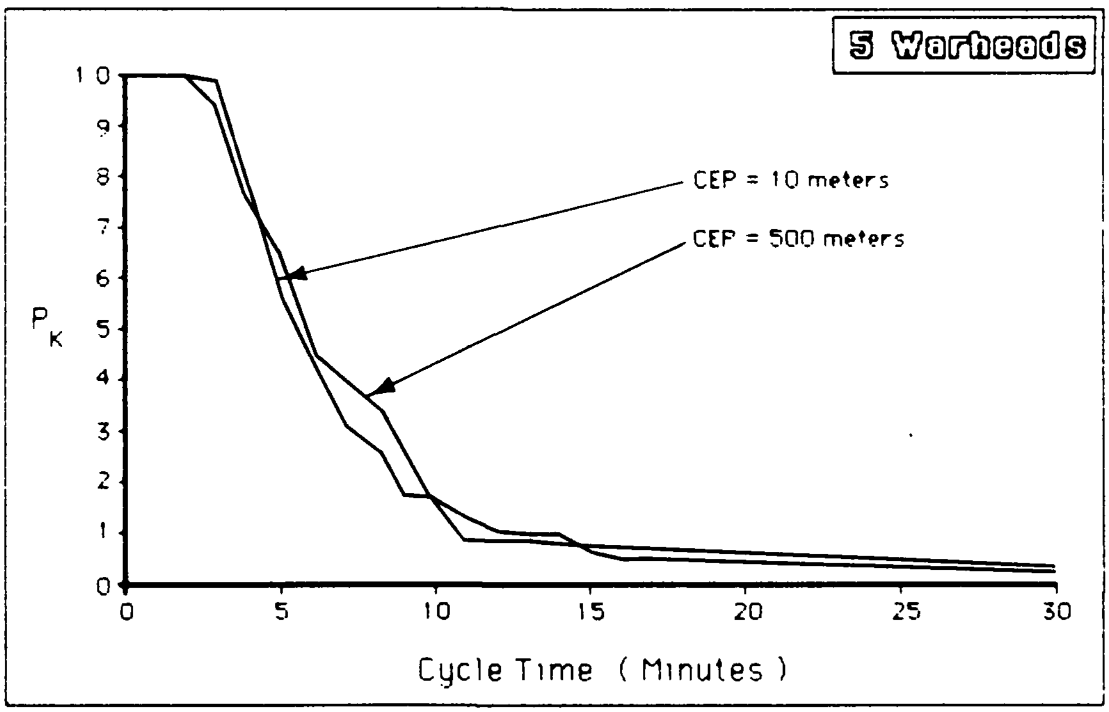

Figure 38 Increased CEP for the 5 Warhead Case

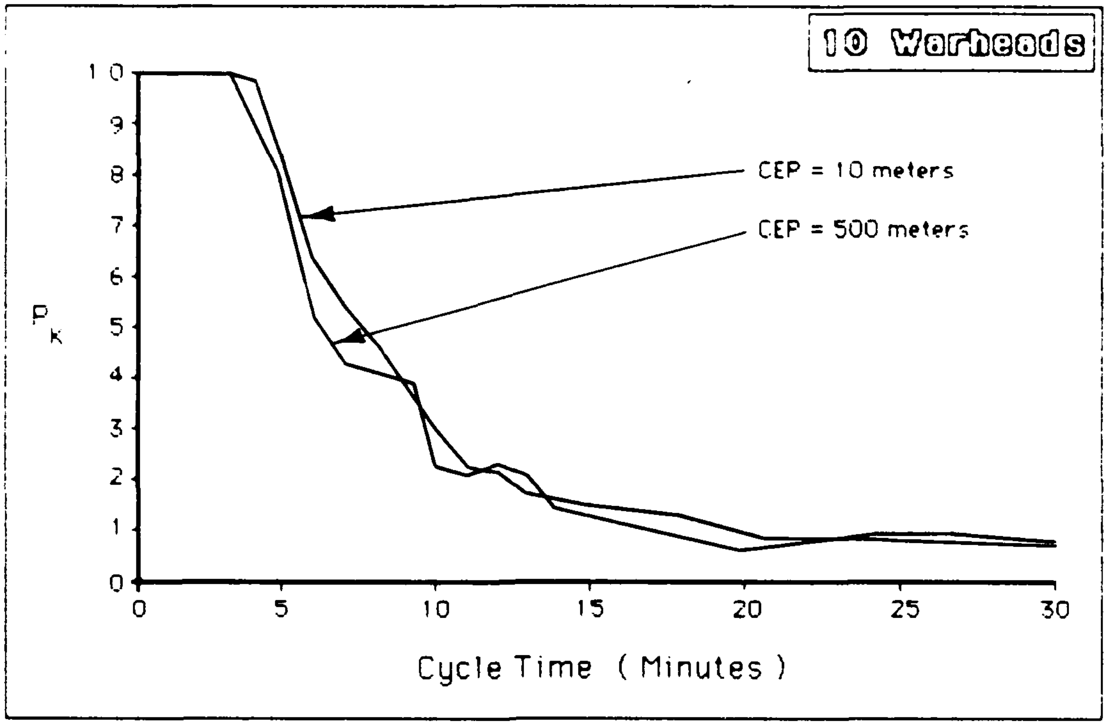

Figure 39 Increased CEP for the 10 Warhead Case

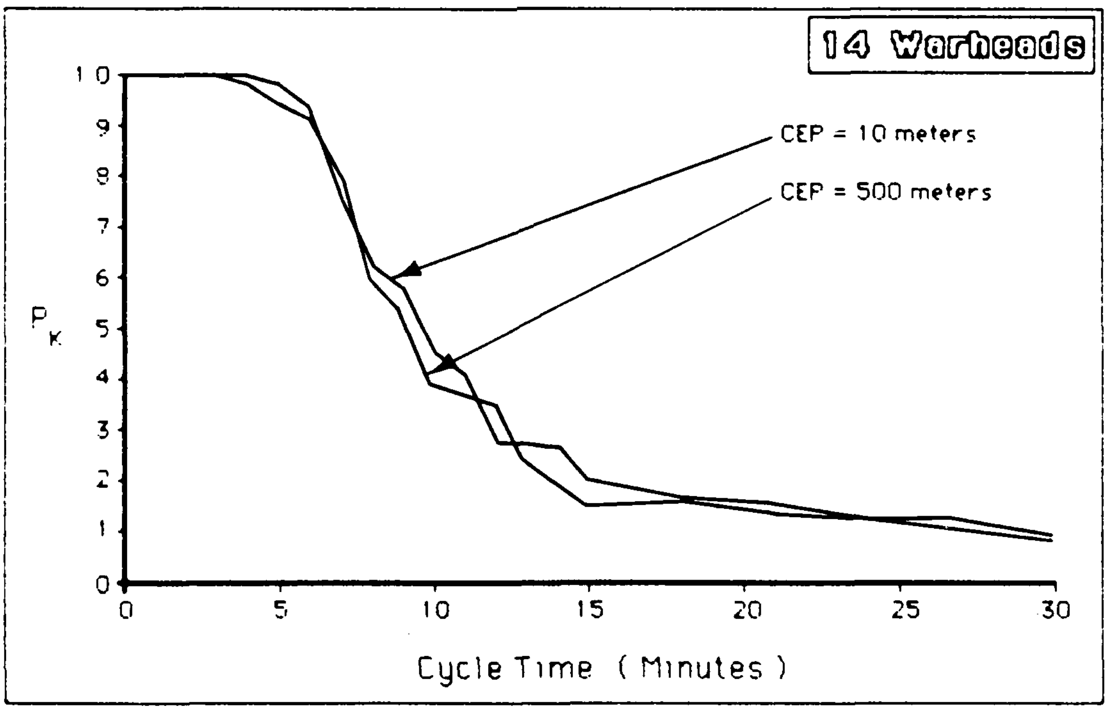

Figure 40 Increased CEP for the 14 Warhead Case

The Effects of Fratricide

Another area of concern in this study is the effect of fratricide on the attacking warheads. Fratricide is the degradation or disabling of one's own nuclear weapons resulting from the effects of prior friendly detonations. Fratricide becomes a potential factor whenever nuclear warheads are detonated relatively close together. (This is precisely why "closely spaced basing," or "dense pack," was proposed as a basing mode for the Peacekeeper missile system.) In this study, at small cycle times, the warheads are relatively close together when they are detonated. Thus, fratricide is a potential factor. The base case model was modified to calculate the effects of fratricide on the results of this study.

For low altitude bursts, there are two primary fratricide kill mechanisms, neutrons and dust clouds. Of the two mechanisms, neutron fluence is more important to our study. Neutrons produced by previous bursts can cause fratricide by "dudding" or completely disabling nearby warheads which have not yet detonated. Since these neutrons travel at speeds approaching the speed of light, the bursts of a closely spaced targeting pattern must occur essentially simultaneously in order to escape neutron fratricide. However, it is very difficult -- essentially impossible -- to fuze closely spaced detonations with sufficient accuracy to avoid the effects of neutrons from neighboring bursts.

Secondly, clouds of dust and debris resulting from previous bursts can wear away a warhead's ablative nose tip and heat shield. This process occurs over a much longer period of time than neutron effects, and consequently the timing of bursts is much less critical. Generally, if the bursts are within a matter of seconds of each other, dust effects will be minimal. Since it is possible to achieve burst timing accuracy on the order of tens of milliseconds, dust fratricide was ignored.

Timing, then, is a critical factor in determining whether or not fratricide may affect a sequence of nuclear explosions. It is currently possible to fuze warheads accurately enough to avoid the effects of dust and debris, however, it is not possible to insure small enough time intervals between bursts to avoid neutron effects. Thus, it was determined that the effects of fratricide by neutrons should be assessed.

The computer program was modified to calculate the effects of fratricide due to neutron fluence. (The additional computer code is included in Appendix G.) The algorithm used to compute neutron fratricide effects is as follows:

1. Determine the order of the detonations by randomly assigning each warhead of the targeting pattern a relative (ordinal) time of burst. The times will range from one to the number of warheads in the pattern. One is assigned to the first warhead to detonate, two is assigned to the next, etc., until the last warhead to detonate is assigned a time equal to the number of warheads in the pattern. Ordering the detonations is an important step since a warhead can only be damaged by fratricide from previous detonations.
2. For each warhead:
    a. Determine the number of detonations which precede the detonation of the warhead under consideration. This is simply equal to the warhead's ordinal burst time minus one.
    b. Calculate the range from each prior burst to the warhead under consideration.
    c. Based on these ranges, the height of burst, and the yield of the warheads, calculate the neutron fluence incident on the warhead under consideration from each of the prior bursts. (Neutron fluence is measured in neutrons per square centimeter.)
    d. Using the cumulative log normal damage function, compute the probability that each of the prior bursts killed the warhead under consideration. The sure-safe and sure-kill intensity levels which are used as parameters to explicitly define the log normal damage function,

are set equal to 10^{14} and 10^{16} neutrons per square centimeter, respectively [9, 350 - 353]. (The log normal damage function is described in detail in Chapter V of this report.)

e. Calculate the probability that the warhead under consideration survives all prior bursts. Since the neutron effects from each of the prior bursts can be considered independent, the probability that the warhead survives them all is equal to the product of the individual probabilities.

f. Calculate the probability that the warhead under consideration kills the HML with overpressure. In order for it to do so, it must have survived the fratricide effects from previous neighboring bursts. Consequently, the probability the HML is killed by the warhead under consideration is equal to the probability the warhead kills it with overpressure multiplied by the probability the warhead has survived fratricide effects.

g. Repeat Steps a. through f. for each warhead in the targeting pattern.

