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This thesis provides a foundation to build a new theater level computerized wargame for the Air Force Wargaming Center, Maxwell AFB, Alabama to replace the Theater War Exercise (TWX), also known as Agile. Given a recently developed land battle, this thesis' effort links US Air Force doctrine with a conceptual model's framework and designs a new air battle module. The integration of both the air and land battles forms a new game, Saber.

This thesis redefines the ground combat units of the land battle, and adds theater air defense units, bases and aircraft packages. This thesis introduces stochastic attrition between the aircraft, ground forces, and theater air defense by joining together unclassified engineering submodels to gain credible interactions between the aggregated entities. The main components of Saber are stochastic attrition, formation of aircraft packages, logistics, intelligence, and nuclear warfare. The goals are to provide and document the algorithms and the related formulas for programmers to construct an object oriented computer simulation.

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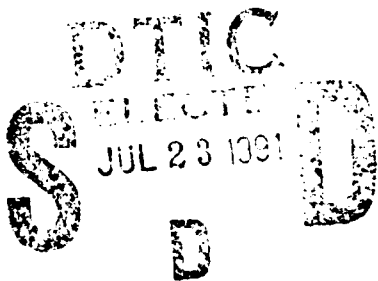
SABER

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 Operations Research

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Captain, USA

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William F. Mann

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Abstract

This thesis provides a foundation to build a new theater level computerized wargame for the Air Force Wargaming Center, Maxwell AFB, Alabama to replace the Theater War Exercise (TWX), also known as Agile. Given a recently developed land battle, this thesis' effort links US Air Force doctrine with a conceptual model's framework and designs a new air battle module. The integration of the both the air and land battles forms a new game, Saber.

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SABER: A THEATER WARGAME

I.   Introduction

This thesis provides a foundation to build a new
theater level computerized wargame for the Air Force
Wargaming Center, Maxwell AFB, Alabama to replace the
Theater War Exercise (TWX), also known as Agile. Saber is a
theater level, two-sided, airpower employment computer
wargame that can play any scenario. Given a recently
developed land battle, this thesis' effort links US Air
Force doctrine with a conceptual model's framework and
designs a new AirLand theater wargame.

This thesis redefines the ground combat units of the
land battle, and adds theater air defense units, bases and
aircraft packages. The model's main components are:
stochastic attrition between aircraft, ground forces, and
theater air defense; formation of aircraft packages;
logistics; intelligence; and nuclear warfare. The wargame's
example scenario is the Persian Gulf War. The wargame
simulates combat by joining together unclassified

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engineering submodels to gain credible interactions between the aggregated entities. Using this thesis, programmers can use these documented algorithms and the related formulas to construct an object oriented computer simulation.

1.1   Background

Saber evolved from the Theater War Exercise (TWX), a four-day, two-sided, theater level, airpower employment, computer wargame. The TWX model is maintained by the Air Force Wargaming Center at Maxwell Air Force Base, Montgomery, Alabama. This wargame serves as an exercise driver, for the students of the Air War College. As an exercise driver the model is used to "simulate wartime operations involving planning, preparation, and execution" (AFSC, 1987:137). More technically, TWX is a "linked array of models and software utilities which uses war gaming, with computer assistance, in the hands of controllers to contribute to the realism of battle for the participants in the battle" (Cushman, 1986:28). The simulation's purpose is to expose senior level joint service officers to the high level decision making process required to plan and execute a theater level air campaign (DAF, 1987; Ness, 1990a).

TWX was written in 1977 to fulfill a requirement established by the US Air Force Chief of Staff, who directed the Air Force to establish "rigorous courses of study

instructing the operators and planners in the threat and application of force" (DAF, 1987:1). To meet the intent of the Chief of Staff's directive, TWX serves as a command post exercise to provide practical application of the Air War College's courses of instruction. The original designers of this wargame were in fact, students at the Air War College (DAF, 1987).

The Theater Warfare Exercise has been the grounds of much modification and thesis work. Originally the model was run on a main frame computer. Contractors scaled the wargame to a personal computer version which the Wargaming Center renamed Agile (Roth, 1990). The Air Force Institute of Technology has had several master's thesis on improving the database management, the installation of expert systems to automate internal decision functions, integration of graphics and users interfaces, and an upgrade of the land warfare module (Brooks, 1987; Kross, 87; Quick, 1988; Wilcox, 1988; Harken, 1989; Ness, 1990a).

In the present game and scenario, Air Force officers take on the roles of the Commander and staff of the Blue Allied Air Force Central Europe and the two subordinate Allied Tactical Air Forces. The players represent the operations, intelligence, and logistics staffs. Their tasks include publishing an air directive, determining aircraft sortie allocation, targeting, establishing sites for

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incoming aircraft, and planning logistics support. Air War College faculty and Air Force Wargaming Center personnel represent and direct the opposing Red units, which mimic Soviet Air Forces (DAF, 1987; Ness, 1990a).

The original model is composed of two main parts, a strictly air component program and an attached ground component module. The model is coded in Leahy FORTRAN and constrained heavily to a fixed European scenario. The students' involvement consists of entering the data into the air module to affect the enemy's air and land units; and then juggling logistics to provide the resources for the Blue aircraft to fly their missions. The inputs are for a two-cycle day. The first cycle consists of 12 hours of daylight and the second cycle is 12 hours of darkness. At the end of the two cycles, the output consists of reams of paper with various types of detailed reports, earning a model nickname of the "paper war" due to the vast quantities of data generated (AFWC, 1990a:56). With so much data to digest, the students become frustrated when their work shows very little effect on the outcome of the land battle.

Up until 1990, the land module was very simplistic. Land units moved on an internal computer schedule, and the application of airpower on the enemy had little result. To correct these problems, Ness developed an Ada based aggregated land wargame to run with the Agile model and

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there now exists a new land battle with the old air battle module.

The land battle module's switch to the Ada language alone provides a user system that is almost self-documenting and more easily maintained (Ness, 1990a:81). In addition, the Ada land based model also has the flexibility to play a multitude of scenarios. The advantages of the new land module exceed the capabilities of the current air battle module.

1.2 Problem

This thesis develops a new AirLand Battle theater wargame. Given the new land battle, this thesis' effort links US Air Force doctrine with a conceptual model's framework and designs a new air battle module. The integration of the air and land battles causes a new model to evolve, Saber. The Electrical and Computer Engineering Department at the Air Force Institute of Technology will use the algorithms and formulas to construct an object oriented computer simulation.

1.3 Study Constraints and Assumptions

The following constraints and assumptions affect the report:

-A follow-on thesis project will code this wargame into Ada.

-The model will be an aggregated model. An aggregated model is a simulation that combines individual systems into a composite force representing the combined strength of the individual pieces.

-A new theater air battle will be constructed to use Ness' new land battle.

-Naval operations will not be attempted to be modeled at this time.

-The wargame will use only unclassified data and algorithms.

-The new game will have the flexibility to play any scenario or theater of operations.

-US theater headquarters' "command, control and communications will be modeled by the player's interaction in the game and not by the computer simulation" (Ness, 1990a:5).

-"Verification and validation of the new land (and air) battle would be conducted by the Air Force Wargaming Center" (Ness, 1990a:5).

1.4   Objectives

There are two major parts to this problem. The first portion is to determine how the US Air Force doctrinally conducts a tactical air theater campaign and to link it to the model. This process is critical in making the model credible. This investigation will include the tactics, use of aircraft and other weapons, air base operations, and interactions with land maneuver units. The second part of the problem is assembling the model and its components (see Figure 1) (Roth, 1990; Garrambone, 1990). In priority, the model ingredients are:
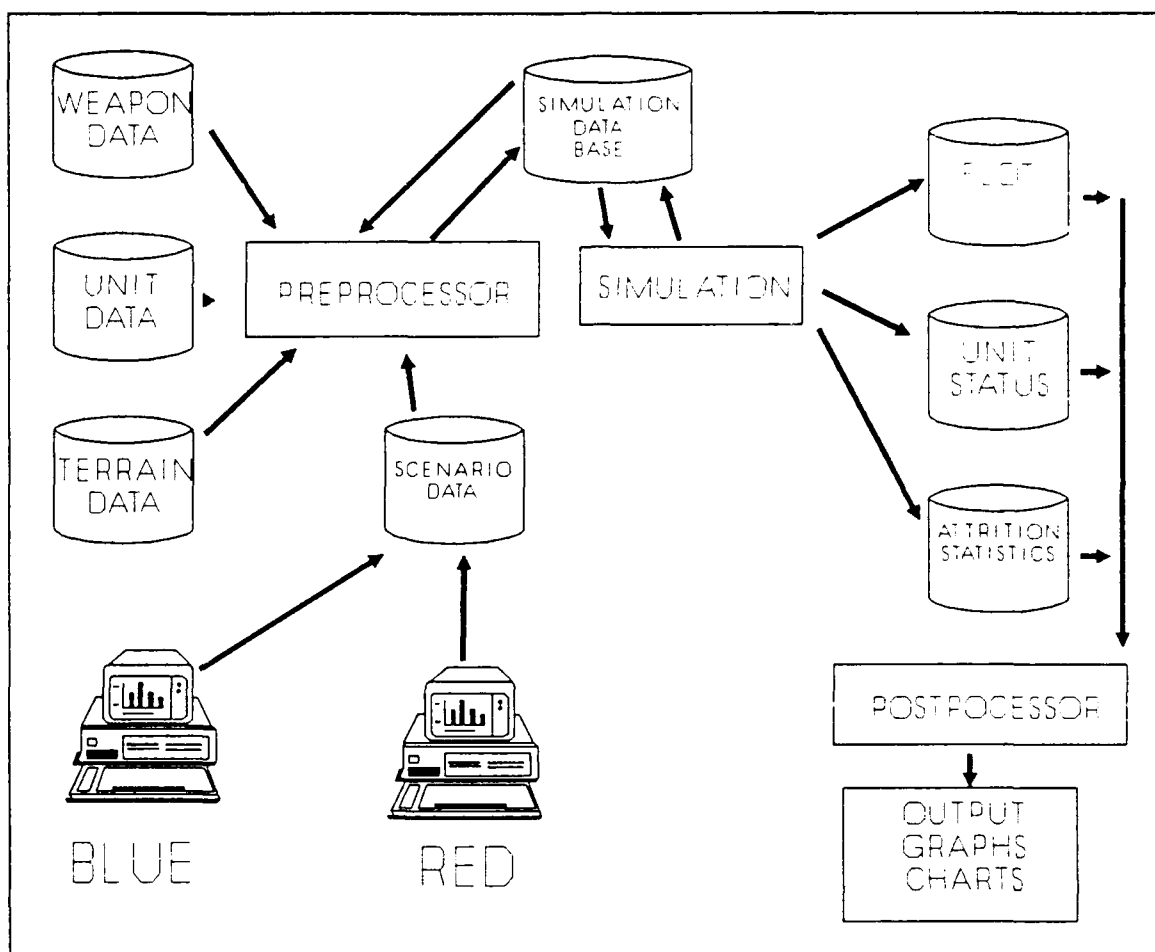
Figure 1. Typical Combat Model

-A sample data base, required to represent major entities and their characteristics within the model. These characteristics are the input variables for the mathematical formulation. This data base will lend flexibility in updating scenarios and the model. Without this data base, one has to embed data, which clouds the model and makes scenarios difficult to create (Garrambone, 1990). Examples of the major categories of entities are aircraft, weapons, air bases, and air defense units.

-Aircraft packages, entities created through the result of aircraft allocation. These packages are a composite of available aircraft, weapons, missions and an intended target.

-An air-to-air module, needed for the Blue and Red air packages to provide aircraft attrition and affect the opposing packages' mission accomplishment.

-An air-to-ground module, to calculate the damage to resources, combat power, and movement values of a ground target.

-A ground-to-air module, expressing the result of a ground unit's guns, and missiles on aircraft packages.

-A logistics module, needed to maintain real world constraints on the play of the wargame. Attacks on logistics would decrease the resources available to the players. The module will have three functions; transportation, supply, and maintenance. Transportation is the movement of supplies from supply depots to the air bases. The movement can occur through pipelines, surface transports or air transports. Supplies are those consumables needed by the aircraft to be able to accomplish their missions. Supplies would be fuel, weapons, and spare parts. Maintenance is the scheduled or necessary work needed to prepare an aircraft to fly. This work can either be routine or the result of battle damage. Maintenance is a

function of manpower, maintenance hours, facilities and supplies.

-An intelligence module, to collect the information provided by many sensors. Intelligence reports are a result of land units in contact, reconnaissance flights, returning combat sorties from enemy territory, and satellite overflights.

-A nuclear system, for targeting, planning and execution of nuclear weapons.

1.5 Scope

This thesis is to provide the conceptual framework for a computer programmer to code this model. The Electrical and Computer Engineering Department has a working Ada land module. This new land model can interface with the present PC Agile model. Using the land module as a starting point, This thesis will design a new air battle module that makes the wargame into a single AirLand Battle computer simulation.

The Wargaming Center desires an upgrade of the present Agile model along the lines of TAC Thunder. TAC Thunder is a theater level analyst's tool used at the Air Force Center for Studies and Analysis (AFCSA).

The Wargaming Center wants to be able to shift the geographic location of the wargame to any part of the world,

and this cannot be done with Agile as most of the initial data is hard coded into the model.

The Wargaming Center desires speed over accuracy and wants to understand the concepts built into the model.

The model must provide detail but be simple to use. It is not desirable for the students to be able to follow the battle by the tail number of the aircraft.

The model must have the ability to incorporate additional improvements and features. As new tactics or systems evolve, the model should be flexible enough to allow additional improvements and features.

1.6 Sequence of Presentation

Given the land based model, this thesis links Air Force doctrine with a model's conceptual outline. The literature review shows the command and control systems for both Soviet and US Air Forces. The scenario uses these concepts in a South West Asia (SWA) scenario.

Next the thesis develops the mathematical formulation required for a new air theater wargame. Using the doctrine and scenario, the key entities are identified and their characteristics determined. Using mathematical models found in the literature search, this wargame strings these models throughout the simulation for the entities to interact to result in credible outcomes.

Lastly, to describe the format of input and output and how the game interacts with the players.

This entire descriptive thesis' purpose is to build the major components for an Ada programmer to be able to develop a program. The Study Matrix (Figure 2) shows the key components and processes that this thesis models.
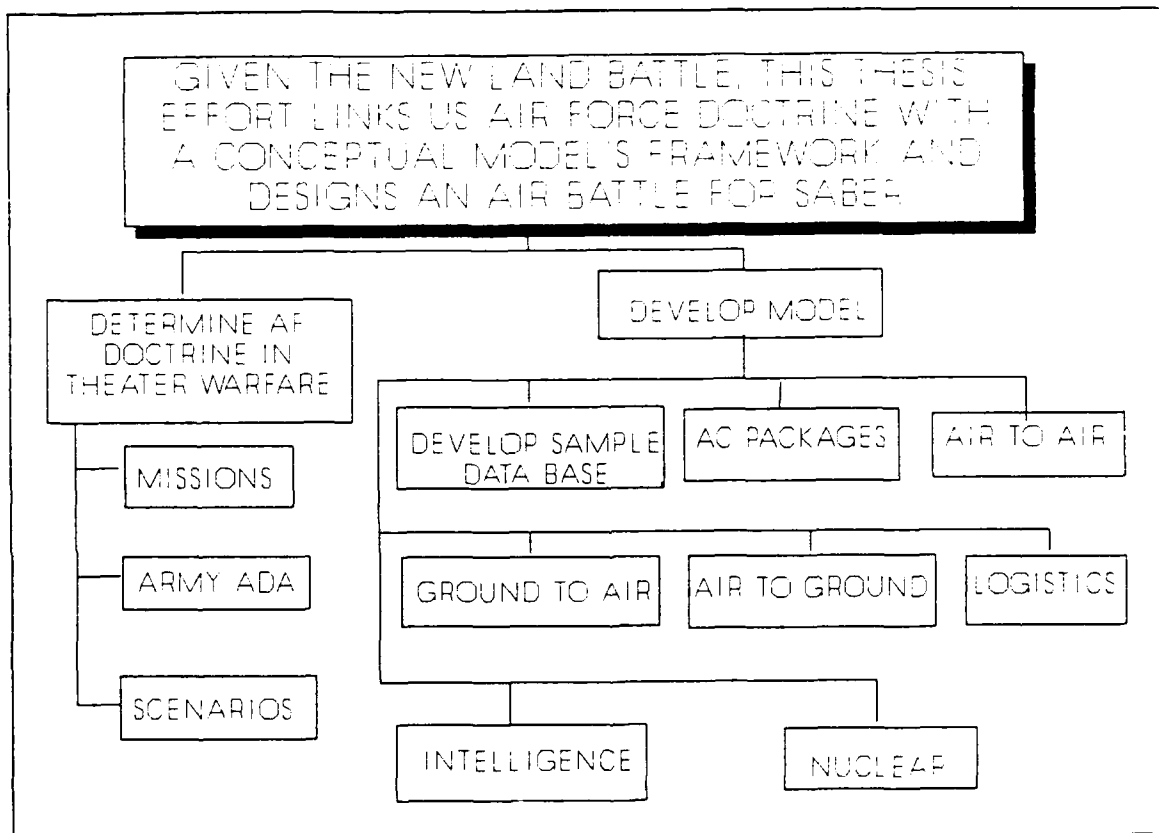
Figure 2. Study Matrix

II. Literature Review

2.1 Introduction

The purpose of this chapter is to review some of the literature about US Air Force and Soviet doctrine, theater warfare models, wargaming, and mathematical models. All Air Force doctrine can not be found in a single book and, to lend credibility to this modeling effort. this doctrine needs to be precisely defined. Analyzing the enemy's doctrine is another requirement. For the most part, the field of theater warfare models remains rich and expansive. Since the designing of the Theater Warfare Exercise (TWX) in 1977, the field of theater warfare models and its literature has grown in degree and complexity. This literature must be exploited to improve the current TWX model. Wargaming by amateur hobbyists is another area that can contribute to this simulation improvement. It is also necessary to use some mathematical models that describe basic and specific outcomes of combat processes. Therefore, this review covers the basics of Air Force doctrine, fundamental missions, command and control, linkage between the Air Force and Army air defense artillery (ADA), and Soviet military doctrine. Additionally, an introduction to the modeling of theater

warfare, an examination of some of the literature on theater warfare models, commercial wargaming, and a survey of modeling techniques will be introduced.

2.2   Air Force Doctrine

To model theater level warfare correctly, the Air Force's war fighting doctrine needs to be clearly explained. "Doctrine is the fundamental principles by which the military forces or elements thereof guide their actions in support of national objectives. It is authoritative but requires judgement in application" (AFSC, 1986:118).

The stated basic doctrine in air warfare is to gain freedom of action in the air environment (DAF, 1984b:vi; DAF, 1990). This implies that air superiority is the basic goal of the Air Force. "The fundamental mission of all tactical airpower is to support the operations of surface forces. In spite of this fundamental mission, the priority of tactical airpower is air superiority" (Drew, 1984:7). Therefore, the prevalent attitude is for the Air Force to win the air war, before assisting with the surface war.

