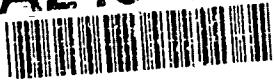
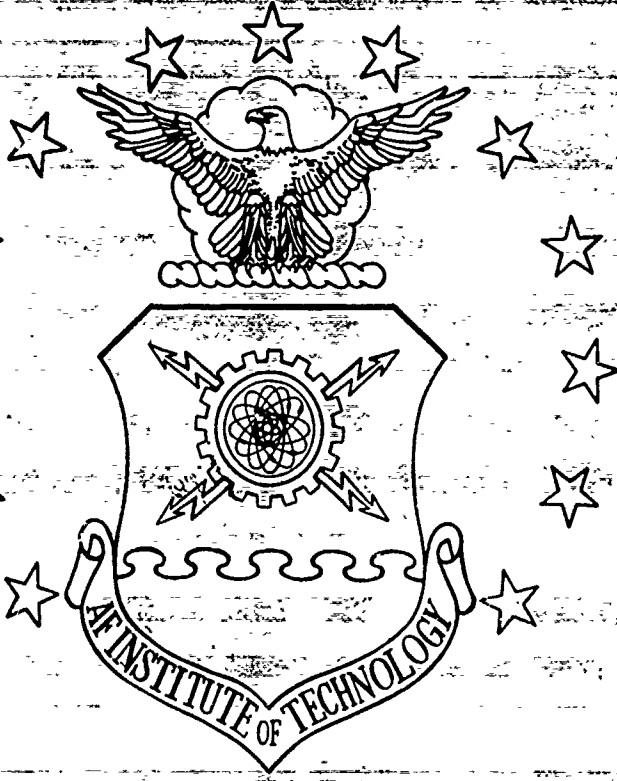


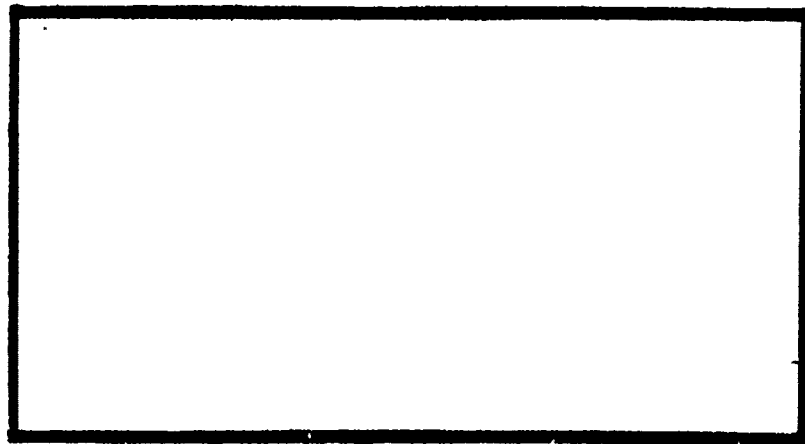
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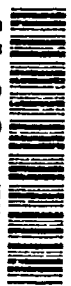


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SWATTER (Space-based Weapons Against Tactical
TErrestrial-based Resources): A Design for Integrating
Space into a Theater Level Wargame



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 Space Operations

Duane R. Cozadd, B.S.
Major, USAF

December, 1991



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THESIS TITLE: SWATT_{ER} (Space-based Weapons Employed Against Tactical Terrestrial-based Resources): A Design for Integrating Space into a Theater Level Wargame


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Duane R. Cozadd

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Abstract

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This thesis provides the foundation to expand the newly developed theater level computerized wargame, SABER, at the Air Force Wargaming Center, Maxwell AFB, Alabama to include space conflict at the theater level of simulation. Building upon the recently completed SABER, this thesis effort expands the conceptual framework of the model by integrating the dynamics of space warfare into the current theater level model. This expansion forms a new game called SWATTER.

This thesis adds the space units required to integrate the land and air battles with the possible interactions from space. This thesis expands the stochastic attrition processes to include interactions between space forces, ground forces, and air forces with the use of unclassified engineering models. The use of these models results in credible interactions throughout SWATTER. The main components of SWATTER include, satellite constellation determination, mapboard representation of the satellite constellation, detection and targeting processes, intelligence, command and control processes, laser weapon interactions, and stochastic attrition. The goal is to provide sufficient documentation on the necessary algorithms and related equations for programmers to build a computer simulation with a reasonable run time and credible output. *K*

SWATTER (Space-based Weapons Against Tactical TErrestrial-based Resources): A Design for Integrating Space into a Theater Level Wargame

I. Introduction

1.1 Background

Since President Reagan first proposed his Strategic Defense Initiative (SDI) in 1983, space has been receiving increasing attention as the next arena for the deployment of military forces. Supposedly space has been remarkably free of militarization since the dawning of the Space Age, regardless of the fact the military has used space for surveillance, communications and navigation; this state of affairs (given the darker side of humanity) will probably soon come to an end. While the strategic implications of space are quickly recognized and frequently debated, the tactical possibilities are not immediately obvious. In the future, deployment of a space-based defensive shield may present the possibility of engaging conventional surface forces as well as meeting the needs of the Strategic Defense Initiative. To better understand the implications of this possible employment, more research is necessary to learn of the weaknesses and strengths of such a system. Unfortunately, there are few indications that these tactical possibilities are being investigated at the unclassified level.

Current proposals for SDI envision a three layered strategic defensive shield. The first layer could consist of lasers, particle-beam weapons, interceptor rockets and possibly rail guns. The first two types of weapons are frequently called directed energy weapons (DEW) while the last two are usually called kinetic energy weapons (KEW). These weapons would be employed in the boost phase and post-boost phase of an intercontinental ballistic missile (ICBM) attack. The second layer, frequently called the midcourse correction layer would probably consist of KEWs or particle

beam weapons employed during the midcourse correction of the ICBMs. During the midcourse correction, reentry vehicles would be released, making a much more difficult target for lasers to destroy due to the ablative coating preventing or slowing the transfer of heat energy to the reentry vehicles. The final layer, called the terminal phase, envisions rocket interceptors to destroy the reentry vehicles prior to atmospheric penetration (28:24-44).

When examining this three layer defense, it becomes obvious KEWs employed from space against surface targets would not be cost effective and the use of surface-based kinetic weapon systems would be far better. This is true because the weight and cost penalties of placing kinetic weapons in space would result in weapons with a much smaller destructive yield than can be fired from the surface or air. Therefore, the most likely space-based candidates are the DEWs. Further paring of this list is possible when considering lasers are the result of a more mature technology than particle beam weapons and are much closer to achieving the power required for weapons employment. In addition, particle beams penetrating the atmosphere would have even more severe degradation effects than lasers would (13). Therefore, any investigation into using space-based weapons on the conventional battlefield would probably center on a laser weapon.

Unfortunately, many of the methods for investigating the possible tactical and doctrinal implications of weapon systems are geared to weapon systems which have already been developed. Many investigative methods do not lend themselves to futuristic systems not yet developed. However, one method is sufficiently flexible to allow the examination of future issues. This method is the wargame. With this in mind, one avenue of investigation could be a wargaming scenario to examine the effects of space-based weapons employed upon the modern battlefield. However, there is no war game which currently integrates space assets in a comprehensive manner on today's battlefield (18:13). The U.S. Government needs to be able to analyze and evaluate the different implications of space and space control available from these space assets.

1.2 Purpose

This thesis provides one method for the analysis of space assets on the modern battlefield. SWATTER (Space-Based Weapons Against Tactical TErrestrial-Based Resources) will become one tool the analyst should be able to use to answer the

what-if questions which are inevitable when examining space assets. The purpose of this thesis was to develop the computer program design of a low resolution wargame to model the possible capabilities and interactions of a laser weapon satellite system, primarily intended for space defense, on a conventional battlefield. Since the emphasis is on the effects of space-based lasers, this design builds upon the structure previously developed in Capt. William F. Mann's thesis, *Saber, A Theater Level Wargame* (26). While Capt Mann's thesis models the conventional aspects of theater conflict; this research concentrated on methods of integrating DEWs into his design proposal. This design, although primarily based upon Capt Mann's thesis (and the implementation of his design by the Department of Electrical Engineering at the Air Force Institute of Technology), should be sufficiently flexible for integration into other theater level wargames. A better understanding of possible methods of conventional employment and the capabilities and weaknesses of a space-based laser weapon would result. This thesis is also in support of the Air Force Wargaming Center's drive to better integrate space forces into war game simulations for the development of the future leaders of the Air Force.

To accomplish this task, several key areas were investigated to accurately model such a weapon system. One such area was wargaming fundamentals to assist the researcher in developing the design for this model. Other areas also included determining important characteristics which could affect the output of laser weapons, information on the determination of orbital constellations, and validation techniques.

1.3 Methodology

The methodology employed in developing SWATTER began with researching the basic areas of future SDI deployment options, wargaming, laser physics, and other areas. After this basic research was accomplished, the researcher culled the data available and determined the key issues to consider, as well as the important characteristics which should be modeled in the wargames. After these key issues were determined, the researcher incorporated these areas into the algorithms required by SWATTER. The actual programming of these algorithms will be accomplished by others who believe in the importance of the learning and research objectives SWATTER will offer. Once these key areas are in the final model, verification and validation of SWATTER will occur.

1.4 Model Considerations

Wargaming techniques could include methods for considering command and control, targeting, acquisition, and tracking, kill probability, and aggregate modeling. Many areas appeared to lend themselves to stochastic probability methods.

Currently, basic research continues into laser characteristics. Several areas immediately became obvious factors for consideration when modeling the output of a laser. These areas included atmospheric attenuation, atmospheric absorption, thermal blooming, diffraction of the laser beam, and energy output at the source. Several assumptions are going to be made in the area of lasers. Since this thesis incorporates a theoretical model of a weapon system it was assumed the demanding technical challenges facing laser weapons had been met. These challenges include finding appropriate tracking techniques, optical systems able to react quickly to a changing hostile environment, a large enough fuel source to permit multiple firings of the laser, and sufficient energy output to hit the target with sufficient force to damage or destroy the target. While projections about many of these areas are beyond the scope of this thesis, several simplifying representations of these ideas should be included in the wargame.

Methods for basing satellite constellations (the organizational orbital basing of a minimum number of satellites to accomplish a specified mission in an efficient manner) are at best sketchy in the open literature. These basing modes will be represented by statistical methods to give a specified percentage of area coverage for a specified percentage of the time. This portion of the model will also have to account for the physical characteristics of the specific laser system being modeled to determine effective range, and number of satellites for a specified coverage.

Finally, any computer model of reality should be validated (30). Although beyond the scope of this thesis, any organization implementing this design should accomplish a verification and validation effort to insure the results are in keeping with our current understanding of what we believe the future will hold. Unfortunately one of the most common techniques, comparison against other models, is not likely. During the research stage, no models were found which completely covers the areas of interest in SWATTER. Several models were found which modeled incomplete portions of SWATTER in the areas of satellite constellations (21), logistics (18), and space warfare (6). However, these models were discarded as inappropriate in resolution, methodology, or purpose for comparison against SWATTER.

Although model comparison can not be used in validating SWATTER, other techniques are of use in the validation effort. The most likely methods of validation will probably include a review of SWATTER by peers and experts in the satellite field and the empirical judgment (just good old-fashioned common sense) of the model users (14).

II. Literature Review

2.1 Introduction

This chapter reviews some of the literature available to determine the requirements for successfully incorporating a space-based laser system into a theater-level wargame. Since this design will be incorporated into existing theater-level wargames, doctrine will not be examined in detail but should be tailored to reflect the host wargame. However, proposed basic Air Force space doctrine should be recognized and incorporated into this design. Although doctrine will be incorporated, sufficient flexibility must remain to allow experimentation into different modes of operation where new concepts will be allowed to develop. Since doctrine is a function of the host game, research was concentrated in several areas specifically concerned with incorporating space-based DEWs into a wargame. Additionally, the areas identified for further development and research were laser capabilities, wargaming design, satellite constellation determination, battle management, and countermeasures.

2.2 Space Doctrine

A basic understanding of proposed Air Force space doctrine was necessary before incorporating DEWs into any wargame. The draft proposal of Air Force doctrine addresses issues of terrestrial force enhancement through better use of space systems for navigation, weather, and communications (24:24). In addition, Air Force doctrine will have to address the issue of space control through weapons with an ASAT capability and a missile-defense system (24:24). Finally, Air Force doctrine is tied to the proposal that military satellites should remain under centralized control (24:24).

While SWATTER does not directly address force enhancement through communications, navigation, and weather systems, SWATTER does address force enhancement through the deployment of DEWs in support of a theater commander's objectives. SWATTER also allows the inclusion of the concept of centralized control and incorporates the deployment of an ASAT capable missile-defense system.

Although Air Force doctrine does not address the use of space for intelligence gathering, many observers feel this is one important aspect of space employment by

the Air Force (7). SWATTER incorporates a basic intelligence gathering function for further exploration in this area.

2.3 Laser Capabilities

A thorough understanding of laser weapons was necessary before their incorporation into a wargame. This section deals with the issues of basic laser principles, current limitations, and laser lethality. These issues have a direct bearing on how the laser weapon is modeled and employed.

2.3.1 Basic Laser Principles. A laser exhibits certain physical properties. These properties include coherence, directionality, monochromaticity (single frequency or color due to the extremely narrow frequency range, or bandwidth, occupied by the laser beam), and luminance (commonly called brightness) (33:5-47). All of these properties are interrelated and are really different manifestations of the coherence of the laser light (33:47). The military interest in lasers is generated by the properties of luminance, directionality, and coherence with the resulting capability of placing large amounts of energy upon a target at long distances at the speed of light (13:96).

The best way to understand why a laser possesses these properties is to examine the basic principles behind the creation of a laser beam. A laser requires three items to accomplish the propagation of a coherent light source. These items include a molecular or atomic population inversion, an active medium, and a feedback mechanism (33:51).

Laser initiation occurs when the active medium is stimulated by an external energy source to a higher internal (molecular or atomic) energy state. The pumping action of the external energy source results in a situation where fewer molecules (or atoms) occupy the molecular ground states since the molecules have absorbed energy and moved to a higher discrete energy state. When more molecules occupy a higher adjacent energy state than occupy the energy state immediately below it a population inversion has occurred. In accordance with basic physical principles, the population inversion is unstable and will spontaneously degenerate to the lower energy state. When the molecule drops to the lower energy state, a specific amount of energy is released. This discrete energy becomes a photon of electromagnetic radiation, or light. If the photon interacts with another excited state molecule it will cause the new molecule to also release a photon. During the state change of the second molecule,

the new photon will match itself to the photon which triggered the molecular energy loss. The second photon will now exhibit coherence with the first photon as it travels in the same direction and in the same frequency phase as the first. The photons will encounter a feedback mechanism, usually mirrors, returning the photons back through the active medium where more coherent photons will be released intensifying the laser beam. Since these photons are in phase, they will exhibit the property of constructive interference and will demonstrate the previously identified properties of laser light. The laser action will continue as long as a pumping source is able to maintain the active medium's population inversion (33:51-77), (42:52-53). With the proper selection of an active medium and the selection of the appropriate energy states, lasers can be built to emit specific wavelengths of light to accomplish different purposes. The laser can also be characterized by its output. The light emitted can occur in a continuous wave mode or it can occur as a series of pulses.

2.3.2 Current Limitations of Lasers. Lasers are constrained in numerous ways. One of the the more serious constraints currently preventing deployment is the insufficient power output of lasers. Conservative estimates range from one to three orders of magnitude increase as being the absolute minimum energy output before deployment (2:S10-S11). Other constraints also exist on the physical transmission properties of laser light.

While the emptiness of space does not contribute to the degradation of a laser beam, the basic physics of light do contribute to the weakening of beam strength over distance traveled. The general equation for beam spot size radius as a function of propagation distance is given by equation 1 (13:73).

$$W(Z) = W_0 \left(1 + \left(\frac{\lambda z}{\pi W_0^2} \right)^2 \right)^{\frac{1}{2}} \quad (1)$$

where W_0 is the beam radius, or optics radius, and λ is the radiation wavelength.

In the near field range where Z (distance traveled) is less than $\frac{\pi W_0^2}{\lambda}$ the spot size remains nearly constant. In the far field, the beam behaves like a normal point light source (13:73).

Therefore, the beam spread of laser light is limited, collimated, as long as the distance traveled is less than the Rayleigh Range defined in equation 2 below (13:73).

$$Z_R = \frac{\pi W_0^2}{\lambda} \quad (2)$$

For distances greater than Z_R beam strength will decrease due to the more familiar formula used for incoherent light, the inverse square of the distance propagated. In general, the preceding equations leads to the conclusion that large optics (W_0) and short wavelengths (λ) are desirable (13:74).

After the beam enters the atmosphere, other effects come into play. These processes include scattering, absorption, refraction, atmospheric heating and laser induced air breakdown (13:76-95). To overcome some of the effects of absorption and refraction, special care must be used in wavelength selection for atmospheric transmission properties. In addition, excess power must be generated to reach the target with sufficient energy for a probability of a kill (42:55,57). Atmospheric heating could possibly be overcome by increased optical surfaces (42:57) as well as a laser pulse firing scheme. A laser pulse firing scheme could also overcome the problems associated with laser induced air breakdown (13:95). For the purposes of this thesis, *a major assumption* will be made concerning the technical difficulties of absorption, refraction, atmospheric heating (thermal blooming), and laser induced air breakdown. This thesis will assume these difficulties have been overcome with judicious use of a pulsed high power laser of a specific wavelength fairly transparent to most atmospheric effects. However, the atmospheric effects of precipitation must still be accounted for.

The atmospheric effects of precipitation causes considerable attenuation when the laser beam must propagate through rain, fog, or snow. Precipitation can become a dominant factor and must be accounted for when using lasers (13:161-163).

Any analyst attempting to model a laser weapon in a wargame must be cognizant of these factors and represent them in some way which is easily modeled. In other words, modeling weather accurately is mandatory to accurately model the use of laser weapons on the battlefield.

2.3.3 Laser Lethality. Since the basic principles behind a laser weapon have been discussed, the next area for examination is the lethality of laser weapons. First, the basic interaction of a laser weapon against a target will be examined, then the possible specific interactions with different target types will be covered.

The interaction between a 10 GigaWatt laser with a pulse time of .1 μ sec against an aluminum surface is modeled below. The following example comes from the course notes for the Physics 523 class at the Air Force Institute of Technology (13:116-118).

This example contains several assumptions. These include: 1) the specific heat ratio (γ) of aluminum as 1.67; 2) the absorption (α) of the laser radiation wavelength by aluminum is ten percent (in other words, 90 percent of the incident radiation from the laser is reflected); 3) the mass density (ρ) of aluminum is 2.7 gm/cm^3 ; 4) the heat capacity (C_p) of aluminum is approximately one $\frac{\text{J}}{\text{gm}^\circ\text{K}}$; 5) aluminum's heat of fusion (L_m at the melting point) is approximately 400 J/gm; 6) and aluminum's heat of vaporization (L_v) is approximately 10,500 J/gm (13:116-117).

The initial portion of the fired laser beam will strike the aluminum and have a significant amount reflected. However, the portion absorbed will vaporize a very small layer of the aluminum and heat it to approximately 3000° K. This vapor is opaque to the laser and the absorption coefficient rises to nearly 1.0 from its original value of 0.1 (13:116).

Due to the opacity of the aluminum vapor, the laser beam will now interact (couple) primarily with the aluminum vapor. Due to the increased absorption of the beam energy the outer layers of the vapor will rapidly heat to temperatures above 50,000° K. The vapor has now become an ionized plasma and radiates in the ultraviolet (UV) and soft x-ray regime (13:117).

This plasma energy is carried to the aluminum surface by (UV and x-ray) radiation and convection. Assuming only twenty percent of the laser energy is effectively received by the aluminum surface (α is assumed to be higher due to the plasma interactions) it is possible to determine the depth of aluminum material lost with equation 3 (13:117).

$$depth = \frac{\alpha I t}{\rho C_p (T_v - T_o) + L_m + L_v} \quad (3)$$

T_v and T_o are the temperatures of vaporization and ambient respectively. Using an approximate difference of 3000° with I equal to 10×10^9 Watts ($\frac{\text{Joules}}{\text{sec-cm}^2}$) and t equal to $.1 \times 10^{-6}$ seconds yields a loss of only 5×10^{-3} cm of surface material.

However, the loss of such a small amount of material is not the entire effect of the laser weapon. The major effects will come from the overpressurization caused

by the expanding gases from the vaporization interaction. The vapor is limited by conditions to expanding at only the acoustic velocity (v_s) which exists locally (the local speed of sound). This velocity is given by equation 4 (13:117) (41:38).

$$v_s = \sqrt{\gamma RT} \quad (4)$$

R is constant which is specific for any gas. It is derived by dividing the universal gas constant by the molecular weight of the gas in question. The interesting fact about acoustic velocity is its relative independence from pressure meaning the velocity can be determined independent of altitude. Using the previously stated values v_s equals roughly 1600 meters/sec.

Using the characteristic expansion time for the vapor in equation 5 (13:117) gives the time it takes for the vapor to expand an equivalent distance of the depth of the material.

$$t_c = \frac{\text{depth}}{v_s} \quad (5)$$

Using the previously determined values results in a t_c of approximately 3×10^{-8} sec. with a laser pulse time of .1 μ sec the vapor will expand to approximately twice its original volume. This means the vapor will have approximately half the original ρ value. Substituting this new value into the ideal gas law (equation 6) will result in the aluminum vapor pressure on the surface of the material.

$$p = \rho RT \quad (6)$$

$$\begin{aligned} p &= (.5)(2.7 \text{ gm/cm}^3) \left(\frac{8.3 \times 10^7 \text{ erg/(gmole}^\circ \text{K)}}{27 \text{ gm/gmole}} \right) (5000^\circ \text{K}) \\ &\simeq 2 \times 10^{10} \text{ erg/cm}^3 \\ &\simeq 2 \times 10^4 \text{ atm} \\ &\simeq 300,000 \text{ psi} \end{aligned}$$

Obviously, with such large local pressures on a material, a laser beam is quite capable of punching a hole through the material. Even if it doesn't burn through the resulting shock on the material may weaken it or cause spalling on the interior.

This example was with only 1 kilojoule of laser energy on target. The criterion for a kill in this wargame is 10 kilojoules (KJ). An important point is that for the 10 KJ criterion to be a satisfactory measure of effectiveness the laser energy must be deposited in an extremely short period of time (almost instantaneously) to prevent energy dissipation through convection, conduction, or radiation. With this caveat, the 10 KJ criterion is a conservative estimate by an order of magnitude and also allows for the consideration of materials with an α of only .01 to achieve the same result. In addition, this criterion also allows for other materials which may be more resistant than aluminum. Finally, 10 KJ is fairly well recognized as typical of the minimum lethal energy delivered by more conventional weapons (9:9-45).

Now that the basic interaction of a pulsed laser weapon has been discussed, the interaction can be examined in closer detail by looking at the numerous ways the laser interacts with different target types. These types include missiles, armor, sensors, troops, aircraft, soft vehicles like trucks, and geographic targets. Each type is covered below.

2.3.3.1 Interaction with Aircraft. The interaction with aircraft is fairly straightforward. The laser beam will probably punch directly through the metal skin of the aircraft. The only question remains is the probability of hitting a critical area causing the aircraft to be destroyed or possibly preventing it from accomplishing its mission. A significant percentage of the surface area of the aircraft covers critical aircraft subsystems. These subsystems include fuel cells and plumbing, weapon bays, engines, and electronic equipment. Almost all of these subsystems would result in catastrophic aircraft loss if subjected to the amount of laser energy discussed. In addition, a pressurized aircraft at altitude could suffer a rapid decompression if the aircraft skin is suddenly punctured. Depending on the aircraft, the aircraft altitude, and the mission, the aircraft may have to abort the mission. The protection of the aircraft through increased use of armor would come at tremendous cost in terms of aircraft payload and performance and would therefore, be unlikely.

2.3.3.2 Interaction with Armor. The use of a laser weapon against an armored vehicle is a questionable proposition. The increased use of composites and ceramics in armor makes the use of laser weapons in this manner an unknown. No known source of freely available literature was found addressing laser interactions on armor. However, the tremendous energies probably does weaken if not destroy the

armored vehicle. In addition, there are weak areas in any armored vehicle which are not protected as well as the rest of the vehicle. However, steel or aluminum armor would be very susceptible to laser damage as outlined in the above example. Finally, the previously mentioned possibility of spalling could spell havoc with the interior of the vehicle and its occupants.

2.3.3.3 Interaction with Missiles. Missiles would be highly susceptible to laser attack especially in light of the fact the laser constellation was designed with such a purpose in mind. Generally, lasers are considered sufficient for the task of missile destruction if it is able to deliver 10 KJ/cm^2 and hold it on the target for one second when using a continuous wave laser (43:2). However, the pulse laser should be able to puncture the skin with the overpressure effect caused by plasma coupling in less than one second. This effect should be relatively consistent between liquid or solid fueled rockets (43:2). In addition, most research into missile destruction does not address the subject of combustion and detonation of the rocket fuel by the laser (43:2) which would increase the probability of missile destruction. Assuming a puncture occurs, the missile can be killed in one of two ways. The first method of kill would be an instantaneous burst of the missile due to the high pressures inside the rocket engine chamber or ignition of the fuel by the laser beam. The second method would take longer to confirm as a kill but is still effective. If the laser beam just punctured the case without an instantaneous kill, the puncture would provide an avenue for an exhaust jet causing rocket control problems leading to a slow kill (43:2).

2.3.3.4 Interaction with Soft Vehicles (i.e. unarmored). Soft vehicles such as trucks and jeeps would be susceptible to laser effects. However, the fuel tanks and engine components make up such a small portion of the total surface area, when viewed from above, the likelihood of a kill is decreased. The laser may just puncture the vehicle without causing any serious damage. However, if the vehicle is loaded with flammables or explosives, the probability of kill increases greatly due to the amount of space devoted to cargo particularly susceptible to lasers.

2.3.3.5 Interaction with Sensors. Sensors are readily degraded or destroyed by laser effects. The sensor will probably immediately become flash blinded by any laser beam in its field of view within the appropriate sensor radiation band. Furthermore it will probably quit working if the temperature of the sensor is raised

approximately 50° K and destroyed if the temperature increases more than approximately 500° K (13:111). If the laser beam radiates in the Infrared (IR) wavelengths it could wreak havoc with night-vision goggles, forward-looking IR sensors, and the aircraft IR sensors used on night attack missions.

2.3.3.6 Interaction with Geographic Targets. Geographic targets encompass a wide range of target types with a wide variety of materials. They could include hydroelectric dams, power generating stations, hardened command posts, supply dumps, and much more. The laser weapon could be employed as a type of indirect fire (similar to artillery) against some of these targets. Supply dumps could be handled on the basis of the types of materials being stored. Petroleum, oil, and lubricants (POL), and ammo dumps would be very susceptible to laser effects. On the other hand, if the target is primarily foodstuffs, there is not much utility in blowing up a few canned hams. The electrical generating plants, dams, and hardened command posts are generally composed of reinforced concrete. There is little data on laser interactions with concrete. However, concrete probably has a much higher laser absorption coefficient which would only increase the temperature on the concrete. Since concrete is a poor thermal conductor, tremendous thermal stress will probably occur under laser attack. In addition, the high temperatures associated with such an attack would probably cause molecular disassociation of the water molecules in the concrete thereby weakening the concrete structure. While a laser attack on concrete structures may not result in a kill in the first attack, it will lead to progressive weakening of the structure under repeated attacks.

2.3.3.7 Interaction with Troops. The final item to examine is the laser attack interaction on troops. Laser attacks could result in obvious immediate physical harm. Effects include the ignition of clothing, extensive burns on the skin, eye injuries, and possibly death. The primary laser burns on the flesh and the secondary burns caused by ignited clothing are very important effects. However, the possibility of eye injury is currently causing great concern among several of the doctors at the Letterman Army Institute of Research (27:1). The particular ocular eye injury is laser wavelength specific. Visible and near IR wavelengths are focused on the retina, while far IR tends to burn the cornea. UV wavelengths tend to injure the cornea and lens. The extent of the injury is a function of laser power, exposure time, area exposed and the laser characteristics. The pulsed lasers appear to have the most

damaging effects. The range of ocular injuries range from glare effects to flash-blindness to retinal burns to actual hemorrhaging within the eye (27:1-2). Other important psychological effects also may occur in an area under the danger of laser attack. These effects are termed suppressive and exposure effects (27:3). Psychological exposure effects will be the effects felt by the soldiers who actually undergo laser attack ("shell shock" was a popular although inaccurate term at one time) (27:3). The suppressive effects come from the fear of laser exposure and attempts to limit such exposure (27:3).

The fear of laser exposure and loss of eyesight may be very debilitating to some individuals. Individuals may also be less effective due to protective equipment wear. This protective equipment may place physical limitations on each individual soldier's performance as well as elevate the individual's psychological stress. In addition, the soldier's desire to prevent eye injury may disrupt visual tasks (search patterns). Altogether, laser effects on the battlefield may have a debilitating effect on the performance of individual soldiers (27:11).

The laser effects may also be byproducts of attacks on different targets in the nearby area. The laser damage may be caused by the reflection (some metals may have reflection coefficients as high as 90 per cent of the laser beam) of laser light from an attack on an armored vehicle. Task performance may also be degraded due to the protective gear worn as well as any attempt to prevent the occurrence of such an injury. These effects are not confined to the surface either. An aircraft under laser attack may also result in degraded crew performance due to the same reasons.