3. Finally, the overall probability that the HML survives the overpressure from the entire attack is equal to the product of the probabilities that it survives each individual burst. Then, the overall probability of kill is equal to one minus the overall probability of survival.

Neutron fratricide effects, as previously explained, are only significant when two or more warheads are detonated fairly close to each other. In the attack scenario modeled in this study, the distance between bursts is ultimately determined by the relationship between the "area of uncertainty" that is being attacked and the lethal area of the warhead. (Weapon laydown patterns are discussed in detail in Chapter IV of this report.) Given a small area of uncertainty, the weapon laydown pattern will be quite dense, i.e., a small distance between the bursts. With a larger area of uncertainty, the corresponding

AD-A172 453 SURVIVABILITY OF THE HARDENED MOBILE LAUNCHER WHEN ATTACKED BY A HYPOTHET..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. 2/2

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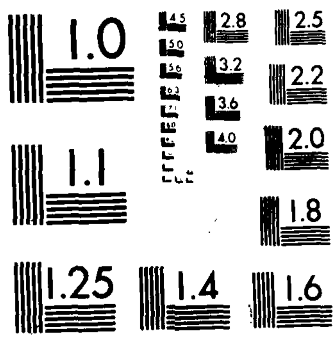


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

weapon laydown pattern will be more spread out, i.e., a greater distance between bursts. The area of uncertainty is based on the intelligence / retargeting cycle time of the attacking ICBM system -- the shorter the cycle, the smaller the distance between the bursts. Thus, it is expected that fratricide effects would be most significant for smaller cycle times and large numbers of warheads, since this combination produces the densest weapon laydown patterns.

This expected result was confirmed in this study. As in the previous analyses, the five, ten, and fourteen warhead cases were examined. (The one warhead case was not studied since fratricide is not a factor in a one warhead attack.) It was determined that fratricide effects were essentially limited to cases with cycle times of less than four minutes. When the cycle time is greater than four minutes, the weapon laydown patterns guarantee sufficient separation between bursts to preclude fratricide effects.

When cycle times less than four minutes were examined, the results were somewhat surprising. While fratricide did occur as expected, it had a negligible effect on the P_K of the HML. Further analysis determined the reason for this. When the cycle time is less than four minutes, some percentage of the attacking warheads will be destroyed by fratricide. However, when cycle times are small, the area of uncertainty that is being attacked is also small, therefore fewer warheads are required to completely blanket it with lethal amounts of overpressure. As cycle time decreases from four minutes the increase in fratricide kills is very nearly matched by the decrease in warheads necessary to barrage the area of uncertainty. The net result, then, is to nullify the effect of fratricide on the P_K of the HML. It is therefore concluded that fratricide need not be considered when analyzing an attack of this nature.

IX. Observations / Recommendations

Primary Observations

1. The most significant observation to be made from this thesis is that the hardened mobile launcher system appears to be extremely survivable with respect to the hypothesized threat system. The starting point for this thesis was the BMO baseline which indicates that approximately fourteen warheads per HML are required to achieve a .9 P_K with a barrage attack (given 500 HMLs and 16,000 square miles of land area). The results of this thesis show that an incredibly advanced technology is required to reduce the number of warheads necessary to achieve a .9 P_K. For example, a .9 P_K can be achieved with ten warheads if a system can be developed with the capability of completing an intelligence / retargeting cycle every 4.7 minutes (or less). Likewise, the number of warheads necessary can be reduced to five per HML if the cycle time can be reduced to 3.5 minutes. To reduce the exchange ratio to one warhead per HML, a cycle time of 2.3 minutes or better must be achieved. Even to achieve a P_K of .5 with less than fourteen warheads per HML, a cycle time of 9.6 minutes or better is required.

2. The P_K of the HML depends greatly on the land area of its dispersal base(s). This can be shown by comparing the results of this study to the BMO baseline results. Their results indicate that a .9 P_K can be achieved if the Soviets barrage attack the HML bases with approximately fourteen warheads per HML. This figure assumes that 500 HMLs are dispersed over a 16,000 square mile land area. The results of this thesis are that, even with fourteen warheads, a .9 P_K cannot be achieved with cycle

times greater than approximately 6.2 minutes. The discrepancy is caused by the fact that the BMO study is constrained by the 16,000 mile land area, while this thesis, since it examines only one HML at a time, essentially assumes unlimited land area. The P_K curves and some rough, "back-of-the-envelope" calculations can be used to demonstrate how land area and P_K are related. Suppose it is assumed that the Soviets may be willing after all to expend fourteen warheads per HML. The current BMO baseline indicates they could achieve a .9 P_K. Suppose now that U.S. strategic planners wish to reduce that P_K to .1 by increasing the size of the dispersal area. The fourteen warhead P_K curve shows a .1 P_K at a cycle time of approximately 28 minutes. The area of uncertainty associated with a 28 minute cycle time can be calculated using the formula, Area = πR^2, where R is the radius of uncertainty. R can be computed using the formula, R = (.85 * cycle time * max speed of the HML) / 60. (This formula is discussed in Chapter IV of this report.) Assuming the HML's maximum speed to be 38 miles per hour, the area of uncertainty is approximately 714 square miles. With a force of 500 HMLs, the total area to be attacked is 500 * 714 = 356,893 square miles. (This is roughly ten percent of the total land area of the United States, which is not entirely unreasonable, since dispersal on the interstate highway system was once considered as a possible dispersal tactic for the HML.) Thus, the P_K can be reduced from .9 to .1 by increasing the dispersal area from 16,000 to 356,893 square miles.

3. HML survivability is moderately sensitive to improvements in its speed and hardness capability.

   a. The base case study modeled the HML's speed with a triangular probability distribution. The parameters of the distribution were the HML's minimum speed, its most likely speed, and its maximum speed. The values of these parameters in the base case were 12, 30, and 38 miles per hour, respectively. Sensitivity analysis was performed by increasing the values of these parameters to 15, 35, and 60 miles per hour, respectively. This produced measureable reductions in P_K across the entire threat range. However, no clear implication can be made from these reductions in P_K. To illustrate this, observe in Figure 24 that the Soviets can achieve a .9 P_K by expending five warheads (per HML) with a 3.5 minute cycle capability. If it is assumed that 3.5 minutes is a technological limit, then with increased HML speed, the P_K falls drastically to .24. Initially, this appears to be a very significant improvement. However, if the cycle time of the threat weapon system can be reduced by approximately one minute, the P_K climbs back to the .9 level. Thus, in determining the cost effectiveness of improvements in HML speed characteristics, the technological constraints of the threat weapon system must be known with great accuracy.

b. The base case modeled HML hardness at 30 psi. Sensitivity analysis was performed by increasing hardness to 50 psi. The result was a decrease in P_K virtually identical to that exhibited when sensitivity analysis was performed on the HML's speed (item #3.a., above). Thus, the same conclusions regarding the cost effectiveness of such an improvement can be drawn.

c. When speed and hardness were increased simultaneously to the levels in items 3.a. and b., above, a greater decrease in P_K occurred (as expected). The size of the decrease is slightly less than the sum of the individual decreases when speed and hardness were varied separately.

Secondary Observation

Fratricide effects resulting from neutron fluence need not be considered when studying an attack of this type. While fratricide effects are experienced by the attacking warheads (for small cycle times), the net effect of fratricide on P_K is negligible.

Suggestions for Future Research

1. It was shown in Chapter VII, that since this study simulates an attack on a single HML, the potentially destructive effects from neighboring attacks are not considered. A rough method to account for these effects was discussed. However, a more detailed examination of the interactions between neighboring attacks would provide more realistic P_K values for the larger cycle times. Such a study might also detect synergistic effects between neighboring attacks that might affect (and even improve) P_K values across the range of threat capabilites.
2. It was determined in the course of this study that the period of time between the ICBM's last update and when the HML stops its random movement is a critical period of time. The distance the HML moves during this time has a direct bearing on its survivability. It may therefore be possible to design a model based on this time period alone that will provide essentially the same results with faster computer run times. It is therefore recommended that anyone who wishes to pursue this problem, first explore the possibility of creating a more efficient, yet equally effective computer model.

Recommendations

The HML is an extremely survivable system, both against today's threat and against the future threat hypothesized in this thesis. Its survivability against today's threat was recently assessed by Senator Albert Gore, Jr., in an article in Arms Control Today:

> If Midgetman is deployed in hardened mobile launchers (built to withstand blast pressures of 30 pounds per square inch) on just four existing military bases, the Soviet Union would have to attack with about one-half its present ICBM throw-weight to destroy the system, even if the launchers do not respond to the impending Soviet attack. If the launchers do respond by dispersing to an even larger area, then within 15 minutes the price to attack will approach *all* Soviet heavy ICBMs. And if the launchers run for 20 to 25 minutes, the price then reaches out towards the combined throw-weight of the entire Soviet inventory of ballistic missiles, both land and sea based. [10,15]

The HML's survivability against an advanced hypothetical threat weapon system was examined at length in this thesis. It was found to be extremely survivable against all but the most sophisticated configurations of the hypothesized threat.

It is the opinions of the authors of this thesis that the HML's survivability should allow strategic planners to feel a sense of confidence in the system's ability to ride out a Soviet first strike. However, this confidence should not become complacence. The very fact that the HML appears to be so survivable will probably make research into methods of defeating the HML a high priority in Soviet military research. Thus, improvements in the Soviets' ability to counter strategic relocatable targets (SRTs) must be carefully monitored, and the appropriate actions must be taken by U.S. strategic planners to insure that HML survivability remains high.

Observations 2 and 3 of this study (above) provide some guidance in the directions that should be taken to maintain high HML survivability levels. Observation 2 states that a large land area is critical for high survivability, while observation 3 states that technological improvements to the HML's characteristics (specifically speed and hardness) have a somewhat smaller effect on overall system survivability. The effects from increased technological capabilities are also somewhat more difficult to measure and depend to some extent in our ability to measure advances in Soviet technology.

Therefore, it is recommended that:

1. Advances in Soviet anti-SRT technology be closely monitored.
2. Contigency plans be made now to expand the land area on which the HMLs are

based, if and when it becomes necessary to respond to an advancement in Soviet technology.

3. Improvements in HML technology should be viewed as a secondary method of improving system survivability, and should be undertaken only if the current Soviet technology is very well understood. The cost effectiveness of improved HML characteristics must be evaluated in light of the Soviets ability to respond to the advances.