This doctrine is also prevalent in the Air Force's mission, as outlined in the 1986 Joint Staff Officer's Guide:

>   The Department of the Air Force is
> responsible for preparing the air forces necessary
> to effectively prosecute war. Some of the primary
> functions of the Air Force are as follows:

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          -To organize, train and equip the Air Force forces
               to conduct prompt and sustained combat
               operations in the air;
          -To gain and maintain general air supremacy;
          -To defeat the air forces;
          -To control vital air areas;
          -To establish local air superiority;
          -To furnish close combat support and logistical
               air support to the Army;
          -To furnish air transportation to the armed
                    forces; and
          -To offer an organization capable of furnishing
               adequate, timely and reliable intelligence.
               (AFSC, 1986:1-14)
```

2.3   Fundamental Missions

Air Force Manual 1-1, Basic Aerospace Doctrine,
explains the fundamental missions of the Air Force. Some of
these missions are counter air, air interdiction, close air
support, aerospace surveillance, and reconnaissance (DAF,
1984b:3-2). These fundamental missions have further
specific missions to accomplish these tasks. Figure 3
presents a pictorial representation of these missions.

2.3.1   Counter Air. Counter air is control of the
aerospace environment. Offensive counter air (OCA) and
defensive counter air (DCA) compose the two parts of counter
air operations. Offensive counter air operation's purpose
is to destroy, disrupt, or limit enemy air power as close to
the source as possible. Defensive counter air missions
reduce or nullify the enemy's air attack (DAF, 1984b:3-3).
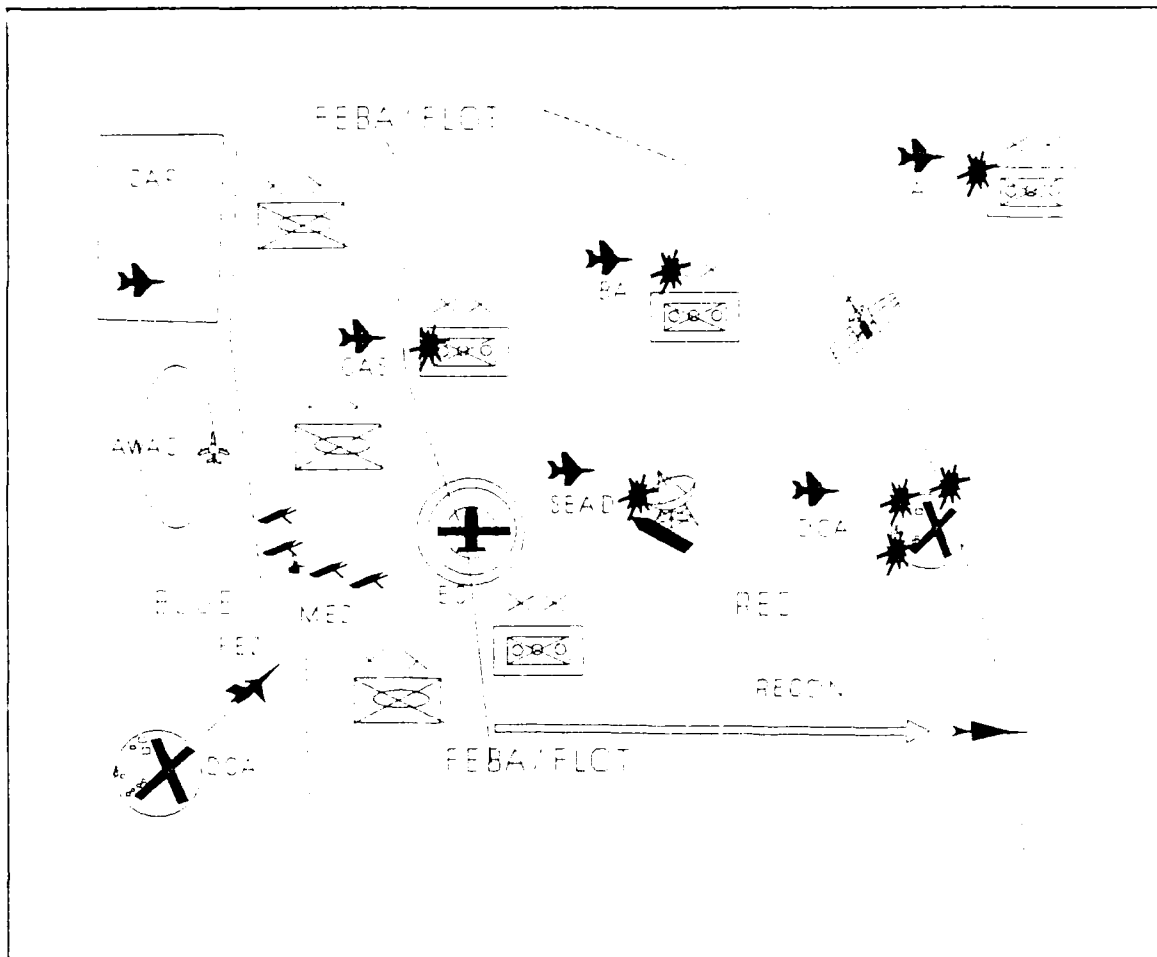
Figure 3. Fundamental Missions

2.3.1.1 Offensive Counter Air. Offensive counter air operations may contain many aircraft with differing specific missions to conduct this operation. Destruction of an enemy's air base may be an example of offensive counter air operations. For this specific operation, strike aircraft conduct the air-to-ground assault on the air base. These aircraft may be joined by an air escort to defend the strike aircraft from the enemy's defensive aircraft. Electronic combat and suppression of

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enemy air defense (SEAD) aircraft could accompany the strike planes to suppress surface-to-air missiles and detection by the enemy's radar. SEAD is also an OCA mission.

Suppression of enemy air defense (SEAD) is the use of aircraft that seek and neutralize enemy surface ADA sites. This can be either by an electronic or physical attack. These missions have special aircraft, such as the EF-111 fighter bomber and the F-4G, "Wild Weasel" (DAF, 1984a:2-3; DAF, 1984b:3-3).

Another OCA mission is a fighter sweep. A fighter sweep's job is to destroy the enemy's air force in the air over non-friendly territory (DAF, 1984a:2-3).

2.3.1.2 Defensive Counter Air. Defensive Counter Air (DCA) is the process of "detecting, identifying, intercepting, and destroying enemy air forces that are trying to attack friendly forces or enter friendly air space" (DAF, 1984b:3-3). DCA is more than defensive aircraft intercepting the enemy's planes. DCA also includes the detection of enemy airplanes by airborne and ground sensors, the use of combat air patrols, fighters on strip alert, and the integration of Army ADA weapons into a cohesive defensive structure (DAF, 1984a:2-3; DA, 1984a:9-2).

The integration of Army capabilities is not well defined in either AFM 1-1 or FM 44-1-2. Both documents state that the theater commander assigns a single commander to be responsible for air defense and air space control. This officer is usually an Air Force officer who coordinates and integrates the entire defense. The US Army Concepts Analysis Agency's (CAA) COMO Hammer 88 Validation Study contains a probable scenario of this integration (see section 2.5). This study is on COMO IAD or COmputer MOdeling Integrated Air Defense. This report explains in detail a field exercise of air defense Patriot and Hawk batteries against 77 attacking aircraft in England. The purpose of this study was to validate CAA's COMO IAD, using field conditions. The scenario for this test explains the command and control procedures for defensive counter air (DA, 1989).

2.3.2 Air Interdiction. The purpose of air interdiction is to "destroy, neutralize, or delay the enemy's military potential before it can be brought to bear effectively against friendly targets or forces" (DAF, 1984b:16). This operation includes attacks on the enemy's combat forces, supplies, transportation network, communications, and morale (Cole, 1982:10). The effects of these attacks may not contribute to an immediate result on

the battlefield, but have an ability to degrade the enemy's future warfighting potential.

There are two types of interdiction: air interdiction (AI) and battlefield air interdiction (BAI). Air interdiction occurs in the rear of the enemy's territory and requires minimal coordination with the surface commanders. Battlefield air interdiction occurs on enemy units that will have a direct impact on the surface battle of the near future. BAI requires coordination with the surface commanders as to the targets and to the proximity of the attacks to friendly troops (DAF, 1984a:2-4).

2.3.3 Close Air Support. Close air support (CAS) is the use of the aircraft firepower on enemy combat forces that are in contact with the friendly surface forces. Probably the most controversial and most dangerous missions performed are those of close air support. CAS is the most controversial mission because of the interservice rivalries for the control of this type support. Close air support is the most dangerous because of the intermingling of combatives amongst large quantities of air defense weapons (DAF, 1984a:15; Carlin, 1985:9).

2.3.4 Aerospace Surveillance and Reconnaissance. Surveillance and reconnaissance are the most heavily

used peacetime and wartime operations the Air Force
operates. At the strategic level there are space systems
and sophisticated planes to collect both electronic and
photographic information of the enemy's operations and
intentions. At the theater reconnaissance level, the use of
Airborne Warning and Control Systems (AWACs) and tactical
airborne and ground radars provides detection,
identification and control of defensive counter air assets
to meet the enemy's air attack. Tactical reconnaissance
flights provide the information of the air and surface
operations on the enemy's side of the forward line of troops
(FLOT).

2.4   US Army Air Defense Artillery

From the Army's point of view, there are two main
classes of Army air defense weapons: short-range air defense
weapons (SHORAD) and high-to-medium-altitude air defense
systems (HIMAD). Together the systems are linked by special
communications networks and at times fall under the
operational control of the US Air Force.

SHORAD supports maneuver units of infantry, armor and
armored cavalry. SHORAD consists of Vulcan anti-aircraft
guns, Chaparral missiles, and man-portable air defense
(MANPAD) systems such as Redeye and Stinger. These weapons
are portable and keep up with the maneuver forces to provide

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protection against low flying aircraft and helicopters. They also provide short-range defense for key installations, bridges, and command posts. A major drawback of most SHORAD weapons is a requirement to optically track the enemy aircraft (DA, 1984a:1-1 to 1-19).

HIMAD include the Patriot and the Hawk missile systems. HIMAD missiles defend the theater commander's high priority assets against hostile high performance aircraft. Both missile systems have organic radar systems and specialized communications systems (DA, 1984a:2-1 to 3-5). The average intercept range for the Patriot is 40 kilometers; and the average intercept range for the Hawk is 29 kilometers (DA, 1989:4-10).

An important consideration for theater air defense assets is the need for the target to be illuminated by a radar beam. One radar system searches and detects the aircraft. Another radar tracks the target and illuminates the target. The reflected radar off the target guides the missile. Both acquisition and tracking can be done with one radar as with the Patriot system or with multiple radars as with the Hawk system (DA, 1984a:2-7 to 2-11).

2.5 Integration of DCA

The following scenario for integrated defensive counter air operations is from the CAA's COMO Hammer 88 Validation Study.

> Blue air assets consist of interceptors on combat air patrol (CAP) and in various readiness states at airbases. Command and control centers receive target information from remote or collocated sensors, orbiting Airborne Warning and Control System (AWACS)-type aircraft, and HIMADs. The command and control centers assign and guide interceptors toward target aircraft. HIMADs fire at targets they are tracking but are restricted by the command and control center from engaging those targets which are fully allocated to other HIMADs and interceptors. A region can be defined as a SHORAD attrition zone. All Red aircraft flying into this zone are subject to attrition depending on the density of the sites, rate of fire, and kill probability. An interceptor defense line limits the flight of interceptors to protect against fratricide. Red attacking assets consist of orbiting standoff jammers (SOJ), escort jammers (ESJ), escort fighters, and bombers and air defense suppression aircraft with self-screening jam (SSJ) capability. (DA, 1989:C-2)

For DCA, the theater assets come under control of the Air Force. The Army air defense missile units and Air Force fighters must now have a method of engaging the enemy without the Army missiles engaging friendly aircraft. This is done by a Missile Engagement Zone (MEZ) and a Fighter Engagement Zone (FEZ). The MEZ is usually found up closer to the FEBA and is made up of Hawk and Patriot batteries. The FEZ is behind the MEZ and consists of the fighters on CAP and strip alert. The above description varies depending

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upon the situation and needs a sophisticated command and control network. (Towe, 1990)

2.6　Command and Control

The Air Force's command and control system is the Tactical Air Control System (TACS).　In theory, a Tactical Air Force (TAF) is assigned to a joint operation.　The Joint Operations Commander is in charge.　His subordinates are the Land Component Commander and the Air Component Commander. Both the Land and Air Component Commanders are coequals. The Air Component Commander is usually the Tactical Air Force (TAF) Commander.

The Tactical Air Force Commander has the Tactical Air Control Center (TACC) as his operation center/command post. The TACC does the required planning, directing, and coordination of tactical air operations.　Based on the TAF Commander's guidance the TACC develops the specific taskings of the subordinate units.　These taskings are published in an Air Tasking Order (ATO).

The ATO prescribes the processes of allotment, apportionment, and allocation of the tactical air resources. "Allotment is the temporary change of assignments of tactical forces between subordinate commands.　This occurs usually in a theater with multiple TAFs" (DAF, 1984a:2-4). "Apportionment is the determination and assignment of total

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expected effort by percentage and/or priority that should be devoted to various air operations or to certain geographical locations" (DAF, 1984a:2-4). "Allocation is the computation by the TACC of the apportionment decisions to the total number of aircraft sorties by aircraft type and mission" (DAF, 1984a:2-4). Distribution of allocated aircraft is done by lower levels.

Subordinate to the TACC are the Air Lift Control Center (ALCC), Combat and Reporting Centers (CRC), the Ground Attack Control Center (GACC), and the Air Support Operations Centers (ASOC).

The Air Lift Control Center (ALCC) monitors the strategic airlift missions that enter the TAF's region and coordinates all intra-theater airlift operations. The ALCC optimizes airlift operation of logistics and coordinates the air assault or airborne missions in the area (DAF, 1984a:5-4).

The Combat Reporting Centers (CRCs) are the TAF's decentralized control centers of smaller sectors. CRC's main mission is to direct the sector's air defense and airspace control function. The centers also monitor all air missions in it's sector and relay changes to airborne aircraft and subordinate units. The CRC also supervises subordinate Combat Reporting Posts (CRP) which are airborne radar surveillance aircraft (i.e. AWACs) or ground based

radars (DAF, 1984a:5-5, 5-7). Army air defense is also part of CRCs (Allen, undated:28).

The Ground Attack Control Center (GACC) is the primary control center for time-sensitive interdiction targets (DAF, 1984a:5-6). The GACC receives intelligence from the Joint Surveillance Target Attack Radar System (JSTARS) or by other means, and match target to air force resource according to the Air Tasking Order. The GACC will receive the air picture from the CRCs, CRPs, and AWACs. The GACC must also closely coordinate with the Air Support Operations Center.

The TACC is a flexible organization, that can be reorganized to fit the needs of the situation (Walsh, 1984). According to Walsh, the TACC may be organized into a Combat Plans Division, Combat Operations Division, Combat Operations Intelligence Center (COIC), and the Tactical Fusion Center (TFC). The Combat Plans Division is the resource giver and tasks units with the ATO. The Combat Operations Division executes the current day's air war. The COIC is the future-oriented analysis that conducts collection management, targeting, capabilities and analysis. The TFC handles the immediate intelligence needs and disseminates the perishable information. In his report, Walsh makes no mention to the GACC.

The Air Support Operations Center (ASOC) plans, directs, and coordinates the immediate air strikes needed by

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the Army (DAF, 1984c:5-11,5-12). The ASOCs are attached to every Corps. ASOCs usually handle requests for CAS, BAI, reconnaissance and tactical airlift. The ASOC will also exchange data between the different Army units and the Air Force. Subordinate to the ASOC are the Tactical Air Control Parties (TACP). A TACP is found at every division, brigade, and maneuver battalion. A TACP is a small group of experienced Air Force personnel collocated with the unit's headquarters. The TACP processes the unit's request for air support and directs the CAS aircraft if needed.

A Wing Operation's Center (WOC) is the air base's planning staff (DAF, 1984a:5-13). The WOC consists of whatever facilities are available to support that particular unit. Each base has a requirement to establish a WOC. From the WOC, the squadrons assigned to that base receive their missions.

2.7   Soviet Military Doctrine

While the Soviet Union may no longer be the West's number one enemy, the world still thinks "bipolar." This means that air doctrine follows either a US/NATO or a Soviet view on doctrine. Being such, it is necessary to cover some basic Soviet doctrine.

Most of the Soviet doctrine comes from the experiences of the Great Patriotic War (Soviet Doctrine, undated:xiii to
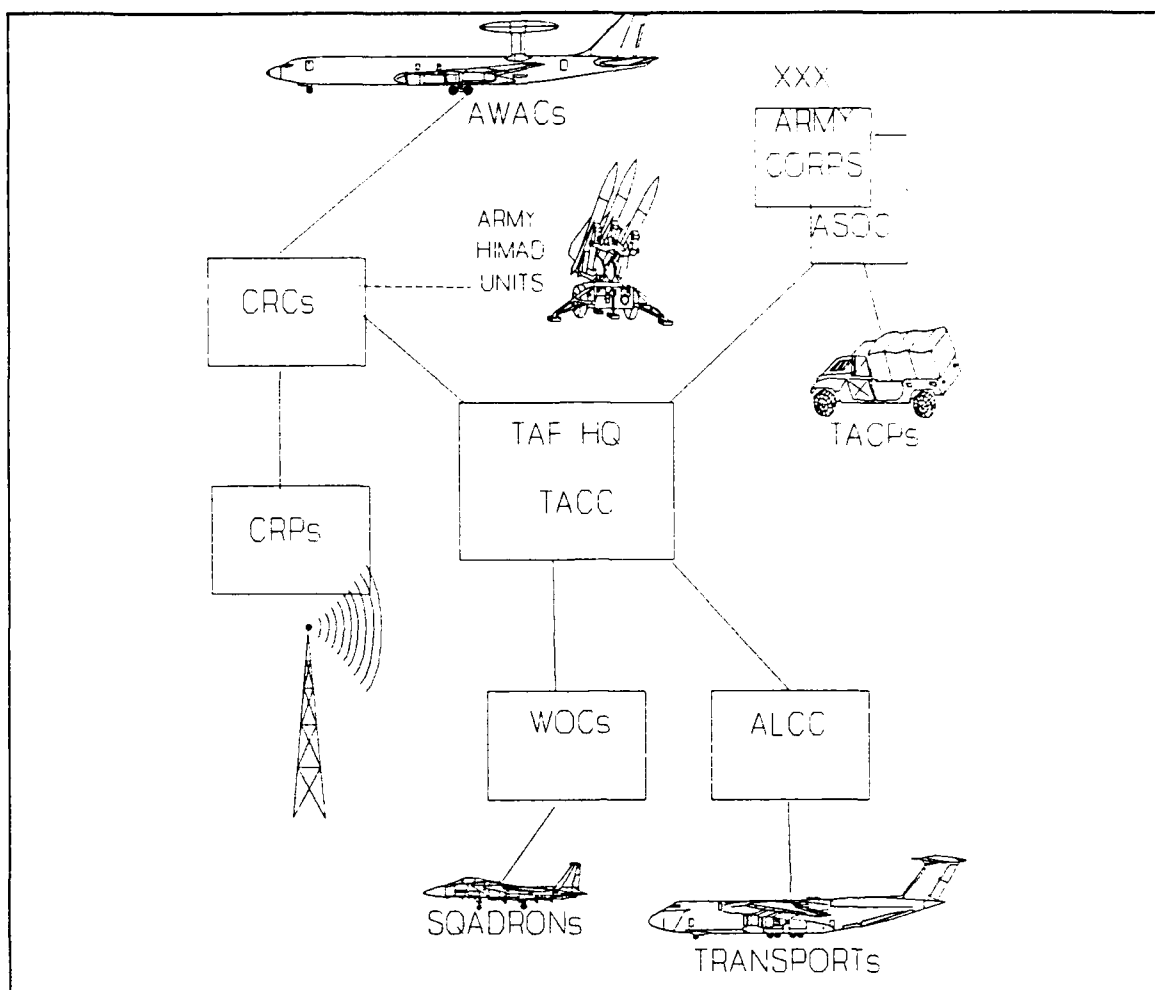
Figure 4. Tactical Air Control System

xix). A result of their experience in WWII is the ground
forces' domination over all other military forces. This
makes the Soviet Air Force and Navy subordinate to the
ground forces. Even when the US and Soviet military
doctrine do have some commonalities, a person finds that the
emphasis is quite different.

The greatest differences in doctrine are in several
areas. The Soviets believe in the mass of armored
formations where speed and a continuous tempo is demanded.

Their literature places a great deal of emphasis on deception. Deception and surprise were bitter lessons that the Soviets learned as the Germans gave them major defeats in the beginning of WWII. The Soviets believe that the use of chemical and nuclear weapons are just another tool to use in warfare.

2.7.1 Soviet Air Doctrine. Soviet air doctrine is still evolving (Cole, 1982:21-35). But the Soviets believe that the first step in war is to gain Air Superiority, with massed surprise attacks on Blue airfields being the preferred method. This is followed up by concentrated air attacks on Blue air defense capabilities. The second step is Air Cover. Air Cover is the protection of Red ground units from air attack. According to Cole, 40% of the Soviet frontal aviation aircraft are dedicated to defending ground units from air attack.

Air Strikes are considered an extension of artillery fire. The great bulk of these missions are preplanned strikes. Their targets are against command posts, tactical delivery means, support units, and reserves. This concept is similar to the US BAI mission. The major difference is the minimal support for CAS. Soviet attack helicopters have taken over this role and aircraft are only doctrinally assigned to CAS missions in certain operations. These

operations are mountain operations, airmobile assaults, and river crossings.

There are other similar US/Soviet missions. For example, the Soviets have a concept of isolating the battlefield that corresponds to the US AI mission. Reconnaissance also has an important joint requirement in that the stress of continuous combat operations places a great need in field intelligence. To make the gains and keep the momentum described is Soviet doctrine, the commanders can not afford to be surprised.

Soviet doctrine prescribes the use of chemical and nuclear weapons. They are well equipped to carry out both types of attacks. There is little difference in the delivery of chemical weapons from the use of conventional weapons. Chemical weapons would aid in their air superiority, air strikes, and isolation of the battlefield operations. Nuclear targets are the enemy's nuclear delivery systems and storage sites. The next important targets are headquarters, reserves, depots, and communication centers. In both chemical and nuclear operations, the Soviets stress surprise and the immediate use of ground forces to exploit the weapons capabilities.

In war, Soviet forces come under the control of a Theater of Military Operations (TVD). The TVD establishes the overall strategic objectives. Subordinate to the TVD is

the Front. The Front commander is in charge of both the land forces and the Tactical Air Army (TAA) assigned to the front. There is no overall air component commander as in the US forces. The TAA Commander executes air missions assigned by his Front commander. The process of apportionment, allocation, and tasking still occurs, but in reference to the Front's guidance. This may have a disjointed effect in overall air mission effectiveness as compared to the US system.

2.7.2 Soviet Air Defense. The Soviet air defense is different than the US organization, and is organized as national or military air defense (Suvorov, 1982:73-74). At the national level, the Soviets have a separate air defense organization for the defense of the Soviet Union territory. This organization has its own interceptor aircraft and fixed anti-aircraft missiles. The ground forces have an integrated military air defense system that is mobile and a permanent part of the fighting units.

The Soviets have a more numerous and varied air defense system (DA, 1984a:15-1 to 15-6). They have a large number of air defense guns and mobile surface-to-air missiles to form their air defense umbrella. As newer weapons come into the Soviet's inventory, the older weapons are still kept or

given to Soviet block countries. This is why the Soviet's
have such a wide variety air defense systems.

2.8   Theater Warfare Models

The Air Force has a hierarchy of air-to-air models.
Friel explains this hierarchy in great detail. The models
begin with one versus one. An example is P001A, an air
defense gun versus an aircraft. The next level of modeling
is few versus few, i.e. TAC Brawler, PACAM 8, or AASPEM.
Finally there are the theater models; TAC Warrior, TAC
Thunder, Agile, and SOTACA. Each of these models fills a
particular niche, but there are limitations common to each
type of model (Friel, 1984:127-144).

A one versus one model is a very detailed
representation of the dynamics of two competing weapon
systems. At this level, modeling of surface-to-air missiles
(SAMs), aircraft, air-to-air missiles, and projectiles are
done in great detail. These models are very useful for
determining engineering trade-offs or to experiment with new
tactics for one-on-one combat engagements. A common problem
with one versus one models is that the answer is in
isolation to other effects. An example is an aircraft whose
tactic to break engagement from an air-to-air combat may put
the plane in danger from a SAM battery.

Few versus few becomes more complicated but also adds the synergistic effects of different systems. Now the models add some interaction of air-to-air, ground-to-air and air-to-ground combat. Again, an isolation of effects might occur. Friel gives the example of modeling a flight of four A-10s against an armored company. Neither the effect of the neighboring companies' fire nor the effect of the that armor unit being under direct fire of a friendly unit are modeled. The biggest factor not modeled is the quality of the aircraft and sortie generation. Quality aircraft need less maintenance and can rapidly return to the battlefield. Few versus few modeling only focuses on a few particular engagements and not prolonged campaigns.

Theater models consider logistics, sortie generation, and the qualities of a total air force. Unfortunately, the models sacrifice some level of detail for aggregation and contain a quantity versus quality dilemma for operational studies. Also, the models require an extreme amount of information to produce credible scenarios. However, the biggest advantage of theater models is the duration of the battle they can portray.

Duration causes the modelers to think about more time dependent details which can be overlooked in the smaller models. These simulations must include air bases, spare parts, fuel, the amount of weapons on hand; the amount of

maintenance needed by the aircraft becomes important.

Sometimes, the results of the one versus one and the few

versus few models become inputs for the theater models. The

modelers must weld the integration of all factors together

to build a credible model capable of capturing the

synergistic effects of weapon systems and the criticality of

scarce resources (Friel, 1984:127-144).

2.9   Problems with Theater Models

Many theater warfare models exist with varying degrees

of detail and complexity. The newest models are often

classified and many of the older models have fallen into

discredit. But frequently, it is from the lessons of the

older models that the newer models base their concepts.

In his thesis on SOTOCA, Buckingham reports that air-

to-air encounters use pairwise system comparisons supplied

by the user to generate battle outcome (Buckingham, 1990:19-

31). These values are not unlike the system Dunnigan

describes as assigned numerical quantities for a plane's

capabilities (Dunnigan, 1988:163-175). Both systems provide

a relatively simple method of determining aircraft

attrition.

SOTACA does have problems that counteract the

advantages of the pairwise comparisons. CAS attacks only

degrade the enemy's air defense units with little result on

the total enemy force. Also, supporting missions of fighter escort and suppression of enemy air defense must be flown with the primary mission or the primary mission is aborted (Buckingham, 1990:29-31).