2.4 Wargaming Design

The next area to examine is how to incorporate these weapon systems into a wargame. There are certain basic principles to wargame design which must be kept in sight at all times. The two most basic rules as stated by James F. Dunnigan, one of the leading designers of commercial wargames and prolific writer on defense issues as well as on wargames, are:

- "keep it simple
- plagiarize" (11:235-236).

The two basic rules are very important in making any wargame work. If the system is too complex then no one will want to use the game. The second

rule, while somewhat shocking in its irreverence, is really a way of meeting the requirements imposed by the first. Dunnigan is stating the need to use proven gaming techniques to help simulate the reality you wish to create. Peter Perla, a well-recognized wargamer from the Center of Naval Analyses, feels that these two concepts capture the fundamental requirements of any wargame. Basically, these principles result in achieving a sense of reality while keeping the game playable (35:189).

While keeping these two basic requirements in mind, Dunnigan developed a framework of designing and marketing wargames. This ten step framework is included below (11:236-237).

- Concept Development
- Research
- Integration
- Flesh out the Prototype
- Prepare a First Draft of the Rules
- Game Development
- Blind Testing
- Final Rules Edit
- Production
- Feedback

This thesis will keep the basic requirements in mind while attempting to accomplish Dunnigan's first three steps of wargame design. The final steps not directly related to commercial production will be accomplished under the direction of the Air Force Wargaming Center.

The important thing to remember is this wargame will be a wargame of the future. While playability is a key issue, the purpose behind the wargame is education and research. For the game to achieve its stated purpose it must be realistic. Unfortunately, it is impossible to accurately model the future completely. As Perla has said, "The only realizable goal for a model of future warfare is to reflect, in the most complete and coherent way possible, the analysts' (or the analytical community's) beliefs and understanding of the key elements of that combat. By exercising, testing,

and modifying that model, analysts and wargamers can explore the implications, not of some unknowable future reality, but of our current, restricted, and uncertain view of what that reality might be like. We can do no better than to try to identify the hidden interconnections and consistencies of our current thinking as objectively as possible." (35:241)

While SWATTER explores one possible future of warfare it must be given a stage for presentation. In other words, a scenario should be developed which sets the stage for player decisions. In addition, such a scenario must have the flexibility to allow specific updates by the controllers (the umpires) of the game which can influence or alter the decision-making by the individual players (35:203). A scenario is the common starting point for all participants in the game which states the goals of the game while setting bounds and influencing the players interactions. Scenarios should be designed to maximize flexibility and reduce artificial restrictions on the participants (35:204-205). Perla has developed a basic structure for a scenario design. This structure includes:

- Background,
- Objectives,
- Command relationships,
- Resources,
- and Updates during play, and control team instructions (35:208).

SWATTER is given a scenario which is the basic bare bones essentials to meet the restrictions caused by the necessary abstractions in wargame design. This scenario, in chapter III, contains the essential structure which can be fleshed out to meet different goals from game to game. The key will be to incorporate more information in the final implementation which will seem realistic and reasonable.

2.5 Satellite Constellation Determination

The satellite constellation should be sufficient to afford coverage of most major launch ICBM areas as well as sea-launched ballistic missiles (SLBM). Due to their orbital mechanics, satellites circling the equator would not afford complete coverage of the earth's surface. The orbits of the satellites would have to be inclined with

respect to the equator to increase the coverage by the satellites. Unfortunately, when satellites are placed in an inclined orbit it is impossible for a satellite to remain in a position which appears to be stationary with respect to the surface. The coverage by one such satellite would approach global as the inclination approached ninety degrees. However, this coverage would not be continuous, necessitating more satellites to cover the desired area of interest for the desired time span.

The number of satellites required and orbital planes desired are an area of high interest when examining this issue. If horizon-to-horizon coverage by each satellite is desired then the excellent article presented in the Sept.-Oct. 1987 issue of *Journal of Spacecraft and Rockets* (34:459-468) is recommended. However, such a constellation assumes the weapons could reach any target within line-of-sight of the satellite on the surface of the earth. SWATTER assumes the initial deployment will be by limited, relatively low-power weapon systems only able to interact with the surface of the earth directly below their orbital path. Therefore, a method of determining satellite numbers will be explored later in this thesis.

2.6 Battle Management

Battle management is one of the toughest problems facing deployment of a strategic defense system. Many questions must be resolved before actual implementation. Some of the questions include:

- where sensors should be located (40:5),
- what level of sensor discrimination is desired or possible (40:36),
- how to handle sensor difficulties (high target density, low sensor resolution, false observations, missed observations slow scanning frequency, and target hand-off) (40:S-8,7),
- how to classify threat assessment to include self-defense functions (40:7-8),
- what engagement options to implement (how many weapons assigned to each target, shoot at closest target vs sorting routines) (40:S-6,58),
- how to determine a successful engagement (kill) (40:70).

Many of these ideas are covered below in greater detail and, where appropriate, are the major questions a proper wargame design should help answer. While not

all of the ideas are not fully developed by SWATTER, they are included as future research topics for incorporation into SWATTER.

2.6.1 Sensor Management. Upon launch detection, under the SDI mission, the sensors will be required to determine the number of boosters, positions, and their flight profiles for future prediction and possible engagement (40:7). The sensor algorithms will have to perform three functions to properly track boosters (40:7). These functions include scan-to-scan correlation, multiple sensor coordination, and target prediction (40:7).

For the purpose of SWATTER, these algorithms have already been determined and are in place in the satellite constellation. However, several areas must still be addressed in SWATTER to accurately model potential problems of accurately tracking a specific booster from sensor scan to sensor scan. These areas include high target density (sensor saturation), low sensor resolution, false observations, and missed observations (40:7). During the time of observation, the tracking accuracy will improve due to correlation schemes incorporated into the constellation (40:7).

2.6.2 Threat Assessment. As the sensor information is organized and target track maintenance is initiated, threat assessment will begin (40:7). Classification of booster types will help identify the threat potential (40:7-8). Threat assessment would place a high priority on an SS-18 due to the large number (10) of reentry vehicles (RV) onboard. While an SS-25 would be a lower threat since it only carries 3 RVs (40:8). ASAT weapons would also be detected, identified and prioritized at this time (40:8).

As the threat becomes more apparent, the readiness level of the constellation would be adjusted (40:8). Any readiness level would be a function of what status previously existed (DEFCON level) and the current military situation (40:8). Several schemes exist, including a posture requiring human intervention to arm the system in a limited attack scenario to an automatic mode for a massive attack scenario (40:8).

2.6.3 Engagement Options. Weapon-to-target assignment functions are still being actively researched. In the early years of deployment, fairly simplistic algorithms will be used for pairing of weapons to actual targets. As the system becomes more robust certain ICBM targets will be afforded greater protection priority from those ICBMs (40:5-6).

The most common firing doctrines include a shoot-shoot-look-shoot-shoot doctrine (commonly known as SSLSS) and a shoot-look-shoot (SLS) doctrine. The first doctrine allows the firing of a second shot using the same firing information as the first to insure a higher probability of kill if the first shot only damages the target or the first shot malfunctions. If the first shot misses due to targeting information then the second will also miss. The second doctrine allows target assessment between shots which allows the conservation of munitions if a successful kill is accomplished by the first shot. One possible disadvantage accrues if the weapon is no longer able to engage the target due to the change in range between the target and the weapon during the evaluation.

SWATTER assumes the early deployment of a simple engagement architecture where the priorities begin with ballistic missile defense, followed by self-protection of the constellation, and finally followed by any other targets as designated by the controllers. Both types of firing doctrine (SSLSS and SLS) should be available for examination and experimentation within SWATTER.

2.6.4 Kill Assessment. A part of reality which is extremely difficult to model is the uncertainty of battle damage assessment. In other words, how well did the weapon system perform in attacking the target? To give a realistic flavor of the fog of war, SWATTER gives a portion of all kills as confirmed kills and misidentifies some of the misses as probable kills. Due to the nature of the weapons targeted some kills may be easily verified while others may not. For the purpose of this thesis, a kill is any successful attack which prevents the other side from using the weapon system in an offensive manner. However, if the kill is not detected it may still draw fire from systems unaware of the kill. Hard kills are kills where the weapon system is totally destroyed while soft kills are kills where the system is still partially operational but is unable to accomplish its intended mission (as an example, lack of mobility would prevent a tank from participating in offensive operations although defensive fire may still emanate from it).

2.7 Countermeasures

Any Strategic Defense system must contend with the possibility of countermeasures. These countermeasures could be passive decoys to fool sensor technology or the more active step of actually trying to blind the sensors. Furthermore, the

system must be prepared to cope with space mines, nuclear explosions, and anti-satellite (ASAT) weapons (5:47) (15) (23) (32:26). These possible methods of attack and deception against the system are prime ingredients to model in the wargame.

2.7.1 Sensor Attacks. Several methods of attack exist for attacking the sensors of the satellite constellations. Nuclear bursts could be used to attack the electronic components of the sensors through electromagnetic pulse (emp) and radiation effects (38:346). Laser blinding of sensitive optical systems may also be attempted (38:346). The effects of these attacks may be only temporary or may be permanent through sensor saturation or damage.

Methods to overcome these attacks are many and varied. Hardening of the constellations' electrical systems would help protect the sensor from emp (38:346). Separating incoming radiation into very narrow band wavelengths to limit the amount of background radiation from the explosions or laser attack is another feasible solution (38:346). Short discrete periods of sensor operation, and using multispectral sensors so if one sensor is overwhelmed other sensors could continue tracking also may allow sustained operations under sensor attack (38:346).

2.7.2 Space Mines. Space mines are explosive devices predeployed into an orbit from which it can easily attack its target upon command (23:166). To accomplish its mission however, it must be in close proximity to the target with virtually identical orbital parameters (23:166). This precludes the secretive placement of space mines close to a low-earth orbit satellite since the Soviets would probably launch such a system into a different orbit than they currently use for most of their missions (23:167). It is possible to secretly place mines on active satellites being used for other missions. This may allow the space mines to approach a target satellite undetected due to the cover afforded by the legitimate satellite.

To counter obvious spacemines, the most likely US response would be immediate destruction of any elements deployed close enough to any satellite to place the satellite in jeopardy (23:170). Attacks against satellites which may or may not be carrying space mines may be a more risky proposition. One possible method to counter suspected space mines would be the establishment of sterile no-entry zones around satellites. These zones may be activated during periods of heightened tension and any entry into this zone by an unknown or suspect satellite would result in its immediate destruction.

2.7.3 *Nuclear Attack.* Nuclear attack, as mentioned previously, would probably be used for emp effects and radiation saturation of the target as well as possible physical destruction of the target. However, before the use of nuclear weapons, fratricide issues would have to be addressed since any nuclear explosion would be as likely to affect the attacker's satellites and missiles as it would the targeted satellites.

2.7.4 *ASAT.* ASAT attacks could employ nuclear weapons as well as kinetic kill mechanisms for satellite attack. The Soviets currently have an ASAT capability against low-earth orbit satellites. This system depends on several orbits to maneuver the ASAT into position to attack its target. The US developed but never deployed a kinetic kill ASAT which was capable of direct ascent to the target satellite.

These types of attack are easily recognized and could be destroyed by direct attack on the ASAT weapon. In addition, if the ASAT attack is detected in a timely fashion, then it is possible to maneuver the satellite out of harm's way.

2.7.5 *Decoys.* Decoys depend on similar looking objects to confuse the satellite constellation into attacking the decoys. These decoys would have to simulate several different spectral properties (radar cross-section, infrared signature, etc.) to successfully fool multispectral sensors (32:177). Whether it is cost effective to use decoys due to the need to accurately simulate the actual missile remains to be determined (31:77-78). It may just be more effective to build another missile and attempt to saturate the defenses.

2.7.6 *Passive Countermeasures.* Passive countermeasures take many forms. These include hardening, shielding, and rotation of the rocket body (31:76) (42:57). The possibility of protecting a rocket by such methods against a pulsed laser as proposed in SWATTER is highly unlikely. The ability to protect the rocket from such a weapon is negated by the fact it is impossible to passively defend against the momentum imparted by the laser to the rocket body (2:S138).

III. Scenario

3.1 Introduction

A scenario is necessary to give a common starting point from which the game participants address the goals of the wargame (35:205). The goals for this wargame include gaining a better understanding of the possible interactions and capabilities of a space-based laser weapon on the conventional battlefield and provide the players a better appreciation and understanding of space forces. The following scenario is broken up into its political, and military components and is designed to maximize the desired goals.

3.2 Political Climate of the Iranian Scenario

The chosen scenario is set in the future with the projection of several currently observed, diverse, world trends. These trends have been merged into just one of many possible future outcomes. The scenario begins in the early summer of 2010. The current political climate follows.

The world political situation is very confused. There has been much hope and encouragement for peace but the goal has proven very elusive. The United States had finally started the deployment of a space-based defensive shield at the turn of the century. The Soviet Union initially tried to match the SDI deployment with more offensive weapons and also tried, but failed to deploy their own version of "Star Wars". This attempt further weakened the already tottering Soviet economy causing the Soviet leadership to agree to further substantial cuts in offensive strategic nuclear weapons. The START II Treaty was ratified in 2005 and the final nuclear weapons drawdown round, of the two rounds planned, is slated to begin. At the conclusion of the the final round, only 50 percent of strategic nuclear weapons which existed when the treaty was ratified will still be operational. Currently, the first drawdown round has been completed and only 75 percent of the weapons of five years ago still exist.

Internationally, the Soviets have continued to see their prestige decline. Internally, the ethnic minorities continue to demand more autonomy and independence

in their respective republics. In addition, some minorities see the recent START II treaty as a further sign of weakness and have openly begun defying the Soviet authorities with riots, demonstrations, and rumored guerrilla units. The Azerbaijan Republic has been in the forefront of the violence looking for unification with their brethren Azerbaijani across the border in Iran. A small Persian minority in Azerbaijan has also been pressing for closer ties with their Iranian counterparts.

The Iranian Azerbaijanis, although a minority, have been fairly well integrated into Iranian society (19:188) and have become a more powerful voice in the Iranian government as Iran slowly returns to a more moderate course due to the gradual departure of the extremist clerics from positions of power. While not officially sanctioning unification with the Azerbaijanis in the Soviet republic, there is a resurgence of nationalistic pride and a desire to open more communications with their brethren across the border. The gradual decline of Islamic extremism is slowly opening doors to further contacts between Iran and the United States.

Violence against Russians in the non-Russian republics accelerates the exodus of Russians back to the Russian Republic continuing a trend identified in the 1990's (8:15-A). This migration places greater burdens on the social and economic structure of the Russian Republic further exacerbating the general feeling of despair and anger amongst the Soviets people. Many of the people blame President Gorbachev (25:15-A) and his ideological successors for the current woes of the economy. The Soviet military finds itself increasingly shortchanged continuing a trend noticed in the 1990's when 9200 military families were not provided homes (25:15-A).

In early July, rioting and demonstrations rocked the town of Baku in the Azerbaijan Republic (Figure 1) leaving hundreds dead or wounded. Minorities went on a rampage through the neighborhoods massacring many Russians. Demands for better protection of Russian nationals and general outrage in the Russian Republic toppled the moderates currently in power. The hardliners, with tacit support from the military, took over the Soviet government. The military moved into Azerbaijan with several divisions of armor and infantry and declared a state of emergency. Martial law was instituted to crush the rebellion. The military move did not pacify the Republic, instead it only seemed to ignite the smoldering nationalistic fury of the people. Iran accused the Soviet government of atrocities against minorities in Azerbaijan. The Soviets, in turn, accused Iran of subversive activities in the Republic. Denunciations between the two countries became harsher and more strident.

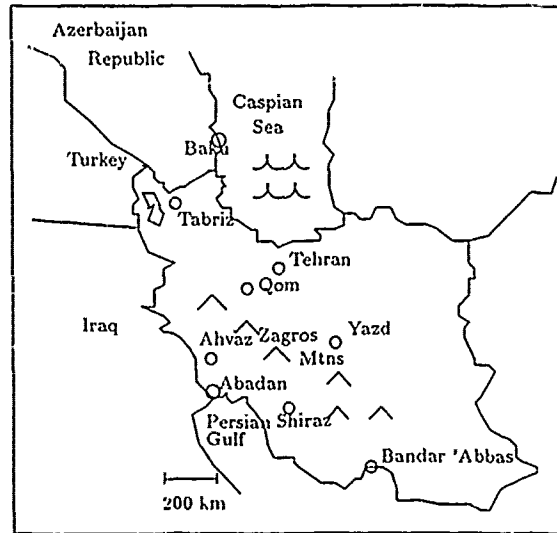


Figure 1. Map of Iran and Surrounding Areas

US reconnaissance satellites showed several Soviet divisions massing on the Iranian border. The President passed an urgent message to the Soviets urging restraint. The intelligence was also shared with the Iranians through indirect channels. Although improving, the US relationship with Iran can not be construed as warm and the warning was disregarded. The US military was placed in a high state of readiness and began preparing contingency plans for different means of containing the possible Soviet expansion. Intelligence sources did not believe an attack was imminent but the whole episode was intended to convince other Soviet republics of the vigor and strength of the central government despite the decline of the Gorbachev years. It was also believed that the Kremlin saw the move into Azerbaijan as a means of unifying the Russian people, and as a means of regaining some of the political control lost in the moderate years.

On 1 August 1980, Soviet divisions roll across the Iranian border. Resistance was scattered and light. By the third day, the Soviet theater commander had established his headquarters in Tehran. The Soviet Union proclaimed an Azerbaijani state carved from the the northwest corner of Iran and immediately recognized the puppet government it had installed in the new country. The Iranian leadership had fled south to Ahvaz and requested help from the United Nations. Due to the Soviet veto in the Security Council, the UN was hamstrung and unable to offer any assistance to Iran. The Iranians turned to the US for assistance.

The US Congress authorized the President to unilaterally begin an immediate airlift of men and materiel to the Persian Gulf coastal city of Bandar-e-Shahpur. An immediate defensive perimeter was established around the nearby oilfields and the wait began as the American commander awaited the resupply effort to provide him with a credible fighting force. The President stated the US goals as the removal of all Soviet forces from Iran and the reestablishment of the pre-invasion Iranian borders.

The Kremlin reacted indecisively. Apparently, the Soviets did not believe the US would respond with a military option to their invasion. The Soviet military had watched the reduction in US forces in the 1990's and did not believe the US had the capability to attempt what had been accomplished in 1990 against Iraq. Several weeks passed as the Soviet High Command weighed the options and the Politburo attempted to bluff the US into accepting the new country of Azerbaijan. The Tudeh, the Iranian Communist Party, was established as a puppet government in Tehran. The new government invited the Soviet Union into Iran to help overcome reactionary elements in society and to oppose the US actions.

Internationally, very few countries in the region were willing to condemn the Soviet invasion. Most of the countries declared neutrality and prohibited any overflight rights to the United States. Saudi Arabia and Israel are the only notable exceptions as both countries granted overflight rights to the US. Iraq also expressed a wish for neutrality, but the intelligence community viewed the Iraqis as an unknown.

Intelligence reports hinted at increased activity at Sary Shagan, Dunshabe, and Semipalatinsk. All of these are reputed sites of Soviet DEW research and indications are of a major operational test of the system within the next month. Increased activity has also been detected at the Soviet launch facilities located at Tyuratam where the Soviet co-orbital ASAT weapon is reportedly kept (10:26).

Currently, the Soviets view the situation with dismay as the new C-17s continue to disgorge enormous quantities of men and materiel. The American buildup has been much quicker than anyone could have ever imagined. American fighter units deployed to Kuwait and to bare-base airstrips being constructed along the Iranian coast. The sealift stock is starting to arrive in Iran during the first week in September. The equipment stockpiled in Saudi Arabia and Kuwait following the war with Iraq has already arrived. The Soviet generals decide the time has come to act before the opportunity to decisively defeat the Americans is lost.

Photo-reconnaissance satellites detect the Soviets as they start advancing towards Qom. Intel isn't sure if it is a Soviet bluff or a prelude to attack on American positions. The President reiterates the demands for the liberation of Iran. He also affirms he is not interested in striking the Soviet Union but has given his commanders the right to respond against any attack launched from Soviet territory.

Intelligence reports on the unrest in the Asiatic Soviet republics indicates rioting is occurring to protest Soviet intervention and for forcing a possible confrontation with the US. Intel believes the Soviet Army has several divisions tied down in pacification efforts which were originally slated to reinforce the units in Iran.

In mid-September, the Soviet Army has consolidated its new position in Qom. One of the American photo-reconnaissance satellites has just ceased functioning for no apparent cause. While not devastating, it has decreased the amount of sensor coverage available over Soviet positions. The replacement satellite has been scheduled for launch in approximately three weeks. Resistance cells are forming among the Iranians and some information is reaching the Americans from these human intelligence sources.

During the last week of September, the Soviets renounce the first use of tactical nuclear weapons, causing tremendous pressure on the US President to do the same. However, after much heated discussion with the Joint Chiefs of Staff, the President remains silent on the first use issue. A report reaches the President indicating advance elements of the Soviet Army have entered the Zagros Mountains and appear to be advancing toward the American positions.

3.2.1 Military Situation of the Iranian Scenario. The US forces, as in Mann's thesis, would be under the command of Central Command (CENTCOM). There would be a Land Component (LC) Commander (Third Army) and an Air Component (AC) Commander (26:49-50). The makeup of the Third Army will be determined at the beginning of the wargame based on the areas of interest to be examined and the amount of men and equipment which can reasonably be transferred to the theater of operations. The Air Component Commander would be in command of a tactical air force. One important addition to the staff of the Air Component Commander would be the position of Space Operations Liaison Officer (SOL). The SOL would be the liaison between Strategic Defense Initiative Organization (SDI), responsible for the space-based ICBM shield, and the theater commander through the Air Component Commander.

Unknown to the Soviets, NCA has determined an excess capacity exists in the "Star Wars" shield due to the recently accomplished drawdown of nuclear weapons. A portion of this excess capacity has been authorized for use by the theater commander. After a careful review of the capabilities of the SDI constellation, the laser weapons in low-earth orbit have been determined to be the most advantageous to the theater commander. Unfortunately, the commander does not have free reign with the use of these forces. Before employment of these weapons, the commander must go through the Space Operations Liaison to obtain approval of the planned mission from the SDI. This restriction presents the problems of mission planning with a possible disapproval or the delayed approval of specific elements in his battle plans. Understandably unhappy with the arrangement, the commander begins to lobby for one of several options. These options include:

- Give the Space Operations Liaison operational control and authority over a specific portion of the satellite constellation and place him on the Theater Commander's staff.
- Give the Space Operations Liaison operational control and authority over a specific portion of the satellite constellation and place him on the Air Component Commander's staff as a full-fledged member.
- Move the Space Operations Liaison from the Air Component Commander's Staff to the Theater Commander's Staff.

The Space Operations Liaison Officer has also presented the Theater Commander with several possible methods of employing the laser weapons in support of the commander's objectives. After careful review of the systems the SOL believes the following options exist.

- The laser weapons can be employed against missiles only within specific geographic confines.
- The weapons can be employed against satellites in low-earth orbit.
- The weapons can be employed against any airborne target within specific geographic confines.
- The weapons can be employed against any detectable target, surface or air, within specific geographic confines.

- The weapons can be employed against targets at specific geographic locations by programming specific coordinates.

The SOL emphasizes several key points to the Air Component Commander. First, he emphasizes the weapons would be very effective against missiles and other space satellites since the multispectral detection systems were specifically designed for detection, tracking, and targeting missiles and other space objects. Second, the infrared (IR) portion of the detection systems would be fairly effective in detecting afterburning aircraft but less so against aircraft with cooler exhaust. The detection systems radar would be more effective against large formations of aircraft or large individual aircraft while somewhat limited in detecting smaller fighter aircraft. Third, against surface targets the detection systems could be highly variable in reliability depending on surface terrain, target size, ground clutter, and the target's radar and IR signatures. He also emphasizes that the geographic boundaries would be kill zones. Anything meeting the criteria of a target, American or Soviet, would become targeted. The programming of the system currently precludes, in most cases, identification of friend or foe but the computer analysts are feverishly working on a way of incorporating current IFF (Identification, Friend or Foe) systems into the constellation. Next, he mentioned the importance weather could play. Any cloud cover or precipitation would rapidly attenuate the laser weapon beam conceivably making the beam ineffective. While the weather is not currently a significant factor, starting in November and running through April is the local rainy season. The rainy season has over 87 percent of the annual precipitation occurring during the winter months. Of course, this is somewhat mitigated by the fact Iran has an annual average precipitation of only 9.7 inches (3). Finally, the SOL pointed out the use of beam weapons against geographic targets would be less effective since it would be more of an area fire weapon unless the objective is large enough for the sensors to detect and target.

The SOL also mentioned the constellation currently uses only detection systems organic to the constellation. These detection systems, while good, did not require the high resolution currently available from photo-reconnaissance satellites. The systems engineers are currently investigating the possibility of integrating the spy satellite's resolution abilities into the constellation. With this improved resolution the targeting of ground-based systems would naturally improve.

The SOL also pointed out the satellite constellation has a specific priority list for targeting and attacking specific targets. The specific order in terms of decreasing priority is:

- Strategic defense against missile attacks aimed at the United States and Canada,
- Self-defense against recognized threats to the satellite constellation,
- Attacks against targets as specified by the NCA.

The first priority is the very reason for the system's existence and would not be lessened. In the area of self-defense the satellite constellation would always recognize a missile attack against itself. However, due to the close proximity of many peaceful satellites in orbit, the constellation could be vulnerable to a space mine attack until the sterile no-entry zone is activated by the NCA. In addition, the constellation may not be able to distinguish other types of attack on itself. After assuring the constellation's continued existence to meet its first priority, the constellation could then be directed against targets as ordered by the theater commander.

3.2.1.1 Soviet Space Doctrine. Emphasis should be on a doctrine encompassing all elements of Soviet thought. This doctrine hinges on their concepts for space control. The objectives of Soviet space control, according to *Soviet Military Strategy in Space*, include

- "protection of Soviet tactical and strategic strike capabilities;
- support of Soviet tactical and strategic operations;
- protection of Soviet and client state territories from enemy threats;
- prevention of the use of space by the enemy for military, political, or economic gain;
- unhampered utilisation of space assets to further the Soviet system and goals" (22:198).

Incorporating these concepts into a space doctrine would result in an aggressive offensive posture of Soviet space forces. While the United States views space control as only a small portion of space operations dedicated to the protection of

national assets and denial of like assets to the enemy, the Soviet Union space control is looked upon "as all actions required to project and employ military power - offensive and defensive - through space while simultaneously denying the enemy similar capabilities" (22:197). Obviously the Soviets are dedicated to using space to their own advantage.

3.2.1.2 US Space Doctrine. As previously stated, US Space Doctrine will most likely hinge on the mission of space control and the use of an ASAT capability and a missile defense system to accomplish this mission. US Space Doctrine will also rest upon a centralized command authority and will be dependent upon a robust launch system to build and maintain the capability necessary for this doctrine (24:24).

3.2.2 Goals and Assumptions Behind the Scenario Design. This scenario has been designed with several key assumptions to help reach the desired goals previously mentioned. These assumptions allow the user to get a clearer picture of the possible interactions between space based weapons and the conventional battlefield and a deeper understanding of the possibilities inherent in the military use of space. The assumptions also prevent the wargame from exceeding the desired bounds of interactions by placing natural restrictions on possible occurrences which may not be beneficial to the desired learning experience.

The very first assumption at the beginning of the scenario pits the US and the USSR in an asymmetric opposition. The US has a space-shield and the USSR does not. This limits most of the interactions of the space weapons to the immediate battlefield which is the scope of this model. Without this assumption the model would probably degenerate into a battle for space control between competing SDI systems with very little interaction with surface-based theater forces. Additionally, the scenario is restricted to a primarily bipolar confrontation which immensely simplifies doctrinal, and allied command and control issues.

While command and control issues are simplified since additional countries do not have to be included in the command structure, other command and control issues can be studied in greater detail due to the initial setup of the SOL advising the Air Component Commander. This allows the study of issues concerning the efficacy of requiring mission approval by the SDI and the possibly longer lead times required

and the probability of mission requests being denied. The listed options to changing the structure allows the exploration of other possible command structure options.

In addition to command and control issues, the scenario implicitly limits the use of strategic nuclear weapons and prevents the escalation to global warfare. However, the scenario allows the possible exploration of possible tactical use of nuclear weapons on the battlefield. Although the scenario does allow the possibility of escalation to theater nuclear weapons there is enough leeway built into the scenario to permit the wargame control group the option of denying nuclear weapons at the theater level. The realistic consideration of nuclear options, even if denied by the control group, contributes to a serious evaluation of such options while enhancing the realistic feel of the wargame.

The scenario is also designed to give the participants enough information to begin considering possible employment options of the space-based laser weapons. The scenario also implies certain vulnerabilities in the satellite weapons constellation both in target detection and acquisition, and to outside attack from other sources. These other sources may also have played a part in the destruction of the photo-reconnaissance satellite but the evidence is not concrete. If the Soviet laser weapons are active then the control group can inform the US player of when and where (near one of the Soviet ground-based DEW systems) the failure occurred. Preferably this information will be given only if the American player thinks to ask for it. Conversely, if the Soviet DEW systems are not included, the control group can give an arbitrary location of the failure. This flexibility allows the sowing of certain elements of uncertainty in the planning process. Even if Soviet DEW systems are not included, the scenario should force the American forces to consider the possibility. An important point to remember is if the photo-reconnaissance satellite is destroyed by Soviet forces clandestinely, then the satellite must be destroyed by the DEW system. The Soviet co-orbital ASAT system takes several orbits to destroy its chosen target. Far too many other sensors exist world-wide which would allow the detection of the ASAT throughout its interception flight.