Appendix A: Computer Code Listing

```
1 REM         Program to calculate probability of kill against Hardened
2 REM         Mobile Launcher when attacked by retargetable ICBMs.
3 REM
4 REM         Written by Capt Scott F. Merrow and Lt David J. Gearhart
5 REM         for an AFIT Masters Degree thesis.
6 REM         14 February 1986
7 REM
8 REM         Included are subroutines Ground.695 and Damage.695, which
9 REM         were written by LtCol Larry McKee for AFIT course NE.695.
11 REM
13 RANDOMIZE TIMER
14 BEEP
15 PRINT "Enter ISS (psi)"
20 INPUT ISS
25 PRINT "Enter ISK (psi)"
30 INPUT ISK
31 REM
32 REM         ISS and ISK are the sure safe and sure kill intensity levels
33 REM         for computing damage due to overpressure.
34 REM
35 PRINT "Enter Number of Attacking Warheads"
40 INPUT NUMRVS
45 PRINT "Enter Yield in KT"
50 INPUT YIELD
55 PRINT "Enter CEP in Meters"
56 INPUT CEP
57 PRINT "The program will compute an optimal height of burst"
58 PRINT "based on weapon yield and range from target to burst."
59 PRINT: PRINT "However, for a 'cookie cutter' damage assessment"
60 PRINT "a static height of burst might be preferred.  The program"
61 PRINT "will allow this approach, too.": PRINT
62 PRINT "For optimal height of burst routine, enter 1"
63 PRINT "For static height of burst enter 0"
64 INPUT STATIC
65 IF STATIC <> 0 THEN GOTO 68
66 PRINT "Enter height of burst in feet"
67 INPUT HOB
68 PRINT "Enter the Number of Trials"
69 INPUT TRIALS
70 REM -----------------------------------------------------------------
75 REM
80 REM  -----------------------------------------------------------------
82 REM
84 REM     This section initializes the values of several variables
86 REM
88 REM
90 MINMPH = 12        :REM     MINMPH is the HML's minimum speed.
100 MAXMPH = 38     :REM     MAXMPH is the HML's maximum speed.
110 MLKMPH = 30      :REM     MLKMPH is the HML's most likely speed.
115 REM
120 SETUP = 2
125 REM          SETUP is the amount of time the HML needs
126 REM          to assume its hardened configuration.
127 REM
130 DETECT = 1.5      :REM     DETECT is the launch detection time.
135 REM
200 DIM XRV (20): DIM YRV (20): DIM BURSTX (20): DIM BURSTY (20)
210 REM  -----------------------------------------------------------------
```

```
300 REM
301 REM   ----------------------------------------------------------------
302 REM     This section displays a heading for each run.
303 REM
304 REM
305 IF NUMRVS = 1 THEN GOTO 315
310 LPRINT: LPRINT NUMRVS; " Warheads": GOTO 317
315 LPRINT: LPRINT NUMRVS; " Warhead"
317 LPRINT TRIALS;" Repetitions"
320 LPRINT "Yield = "; YIELD
325 LPRINT "CEP = "; CEP
330 LPRINT "ISS = "; ISS
335 LPRINT "ISK = "; ISK
339 LPRINT: LPRINT
340 IF STATIC <> 0 THEN GOTO 351
341 HOB = HOB * .3048: OHOB = HOB: GOSUB 20100
343 REM   ----------------------------------------------------------------
344 REM
345 REM   ----------------------------------------------------------------
346 REM     This section computes values for variables TIME1 and TIME2.
347 REM     TIME1 is the amount of time the HML moves from launch detection
348 REM     until the attacking warheads' last valid update.  TIME2 is the amount
349 REM     of time the HML moves from the last update until detonation.
350 REM
351 FOR CYCLE = 1 TO 30 : LPRINT:LPRINT "Cycle = ";CYCLE
352 TOTPK = 0
353 IF STATIC = 0 THEN GOTO 360
354 GOSUB 5000
355 HOB = SOHOB * (YIELD ^ (1 / 3)) * .3048: OHOB = HOB :REM   .3048 converts feet to meters
356 REM
357 REM           Subroutine 5000 computes scaled optimum height of burst (SOHOB).
358 REM           SOHOB is then re-scaled to the actual height of burst  (HOB).
359 REM
360 FOR COUNT = 1 TO TRIALS
380 R1 = RND
390 FLTTIM = 26 + (R1 * 8)
392 REM
394 REM     FLTTIM is the ICBM's total time of flight.
396 REM
460 TTG = FLTTIM
462 REM
464 REM     TTG is the time to go until detonation.
466 REM
470 R2 = RND
480 UPDTIM = R2 * CYCLE
482 REM
484 REM     UPDTIM here represents the time to the warheads' first update.
486 REM
490 IF UPDTIM > TTG THEN GOTO 550
500 TTG = TTG - UPDTIM
510 IF CYCLE > TTG THEN GOTO 540
520 UPDTIM = CYCLE
524 REM
526 REM     UPDTIM here represents the time to the NEXT update.
528 REM
530 GOTO 490
540 TTG = TTG + UPDTIM
550 TIME1 = FLTTIM - TTG - DETECT
554 REM
556 REM     TIME1 is the time from launch detection until the attacking
557 REM     warheads receive their last valid intelligence/retargeting update.
558 REM
560 IF TIME1 < 0 THEN TIME1 = 0
570 TIME2 = TTG - SETUP
574 REM
576 REM     TIME2 is the time between the warheads' last update and the
577 REM     time when the HML must stop moving.
578 REM
580 IF TIME2 < 0 THEN TIME2 = 0
590 REM   ----------------------------------------------------------------
740 REM
```

```
750 REM  ------------------------------------------------------------------
752 REM     This section determines the attacking warheads' aimpoints and the
753 REM     HML's location at detonation.
754 REM     This section calls subroutine 3000.  Sub 3000 generates random motion
755 REM     of the HML for periods of time equal to TIME1 and TIME2 to determine
756 REM     weapon aimpoints and the HML's final location.
757 REM     This section also calls subroutine 7000.  Sub 7000 computes a miss
758 REM     distance based on the ICBM's CEP.  Variables X2 and Y2 are the
759 REM     X and Y coordinates of the miss distance.
760 REM
762 GOSUB 3000
765 FOR NUM = 1 TO NUMRVS
766 REM
767 REM     NUMRVS is the number of warheads attacking each HML.
768 REM
770 GOSUB 7000
780 BURSTX (NUM) = ((XRV (NUM) + XRV) * 5280 * .3048) + X2
790 BURSTY (NUM) = ((YRV (NUM) + YRV) * 5280 * .3048) + Y2
791 REM
792 REM     BURSTX and BURSTY are the coordinates of the detonations.
793 REM     XRV and YRV are coordinates of the central aiming point -- the
794 REM     point where the ICBM last saw the HML.
795 REM     XRV (NUM) and YRV (NUM) are offset aim points for cases when
796 REM     more than one warhead is aimed at each HML.
797 REM     X2 and Y2 represent aiming error.
798 REM     (* 5280 * .3048) converts miles to meters.
799 REM
800 NEXT NUM
810 PX = XHML * 5280 * .3048     :REM      PX and PY are the HML's coordinates
820 PY = YHML * 5280 * .3048     :REM      (in meters) at time of detonation.
830 REM ------------------------------------------------------------------
831 REM
832 REM ------------------------------------------------------------------
836 REM     This section computes damage levels.
840 REM     This section calls subroutines 8000 and 9000.
844 REM     Sub 8000 (Ground.695) calculates the peak overpressure incident on the HML.
848 REM     Sub 9000 (Damage.695) translates the overpressure level into a
852 REM     probability of damage  (PD).
856 REM
860 TOTPS = 1
870 FOR BURST = 1 TO NUMRVS
875 GZX = BURSTX (BURST)    :REM        GZX and GZY are the X and Y
880 GZY = BURSTY (BURST)    :REM        coordinates of the bursts.
890 GOSUB 8000
900 INTENS = DPT
910 GOSUB 9000
950 PS = 1 - PD
960 TOTPS = TOTPS * PS
970 NEXT BURST
975 PK = 1 - TOTPS
980 TOTPK = TOTPK + PK
982 NEXT COUNT
984 AVGPK = TOTPK / TRIALS
985 PRINT: PRINT "Pk = ";AVGPK: PRINT
986 LPRINT "Pk = ";AVGPK
987 LPRINT "HOB = "; OHOB: LPRINT "Ru = "; RU: LPRINT "RL = ";RL
989 NEXT CYCLE
990 BEEP: BEEP: BEEP
991 END
992 REM ------------------------ End of Main Routine -----------------------
```

```
3000 REM
3005 REM ------------------------------------------------------------------
3010 REM      This subroutine determines the location of the RV's aimpoints
3020 REM      and the location of the HML at time of detonation.
3030 REM
3040 REM
3060 X0 = 0      :REM     X0 and Y0 are the X and Y coordinates
3070 Y0 = 0      :REM     of the HML's current location.
3080 IF TIME1 = 0 THEN GOTO 3110
3090 TTG = TIME1
3100 GOSUB 3800      :REM  Subroutine 3800 generates random movement of the HML
3105 REM                       for an amount of time equal to TTG (time to go).
3110 XRV = X0
3120 YRV = Y0
3121 REM
3122 REM     XRV, YRV are the HML's location when the attacking
3123 REM     warheads receive their last valid update.
3124 REM
3125 GOSUB 10000      :REM     Sub 10000 computes aimpoints for multiple warheads.
3130 TTG = TIME2