Problems with theater level wargames are not new. In 1980, the General Accounting Office wrote a harsh report on the prevalent theater models (CEM, IDAGAM, and LULEJIAN), where aggregated models with the soldiers, tanks, and aircraft were lumped into a single "firepower score." "The basic problem in developing an aggregation scheme is a linear weighing problem (e.g., how many rifles are equivalent to a tank, flamethrower, or an aircraft?) (GAO, 1980:54)." The preferred model was the VECTOR model that provided much more detail of the individual systems. In VECTOR, the individual systems use weapon performance factors, acquisition parameters, line of sight calculations, and factors describing force employment. This level of detail enables maneuver and precise attribution of killer/victim relationships to determine the results. This detail endows the model with a transparency that is not found in the other models (GAO, 1980:55-56).

It is the theme of transparency that is the subject of many other conceptual wargames. Some ideas incorporated into Saber came from the Military Operations Research Society's (MORS) proceedings and published reports on

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improving theater models (Sikora, 1987; Low, 1981; Cordesman, 1976). Other ideas come from conceptual models for new theater wargames have been written by several authors (Fox, 1985; Cole, 1982; Madden, 1981). The problem with these articles are that the authors neither present ideas of how to construct a wargame nor what the mechanics should be inside.

2.10   Building Wargames

As a designer of commercial wargames, James Dunningan writes two basic rules for building a wargame. These rules are to keep it simple and plagiarize (Dunnigan, 1980:235-238; Perla, 1990:187). Peter Perla echoes Dunnigan's rules and explains that plagiarism is the use of already known ideas to build new wargames. Wargame designers should capitalize on proven and reliable methods. In that way the designing process is kept as simple as possible. Following these two rules, Dunnigan outlines ten steps for the development of wargames (Dunnigan, 1980:236-239). They are:

1. Conceptual development
2. Research
3. Integration of ideas into the prototype
4. Fleshing out the prototype (adding the chrome)
5. First draft of the rules
6. Game development
7. Blind-testing
8. Final rules edit
9. Production
10. Feedback.

Perla writes that Dunnigan has evolved two basic concepts when developing games (Perla, 1990:189). The game must accurately simulate the events that are to be portrayed. Secondly, the designer must choose the proper level of focus and simulation. Examples given by Perla are that if the game is a historical simulation, the game should have portrayed the important events. If the game is at a theater level, then the players should not be trying to choose individual tactics for very low subordinate units. In other words, keep the players "out of the weeds," and concentrate on the role that they are playing.

The last important thought Perla relates is "wargaming is an act of communication. Designing a wargame is akin more to writing a historical novel than an algebraic theorem" (Perla,1990:183). The "problem is turning a collection of mathematical models into a game" (Perla, 1990:190).

2.11 Mathematical Models

Numerous useful modeling mechanisms are available in volumes 1 and 2, Engineering Design Handbook (DA, 1977; DA, 1979). A stated purpose of these books is to "conserve time, materials, and funds by outlining approaches to problems which have proven to be helpful over the years" (DA, 1977:1-4). Though time dated, these books still cover

fundamental problems in weapon system probabilities, attrition, and detection. The books give a short background on the topic, a quick proof down to workable formulas, and then a few practical examples.

The documentation of current wargames provides valuable information. TAC Thunder, and to a lesser extent Agile, provide basic algorithms for combat simulations. TAC Thunder's manuals gives good detail and rationale for its mechanisms (AFCSA, 1990a; AFCSA, 1990b). Agile manuals contain some algorithms, but little of the rationale behind the air attrition formulas used in the model (Ciola, 1982).

Przemieniecki's book also holds algorithms for combat models and weapon system deliveries (Przemieniecki,1990). The book gives not only the formulations, but the proofs to support the algorithm. This helps in the understanding of foundations of the other references.

An important concept of comparing the air-to-air abilities of aircraft was given by Dunnigan, who describes how aircraft compare to one another and what measures of effectiveness are used to get these comparisons (Dunnigan, 1988:164-175). Dunnigan not only describes planes but also rates the performance of missiles and air defense weapons. Though his creditability is mostly from commercial wargame design, Dunnigan presents a method that is comparable to a widely used analysis model of SOTACA.

2.12 Summary

The purpose of this literature review was to provide insight into US Air Force doctrine, Soviet military doctrine, theater warfare models, wargaming, and mathematical models. Starting with the US Air Force, the specific missions and linkage between systems have been loosely defined with further comparisons between the US and Soviet military doctrine. These doctrines will be the starting point for the conceptual model's scenario. Next, an introduction of theater level models and their problems were provided and a quick survey of how to build wargames and the available information in modeling was discussed.

This literature review will form the basis for describing a plausible scenario and later will be used in the building of a wargame to mimic the operations of war.

III. Scenario

3.1   Introduction

This chapter describes the scenario used to build the
conceptual model.   The overall approach is to describe a
general scenario of how Blue versus Red would fight in
theater level warfare.   After the scenario is built within
current doctrines, the underlying processes are next
examined.   These processes include command and control,
interactions of different entities, and factors important in
predicting the outcomes of the interactions.   The processes
discussed will include the key assumptions to be followed
throughout the model.   Following this step will be a
description of the concepts employed to determine the
mathematical processes used to describe the interactions of
different objects.

3.2   General Scenario

The chosen scenario is from the Dayton Daily News front
page story of 26 November 1990 (Greve, 1990).   The article
is "How a War with Iraq Might Unfold."   This scenario was
chosen due to the many combat processes, the level of
current events, and the unclassified nature of the
information.   The situation evolves as follows.

Diplomatic efforts with the Iraqi government have failed. The invasion of the neighboring country of Kuwait has the United Nation's community in an uproar. The United States and other nations have decided to use the ultimate political means.

The war is not a surprise to Iraq. Political and religious fervor has risen tremendously. The debates in both the United Nations and the United States Congress have provided much information to the Iraqi military of the upcoming war.

Iraq lies between many countries (see Figure 5). In the south and west is Saudi Arabia with the large bulk of the multinational forces. The US has four Corps of land forces and many US aircraft. The Persian Gulf and Iran are to the east. Iran is a non-player who may be sympathetic to their new found friend of Iraq. US airplanes dare not use Iranian airspace for fear of enlarging the war. The Persian Gulf gives the Marines a way to capitalize on their amphibious techniques with US Navy support. Syria and Turkey lie to the north and have their own combat troops poised for attack. Even if these forces do not make gains, the presence of troops will tie down some of the Iraqi troops. NATO planes fill the Turkish air bases, awaiting to strike from the north.

Figure 5. Map of South West Asia

Phase one of the operation is the reconnaissance of the Iraqi defenses. Satellites and reconnaissance planes pinpoint troops, air bases, depots, and choke points. Priority targets to be identified are the Iraqi SCUD missiles and chemical warfare plants. New satellites are placed in orbit to strengthen the reliability of intelligence.

Satellites provide the bulk of the strategic information. Modified orbits enable a better inspection of troop concentrations of mobile reserves. National security assets have pinpointed the principal chemical warheads, but there are doubts that all facilities have been found.

Tactical reconnaissance provides the information of individual SAM sites and troop locations. Remotely piloted vehicles (RPVs) provide an excellent way of getting detailed local data. JSTARs provide information on vehicle movement.

Phase two starts the combat, and the US Air Force
attempts to establish air superiority. Electronic combat
planes jam the SAM sites radars as strike aircraft, cruise
missiles and medium range surface-to-surface missiles stream
over the borders. The primary missions are SEAD, OCA, and
AI on the missile sites and depots.

The Iraqis fight back flying defensive air missions and
launching their own strike missions. Chemical warheads from
SCUD missiles target air bases, troop concentrations, and
cities. The purpose of these strikes is to use political
terror as a weapon instead of a military significant
response.

After US aircraft destroy the Iraqi air defense and
their air force, the ground attack begins. Mechanized
forces attack from the south into Kuwait. The Marines
conduct an amphibious assault from the gulf. Airborne and
air assault troops conduct vertical envelopments to control
key terrain. The friendly air forces continue the war for
air superiority, but now the priorities changes to the
support of the air assaults and CAS for the ground combat
units.

Iraq rushes tactical and strategic reserves of armor
heavy forces to reinforce front-line forces. Friendly air
needs to find and subject the reserves to intense BAI and AI

operations. Using air dropped mines delays the reserves in the mountain passes and rugged terrain.

While losses are heavy on both sides, the US is able to push the Iraqis out of Kuwait. Satellite failures cause the US commanders to scramble for the management of scarce intelligence. Saddam threatens the use of more chemical weapons and secret nuclear missiles.

3.3 Detailed Scenarios and Assumptions

Details of this scenario are provided by personal interviews, Air Force doctrine and a generalized understanding of the learning objectives involved for the players using this model. These assumptions will be specifically modelled as a part of the war game.

The detailed processes are many. The processes include electronic combat, suppression of enemy air defense, offensive counter air, air interdiction, airborne assaults, air assaults, amphibious operations, uses of satellites, and other operations.

Electronic combat planes are jammers of enemy radar systems. The EC-130 is an example. This is a prop cargo plane that loiters near the FLOT and interferes with the SAM sites. The effects are degradations of the acquisition radar, communications of the netted sites, and the homing

systems of the missiles. Another jammer is the EF-111, which could accompany strike packages.

With the help of the jammers, the SEAD aircraft attack the SAM sites. The most notable SEAD aircraft is the EF-4G, Wild Weasel, which can use anti-radiation missiles to hunt down enemy radars. B-52s can lumber up to the FLOT and fire TACIT RAINBOWS. TACIT RAINBOW is a cruise type missile that loiters over the battlefield awaiting emissions from the enemy radar systems. Once the radar is detected, the TACIT RAINBOW homes in on the target and destroys it.

The offensive counter air missions attack the enemy air fields. Principal targets are the air base's aircraft, maintenance, fuel, ammo and runways. Specially designed Durndel bombs crater the runway grounding the enemy aircraft. Air dropped mines make the task of fixing the runways difficult and time consuming.

Air interdiction targets the war making capabilities of the enemy and the reserves. Air droppable mines can be extremely effective in delaying mobile reserves. Supply depots, headquarters, factories, and missile sites are also targets of AI.

Cruise and intermediate surface-to-surface missiles also aid in the interdiction operation. For the Iraqis, the SCUD missile and suicide aircraft missions maybe the only weapons of interdiction.

Close air support increases the combat power of the ground forces and decrease the enemy's ground capabilities. Often there is a synergism of combat power that is the result of employing air power simultaneously with ground forces. This multiplied force can give the extra edge needed in both defensive or offensive missions.

The real-time eyes of the air battle are the airborne early warning planes. These planes can sort out the confusion and provide the early warning necessary for an effective defensive air campaign. An early warning system relying solely on ground based radars has difficulty in picking up low flying aircraft (Carter, 1989). A loss of an airborne early warning plane is a severe blow to the defensive counter air plan. Each side should have a representative number of these aircraft which can be targets for fighter sweeps.

Airborne operations consist of cargo aircraft dropping paratroopers behind the enemy's front lines. For this operation, the airborne forces need priority of cargo aircraft, suppression of the enemy air defenses, escort protection from incoming fighters, and plenty of CAS. The success of an airborne operation is an important matter. Its failure would have large political ramifications.

Air assault operations are Army helicopters transporting ground forces. While the need for cargo

aircraft is not as great as the airborne operation, the other needs are the same.

Amphibious operations are complicated and complex. Marines land by helicopter, landing craft, and special armored vehicles. Air support is provided by the US Navy and the Marines' own organic CAS.

Air defense systems are of two types. One is an organic capability assigned to each ground unit. These weapons are for point defense and self-protection. Their weapons are characteristically short ranged guns and missiles. The other air defense is the theater air defense missiles. These missiles are under the operational control of a joint army/air organization that is to provide defensive counter air operations. The missiles forces should have a missile engagement zone (MEZ) from the FLOT to cover most of the ground combat units. Behind this zone is the fighter engagement zone (FEZ). Careful consideration of these zones can conserve strength and reinforce weaknesses.

Aircraft detection depends on the quality of the detection system, weather, electronic combat, and altitude of the planes. Planes can best perform their missions if flying at a medium altitude. The lower the plane flies, the less able the ground radar can pick them up. This flying also causes more wear on the pilots and planes, and more fuel expended.

A side enjoys air superiority if it has neutralized both enemy air attacks and SAM sites. This allows pilots to fly at medium altitude. Then the planes can do their mission better, have more sorties, and support the ground war better.

Satellites provide information, communication and the ability to get precise fixes of forces on the ground. In this scenario, satellites provide intelligence information to the Blue side. Later in the war, the Blue side finds out that Red is using weather satellites and an old communication satellite for military purposes. The Blue forces then attempt to neutralize these forces through electronics and physical destruction. Also the Blue forces experience a loss of a key intelligence satellite. The players request the launch of a Lightsat to replace the intel value of the lost satellite.

The war can escalate to a nuclear exchange. A secret Iraqi missile base can be discovered late in the game. The target for these missiles is Israel and the US forces in Saudi Arabia. The Blue players succeed at stopping the atomic missiles by recognizing the threat through obscure and incomplete intelligence.

3.4   Missions

To model the above scenario, missions need to be

identified and defined. These missions will translate
themselves into the player inputs.

The primary Air Force missions to be modeled are:

Offensive counter air - Strike aircraft attacking on
enemy air fields.

Fighter Sweeps - Fighter aircraft searching to destroy
enemy aircraft in aerial combat.

Defensive Counter Air - Fighter aircraft on strip alert
awaiting orders to intercept hostile aircraft.

Air Interdiction - A strike package's target of enemy
fighting potential that will not have an immediate effect on
the battle.

Battlefield Air Interdiction - A strike package's
target that will have a near term effect on the battle and
is used to lower the enemy's strength or delay his ability
to join the battle.

Close Air Support - A strike package's target that is
in battle with friendly ground forces.

Reconnaissance-The information of strength, location or
status of an enemy unit or facility. Missions are given to
either aircraft, satellites, or Special Forces teams.

Suppression of Enemy Air Defense (SEAD) - Aircraft
attempting to destroy or hinder the ability of theater
surface-to-air missile sites.

Electronic Combat - The attempt to deny the enemy the effective use of radar, communications, or missile guidance systems.

Command, Control, and Detection - The ability to detect, maintain surveillance on the enemy and be able to optimize the friendly resources to defeat the enemy's threat. Examples are AWACs and ground control intercepts.

Army ADA - Theater level surface-to-air sites that are under Air Force control.

Satellites - An important intelligence and communication link.

Reserve - Mission capable aircraft held back for specific missions.

Missiles - Surface-to-surface intermediate and long range weapons with high explosive, chemical, and nuclear warheads. A few surface-to-space missiles would be available to the Blue force with payloads of satellites, atomic weapons, or anti-satellite weapons.

Nuclear and Chemical Missions- Aircraft delivery of these specific munitions are in a different module than the conventional strikes. These missions are the result of conscious decisions of the players.

In support of the primary mission listed above, there are support missions. These missions are: escort or CAP, SEAD, electronic combat, and refueling.

MISSIONS

PRIMARY	ESCORT	CAP	SEAD	EC	REFUEL
OCA	X		X	X	X
FS			X	X	X
CAP			X	X	X
DCA					
AI	X		X	X	X
BAI	X		X	X	X
CAS		X	X	X	X
RECCE	X		X	X	X
SEAD	X			X	X
EC	X		X		X
C2	X		X	X	X
ADA					
SATELLITES					
MISSILES					
RESERVE					
NUKE & CHEM	X		X	X	X

Figure 6. Mission Matrix

Administrative moves such as new incoming aircraft beddown and moves of planes between bases are handled under logistics and transportation.

3.5 Command and Control

In this scenario, the Blue forces are the pure US forces. The forces are under the command of Central Command (CENTCOM). There is a Land Component Commander (Third Army) and the Air Component Commander. The land forces under the

Third Army are composed of four US Corps. The Air Component Commander has a Tactical Air Force.

The Land Forces are now defined using standard US Army doctrine and newspaper reports. The four Corps are the 18th Airborne Corps, 3rd Corps, 7th Corps, and a composite Corps of Marine divisions and British Armored Brigade(s). See Figure 7. Each corps has two to five divisions with it. Each division has two to five maneuver combat brigades. Each brigade has two to five maneuver battalions.

One of the important assets to the ground forces is the integration of Air Force personnel into the planning areas. From CENTCOM to the maneuver battalions, there are Air Force officers assisting the Army in the planning and execution of air operations. The organization looks like this:

3.6   Summary

This chapter uses the doctrine of the US and Soviet forces to portray a robust and detailed combat scenario. This chapter not only uses the doctrine, but also includes the actual war to reinforce the scenario. Since this scenario is ongoing and therefore credible, the wargame must be able to model all parts of this scenario to the proper level of detailed. It is the object of this model to faithfully represent this scenario.
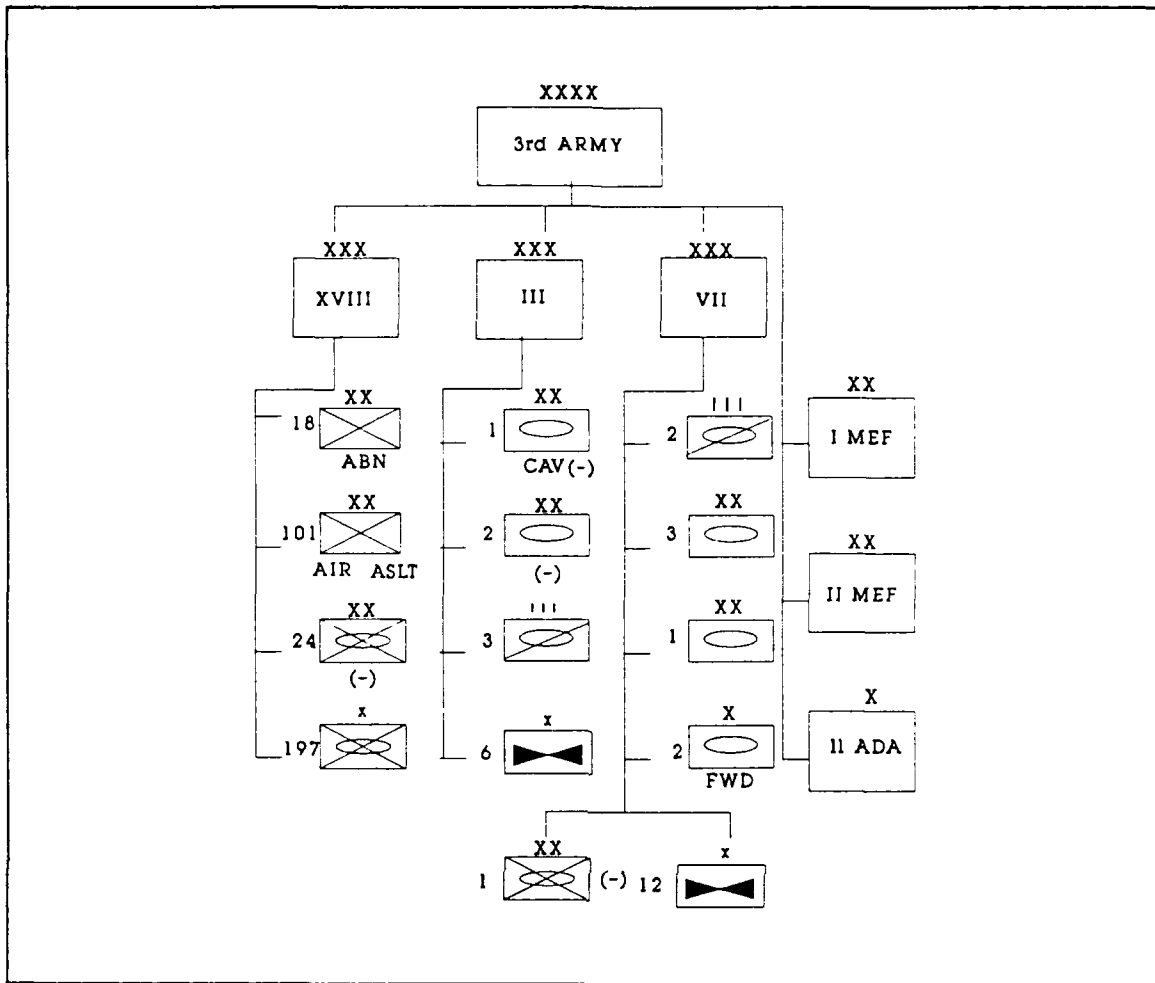
Figure 7.   Third Army
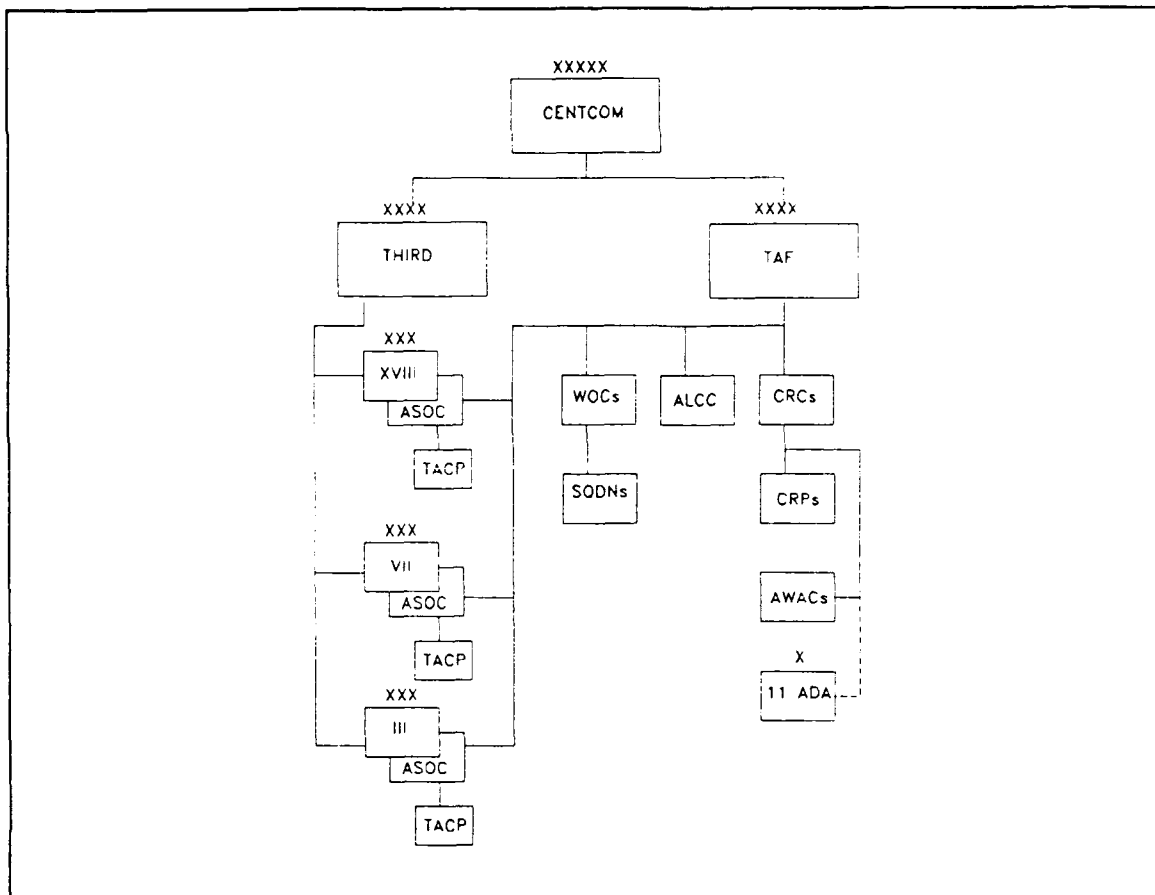
Figure 8. CENTCOM

IV. Model

4.1 Introduction

This model needs to take the players' input, simulate the combat process, and be able to give the players output. The input needs to be in an understandable form that is close to what is done in reality. For the most part the combat simulations follow a decrement process that expends resources, aircraft, and ground forces as the model represents battle. In a sequentially run model, output is the feedback on the last input results which forms the basis of the next input.

If the scenario is credible and the proper combat processes have been correctly portrayed, then the model will behave in a reasonable fashion. A tradeoff occasionally between detail and run time may be necessary. In fact, the model may over describe a particular process without any benefit. Therefore, several processes may need to be combined by the programmers to achieve the proper balance of detail and model run time. As computers improve and run-times decrease, more detail can be added later.

The outline for this chapter is to lay the foundation for the basic processes. The land battle is briefly described. Then the joint environment shared by the land

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and air battle is introduced. The conduct of the air battle is next, followed by detection mechanisms and how intelligence uses detection. Finally the chapter describes the overall model's process linking many of these ideas together.

4.2 Land Battle

Ness completed the land battle, where ground units move on a hex based terrain. The combat units are supported by other units, which lend strength to their combat operations. In this model, opposing units begin combat when they are in adjacent hexes. The attrition process is deterministic with two rates on attrition based on the combat ratio. Combat units have a firepower score that is the principal component of the combat power. Unit posturing, attached units, and supporting units can raise the level of combat power of a combatant.

To portray air/ground interactions, there needs to be modification of Ness' ground entities to fully conform with a new air model. These changes deal with an expansion in defining the ground entities and the development of a system that can compare firepower to some physical counter stored in the entity. An example that generates this question is if a flight of aircraft destroy 12 tanks, 3 ADA guns and 34 trucks, how does this effect the firepower, surface-to-air

index, and logistics capabilities of the unit? These relationships will be defined in the next chapter.

4.3   The Environment

The model needs an environment in which to work in. The land model has hexes, but there needs to be a clock, and weather to be shared by the air and land forces. Finally there needs to be "terrain" for the air battle to operate in.

4.3.1   Clock. A most important part of the model is the clock mechanism. The land model has two cycles; day and night, which uses an internal time step that can be varied. But the land model has a fixed cycle length. This needs to be changed. Both cycles should be variable to portray actual field conditions. In this example assume that the day is 14 hours and the night is 10 hours long. Next, the day needs to be further subdivided into time periods. Again, this time period can be variable, but it should represent the time that it takes to accomplish one sortie. The longest mission time is assumed to be two hours for fighter aircraft without refueling. This makes a time period 2 hours long, so the day cycle has seven time periods and the night cycle has five time periods. Therefore the time step appears in Table 1.