With these scenario assumptions understood by the control group and implicitly, even if incompletely, understood by the players, then a much more realistic wargame within the defined boundaries should result.

IV. Model

4.1 Introduction

A credible combat model needs to portray a reasonable approximation of combat. The model must be able to take the players' input, run the combat simulations, and provide a credible output. This credible output becomes the basis for the next round of inputs. With appropriate scenario design and proper modeling of the combat processes, SWATTER will give a reasonable and credible approximation of the internally modeled combat processes.

The purpose of this chapter is to outline the basic modeling processes and lay the foundation for SWATTER design. A brief description of the land and air battle is necessary and will be followed by the SWATTER environment. Finally, the issues of the space battle and its interaction with the surface entities will be covered.

4.2 Land Battle

The SWATTER land battle, building on the work accomplished by Capt. Marlin Ness (29) and Capt. Mann (26), is fairly representative of most land combat simulations. In the Ness model, all ground units move on a hex based terrain. The Ness land model assigned different values within the hexes which affects the movement rates of the ground forces. These values were chosen to represent weather, terrain within the hex, and obstacles moving through the hexside. Support units are also represented add to the combat strength of the combat units. Ness added methods for incorporating logistics and intelligence functions within the land battle. Finally, Ness linked the firepower index, the relative measure of power a unit can bring into combat, to the hex effects. Mann created the mathematical relationships for weapons to be able to attrite the individual units within an entity (26:54). This linking allows the interaction of specific weapon systems (aircraft in Mann's case and space-based DEWs in the case of SWATTER) on the entity. In other words, if an aircraft (or spacecraft) destroys several tanks then this destruction should result in a lowering of the firepower index or any other indexes which may apply in each specific attack. While such a method was not necessary within Ness's model, since it was

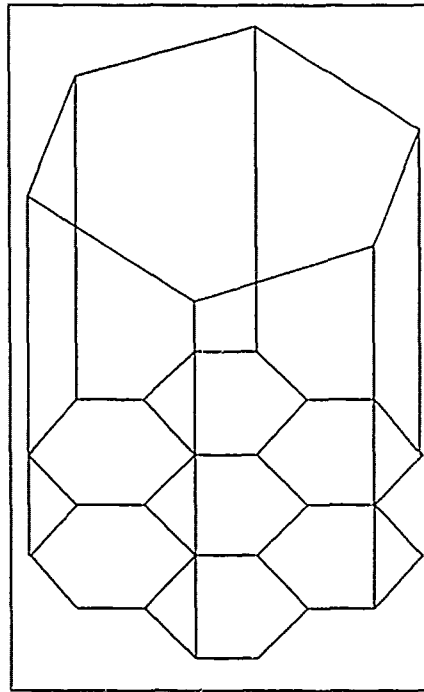


Figure 2. Ground hexes nested within an air hex

dependent primarily upon attrition equations for combat resolution, such a method is required due to the highly precise application of firepower by the relatively few weapon systems as represented by air or space platforms.

4.3 Air Battle

Mann also added a means of incorporating air-to-air combat and air-to-ground combat into his wargame through the use of nested hexes. The high speed of aircraft required a much larger hex for the representation of movement and combat through the theater. The air hex consisted of seven ground hexes nested inside (ref. Figure 2). One ground hex is 25 kilometers wide (distance is measured between parallel sides, in other words across the flats) and one air hex is three ground hexes wide (26:57-58).

In addition, Mann developed seven layers of altitude hexes. The addition of altitude increases the many possible methods of employing weapon systems and Mann developed the suitable linkages for modeling attrition of; aircraft by aircraft, surface forces by aircraft, and aircraft by surface forces. The method of attrition used by SWATTER is explained later and is a modification of Mann's method. The

air hexes and their associated altitudes are integrated into SWATTER but will be modified. The hex layers proposed by Mann include:

1. terrain,
2. tree top altitude from 0 to 61 meters (m) relative to the surface,
3. low altitude from 61 to 610 m,
4. medium altitude from 610 to 3,048 m,
5. high altitude from 3,048 to 9,144 m,
6. very high altitude, from 9,144 to 30,480 m, and
7. space from 30,480 m and up(26:59-60).

For the purpose of SWATTER several of these altitude layers can be combined into a smaller number since the tremendous distances involved when firing a DEW will have no overall effect upon these altitude hexes. SWATTER only requires five altitude blocks and accomplishes this through the consolidation of terrain and tree top hexes together with the low altitude hex.

Mann incorporated the use of resource holders into the model to represent airbases, depots, missile bases, and staging areas for the model (26:62), these resource holders are the target entities for the air battle and supply the required weapon systems and support equipment for the air battle.

4.4 Environment

SWATTER is designed to interact with the wargame environment of the model. The previously discussed models include ground and air hexes, but a clock mechanism is also included. This clock allows the mission segments to take place and also allows the scheduling of atmospheric phenomena to simulate changing weather conditions.

4.4.1 Clock. Mann improved upon the clock used in Ness' model by dividing the original day/night cycle into two hour increments (26:55-56). The biggest reason for dividing the time cycle is to allow the planning of subsequent missions (26:56). This allows the orderly and sequential planning necessary for missions which call for aircraft surges, preemptive missions, strike missions, and battle damage assessment (BDA) following the strikes. Another possible method would be to uniformly assign

missions throughout the time blocks within the mission cycle (26:56). SWATTER can use either method but the planning phase method would be more realistic since it would require the input of a specific time for attack and would more closely model reality. To more fully integrate SWATTER, the time increments could be further subdivided into minutes or seconds to allow a more realistic interaction of the constellation against space targets. If the realism unnecessarily complicates and slows down the wargame the longer increments can still be used and an aggregate probability for killing space targets could also be used.

4.4.2 Weather. Mann's model portrays the use of weather and weather effects based on definitions of good, fair, or poor. In addition, his model addresses daytime and nighttime issues (26:57) of visibility, etc. While SWATTER addresses these issues in a similar manner, some differences will have to be covered.

4.4.2.1 Atmospheric Effects. Mann's proposal lumps weather into three categories; good, fair, and poor. (These weather conditions will be defined in a later chapter for the purposes of SWATTER.) While these categories are sufficient for land warfare, he failed to address some of the issues facing both aircraft and space-based DEWs.

For aircraft, cloud ceilings (measured from the ground) and cloud tops must be included. A ground hex may have poor weather due to fog but the air hex directly above may have good weather which would allow air combat. Alternatively, a medium altitude hex may have poor weather but the low altitude, tree top, and terrain hexes would have good weather allowing a multitude of low altitude missions. The inclusion of ceilings and cloud tops allows the determination of which missions are affected by the weather.

The weather and the hexes they are located in could affect both target detection and fire (by the DEWs) against those targets. Laser weapons fired through weather would attenuate quite rapidly due to absorption and dispersion. Obviously, the amount of cloud cover would play an important factor in modeling the target acquisition and destruction process. SWATTER assumes a weather factor of poor assigned to a hex indicates a complete cloud overcast (or undercast when viewed from above) condition. In such cases, the only detection process which may be able to penetrate this weather is a radar detection process. However, radar would also

suffer some attenuation effects. SWATTER would not be able to fire into or through a hex with a poor designation. However, insufficient information exists for detection and targeting in the good and fair designated hexes.

As an improvement, SWATTER adds the types of cloud cover modeled in each hex. SWATTER uses the Federal Aviation Administration's and the National Weather Service's definitions for different levels of cloud cover. These terms and definitions are:

clear Cover is less than 10 percent of the sky (1:144).

scattered Cover is from 10 percent to less than 50 percent of the sky (1:144).

broken Cover is from 50 per cent to less than 90 percent of the sky (1:144).

overcast Cover is from 90 percent to 100 percent of the sky (1:144).

Weather in the model is a dynamic and changing variable. The beginning scenario weather is input into the model and allowed to simulate drift. SWATTER will build on this dynamism by using a random number draw from a uniform distribution to simulate the changing character of cloud cover over time and to introduce an additional element of uncertainty into the process. As a default mechanism, where the weather is not designated, the default value for the hex will be clear.

4.4.2.2 Daytime or Nighttime. Detection by visible light sensors is enhanced during daylight hours, while IR sensors are degraded due to the reflected background radiation. During nighttime detection the reverse is true, IR sensors are enhanced by the removal of background radiation while visual sensors are degraded. Although the atmosphere has small changes in transmission properties due to the day/night cycle, these properties will be ignored. That is, SWATTER assumes radar is unaffected by the day/night cycle.

4.4.2.3 Space Hexes. Mann's thesis proposes the use of space hexes for movement of satellites. While hexes may be appropriate for use by the reconnaissance satellites envisioned by Mann, the dispersion, numbers, and sheer speed (a satellite in low-earth orbit travels around the globe in approximately ninety minutes for an apparent ground velocity of over 18,000 knots) precludes a hex system for a constellation of DEWs and their supporting satellites. The sheer magnitude

of tracking the placement of all the satellites required would become computationally intensive and significantly affect the playability of the wargame. SWATTER proposes the use of an initially homogeneous entity not directly represented on the map. Once this homogeneous entity is defined the spacing between orbits can be determined, and these orbits with their associated satellites can then be represented in the theater.

4.5 Space Battle

SWATTER begins with a mission priority already established for the first two strategic missions. The first priority is detection and destruction of strategic missiles aimed against the United States. The second priority is self-defense against attacks on the constellation. Embedded within the second priority is the option of turning on a sterile no-entry zone for the constellation. This option would heighten the readiness of the constellation and help prevent an attack on the constellation by space mines. Following these two priorities the US player could prioritize the missions he wishes accomplished and at anytime he can change the priorities to reflect the player's own changing needs. Any mission planned by the US player would have a time delay scheduled and a possibility of mission denial based on the command structure in effect at the time the mission is requested. This will force the players to plan the missions far enough in advance to receive approval before force employment, or else the attack may be delayed and will not be coordinated with other attacks. When the clock reaches the mission time (or the delayed time whichever is greater) SWATTER will again check to insure the first two priority missions are not called into effect. If the first priority mission has to be employed the player-requested mission is automatically canceled. If the second priority mission is employed there is a possibility of the requested mission being canceled based on where the constellation is being attacked. If the player-requested mission is not canceled by this point it may be canceled by the SDI for other reasons. The probability of this possible final cancellation will be highly dependent upon the command structure in place at the time of the final decision. Assuming the requested mission has survived all possible cancellations, the target can be engaged, assuming it has been detected and tracked (if the target is undergoing area fire then detection by the constellation is not necessary). It is also possible for the theater commander to establish a priority of missile defense within his theater. This would require him to hold some of his firing capability in reserve in case of Soviet theater missile attack.

4.6 Detection

Detection of the desired targets is a function of the size of the target, the resolution of the detector, the target's infrared and radar signatures, weather, altitude, and terrain. Once detected, maintaining the target contact will be enormously simplified due to the continuous coverage afforded by the satellite constellation.

The size of a target plays an important part in detection in the visible spectrum of electromagnetic radiation. However, the rumored abilities of reconnaissance satellites are rapidly making size irrelevant. The reputed resolution of spy satellites in the early 1960's was approximately five feet (7:92). The Keyhole satellites, reported in the popular press, are reputed to have an optical resolution from two inches (7:248) to one foot (12:319). Other electromagnetic wavelengths would have lower resolution due to wavelength dependencies.

The IR and radar signatures also play an important role in detection. Although the IR and radar resolutions are not as great (which would allow better target recognition if not outright identification) as the visible wavelengths, the IR and radar wavelengths frequently allow detection where visible light would not. In addition, certain systems have unique IR and radar spectrums which would help in the identification process. IR is extremely effective against targets with a large heat source such as missiles, and aircraft. In certain cases it would also detect vehicles on the surface due to reduced background interference (tanks running at full power at night). Radar would give a greater all-weather detection capability and is usually very effective in detecting objects. Due to the size, number, and spacing of the sensors within the constellation, SWATTER also has a very effective capability for detecting moving as well as stationary targets.

Weather, for the most part, would have an adverse impact upon target detection due to the blocking of certain wavelengths of the electromagnetic spectrum (visible and IR) and the attenuation of other wavelengths (radar). Day and night effects are also captured in the model. Radar would remain fairly constant but visible light sensors would decrease in effectiveness. However, IR sensor effectiveness would increase as the surface and adjacent air masses cooled improving the contrast of hot target objects.

The target altitude also affects detection. The higher the altitude the less the background radiation would interfere. Although resolution would improve slightly,

it would be negligible at most altitudes due to the extreme height of the sensors in relation to the target.

Terrain would also affect detection. Rough terrain would help shield a vehicle from radar detection. Foliage could block radar and shield the target from visible light detection while lessening the IR signature received by the sensor. In addition, undulating terrain could help mask low flying aircraft.

Due to all these effects, targets can be broken into several categories with decreasing probability of detection. Furthermore, these categories can be modified by the circumstances covered in the previously mentioned issues. In all, there exists four broad categories. These categories are: missile targets, space targets, atmospheric targets, and surface targets.

The first category, which happen to be the type most likely to be detected, is the missiles. The multispectral sensors would pick up these as they were launched almost immediately due to their high intensity IR signature. Additionally, the constellation would be programmed to recognize and possibly identify by type due to the unique spectrum of the rocket exhaust.

The second category includes vehicles already established in space. These would not have the IR signature of a rocket unless it was maneuvering with thruster rockets. However, the satellites would have to thermally control its environment and radiate excess heat for all systems to remain functional. This IR signature would stand out in space unless it had the sun, moon, or earth in the background. Visual and radar detection of such systems would be enhanced if the altitude was in close proximity to the SWATTER constellation. Radar would also have less background clutter to contend with in the space environment but optical sensors may have to worry about background interference from the same sources as the IR sensors.

Aircraft in the atmosphere are in the third category. Generally, the larger aircraft would have a better radar return and would be easier to pick up visually. However, smaller fighter aircraft have larger IR signatures especially when operating with engines in the afterburner range. Weather would be a definite player in the detection of these aircraft.

The final category would be surface targets. Assuming SWATTER used a compromise sensor resolution of three feet, it should be capable of detecting tanks visually in the open. Radar would probably enhance the detection probability while

IR sensors may be able to detect the engines running. With the assumed resolution of three feet, SWATTER could detect most land vehicles. However, this resolution would prevent the detection of troops. Troop concentrations may be detected due to increased IR signatures from fires, and vehicular activity in an area. A slightly elevated IR signature may be detected at night in normally unpopulated regions. Recognition and identification of troops would be extremely unlikely at this resolution. Large surface targets like hydroelectric dams and power plants would probably be easily detected by visible light sensors and radar.

Detection of these target types can be easily modeled through assigning a detection probability to each target and modifying each probability due to terrain and other factors.

4.7 Command, Control, and Communication

If a target is detected by a single sensor then the entire constellation knows the same information, that is, if the sensor detects a missile attack then the entire constellation knows a missile attack is under way. On the other hand, if a suspected troop concentration is detected, the system only knows the location of a probable troop concentration. In other words, the system has perfect knowledge between sensors at the beginning of the scenario. This perfect knowledge can be put to use immediately in targeting and commanding the different weapon platforms for coordinating fire attacks. However, as time progresses and the satellite constellation comes under attack, this perfect information transfer would probably not occur. To help represent this command and control capability of the constellation, a global variable (similar to the one proposed by Mann (26:69)) would be established. Another, similar variable for the communication between sensors, the handoff variable, would represent the ability of the constellation to pass sensor information to following sensors for maintaining continuous target tracking. Initially, the values of these variables would be one. As attacks occur against the sensors and the command and control satellites, these values would decrease to represent the loss of information between sensor platforms and would also result in less coordination between the firing platforms.

4.8 Firing Capability

In the early stages of the war when all of the satellites are operating at peak capacity, the probability of the constellation firing should be near 100 percent. However, as the constellation approaches the exhaustion of allocated resources, the satellites may not be in position to fire at the desired times. The constellation may also exhaust certain satellites capabilities to the point where there will be gaps in the coverage provided by the system. Alternatively, the constellation may be manipulated to optimize the attacks at specific times. Several possible arbitrary methods of representing these options will be presented later.

4.9 Firing Correction

Due to the unique nature of the sensors employed in the constellation and the previously discussed effects of laser fire, SWATTER will have almost instantaneous assessment of the firing accuracy of the shots just fired. While this knowledge would have no effect upon shots fired in volley with the same targeting information (i. e., the shots fired simultaneously under SSLSS), the subsequent second volley would improve due to the system being able assess the hit or miss of the previous rounds. One method for modeling this ability will be presented later.

4.10 Reserves and Resupply

A constellation of the size of SWATTER would probably have several satellites in reserve. These reserves are known as on-orbit spares. An on-orbit spare is a fully mission capable satellite placed in orbit with only caretaking systems activated. Depending on the system, on-orbit spares may be brought on line within a number of hours or it may take several days for a complete systems' checkout. SWATTER should have the capability to model the call up of on-orbit spares by increasing the command and control variable, if previously damaged, or increasing the firing capability if a firing platform had been previously lost.

Additionally, the placement of such an extensive constellation as envisioned by SWATTER, would require a robust launch system in keeping with the proposed Air Force space doctrine. This robust launch system may allow the launching of replacement satellites within a short time of several weeks or months. Alternatively, assuming the laser weapons are refuelable, refueling missions may be launched in

terms of days or weeks. Both missions, replacement and refueling, may include technicians able to effect minor repairs on satellites if the space shuttle is used.

The first type of mission would allow an improvement in previously damaged sensors or command and control satellites through the improvement of command and control or sensor handoff variables. In addition, a new firing platform could be launched which would replace previously damaged platforms or increase the number of firing rounds allocated to the theater commander. The second mission would only increase the firepower allocation to the theater commander through satellite replenishment. Both missions may allow incremental increases of firepower and command and control through repair of minor damage by the technicians aboard the space shuttle.

4.11 Laser Effects Upon Troops and Equipment

Laser fire upon troops will probably have an immediately debilitating psychological effect upon troops who are not expecting such fire. Once such fire is expected, troops will also probably begin taking actions to limit injuries from such attacks and which may hamper their accomplishing assigned missions due to effects previously cited in chapter two. After a time, protective clothing, similar to chemical warfare gear, would be issued also causing modifications to unit effectiveness. A modifier to the firepower index of the unit would satisfactorily reflect this decreased unit effectiveness.

Laser attacks upon equipment may not destroy the target but could injure or spook the crews operating the equipment resulting in a decreased weapons' accuracy. In addition, lasers may also destroy IR sensors forcing aircraft to operate at higher night altitudes and decreased night weapon accuracy.

4.12 Kill Assessment

Hard kills will be easily confirmed for many weapon systems. Missiles in the boost phase will immediately blow up or begin experiencing control difficulties ultimately resulting in breakup of the booster rocket and warheads. Aircraft which are hard kills will immediately explode or almost immediately impact the ground. Munitions supply trains, POL dumps, or any vehicle whose munitions are ignited will provide vivid evidence of hard kills. However, some weapon systems may not

exhibit properties which will lead to easy kill confirmation. Trucks and tanks which are killed in a less spectacular hard kill manner will still be just as dead. However, the sensor systems will not be able to give an unequivocal answer during the battle damage assessment (BDA). Some hard kills may be listed as failures as well as probable kills for the US players. However, the target's owning player, the Soviets, would know the actual status of his systems after a specified time delay.

Soft kills will be harder to detect. Individual aircraft may not be able to complete the mission but the evidence of an actual failure may not be forthcoming. However, if an obviously aggressive aircraft strike package is turned back before striking, then a high percentage of soft kills probably occurred within the strike package. Soft kills of weapon systems may be reported as probable kills or even as failures to the theater commander.

Sometimes kill failures may appear as a probable kill. An attack against a tank may appear to be a kill if the division has just stopped in its objective hex. However, the tank may have just stopped upon reaching its assigned position. After the laser strike is over the tank may be falsely reported as a kill but the tank may begin rolling again when assigned a new objective.

The theater commander could specify how important the kill verification is. He may decide he wants unequivocal verification of kills which could result in multiple kills of the same target and would rapidly deplete his limited laser resources. Or he may be willing to accept a probable kill which may result in an incorrectly identified target slipping through the defenses and completing its assigned tasks. However, this last option would allow the husbanding of a limited laser resource.

Accounting would be very important in this phase. The computer would have to track what is reported to the theater commander as well as the actual status of the weapon system and report this status to the Soviet commander after a suitable time delay. SWATTER should also allow systems to be killed multiple times which could result in inflated BDA reports to the theater commander or overly pessimistic reports if killed targets are reported as functional.

4.13 Overall Model Interaction

Before the simulation can begin, SWATTER requires several inputs to function properly. The data base must be entered for the different entities and their individual

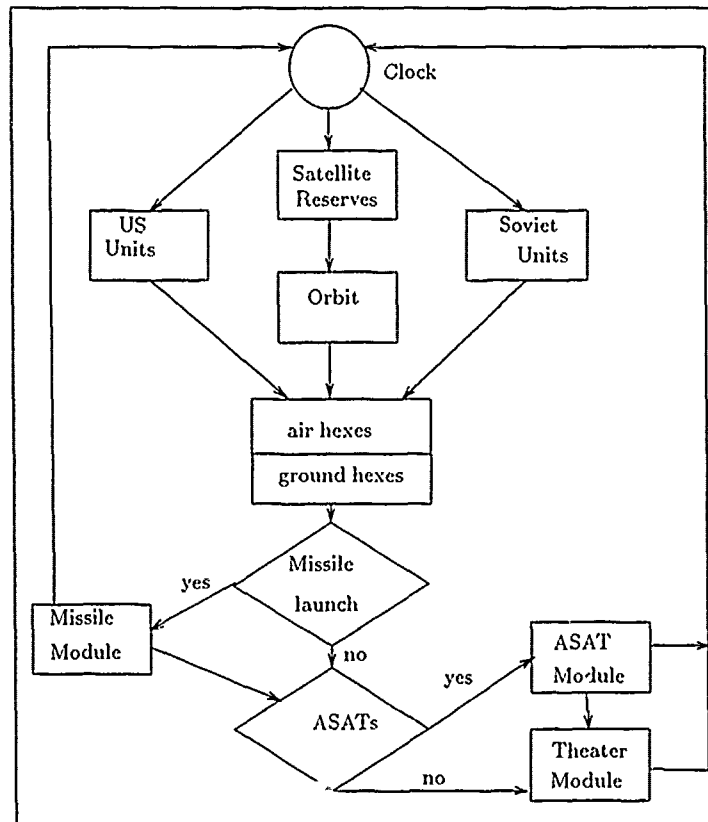


Figure 3. SWATTER Flow Chart

properties, the air and ground hexes must have the database entered for the weather, and the satellite shield has to be defined before SWATTER can begin.

The simulation begins with the placement of all entities, weather in the appropriate hexes, and the satellite orbits passing over the theater. Following the flow in Figure 3, the clock advances to the next scheduled event, or next time increment depending on the mechanism used in the model. After the time increment is determined, the weather for the individual air and ground hexes is entered, the surface entities are placed in appropriate hexes, and any scheduled reserve satellites are placed into service. At this time the orbits crossing the theater are also determined.

The first major decision branch SWATTER must examine is if the model has any missile launches. If the answer is yes then the model takes the missile module branch. This sequence occurring first allows the simulation of strategic missile

defense. If the answer is no or the missiles are tactical in lieu of strategic, then SWATTER moves onto the next decision dealing with ASATs being activated.

Just like the missile launch, if the ASATs are activated SWATTER branches off into the ASAT module. This module is concerned with representing the self defense of the satellite constellation as a function second in priority to strategic missile defense. The ASAT module would come into play if either space mines, direct ascent ASATs, or co-orbital ASATs are employed. If the ASATs are not activated or local theater resources are not used, then SWATTER continues to the theater module.

If SWATTER has not used its firing abilities in missile defense or against threats to the satellite constellation, then the simulation allows the employment of SWATTER resources against tactical earth targets. After this final stage of combat is resolved the clock is advanced to the next time increment and the process begins anew.

While there are many similarities between each of these modules, there are enough differences for each module to be covered in detail below.

4.13.1 Missile Module. The first priority upon entering the missile launch module is determining if the missile is a strategic attack against the US or Canada (reference Figure 4). If the missile is determined to be strategic, SWATTER immediately inspects the strategic reserve, those shots of the constellation held back for strategic missile attacks, to determine amount of firepower held in reserve. Then the model immediately determines the ground track from launch to predicted impact point (as entered by the missile's owning player) and determines the random weather effects for each ground and air hex crossed. If multiple missiles are fired simultaneously from the same launch points to the same targets, this determination is made only once. Based on the final weather factors, the probability of detection of each missile in each hex of its flight path is determined. After detecting the missiles, the model examines the strategic reserve, and determines if SWATTER is able to fire based on the amount in reserve and a random number draw. If the answer is no, SWATTER immediately compiles a report on the detected missiles for the US player and then advances the clock to the next time increment. If SWATTER is able to fire: prioritization of targets occurs; combat is resolved; battle damage assessment is conducted; and, if shots remain, prioritization occurs and the process begins again. SWATTER assumes once the constellation is able to fire, it can continue to fire until

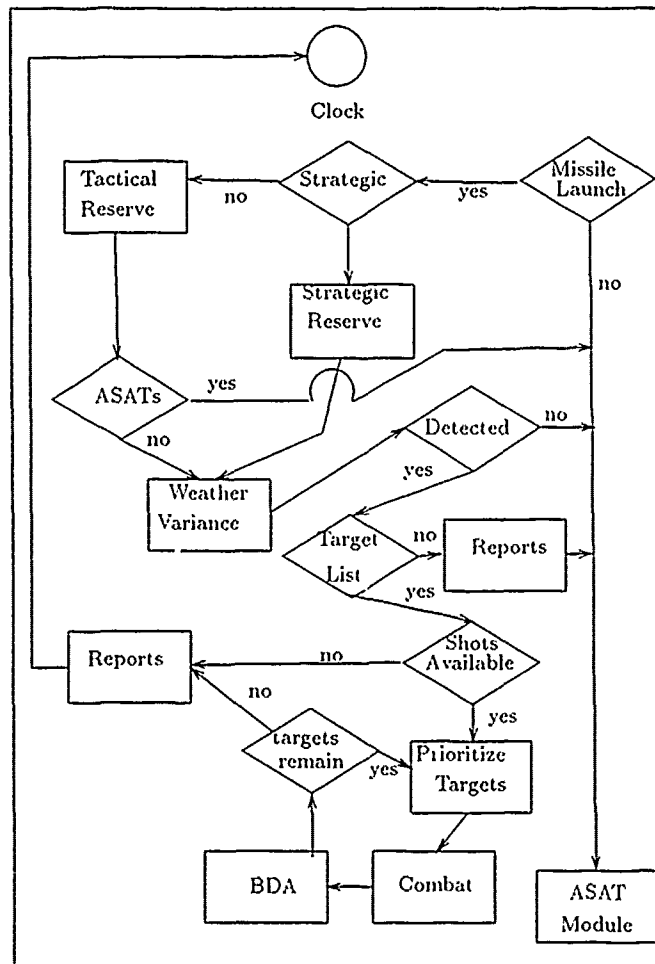


Figure 4. Missile Module Flow Chart

the target is destroyed, the target reaches its objective hex, or until the strategic reserve firepower is exhausted. As soon as SWATTER can no longer fire due to lack of targets or shots, a report for the US player is generated with all purported kills and any missiles which were detected but unharmed. The Soviet player also receives a report but this report will be more accurate than the one received by the US player.

If the missiles are determined to be tactical theater missiles, SWATTER first determines the number of shots in tactical reserve and then, if ASAT weapons (excluding space mines) have been activated. If these ASATs (excluding space mines which can not be detected due to being hidden on other satellites) are activated, the

preservation of the satellite constellation takes priority and the theater missiles are not attacked. SWATTER also assumes the sensors in the constellation are engaged in self-defense efforts and are unable to detect the tactical theater missiles. If the space mine module is not called into play, SWATTER generates weather, combat, BDA, and reports in the same manner as the strategic missile attack.

4.13.2 ASAT Module. When entering the ASAT module (reference Figure 5) upon ASAT attack determination by SWATTER, the first area examined is the strategic reserve to determine if any defensive fire is available to the constellation. The weather variance is again determined for all non-space hexes entered by the ASAT and then the detection probability is again calculated for each hex traversed by the ASAT. If no detection occurs, SWATTER moves on to the theater module. If detection occurs (almost 100 percent for the direct ascent and co-orbital ASATs, and zero for the space mines), SWATTER immediately matches the targets against a target list and next determines if shots are available based on a random number draw and the strategic reserves. If no shots are available, the reports are generated and the clock advanced. If shots are available, SWATTER prioritizes the targets in order of the highest detected threat and resolves combat, BDA, and target reengagement in the same manner as the other modules.