3220 GOSUB 3800      :REM  Subroutine 3800 generates random movement of the HML
3225 REM                       for an amount of time equal to TTG (time to go).
3226 REM
3230 XHML = X0      :REM          XHML and YHML are the HML's
3240 YHML = Y0      :REM          coordinates when it stops moving.
3310 RETURN
3320 REM ------------------------------------------------------------------
3330 REM
3800 REM ------------------------------------------------------------------
3810 REM      This subroutine generates random movement of the HML
3820 REM      for a given amount of time  (TTG).  It does so by generating
3825 REM      a random point for the HML to move toward.
3830 REM
3840 REM
3850 R10 = RND
3860 DIR = R10 * 2 * 3.14159
3870 R11 = RND
3880 DIST = R11 * (MAXMPH / 60) * FLTTIM
3890 X1 = DIST * COS (DIR)
3900 Y1 = DIST * SIN (DIR)
3910 X = X1 - X0
3920 Y = Y1 - Y0
3930 R = SQR ((X ^ 2) + (Y ^ 2))
3940 IF X0 > X1 AND Y0 > Y1 THEN GOTO 4000
3950 IF X0 = X1 AND Y0 > Y1 THEN GOTO 4000
3960 IF X0 < X1 AND Y0 > Y1 THEN GOTO 4000
3970 Z = X / R
3980 THETA = -ATN (Z / SQR (-Z * Z + 1)) + 1.5708
3990 GOTO 4020
4000 Z = X / R
4010 THETA = (2 * 3.14159) - (-ATN (Z / SQR (-Z * Z + 1)) + 1.5708)
4020 GOSUB 5400
4024 REM
4025 REM           Subroutine 5400 computes the HML's speed
4026 REM           based on a triangular distribution.
4027 REM
4070 IF R >= ..1PH / 60) * TTG  THEN GOTO 4130
4080 X0 = X1
4090 Y0  = Y1
4100 MOVTIM = (R / MPH) * 60
4110 TTG = TTG - MOVTIM
4120 GOTO 3850
4130 R = TTG * MPH   60
4140 X = R * COS (THETA)
4150 Y = R * SIN (THETA)
4160 X0 = X0 + X
4170 Y0 = Y0 + Y
4180 RETURN
4185 REM ------------------------------------------------------------------
4190 REM
```

```
5000 REM ------------------------------------------------------------------
5005 REM
5010 REM     This subroutine determines scaled height of burst (SOHOB
5020 REM     in feet based on the variables CYCLE and YIELD.  Feet are
5030 REM     converted to meters upon return to the calling routine.
5035 REM
5036 REM          Variables:
5037 REM          XGDRG = expected ground range from target to burst
5038 REM          SXGDRG = scaled expected ground range
5040 REM
5050  XGDRG = .5 * MAXMPH * CYCLE * (5280 / 60)
5060 SXGDRG = XGDRG / (YIELD ^ (1 / 3))
5070 IF SXGDRG >= 0 AND SXGDRG < 90 THEN SOHOB = (1 / 3) * SXGDRG: RETURN
5080 IF SXGDRG >= 90 AND SXGDRG < 120 THEN SOHOB = (2 / 3) * SXGDRG - 30: RETURN
5090 IF SXGDRG >= 120 AND SXGDRG < 360 THEN SOHOB = (19 / 24) * SXGDRG - 45: RETURN
5100 IF SXGDRG >= 360 AND SXGDRG < 490 THEN SOHOB = (14 / 13) * SXGDRG - (1920 / 13): RETURN
5110 IF SXGDRG >= 490 AND SXGDRG < 640 THEN SOHOB = (14 / 15) * SXGDRG - (232 / 3): RETURN
5115 IF SXGDRG >= 640 AND SXGDRG < 920 THEN SOHOB = (5 / 14) * SXGDRG + (2040 / 7): RETURN
5120 IF SXGDRG >= 920 AND SXGDRG < 1200 THEN SOHOB = (1 / 7) * SXGDRG + (3420 / 7): RETURN
5130 IF SXGDRG >= 1200 AND SXGDRG < 1460 THEN SOHOB = (4 / 13) * SXGDRG + (3780 / 13): RETURN
5140 IF SXGDRG >= 1460 AND SXGDRG < 1690 THEN SOHOB = (14 / 23) * SXGDRG - (3420 / 23): RETURN
5150 IF SXGDRG >= 1690 AND SXGDRG < 2020 THEN SOHOB = (3 / 11) * SXGDRG + (4610 / 11): RETURN
5160 IF SXGDRG >= 2020 AND SXGDRG < 2620 THEN SOHOB = (13 / 60) * SXGDRG + (1597 / 3): RETURN
5170 IF SXGDRG >= 2620 AND SXGDRG < 4180 THEN SOHOB = (-1 / 78) * SXGDRG + (88420' / 78): RETURN
5180 IF SXGDRG >= 4180 AND SXGDRG < 7020 THEN SOHOB = (13 / 71) * SXGDRG + (22340 / 71): RETURN
5190 REM ------------------------------------------------------------------
5200 REM
5400 REM ------------------------------------------------------------------
5421 REM     This subroutine computes the HML's speed (MPH).  It is drawn
5422 REM     from a triangular distribution with the HML's minimum and
5423 REM     maximum speeds (MINMPH and MAXMPH) at the ends of the
5424 REM     distribution, and the HML's most likely speed (MLKMPH) as
5425 REM     the distribution's modal value.
5427 REM
5428 REM
5430 R12 = RND
5432 SEGMNT = (MLKMPH - MINMPH) / ((MLKMPH - MINMPH) + (MAXMPH - MLKMPH))
5434 IF R12 >= SEGMNT THEN GOTO 5446
5436 A = 1
5438 B = -2 * MINMPH
5440 C = (MINMPH ^ 2) - (R12 * (MLKMPH - MINMPH) * ((MLKMPH - MINMPH) + (MAXMPH - MLKMPH)))
5442 MPH = (-B + SQR ((B ^ 2) - (4 * A * C))) / (2 * A)
5444 GOTO 5454
5446 A = 1
5448 B = -2 * MAXMPH
5450 C = ((R12 * (MAXMPH - MLKMPH) * ((MLKMPH - MINMPH) + (MAXMPH - MLKMPH))) - ((MAXMPH - MLKMP
H) * (MLKMPH - MINMPH)) + (2 * MAXMPH * MLKMPH) - (MLKMPH ^ 2))
5452 MPH = (-B - SQR ((B ^ 2) - (4 * A * C))) / (2 * A)
5454 RETURN
5460 REM ------------------------------------------------------------------
7000 REM
7010 REM ------------------------------------------------------------------
7020 REM          This subroutine uses Circular Error Probable (CEP)
7030 REM          to compute a miss distance for the attacking warhead.
7040 REM
7060 R10 = RND
7070 R = SQR (((CEP ^ 2) / LOG (2)) * LOG (1 / (1 - R10)))
7080 R11 = RND
7090 THETA2 = R11 * 2 * 3.14159
7100 X2 = R * COS (THETA2)
7110 Y2 = R * SIN (THETA2)
7120 RETURN
7130 REM ------------------------------------------------------------------
```

```
8000 REM
8004 REM -------------------------------------------------------------------
8006 REM
8010 REM     GROUND.695
8012 REM
8014 REM     This subroutine was written by LtCol Larry McKee
8016 REM     for use in AFIT course NE.695.
8020 REM
8022 REM     The subroutine computes the amount of overpressure
8024 REM     incident on the HML from each burst.
8026 REM
8028 REM     Variables:
8030 REM          SGR = Scaled Ground Range
8031 REM          PX, PY are the HML's coordinates.
8032 REM          GZX, GZY are the coordinates of the burst.
8033 REM          SOTP = Scaled Origin of the Triple Point
8034 REM          SR1 = Scaled Slant Range
8036 REM          REFSR = Reference Slant Range
8040 REM
8050 SGR=SQR((PX-GZX)^2+(PY-GZY)^2)/YIELD^(1/3):SHOB=HOB/YIELD^(1/3):P0PSI=14.6
8060 IF SHOB <=5  THEN DPT=.001 * EXP (31.3 * SGR ^ (-.2136)) : RETURN
8070 IF SHOB<=305 THEN SOTP=.2427+.7924*SHOB+.0009695*SHOB^2-2.444E-06*SHOB^3+3.532E-08*SHOB^4
8080 IF SHOB<=305 THEN SOTP=SOTP-5.515E-11*SHOB^5+4.907E-14*SHOB^6
8090 IF SHOB>305 THEN SOTP=95*(EXP(SHOB/175)-1)
8100 IF SGR<SOTP THEN 8190
8110 SR1=SQR(SHOB^2+SGR^2):X=LOG(SR1)
8120 ALPHA=EXP(.3549*X^3-6.7133*X^2+41.468*X-82.819)
8130 BETA=EXP(.25192*X^4-5.8741*X^3+50.298*X^2-185.95*X+248.8)
8140 GAMMA=EXP(.1826*X^4-4.36786*X^3+38.6017*X^2-149.59*X+216.26)
8150 DP90=.01*EXP(40.3*SR1^(-.295)) :DP0=.001*EXP(31.3*SR1^(-.2136))
8160 DPA=DP0+(DP90-DP0)*(SHOB/SR1)^2:DPB=(SGR/SR1)^(2*BETA)*(SHOB/SR1)^ALPHA*EXP(GAMMA)
8170 IF SR1 < 100 THEN DPT = DPA : RETURN
8180 IF SR1 >= 100 THEN DPT=DPA+DPB : RETURN
8190 REFSR=SQR(SGR^2+SHOB^2):DPF=EXP(.19*(LOG(REFSR/1000))^2-1.5*LOG(REFSR/1000)-.1):SIND=SHOB/R
EFSR
8200 DPT=2*DPF+6*DPF^2*SIND^2/(7*P0PSI+DPF) : RETURN
8210 REM -------------------------------------------------------------------
9000  REM
9004 REM -------------------------------------------------------------------
9006 REM
9010 REM     DAMAGE.695
9012 REM
9014 REM     This subroutine was written by LtCol Larry McKee
9016 REM     for use in AFIT course NE.695.
9020 REM
9022 REM     This subroutine uses a cumulative log normal damage
9024 REM     function to calculate the probability of damage for
9026 REM     given overpressure levels.
9027 REM     (Note:  This subroutine can calculate damage due to damage
9028 REM     mechanisms other than overpressure.  However, in this
9029 REM     model, only overpressure is considered.)
9030 REM
9032 REM     Variables:
9034 REM          INTENS = amount of overpressure incident on the HML
9036 REM          PD = probability of damage
9038 REM          ISS = Sure Safe level of overpressure
9040 REM          ISK = Sure Kill level of overpressure
9042 REM
9050  IF INTENS<1E-10 THEN PD=0 : RETURN
9060  AA = (LOG(ISK) + LOG(ISS)) * .5
9070  BB = (LOG(ISK) - LOG(ISS)) / (2*2.054)
9080  Z = (LOG(INTENS) - AA) / BB
9090  IF Z >= 0 THEN PD=1-.5/(1+.196854*Z+.115194*Z^2+.000344*Z^3+.019527*Z^4)^4
9100  IF Z < 0 THEN Z=ABS(Z) : PD=.5/(1+.196854*Z+.115194*Z^2+.000344*Z^3+.019527*Z^4)^4
9110 RETURN
9120 REM -------------------------------------------------------------------
```