```
                        Day 1

    Cycle 1 Day                   Cycle 2 Night
    Time Period                   Time Period

    1-0600 to 0800
    2-0800 to 1000                 8-2000 to 2200
    3-1000 to 1200                 9-2200 to 2400
    4-1200 to 1400                10-0000 to 0200
    5-1400 to 1600                11-0200 to 0400
    6-1600 to 1800                12-0400 to 0600
    7-1800 to 2000
```

Table 1. Time Periods For One Day

The advantage of the time period is to allow the players to plan subsequent missions. This allows planners to surge aircraft to overwhelm the defenders, to conduct preemptive SEAD missions, or conduct reconnaissance missions at the end of the day to assess damage.

Assigning missions to a particular time period is not the only option. Air missions can be executed by a priority system. This system subdivides the total number of missions and uniformly assign the missions to each time block within a cycle. TAC Thunder follows this approach. While the advantage of this approach is less input of the start times, the loss is the ability of surge and proper sequencing of missions by the players. A mixture of both procedures may be possible.

4.3.2 <u>Weather</u>. Good, fair and poor weather are represented in the land model. This convention can be followed in the air model as well. Weather can be in its own data base. As the clock progresses, so can the weather. The particular data file for that period can be read in and put into the air and land battle. In good weather, land units and aircraft have good visibility, better detection of enemy units, and ease of movement. As the weather worsens, the above unit capabilities also decrease. Additionally, twilight and darkness also degrades detection, attrition, probability of kills, and movement. Darkness and poor weather may also prohibit some aircraft from flying and some anti-aircraft systems from being effective.

4.3.3 <u>Air Hexes</u>. Ness made his land battle consisting of regular hexagons. The hex size can range from ten to fifty kilometers across the flats. The present database uses twenty five kilometer hexes with hex vertices pointing north (See Figure 9). (Ness, 1990:58)

With the ground units moving on land hexes, the air units can move in their own air hexes. The idea is to superimpose the air hexes on top of the land hexes (See Figure 10). These hexes are stacked and represent different levels of altitude. These air hexes need to be larger than the ground hexes to represent the correct resolution for the
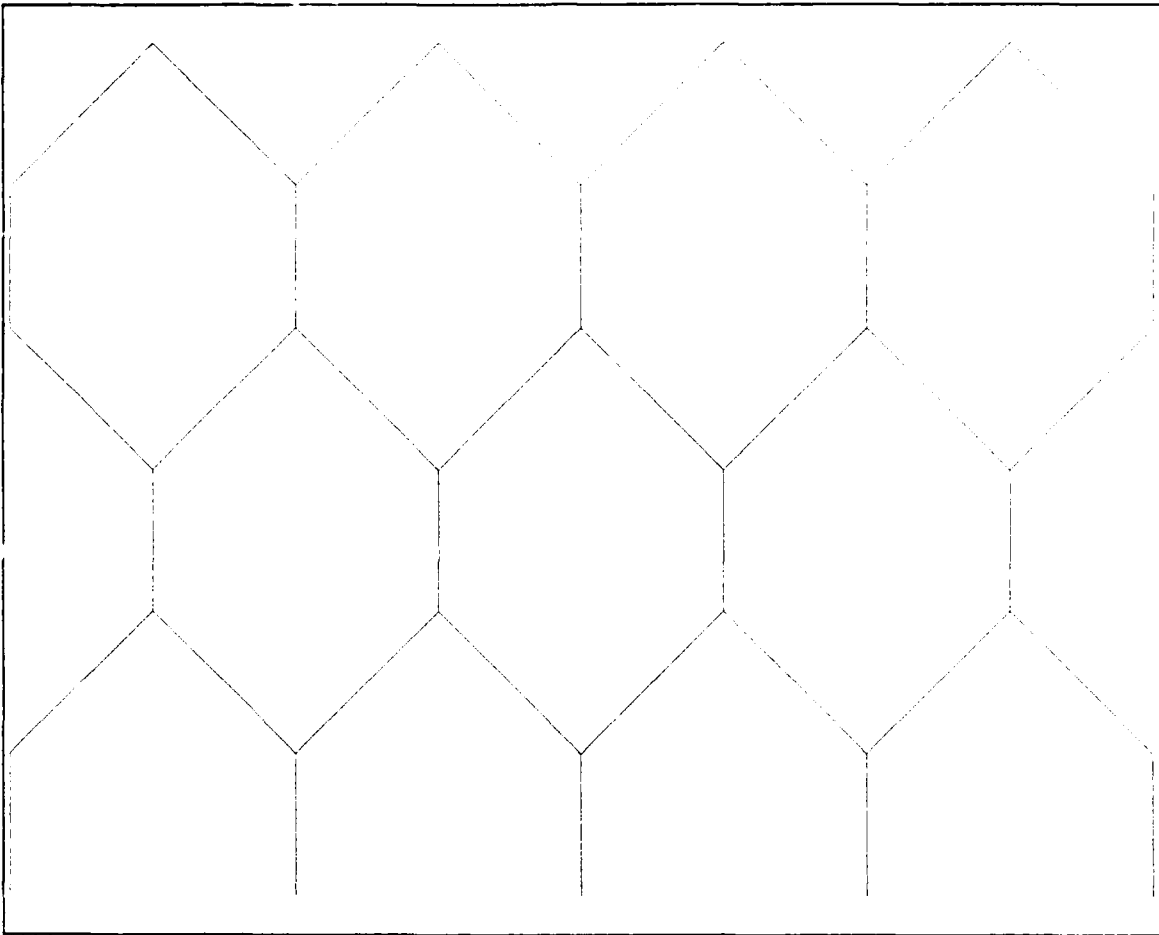
Figure 9.   Ground Hex

aircraft performance.   While a ground hex is ten to fifty
kilometers wide, aircraft can use a larger hex of 75
kilometers.   The idea of nested hexes can also be used.
Every seven ground hexes represent one air hex.

To represent levels of altitude, air hexes can be
stacked.   The number of stacked air hexes can be variable,
depending on considerations for the computer space and the
amount of resolution desired.   Ideally, there should be
seven stacked hexes.   The proposed hex levels are:
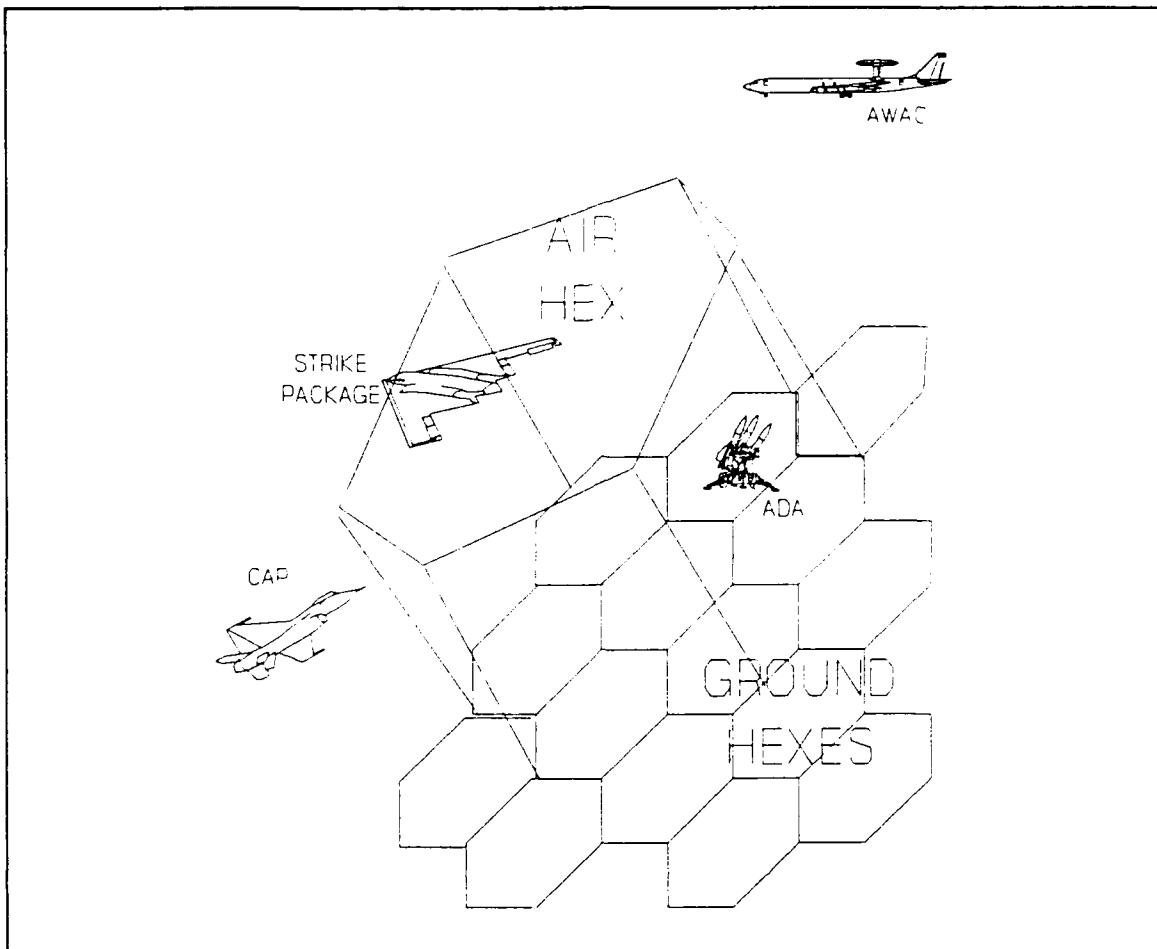
Figure 10. Air Hex

1. The terrain hex is the base hex;

2. Tree top level altitude, from 0 to 200 feet (0 to 61 meters) from the relative surface of the land hex;

3. Low altitude, from 200 to 2,000 feet (61 to 610 meters);

4. Medium altitude, from 2,000 to 10,000 feet (610 to 3,048 meters);

5. High altitude, from 10,000 to 30,000 feet (3,048 to 9,144 meters),

6. Very high, from 30,000 to 100,000 feet (9,144 to 30,480 meters), and

7. Space, from 100,000 to geosynchronous orbit (30,480 meters plus).

Terrain has an implicit impact on the tree top flying level. If the terrain hex is rated poor, representing mountainous terrain or thick jungle, then the second level hex level reflects the qualities of that hex. In this case, the flying is harder, the fuel usage is greater, more maintenance has to be pulled on the aircraft, but the detection of that aircraft is more difficult and the chances of a ground based SAM or AA gun engaging this aircraft is less. For a good mobility terrain hex, the aircraft are detected and engaged more readily, but flying is a little less demanding on the fuel, range, maintenance, and the crew.

Surface-to-air missiles have limitations of aircraft detection, range and height. These can be modeled using the above system of air hexes. An example is a theater SAM site. The site has an unjammed detection range of 50 kilometers, a missile range of 40 kilometers, and an effective missile height from medium to high altitudes. This means that aircraft in the low and very low levels are not detected. In this example, the SAM site is in a ground hex that is twenty five kilometers across, but it can

influence targets in air hexes at levels 4 and 5. A pointer type system found in the Ada computer language would be most helpful here. Once the aircraft package enters the hex, the air defense units pointing to that hex are identified. The computer can then use a hex screening pointer system to determine if the ADA unit detected the aircraft.

A radar jammer in the SAM's sphere of detection decreases the SAM's detection probability.

Levels of altitude are adjusted to the limitations of the SAM units in the area. Soviet ADA systems then can be confined to only certain regional air hexes. Soviet air defense limitations can be found in numerous references (FM 100-2-3, 1984:5-89 to 5-104; FM 44-1-2, 1984:15-1).

An air hex contains weather plus the Blue and Red electronic combat jamming levels information. The pointing system would be extensive. The pointers correspond to the stacked air hexes, showing targets on the ground hexes, theater air defense units, radar searches of AWACs and GCI, fighter cap zones, aircraft in that zone, missiles (cruise, Tacit Rainbow, Scuds), satellite positions, missile engagement zones, and fighter engagement zones.

Each of the 1 through 6 levels of hexes has its own degree of weather. For example, level 1 may have ground fog and level 4 may have dense cloud cover. The weather

conditions can move along to represent drifting clouds or cloud dissipation.

Each level has different restrictions on entities that can exist on that level. The following examples of entities or processes inhabiting each level are:

1. Ground units

2. Nap of the earth flying aircraft, cruise missiles, AA guns and small arms firing at aircraft, airborne early warning radar;

3. Low level flying aircraft, AA guns, MANPADS, short range optically sighted SAMs, ground control intercept, airborne early warning radar;

4. Aircraft, medium range SAMs, and most radars;

5. High performance aircraft, bombers, high altitude SAMs;

6. High performance reconnaissance planes; and

7. Reconnaissance and communication satellites, and strategic missiles.

4.4   Air Battle

The air base, depots, staging bases, and missile bases are the holder of resources. Each base has an identifier, situational awareness, resources, and then the aircraft or missile entities. These bases have a common format or structure. One can think of each base as a row in a matrix

or spreadsheet. The columns of this matrix are the common variables and the entries represent the amount of resources the base has. A transportation function moves resources from the depots to the bases or bases to bases. An aircraft beddown procedure would move new aircraft from the staging base to the air bases.

The players input their missions with a priority or start time. When the clock polls the mission inputs it selects the highest priority mission for the time period. An aircraft package is formed. A decision process polls the air bases checking for aircraft and resources to form the package. There has to be the fuel, ammo, maintenance, and runway available for the aircraft to takeoff. If the resources are available, the package is formed. The resources and aircraft are then subtracted from the bases.

To form the aircraft package, the decision process passes the number and types of ammunition and planes to the package. The package then reaches down to an aircraft database, a weapons database, and a nuclear and chemical weapons database to pull the characteristic of systems into the aircraft package.

The simulation places the aircraft package into an area mission matrix or a strike package queue. The area mission matrix points into the air hexes. DCA, CAP, C2, SEAD, EC, satellites and reserve are typical area missions. If an

enemy entity is detected in these air hexes, a combat process starts. (Explained in sections 6.8 and 6.10). A strike mission is OCA, BAI, AI, CAS, RECCE, or missiles. These strike missions move from their start point and progress from air hex to air hex. At each air hex, the computer checks the units looking at that air hex and if the enemy air defense or counter air missions detect the aircraft package. If detected, the aircraft package resolves the detection through a combat process. Once at its target, the strike package attacks the entity and the surviving aircraft return to the start point through a hex by hex movement.

Combat process are air-to-air combat, surface-to-air missiles, suppression of enemy air defense sites, and air-to-surface attack. In air-to-air combat, two opposing aircraft packages fight. Aircraft and weapons are decreased on each side based on stochastic attrition. Surface-to-air missile sites expend missiles to decrease the number of planes in an aircraft package. Suppression of enemy air defenses is a fight between aircraft and SAM sites as both sides expend munitions to decrease each other. In SEAD missions, the SAM site destroys aircraft, and the aircraft damages the SAM site's missiles, radar, and launchers. The most difficult combat process to model is air-to-surface attack.

Air-to-surface attack is the most difficult because of the different targets that need to be modeled. The aircraft must be able to destroy or damage the enemy base, ground unit, or supply train. This process includes a decision system for attacking the ground entities and a method for determining the amount of damage caused by the air-to-ground munitions. In turn, the enemy entity must be able to use its air defense ability to destroy the incoming hostile aircraft and ruin the aim of the attacking aircraft. A surface-to-surface missile can be modelled the same way, with the missile delivering its warhead, and then self-destructing.

There are three alternatives to consider as combat outcome. One alternative is that none of the planes survive. The second alternative is that the planes continue to complete their mission. The last alternative is that the planes return home without completing their mission. This can occur when an aircraft package loses all of the primary aircraft and thus the escort planes return. This can also happen when the package has lost so many of the original aircraft, that the survivors return. This percentage is the "chicken factor" for a side and is a predetermined percentage by the user.

4.5   Detection of Ground Units

Detection can be done by being in contact, reconnaissance overflights, detection of aircraft going to or returning from a mission, Special Forces (SF) teams, satellites, or detection of communications signals. If one really wanted to get detailed, there could be the capability for portraying "phantom units" to deceive the enemy. Each ground unit has an "intelligence inuex" which reports how much the opposing forces know about the other side (Ness, 1990:69-71).

Ness developed this intel index for the land based module. This index ranges from 0.0 to 1.0 with 1.0 representing perfect knowledge. As more sensors are aimed at a unit, the higher the intel index becomes. The intel index is also time sensitive and decays over time. As described by Ness, there will be three levels of intel. A unit will be a suspected unit for a low intel index, a partially identified unit for a medium intel index, and a positively identified unit with a high intel index.

4.6   Detection of Air Units

There will be two different types of detection. The first type of detection is done by AWACs or GCI.   The second type of detection is done locally by the individual entities.

4.6.1   AWACs and GCI. AWACs and GCI have a great
ability in detecting aircraft, but need to be tied into a
command and control system to pass the information on to the
other entities. If an enemy aircraft package is detected by
these assets, then air defense assets and defensive counter
air resources will have a greater probability for detecting
the enemy package. If there is no detection by these
packages, then the individual entities must detect the
aircraft on their own.

Airborne early warning radar planes will have the
capabilities to detect all planes from levels 2 to 6.
Ground based radars will have the capabilities to detect
planes in levels 3 to 6. The range of these detections will
be represented by the pointers at the air hexes.

AWACs have divine power. They can detect from the
layer below outer space to the tree top levels. Ground
Control Intercept have shorter range and are poor at picking
up low flying planes. This is due to the difficulty of
detecting aircraft flying close to the earth's surface. At
lower levels the GCI can pick up aircraft only 30 kilometers
away. They are better at detecting enemy aircraft at higher
levels. An aircraft can fly at the lower levels to avoid
detection, but will suffer higher causalities, accidents,
and maintenance costs. The additional maintenance costs
will be assessed when the aircraft return from a low level

flight by decreasing the maintenance assets available.

4.6.1.1   Results of AWAC or GCI Detection.   A
detection of an enemy offensive mission initiates a DCA
mission. The detection is done by AWAC or GCI. If long
range detection is accomplished, the DCA is sent out to
intercept vicinity of the FEZ and MEZ line. The DCA
aircraft then must also detect the enemy aircraft. If the
enemy air is found by air defense or CAP, DCA is scheduled
to attack the enemy a number of air hexes beyond the initial
intercept point.

The following three examples demonstrate possible
scenarios for detection:

-An AWAC detects an enemy formation of 40 planes in
enemy territory. A DCA package of 12 fighters are sent to
intercept. The DCA package intercepts the enemy package on
the FEZ and air combat begins.

-There is no AWAC and there are holes in the GCI. The
first indication of enemy aircraft is the detection of 36
planes by theater air defense assets. 8 fighters attempt to
intercept at two air hexes behind the FEZ. Meanwhile, a 4
ship CAP also engages the enemy flight at the FEZ. The
additional contact enables the DCA to successfully intercept
the enemy aircraft.

-Meanwhile, an enemy flight of 12 strike aircraft fly low across the FEBA. Again the GCI do not detect the aircraft plus the command, control, and communication network is very poor. The enemy air strike hits a major air field with no warning. The defenders are not alerted. The air base takes a heavy beating. DCA fighters attempt to find the enemy aircraft, but heavy cloud cover prevents their detection of the enemy.

4.6.1.2 Command, Control, and Communication. Assume that the AWAC or GCI has detected the aircraft package. This information must be passed on to the users of this information by a command, control, and communications network. A global variable (C3) can represent command, control, and communications. With a AWAC or GCI detection and a C3 of 1.0, the exact location of the aircraft package is known. All counter air entities will immediately detect the aircraft package when the package enters the air hex that the counter air entities have been forecasted to be pointing to. If the C3 probability is less than 1.0, then there is a random number draw to determine if the information was passed on to the other entities.

The command, control, and communication variable is a function of the presence or survival of certain ground entities. ADA headquarters, communication networks, and key

strategic targets can be linearly linked to this command and control network. At full strength, the C3 value is 1.0. As these entities are attacked, the computer degrades the C3 aspect by some amount. C3 will have the capacity to regenerate with time.

4.6.2   Local Detection. The second type of detection is a local detection by an aircraft or ADA unit. Detection of air units can be done by radar or optical sightings. Both use a pointer technique for a possible detection. A search algorithm will then be used to determine if actual detection occurred. Degradation of the detection by either EC or poor weather will decrease the effective detection range.

4.6.2.1   Area of Search. Aircraft and HIMAD units have a local area of search defined in a radius of kilometers. The aircraft packages and HIMAD units use this search radius to establish a list of air hexes that they can look into. Once an enemy air package enters an air hex on this list, the detection algorithm determines if the enemy air package is detected. The algorithm is explained in section 6.7.

4.6.2.2 <u>Electronic Combat</u>. Probability of detection will be the result of a search algorithm that will return a percentage chance of detection, $P(t)$. This percentage is multiplied by the reciprocal of the Electronic Combat (EC) rating of the aircraft. A normal aircraft would have an EC rating of 1. A Stealth aircraft might have an EC of 10. The result is that the Stealth would have a 1/10th chance of detection as compared to a regular aircraft. Therefore, if the $P(t)$ for a particular radar site in a air hex is .6, then a regular aircraft would have a 60% chance of being detected. A Stealth would have a (.1 * .6) chance or a 6% chance of being detected.