4.13.3 Theater Module. If all other modules have been successfully traversed, SWATTER finally enters the theater module (Figure 6). If no targets are available the clock is advanced and the whole process is repeated from the beginning. If targets are available, the offensive reserve, shots available for offensive firing is examined, the weather variance in each target hex is determined, and the detection process resolved (area fire targets automatically have a 100 percent detection probability). All detected targets are compared to a target list to insure they are indeed targets. Once identified as targets, they are prioritized according to priorities established by the theater commander. Again, SWATTER determines if shots are available based on the offensive reserve and a random number draw. However, this step is significantly different than the others due to the limited number of shots per satellite and the limited number of satellites passing over the theater at the time. The first time SWATTER examines the availability of shots in this module, it must also determine the total number of shots available for the clock cycle. Combat will follow with BDA, and target reengagement until detected targets are destroyed, or the number of shots available are exhausted.

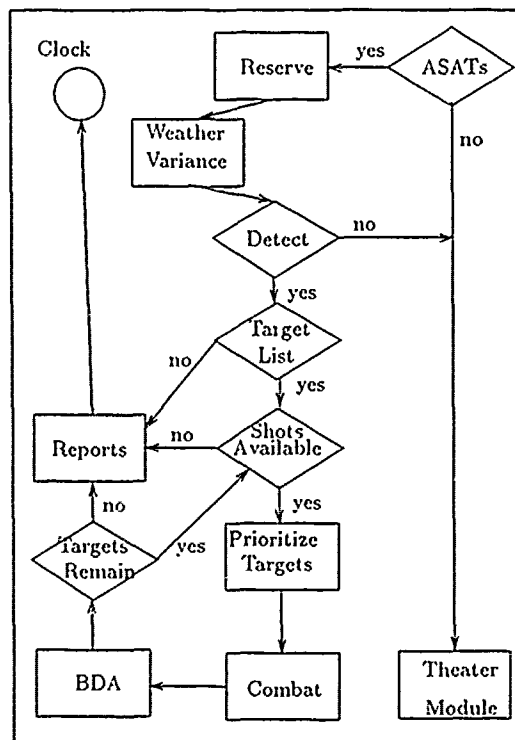


Figure 5. ASAT Module Flow Chart

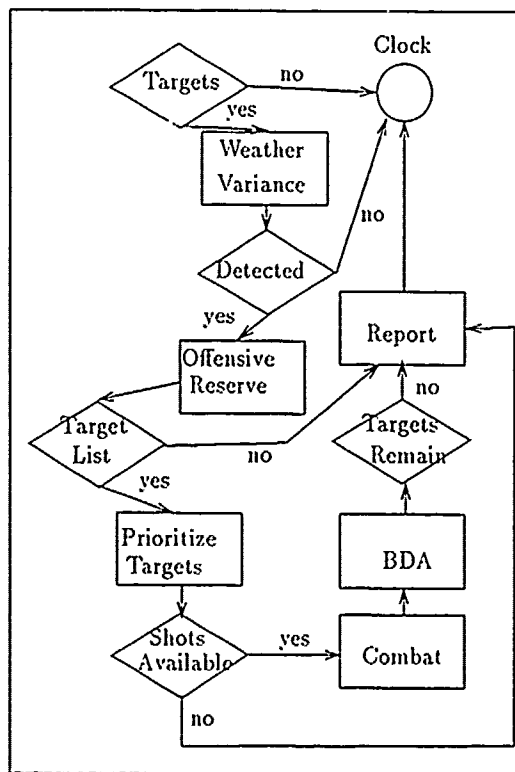


Figure 6. Theater Module Flow Chart

With this basic understanding of the processes involved within the model, it is now time to examine the entities and their associated data bases to flesh out the model.

V. Database and Entities

5.1 Introduction

One of the recurring problems in Ness' land model was the lack of documentation for the interaction of the entities which would have firepower scores, destructive indexes for aircraft, and sometimes surface-to-air indexes. Unfortunately, Ness did not explain how these values were reached nor how these values affected the interaction between the entities (26:84). To correct this problem, a reference system for determining the linkages and interactions between entities was developed by Mann. Mann allows the entities to be aggregated upward for combat effectiveness and allows the entities to be disaggregated downward to the individual vehicle level for modeling the effectiveness of attacks on a unit.

SWATTER will build upon the work accomplished by Mann. However, if SWATTER is incorporated into another theater level model, then some understanding is necessary on how Mann tied individual weapon effects into his aggregate model. With this understanding, SWATTER will be more easily incorporated into other models. After examining the basic interactions, emphasis will be placed on SWATTER specific interactions and the resolution of combat between terrestrial forces and the satellite constellation.

5.2 Model Representation of Entities

5.2.1 Ground Combat Entities. Ness, in his model, assigned firepower scores (a measure of the individual units strength in combat) to individual units in a manner never satisfactorily explained. Mann, on the other hand, tied the firepower score directly to the relative strength of each unit as measured in terms of "battalion equivalents" used by the Army Command and General Staff College (26:86). Table 1 adapted from Mann' work (26:87) uses the Soviet motorized rifle battalion (MRB) equipped with BTRs (wheeled armored personnel carriers) as the baseline for measuring other battalions. Using these values multiplied by a factor of ten, Mann was able approximate the firepower scores used by Ness. This listing in Table 1 is not a complete listing but a representative sample of how to handle firepower score

Table 1. Battalion Equivalents

Unit	Value
Soviet MRB (BTR-equipped)	1.0
Soviet MRB (BMP-equipped)	1.5
Soviet tank battalion (of a tank regiment)	1.6
Soviet anti-tank battalion	1.0
Soviet divisional helicopter squadron	1.0
Soviet attack helicopter squadron	2.0
US Mechanized battalion (M2-equipped)	2.0
US Armor battalion (M1-equipped)	4.0
US Attack helicopter battalion (AH64-equipped)	4.0
US divisional cavalry squadron (AH64-equipped)	1.5

Table 2. Armored Division Values before Artillery Support

Number	Battalion Type	Value	Unit Total
4	US Mechanized infantry bn	2.0	8.0
6	US Armor bn	4.0	18.0
1	US Attack helicopter bn	4.0	4.0
1	US Cavalry squadron	1.5	1.5
Total Value			31.5

aggregation and disaggregation. SWATTER uses the same system as Mann and is based on the Army's J-series tables of organization and equipment (TOE) (26:86).

5.2.1.1 Aggregation into the Division Level. Using these battalion equivalents it is fairly easily to aggregate a division level force into a single firepower score. Using the numbers given by Table 1 an armored division can be constructed from the sum of the battalions making up the division. For example, an armored division has six armor battalions (bn), four mechanized infantry battalions, one air cavalry squadron, one attack helicopter battalion, three artillery battalions, and one battery of multiple launched rocket systems (MLRS). Using Table 1 for the values of these battalions results in a combined division strength in Table 2 without the artillery or MLRS, which are handled separately.

After the division value is determined it is multiplied by ten for the firepower score. Artillery fire support is added afterwards as an additional firepower score

to the entire division firepower score (26:88). This allows the divisional artillery to remain in place to support new divisions moving up as the original owning division retires to the rear (26:88).

5.2.1.2 Disaggregation of a Battalion for Combat Resolution. With the use of Mann's method of linkages, it is possible to determine the outcome of attacks on a specific number of vehicles within a battalion. For example an airstrike would attack each individual vehicle within the battalion as a point target. After the individual attacks are determined the total number of tanks destroyed are tallied. By using his disaggregation method, explained below, it is possible to adjust the total firepower score of the armor battalion downward due to the loss of these individual units.

Using the battalion equivalent value given in Table 1 and multiplying this number by ten for the firepower score will give the overall measure of combat strength of the battalion. Based on the composition of the battalion, it is possible to determine individual unit firepower scores within the battalion. For example, a US armor battalion has a firepower score of thirty. This battalion normally has 58 tanks (26:89). Dividing the number of tanks into the battalion firepower score results in the individual tanks' contribution to the overall firepower score, in this case approximately 0.5. If six tanks are destroyed then the battalion firepower score is decreased by three to a total of twenty-seven.

This linkage of firepower score with individual units within the battalion allows Mann to attrite the battalion and ultimately the division. This linkage is the same one SWATTER will use to attrite ground units.

5.2.2 Air Entities. Mann uses a different system for the formation of aircraft strike packages. The primary measure of mission effectiveness varies with the type of mission. If air-to-air combat is the mission, then the aircraft in contact with the enemy use their combat capability ratings for outcome determination (26:106-107). For air-to-ground missions the destructive capability of the strike aircraft is a function of the accuracy of the aircraft and weapon, target size, and the munitions interaction with the target (26:107). In addition Mann's thesis also accounts for many other factors in air combat including electronic countermeasures, radar search area, and weapon characteristics. Many of these do not directly impact SWATTER or must be handled differently when attacking from space.

5.2.3 Base Entities. Generally, Mann incorporated bases into his work as a holder of resources, whether they were supplies, missiles, or aircraft. Mann has identified several base types. These types are: 1)airbases; 2) depots; 3)staging bases; and 4) missile bases. A logistics module is incorporated into his work which also allows for the resupply of these bases. The interaction of SWATTER with these bases will be explained in a later chapter.

5.2.4 Space Entities. Generally, space entities include any man-made object in orbit around earth. This will include communication and navigation satellites, space mines, ICBMs transiting space toward their targets, ASATs, and manned spacecraft. These entities will all possess similar qualities which are accounted for in SWATTER. The most important differences between these entities and SWATTER entities include; the fact SWATTER can directly affect the theater conflict from space while the others only play a supporting role or must leave the space environment to affect the theater, and the fact SWATTER is able to target these entities using the following processes.

Generally, space objects will be detected and tracked by SWATTER. Once detected and track maintenance is initiated, SWATTER will attempt to identify the type of space object it is. Using multispectral sensors will allow a high degree of accuracy in identifying types of ICBMs. Once identification is made, SWATTER will assess the object against a target priority list. If the detected object is currently the highest priority object detected on the target list then SWATTER will engage the object. If additional resources remain for other targets on the list SWATTER will attack the next highest priority. If SWATTER is unable to identify the target then SWATTER will examine the object track and attempt to determine the possible threat the object poses. For example, if SWATTER positively identifies an ICBM as an SS-25 and an SS-18 is also detected, the SS-18 would be engaged first due to the priority given the greater threat posed by the SS-18. If the missiles are not positively identified but appear to threaten the continental US and SWATTER respectively, then SWATTER will engage the missile threatening the US first before engaging the other missile for self-defense.

5.2.5 SWATTER Entities. SWATTER is a constellation (a grouping of satellites with a common purpose, in this instance strategic defense) consisting of multispectral sensors, command and control (C^2) satellites, and weapon platforms. Due

to the large number of satellites involved and the tremendous amount of computation involved with tracking each individual entity at high speed throughout its orbit, SWATTER will be treated as an initial homogeneous entity with the sensors, C^2 , and weapons dispersed uniformly through out the constellation.

5.2.5.1 Scenario Input. The altitude and the effective range of the weapon will determine the number of weapon satellites in orbit to give the coverage desired at the beginning of the scenario. In addition, the control group would enter the number of sensor satellites, the on-orbit spares, and the C^2 satellites prior to beginning the wargame. Several of these satellites may be multifunction satellites where their destruction may result in simultaneous decrease in capabilities in several mission areas. Other attributes of SWATTER must be input, either as a startup data base or scenario input file, by the control group prior to starting the game and include:

- Launch delay to place replacement satellites in orbit from the time of request to the time the satellite is operational
- The length of time before an on-orbit spare is able to replace a destroyed satellite
- The amount of time required after a satellite loss before the constellation again assumes a homogeneous distribution
- The probability of the constellation being able to fire (discussed in detail in the next chapter)
- Satellite firing philosophy (S-L-S versus SS-L-SS)
- Whether SWATTER has a sterile no-entry zone around the constellation and if it does is it currently activated (if not activated the control group can decide when and if to activate it based on the situation and if the theater commander requests activation)
- Whether ground-based lasers are active and able to attack satellites
- Ground-based laser firing philosophy
- The number of shots allowed before the ground-based laser must allow operating components to cool

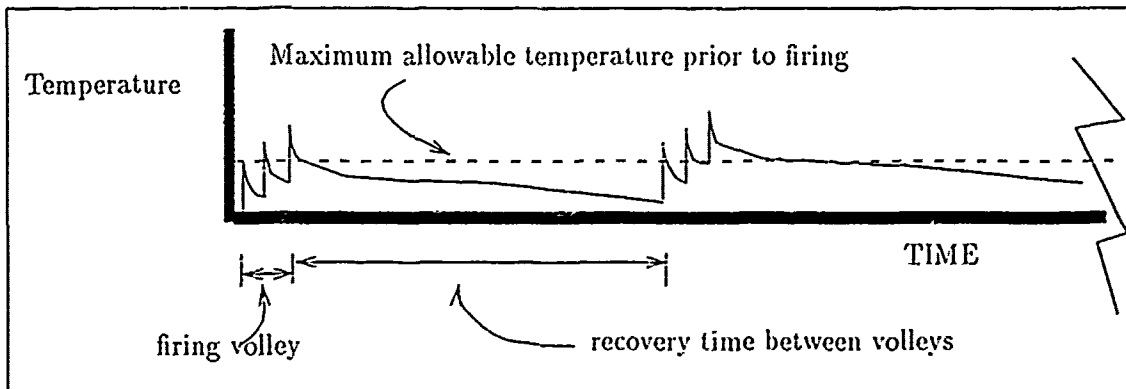


Figure 7. Volley Fire and Recovery Time for a Pulse Laser

- The amount of time required for ground-based laser components to cool
- The number of shots allowed before a satellite must allow operating components to cool
- The amount of time required for satellite components to cool

The last four items require a little more explanation. Due to the tremendous amounts of energy placed upon the optics of the weapon system, enormous heat energy is absorbed. As this heat is absorbed by the weapon system, the optics may warp and the whole system becomes less effective. Once a certain temperature is reached, further fire may result in significantly greater targeting inaccuracies due to the warping of optical surfaces and damage to the weapon may result as well. The need for knowing the last four items should be apparent in figure 7. SWATTER assumes a firing doctrine to prevent these effects.

After these inputs are entered, the number of satellites over the theater, the time between satellite passes, and the area of the theater each satellite is able to cover can be calculated by a preprocessor or manually by the control group. These preprocessing inputs are covered in more detail in Appendix A.

After the rudimentary scenario requirements have been determined by the control group, the theater commander can make some basic command decisions regarding the employment of his allocated percentage of the total constellation. The theater

commander must decide on targeting priorities, attempt to establish his desired command structure, and determine how much of SWATTER's capabilities to maintain in reserve in case of theater ballistic missile attack. Finally, the theater commander may throughout the game allocate specific fire missions against geographic targets rather than just depending on the targeting priority list he has established. These theater commander inputs are covered in more detail in Appendix B.

Finally, the wargame will run using stochastic probabilities to determine satellite command and control, detection, hits, and destruction of targets by SWATTER. These probabilities will be included in data files with the specific attributes of each weapon system in the wargame.

5.2.5.2 Command and Control, and Sensor Handoff. SWATTER will include a probability function to represent command and control of the constellation. As the C^2 systems are attacked the entire system will degrade in effectiveness. With the loss of some C^2 resources, the ability of the sensors to handoff firing information to the weapon platforms will decrease. Finally, the degraded systems may not be able to completely correct subsequent firings by the weapons platforms based upon previously observed firings.

The ability of sensors to successfully handoff to another sensor the tracking responsibility of a specific target would be a function of the target type and would also be influenced by the differences existing from sensor pass to sensor pass. If no target has been detected, the handoff variable is not used since it is only a measure of the effectiveness of the sensors to handoff known targets.

Both of these functions are assumed to affect the constellation uniformly. The handoff factor is constant throughout the simulation and is only a function of target type and an immediately previous successful detection. However, the global command and control variable will change over time as the constellation is attacked and is a measure of decreasing effectiveness due to destruction of the C^2 functions.

5.2.5.3 Detection. SWATTER will incorporate into each target an attribute which is simply a measure of how effectively the sensors can see the target in the open. These attributes should be a function of target size, target reflectivity of visible light, and target IR intensity due to engine heat. Factors which would affect detection are included as additional probabilities which must be accounted

for. These include weather, altitude, whether or not afterburner is in operation, and may include day/night considerations.

5.2.5.4 Hit Probability. To determine if a hit occurs, SWATTER will use a Circular Error Probable (CEP) function to model hits and misses. CEP is defined as the radius of a circle measured from the intended aimpoint on the target to the point where the desired percentage of shots will fall within the stated radius. The most frequently used percentage is fifty percent. SWATTER will also use fifty percent as the desired percentage. Therefore, in SWATTER a one meter CEP would mean there is a fifty percent probability that a specific shot will land within one meter of the aimpoint.

5.2.5.5 Target Destruction. Target destruction (a hard kill) will generally be determined after a hit is recorded. Since SWATTER is using a very narrow laser beam, the effects of a hit resemble the destructiveness from a point target kill. There is no radius of lethality since the laser beam does not explode like most conventional munitions. This probability of kill would be a measure of how much surface area of the target as viewed from above is devoted to critical areas such as fuel and munitions stores as well as target hardness. For example, an aircraft viewed from above may have fifty percent of its surface area over enclosed fuel tanks, and carried munitions. Aircraft would also have very little armor protecting these vital areas. Therefore, this aircraft would have a probability of a hard kill of fifty percent. In addition, if the target is hit but not destroyed there should exist a certain probability of a soft kill (i.e. the aircraft could not complete the mission due to systems being damaged or destroyed). Finally, the remaining probability would result in only minor damage with no overall effect on the target's mission effectiveness.

5.2.5.6 Other Considerations. Several other areas must also be included in SWATTER. One such area would be the effect SWATTER would have on troops under fire. Another would be attacks on targets which do not have the ability to suffer hard kills (including bases, and hardened command structures). These effects will be addressed further in the following chapter.

VI. Algorithms

With the proper data information and the proper supporting algorithmic functions, SWATTER can realistically represent to the appropriate level of detail the use of space weapons against earth surface targets. The algorithms are from two main areas of data processing. The first area is the processing required to input the model scenario and the restrictions which will apply to the scenario contents. This area will be known as preprocessing algorithms. The incorporation of the information required to make SWATTER work is indeed data intensive and requires sufficient preparation by the control group to make the wargame realistic. The second area of algorithms is concerned with making the wargame function during actual play. This area will be called the active algorithms and includes such things as detection, hit determination, probability of kill, and other phenomena.

6.1 Preprocessing Algorithms

Preprocessing algorithms are concerned with taking all available information on the scenario and inputting it into the system in such a way that the computer is able to realistically execute the scenario plan. Preprocessing algorithms include the orbital parameters used to achieve a reasonable approximation of a satellite constellation and also include algorithms which help represent the general scenario presented to the players. An important point for the control group to remember is to simulate the "fog of war" state of affairs by providing incomplete information on some aspects of the opposing forces scenario being preprocessed.

A scenario has many options built-in. These options should be determined by the control group prior to briefing the the players. Both the Soviet and US sides need fairly good information about their respective sides. However, the information about their respective opponents would be far less than complete. Although good information should exist for a player's own side, this information should not by any means be complete information. With incomplete information, the players can explore policy decisions which they may not normally implement. That is, the players will examine policy decisions realistically if the possibility, at least in their minds, for implementation exists. General scenario limitations include the policy decisions

the the control group wishes to represent and also include physical limitations on the equipment which the players own. These preprocessing requirements can be handled quite easily and is broken up into the US and Soviet requirements, satellite constellation algorithms, and weather.

6.1.1 US Scenario Limitations. The US player has several restrictions built into the scenario. Some of these restrictions are programmed prior to the game and can not be changed while others may change during the course of the simulation. Some areas which will be predetermined include theater command and control structure, political constraints, and SWATTER satellite structure.

Command and control restrictions will be based on the command structure determined to be in effect at the time. The scenario would normally start with a SOL in an advisory capacity to the air component commander. This SOL would provide assistance and advice to the AC and would relay requests to the SDI organization owning the satellites. However, this structure would prove unwieldy and would require a specific time delay built into the simulation before a mission decision is reached. In addition, the SOL would not have any authority over the satellite constellation at this point and mission approval would come from the SDI organization. If the theater commander is able to convince the NCA to move the SOL to his staff then the time delay for mission approval would be shortened. If the theater commander is able to convince the NCA to apportion some of the satellite constellation resources directly to the SOL with authority to control those resources the wait time before mission approval would be drastically reduced and mission approval would increase dramatically. The type of command authority in effect would be given to the theater commander at the beginning of the scenario with estimates of mission delay times and likelihood of mission approval. In addition, the commander would be forced to plan on resources which may or may not be available in the future. The theater commander should also be made aware by the control group that a change of command structure may be possible (even if for the particular scenario it is not). This will allow the participants the opportunity to discuss alternative command structures.

Therefore, four situations (or as many command structures the control group will allow) should be preprogrammed at the beginning of the scenario. The active structure will be flagged and the appropriate delay times and approval rates for that structure will be activated until a new structure is chosen.

Four possible command structures with example inputs are:

- The initial scenario structure with the SOL under the air component commander in a liaison status only could have a 6 hour time delay with an approval rate of 70 percent.
- A second structure would elevate the SOL up to the theater commander's staff with a decrease in mission approval time to 5 hours and a slight increase in approval rate to 75 percent.
- The next structure would leave the SOL under the AC but would give the SOL command authority over an allocated portion of the constellation. Since the need for approval from the SDI organization would be eliminated the time delay would significantly shorten and the approval rate would increase. One set of possible values would be a two hour delay with a 90 percent approval rate.
- The final structure would have the SOL directly under the theater commander with command authority over the allocated constellation. With the shortened lines of command the time delay would be minimized and the approval rate maximized due to less opportunity for misunderstandings to arise. This type of structure could have a mission delay time of 1 hour with a 95 percent approval rate.

These values for the command structure are only examples and are diagrammed in Figure 8. The different structures diagrammed are: a) initial setup; b) SOL advising the theater commander directly; c) the SOL given operational authority directly under the AC; and d) the SOL given operational authority directly under the TC. The values the control group feels appropriate for the command, control, and communication lessons to be learned would be entered in the preprocessing stage.

As for the political constraints, they would be controlled by the control group. The control group can allow or disallow the use of tactical nuclear weapons by representing the NCA as the releasing authority of these weapons. The theater commander would have to gain a release from the NCA before employment.

SWATTER satellite constellation structure will require the most intensive preprocessing. This structure will have certain restrictions and limitations which would

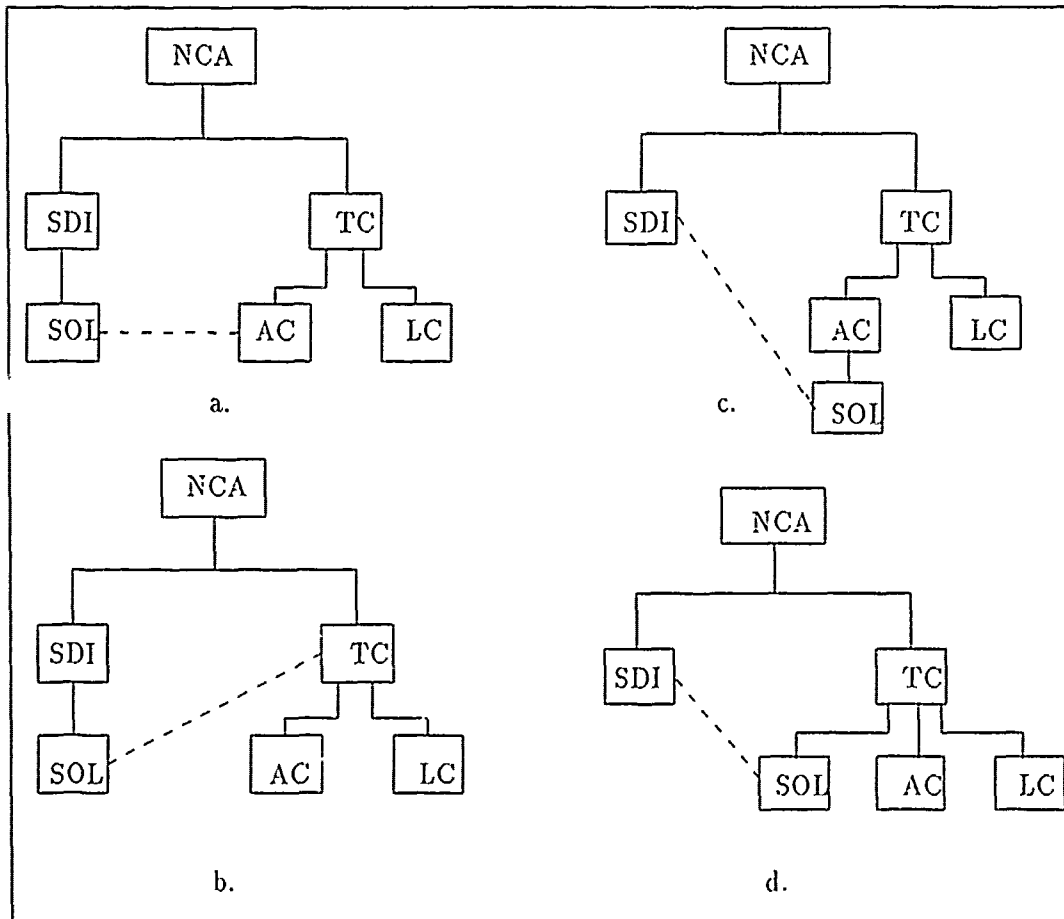


Figure 8. Possible Command Structure

be in existence prior to employment by the theater commander. These limitations would be a function of the satellite constellation and decisions determined by others when the constellation is first deployed. Therefore, these restrictions will be determined beforehand by the control group and will be constant throughout the simulation. These limitations will be explained separately in greater detail later. However, some of the structure is fairly easy to represent and is covered below.

The command and control structure, and the basic satellite operating conditions and limitations in place at the time of hostilities needs to be entered prior to the wargame start. Simple methods for activating and de-activating certain properties (sterile no-entry zones, for example) of SWATTER must be included. In addition, certain properties of the constellation must be defined once they are activated.

The control group must determine if satellite replacements made through a launch capability are to be included in the wargame. If the launch capability is included in the game then a specified time from the launch request to actual launch time and operational capability must also be included. Since such a constellation would require a robust launch capability to place SWATTER in orbit, the launch preparation time would probably be only a matter of a few weeks, if not days. These launch lead times could be represented by an average time to launch. The standard deviation would represent flawless launches which are given high priority, as well as the flawed launches where nothing ever goes right.

On-orbit spare satellites would require a precalculated time to be brought on-line in the constellation at the desired locations. If on-orbit spares are allowed by the control group, another average time should be included to represent the satellite activation time along with a standard deviation to represent the occasional problem and the occasional flawless execution. This average time may number in the hours but more likely will be specified in terms of days by the control group.

A similar idea to the on-orbit spares is the idea of reconfiguring the constellation for optimum results. For the purpose of SWATTER, the optimum constellation is homogeneously distributed throughout the latitudes it is employed. However, attacks against the constellation may provide periods of less than optimum coverage, a condition the Soviet players may try to exploit. The control group must indicate the time required to maneuver the satellites to compensate for losses before the constellation can be again assumed to be homogeneous.

Certain weapon parameters will be determined before game start as well. One such parameter is the ability of the weapon platforms to recover between subsequent shot volleys. The laser may only be able to fire a specified number of shots before stopping to allow the optics to cool from the tremendous energies they are required to handle. The time between shot volleys must also be specified to allow optics a cool down time. In addition, the firing doctrine incorporated by SWATTER must be input before the game as it will determine the number of shots permitted at a target within a specific time period. A SLS doctrine husbands resources by making corrections before subsequent shots are fired by the constellation. A SSLSS doctrine results in a larger use of munitions but each fire period will have a greater probability of kill. While the doctrine is determined in the preprocessing phase, actual shots and subsequent corrections will be covered in the active algorithms. In addition, the control group must determine how many shots are devoted to the theater commander's use.

6.1.2 Soviet Scenario Limitations. The Soviet player also has certain limitations and restrictions. The Soviet launch delay for their co-orbital and direct ascent ASATs, if allowed by the control group, must be entered prior to the game start. A determination on the use of space-mines by the Soviets must also be made at this time. Additionally, the ground-based laser (GBL) system must be activated by the control group with parameters similar to the US weapons including the firing philosophy, number of shots before cooling is required, and cooldown time.

Two important points are important to emphasize concerning the GBL. First, the GBL does not have the limited fuel supply space-based lasers have and the number of shots available are not as constrained. Finally, the GBL does not have to contend with the weight restrictions of a space-based system which allows the GBL to have a larger power output and a larger, active cooling system. These two considerations must be accounted for when determining the laser restrictions for the Soviet player.

6.1.3 Satellite Constellation Algorithms. A better simulation of space-based phenomena in a wargame will result from a better understanding of some of the basic relationships involved in orbital mechanics. The information presented was simplified throughout by making several assumptions. Thus the orbital mechanics are more easily understandable and more manageable for its incorporation into the

wargame. While these assumptions simplify the mechanics involved, they do not detract from the purpose of SWATTER, the familiarization of future Air Force leaders with space. These algorithms are not intended to provide space training. Therefore, these assumptions include:

- The earth is a perfect sphere of uniform density and Earth-Moon-Sun interactions are ignored.
- The satellites possess sufficient maneuverability to ignore atmospheric drag.
- The orbits of the SDI satellites are circular.
- The satellite constellation is treated as an aggregate entity with little reference to any specific orbital parameters.
- For local area effects, all equations assume a flat surface.