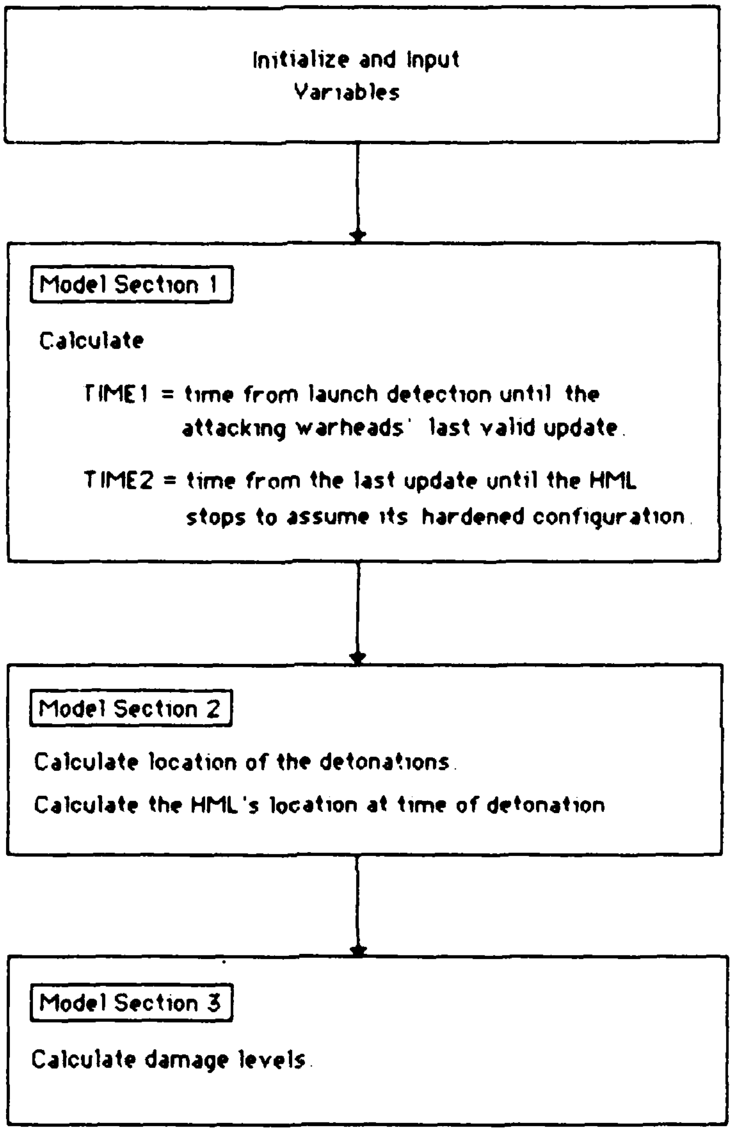
```
10000 REM
10010 REM ----------------------------------------------------------------
10012 REM     This subroutine computes aimpoint locations
10014 REM     for various numbers of attacking warheads.
10016 REM
10018 REM
10019 IF STATIC = 0 THEN GOTO 10030
10020 GOSUB 20100
10030 RL = (RADIUS/.3048)/5280   :REM   RL = lethal radius of the warhead
10040 RU = .85 *MAXMPH * CYCLE/60
10045 REM     RU = the radius of uncertainty within which the HML is located.
10050 IF RL >= RU THEN GOTO 11000
10060 IF NUMRVS = 1 THEN GOTO 11000  :REM   This section identifies the
10070 IF NUMRVS = 2 THEN GOTO 11040  :REM   number of attacking
10080 IF NUMRVS = 3 THEN GOTO 11070  :REM   warheads (NUMRVS) per
10090 IF NUMRVS = 4 THEN GOTO 11200  :REM   HML and directs the
10100 IF NUMRVS = 5 THEN GOTO 11400  :REM   program to the proper
10110 IF NUMRVS = 6 THEN GOTO 11480  :REM   location within the
10120 IF NUMRVS = 7 THEN GOTO 11560  :REM   subroutine.  Optimal attack
10130 IF NUMRVS = 8 THEN GOTO 11650  :REM   patterns are then
10140 IF NUMRVS = 9 THEN GOTO 11720  :REM   determined.
10150 IF NUMRVS = 10 THEN GOTO 12000
10160 IF NUMRVS = 11 THEN GOTO 12810
10170 IF NUMRVS = 12 THEN GOTO 12900
10180 IF NUMRVS = 13 THEN GOTO 13050
10190 IF NUMRVS = 14 THEN GOTO 13210
10900 REM
10910 REM          1 warhead per HML
10920 REM
11000 FOR J = 1 TO NUMRVS
11010 XRV (J) = 0: YRV (J) = 0
11020 NEXT J
11030 RETURN
11036 REM
11037 REM          2 warheads per HML
11038 REM
11040 YRV (1) = 0: YRV (2) = 0
11050 IF RU > 2 * RL THEN GOTO 11060
11055 XRV (1) = RU - RL: XRV (2) = - (RU - RL): RETURN
11060 XRV (1) = RU / 2: XRV (2) = -RU / 2: RETURN
11066 REM
11067 REM          3 warheads per HML
11068 REM
11070 IF RL < RU / 2.155 THEN GOTO 11120
11075 IF RL > RU / 2 THEN GOTO 11100
11080 RAD = RU - RL
11090 GOTO 11130
11100 RAD = RL
11110 GOTO 11130
11120 RAD = .536 * RU
11130 FOR J = 1 TO 3
11140 XRV (J) = RAD * COS (J * 2 * 3.14159 / 3)
11150 YRV (J) = RAD * SIN (J * 2 * 3.14159 / 3)
11160 NEXT J
11170 RETURN
11196 REM
11197 REM          4 warheads per HML
11198 REM
11200 IF RL >= RU / 2.4142 THEN GOTO 11230
11210 RAD = (RU + 2.4142 * RL) / 2
11220 GOTO 11270
11230 IF RL >= RU / 2 THEN GOTO 11260
11240 RAD = RU - RL
11250 GOTO 11270
11260 RAD = RL
11270 FOR J = 1 TO 4
11280 XRV (J) = RAD * COS (J * 3.14159 / 2)
11290 YRV (J) = RAD * SIN (J * 3.14159 / 2)
11300 NEXT J
11310 RETURN
11396 REM
```

```
11397 REM          5 warheads per HML
11398 REM
11400 IF RU > 2.701 * RL THEN DIST = (2.701 * RL + RU) / 2: GOTO 11430
11410 IF RL < .5 * RU THEN DIST = RU - RL: GOTO 11430
11420 DIST = RL
11430 FOR K = 1 TO 5
11440 XRV (K) = DIST * COS (K * 72 * 3.14159 / 180)
11450 YRV (K) = DIST * SIN (K * 72 * 3.14159 / 180)
11460 NEXT K
11470 RETURN
11476 REM
11477 REM          6 warheads per HML
11478 REM
11480 IF RL <= RU /3 THEN DIST = (RU + RL) / 2: GOTO 11510
11490 IF RL <= RU / 2 THEN DIST = RU - RL: GOTO 11510
11500 DIST = RL
11510 FOR L = 1 TO 6
11520 XRV (L) = DIST * COS ((L-1) * 3.14159 / 3)
11530 YRV (L) = DIST * SIN ((L-1) * 3.14159 / 3)
11540 NEXT L
11550 RETURN
11556 REM
11557 REM          7 warheads per HML
11558 REM
11560 XRV (1) = 0: YRV (1) = 0
11570 IF RL <= RU / 3 THEN DIST = (RU + RL) /2: GOTO 11600
11580 IF RL <= RU / 2.732 THEN DIST = RU - RL: GOTO 11600
11590 DIST = SQR(3) * RL
11600 FOR M = 0 TO 5
11610 XRV (M+2) = DIST * COS (M * 3.14159 / 3)
11620 YRV (M+2) = DIST * SIN (M * 3.14159 / 3)
11630 NEXT M
11640 RETURN
11646 REM
11647 REM          8 warheads per HML
11648 REM
11650 XRV (1) = 0: YRV (1) = 0
11660 IF RU >= 3.305 * RL THEN DIST = (RU + RL) / 2: GOTO 11690
11670 IF RU <= 2.802 * RL THEN DIST = 1.802 * RL: GOTO 11690
11680 DIST = RU - RL
11690 FOR N = 0 TO 6
11700 XRV (N+2) = DIST * COS (N * 2 * 3.14159 / 7)
11710 YRV (N+2) = DIST * SIN (N * 2 * 3.14159 / 7)
11714 NEXT N
11715 RETURN
11716 REM
11717 REM          9 warheads per HML
11718 REM
11720 XRV (1) = 0: YRV (1) = 0
11730 IF RU >= 3.613 * RL THEN DIST = (RU + 1.613 * RL) / 2: GOTO 11760
11740 IF RU <= 2.9239 * RL THEN DIST = 1.9239 * RL: GOTO 11760
11750 DIST = RU - RL
11760 FOR I = 0 TO 8
11770 XRV (I + 2) = DIST * COS ( I * 3.14159 / 4)
11780 YRV (I + 2) = DIST * SIN ( I * 3.14159 / 4)
11790 NEXT I
11800 RETURN
11996 REM
11997 REM          10 warheads per HML
11998 REM
12000 XRV (1) = 0: YRV (1) = 0
12010 IF RL < RU / 3 THEN DIST = RU - RL: GOTO 12030
12020 DIST = (2 * RU) / 3
12030 FOR K = 2 TO 10
12040 XRV (K) = DIST * COS ((K - 1) * 40 * 3.14159 / 180)
12050 YRV (K) = DIST * SIN ((K - 1) * 40 * 3.14159 / 180)
12060 NEXT K
12070 RETURN
12806 REM
```