4.7 Intelligence

There must be a fusing of intelligence and operations functions for the TACS to work effectively. There are three types of intelligence processes; collection, intelligence reports, and targeting. Collection of information is through the use of intelligence gathering resources: national assets, radio intercept, surveillance aircraft, satellite, contact by the ground units, JSTARS, and aircraft debrief. The raw data is transformed into intelligent reports that are usable to the operations and planning personnel. From this information, targeting can be conducted by a sort and ranking system.

Each entity has an "intelligence index". This goes for every unit, base, supply train, movement of aircraft, and flight package. When an intelligence gathering asset conducts a search for information over an area, or on an entity, the level of identification is raised. There are a number of levels of cognitive recognition. There is cueing information, detection, classification, recognition, and identification. (Hartman, 1985a: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." (Hartman, 1985a:4-1 to 4-2)

This "intelligence index," now called intel index, has numerical ratings from negative numbers to positive one. The negative numbers to zero offers no information to the other side as the entity is deeply camouflage or deception is being used. As the reconnaissance entity queries the area, the enemy entity's intel index is raised a certain positive amount. Once an entity is above zero, its intel index can range only from zero to one. Another method is for the computer to insert the entities into the wargame on a certain day via the database.

4.7.1 <u>Deception</u>. Deception is one of the principles
of Soviet military doctrine. Deception also had a major
role in the invasion of Europe in WWII with Patton's
imaginary US First Army waiting to strike across the channel
(US Military Academy, 1980). There should be the capability
to depict large units with a very low firepower score. Only
at the highest level of their intel index should it be
revealed that the unit is empty.

4.7.2 <u>Advanced Intelligence</u>. Communications
eavesdropping, spies, wire-taps, and deserters are ways to
get intelligence. While representing these process may be
inappropriate for this game. Using some of the knowledge of
the enemy's plans should be interjected into the game. A
small portion of the enemy's war plans should be given to
the Blue players. This would mean that Red would have
already have entered the next day's plan. The scenario
could be the leaking of a large Red strike to include the
enemy's strength, start point, time, and target. Of course,
there should also be a way disinformation is provided by the
computer.

These advance notices on the enemy's plans should not
be work-arounds. A work-around is a method of overcoming a
game's shortcomings. The software engineer must program
advance notices of Red's plan into the game, so that the

Blue planners get information in a timely manner and can use it to conduct the proper planning.

4.7.3   Intelligence in the Land Model.   The land battle intelligence submodel controls and calculates the intel indexes at this time (Ness, 1990b:21). Ness' model includes the loss of intelligence over time and the use of both Army Military Intelligence, Special Forces, and units in contact. Intel indexes range from 0.0 to 1.0 with 1.0 being perfect information.

In Ness' model, the intel index of a unit produces an intelligence filter. This filters determines how much information the opposing side could accurately get about a unit. The intelligence filter ranges from 0.0 to 2.0 The intel index represent the lower bound of information and the upper bound is 1.0 + (1.0 - intel index). Ness then draws a uniform random number from between the upper and lower bounds to represent the intelligence filter and an amount of randomness of intelligence accuracy. Using this method, the closer the intel index is to 1.0, the less variance will be allowed, and the more accurate the report. The lower the intel index, the higher the variance and the less accurate the information. The computer would not provide the intel index to the players, so the players would not know how accurate the information is.

In the land model, there are also three ranges that correspond to different levels of accuracy. If the random draw is from 0.0 to 0.4 or 1.6 to 2.0, the unit is only a suspected unit. If the intelligence index is from 0.4 to 0.8 or 1.2 to 1.6, the unit is identified as its true class (i.e. armor, infantry or artillery) and parts of the information. When the intelligence index ranges from 0.8 to 1.2, then the computer reports the unit's name, branch, and the available information.

Ness' model also included intelligence on terrain hexes mobility and obstacles. By expanding on the basic concepts, the programmers can give this game the ability to have forms of deception and the camouflaging of units and air bases.

4.7.4   Satellites. Intelligence may be acquired by satellites which pass over a certain number of hexes in a time period, or query only a certain number of hexes in a day. Satellites are degraded by weather and may not be capable of detecting all types of entities. Some satellites may only be capable of detecting missile launch whereas others can provide very detailed information on only a small number of hexes or locations.

4.7.5   Reconnaissance. Reconnaissance missions are performed with some very sophisticated aircraft which

operate at very high altitude and very high speeds. They gather data over the routes that they fly or just over specific targets. Partial information is obtained while the mission is in flight, but only after the aircraft returns from enemy territory can the full data be analyzed. Therefore, for these recce missions, the hexes flown over and the entities within the hexes have their intel indexes raised. The computer increases the intel index only when the mission is complete. If the enemy side destroys the plane, then the intel indexes remain as before.

All returning strike packages result in an increase in their targets' intel indexes. This represent pilot debriefs and the results of aircraft sensors being downloaded.

The amount of increase of the intel index depends on the quality of the sensor. Ground units in contact should have the highest increase towards perfect knowledge. Ground units that are detected moving in the daylight should have a high intel index. Special Forces (SF) units, secret bases that have little activity, and units in a holding area away from the front should have a low or negative intel index. An example is a base used for the US Stealth fighter that only operates at night. Another example is a secret mobile missile base that is only detectable after repeated searches with high quality sensors.

4.8   Overall Model Process

The overall model contains many processes and utilizes many different databases. The following is a description of the layout and interaction of the model.

The model reads in the initial data files. These files contain the characteristics of the entities. The first major process is the weather. Using the concept of air hexes, each air hex contains an initial value for the weather. The computer updates this value with every time period when provided with weather adjustment factors. The periods are some fixed time step that represents a portion of the day. Ideally they should represent the average time it takes to conduct a mission. The time periods carry the characteristics of the time period and whether it is day or night. The user input is read into the computer in a batch mode. Input is for an entire day and night cycle.

If there is a great variance of mission time for aircraft, the entire process is complicated. If there are missions that take longer than average, then these aircraft packages are held in their mission queues, and are only activated when they would be at their time on target. If there are a number of missions that take less than the average time, then the time step can be decreased or these type of aircraft are allowed multiple sorties during a time period.

As the clock progresses, the computer loads any changes to the database that need to be loaded and then checks the player input. If there are missions that need to be conducted, the aircraft packages for both sides are loaded into their respected area mission matrix or their strike mission queues.

These aircraft packages are formed from the bases matrices (See Figure 11). The base matrices are the holders of resources. Each row represents a different base. Each column represents the identities, situational awareness, resources, weapons and aircraft for that base. These bases are polled to determine if the correct resources and aircraft are available to build that mission. If the aircraft and resources are available, an aircraft package is formed and the amounts are decreased from the base's resources. The aircraft package draws the number of planes and weapons from the bases and then reaches into the aircraft and weapon databases to find the correct warfighting attributes for the airplanes in that package.

Logistics and aircraft beddown are column manipulations between the rows. Players direct the assets of a depot to be transferred to a certain base. The computer removes this amount from the depot and places the resources in the logistics queue that represents supply trains in transit. AC beddown brings new aircraft with their maintenance crews
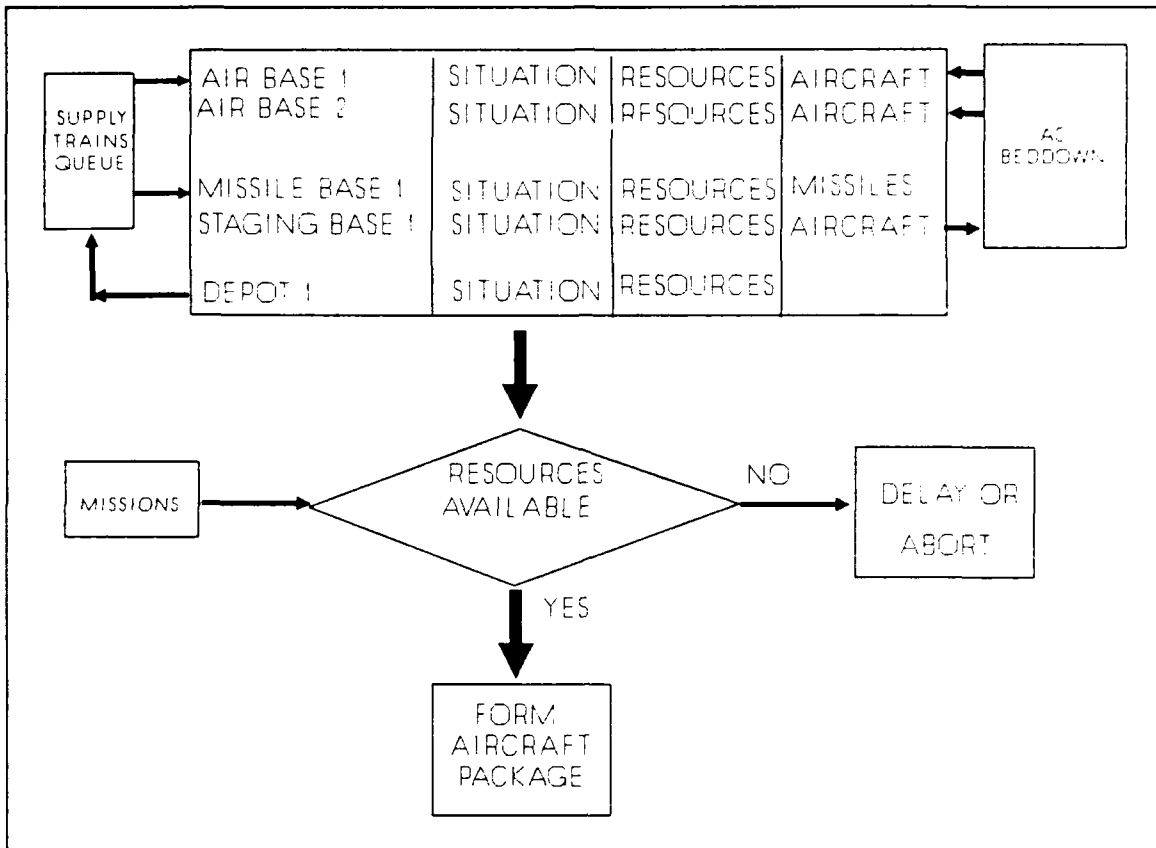
Figure 11. Bases

and repair kits from staging bases into the theater's bases.

The ground units are loaded and the units establish their positions at the appropriate ground hex and mark air hexes that they could influence. The land actions are fought at the end of the time step after the air battles are fought. This is so the air campaign can influence the ground campaign before the land units fight.

If the computer can not execute a mission due to the lack of resources, that mission is delayed. The delayed mission is held until the next time period. The computer executes all delayed missions first. At the end of the

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cycle, the missions that are still delayed are aborted. A report is written for every delayed and aborted mission with the reason why.

Once the area and strike missions are loaded, the wargame processes the area missions. The C2 missions are established on both sides to establish the detection pointers. Next the electronic combat missions are processed. Then the CAP and DCA are established. Each mission needs to be tested to determine if there are any conflicting missions between Red and Blue. If there are conflicting missions, combat process are conducted to resolve the issues. Once all the area missions are resolved, the air missions matrices will have established their information links to the air and ground hexes.

The computer will processes the strike missions in order of priority. The strike mission queue represent the aircraft already in the air. This is to resolve air strikes at bases while any aircraft is in flight. The queues now begin to execute their highest priority missions first. The strike missions begin at their start point, and their travel algorithm begins. (See section 6.3 for algorithm.) This algorithm determines the path of least danger. The path is stored in the aircraft package, and the strike package moves through each air hex as it conducts its mission.

As the aircraft package enters an air hex, the computer checks to see if the package has been detected by AWACs or GCI. If the package is detected, the package's detection variable is raised to the next higher level or maintained at "positively identified." Next, it checks the enemy theater ADA units to see if they are looking into the air hex. As the package travels, the computer checks the enemy air missions and checks to see if the package has reached its target. If there are no conflicts to resolve, the package moves along to the next air hex. See Figure 12.

Again, if there is a conflict, there can be only three outcomes. The package may be utterly destroyed, the package may have taken so many hits that it decides to abandon its mission and return home, or the package may still have sufficient combat power to continue. If the package continues and successfully arrives at the mission site, the aircraft conduct their mission, and return to their start point using a backwards route or a return path that is recalculated. At the end point, the planes are loaded back into their bases and the appropriate supplies the aircraft have remaining are loaded back into the base or counted as consumed. Unactivated packages, such as DCA missions that were not called upon, are loaded back into the bases with no losses of supplies.
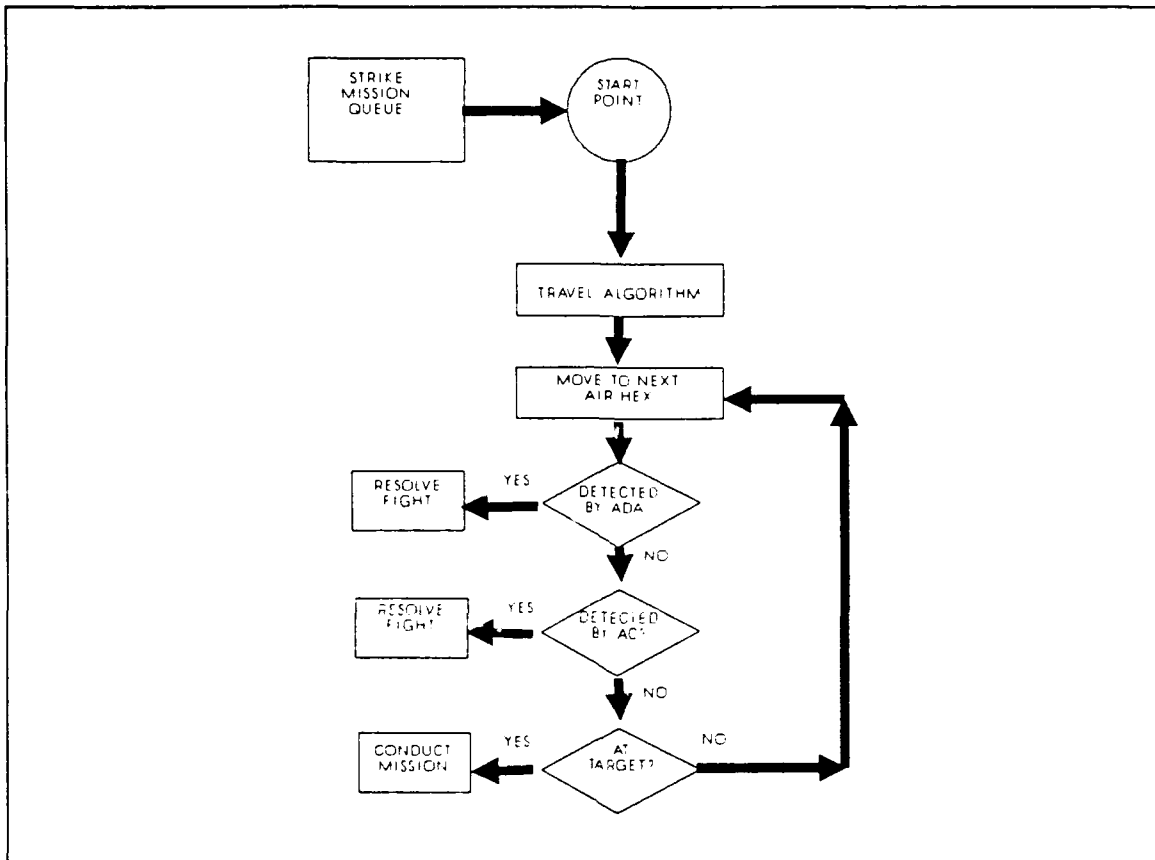
Figure 12.   Strike Package

Once all the strike missions have been conducted, the area missions are checked to determine if they can continue on.   Those that can remain are kept in the area mission matrix, and those short on supplies or out of time return to their bases.   The clock advances, changes to the database are registered, ground units move and fight, and the simulation examines the players' input to see if orders exist for the next time period.   Figure 13 shows a conceptual overview of the model.
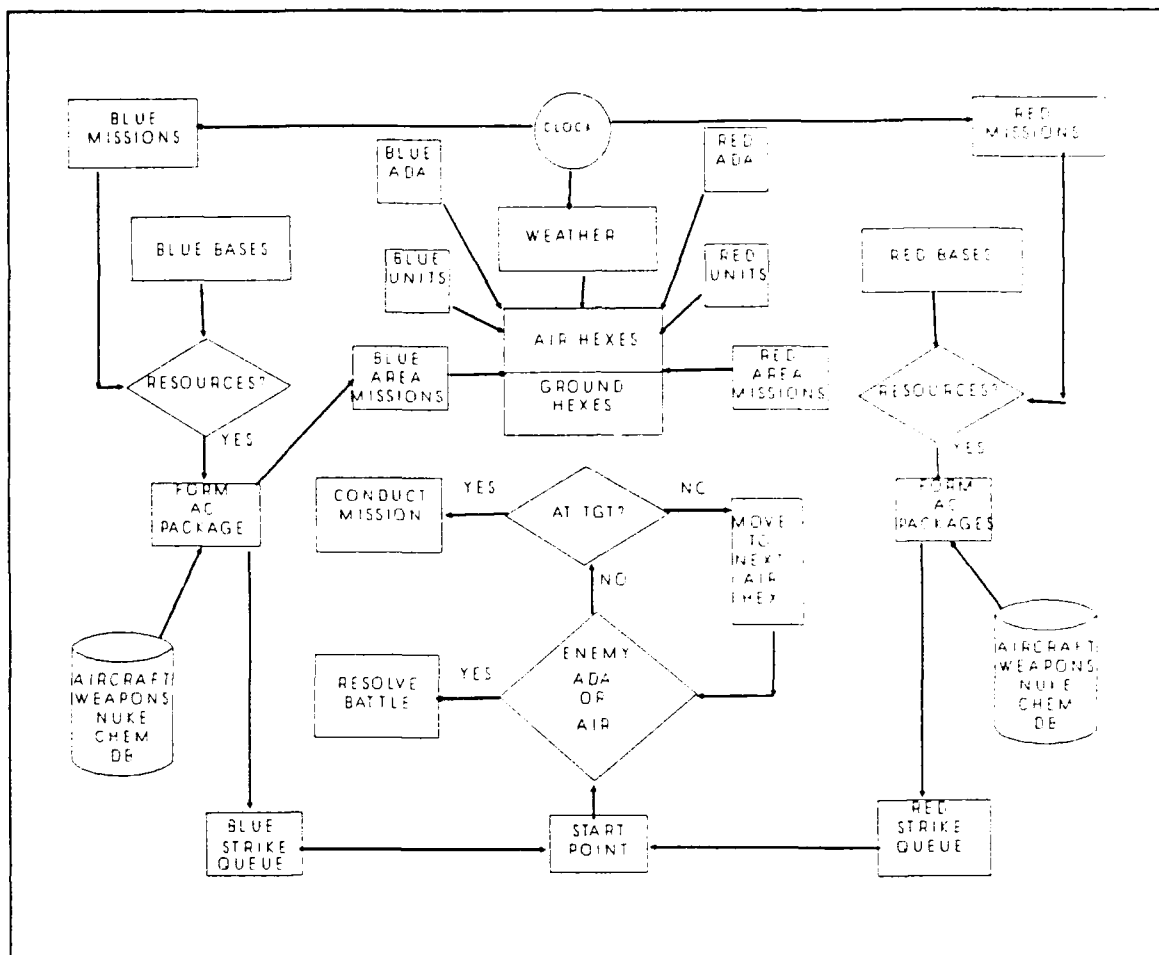
Figure 13.   Model Flow Chart

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V.   Database and Entities

5.1   Introduction

A reoccurring problem exhibited by both Agile and Ness' land model is that the entities' lack documented references for their interactions. Units have a Firepower Score, objects have a surface-to-air index (SAI), planes have a destructive index, but what do these values mean? In the Agile's Land Battle Methodology (Air Force Wargaming Center, undated:10) an aircraft sortie is equated to the effectiveness of a volley of ten artillery rounds, but where the source of this data is remains unanswered.

In this chapter, a reference system is established. This reference system is important not only to understand the model, but to allow for future changes. If an additional new ADA weapon were to be introduced into Agile, how would it be done? At this time, one must enter a surface-to-air index (SAI) for ground objects. If no one understands where the current numbers come from or what they represent, future changes are difficult.

A solution for this reference system is to model the individual components of the entities, such as tanks, infantry squads, and missile launchers using their engineering characteristics. Since these characteristics have physical dimensions, air-to-ground effects can use a

stochastic hit or miss process using the circular error of probability of hit of the weapon system versus the dimension of the target objects. Air-to-air fights may also use this stochastic process. In the case where theater SAMs have a probability of kill versus aircraft, a random number draw can determine kill or miss.

Ness' aggregated land battle remains a deterministic model. The number and types of tanks, armored personnel carriers, and infantry squads determines a Firepower Score for their unit. By using this system, the aircraft packages have the correct model resolution and the ground battle can be resolved by a simplified expected value process.

5.2 Ground Units

The world is polarized into the Soviet or the US sphere of tactics. Each side has their own characteristic weapon systems and their own different organizational structures that employ these systems. These different organizations have Tables of Organization and Equipment (TOEs) which prescribe the men and equipment that make up their units.

The players of the wargame receive guidance from the Joint Operations Commander who is the senior faculty member. The students come up with the plan at the Army and Tactical Air Force level. The subordinates units of the Army are the Corps, and below the Corps are the Divisions. The

accepted concept is that a higher headquarters monitors the subordinates two levels down. Therefore, it would be standard for an Army to track its divisions.

Divisions are the common units in this wargame and, for the US, may include armored, mechanized infantry, airborne infantry, air assault infantry, light infantry, and marine infantry divisions.

5.2.1 Battalion Equivalents. In order to establish a measure of unit worth, the US Army Command and General Staff College at Fort Leavenworth, Kansas established a method of comparing units in terms of "battalion equivalents" (U.S. Army Command and General Staff College, 1988). See Table 2. This index uses the Soviet motorized rifle battalion (MRB) equipped with the BTR as a baseline for measurement, BE/BTR. All US values are based on J-series tables of organization and equipment (TOE).

In Ness' working models, his units possess a Firepower Score that gauges the strengths of the combat units. By using a multiple of 10, the combat values are in the same range as those Firepower Scores. This gives an analyst a measure to use when working with different TOEs or new unit variants. Therefore, this new model database will use the battalion equivalents, times a factor of ten.