The first two assumptions allows simplification of the equations required for the treatment of a satellite's orbital performance. This allows the examination of some of the basic motion equations without having to account for perturbations caused by the gravity of the sun and moon as well as the effects caused by the oblate shape of the earth. In addition, atmospheric effects do not have to be included since sufficient maneuverability would allow orbital thrust firings to correct for drag effects. Although the first two assumptions allow reasonable approximations of the orbital mechanics involved, there are other more computationally intensive representations available if greater accuracy is desired using NORAD orbital element sets (20:1). The third assumption simplifies the calculation of orbital parameters and immensely simplifies the tracking of the satellite constellation. The fourth assumption is highly important since very little has been published in the open literature on basing schemes for satellites with such an ambitious mission as earth coverage for protection from strategic weapons. Therefore, this assumption allows the entire constellation to be treated as a homogeneous entity. The final assumption simplifies the equations used for determining local area effects since the circumferences of the spheres involved are tremendously large in comparison to the local area. Any errors induced would be negligible and would unnecessarily complicate the wargame design.

Generally, an SDI system envisions a layer of interlocking weapons employed in earth orbit for defense against ICBMs. There is much ongoing discussion on the

correct altitude for deployment, whether the constellation should be deployed in low-earth orbit or some higher orbit. Effective weapon range and launch capability may well be the deciding factors on deployment altitude. For the purpose of this project, low-earth orbit is considered to be the basing mode for the initial deployment of such a system due to the probability of fairly short weapon ranges. This may be changed later on as new technology comes on line and the significantly increased booster capabilities required for the launch of payloads into higher orbits becomes available. Low-earth orbit, while not specifically defined by a governing body nor universally accepted by all authorities, for the purpose of SWATTER it is generally defined as an altitude of 100 to 532.3 nautical miles(NM) or 185.2 to 1000 kilometers (km) (4:152) (34:459). In addition, SWATTER gives complete earth coverage of selected areas but does not have sufficient firepower to overcome massive ICBM attacks.

The next issue to examine is that of satellite coverage. Basic geometry defines the number of weapon platforms required to provide simultaneous and complete coverage. Referring to Figure 9 the required coverage would provide a defensive zone or picket fence for ICBMs in the boost phase to penetrate. The effective weapon range would allow a satellite to begin picking them off as they entered the satellite's zone of coverage. Finally, as the ICBMs passed through the satellite constellation altitude they would be entering the zone of 100 percent coverage on their way to their final boost-phase altitude of approximately 400 km and ultimately to their apogee (maximum altitude) of approximately 1200 km (28:25). The number of satellites required to give 100 percent coverage at constellation altitude is easily determined.

First, the area of the given sphere of coverage must be determined using equation 7. Where A_s is the surface area of a sphere, R_e is the radius of the earth (6378.145 km) and R_o is the orbit altitude above the surface in km.

$$A_s = 4\pi(R_e + R_o)^2 \quad (7)$$

Next, using equation 8 with R_w as the effective weapon range, the coverage area, A_w , of a satellite weapon in the sphere can be determined.

$$A_w = \pi R_w^2 \quad (8)$$

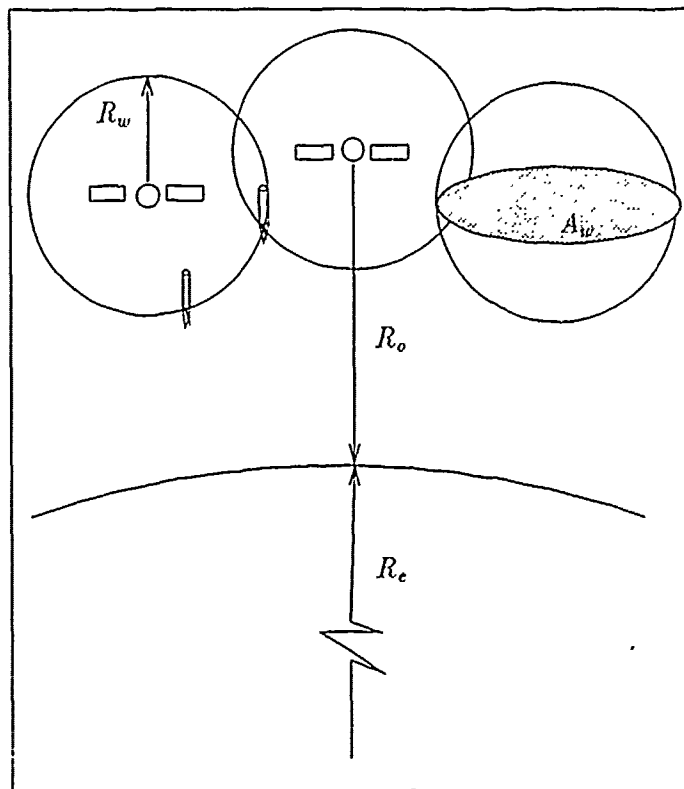


Figure 9. Satellite Coverage of a Missile Attack

Dividing the total area of the sphere by the weapon coverage area results in an approximate number of satellites required for the particular altitude of the constellation and specific weapon effectiveness (Weapon effectiveness is defined under laser lethality). Combine this with a correction factor of $\pi/2$ (36:250) and this results in equation 9 where N is the required number of satellites.

$$N = \frac{4\pi(R_e + R_o)^2}{2R_w^2} \quad (9)$$

The correction factor is necessary to compensate for the fact the weapon coverage area is circular and must overlap for complete coverage (36:250). One interesting point should be known. This number, N , provides uniform coverage, but orbital motion may result in occasional momentary clustering of satellites resulting in higher densities in some places and lower densities in others. This effect will be accounted for through the use of the constellation shot flexibility covered in section 6.2.5.1.

Expanding the weapon coverage into three dimensions, it is apparent the weapon actually covers a spherical volume in space. If R_o is less than R_w than the weapon actually has sufficient range to reach the surface of the earth (ignoring atmospheric effects) (reference Figure 10). However, due to the spherical nature of the effective weapon range, complete earth coverage of the surface will not result.

The apparent area covered by the satellite as projected on the surface of the earth would be smaller than actual area covered at the constellation sphere. A reasonable approximation of the apparent earth area underneath the weapon area would be obtained by dividing the number of satellites into the earth's surface area. The earth's surface area can be obtained by using equation 7 and setting R_o equal to zero. The resultant answer is 511,209,175.8 square km. Dividing this number by N gives the apparent surface coverage of the individual satellite. Substituting this area into the basic equation of a circle, of which equation 8 is a variation, allows the determination of the apparent radius of the transposed surface weapon coverage area. Doubling this radius will give the apparent distance between satellites to an earth-based observer. Armed with this apparent distance, apparent surface velocities and times of passage can be determined.

6.1.3.1 Satellite Period and Apparent Surface Velocity. An interesting fact about orbital mechanics is that the time to orbit the earth (period) can be

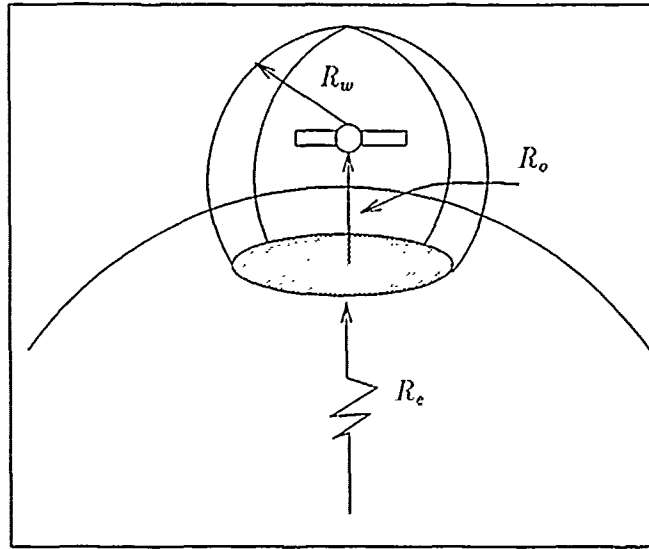


Figure 10. Weapon Interaction on Earth Surface

defined strictly as a function of altitude when the orbit is circular. Equation 10 defines a period (P) in terms of an earth gravitational parameter, μ , and a (which, in a circular orbit, is the sum of R_e plus R_o) (4:33).

$$P = 2\pi \sqrt{\frac{a^3}{\mu}} \quad (10)$$

This equation simplifies by using the internationally accepted value of $3.986 \times 10^5 \text{ km}^3/\text{sec}^2$ for μ resulting in equation 11 which gives the answer in seconds (4:429-430).

$$P = 9.952 \times 10^{-3} a^{\frac{3}{2}} \quad (11)$$

Dividing the circumference of the earth by the period and neglecting earth's rotation (a reasonable assumption for high inclination orbits which will be explained later) will give the apparent velocity of the satellite on the surface. After taking the resultant number and dividing it into the apparent distance between satellites, as previously determined, will result in the time increment between satellites. Satellite direction will be covered under the section on orbit inclinations.

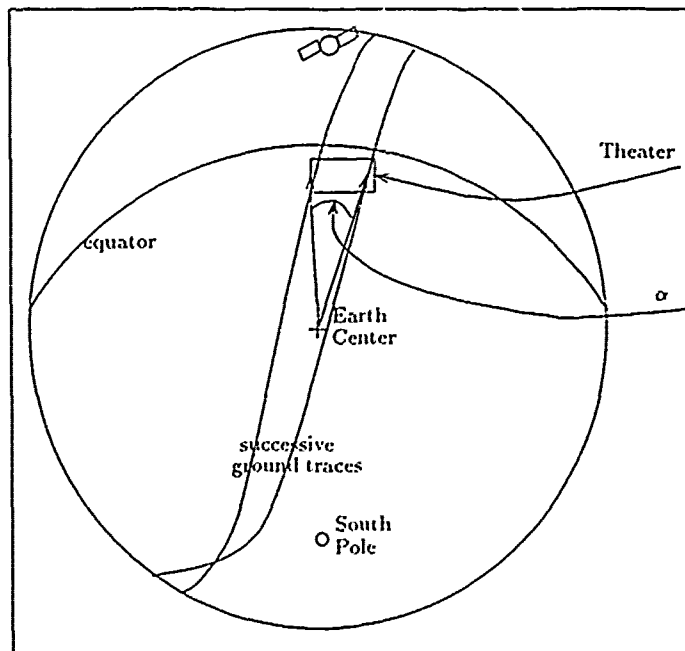


Figure 11. Earth's Rotation and Subsequent Ground Track Displacement

6.1.3.2 Earth Rotation. While the satellites are proceeding in their orbits, things on earth are not standing still. The earth completes one rotation from west to east every 23 hours and 56 minutes (4:306). If you divide the circumference of the earth by the period of rotation you get the velocity for the earth's surface at the equator moving west to east. At higher latitudes the surface velocity is much smaller since the surface is much closer to the axis of rotation. The correction factor is $\cos \delta$ where δ is the latitude in degrees. This rotation and subsequent displacement is shown in Figure 11.

6.1.3.3 Orbit Inclinations. Orbital inclinations (the angle the flight path of the satellite makes as it crosses the equator) are a function of launch pad location, and mission requirements. The physics behind launches will not allow a satellite to be launched with an inclination less than the latitude of the launch pad. Inclination angles higher than the launch pad latitude are possible, however. Other physical properties must take into account the earth's rotation. Generally, most satellites are launched from west to east to take advantage of the velocity imparted by the rotation of the earth. Such an orbit (prograde) allows a larger satellite for a

given rocket as compared to a retrograde orbit (an orbit with an east to west component). Although launch pad location is an important factor, the most important determinant on satellite inclination is the intended mission.

The intended mission will frequently determine the type and altitude requirements of a specific satellite. If a low-earth orbit satellite is to completely cover the earth's surface each day then a polar (north-south) inclination allows a satellite to cross over each portion of the globe twice a day. Reconnaissance satellites frequently use this inclination. Communications satellites use an orbit at approximately 36,000 km (geosynchronous altitude) for maintaining orbit over one geographical area at all times. Unfortunately, a geosynchronous orbit does not allow the satellite to remain at one point over the earth unless the point is at the equator.

Based on these basic factors, this wargame design will assume polar orbits when possible. If a polar orbit is not possible the satellite ground trace will have a general west to east component of travel on the earth's surface. Meanwhile the successive ground traces of the satellites will slowly progress westward due to the rotation of the earth. The polar orbits will allow for complete earth coverage while the west to east component will follow the general prograde direction in orbits with inclinations less than ninety degrees. An area not examined in this project but may be included in further studies, could be the determination of any advantages which may accrue from a retrograde orbit.

6.1.3.4 Partial Orbital Coverages. While complete and simultaneous coverage is the preferred method of deployment, this type of coverage may not be the type offered by the constellation in existence at the time a conflict may occur. The constellation may not have been completed at the time hostilities began, or it may not be as extensive due to treaty limitations, or it may not be as envisioned due to the large cost required in placing this type in orbit. There are two possible means for accounting for incomplete satellite coverage. The satellite constellation can be determined as a percentage of the total required and reducing the number of passes at a specific location, or a constellation may provide continuous complete location coverage only over a portion of the globe.

6.1.3.5 Partial Coverage Over the Entire Surface. The first option for determining partial satellite constellations may be used when hostilities erupt before

constellation completion, or when a complete constellation may be too costly and a partial constellation is considered sufficient to deter an attack on the United States. Such a constellation would still cover the entire globe but there would be portions of time when no coverage existed at specific geographic locations for brief periods. This constellation would be sufficient to introduce an element of doubt into the planning of any offensive strike against the United States.

The simplest method of computation would be to determine the beginning number of satellites at the start of the wargame and make a percentage comparison against the required number for complete, simultaneous coverage as previously determined. This percentage can be used as a basis for either lengthening time between passes or reducing the number of passes over geographic locations.

6.1.3.6 Complete Coverage Over Specified Latitudes. An alternative solution may be to use complete simultaneous coverage over only a portion of the globe. This would envision a continuous band of coverage out to only a specified latitude both north and south (Figure 12). This type of coverage may be more appropriate for a limited protection scheme against a perceived Third World threat. Alternatively, this deployment may be the result of incomplete deployment when hostilities begin as well the previously mentioned complete global coverage with an incomplete constellation. The band of an incomplete constellation could possibly result from a deployment scheme if it is determined to be more advantageous (although not likely) to deploy inclined orbits covering the earth's surface around the equator prior to deploying polar-orbiting satellites.

In Figure 13 the representation of the sphere's area as a band instead of a complete sphere is given by equation 12.

$$A_s = \pi^2(R_e + R_o)h \quad (12)$$

The previously discussed correction factor has already been included in equation 12. The definition for h becomes clear upon examining Figure 13. The symbol $\frac{h}{2}$ represents the perpendicular distance from the equator to the end of the zone of coverage specified by the latitude. Equation 13 gives the appropriate solution for determining h .

$$h = 2(R_e + R_o)\sin\delta \quad (13)$$

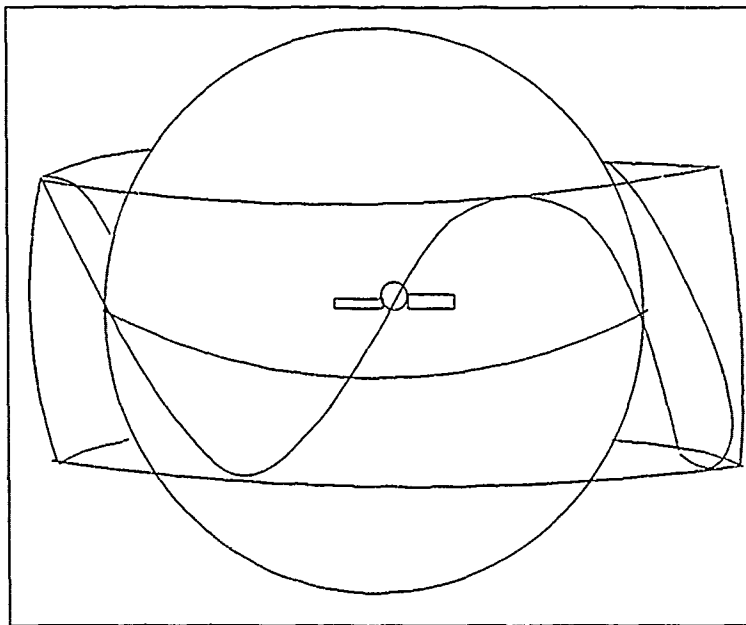


Figure 12. Coverage by an Inclined Orbital Constellation

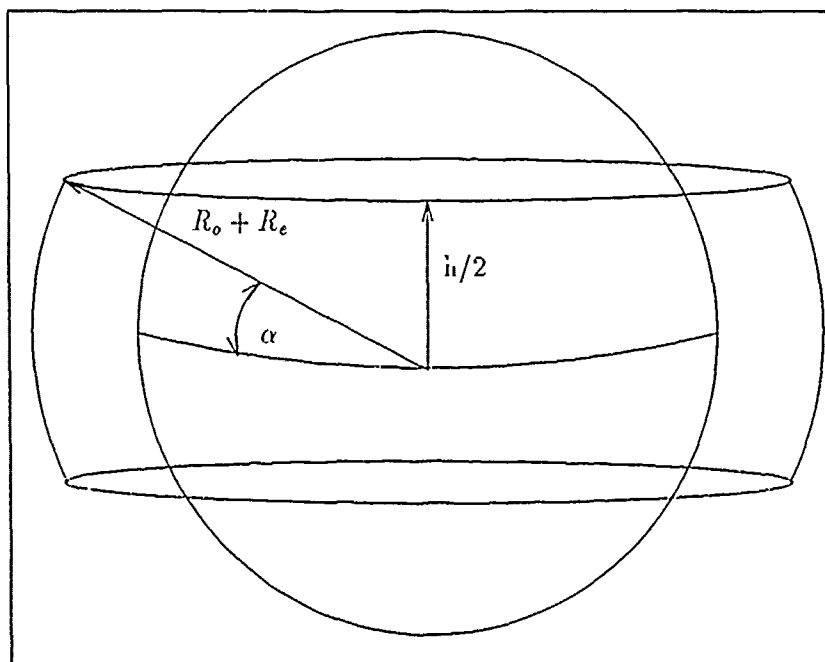


Figure 13. Determination of the Area of a Spherical Band

Using this area instead of the area as determined by a complete sphere allows the calculation of N satellites from equation 9. These satellites would also exhibit a more west to east component of velocity than spherical coverage with its polar orbits would.

6.1.3.7 Sensors and C² Satellites. The sensors and command and control functions may be mounted on the satellites with the weapons platforms but are more likely employed on separate platforms. This would prevent the formation of high priority targets due to the possibility of destroying several mission functions with one satellite kill. However, due to deployment costs of a large constellation with single purpose satellites, there is still a possibility of high value satellites being deployed.

The sensors would be multispectral with redundancy built into the constellation through a large number of sensor satellites. To simulate the redundancy, the number of sensor satellites must be entered prior to the beginning of the game. In addition, any sensors which are part of a multipurpose platform i.e. mounted with a weapon system or command and control system, must also be clearly identified.

The command and control systems would be redundant with multiple crosslinks to maintain adequate command and control of the entire constellation. C² systems would be responsible for the handoffs between sensor platforms as their orbit passes over the theater. In addition, the C² systems would order targeting priorities and pass targeting information to the weapon platforms.

To properly track multispectral sensors, weapons platforms, and C² mounted on multipurpose platforms the percentage breakdown of each type of multipurpose platform and the total contribution to each mission must be determined. For example, assume the constellation is required to have 550 weapon platforms due to the factors previously discussed. In addition, assume the control group decides the constellation must have 450 sensor platforms and 250 C² platforms. However the total constellation is composed of only 1000 satellites. Obviously there are several multipurpose satellites in the constellation. One method of entering the breakdowns for this example is given in Table 3.

6.1.4 Weather. Mann proposed incorporating weather into his model through the use of a preprocessed data file (26:57). A similar method is probably appropriate for SWATTER. However, SWATTER allows for a little more dynamic weather

Table 3. Constellation Mission Breakdown

Satellite Type	Number Required	Percent of Constellation
Weapon	400	40
Sensor	300	30
C^2	100	10
Weapon with Sensor	50	5
Weapon with C^2	50	5
Sensor with C^2	50	5
Weapon, Sensor and C^2	50	5
Total	1000	100 %

changes through generating random changes in the cloud cover, to represent cloud dissipation and regeneration, within each ground hex. The dynamics of this changing cloud cover will be explained in the discussion on active algorithms.

6.1.5 Preprocessing Revisited. SWATTER generally requires an enormous amount of data to be entered before the wargame commences. This data can be entered in numerous ways. The most feasible method would be the use of data files for many of the functions throughout SWATTER. Although, SWATTER does require the user to generate some of the satellite constellation data based on scenario limitations and other data, this portion of SWATTER could be handled quite easily through the use of a simple preprocessing software package. This package could ask the control group pertinent questions and generate the required data for use in the active algorithms. If a preprocessor is not developed, the control group will have to carefully generate the required data manually through an ASCII word processor.

6.2 Active Algorithms

The active algorithms are the ones concerned with processing the information and decisions made during the wargame and rendering the outcome of the efforts by the players. The algorithms are many and varied and are directly concerned with determining the actions to take and the outcomes of these actions. Many areas of algorithms need to be covered. These algorithms include satellite movement and representation of this movement upon the surface, detection determination, probability of shooting, probability of hitting the target, probability of kill on the target,

command and control representation, satellite replacement or repair, weapon attacks on the constellation, weather determination, and interactions on the previously mentioned algorithms. While some of these ideas may include preprocessing algorithms they are included here since they are easier to understand in context with the active algorithms associated with them. The first area to examine will be the satellite movement and how this interacts with targets on the surface.

6.2.1 Satellite Movement. The tremendous speeds associated with a satellite make it a very difficult task to model individual satellites in orbit while keeping the simulation running fast enough for playability. For example, a constellation with a weapon range of 200 km established at an altitude of 200 km would require almost 6800 weapon platforms as well as associated C^2 and sensor satellites. These satellites are traveling around the earth once every 85 minutes at an apparent ground velocity of 474 km/min. A satellite in such an orbit would cross an air hex in 9 seconds and a ground hex in 3 seconds. With complete earth coverage, a satellite in the same orbital plane would follow the preceding one every 39 seconds. Tracking all of these satellites, even with the highly simplifying assumptions made, would make the game very unplayable due to the increased computational time required.

To simplify the computation involved, the constellation is assumed to exist as a fairly homogeneous constellation. Due to the high speed of the satellites, strips of the theater ground hexes will be examined for interactions with the satellite constellation. These strips will be aligned with the flats of the hexes. In the implementation of Mann's model, the flats are oriented north and south (39). This orientation is the optimum orientation for modeling the constellation effects as will become apparent later.

During its orbit, each satellite tracks, or traces, over a specific ground track. For a polar orbit these traces run north and south over the surface (Figure 14a). For inclined orbits these ground traces follow a diagonal track on the hexes (Figure 14b). This orientation allows most types of circular orbits to be easily represented within SWATTER. The most noticeable exception is an equatorial orbit with no inclination. Fortunately, such an orbit has marginal utility when considering an SDI weapon system.

A timer will begin at the time the first satellite would start to track over the desired strip of hexes. After the satellite passes over the ground trace a subsequent

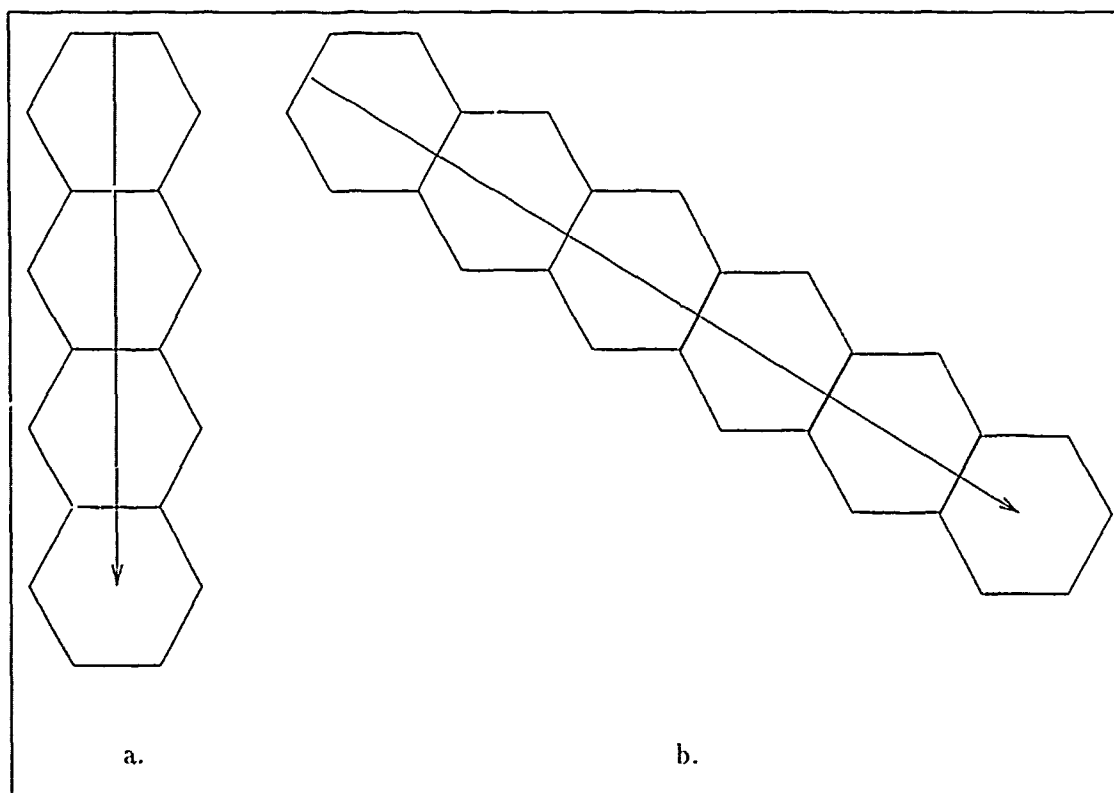


Figure 14. SWATTER Ground Traces

satellite will pass over the previous ground trace except for the small distance the earth has rotated to the east since the previous pass. Equation 14 gives the amount of rotation, $\Delta\alpha$, each location on the earth rotates in km per second with the latitude, δ , of the location given.

$$\Delta\alpha = \cos\delta * 0.465\text{km/sec} \quad (14)$$

Once the hex strip has rotated 25 km, the orbital plane is placed one hex strip west of the previous hex strip examined. For example, assume δ is 63° N and the satellites are 39 seconds in trail. Based on these number the earth surface rotates west at 0.21 km/sec and the entire hex strip moves one hex west after 118 seconds after three weapon satellites have passed overhead.

The entire theater covers a large area of hexes so it is possible for several satellites to be crossing the theater simultaneously. Since the satellites would have the same inclination and would be broken up into several distinct orbital planes it is fairly easy to determine the number of hex strips being crossed in the theater simultaneously (Figure 15). In examining a weapon system established at 200 km altitude with a weapon range of 200 km, each ground hex strip would be separated by approximately 310 km, or roughly 12 hexes.

Each satellite plane is fixed in space with each satellite remaining in its plane and revolving in the same direction. However, the earth is rotating and the direction of satellite movement will appear to change depending on the portion of the orbital plane the hex is moving under. If Figure 16 is examined, it becomes apparent when the theater is under the orbital plane A, satellite movement appears to have a southern flow. However, after the theater has rotated to the opposite side of the orbital plane (approximately twelve hours later), the satellite movement appears to follow orbital plane B and has a northern flow. The important point to remember is the orbital plane does not change but the earth rotates beneath the plane.