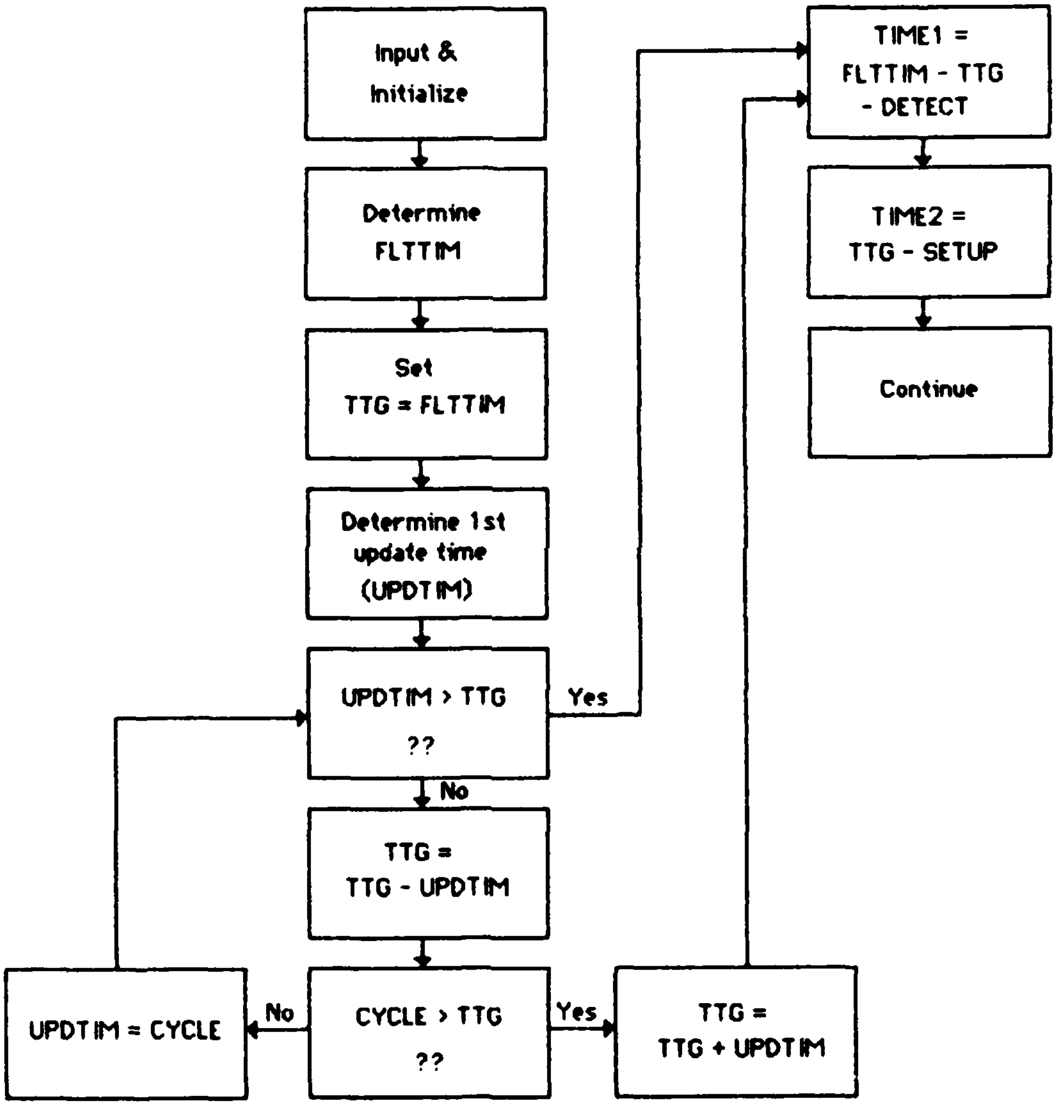
```
12807 REM          11 warheads per HML
12808 REM
12810 XRV (1) = 0: YRV (1) = 0
12820 IF RU >= 4.236 * RL THEN DIST = 3.236 * RL: GOTO 12850
12830 IF RU <= 2.9021 * RL THEN DIST = 1.9021 * RL: GOTO 12850
12840 DIST = RU -RL
12850 FOR J = 0 TO 9
12860 XRV (J) = DIST * COS (J * 3.14159 / 5)
12870 YRV (J) = DIST * SIN (J * 3.14159 / 5)
12880 NEXT J
12890 RETURN
12896 REM
12897 REM          12 warheads per HML
12898 REM
12900 IF RU <= 2.7321 * RL THEN GOTO 12940
12910 DIST1 = 2 * RL
12920 DIST2 = 4.4641 * RL
12930 GOTO 12960
12940 DIST1 = RL
12950 DIST2 = 1.7321 * RL
12960 FOR K = 0 TO 5
12970 XRV (K+1) = DIST1 * COS (K * 3.14159 / 3)
12980 YRV (K+1) = DIST1 * SIN (K * 3.14159 / 3)
12990 NEXT K
13000 FOR L = 7 TO 12
13010 XRV (L) = DIST2 * COS ((2*L-13) * 3.14159 / 6)
13020 YRV (L) = DIST2 * SIN ((2*L-13) * 3.14159 / 6)
13030 NEXT L
13040 RETURN
13046 REM
13047 REM          13 warheads per HML
13048 REM
13050 XRV (1) = 0: YRV (1) = 0
13060 IF RU > 4 * RL THEN GOTO 13100
13070 DIST1 = 1.7321 * RL
13080 DIST2 = 3 * RL
13090 GOTO 13120
13100 DIST1 = 2 * RL
13110 DIST2 = 3.4641 * RL
13120 FOR I = 2 TO 7
13130 XRV (I) = DIST1 * COS ((I-2) * 3.14159 / 3)
13140 YRV (I) = DIST1 * SIN ((I-2) * 3.14159 / 3)
13150 NEXT I
13160 FOR J = 8 TO 13
13170 XRV (J) = DIST2 * COS ((2*J-15) * 3.14159 / 6)
13180 YRV (J) = DIST2 * SIN ((2*J-15) * 3.14159 / 6)
13190 NEXT J
13200 RETURN
13206 REM
13207 REM          14 warheads per HML
13208 REM
13210 XRV (1) = 0: YRV (1) = 0
13220 IF RU >=4 * RL THEN GOTO 13270
13230 DIST1 = 1.7321 * RL
13240 DIST2 = 3 * RL
13250 DIST3 = 3.4642 * RL
13260 GOTO 13300
13270 DIST1 = 2 * RL
13280 DIST2 = 3.4641 * RL
13290 DIST3 = 4 * RL
13300 FOR I = 2 TO 7
13310 XRV (I) = DIST1 * COS ((I-2) * 3.14159 / 3)
13320 YRV (I) = DIST1 * SIN ((I-2) * 3.14159 / 3)
13330 NEXT I
13340 FOR J = 8 TO 13
13350 XRV (J) = DIST2 * COS ((2*J-15) * 3.14159 / 6)
13360 YRV (J) = DIST2 * SIN ((2*J-15) * 3.14159 / 6)
13370 NEXT J
13380 XRV (14) = DIST3 * COS (3.14159 / 3)
13390 YRV (14) = DIST3 * SIN (3.14159 / 3)
13400 RETURN
```

```
20000 REM ------------------------------------------------------------
20005 REM
20010 REM ---------------------------------------------------------------
20020 REM          This subroutine computes the lethal radius of the weapon
20030 REM          based on the optimal height of burst in meters (OHOB) and
20040 REM          yield in kilotons (YIELD).  The subroutine returns the value
20050 REM          of the lethal radius (RADIUS) in meters.
20060 REM
20100 SOHOB = OHOB / ((YIELD ^ (1/3)) * (.3048))
20110 IF SOHOB > 787 THEN SLERAD = 0: GOTO 20400
20120 IF SOHOB <= 787 AND SOHOB > 778 THEN Y1 = 787: Y2 = 778: X1 = 0:  X2 = 100: GOTO 20300
20130 IF SOHOB <= 778 AND SOHOB > 757 THEN Y1 = 778: Y2 = 757: X1 = 100:  X2 = 200: GOTO 20300
20140 IF SOHOB <= 757 AND SOHOB > 716 THEN Y1 = 757: Y2 = 716: X1 = 200:  X2 = 300: GOTO 20300
20150 IF SOHOB <= 716 AND SOHOB > 664 THEN Y1 = 716: Y2 = 664: X1 = 300:  X2 = 400: GOTO 20300
20160 IF SOHOB <= 664 AND SOHOB > 617 THEN Y1 = 664: Y2 = 617: X1 = 400:  X2 = 480: GOTO 20300
20170 IF SOHOB <= 617 AND SOHOB > 596 THEN Y1 = 617: Y2 = 596: X1 = 480:  X2 = 540: GOTO 20300
20180 IF SOHOB <= 596 AND SOHOB > 580 THEN Y1 = 596: Y2 = 580: X1 = 540:  X2 = 625: GOTO 20300
20190 IF SOHOB <= 580 AND SOHOB > 540 THEN Y1 = 580: Y2 = 540: X1 = 625:  X2 = 640: GOTO 20300
20200 IF SOHOB <= 540 AND SOHOB > 500 THEN SLERAD = 640: GOTO 20400
20210 IF SOHOB <= 500 AND SOHOB > 400 THEN Y1 = 500: Y2 = 400: X1 = 640:  X2 = 620: GOTO 20300
20220 IF SOHOB <= 400 AND SOHOB > 300 THEN Y1 = 400: Y2 = 300: X1 = 620:  X2 = 607: GOTO 20300
20230 IF SOHOB <= 300 AND SOHOB > 200 THEN Y1 = 300: Y2 = 200: X1 = 607:  X2 = 598: GOTO 20300
20240 IF SOHOB <= 200 AND SOHOB > 100 THEN Y1 = 200: Y2 = 100: X1 = 598:  X2 = 595: GOTO 20300
20250 IF SOHOB <= 100 THEN Y1 = 100: Y2 = 0: X1 = 595:  X2 = 592: GOTO 20300
20300 SLERAD = X1 + ((X2 - X1) * ((SOHOB - Y1) / (Y2 - Y1)))
20400 RADIUS = (SLERAD * (YIELD ^ (1/3))) * (.3048)
20410 RETURN
20420 REM
20430 REM ---------------------------------------------------------------
```