```
CODE         UNIT                                              VALUE

R            Soviet MRB (BTR-equipped)                         1.0
P            Soviet MRB (BMP-equipped)                         1.5
T(TR)        Soviet tank battalion (of a tank regiment)        1.6
T(ITR)       Soviet tank battalion (of an independent TR)      2.6
T            Soviet tank battalion (ITB or MRR-assigned)       2.0
AT           Soviet anti-tank battalion                        1.0
H            Soviet divisional helicopter squadron             1.0
SAH   Soviet attack helicopter battalion            2.0
M            US Mech battalion (M2-equipped)                   2.0
A            US Armor battalion (M1-equipped)                  3.0
AH           US attack helicopter battalion(AH64-equipped)4.0
CAV   US divisional cavalry squadron(AH64-equipped)1.5
```

Table 2. Battalion Equivalents

5.2.2 US Army TOEs. The US Army has two manuals for consideration of units and logistics (DA, 1987a; DA, 1987b). The first manual gives the organizational structure, personnel, and equipment summary of many different Army units. Examples are the armored division and the mechanized division. The second volume deals with planning factors. These planning factors cover a large range of activities to include engineering, supply consumption, transportation and movement, personnel services, health service support, and operational force planning.

Using the TOEs and the battalion equivalents, one can aggregate up to division level and disaggregate down to the vehicle level. In doing so, the units will have their own standard measure.

5.2.2.1 Mechanized and Armored Divisions.

A mechanized infantry division has 5 mechanized infantry battalions, 5 armor battalions, 1 air cavalry squadron, 1 attack helicopter battalion, 3 artillery battalions, and one battery of multiple launched rocket systems (MLRS). Using the battalion equivalent system the values of the units involved in direct fire combat are:

```
5 Mech Inf Bns * 2.0 =        10.0
5 Armor Bns * 3.0 =           15.0
1 CAV Sqdn * 1.5 =             1.5
1 Attack Helo Bn * 4.0 =       4.0
              TOTAL =         30.5
```

Adding to this are 72 tubes of 155 mm self-propelled artillery and 9 MLRS which are organic to the division.

In the new land model, fire support is handled as an additional strength to a unit. The division artillery, DIVARTY, must be tied to a unit and be able to provide the artillery support necessary. The DIVARTY must also be detachable. In US doctrine, it is not unusual to pull back a division but to keep its DIVARTY in place to support a new division. A process akin to adding and subtracting combat vehicles between units

An armored division is similar to the mechanized division. The major difference is that there are 6 armor battalions and only 4 mech infantry battalions making this division's combat value 31.5. It also has 72 155mm SP artillery pieces and 9 MLRS.

Using the battalion equivalents times a multiple of ten, one can also divide the Firepower Score downward. In an armored battalion, there are 58 tanks. In an mechanized infantry battalion, there are 54 Bradley fighting vehicles and 36 dismountable infantry squads of 6 men each for 216 men. A tank therefore, has a Firepower Score of approximately .5. A Firepower Score of .3 per Bradley and .1 for a 6 man dismount team is equivalent the Firepower Score of 20 given to the Bradley battalion. This type of scoring system does not provide numbers for all the other weapon systems, like mortars or scout platoons, but does provide a simple method for a unit of reference. There are 21 attack helicopters in the attack helicopter battalion and 8 attack helicopters in the Cavalry Squadron. This equates to a Firepower Score of 1.9 per AH-64.

The total composition of an armored division is imposing. The Firepower Score is 315 with 348 tanks, 216 Bradleys, 144 infantry squads, and 29 attack helicopters. The organic fire support is 72 tubes of artillery and 9 MLRS. In total the armored division has 7044 vehicles and 172 aircraft (US Army CGSC, 1984:F-4). The personnel strength comes to 17,000 soldiers.

    5.2.2.2   Airborne Infantry Division. The US Airborne Infantry Division has 9 infantry battalions, a

DIVARTY, a combat aviation brigade, an ADA battalion, and an Engineer battalion.

Each infantry battalion has three infantry companies and one antiarmor company. The infantry battalion has a total of 21 infantry squads. Because these squads do not have vehicles, the squads can put 50% more troops into their dismounted elements. This would give them a Firepower Score of .15 each. The antiarmor company has 20 TOW missile launchers on HUMMVs (DA, 1987a:4-162). Assume that these TOW systems have a Firepower Score of .1. This would give the infantry battalion a total Firepower Score of 5.5.

The ADA battalion has 27 Vulcan air defense guns and 60 Stinger launchers. (DA, 1987a:4-184)

The attack helicopter battalion has 21 attack helicopters and the rest are transport helicopters (DA, 1987a:4-145). The Firepower Score is (21 * 1.9) or 40.

The total Firepower Score is:

9 Infantry battalions	49.5
1 Attack Helo Bn	4.0
TOTAL	53.5

The DIVARTY has 54 tubes of towed 105 mm artillery (DA, 1987a:4-157).

The 82nd Airborne is the only US airborne division.

5.2.2.3　Air Assault Division.　An air assault division is similar to the airborne division, except that it has more helicopters.　There are 9 infantry battalions, an air recon squadron, a combat aviation brigade, a DIVARTY, an ADA battalion and an engineer battalion.

The difference is the large number of helicopters in the division.　The Combat Aviation Brigade has 2 UH-60 Blackhawk battalions, 1 battalion of CH-47 Chinook helicopters, and 4 Attack Helicopters battalions.　In all, the Combat Aviation Brigade has 84 attack helicopters, 32 CH-47, 67 observation helicopters, 44 UH-1s, and 90 UH-60s (DA, 1987a:3-157).　The Air Reconnaissance Squadron has an additional 16 attack helicopters, 24 observation helicopters, and 10 UH-60s (DA, 1987a:3-165 to 3-166).

The total Firepower Score is:

9 Infantry Battalions	49.5
4 Attack Helo Bns	160
1 Air Recon Sqdn	15
TOTAL	224.5

The DIVARTY has 54 towed 105 mm howitzers.

There is only one US air assault division.　That division is the 101st Air Assault.

5.2.2.4　Light Infantry Division.　A Light Infantry Division is organized to be rapidly deployed

worldwide. The division has 9 infantry battalions, a DIVARTY, a combat aviation brigade, an ADA battalion, and an engineer battalion. Its combat aviation brigade has an attack helicopter battalion and an reconnaissance squadron.

The light division's Firepower Score is:

9 Infantry Battalions	49.5
1 Attack Helo Bn	40
1 Recon Sqdn	15
Total	104.5

The DIVARTY has 54 towed 105 mm howitzers (DA, 1987a:2-135).

Examples of light infantry divisions are the 7th Light and the 10th Mountain.

5.2.2.5 <u>Separate Brigades</u>. Separate brigades are approximately one third the size of a division. They have a greater amount of logistical support than a normal brigade. Separate brigades can operate independently, be attached to a division, or may be placed under the control of a Corps. Examples of separate brigades are the 256th Louisiana National Guard Brigade and the 197th Infantry Brigade.

5.2.2.6 <u>Additional Units</u>. While the basic fighting divisions are defined, there are additional

supporting units within a Corps. These units can be
specially tailored for the Corps missions and include
additional artillery units, engineers, and theater air
defense units.

5.2.3   Soviet Units. Soviet units are less
diversified then the US units, and the Soviets have more of
them. Prior to the force reduction promises, the Soviet
Union had 214 active divisions (DOD, 1989b:64). The two
common divisions in the Soviet Army are the Motorized Rifle
Division (MRD) and the Tank Division (TD) (DA, 1984b:1-4).

5.2.3.1   Soviet Motorized Rifle Division. The
Soviet Motorized Rifle Division (MRD) usually has one BMP
motorized rifle regiments (MRR), two BTR motorized rifle
regiments, one tank regiment, an artillery regiment, a SAM
regiment, a helicopter squadron, and an engineer battalion.
   The Soviet Motorized Rifle Regiment (MRR) is the common
element of the Soviet ground force. It is either equipped
with the newer BMP fighting infantry vehicle or the BTR
which is basically a wheeled armored personnel carrier. The
BMP has an antitank missile system and either a 76 mm cannon
or a 30 mm automatic cannon. The BTR has only 14.5 mm
machine gun. Each MRR has its own tank battalion.

The Firepower Score of a BTR MRR is:

3 BTR MRBs	30
1 Tank Bn (T)	20
TOTAL	50

The Firepower Score for a BMP MRR is:

3 BMP MRBs	45
1 Tank Bn (T)	20
TOTAL	65

Therefore the motorized rifle division is:

2 BTR MRR	100
1 BMP MRR	65
1 Tank Reg	48
1 Antitank Bn	10
1 Helo Sqdn	10
TOTAL	233

The MRD's artillery is very large (DA, 1984b:4-34). The tube artillery consists of 18 152-mm self-propelled howitzers, 36 122-mm self-propelled howitzers, and 72 122-mm towed howitzers. The rocket artillery consists of 18 122-mm rocket launchers and 4 FROG surface-to-surface missile launchers.

Conducting the same calculations downward as done for the US units, the linear weights for the BTR, BMP, infantry squads, and the tanks can be found. A BTR battalion has 37

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BTRs and 27 seven man squads. Each BTR then has a Firepower Score of.2 for the vehicle and .1 per squad. A BMP battalion has 36 BMPs and 27 six man dismountable squads. Therefore, the BMP has a firepower score of .34 per vehicle and .1 per squad. There are 40 tanks in a MRR tank battalion for a firepower score of .5 per tank.

5.2.3.2   Soviet Tank Division. A Soviet Tank Division (TD) consists of three tank regiments and one BMP motorized rifle regiment. This BMP MRR is the same unit organization as the MRD's MRR. Each tank regiment has three tank battalions and one BMP motorized rifle battalion. It is important to note that these tank battalions only have 31 tanks apiece as compared to the MRD's tank battalions of 40 tanks apiece.

A tank regiment's Firepower Score is then:

3 Tank Bns (TR)	48
1 BMP Bn	15
TOTAL	63

A Soviet tank division then has:

3 Tank Regiments	189
1 BMP Regiment	65
1 Helo Sqdn	10
TOTAL	269

The tank division's artillery is the same as the MRD's artillery.

   5.2.3.3   Tactical Air Armies.   A Soviet Front has its own Tactical Air Army (TAA).   A TAA has a common structure.   According to Suvorov, this structure is.

> "Three Fighter Divisions
> Two fighter-bomber divisions
> One bomber division
> One regiment of fighter/reconnaissance aircraft
> One regiment of bomber/reconnaissance aircraft
> One or two regiments of light transport aircraft
>
>   Fighter, fighter/reconnaissance and fighter-bomber sub-units have the same organizational form: a flight has 4 aircraft, a squadron 12 (three flights), a regiment 4C (three squadrons and a command flight), a division 124 (three regiments and a command flight).
>   Bomber and bomber/reconnaissance sub-units, too, are identically organized: A flight has 3 aircraft, a squadron 9 (three flights), a regiment 30 (three squadrons and a command flight), a division 93 (three regiments and a command flight).
>   In all, an Air Army has 786 combat aircraft and between 40 and 80 light transport aircraft " (Suvorov, 1982:80-81)

These aircraft are an integrated part of the ground forces.   While they do not possess a Firepower Score, it should be realized that the Soviets follow a rigid blueprint, and these aircraft do belong to the Soviet Army Front Commander.   Aircraft entities will be covered in more detail in Section 5.5.

5.2.4   Iraq. The Soviets trained and equipped the
Iraqi military and therefore the regular army units follow
the Soviet units TOE. The militia and light infantry forces
have less effective Firepower Scores than these calculations
would suggest, but these scores are more subjective. This
may introduce the need for a "quality indicator" to the
troop levels. The latest information on the Iraqi units is
available t rough unclassified military sources (Jacobson,
1990:32-37).

5.2.5   Sample Ground Unit and Linkage to Models. The
reason for this definition of units, is to link Ness'
abstract Firepower Score, SAI, and logistics indexes to the
number of entities. Firepower is now a function of the
quality of the unit, the number of tanks, APCs, infantry
squads, the amount of artillery, the defensive position, and
the number of air sorties. The surface-to-air index is a
vector of short-ranged weapons that the unit uses to defend
itself once attacked. This vector identifies the number of
weapons the unit has. Logistics is a function of the number
of trucks the unit has. The amount of fuel and ammo is a
function of the number of trucks. Now that a linkage
between the abstract force and its the number of targets
have been made, the Air Force can attack and destroy these
entities.

In the case where the aircraft package attacks the ground entities, the entities have some number of vehicles that are of a dimension x by y. Using an algorithm that uses the targets' size, the computer can calculate for z number of bombs against a unit with a certain SAI the number of hits. The hits are then examined to determine the number of kills. These kills are then translated into a decrease in the unit's Firepower, SAI, and logistics. While this method uses a linear weight for the ground units, the aircraft packages are using stochastic type attrition. This stochastic attrition is a function of the plane/munitions circular error of probability, the unit's SAI, the weather, targeting and random numbers.

Ness defined the land battle units with many of the characteristics below. This example follows the same outline, but adds the individual fighting units or targets to his original work. The ground entity's characteristics are:

```
Target Number: B213
Corps Id: 7th US
Side: Blue
Unit Name:  82nd Airborne Division
Unit Type: Armor, Mech Inf, Airborne Inf, Artillery, etc.
Mission: Attack, Defend, Move, Withdraw, or Support
Present Location: in Lat Long
Mission Location: in Lat Long
Region: Center or Boundary
Direction of Movement: West
In attrition: True/False
Under Chemical/Nuclear Attack:Persistent/Nonpersistent/False
MOPP Posture: 0 to 5
```

Combat Power: Total combat power of unit, to include
      Firepower, supporting artillery, defensive posture, and
      CAS.
Firepower Score: The unit's direct fire weapons.
Quality of troops: 0.0 to 1.0
Tanks:
Bradley Fighting Vehicles:
Mech Infantry Squads:
Light Infantry Squads:
HUMMV TOWs:
Attack Helicopters:
Artillery: (MLRS, 155, 105, CAS) (organic and support)
Soviet Tanks:
BTRs:
BMPs:
Soviet Infantry Squads:
Soviet Attack Helicopters:
Artillery: (MLRS, 155, 105, 122, CAS) (organic and support)
SAI: (vector)
Percentage of SAI Used: A large unit's ADA assets that could
      be expected to engage aircraft attacking one maneuver
      battalion.

POL:
POL Percent:
Fuel Trucks:
Ammo:
Ammo Percent:
Ammo Trucks:
Water:
Water Percent:
Water trucks:
Hardware Percentage Resupply:
Engineers: (organic and support)
Engineer vehicles:
Depot Target number that is supporting the unit:

In Contact: True/ False
Intel Index:
Intel Filter:
Was Inteled: True/False
Breakpoint: Threshold Firepower Score where unit
      automatically begins to Withdraw.
Grid Time:
Is a Combat Support Unit: True/False

List of Supporting Units and Percentage of Support:

With the units now defined, Ness' program needs to be altered to represent this new unit structure. His processes of attrition, resupply, and movement still remain the same.

5.3   Air Defense Artillery and Missiles

In both the US and Soviet Armies the military air defense is divided up into SHORAD and HIMAD systems. The two different types of air defense artillery operate in separate manners. SHORAD is a self-defense system represented by the surface-to-air index (SAI). HIMAD batteries are theater assets and are represented as separate entities.

5.3.1   Surface-to-Air Index (SAI). Each ground unit should carry a characteristic of SAI. This characteristic represents the entities ability to shoot down hostile aircraft. It represents the small arms fire, anti-aircraft guns, and short-range missiles fired for its own air defense as the hostile aircraft are attacking that entity. This index not only kills enemy airplanes, but decreases the accuracy of the planes' ability to place bombs on target.

A US heavy division carries the most organic air defense for the Blue force. This is in the air defense artillery battalion, which consists of 36 air defense guns and 60 MANPADS launchers (DA, 1987a:1-237). The Soviets

have distributed their weapons out to the individual subordinate units. Even so, the motorized rifle division has 16 air defense guns (ZSU-23-4), 120 MANPADS (SA-14), and 36 truck mounted air defense missile systems (20 SA-6s and 16 SA-9s) (DA, 1984b:4-34). The Soviet tank division has the same anti-aircraft defenses, but has only 93 MANPADS instead of the 120 SA-14s a MRD owns (DA, 1984b:4-107).

The SAI values will be a vector representing the number of weapons present. The vector will be: (the numbers of SA-6s, the numbers of SA-9s or Chaparrals, the number of Stingers or SA-14s, the number of air defense guns, and the presence of half a company or more of small arms fire). A US heavy division has a SAI of (0, 0, 60, 36, 1). A Soviet MRD would have a SAI of (20, 16, 120, 16, 1). An US air base might have a SAI of (0, 4, 2, 0, 0).

With this SAI vector, the computer can now use the ADA Value algorithm used at the US Army National Training Center for determining a unit's short-ranged air defense against attacking aircraft. Section 6.9 explains the use of this algorithm. The SAI will also be tied to the number of air defense vehicles a ground unit has left. As the unit experiences combat and vehicles are destroyed, the SAI decreases. Increases in SAI occur only when the unit receives new quantities of hardware or is reinforced by an ADA unit.

5.3.2 Theater HIMAD Units.

Theater surface-to-air missiles (SAM) sites are large missiles batteries that have the capabilities to fire at aircraft packages and missiles packages. The (SAM) sites have radar units, missiles, and transporter-erector-launchers (TELs). Each HIMAD entity represents an ADA battery.

The battery consists of the same structure as a ground unit with some additional characteristics. The unit type is ADA, and the missions include move, fire, or not active. The additional characteristics are:

Number of Launchers (TELs):
Number of Radar Fire Control Radars:
Number of Acquisition Radars:
Quality of Acquisition Radar: 0 to 2
Number of Missiles:
Single Shot Probability of kill (SSPK) of Missiles:
Maximum Range of the Missiles at Levels 2 - 7:(vector)
Range of Radar at Levels 2 - 7: (vector)
Time to Reload and Reacquire Targets: Hours

5.4 Bases in General

Bases in the model have a common structure which can be divided into four main categories. They have an identity, situational awareness, resources, and aircraft or missiles. The identity tells the player who the base belongs to and where it is. Situational awareness is the base's cognitive ability to know if they have been attacked or how much intelligence to report after being reconed. Bases are the holders of resources. These resources are fuel, ammo, weapons, and runway. The logistics mechanism moves

resources from the depots to the bases. Finally, the bases contain aircraft or missiles. These aircraft and missiles are the users of the resources. An aircraft beddown module moves new aircraft from the staging base to the forward bases.

5.4.1   Air Bases. The air base is a holder of resources for the aircraft. It holds resources up to a capacity level and receives additional resources from the logistics module. The aircraft are the users of these resources. For the aircraft to be released from the air base, the required resources must be available. The aircraft consume these resources as they leave. The aircraft come back with all its resources and air-to-ground munitions expended when they return, except for unused air-to-air ordinance. An air bases will have the following characteristics defined in its database.