Therefore, every twelve hours the ground hex would pass under the same orbital plane but the satellite movement will appear to have changed directions. To represent this constantly changing direction of apparent satellite movement, SWATTER will randomly chose the direction of satellite movement, but not the inclination, at the beginning of the scenario and change the satellite movement direction automatically every twelve hours. It is important to remember if the satellite orbital plane is

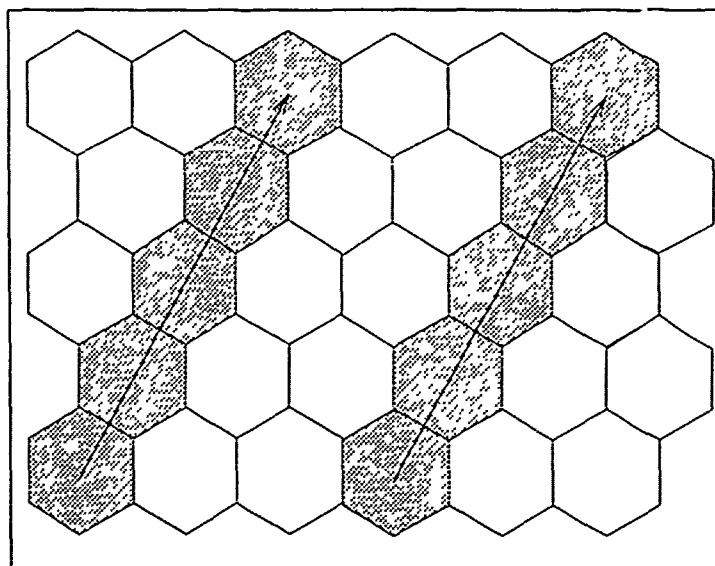


Figure 15. Multiple Orbital Planes Over the Theater

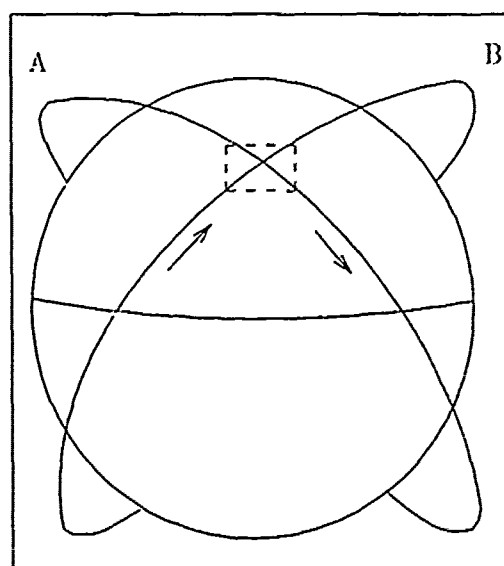


Figure 16. Relationship between a Theater of Operations and an Orbital Plane

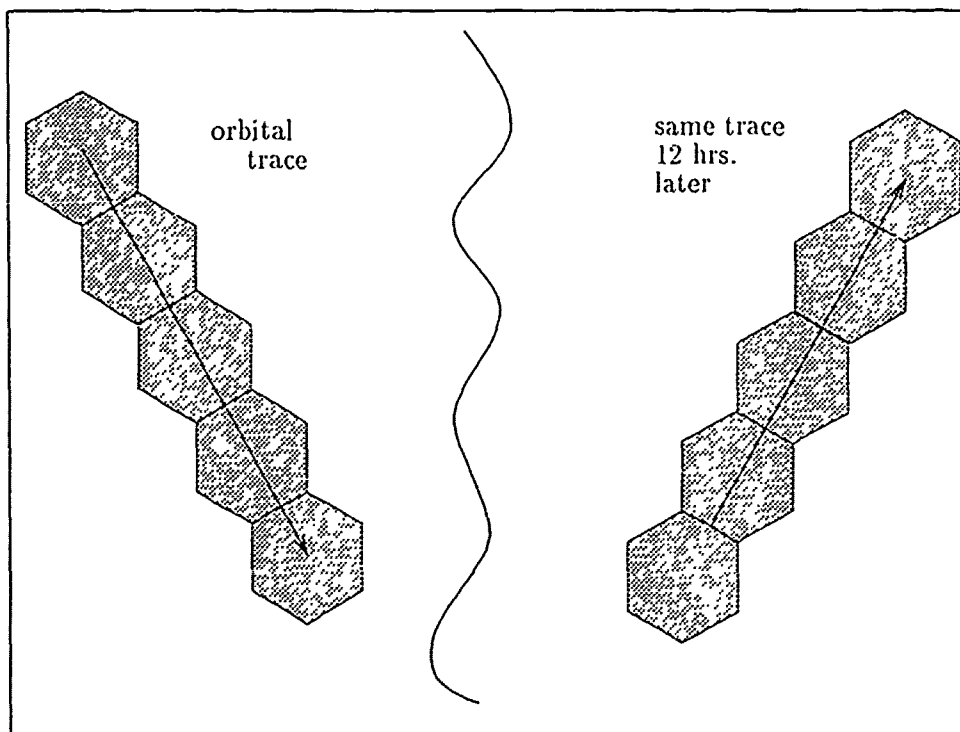


Figure 17. Orbital Inclination Changes

inclined then when the satellite flow changes the inclination of the ground strip will also change. If the inclination at the first pass gives a southeasterly travel on the ground trace, then the next pass, twelve hours later, would have a northeasterly flow (Fig. 17).

Since the earth rotates and the orbital planes remain fixed, the target hex would pass beneath the same orbital plane approximately twelve hours later. However, the satellites which previously passed over the hex strip may not be the same ones passing over the hex strip at the new time. For the same satellites to pass over the same hex strip twelve hours later, the satellite must have traveled the same fraction of an orbit as the portion of the orbit the earth has moved under. Referencing Figure 16 for a polar orbit with an initial velocity vector south and where plane A is the point where the satellite is over the theater located at 60° N. twelve hours later the theater will again pass under the orbital plane at B. However the same satellite will not pass over unless the satellite has completed several complete revolutions plus a fraction of an orbit equivalent to 240° or $\frac{2}{3}$ of a period.

An important point to remember is the fact that if the satellite is able to pass over the theater at twelve hours then the same satellite will not pass over at A again at 24 hours. This is due to the fact the satellite travels several complete revolutions plus the previously mentioned specified fraction within twelve hours. In Figure 16 the fraction was determined to be $\frac{2}{3}$. However, since the orbit from B is over the top, point A is only 120 degrees, or $\frac{1}{3}$ of an orbit from point B. Therefore, in Figure 16 the satellite would be approximately 60° past point A after a 24 hour time period. The only point where the same satellites could pass over the same point every twelve hours (at least in a circular orbit) would be a point located on the equator.

Due to the fact that satellites are extremely unlikely to make multiple passes over the same ground point in a 12 or 24 hour time period, a simplification for SWAT-TER has been made. As soon as a ground hex strip (which in reality represents the orbital plane) leaves the theater, any special characteristics which become associated with the ground trace (hex strip) becomes lost after the trace has departed the theater. For example, any satellites lost due to enemy fire or other causes would appear as a lack of firepower every 85 minutes (for a 200 km orbit) while the trace remained within the theater. After the trace departed the theater the constellation would assume the homogeneous character in existence at the beginning of the scenario except for the difference caused by the loss of the satellite from the constellation as a whole. This assumption is also fairly valid due to the fact the satellite operators would immediately begin making adjustments to the constellation to minimize the problem caused by the satellite loss.

The laser weapons can always reach targets in the air hexes which are directly above the ground hex strip directly below the satellite. In addition to the hex strip directly below the satellite orbit plane, the adjacent hex strips must be examined if the weapon system has an effective weapon range greater than the orbit altitude and therefore, may have the capability to reach the adjacent hex strips. While this area would be determined during the preprocessing stage, it is easier to understand if covered in conjunction with the rest of the satellite movement phase of the active algorithms.

Referring to Figure 18, the satellite is directly over one hex in the ground hex strip. The air hex is centered over the ground hex left and directly adjacent to the ground hex below the satellite. Since SWAT-TER only uses five altitude blocks and combines Mann's tree top altitude with the ground hex, the only way SWAT-TER

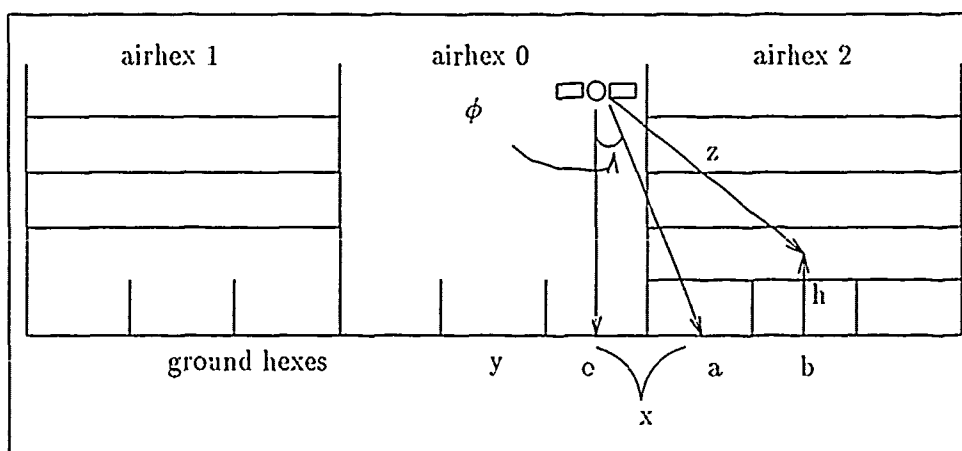


Figure 18. Weapon Effects on Adjacent Hexes

could attack tree top aircraft would be if SWATTER could attack the adjacent ground hex. However, for the purpose of the wargame, SWATTER can reach all other air hexes associated with the ground hex strip.

The adjacent ground hex strip may be attacked if the weapon range is sufficient to reach the center of the adjacent hexes. Again referring to Figure 18 the range to adjacent hexes is easily determined. The distance to hex of interest (hex a) is determined. In this case, the distance between the centers (x in equation 15) of the two adjacent ground hexes is 25 km. Using equation 15 the angle ϕ from the satellite to the new target hex can be determined.

$$\phi = \arctan \frac{x}{R_o} \quad (15)$$

The distance (z) from the satellite to the potential target hex is then computed using equation 16.

$$z = \frac{x}{\sin \phi} \quad (16)$$

The orbital altitude is shown as 200 km and assume the weapon has a range of 205 km. Based on these assumptions the angle from the satellite to the potential target hex (a) is 7.125° and the distance from the satellite to hex a is 201.6 km. Examining hex b as a potential target reveals ϕ is equal to 14.04° and z is equal to

206.2 km. Therefore hex b is not a targetable hex. Because of the extra weapon range, the preprocessor would determine the ground hex strip would include hexes o, a, and y (due to geometric symmetry). Therefore, the hex strip tracked by each satellite orbit would be three hexes wide. These wider strips would also be under direct attack by the same orbital plane for a longer time as well. In other words, an earth hex would have to rotate 75 km from the moment it first came under the influence of an orbital plane until the moment it left the area of influence.

Range determination to air hexes would have to be handled slightly differently in the preprocessing stage. The preprocessing stage would use the center of the altitude block and the center of the air hex of interest for determining the utility of targeting. The distance to the air hex would be measured from center of the ground hex the satellite is centered over to the center of the desired air hex. SWATTER will take the center of the altitude block (h) being examined to determine range to the target air hex. Using equation 17 below gives the angle from the satellite to the air hex.

$$\phi = \arctan \frac{x}{R_o - h} \quad (17)$$

Determining the satellite distance doesn't change for air hexes. Once ϕ is determined the distance is again determined using equation 16.

In Figure 18 the distance between ground hex o and air hex 2 is 50 km. Assuming the air hex of interest is an air hex at high altitude, the center (h) of the altitude block is approximately 6000 m. Based on the previously mentioned equations, ϕ is 14.45° and x is 200.3 km. Therefore, the laser is able to reach high altitude hexes in air hex 2. However, air hex 1 with its high altitude block is 100 km away and has a ϕ of 27.3° resulting in a x equal to 218.3 km. If the satellite was centered over its own air hex 0, ground hex y, both adjacent high altitude air hexes would be at a range of 208 km from the satellite and could not be fired upon.

The preprocessor would have to expand the ground hex strip to include the adjacent air hexes (Figure 19). The tracking of the satellite orbit over the hex strip would have to account for the fact that when the satellite enters the leading edge of an air hex strip then the previous air hex strip may still have altitude blocks within weapon range. At the same time the air hex next in succession after the current one may not be within weapon range. As the ground trace progresses through the

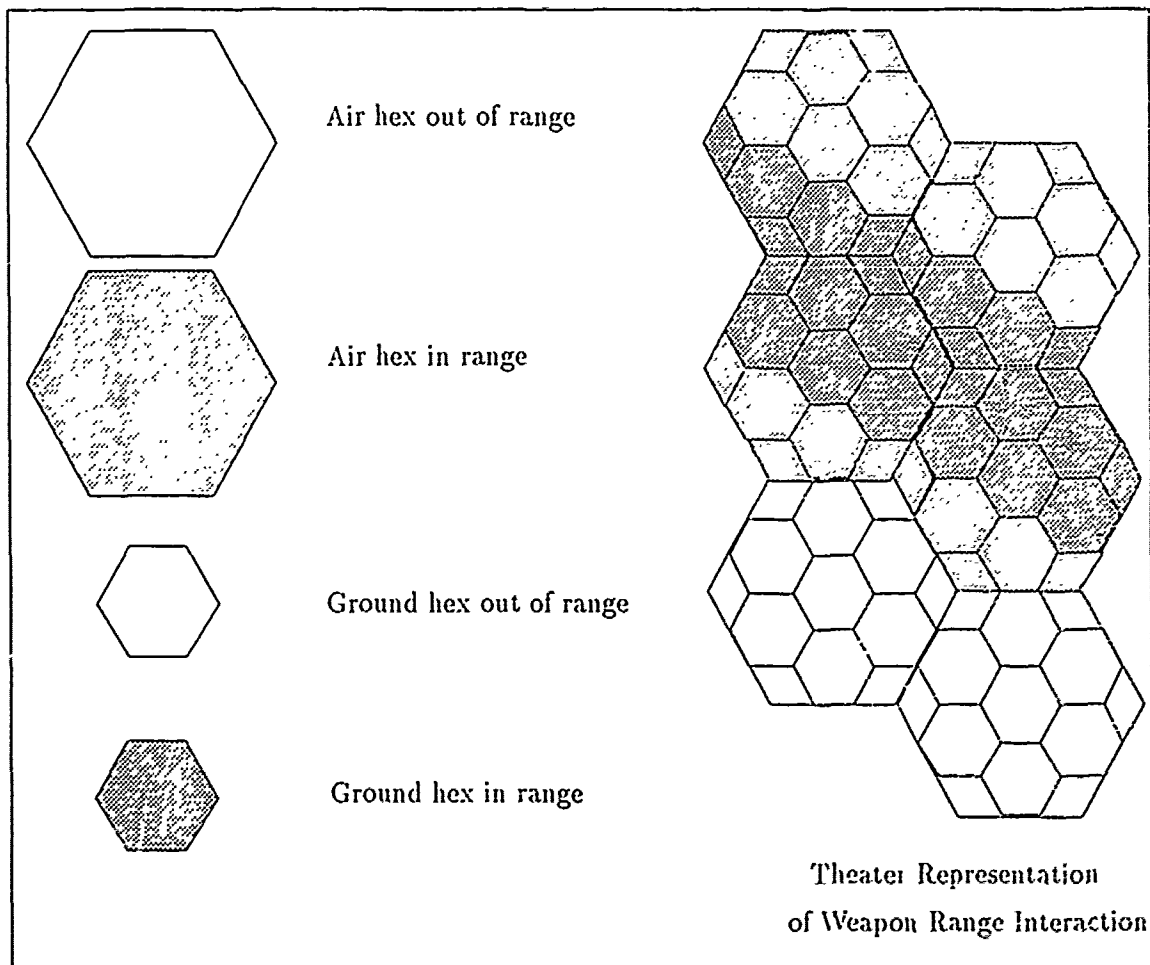


Figure 19. Laser Interaction on Adjacent Air and Ground Hexes

air hex into the central ground hex, neither adjacent air hex may be within weapon range. Finally, as the ground trace reaches the trailing edge of the hex strip, the previous air hex strip may be out of range but the next successive air hex strip may be within range.

6.2.2 Detection Determination. Since the satellite constellation provides almost instantaneous detection coverage of the entire theater, typical detection formulas which depend on intermittent detection sweeps would not work. Due to the continuous detection by the constellation, the best and simplest methodology is to use simple probabilities for detection of targets. These probabilities would be as-

signed to each type of target in its associated data file. Each type of target would have a specific probability associated with the characteristics exhibited by the target. Characteristics of the weapon system which would be accounted for in the detection probability would include the target size, intensity of radar return, and IR return. In addition, several modifiers would be used for determining the overall detection probability of each individual target based on local conditions. These modifiers would account for the command and control exhibited by the constellation, handoffs between orbital planes, weather, terrain, and altitude. Therefore, the basic SWATTER detection equation would be the one seen in equation 18 where P_{det} is the probability of detection, C is the command and control modifier, S is the sensor status modifier, W_q is the weather quality modifier, W_c is the weather ceiling modifier, T_{alt} is the terrain modifier, H_{type} is a sensor handoff modifier, and P_{tgt} is the individual target probability before modification.

$$P_{det} = C * S * W_q * W_c * T_{alt} * P_{tgt} + H_{type} * C * (1 - (C * S * W_q * W_c * T_{alt} * P_{tgt})) \quad (18)$$

The first half of equation 18 is the basic detection of the target. The second half of the equation takes the probability of no detection for the orbital plane and decreases the overall failure to detect by a factor of the ability of the sensors to handoff to subsequent sensors. In addition, the status of the command and control functions can affect the ability of the sensors to affect the handoff of the detection information.

The handoff modifier H_{type} represents the ability of the satellite constellation to pass information from sensor to sensor and keep track of the targets detected. SWATTER uses H_{type} to pass known information on each target between the orbital planes (ground hex strips) of the constellation. H_{type} is really dependent upon the type of target being detected. While the range of H_{type} can be from 0 to almost 1, the type of mission SWATTER is deployed to meet would cause H_{type} to be high once a missile target is detected in the air. However, limitations in the system and the mission needs would make H_{gnd} on ground targets a lower value while aircraft would have an intermediate value. These values are arbitrary and care should be made in their selection. If the value is extremely close to one, then once a target is detected SWATTER would maintain almost perfect coverage with almost no chance

Table 4. Sample Data Base for Detection Probabilities

Characteristics	T-72	Mig-25
H_{type}	0.5	0.7
T_{alt}	0.3	0.85
P_{tgt}	0.4	0.6
P_{tgt} with afterburner	-	0.85
P_{rec}	0.1	0.8
P_{id}	0.4	0.8

of losing target contact. While such an attribute would be highly desirable and quite likely in missile detection and tracking, the likelihood of such a value for ground targets is slim. This value would be entered in the preprocessing stage as part of the individual equipment's data base and would remain constant throughout the wargame. However, until the individual target is detected, the value for H_{type} is zero. If a target is detected and subsequently lost, H_{type} is again set to zero.

The sensor status modifier, S , has a range from zero to one and is simply the percentage of currently operable sensors as compared to the starting number of sensors at the beginning of the wargame.

While using Table 4 for an example data base and setting several of the modifiers (which will be explained in greater detail later) to specific values, the detection probability can be determined for several cases. For the purpose of these examples, the variables C , S , W_q , and W_c are set equal to one.

Based on the numbers presented several detection probabilities for the different equipment and conditions can be determined. The first time detection probability of the tank is 0.12. Meanwhile, the aircraft has two possible detection probabilities based on engine operation. If the aircraft is operating with afterburner (AB), the probability of detection is 0.72 while without AB the probability drops to 0.51. However, on subsequent orbital planes passing over the aircraft after detection, the probability for remaining in contact jumps to 0.85 without AB and 0.91 with AB. The probability of maintaining tank contact, once achieved, for subsequent passes jumps to 0.56. However, if at any time contact is lost, the probability of detecting targets reverts back to the original probability. If a target is not detected at the beginning of an orbital plane passage it remains undetected throughout the passage.

Due to the ubiquitous coverage provided by the constellation, every satellite on a specific orbital plane has the same detection and targeting information available to it. Also, due to the large number of satellite sensors and specific design purpose, the entire constellation can function in the same manner as a synthetic aperture radar and provide basic velocity, heading, and altitude information as well as identify some types of weapon systems.

The process for identifying a target is quite simple. There are several levels of target recognition. In increasing degree of information, these levels are: cueing information, detection, classification, recognition, and identification (16:4-1 - 4-2).

"Cueing information provides the approximate location for further search. Detection means that an observer decides that an object in his field of view has military interest. Classification occurs when the observer is able to distinguish broad target categories. Recognition allows discrimination among the finer classes of target. Identification provides precise target identity." (16:4-1 - 4-2)

SWATTER starts the identification process at the classification level. If SWATTER has detected a target, then sufficient information exists from the basic parameters of airspeed and altitude to determine whether they are land vehicles, aircraft, or missiles. The first time a target is detected, the probability of recognition (P_{rec}) is consulted in the entity data base. If the recognition attempt is successful (fighter aircraft or armored vehicle in the example given), then an attempt at type identification (T-72 or Mig-25) is made. The data base is again consulted to determine the probability of positive identification given recognition has been successful. If the vehicle is not successfully recognized no attempt is made at identification. The next successful detection pass by an orbital plane will repeat the recognition and identification phase. This allows the information to increase or decrease in content due to changing conditions.

After an appropriate time delay (probably many minutes and possibly hours for the command structure in place, as well as to allow processing time by the SOL and his staff), all of the information determined by the constellation regarding the detected targets would be passed to the theater commander.

If the orbital plane is passing over a massed formation or an air package, the first time detection is based on the unit within the package or formation with the

highest probability of detection. If the package has previously been detected then maintaining the contact is based on the highest handoff factor of detected vehicles in the package. In addition, a random number draw is accomplished which may result in only a portion of the number and possibly types of vehicles being reported. The determination of the amount of information available for this report would be handled in a manner similar to the INTEL index used by Ness (29:69-70).

The Ness model uses an INTEL index which determines the amount and accuracy of the information going to the theater commander. Each individual unit has an intelligence index which determines the accuracy of the information the opposing player gains about the unit. The intelligence index ranges from zero to one with one as perfect information. Based on the intelligence index, an intelligence filter is constructed. This intelligence filter is based on a random number distribution centered on 1.0 and ranging from zero to two. Based on the intelligence index of the unit, the filter is truncated on both sides of one to correspond to the value of the index. For example if the index is 0.7, the filter would be truncated from 0.7 to 1.3. At this point a random number draw is made within the new range of the intelligence filter. This number becomes the factor by which the unit's firepower is multiplied and the resultant number is reported to the opposing player. In other words, if the unit has a firepower of 100 and the previous example had a random number draw which resulted in a filter number of 1.2 then the opposing player would receive a report of the unit's firepower being 120 (29:69-70) which is an overestimate due to the filter value randomly chosen.

Ness also included different information about the unit based on the value of the index. If the value was less than 0.4 it was reported as a suspected infantry unit. If the value ranged from 0.4 to 0.8 it was reported as an armor unit but with a correct unit designator. Finally, if the unit had an index ranging from 0.8 to 1.0, all unit information was reported correctly (29:70).

However, SWATTER will use the intelligence filter differently. The unit intelligence filter will be based upon whether SWATTER has correctly classified, recognized, and identified the target. If SWATTER has only classified the target, the intelligence filter would be chosen by random number draw on the normal distribution in the range from 0.0 to 0.4 (or 1.6 through to 2.0 for the upper end). This number would be multiplied by the actual number of only the detected vehicles in

the formation and the resultant reported to the theater commander. This report would only indicate class and suspected number.

If the target is recognized, the filter values exist from 0.41 to 0.8 and 1.2 to 1.59. This value would be multiplied by the total number of vehicles in the package (including vehicles not detected during the detection stage) and reported to the TC. In addition, the report would list the recognized vehicles. For example, for a filter value of 0.7 this report may state 42 aircraft (of 60 total within the strike package) are in a hex and some have been recognized as bombers.

If the target is identified, the filter can assume values from 0.81 to 1.19. Again this value would be multiplied by the actual number of vehicles in the hex and the resultant number reported to the TC. In addition to the identified vehicles, any other vehicles in the hex of interest will be recognized. For example, a filter of 1.1 could report 55 aircraft (out of an actual number of 50) made up of B-52s and fighter escorts.

6.2.3 Target Priorities. Once the targets have been detected, they must be ranked in order of importance to determine which targets SWATTER will attack. The target priorities list is established by the theater commander at the beginning of the wargame. The first two priorities can not be changed but are a function of the constellation mission. The first priority is strategic defense against ICBMs while the second is self-defense of the satellite constellation. After these two priorities, the theater commander can determine his own order of priorities. Since the constellation immediately knows all detected targets within the hex strip, SWATTER can immediately assign satellites to targets based on the priority list. However, the length and direction of the satellite trace across the theater in relation to the following distance between subsequent satellites may work to the disadvantage of SWATTER. For example, if the highest priority target occurs on the hex strip at a point just before the first satellite exits the theater and the second highest priority target is at the beginning of the hex strip, the second following satellite may not be able to engage the second target if it waits to determine the outcome of the attack on the highest priority target. In such a case, the second satellite will attack the highest priority target remaining within the hex strip it still has to traverse before exiting the theater.

6.2.4 *General Modifiers.* While certain modifiers which are specific to the detection of targets have already been covered, there are several modifiers which have a more general effect on several processes. One modifier (the handoff modifier) was covered which had a generalized effect on other processes and will not be covered except in general terms in the areas it may affect. The modifiers not previously covered but mentioned include command and control, terrain, and weather. The properties of these modifiers will now be explained in more detail.

6.2.4.1 *Weather.* The weather modifier is actually two modifiers as was previously seen in equation 18. These two modifiers are concerned with the quality of the weather in the target hex and the ceiling in the target hex. Both types of modifiers are handled differently in their determination but not in their effects upon different processes.

W_q is the weather quality within the target hex. Basically this quality of the weather is a measure of the visibility within the target hex. The visibility is affected by the air quality and moisture in the atmosphere. Factors which may affect visibility may include precipitation, smoke, haze, fog, humidity, and dust. The visibility may be independent of the cloud ceiling. SWATTER builds upon the three values of weather given by Mann as good, fair, and poor (26:57). The range of values for the weather quality would range from zero to one. The higher the number the better the weather quality with one being perfect weather. Obviously the worse the visibility, the harder target detection is for light sensors. However, SWATTER uses radar as well as light sensors which would prevent satellites from being completely blinded by almost any weather phenomena. However, radar at certain wavelengths can be heavily attenuated by heavy precipitation. SWATTER defines good weather as having a quality value ranging from 0.2 to 1.0. Fair weather is defined as ranging from 0.6 to 0.89 and bad weather can range from 0.0 to 0.59. SWATTER uses good as the default hex value if no values have been set in the preprocessing phase. The ranges have been set to favor SWATTER's radar detectors when the weather quality has decreased to a less than good rating while at the same time it allows for a downpour's attenuation effects in the poor weather rating category. SWATTER assumes poor weather quality hex automatically has an overcast ceiling modifier as explained later. A weather quality rating of poor automatically prohibits laser fire into the hex due to attenuation effects although detection is still possible. The ranges

have no special significance and can be modified if a different range is felt to be more appropriate.

To help represent the dynamism of changing weather patterns within SWAT-TER, every time a new orbital plane passes over a hex with a potential target within the hex, a random number is drawn from a uniform distribution ranging from zero to one. This random number is multiplied by the difference between the high and low values of the weather quality defined for the hex during the preprocessing. The resultant number is added to the low value for the weather quality range and gives the modifier number for the constellation plane currently overhead. W_q remains constant throughout the satellite orbit pass. A new value is not determined until the next orbital plane moves into range. A new value within the range set at the beginning of the scenario will be determined when every orbital plane passes over. This allows for the constantly changing variability of weather to be modeled.

For example, if 0.7 is drawn for a hex with a weather quality given as fair, the 0.7 is multiplied times 0.29 (the difference between the top and bottom of the fair range) and is added to 0.6 (the bottom of the fair range). The answer is 0.803 and this becomes the modifier, W_q , used through the orbital plane pass for purposes of detection and hit probability.

While the weather quality describes the general condition of the weather within the hex, this description is by no means complete. A significant factor for many types of weapon systems, especially SWAT-TER, would be the cloud cover. It is not uncommon for the weather to have excellent visibility while at the same time having a low ceiling of overcast clouds. Unfortunately, while the visibility would allow SWAT-TER to have a high probabilities of detection and hitting the target, the cloud cover above the target could significantly impact these probabilities.

Therefore, SWAT-TER has incorporated the standard FAA definitions of ceiling types directly into the weather ceiling modifier, W_c . SWAT-TER will use the ceiling of the hex as defined in the preprocessor and again use a random uniform number draw to determine the amount of ceiling in the target hex for the satellite orbital pass. The values used are based on the definitions given for ceilings in a previous chapter. These values must be modified for use within SWAT-TER to give the accurate representation of what SWAT-TER would encounter. For example, a clear sky has less than 0.1 cloud cover. To determine the probability of SWAT-TER seeing through such a layer, the ceiling coverage must be subtracted from one. In the case of a clear sky,

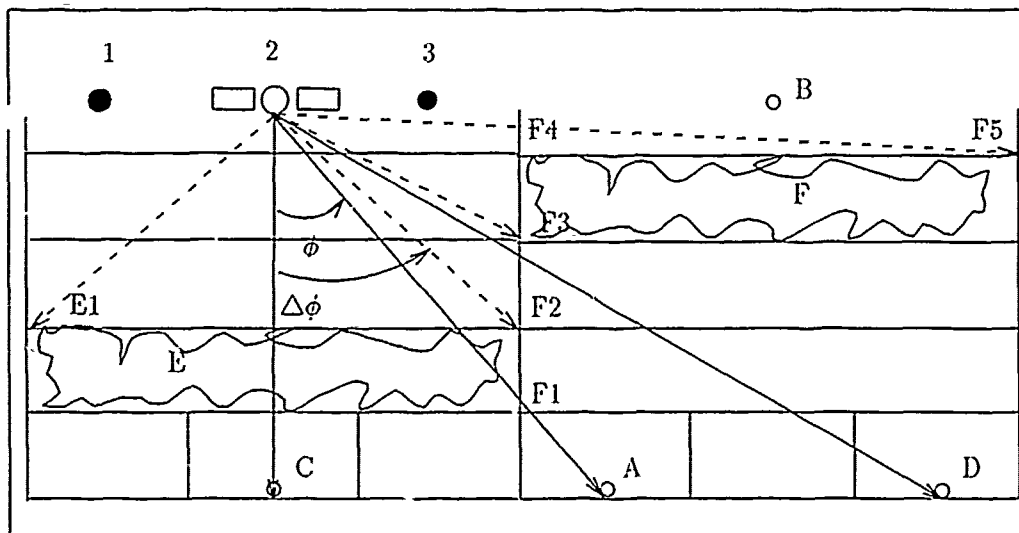


Figure 20. Weather Effects in Adjacent Hexes

the probability of SWATTER seeing through the cloud cover would range from 0.91 to 1.0. This number would then be modified by the random number draw as W_q was and the resultant number would be the weather ceiling modifier, W_c . This modifier is also used in determining the probabilities of detection and hitting the target. If the ceiling is not defined the default ceiling is clear except in cases of poor weather quality. If the ceiling in a hex is undefined and the weather quality is poor then the ceiling default value will be overcast.