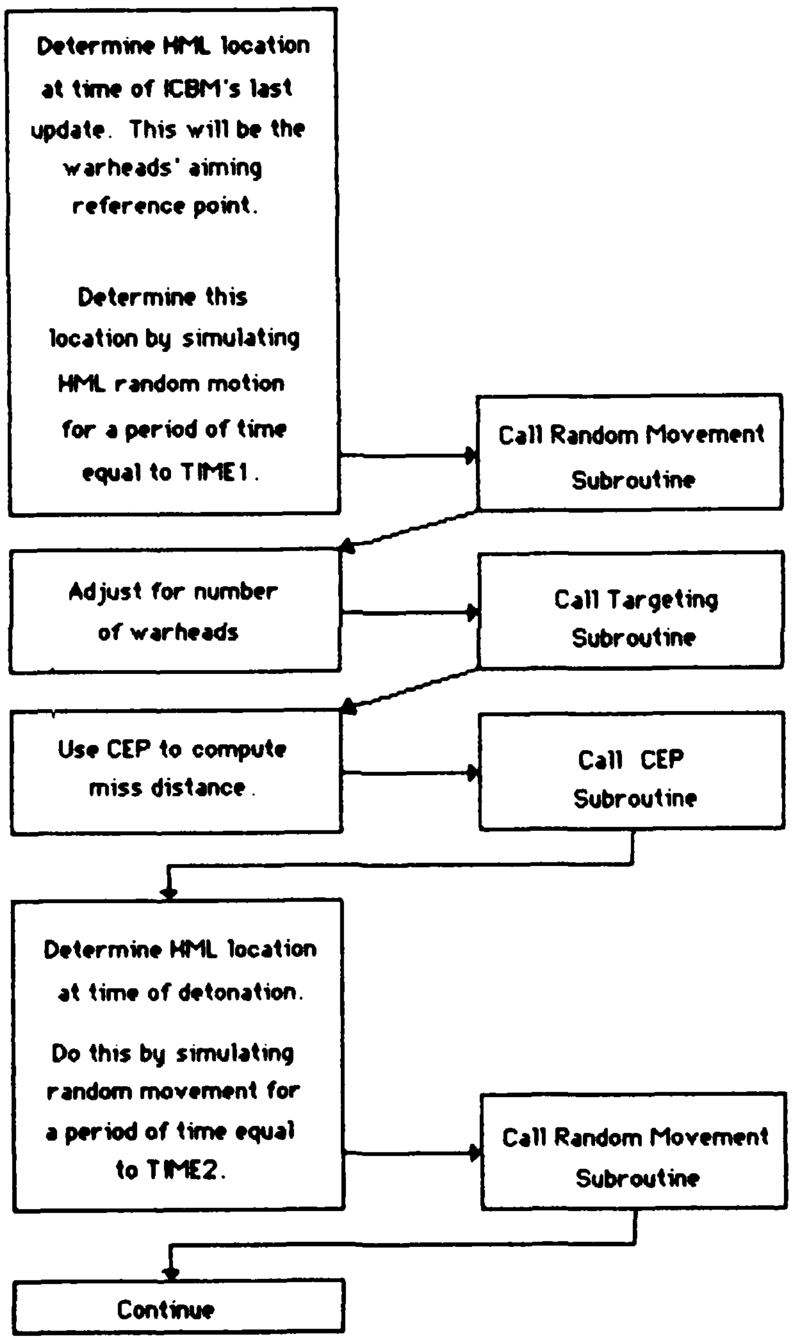
Appendix B: Model Flow Chart



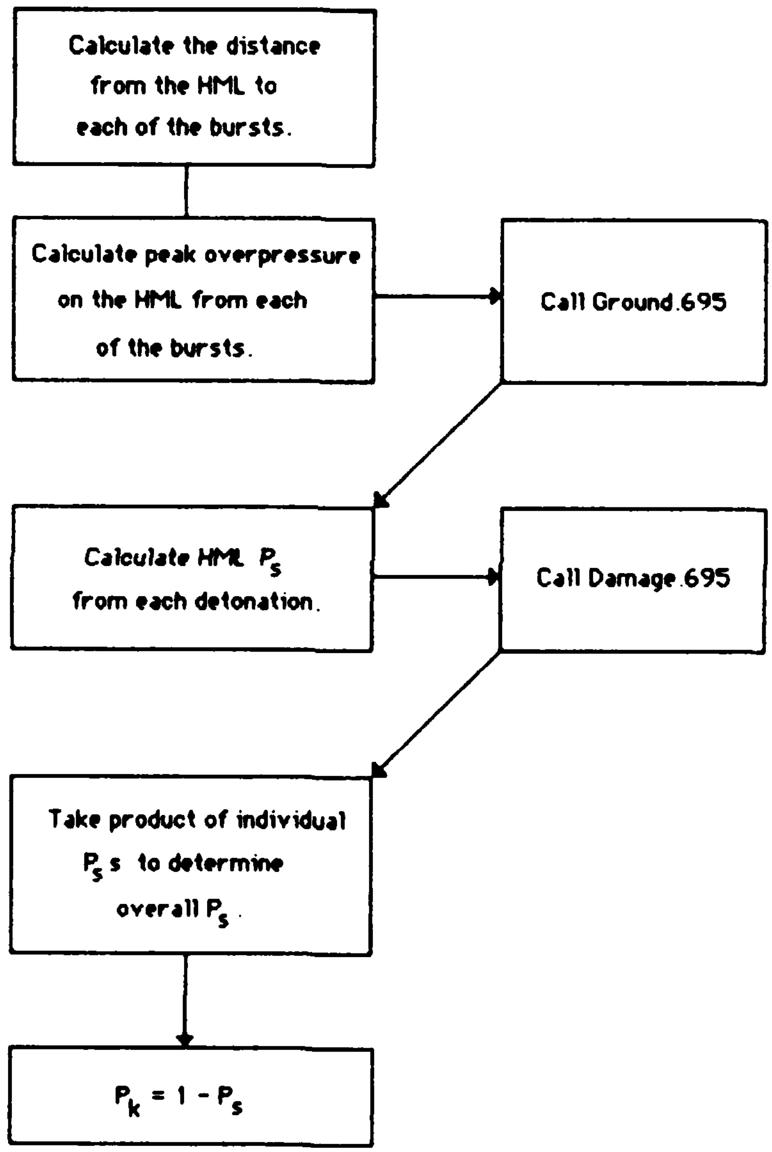
Appendix C: Model Section 1 Flow Chart



Appendix D: Model Section 2 Flow Chart



Appendix E: Model Section 3 Flow Chart



Appendix F: Targeting Patterns

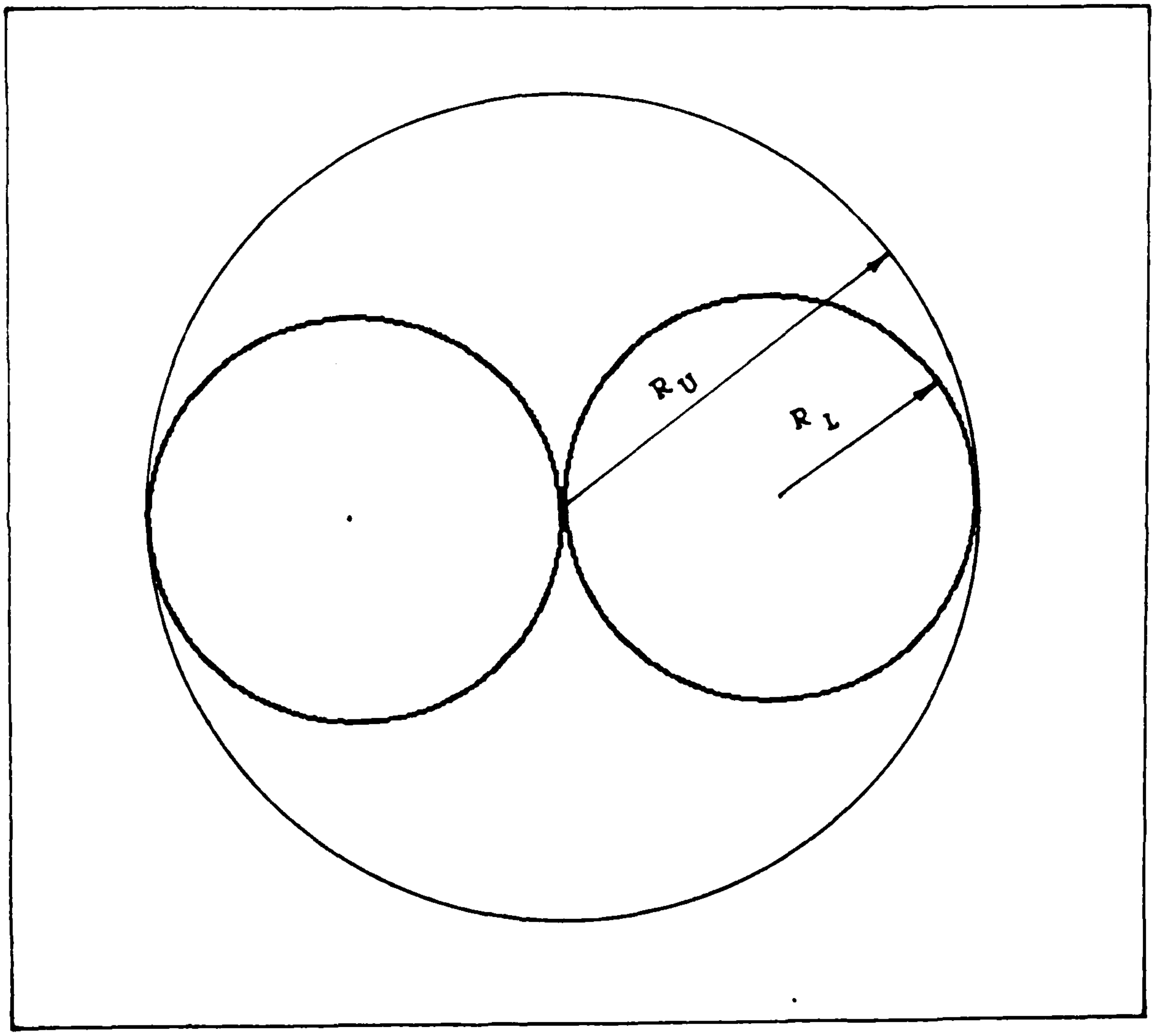


Figure 41: Basic Targeting Pattern for Two Warheads

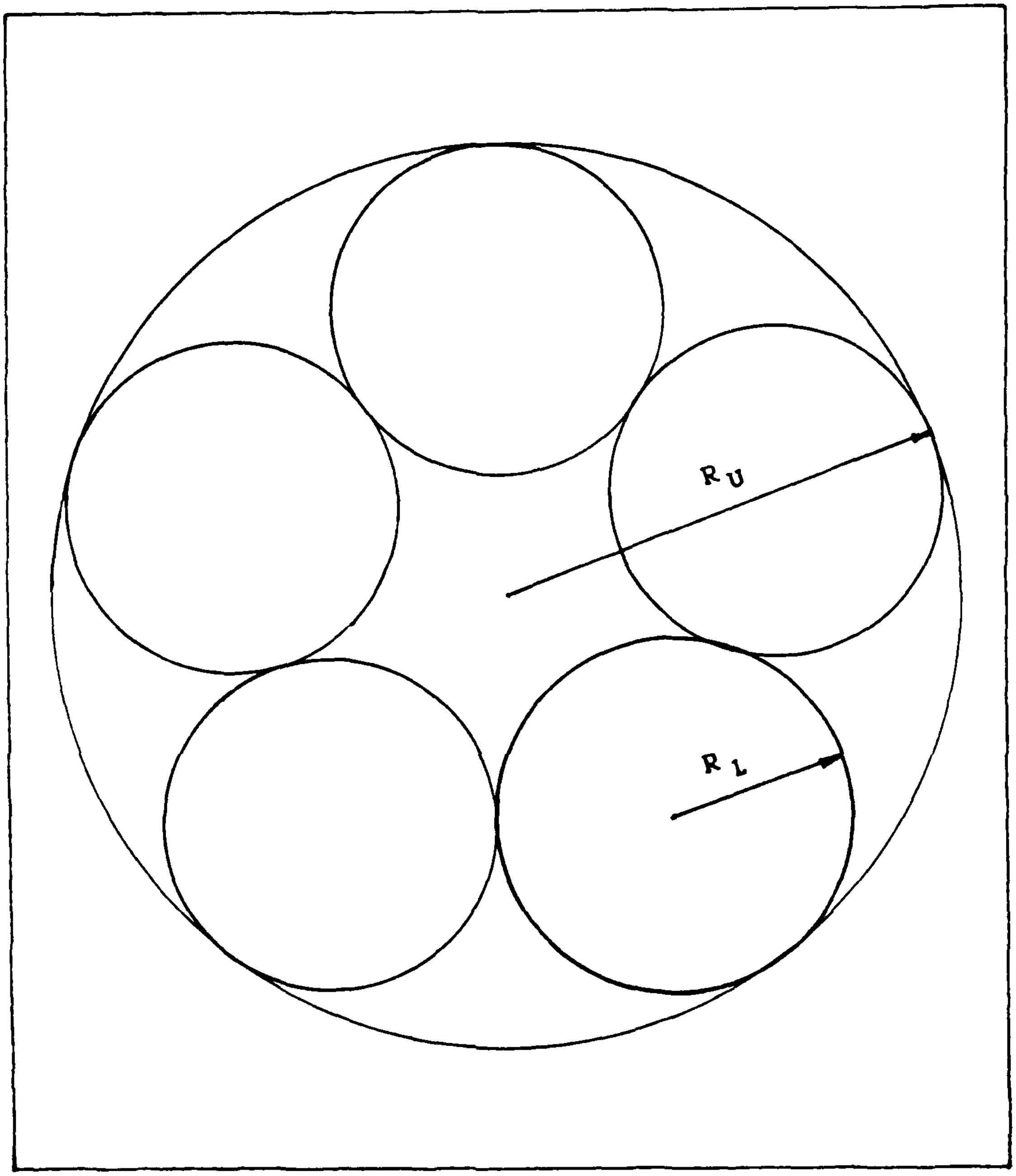


Figure 42: Basic Targeting Pattern for Five Warheads

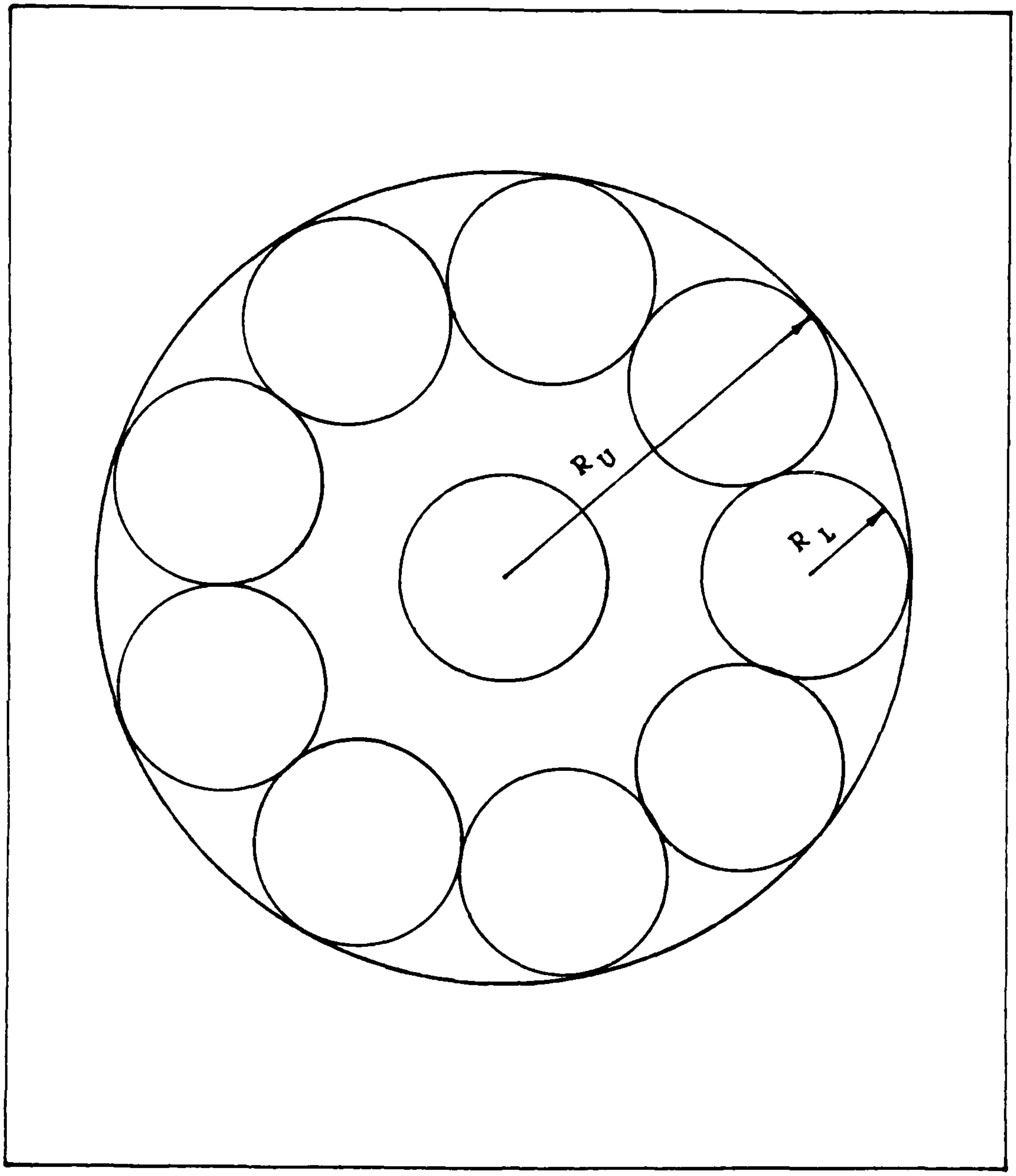


Figure 43: Basic Targeting Pattern for Ten Warheads

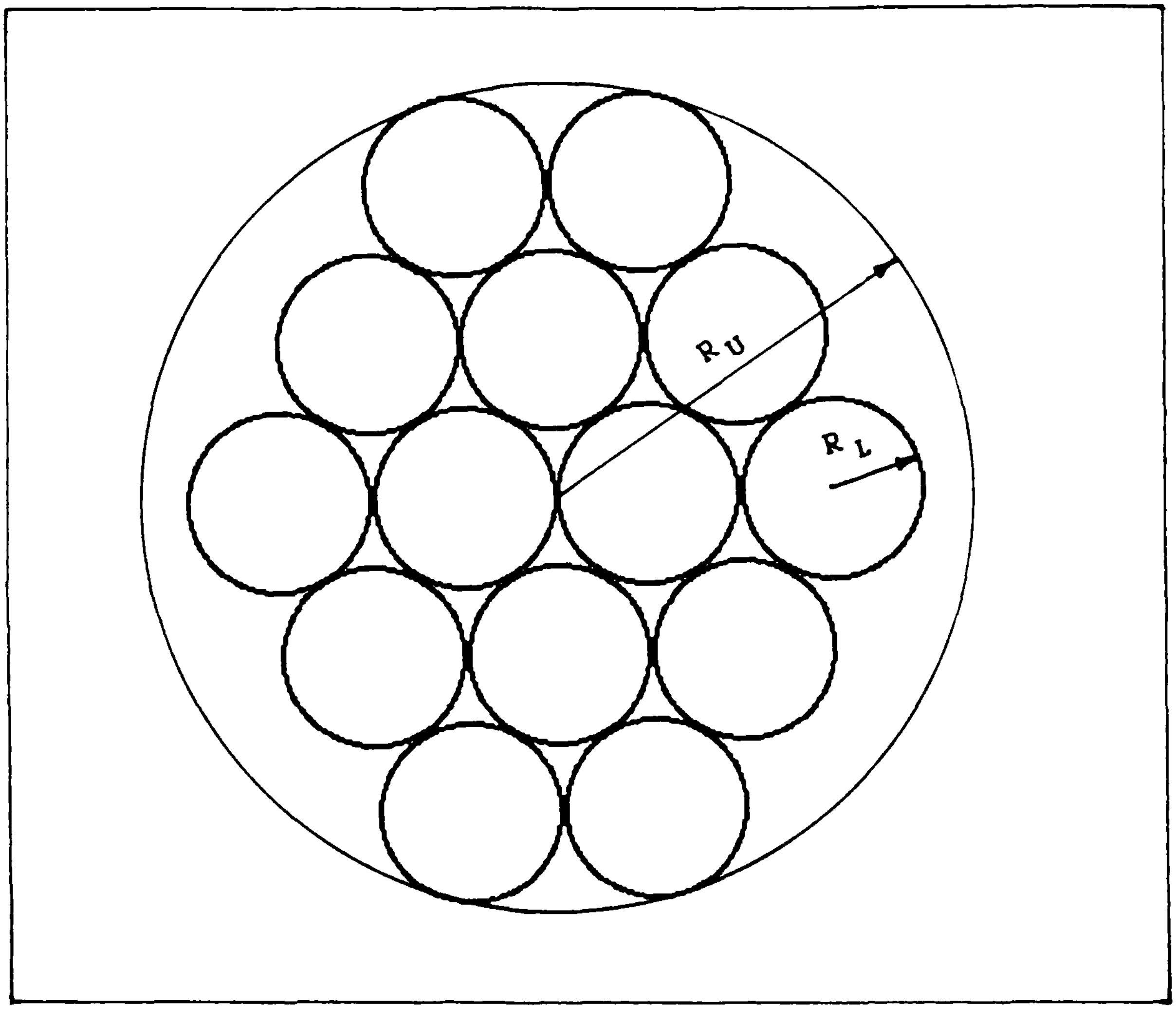


Figure 44: Basic Targeting Pattern for Fourteen Warheads

Appendix G: Computer Code for Fratricide Effects

```
30000 REM
30010 REM ----------------------------------------------------------------
30100 GOSUB 31000 :REM     Sub 31000 puts the bursts in random order
30110 FOR L = 1 TO NUMRVS
30120 BRSTPO = L
30130 PRIORS = BRSTPO - 1
30140 IF L = 1 THEN PSFRAT (L) = 1: RETURN
30150 IF L = 2 THEN GOSUB 32000: PSFRAT (L) = 1-(PKN(L-1)):RETURN
30160 GOSUB 32000
30170 PSFRAT (L) = 1
30180 FOR M = 1 TO PRIORS
30190 PSFRAT (L) = PSFRAT (L) * (1-PKN(M))
30200 NEXT M
30210 NEXT L
30220 RETURN
30230 REM ----------------------------------------------------------------
31000 REM
31010 REM ----------------------------------------------------------------
31100 FOR I = 1 TO NUMRVS
31110 ORDER (I) = INT (NUMRVS * RND + 1)
31120 IF I = 1 THEN GOTO 31160
31130 FOR J = 1 TO I-1
31140 IF ORDER (I) = ORDER (J) THEN GOTO 31110
31150 NEXT J
31160 ORDXRV (ORDER(I)) = BURSTX (I)
31170 ORDYRV (ORDER(I)) = BURSTY (I)
31180 NEXT I
31190 FOR K = 1 TO NUMRVS
31200 BURSTX (K) = ORDXRV (K)
31210 BURSTY (K) = ORDYRV (K)
31220 NEXT K
31230 RETURN
31240 REM ----------------------------------------------------------------
32000 REM
32010 REM ----------------------------------------------------------------
32100 FOR I = 1 TO PRIORS
32110 RVSEPR = SQR ((BURSTX (I) - BURSTX (BRSTPO)) ^ 2 + (BURSTY (I) - BURSTY(BRSTPO)) ^ 2)
32120 GOSUB 33000
32130 PKN (I) = PKN
32140 NEXT I
32150 RETURN
32160 REM ----------------------------------------------------------------
33000 REM
33010 REM ----------------------------------------------------------------
33020 ISS = ISSNTR
33030 ISK = ISKNTR
33040 ALT = HOB
33050 GOSUB 34000
33060 MI = DENS * RVSEPR / 10
33070 XPON = - 6.775 + .005269 * MI -5.4364E-06 * MI ^ 2 - 2.1468E-04 * MI ^ 1.5 -3.8214 * SQR (
MI) + 10.875 * MI ^ (1/3) - 1.3975 * LOG (MI)
33080 ANISN = EXP(XPON)
33090 NEUTRON = 3.2E+23 * YIELD * ANISN / (4 * PI * (RVSEPR * 100) ^ 2)
33100 INTENS = NEUTRON
33110 GOSUB 9050
33115 PKN = PD
33120 RETURN
33130 REM ----------------------------------------------------------------
```

```
34000 REM
34010 REM ------------------------------------------------------------------------
34020 IF ALT > 11000 THEN GOTO 34040
34030 TEMP = 288.2-.006545 * ALT: PRES=101300 *(TEMP/288.2)^5.22:GOTO 34090
34040 IF ALT > 20000 THEN GOTO 34060
34050 TEMP = 216.65: PRES = 22690 *EXP(-.0001582*(ALT-11000)): GOTO 34090
34060 IF ALT > 32000 THEN GOTO 34080
34070 TEMP = 216.65 + .001*(ALT-20000): PRES=5528 *(216.65/TEMP)^34.164: GOTO 34090
34080 TEMP = 288.65 + .0028*(ALT-32000): PRES=888.8*(228.65/TEMP)^12.2014
34090 SNDSP = 20.046 * SQR(TEMP): DENS =.003484 *PRES / TEMP: RETURN
34100 REM ------------------------------------------------------------------------
50000 TOTKIL = 0
50010 FOR I = 1 TO NUMRVS
50020 TOTKIL = TOTKIL + PSFRAT (I)
50030 NEXT I
50040 RETURN
```

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Vita

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ABSTRACT

This thesis evaluates the survivability of the hardened mobile launcher system (HML) against a hypothetical enemy ICBM system. The hypothetical system has two key capabilities: it can obtain near real-time intelligence information regarding the HMLs location, and it can be retargeted in flight (as necessary) according to the intelligence information. Thus, the hypothetical ICBM threat systems can attack individual HMLs directly rather than rely on a "barrage attack" against HML bases.

Monte Carlo simulation is used to approach the problem. The model is an MBASIC computer program written and run on an Apple Macintosh computer. The model simulates the flight of the attacking ICBMs (there may be as few as one or as many as fourteen warheads directed at each HML) and the random dispersal tactics of a single HML. The model determines the locations of the detonations and the location of the HML at time of detonation. Based on these locations, probability of kill due to peak blast overpressure is calculated.

A key parameter in the model is "intelligence/retargeting cycle time" -- the amount of time required to obtain intelligence and retarget accordingly. This time is varied from one to thirty minutes. The model also allows variations in HML speed and hardness and threat system CEP. A subroutine for examining the effects of neutron fratricide on the attacking warheads is also included (although the effects were found to be negligible).

The main result of this thesis is that very small intelligence/retargeting cycle times are required for this to be an effective weapon system against the HML. Thus, with today's technology (or technology of the near future), the HML can be considered a very survivable system.

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