While the determination of weather modifiers is fairly straightforward and simple to use for constellation, orbital planes looking straight down, the times when SWATTER is able to reach adjacent hexes would seem to be complicated by weather located in different altitude hexes which may interfere the ability of SWATTER to detect and hit potential targets. In Figure 20, which is not to scale for picture clarity, this potential problem appears to be immediately clear. For example, if the satellite trace is located at position two and is able to reach possible targets in hexes A, B, C, and D, it is immediately obvious the weather in hexes E and F may be a barrier to detection and the laser weapon. While position two appears to have a clear shot at D, weather in the adjacent target's air hexes at an altitude greater than the target will always interfere with SWATTER.

Table 5. Target Angles versus Weather Angles

pos.	ϕ_A	ϕ_D	$\Delta\phi_{F1}$	$\Delta\phi_{F2}$	$\Delta\phi_{F3}$	$\Delta\phi_{F4}$
1	20.57°	32.01	17.4°	17.61	18.13°	20.23°
2	14.04°	26.57	10.65°	10.78	11.12°	12.47°
3	7.13°	20.57	3.59°	3.63	3.75°	4.22°

To prove the adjacent weather is always a barrier, the air hexes with altitudes greater than the target hex will be examined. If the angle, $\Delta\phi$, from the satellite to the nearest bottom corner and to the farthest upper corner of the altitude hex includes ϕ to the target, weather is a factor which must be accounted for. Table 5 uses equation 17 to determine the lower bound of $\Delta\phi$ for each altitude block over ground hexes A and D from satellites located at positions 1,2,and 3. The angle ϕ is compared against these angles and it is immediately apparent when ϕ is more than the $\Delta\phi$ then weather effects must be accounted for. An important difference when using equation 17 occurs during this determination however. The weather is assumed to exist in the entire air hex (only the ground hex if the weather is in the terrain hex) at the altitudes specified in the weather data base and the distance x is determined from the center of the hex strip of the satellite trace to the edge of the weather hex. Additionally, if the satellite is in the same hex stack as the the weather air hex, then $\Delta\phi$ is measured from the high corner weather altitudes of the air hex (E1 and F2). If the angle ϕ to the target does not fall within the angle determined for the weather effects, then weather effects other than good and clear do not have to be accounted for.

6.2.4.2 Command and Control. The command and control modifier is a measure of the effectiveness of the system as a whole. With SWATTER in perfect working order the modifier is set equal to one. As attacks against the system occur, any attacks against the C^2 satellites results in a decrease in the control effectiveness of the entire constellation. The simplest method for determining this modifier would be to use straight percentages. For example, when using 100 satellites devoted to C^2 and an attack on the constellation destroys two of these satellites the command and control modifier would be decreased to 0.98. If the system is considered to have extensive crosslinking capability with the result that losses affect the constellation

Table 6. Sample Terrain Modifiers for Altitude

altitude	value
low	0.7
medium	0.85
high	0.95
very high	1.05
space	1.15

in a significantly smaller increment, other methods may be used similar to the ones detailed later in the section on shooting probability.

6.2.4.3 Terrain. The terrain can affect the probability of locating a target as well as hitting the target. The rougher the terrain the greater the likelihood of not detecting the target. A tank moving through mountainous terrain is much less likely to be detected than one moving across open plains. Therefore, to incorporate SWATTER into a wargame the terrain modifier used for surface movement should be linked to the terrain modifier used by SWATTER. These modifiers would be entered during the preprocessing phase for the terrain data base.

However, this terrain modifier should only apply to targets on the surface and at treetop level. As the target moves away from the surface, the terrain on the surface has a significantly smaller effect on detection probabilities and no effect on the probability of hitting the target. For the purpose of SWATTER, if the target is above tree-top level, then the terrain hex modifier is not used but an altitude modifier is used in its place. This altitude modifier can be assigned during the preprocessing phase and is a simple measure of the effectiveness of SWATTER at different altitudes. Increasing values from low-altitude to space would be used to reflect the ability of SWATTER to operate in different environments. The value can exceed one in the areas where SWATTER may excel in target detection and destruction. One sample array is shown in Table 6.

6.2.5 Constellation Shot Probability. In the early stages of the conflict the constellation will be able to fire at will. However, as time passes and shots are used or satellites are destroyed, having satellites with firing volleys available over the desired target area will become less and less likely. Additionally, the cooling time required

for a satellite weapon may only allow a certain number of shots by a satellite while its orbital plane is in theater.

6.2.5.1 Constellation Shot Flexibility. During the preprocessing stage the number of shots available to the theater commander was determined as a percentage of the total shots available from the constellation. This number is now converted into a number of actual shots. The theater commander also has the option of further restricting the number of shots by reserving a specified percentage of the shots he has available for missile defense. This reserve is subtracted from the shots the TC has available for a final total of the shots the TC can use in any manner he desires.

The probability of shooting at a particular time over the theater is a function of the number of targets engaged, the time between targets engaged, the flexibility of the constellation, the number of shots available, and attacks on the constellation. Three possible methods for representing this probability are presented. These methods are named marginal, percentage, and optimum.

The first possibility examined, covers a constellation which is fairly inflexible. Assuming the constellation has fired a large number of volleys in close succession, the constellation would have periods of coverage when the weapon platforms which have exhausted their fuel and are no longer able to fire are overhead. In addition, the satellite operators are not able to make adjustments to the constellation which may allow the movement of firing capable satellites into position. The SDI organization does not allow the constellation to have local satellites dip below the capability assigned to the SDI mission. In other words, a satellite assigned a specific percentage of the SDI mission would have to reserve the fuel necessary for that mission and could not be taken below that reserve even if the lost amount is made up by a different satellite located elsewhere in the constellation. This marginal probability could be represented by equation 19. P_{shoot} is the probability of shooting, S_r is the number of shots remaining, and S_u is the number of shots used. This method requires a check on shots remaining before applying the equation because, after all shots are fired, an attempt to use the equation would result in division by zero and possibly end the simulation.

$$P_{shoot} = e^{-\frac{S_u}{S_r}} \quad (19)$$

The percentage method of determining shot probability represents a somewhat flexible constellation. The shot probability is homogeneously reduced throughout the constellation as each shot reduces the probability of the next shot on a percentage basis. This percentage method could be used to represent a constellation where the operators are able to marginally move the satellites to a more advantageous firing position or the TC is willing to use some of his reserve for a fire mission in exchange for another satellite's capability being used to replace the used portion. This is a straightforward method, easily determined as shown in equation 20. The term S_t stands for the total number of shots allocated for fire missions by the theater commander at the beginning of the scenario. This method would not require a shot check before attempting to fire.

$$P_{shoot} = \frac{S_r}{S_t} \quad (20)$$

The final method, named optimum, represents a robust constellation where the satellite operators are able to easily move the satellites into a firing position fairly rapidly, or the SDI organization is willing to accept some gaps in their coverage while other satellites would have large amounts of excess capability in the SDI role. This robust system is represented in equation 21. This equation requires a check on shots remaining otherwise the constellation may continue firing after all shots are exhausted.

$$P_{shoot} = c^{-\frac{S_r}{S_t}} \quad (21)$$

To demonstrate how these probabilities work, assume the constellation consists of satellites with a total of 10,000 shots. The SDI organization has reserved 80 percent of the total for their mission. This leaves the TC with 2,000 shots of the constellation. The TC decides to reserve 1,000 of these shots for missile defense. The TC now has 1,000 shots to allocate as he desires. However, he may not fire when he wants but may be limited by the fire probability scheme in place. The various probabilities for firing under the different methods is shown in Figure 21.

The shots held in reserve are handled in a manner similar to the handling of the primary shots but based on the numbers established for the theater reserve forces. The shots in theater reserve are dedicated to theater missile defense and are only

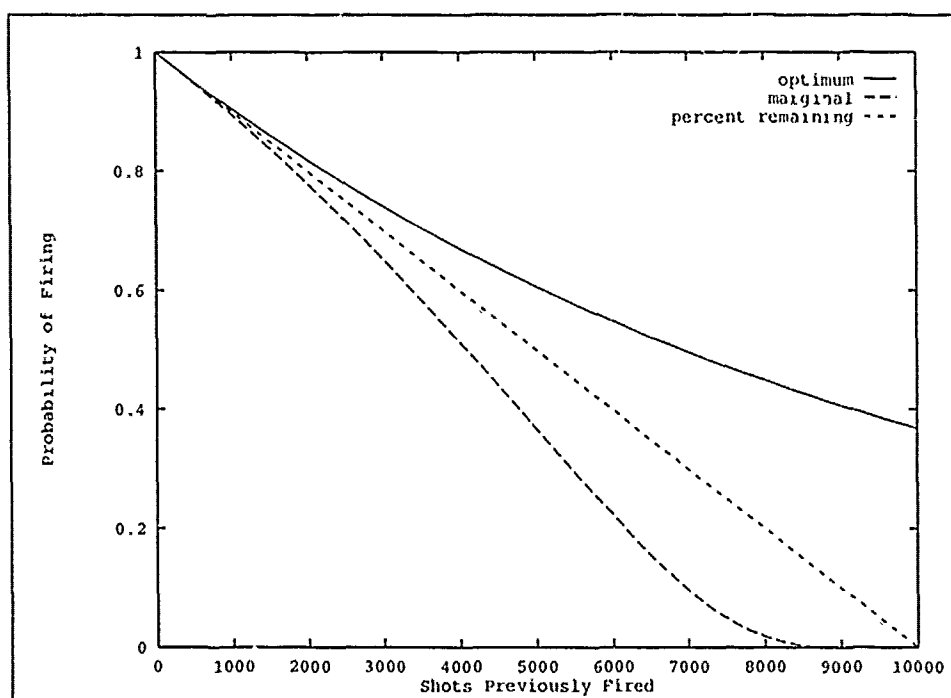


Figure 21. Shot Probabilities Associated with Different Employment Schemes

used in that capacity. However, the type of probability scheme used by the reserve units should be no more capable than the firing scheme used for firing the primary weapons. If the primary weapons are using a straight percentage for shot probability determination, then the reserve forces should use a percentage scheme at best. In other words, the marginal probability system could be used by the reserves but the optimum system shouldn't be used.

6.2.5.2 Shots for Each Individual Satellite While Over Theater. Each individual satellite will be passing over ground and air hexes very quickly. To simplify the number of shots by the satellites as the orbital planes pass over the theater, another preprocessing input is required. This number is simply the volleys each individual satellite is able to place on each ground hex (or air hex) as the ground trace crosses the hex.

The number of shots per volley is determined by the firing doctrine in place at the beginning of the scenario. A SLS firing doctrine would only get one shot off per volley while a SSLSS doctrine results in two shots fired per satellite volley. The total number of volleys is identical to the maximum number of targets, previously detected in the ground (or air) hex, which can be engaged during the time the orbital plane spends over the hex strip. For instance, using an example of a theater located at 63° and a satellite constellation established at 200 km altitude, the hex strip would be under the influence of a particular orbital plane for 118 seconds in which time three satellites would pass overhead. If each of these satellites had 3 volleys apiece then a total of nine targets could be engaged within the hex strip. If the satellites were also using a SSLSS firing doctrine then a total of 18 shots could be fired at a maximum of 9 targets during the 118 seconds the ground hex strip is under the orbital plane.

If a satellite is damaged or destroyed while its hex strip is over the theater, it is unable to fire for the remainder of the time that hex strip is over the theater. To accomplish this for the 200 km orbit, every 85 minutes while the orbital plane is over the theater the number of volleys available for the hex strip currently being traversed would be decreased by an amount equal to the number of volleys aboard the damaged or destroyed satellite. When the next hex strip is entered, the volley count returns to normal assuming no satellites over the new hex strip have been destroyed. Once the hex strip for the lost satellite leaves the theater, SWATTER no longer tracks the specific loss and the overall number of weapon platforms is

decreased homogeneously resulting in slightly longer times between satellite passes as determined in the satellite movement algorithms.

6.2.5.3 Attacks Against Missile Threats and Satellites. Attacks on missile threats are handled somewhat differently than air or ground hexes. When a missile attack is scheduled, the hex of origin and the target hex is specified. Additionally, if the missile is using a depressed trajectory to reach the target then the highest altitude the missile will reach must be entered. SWATTER will assume the highest altitude is reached at the halfway point between the target and the origin. If an altitude is not specified, SWATTER will assume a maximum range missile shot was made and a 45° trajectory will be used for determining the altitude of the missile shot.

Using simple trigonometry, SWATTER will determine the altitude of the missile through each orbital plane it traverses. SWATTER will use the shot probability for the theater missile defense reserve and determine if a kill is made. If a kill is not made, the reserve shot probability will be updated and the next orbital plane will be examined. This continues until the missile is killed or until the missile impacts the target.

One important point to make is if the missile reaches the space altitude block, SWATTER treats the missile the same way it treats satellite targets. SWATTER assumes the missile (or satellite) is in range continuously until it leaves the space block altitude. In such a case, SWATTER would fire volleys until the missile (satellite) is destroyed or leaves the space altitude hex. To represent this probability, a specific time delay (perhaps five or less seconds) would have to be incorporated between volleys for damage assessment and fire control procedures.

6.2.6 Target Hit Probability. SWATTER uses a circular error of probability (CEP) derived from a circular normal distribution for determining if a selected target is hit. The probability of measure for the CEP in SWATTER is 50 percent. In other words, 50 percent of the rounds fired by SWATTER will land within a circle of radius R from the aimpoint used. DARCOM-P 706-101 was used to derive the CEP from the circular normal distribution. Equation 22 is the circular normal distribution (17:13-7) where x and y are distances offset from the target and σ is the standard deviation of the round.

$$f(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (22)$$

To get the CEP of 0.5 equation 22 must be integrated and set equal to 0.5. By transforming the equation into polar coordinate form the resulting equation is in terms of distance r from the aimpoint and the standard deviation. Equation 23 is shown below in its final form with the probability of a round landing within R distance equal to 0.5.

$$P(R) = 1 - e^{-\frac{R^2}{2\sigma^2}} = 0.5 \quad (23)$$

Solving for an R value for a 50 percent CEP results in equation 24 (37:37).

$$\begin{aligned} R^2 &= -2\sigma^2 \ln \frac{1}{2} \\ &= 1.386294\sigma^2 \\ R &= 1.177410\sigma \end{aligned} \quad (24)$$

In other words fifty percent of the rounds fired will land within a circle of radius R based on the weapon's standard deviation of σ multiplied by 1.17741.

To determine the probability of a single shot hitting a circular target, equation 23 becomes an unknown probability of hit in terms of the radius, r , of the target and σ of the weapon system. The result is expressed in equation 25.

$$p_{hit} = 1 - e^{-\frac{r^2}{2\sigma^2}} \quad (25)$$

If the target is square or rectangular the probability of a hit becomes a very mathematically intensive procedure. Fortunately, using the Polya-Williams approximation (17:14-5 - 14-6), these two problems can be simplified in the following equations.

The equation for determining the probability of hitting a square target of the dimensions $2a$ by $2a$ is (17:14-5 - 14-6):

$$p_{hit} = 1 - e^{-\frac{2a^2}{\pi\sigma^2}} \quad (26)$$

While the equation for determining the probability of hitting a rectangular of the dimensions 2a by 2b is (17:14-5 - 14-6):

$$p_{hit} = [(1 - e^{-\frac{2a^2}{\pi\sigma^2}})(1 - e^{-\frac{2b^2}{\pi\sigma^2}})]^{0.5} \quad (27)$$

Therefore, for SWATTER to determine the probability of hitting the target, the target dimensions must be known, and the standard deviation for the shots fired must also be known. Additionally, if the target is in space, aiming accuracy is increased and atmospheric effects are negligible. For a space case, σ must be decreased a specified percentage (possibly up to one-half).

6.2.6.1 Integrating Firing Doctrine into Hit Probability. Given the probability of hitting the target can be determined from the equations in section 6.2.6, the firing doctrine is next integrated before determining the actual number of hits on the target.

The SLS doctrine is most easily incorporated. SWATTER fires one shot, evaluates the performance of the shot, and then fires a second shot with a correction for the shot. To determine the probability of hitting the target is a simple matter of using the appropriate equation from section 6.2.6. The program would then accomplish a random number draw from a uniform distribution from zero to one. As long as the random number draw is less than or equal to the probability of a hit the shot is successful in hitting the target.

The SSLSS doctrine is also fairly easily solved although a little more involved. SWATTER fires two shots, evaluates the performance of the two shots, and then fires a second volley of two shots with a correction factor for the volley. To determine the probability of a hit the appropriate equation from section 6.2.6 is again used to determine individual shot probabilities. These probabilities are now matched to a binomial distribution. The probability of x hits in n shots is given by equation 28 (37:21-22). p is defined as the probability of success, and q is defined as the probability of failure or $1 - p$.

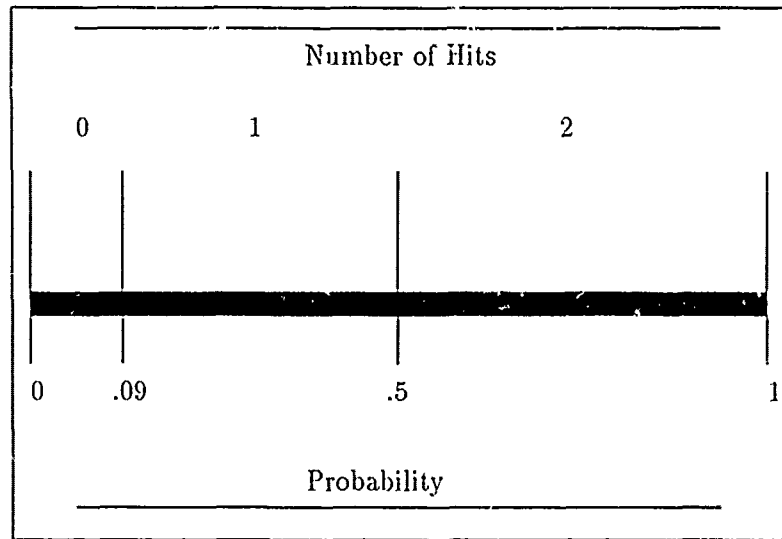


Figure 22. Cumulative Hit Probability for Two Shots

$$P_n(x) = \binom{n}{x} p^x q^{n-x} = \frac{n!}{x!(n-x)!} p^x q^{n-x} \quad (28)$$

The individual probabilities for 0, 1, or 2 hits can be determined from equation 28. The sum of all the probabilities represents all the possible events and should therefore, equal one (37:22). A random number draw is made and the number of hits can be determined based on the individual probabilities in a manner similar to Figure 22 and the following example.

Assume p is equal to 0.7 from one of the equations in section 6.2.6. The possibility of zero hits based on equation 28 is determined to be equal to 0.09 while the probability of 1 or 2 hits is determined to be 0.41 and 0.49 respectively. If the random number falls between 0 and 0.09, inclusively, then zero hits impact the target. If the random number is greater than 0.09 and is up to and includes 0.50, then one hit has occurred. If the random number is greater than 0.50, then two hits have occurred.

Once the number of hits have been determined, the kill probability must be examined in Section 6.2.7. However, subsequent shots fired by SWATTER may be corrected to smaller tolerances during subsequent shots. These firing corrections are examined in the next section.

6.2.6.2 *Firing Corrections.* SWATTER has the capability to determine if a target was hit by a previous shot. If the shot missed, SWATTER also has the capability to correct some of the error factor associated with the miss. The miss can be due to a variety of factors. These factors can include system bias (error introduced by system imperfections), local atmospheric effects, and anomalies associated with pulsed laser power. While SWATTER can not control the anomalies, it can make some corrections for atmospheric effects and system bias. As previously mentioned in the preprocessing section, SWATTER inputs include the normal standard deviation (stated in meters) associated with a single shot and a possible correction factor (again stated in meters which must be less than the standard deviation). The correction factor is subtracted from the standard deviation after it has been modified by the state of health of sensors and the command and control systems. The correction factor is applied on subsequent shots by the orbital trace firing while passing through the theater. Since weather may change between orbital passes by different planes of the constellation and different planes may have slightly different biases, subsequent orbital planes do not get the correction factor until they have fired within the theater. The correction factor is determined in equation 29 by using the previously defined variables of C and S and the correction factor, σ_{cf} .

$$\Delta \sigma = CS\sigma_{cf} \quad (29)$$

It is immediately obvious if the command structure and/or the sensors have been degraded the correction factor is less effective. The correction factor can be applied after the first shot and subsequent shots can not improve on the standard deviation for that orbital plane's pass through the theater. This allows the continued simulation of laser anomalies associated with a pulsed beam and continuously changing atmospheric conditions.

6.2.7 *Target Kill Probability.* Once a hit has been secured upon a target, the probability of killing the target must be determined and resolved. The method of determination varies with the target type. There are three target types to consider. These type are point targets, area targets, and area fire targets.

6.2.7.1 *Point Target Kill Probability.* Each individual point target type (aircraft, vehicles, missiles, etc.) has three target kill probabilities assigned in its data

base. The first probability, p_{nk} , is the probability of no damage given the target is hit. The second probability, p_{ks} is the probability of a soft kill where the target is hit and damaged to the point it is unable to complete the mission (i.e. a tank has its main gun disabled, or loses a track). The final probability, p_{kh} , is the probability of a hard (or complete) kill. These three probabilities add up to a total of one. A random number is drawn and based on where the random number falls within the range of zero to one the target determines whether the target is killed, damaged, or unaffected. The reason for separate kill tables for each point target type is due to each target type having different armor protection, and different vulnerable points exposed to the laser weapon.

The hard kill will generally be a catastrophic and easily recognized confirmed kill, especially for aircraft and missiles. However, for some land vehicles, the probability of reporting the hard kill as a soft kill (or probable kill), or no kill should exist.

The soft kill represents the loss of some of the target's required systems and most of these may be reported as a probable kill. A mechanism should exist to determine if the soft kill is reported as a confirmed kill or no kill.

The hit with no effect is called no kill. Again a small probability should exist for calling this a probable kill.

While SWATTER tracks the actual status of each target, the report with the possible errors included is forwarded to the TC after a suitable time delay. In the meantime, the owning player of the targets is informed of the actual unit status after a suitable time delay.

6.2.7.2 Area Target Kills. Area targets are targets which occupy large surface areas. This type of target includes depots, supply trains, airbases, hardened C^2 sites, missile bases, and other possible targets including dams and power generation stations. In general, most area targets can be handled on a simple percentage basis of area occupied. This is quite similar to the method used by Mann (26:159-160). The differences from Mann's work are noted below, with the only significant exception occurring at hardened targets.

Depots would be handled as a function of the storage area of laser sensitive materiel compared to the total surface area. For example, assume approximately

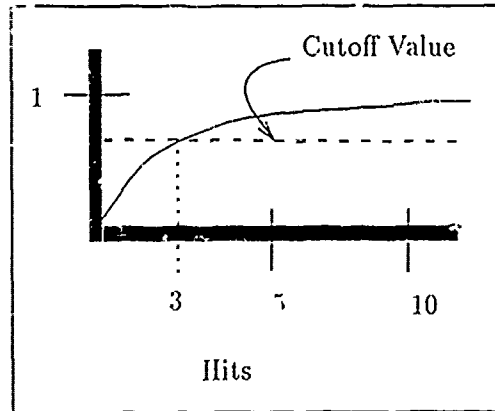


Figure 23. How Cutoff Values Interact with the Cutoff Index

forty percent of a depot storage is devoted to munitions. If a laser struck these munitions, obviously some damage would occur at the depot. Therefore, this depot would have a forty percent probability of some destruction of the materiel stored at the depot. The amount of damage would be based on the damage minimization techniques used at the depot. If no safeguards were used at the depot, the entire amount of explosive materiel may explode and take a significant amount of other materiel as well. However, if the depot uses accepted storage techniques, the materiel lost may amount to only one ammunition bunker being destroyed.

Air bases can be handled several different ways. The laser attacks may be directed against runways resulting in craters on the runway surface, the POL dump may be attacked in a manner similar to the depot, or any aircraft in the open may be attacked individually if detected.

Hardened structures, however, may take several shots for obvious damage to occur. One possible method would be to link an equation similar to equation 30 to an established cutoff value based on the number of shots. As long as the cutoff value is not exceeded, the structure appears to remain sound. After the cutoff index, C_I , passes the cutoff value, the target is destroyed. Each hardened target would have a cutoff value assigned. Figure 23 shows how the cutoff value would work.

$$C_I = 1 - e^{-0.1s} \quad (30)$$

If the hardened area target is hit by conventional weapons after laser attack but before the target is destroyed, the effect of the laser attack can be handled in one of two ways. For a hardened target, the number of bombs to destroy the target could be reduced an amount proportional to the cutoff index, or the amount of damage done by the bombs could be increased by the cutoff index.

Several alternative methods could also be used for target destruction. A simple cumulative function could be used until the target is destroyed or each individual shot could result in a proportional amount of damage decreasing the effectiveness of the target until the target is totally destroyed.

6.2.7.3 Area Fire Kills. Area fire kills are not really kills in the normal sense. Laser weapons directed against specific ground hexes act more in the capacity of suppressive fire against suspected targets. A hit probability does not have to be determined as fire against a ground hex is automatically assumed to hit the target hex. Targets in the hex are not likely to be hit since the detection phase was not employed to direct fire through the sensors. A small probability for hitting targets in the hex should be employed but should be on the order of the amount of surface area covered by the targets in the hex as compared to the total surface area. The use of night vision goggles, or IR detectors in the area under attack could increase the possibility of target damage within the hex. The use of these light enhancing sensors could result in damage to the sensors themselves or actual injury to the individuals operating the sensors with a corresponding decrease in effectiveness.

The primary use of SWATTER in an area fire would be to hinder and distract personnel from carrying out assigned missions. The hindrances would occur from the wear of protective gear and the distractions would occur as troops attempt to minimize the possibility of laser exposure. These factors could combine to reduce the overall unit firepower index by a specified percentage and/or hinder the unit movement factor by a specified percentage. This effect may last longer than the time of the actual attack. Due to the suddenness and unexpectedness of such attack, the hindrances and distractions may last for several time periods even after the attacks have ended.

6.2.7.4 Other Effects of Laser Attacks. If the laser attack occurs as a vehicle is in its attack objective hex, then there is possibility exist for the laser attack

to spook the vehicle operators even if no significant damage has occurred. This can be simulated by increasing the CEP of the weapon system used by the vehicle or decreasing the effective firepower of the the weapon through the firepower index.

6.2.7.5 Friendly Fire and Zones of Fire. With the low probability of SWATTER being able to identify many surface targets and some air targets, the possibility exist for SWATTER to accidentally attack US forces. The TC may well have to specify only a general class of target to hit within specific geographic constraints (zones of fire) if he wishes SWATTER to fire at all. If the TC doesn't specify the zones of fire or he doesn't prevent units from entering zones of fire, then US units which are not identified but are detected could also come under fire in accordance with the targeting priorities set by the TC. This could occur since the constellation would not recognize fratricide issues when targeting detected but unidentified targets.

6.2.8 Spares. Throughout the scenario, if allowed by the control group, the possibility may exist for the reconstitution of the satellite constellation. This reconstitution can be handled through on-orbit spares or actual launches of replacement satellites. To accomplish this function, the number, types, and identification of spares should be determined by the control group beforehand. In addition, the rate at which the respective spares can be generated should also entered prior to the game.

If the spare is launched, the time delay should take several weeks and maybe months. An on-orbit spare may only take days or maybe weeks for activation. The identification of the spare must also be made. If the satellite is a sensor or C^2 satellite (or a multipurpose with these functions on board), then the sensor status modifier or command and control modifier can be increased. The C and S modifiers can never exceed one, so no advantage can accrue from launching an excess of these types. This restriction is not true of the weapon platforms, however.

Any spare weapon platforms launched or activated are immediately counted in the number of shots in the constellation. The first priority of such a satellite would be the replacement of any used or damaged shots dedicated to the SDI role. The second priority would be dedicated to replacing any shots missing from the theater missile defense role. The final priority would be replenishment of shots dedicated

to the discretion of the TC. This final priority can be overstocked resulted in more firing opportunities for each satellite trace.

6.2.9 Repairs and Resupply. SWATTER may also incorporate the ability to repair broken satellites as well as refuel satellites short of laser firing fuel. The parameters for launch rates of a space vehicle to accomplish such a mission must again be determined beforehand. In addition, the number of shots the resupply vehicle can carry and the number of repair missions it can accomplish in one mission must be specified. Since such a mission would be a manned mission, the number available and the capabilities of this type of mission are likely to be limited.

6.2.10 Soviet Countermeasures. The control group may allow the Soviet player to have a variety of countermeasures to attempt to negate any advantages the satellite constellation has bestowed upon the US player. The Soviet player may have missile decoys, ASATs, space mines, a ground-based laser, and nuclear missiles. The command and control and the detection processes of these systems are much simpler than required for the US constellation.

The command and control systems would not have to worry as much about fratricide or about being activated automatically in a high threat environment. All of the systems, except for the space mines, are launched upon demand. In addition, the singleness of purpose (excluding the decoys), destruction of one target satellite tremendously simplifies the necessary command and control functions. The sensors are primarily ground-based with tremendous power available to them to accurately fix the satellites' position and velocity vectors. These ground-based sensors would be able to direct the satellite killers listed above into close enough proximity to those satellites to either kill the satellites, or allow self-contained guidance systems on the killers to take over the intercept problem. Since the Soviet system is much simpler and has a robust detection system, SWATTER does not model these functions for the Soviet systems. Detection is assumed to happen automatically, and command and control is assumed to be perfect. The control group would also have to specify the time required from initial decision for employment to the actual launch on all of these systems except the space mines.

While the killer systems have many similarities, each of these weapon systems must be examined in more detail due to their differences. The differences occur in the kill mechanisms, the method of attack, and the specificity of the attack.

6.2.10.1 *ASAT*. The Soviets have had a capable co-orbital ASAT available for years. By the time of the scenario used in SWATTER it is conceivable the Soviets could deploy a direct ascent ASAT capability. SWATTER can model both types of ASATs.

The co-orbital requires one to two orbits minimum to maneuver into position near a specific satellite and kill it through proximity to an explosion. The direct ascent ASAT uses a missile to accelerate into a killing position directly from the launch facility with no need for multiple orbits. Both types attack specific satellite targets through proximity effects of an explosion and possibly through actual collision with the satellite.

These ASATs can be determined successful through the use of a CEP model similar to the one developed for attacking point surface targets by the US constellation. Attacks on these ASATs by the US constellation can be handled in the same manner as a missile attack is handled. The major difference between the two types of ASATs is due to the amount of exposure to laser fire each system would be exposed to. The direct ascent ASAT would be exposed to laser fire for only a few minutes while the co-orbital ASAT would be exposed to at least one complete orbit within range of laser weapons.

One special type of direct ascent ASAT is the nuclear tipped weapon. While a conventional ASAT attacks a specific target, the nuclear armed ASAT is a weapon of mass destruction which attempts to kill several satellites simultaneously due to the large lethality envelope of its warhead. To determine the number of satellites killed, once exploded the lethal range would be used to determine the area surrounding the explosion. Once this area is determined, it is compared against the area of coverage for the individual constellation satellites (including C² and sensors). The number of satellites determined to be within the lethal range is then considered to be killed.

6.2.10.2 *Space Mines*. Space mines would have to be employed in orbits near the US constellation prior to the scenario start. The most likely employment would be disguised in a satellite with an unrelated mission such as communications or reconnaissance. When the space mine is activated, it would wait until within lethal range before exploding.

To destroy space mines, a sterile no-entry zone would have to be activated around the constellation. Once this sterile, no-entry zone was activated the US

satellites would begin destroying the satellites in orbit similar to the method used to destroy missiles which have reached the space altitude hex.

If the sterile, no-entry zone is not activated, the Soviet player can specify when to fire the space mines for maximum effect. Since the space mines have been deployed in space for some time, the ability to move the mines is limited due to the suspicions such a move would arouse in the American forces. Therefore, like the US constellation, the space mines would be distributed uniformly in orbit. The Soviet player can specify the time of detonation for the first mine. Thereafter, if he is trying to detonate over a specific geographic location, he will be limited to certain times due to the uniform distribution of the space mines. In other words, the Soviet player couldn't detonate all his space mines simultaneously over the theater. The mines would instead make passes over the theater at regular intervals and could be detonated at that time. However, the Soviet commander could decide to detonate all mines simultaneously. The number of space mines over the theater would be determined in the same manner the number of US satellites over the theater was determined. The rest of the space mines not over the theater would just affect the overall US constellation by decreasing the number of sensors, weapons, or C^2 satellites.

6.2.10.3 Ground-Based Lasers. The Soviets may also have a ground-based laser (GBL) for use. The system would have tremendous power available to attack satellites. The ground-based system would also be able to have a much larger, more active, cooling system for optic components. The control group would have to specify the number of shots the laser could fire before cooling would be necessary, the recovery time required for cooling, the CEP, and the CEP correction factor. The firing would be handled exactly like the laser firing by the US constellation.

The Soviet laser would have so much power, the atmospheric effects, such as thermal blooming, would be magnified. However, the aiming controls on the ground-based system would be more precise. Both factors must be accounted for in determining the CEP for the Soviet laser. The Soviet CEP would probably be slightly worse than its US counterpart. Weather effects would also have to be accounted for as it is by the US constellation.

6.2.10.4 Missile Decoys. The Soviets may possess a number of decoys able to simulate a missile attack. While not an actual method for killing the US

satellites, decoys achieve their mission by drawing laser fire and exhausting the firing capabilities of the constellation. If decoys are allowed by the control group, the information which must be preprocessed must include the number of decoys, the probability of deception by the decoy, and the type of missile the decoy is simulating. If decoys are launched with other missiles and are not determined to be decoys by SWATTER, the probability of killing a decoy will be based on the proportion of decoys among the actual missiles. For example, if a missile launch was 40 percent unrecognized decoys, then 40 percent of the missiles killed will actually be decoys killed.

6.2.11 Satellite Destruction and Other Considerations. Fire against the satellite constellation is resolved in the same manner the constellation resolved fire against point targets. There are major differences between satellite target kills and killing US satellites. These differences include the fact the Soviet player does not have to detect the desired target due to the large number of surface-based radar sites. Another difference is the simple command and control structure the Soviets would use for their system would be less complicated and less likely to breakdown or degrade. Finally, the last difference occurs because weather is not a factor the Soviets need to consider to kill any US satellites unless they are using their ground-based laser.

During the targeting of US satellites, the Soviet player needs to specify if he is going after a weapon platform or other satellite. A weapon platform satellite would be easily distinguishable from the other types. However, a sensor satellite and C^2 may not be as easily identified. Therefore, after a hit is determined, the type of satellite destroyed must be determined. Referring back to Table 3 a percentage of the different types can be determined and a random number draw from a uniform distribution can be accomplished for satellite type. For example, the Soviet player may state he is firing at a weapon platform. In Table 3 there are a total of 550 platforms which mount a weapon system. Of the total number of weapon platforms, 73 percent are dedicated to single purpose satellites. The remaining 27 percent is equally divided among the three types of multipurpose platforms which includes a weapon. The random number draw from zero to one would determine which type of platform was destroyed.

While the method for handling C^2 losses and sensor losses has already been discussed, the method for handling weapon platform losses has not. Anytime a

weapon platform is lost, the total number of shots available to the constellation (including the ICBM defense and the theater reserve) is determined along with the number of weapon platforms available prior to the loss. The shots available are divided by the number of platforms to determine the number of shots available on each platform. This number is then subtracted from the total number of shots in the constellation to represent the loss of the weapon.

If the Soviet player is attacking the constellation to weaken the system as a whole he could attack at any time and his results would be applied to the entire system. If the Soviet player wishes to attack a specific portion of the constellation which would appear over the theater at a specific time, the Soviet player must inform SWATTER of his intent when inputting his mission orders. In addition, he must include enough lead time for his notification to allow the chosen weapon systems to be launched or fired and to allow the constellation under attack to come into place.

If the Soviet player is using space mines, the delay time for the first space mine over the theater is equal only to the amount of time necessary to order the space mine to explode. Thereafter, if any space mines are exploded over the theater, it will be done in discrete time intervals based on the spacing between the mines. If the weapon chosen is a direct ascent ASAT, the only lead time necessary is the time required to order the launch and the time for the missile to reach altitude. If the system used is the co-orbital ASAT, the lead time must include the time period for at least one orbit (two if determined by the control group) to maneuver the ASAT into a killing position over the theater. While most of these weapons are fairly straightforward in determining required lead times, the last remaining system, the GBL, is not. It is addressed next.

If the weapon used for attacking an orbital plane over the theater is the GBL, the lead time includes, the time decision lead time plus an amount of time equal to the time required for the constellation to rotate into place over the theater. In other words, the Soviet player could attack the constellation with his laser but since it would only attack orbital planes directly overhead, the east-west distance, or the longitudinal difference, between the firing site and the theater must be accounted for. For example, if the GBL at Dushanbe, located at approximately 70° E fires at an orbital plane, the plane attacked will not rotate over the Iran theater (approximately 60° E) until roughly 40 minutes later.

6.3 Data Capture

The algorithms in this chapter are very data intensive and are very dependent upon the a wide variety of values entered in the preprocessing phase. While the actual values to be used by SWATTER are beyond the scope of this thesis, a starting point for gathering this data is included.

The data is available for SWATTER in many forms and in many organizations. The data may be available in organizations which use it for engineering research or it may come from modeling agencies. Unfortunately, in the interest of playability, some of this data may have to be manipulated into a form which can be entered into SWATTER. In addition, much of the data may be classified and in an attempt to maintain the unclassified nature of this thesis, the sources, availability, and formats of this data were not deeply researched.

The organizations listed below are just some of the possible sources and can be used as a starting point for gathering the desired data.

- United States Army Materiel Systems Analysis Activity (AMSAA), Aberdeen Proving Ground, Md.
- Survivability/Vulnerability Information Analysis Center (SURVIAC), Wright-Patterson AFB, Oh.
- Foreign Technology Division (FTD), Air Force Systems Command, Wright-Patterson AFB, Oh.
- US Space Command, Peterson AFB, Co.
- AF Space Command, Peterson AFB, Co.
- Strategic Defense Command, Huntsville, Al.
- *Interavia Space Directory 1990-91* (44).

With the data these organizations provide, SWATTER will be a highly playable but realistic approximation of space warfare in the near future.

VII. Conclusion

7.1 Summary.

This thesis is the cornerstone to begin the integration of space assets into the Air Force Wargaming Center's theater level wargame currently under development. The purpose of this effort has been to incorporate a space-based laser weapon system, primarily intended for ballistic missile defense, and the genesis of Air Force space doctrine into a conventional theater battle wargame for research and education. The goal was to provide the rationale and algorithms necessary for the construction of a computer simulation. This thesis has admirably met this goal and accomplished the stated purpose.

Chapter I addressed the basic purpose of this thesis and the model considerations necessary for integrating space into the theater level wargame. Chapter II provides the background information necessary to credibly represent space warfare in terms of doctrine, capability, and probable deployment. Chapter III sets the stage with a credible scenario for the deployment of a space-based shield in a theater conflict. In Chapter IV, the areas which need to be modeled begin to take form by defining which areas are important and how they need to be modeled. Chapter V defines the basic SWATTER entities and important characteristics these entities possess for integration into the wargame. Chapter VI ties everything together by simplifying complex, high speed orbital processes and combining them into simple algorithms which allow the model to function realistically with very little loss of fidelity. Additionally, the representation of the satellite constellation within the theater is added along with the detection and targeting processes, intelligence, command and control processes, weapon interactions, and stochastic attrition.

All of the algorithms provided are based on simple orbital mechanics or simple engineering models which are readily available and unclassified. Where appropriate, reference has been made to more complex models if increased fidelity is desired over playability. While primarily designed for integration into the models designed by Ness and Mann, sufficient documentation on aggregation methods and movement algorithms has been provided for integration into other theater level wargames.

7.2 Recommendations.

This thesis is only a very early stage of wargame development. The ideas presented here must still be integrated into a prototype design and linked to the models developed by Ness and Mann. Both of these models are currently under development and refinement. Once past the development stage, the model must still be validated. Finally, SWATTER will meet the ultimate test. This test comes down to the question, "Is it playable?" Hopefully, SWATTER will successfully pass all of these hurdles. If SWATTER does not, at least it will point the correct way for those following.

Recommended additional thesis efforts along the lines of SWATTER include:

- Development and validation of the algorithms presented in SWATTER,
- Better representation of space-to-space warfare,
- Integrating communication and navigation satellites into the theater conflict,
- Developing the data bases required for SWATTER,
- Research into integrating SWATTER interactions with naval forces,
- Automating the Soviet forces.

7.3 Conclusion.

This thesis provides a foundation for the extension of the land-air theater battle into the new medium of space. In addition, SWATTER provides the documentation necessary for those following after to successfully integrate changes to the program and also provides the basic information necessary for integrating new entities not yet envisioned into the data base. It is hoped that SWATTER becomes the vehicle to help future Air Force leaders in their quest to become knowledgeable about space capabilities and limitations.

Appendix A. *Preprocessing Inputs and Associated Algorithms*

During the preprocessing phase a large number of inputs are required. These inputs can be input through either an ASCII word processor or a simple program can be written to query the control group on the information required to run SWAITER. Samples of the required information and the associated algorithms are included below. Entity databases are not covered here but are sufficiently covered in the main text and in the work done by Mann and Ness. This chapter includes examples of the questions (with answers) which need to be completed and several of the algorithms which must be processed before beginning the wargame. If questions are based on a response not given, then they are not answered. They are only included for completeness in demonstrating some of the possible required inputs.

A.1 Soviet Limitations

1. Does the Soviet player have ASATs? No. (The following ASAT questions were not answered due to no ASAT capability.)
2. Do the ASATs include co-orbital ASATs? Number? Orbits required for interception? Time required from employment decision to launch time and standard deviation? Location?
3. Do the ASATs include direct-ascent ASATs? Number? Time required from launch to intercept? Time required from employment decision to launch time and standard deviation? Location?
4. Do the ASATs include space mines? Number? Time required from employment decision to first detonation? Location?
5. Does the Soviet player have the capability to employ nuclear-tipped missiles in an ASAT role? Number? Time required from employment decision to launch time and standard deviation? Time required from launch to intercept? Lethal weapon radius? Location?
6. Does the Soviet player have a GBL? Number? Location? Shots available at each location? Yes. 1. Dushanbe. 1000.

7. How many shots may the GBL fire before stopping to cool the system? How long must the system cool before commencing fire? 10 shots. 120 minutes.
8. What is the CEP of the GBL? What is the fire correction factor for subsequent GBL shots? 5 m. 2 m.
9. What is the firing doctrine employed by the GBL? SSLSS.

A.2 US Limitations

1. What is the current command structure? SOL liaison under the AC.
2. Under the starting command structure, what is the delay time from request to final decision on SWATTER deployment? What is the approval rate on SWATTER deployment? 4 hours. 75 percent.
3. Are other command structures allowed later in the simulation? No.
4. What types? What are their respective delay times and approval rates?
5. Does SWATTER have a sterile no-entry zone for space mines? If not, will the zone be approved at a later time? No. No.
6. Does SWATTER have any replacement satellites? No.
7. How many replacement satellites are on-orbit spares? What type of mission platforms are available? What are their activation times?
8. How many replacement satellites have to be launched? What is the delay time from employment decision to actual operational capability? What type of mission platforms are available?
9. May the Space Shuttle resupply or repair the constellation? No.
10. What is the delay time from Shuttle employment decision to actual repair or resupply? How many shots can each Shuttle mission replenish? How many satellites can each Shuttle mission repair?
11. What is SWATTER's firing doctrine? SLS
12. How many shots may each individual satellite fire before stopping to cool the system? How long must the system cool before commencing fire? 6 shots. 95 minutes.
13. How many shots may each weapon satellite carry? 100.
14. What is the weapon CEP and possible correction factor? 3 m. 1 m.

A.2.1 Satellite Inputs and Algorithms

1. What altitude is the constellation established at? 190 km.
2. What is the effective weapon range of the laser weapon? 205 km.
3. Does the constellation provide complete global coverage? No.
4. What latitude and inclination coverage do you wish SWATTER to provide ? Is this partial coverage complete? 60°. Yes.
5. What is the theater latitude? 33°.
6. What is the length of the theater as measured from north to south? 200 km (or 8 ground hexes).
7. What is the width of the theater as measured from east to west? 400 km (or 16 ground hexes).

Based on the numbers given as responses and the equations previously given in the text, SWATTER immediately begins calculating the number of satellites required, the orbital period, theater rotation, satellite following times, satellite following distances, and the separation between orbital planes.

Substituting the the above numbers into equation 7 would result in a spherical area of 543,771,884.2 km². While equation 8 would result in a lethal weapon area of 132,025.4 km² per satellite. Using these resulting values in equation 9 would result in 6470 required for full earth coverage. Dividing the surface area of the earth by the number of satellites gives the surface coverage by each satellite and can be further reduced to determine distance between each satellite and each orbital plane. In this case the distance between satellites is approximately 158.6 km or six ground hexes.

However, the questions above revealed the constellation only extended to the 60° latitudes. Modifying equation 9 to determine the actual number of satellites requires the determination of area actually covered by the constellation in equation 12. To determine this area, h from equation eq:height must be determined. In this case h is 11,393.7 km resulting in an area, including the overlapping correction factor $\frac{\pi}{2}$, of 739,719,823.4 km². Since the correction factor has already been included in equation 12, equation 9 must account for this and would resemble the form below.

$$N = \frac{\pi(R_o + R_e)h}{R_w^2} \quad (31)$$

Using the numbers previously input or determined, N is now calculated to be 5603 satellites. The separation between the satellites does not change nor does the period of the satellite orbit, 5309.7 seconds, determined from equation 11. Dividing the orbital period into the circumference of the earth results in the apparent ground velocity of 7.5 km/sec for each satellite crossing the theater.

In addition, using the theater latitude in equation 14 results in the local portion of the globe rotating eastward at the rate of 0.39 km/sec. Therefore for the orbital plane to rotate westward one ground hex strip (25 km) requires 64 seconds. During this 64 seconds, approximately three satellites will have traversed the hex strip. Since each orbital plane is separated by 158.6 km and the theater is 400 km wide, at least two and up to three orbital planes can be over the theater at one time. Each hex strip would require 17.1 minutes to move across the entire theater and during that time 48 separate satellites associated with the hex strip will have crossed the theater.

Using equation 15, the angle, as measured from the satellite vertical, to the next adjacent ground hex strip is 7.125° . The next adjacent ground hex strip, based on equation 16, is 201.6 km from the satellite while the next hex strip past the one adjacent is 206.2 km. Therefore the area each orbital plane could attack on the surface is three hex strips wide.

To determine if satellite could reach adjacent air hexes, equations 17 and 16 would be calculated for three cases. The first case would occur when the ground hex strip would determine if air hexes could be reached when the ground hex strip is centered within its own air hex. The second case examines the adjacent air hex when the ground hex strip is offset to the near side of its own air hex. The final case occurs when the ground hex strip is offset on the far side of its own hex strip. The results for these calculations are shown in table 7.

Based on table 7 this particular constellation can always reach the air hexes directly above the any portion of the 3 hex wide ground hex strip. Additionally, if the hex strip is centered within its own air hex it can reach the very high altitude air hexes adjacent to the hex strip. Space hexes are always within weapon range of the constellation as are the low altitude hexes (these altitude hexes are only 25 km across unlike all other altitude hexes) directly above the hex strip.

Once SWATTER has determined the requirements for satellite coverage, it must again query the control group for additional information.

Table 7. Determination of Air Hexes within Range

Altitude	Case 1		Case 2		Case 3	
	ϕ	in range	ϕ	in range	ϕ	in range
medium	20.7°	no	14.1°	yes	26.7°	no
high	21.1	no	14.5°	yes	27.3°	no
very high	22.6°	yes	15.5°	yes	29.1°	no
space	Always within range					

1. SWATTER has determined 5603 weapon platforms are required for complete earth coverage from 60° N to 60° S. If complete coverage is not desired how many weapon platforms are actually available?
2. Are multifunction platforms used? Yes.
3. How many single use weapon platforms are there? 5003.
4. How many single use sensor platforms are there? 1297.
5. How many single use command and control platforms are there? 400.
6. How many multifunction weapon, and sensor platforms are there? 200.
7. How many multifunction command and control, and sensor platforms are there? 200.
8. How many multifunction command and control, and weapon platforms are there? 200.
9. How many multifunction command and control, weapon, and sensor platforms are there? 200.
10. How many total satellite platforms are there? 7500.
11. Are any of the satellite platforms circular in shape? Which ones? Yes. Sensor platforms; command and control platforms; sensor, and command and control multifunction platforms.
12. What are the dimensions facing earth of the weapon platform? 5 m by 4 m.
13. What is the radius of the sensor platform? of the command and control platform? of the multifunction command and control, and sensor platform? 3 m. 3 m. 3 m.

14. Are all multifunction platforms with weapons the same size as the weapon platform? If not, what are the dimensions? Yes.

Once these queries have been answered, SWATTER examines the answers for internal consistency and then determines the percentage makeup of the constellation of the satellites. The weapon platforms are easily distinguishable from the earth and the percentage makeup of the weapon platforms must also be determined separately from the non-weapon satellites. For example, a platform consisting of a weapon, sensors, and a command and control function make up only 3.5% of all the weapon platforms. However, this same platform would be distinguishable as a weapon platform and would probably not be attacked if the desired targets were sensors and command and control functions. Therefore, while an attack on this type of multifunction weapon platform would occur with a probability of 0.035 when targeting weapon platforms, such a successful attack would decrease the sensor satellites and the command and control satellites each by one as well as the weapon platforms. Meanwhile, attacks against non-weapon platforms would not affect the weapon platforms in any way.

Appendix B. *Theater Commander Inputs and Reports*

The Theater Commander (TC) has the ability to make several key decisions throughout the simulation. However, to make those decisions, he must have enough information to make valid determinations on what he is able to accomplish through the use of his space forces. Therefore, the Theater Commander must know some of the unique attributes of the forces available, and also must understand what the key decisions may entail as well as what he may expect as feedback on how his choices are working.

B.1 Attributes of Space Forces

For the Theater Commander to understand how better to use the forces he has available, he must understand some key attributes of those forces. In other words, if the Theater Commander is given a new gun, he must also be given an instruction manual to know how to use it.

Some of the key attributes of SWATTER include:

- continuous surveillance of the theater,
- near real-time reports of what is detected within the theater,
- ability to direct fire upon almost any point within the theater at any time,
- almost instantaneous battle damage assessment of the fire missions,
- very high probability of detection, identification, and kill of any theater missiles,
- a good probability of detection, recognition and kill of aircraft with only a fair probability of identification,
- a fair probability of detecting land vehicles with only a poor probability of recognition, identification, and kill.

Some of these attributes may be presented to the theater commander in a form similar to Table 8.

Table 8. Detection, Identification, and Kill Attributes of SWATTER

Target	Detection	Recognition	Identification	Kill
Missiles	99%	99%	99%	99%
Aircraft	80%	60%	40%	75%
Vehicles	50%	30%	20%	30%

With these attributes, the theater commander can then make his initial decisions on deploying his space forces. The attributes listed can be as specific as the control group desires. They may be given as general aggregations based on an entire class of vehicles or may be further broken down into subgroups. For example, probabilities of aircraft identification and kill could be given for fighters, bombers, and transports.

Other information which should be available to the theater commander includes time delays for reports, time to implement his deployment decisions, the total amount of firepower he has available, and the amount of firepower he can bring to bear in a specified time increment.

B.2 Theater Commander Inputs

Based on the attributes given the Theater Commander, he will decide his initial deployment instructions and give orders based on the theater's geographic coordinates (similar to Figure 24).

These initial inputs could be entered in a format similar to Table 9. This example may be expanded to include more or contracted to include fewer choices for the Theater Commander.

The example in Table 9 shows several methods the TC can use to specify specific target types. For instance in the aircraft category, if a target is detected as an aircraft it is obviously not possible to recognize or identify the type since insufficient information exists. However, once the intelligence function has determined it is a fighter, sufficient information may exist to determine the type of fighter and thus, the owning player. The TC can set specific geographic bounds for his aircraft detection and targeting but he may also specify different bounds for bomber detection and targeting. If no geographic bounds are specified for a specific class then the overall

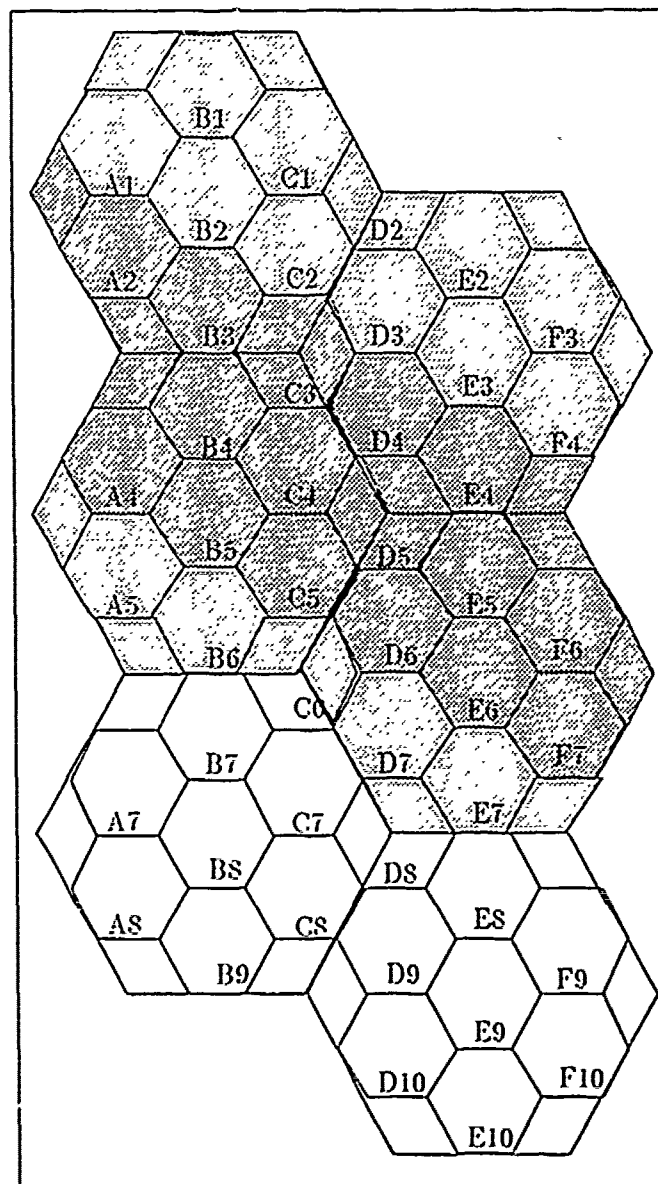


Figure 24. Theater Coordinates

Table 9. Theater Commander Deployment Orders

Target Type	Geographic Bounds	Priority/Level of Detection Required		
		Detected	Recognized	Identified
Aircraft	A2-A8 by A2-E2	5	NA	NA
Fighters	A2-A6 by A2-E2	NA	4	3
Bombers		NA	2	1
Transports				
Vehicles	C2-C5 by C2-F3		NA	NA
Tanks		NA		6
APCs		NA		7
You have 10,000 shots allocated to the theater, how many do you wish to reserve for theater missile defense? 2000.				
Do you wish to add any geographic area-fire targets to your priority list? No.				
Do you wish to add other target priorities to your list? No.				
Command structure in effect requires SDI approval for theater priorities.				
Approval Rate is 70% and the time required is 6 hours.				

class bounds are used. This allows him to specify where his priorities exist and in what order he wishes targets attacked.

The important point needs to be made that the only way to avoid fratricide is by prioritizing only identified targets on the list. For example, using Table 9 for land vehicles, no priority has been established for vehicles in general. In addition, tanks and APCs must be identified before targeting. By extension, since targets must be identified, then only those identified as Soviet (even if misidentified) will be attacked. If a priority had been assigned to vehicles in general, then a mix of Soviet and US tanks, which were detected but not identified, would be equally targeted.

Once this information has been entered, it can not be changed until the next time increment used by wargame has expired. After the time has expired, the TC would have the option of changing anything on his priority list. He can change this list even if the time interval to priority list approval has not expired. The previous unapproved list would be discarded and the new list entered starting the clock cycle over again for priority list approval. If a priority list is disapproved, the priority list in effect at the time would continue to be in effect.

B.3 Situation Reports

The basis for a TC to change his priority list would probably be based upon situation reports. These reports would come from SWATTER and other sources and could resemble the format found in Table 10. This information would not be complete due to the "fog of war" but would accurately reflect information on his own forces due to other reporting channels available.

For example, assume 3 C-130s are in an air hex centered at B5 in Figure 24 and are under attack by a flight of two Mig-25s. In addition, assume 70 T-72s have massed in hex F5. SWATTER now enters the wargame with the priorities established in Table 9 and the outcome occurs in Table 10.

From this information the TC can glean several important points. He learns the laser weapon has not been very effective against armor while it has been very effective against aircraft. Additionally, the comments (which were gleaned from other sources) in Table 10, paragraph 2g., show that due to the aircraft priorities he established in Table 9, two of his own aircraft were destroyed as well as a Mig-25 which was attacking the C-130s. Also note that only tanks identified as T-72s were

Table 10. Situation Report

1. Number of Vehicles Detected	70
1a. Location	F5
1b. Number and Class Recognized	60 Armor
1c. Number and Type Identified	40 T-72s
1d. Confirmed Kills	2 T-72s
1e. Probable Kills	5 T-72s
1f. Shots Fired	150
1g. Comments	
2. Number of Aircraft Detected	5
2a. Location	B5
2b. Number and Class Recognized	
2c. Number and Type Identified	
2d. Confirmed Kills	2 aircraft
2e. Probable Kills	1 aircraft
2f. Shots Fired	20
2g. Comments	Kills were 2 C-130s and 1 Mig-25
3. Time	2100
4. Time of Detection and Engagement	1900

killed due to the TC priorities. Using this information, the TC could change his priorities on his priority list.

After the completion of the wargame, a table similar to the one shown in Table 10 would be generated which would accurately reflect all information and show how effective the laser weapons and intelligence functions of SWATTER really were.

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