```
Target Number:
Side: (Red, Blue, Grey)
Forces:
Command:
Country:
Base-name:
Type of Base: Air base, missile, depot, or staging base
Movement Allowed: Yes/No
Mission: NA, Fire, or Move
Present Location: in Lat Long
Future Location: in Lat Long
Base's Dimensions: (variable array)
Region:
Direction:
```

Weather at airfield=average weather of level 2 & 3
Is the base overrun?
Is the base within enemy artillery range?
Is the base under a chemical/nuclear attack?
How many enemy mines are active?
MOPP Posture: 0 to 5
Is the base under air attack?
Alternate field #1, if base is unavailable
Alternate field #2, if alternate base #1 is unavailable

SAI-surface-to-air index: (vector)
POL/AV- fuel on base (1000s of pounds)
POL/AV- in hardened storage
POL/AV- total storage capability
Maintenance personnel on hand
Maintenance hours accumulated
Maintenance equipment on hand-(category to support different
     types of planes)
Spare parts-engines, electronics, & avionics (in 100s of
     pounds)
Runways or launchers - number and conditions (variable
array)
Maximum ramp space at the field
Shelters
EOD crews: (Explosive Ordinance Disposal)
RRR crews: (Runway Rapid Repair)
Ammo, missiles, bombs, and gun ammo (variable array)
Nuclear weapons: (variable array)
Chemical weapons: (variable array)

Aircraft/missile types and numbers on hand: (variable array)
Total aircraft or missiles:

Army Unit to be moved: (variable array)

     5.4.2   Depots. Depots store bulk resources. Depots

have the same characteristics as the air bases above, except

that aircraft and runway information is not applicable.

Depots can be resupplied at the end of every day through the

reading of new data files. The movement of supplies are

explained in Section 6.4.

5.4.3 Staging Bases. Staging bases are the area of entry for new aircraft. These bases are far enough away so that the enemy can not reach them. It should have enough resources on hand to send fully mission capable aircraft to the other air bases. When the planes move to forward bases, maintenance crews, and repair parts accompany the aircraft. New aircraft arrive at the end of each day through the reading of new data files.

5.4.4 Missile Bases. A surface-to-surface missile base has missiles instead of aircraft. The format for this type of base is the same as the air base. Number of launchers substitute for the runway length. The ammunition is the type of warhead; high explosive, improved conventional munitions, chemical or nuclear. The warheads are paired with the missiles. The missile delivery system is in the aircraft category. A missile base might also have mobility, maintenance, fuel, and SAI attributes.

5.4.5 Interdiction or OCA. Interdiction or offensive counter air operations can be directed against the above bases. When this occurs some of the resources are destroyed and the base may become non-operational for a user defined period. This state represents the confusion and chaos that occurs after the raid. The number of EOD and RRR crews

determine the repairing of fixing the runways, but once the base becomes operational, it may still not be able to conduct missions due to a lack of resources.

When the base is attacked, individual targets which can be destroyed include runways, launchers, SAI, aircraft, missiles, POL, shelters/plane pairs, ammo, and maintenance facilities. Mines and persistent chemicals will delay any missions from originating from a base, until the threat is removed.

5.5   Aircraft

An aircraft is a very complex system to represent requiring many major areas to be modeled. An aircraft needs to be characterized on how well it fights with other aircraft, its ability to destroy ground targets, how well it can search for enemy aircraft, how hard it is to detect the aircraft, the aircraft's speed, and the support requirements it needs to get off the ground.

5.5.1   Air-to-Air Combat. Capability ratings of aircraft in combat are numerical evaluations of that systems effectiveness in performing its mission. These numbers can either be derived by a formula or be subjectively chosen by the user. Whichever the choice, the numbers can range from 1 to infinity. The higher numbers correlate to better

capabilities. These numbers are used for resolving air-to-air fights.

Dunnigan gives an example of numerical capabilities (Dunnigan, 1988:164-165). In his example, the ratings ranged from 1 to 20. Using multiple regression on his data, one can see that his ratings are based on the thrust to weight ratio. By using the following formulas, one can determine the air combat maneuverability of aircraft. The formula for all allied aircraft is:

CMBT = -.7 + [(1/160) * (THRUST/WEIGHT)].

For Soviet aircraft the formula is:

CMBT = -3.0 + [(1/160) * (THRUST/WEIGHT)].

These formulas can be used for new aircraft, or one can assign subjective weights.

5.5.2   Air-to-Ground Ratings. The ability to conduct attacks on ground units will be a function of the accuracy of the weapon/plane pair, the size of the target, and the effect of the munitions on the target. The strike aircraft accuracy for dropping ordinance is the circular error of probability (CEP). This CEP has a measured radius of accuracy in meters. A CEP of 25 meters means that 50% of the ordinance will land inside a circle with a radius of 25 meters from its aim point. A major assumption is the target center is the pilot's aim point.

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5.5.3 Electronic Combat Value.

Electronic Combat (EC) represents the aircraft's ability to escape detection and its electronic jamming capabilities. This number's reciprocal is used to multiply the probability of detection of the enemy sensors. This attribute is discussed in Section 6.7.

5.5.4 Area of Search.

An aircraft can only detect enemy aircraft up to a certain distance away. The farther away the enemy is, the harder it is to detect. The reverse is also true, the closer the enemy is, the easier it to detect. This attribute is calculated in kilometers. This value, as with EC, is discussed in Section 6.7.

5.5.5 Other Characteristics.

An aircraft has other physical characteristics, such as the maximum ordinance the plane can carry, the number of sorties per week the aircraft can do, the combat radius of the aircraft, its loiter time in the air, and whether the plane is refuelable. All these characteristics are important in cross checking the missions given to it and determining how long and often the plane can go up in the air.

5.5.6 Required Resources.

The last requirement is the determination of how much resources are needed to get

the aircraft off the ground. This translates into the
resources on hand at the air base to allow the plane to take
off to accomplish its mission. These resources include
fuel, maintenance hours, spares (spare parts), ammunition,
and usable runway. If any of these resources are lacking,
the plane can not take part in the mission.

5.5.7   Sample Aircraft Database

Side: (Red, Blue, Grey)
Common name: Plane's common name
Designation: Plane's numbered name
Capability: Day or night. Abilities in weather.
Cmbt: Combat is the ability of an aircraft to engage air
     combat with other planes, 1 to 20.
Srt: Sorties are the number of sorties per week per
     aircraft, assuming two days of surge and five days of
     sustained sorties.
Search: The diameter of the sensor's detection area in
     kilometers.
EC: Electronic combat is the ability to degrade enemy radar
     and sensors.
Max speed: (kph)
Normal Combat Radius (km): NCR represents the normal maximum
     distance from the air base to the area that it performs
     its mission. This is figured by allowing one third of
     the distance that an aircraft can fly in a straight
     line with a full tank of fuel. The remaining two-
     thirds is for the mission and the trip back.
Loiter time: The unrefueled amount of time a CAP fighter,
     AWAC or standoff jammer can spend in its assigned area.
Cargo: Amount of cargo able to be transported in 1000s of
     pounds.
Recon Ability: The amount of intelligence able to be
     collected by this platform, e.g. the amount of increase
     this aircraft will have on a enemy's intel index.
Refuelable:yes or no

Maintainability:The ease of maintenance for the aircraft.
     This is the number of man-hours required for each hour
     in the air.
Amount of spares required: in 100 pound increments

Fuel: Amount of fuel needed in 1000s of pounds.
Ramp: The amount of space the aircraft takes up at the air
    base.
Max load of ordinance: in 1000s of pounds
Minimum runway needed to takeoff and land: in meters

Mission/Weapons Pairs: Lists the missions with the preferred
    weapons and either the weapons' CEP for strike mission
    and aircraft or the weapon's probability of kill for
    air combat.

See Table 3 for a sample aircraft database.

Side	Blue	Blue	Blue	Red	Red
Common Name	Warthog	Eagle	Buff	Fencer	Flogger C
Designation	A-10	F-15	B-52	SU-24	MiG-27
Capabilities	Day	All	All	Day	Day
Cmbt	3	12	1	5	6
Srt	16	12	4	8	10
Search	30	60	120	45	20
EC	1	1	2	1	1
Max spd (kph)	644	2,875	1,036	2,415	1,955
NCR	500	1500	16,000	1,200	400
Loiter	2	2	8	2	1
Refuelable	Y	Y	Y	N	N
Maintain	15	52	65	69	61
Amt of Spares	4	2	10	1	2
Fuel	1	4	66	9	2
Ramp	1.25	1.1	12	1	.6
Max load	7.2	10.7	27.2	12	5
Min Runway	200	300	700	300	200
Weapons/CEP					

(Dunnigan,1988a:164-165; AFWC, 1990)

Table 3.   Sample Aircraft Database

5.6   Missiles and Bombs

There are four types of missiles used in the model.

The surface-to-surface missiles are treated as aircraft.

Air combat uses air-to-air missiles. The short-range surface-to-air missiles are incorporated in the SAI, whereas theater surface-to-air missiles are used to conduct combat with the aircraft packages. And finally, air-to-surface missiles bombs are either point target destructive or an area effect weapon.

Air-to-air missiles have three characteristics. The missiles have a weight in 1000s of pounds, a range in kilometers, and a single shot probability of kill.

Air-to-ground ordinance have six characteristics. They have a weight in 1000s of pounds, a plane/missile CEP measured in meters, a range in kilometers, and identification as to whether they are point target or area weapons. If the missile or bomb is an area weapon, the radius of lethality is given. If the weapon is a point weapon, the weapon gives its effectiveness against hard, medium, and soft targets. If the bomb has mines, it gives how many.

Name:
Range: in kms, used to determine if the aircraft has a standoff advantage over SHORAD.
WGT: The weight of the bomb in 1000s of pounds. Used to ensure that the weight of the bombs do not go over the maximum ordinance weight of a plane.
PK AIR: The probability of kill of an air-to-air missile.
CEP: Accuracy of the bomb on ground targets in meters.
PK HARD: Probability of kill of a harden point target, given a hit.
PK MED: Probability of a kill of a medium hard target given a hit.
PK SOFT: Probability of a kill give a hit on a soft target.

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Lethal Area: Radius of Lethal are given a hit on an area
    target.
Mines: Number of mines deployed by the bomb.

    An example database is given in Table 4.

NAME	RANGE	WGT	PK AIR	CEP	PK HARD	PK MED	PK SOFT	LETHAL AREA	# OF MINES
AIM-7	25	.22	.8	0	.0	.0	.0		
AIM-9A	17	.225	.8	0	.0	.0	.C		
AIM-120A	32	.225	.9	0	.0	.0	.0		
AGM-84A	60	.575	0	75	.5	.7	.95		
TACIT R	200	1.0	0	10	.75	.9	.99	75	
AGM-65A	25	.25	0	7	.8	.9	.99		
GBU-12	6	.25	0	3	.8	.9	.99	25	
GBU-10	6	1.0	0	4	.95	.99	.99	75	
DURNDAL	0	.25	0	10	.5	.6	.7	75	6
MK 35	0	.25	0	25	.1	.6	.9	100	
MK 82	0	.25	0	35	.4	.5	.8	25	
MK 84	0	1.0	0	35	.6	.8	.9	75	
20 MM GUN	3	.05	.1	20	.2	.4	.7		
30 MM GUN	5	.07	.1	15	.7	.8	.9		

Air droppable mines are special weapons that either decrease
trafficabiltiy of the hex and hex boundaries or delay the
operations of a base from recovering to an operational status.

Table 4. Weapons

5.7   Aircraft Packages

    An aircraft package is formed to conduct a mission.

The two types of missions are area and strike.   Both

missions have the same general format.   The aircraft package

has a mission identification, a situational awareness, group

characteristics, and finally the individual aircraft with

their individual munitions.

    Partial aircraft packages will be available.   As long

as a user defined number or percentage of the primary

aircraft can fly, the mission is attempted. This includes
primary aircraft flying without escorts, even though escorts
were assigned by the players.

Side:
Mission Id:
Mission's Target Number:
Date-Time-Group Start:
Date-Time-Group End:
Priority:
Mission:
Target: Target Number, Hex Number, or Hex Side
Activated: Yes/No For reserve or DCA aircraft that are on
     strip alert. If the mission is not activated, The
     planes are returned to the Bases without using their
     assets.

Start Point: Lat Long
Target Location: Lat Long
Distance:
Refuel:Yes/No
Altitude: 2 - 7
Path: List of Air Hexes
Loiter time: in time periods

EC of the Package: Lowest EC value
EC of Hex: From the effects of the jammers.
Total EC: Lowest EC value of the package + the contribution
     of the jammers.
Evasive Action: Yes/No
Detected by the enemy's early warning:No, Yes, Positive Id
Speed of Package: Speed of slowest aircraft in group
Starting number of Primary Aircraft:
Present Number of Primary Aircraft:
Chicken Factor: Threshold percentage of primary aircraft
     remaining before the package aborts mission.
Air Munitions left: Yes/No
Ground Munitions left: Yes/No
Return to base when air ammo is NO: Yes/No
Return to base when ground ammo is No: Yes/No

Primary aircraft, Originating Base, Air & Ground Weapons

Escort aircraft, Originating Base, Air Weapons

SEAD aircraft, Originating Base, Ground Weapons

Electronic Combat Aircraft, Originating Base, Air & Ground
     Weapons

Refuel

5.8   Nuclear and Chemical Weapons

     Nuclear and chemical weapons are special munitions.

Since these weapons represent mass destruction, they need a

special database and algorithms to represent their effects.

     5.8.1   Nuclear Weapons. Nuclear weapons are specified

by kilotons (KT) or megatons (MT). A kiloton is the amount

of energy released by the explosion of 1 kiloton (1,000

tons) of TNT. Delivery of the warhead is by missile or

strike aircraft. The target for nuclear weapons is either

in latitude and longitude or a target number. Ness's model

already converts from latitude/longitude measurements to

hexes. A CEP for the weapon will be given depending on the

weapon/warhead delivery system. The explosion's center is

determined from the calculated center of impact. All

nuclear detonations are assumed to be air bursts at optimal

height of burst. Warhead yields that can be represented

range from 1 KT to 5 MT. All weapons are assumed to be

tactical nuclear weapons. See Section 6.12.

YIELD: in kilotons.
CEP: in meters.

5.8.2 Chemical Weapons. Chemical weapons are classified as persistent or nonpersistent. The chemicals rounds have a CEP for the delivery/warhead pair. Each round has a radius of lethality. The persistence of the chemical agent is measured in hours.

```
Name: Name of chemical
Wgt: in 1000s of pounds
Persistency: in hours
Lethality: in meters
CEP: in meters
```

5.9 Summary

The purpose of defining entities is to arrive at some common formulas for defining firepower, SAI, and logistics based on vehicles or small units. By giving each of the vehicles or units physical dimensions, the aircraft can attack these targets and the computer can determine the hits and misses of the air attack. These hits can then be translated into kills, and the kills into a loss of the abstract values. With the overall model explained and the entities defined, the next chapter discusses the mathematical models that are strung together to properly portray the combat results.

VI. Algorithms

6.1 Introduction

In the previous chapters, a scenario is described, an
overview explaining process flow is presented, and the
entities that exist in this model are defined. This chapter
explains the individual mathematical combat submodels that
portray the entities' interactions. The objective of these
mathematical combat submodels is to create processes which
provide credible output results. By stringing these smaller
models together, the larger wargame model is constructed.
The major algorithms which comprise the attrition submodels
are theater surface-to-air missiles, multiple missiles on
multiple targets, determination of the number of aircraft
killed by a binomial distribution, air-to-air combat, and
air-to-ground kills.

Combat models may play attrition in many different
ways, but there are basically two types of attrition,
deterministic and stochastic. Deterministic methods give an
average value that will stay the same with same inputs.
Lanchester equations are an example of deterministic
attrition. Establishing a fixed percentage of aircraft lost
in a certain duel is also deterministic. When there is a
chance of obtaining different outputs with the same inputs,
then there is a form of randomness in the process. This is

the case of stochastic attrition. Stochastic type attrition most nearly models the real life phenomenon.

TWX and Agile both use deterministic attrition. Agile and TWX form a ratio of the attacking sorties versus the defending aircraft. This ratio is then used in a cumulative exponential function with three variables to tweak the results equation to give answers that appear right. While this method gives answers, the personnel at the Air Force Wargaming Center do not know why this formula is used or how the constants were derived. (Ciola, 1982:1,14-15; Grover, 1990)

The TAC Thunder model has multiple level resolutions for air-to-air attrition. The "low" resolution model subtracts a percentage of aircraft lost in specific situations. The "high" resolution model uses a stochastic process to assess attrition. This process is outlined in detail in the TAC Thunder documentation (AFCSA, 1990b; AFCSA, 1990a). By combining features from TAC Thunder and the SOTOCA model, with ideas given by James Dunnigan, a simplified stochastic attrition process can be constructed.

6.2 Forming Aircraft Packages and Base Operations

An aircraft package is entered into the computer by the students/players. The package has a mission, a start point, targets, the aircraft assigned in the various roles, the

priority of the mission, the time period for the mission (optional), and the munitions that the aircraft will carry (optional). If the optional values are not specified, then the computer must insert default values. All aircraft packages for a time period are formed and put into their respective queues. Area missions execute first, followed by the strike missions. At the beginning of the time period, ongoing missions remain in their queue. Delayed aircraft packages from the last time period are formed first. High priority aircraft packages are formed next and fill the queues. Any mission that can not be formed, due to a lack of resources, is put at the top of the list for the next time periods missions. This delay represents the subordinate WOCs attempting to complete assigned missions, but having difficulties in scheduling.

This scheduling of aircraft packages allows a SEAD mission to take out certain enemy SAM sites and a fighter sweep to take out the enemy CAP before the strike packages begin their flight across the FLOT. This also permits a saturation effect on an enemy's defenses. The formation of these aircraft packages are based on sortie generation and resource availabilities. This is a function of the bases' matrix and the logistics modules.

When the aircraft package is assembled, the resources and the planes must be available. Partial resources and

plane assets will allow the package to be partially assembled. If the package has enough for its mission, then the package is formed. Examples of constraints that would stop a mission is that the primary mission aircraft do not have fuel, or that the air base runways are damaged. If a user defined percentage or more of the primary mission aircraft have resources, then the package is formed. The package is formed at the start point, and the travel algorithm is kicked in.

When the aircraft package is assembled, the package carries the characteristics of the aircraft and the weapons. As the package encounters enemy entities, the engagement is resolved and the aircraft losses and weapon usage are decreased from the aircraft original package and reported to the database immediately.

6.3 Movement, Range, Refueling, and Path Determination

When a strike package comes out of its queue, it begins at the start point at a prescribed altitude. The travel algorithm determines a straight line from the package start point to the target. It then searches the air hexes that intersect the line at a constant altitude. Starting with the prescribed altitude, it tallies the enemy units affecting all of the air hexes it must cross at a constant

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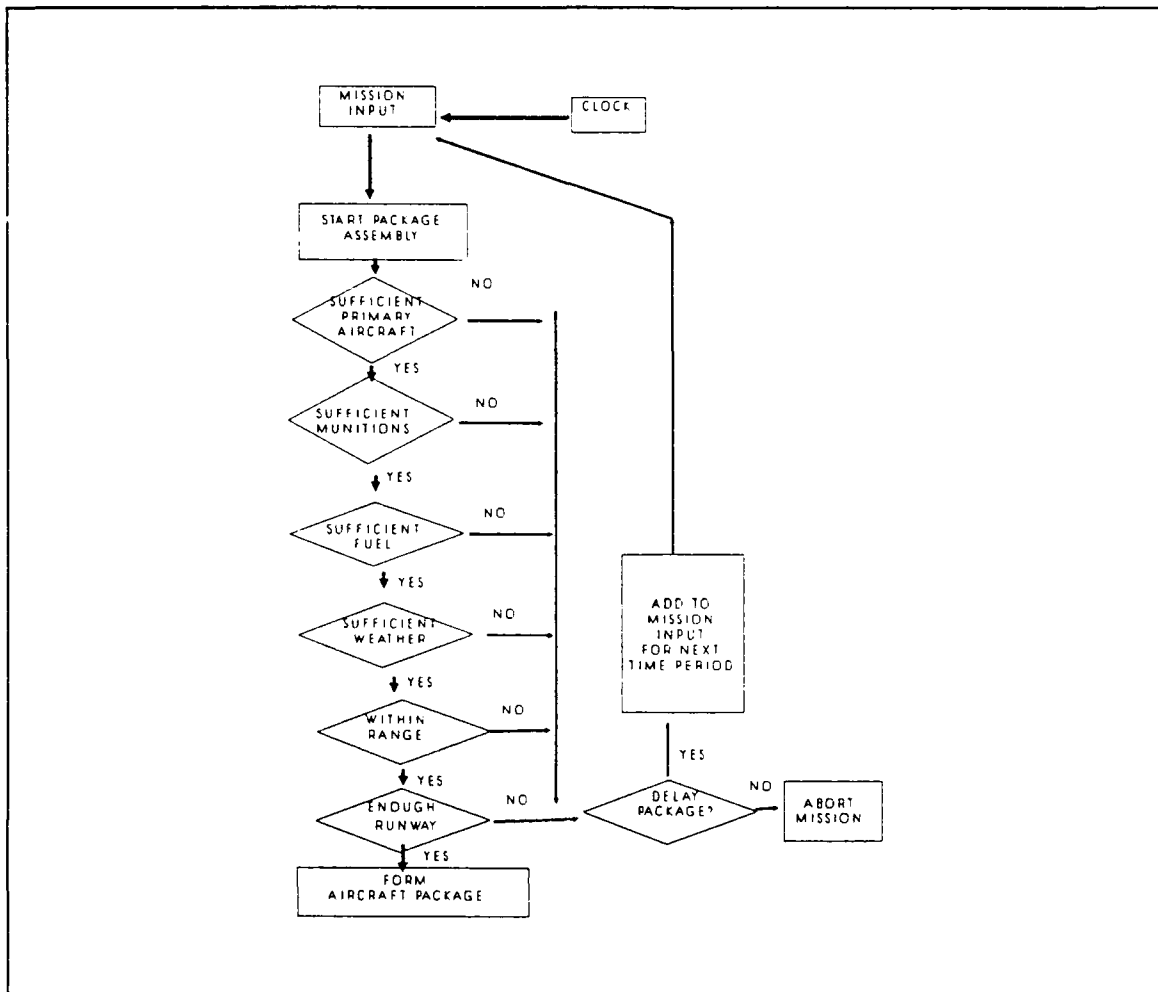
Figure 14.   Forming an Aircraft Package

altitude (i.e., medium, low, and high), where altitude

restrictions correspond to the capabilities and limitations

of the primary aircraft.   The assumption is that the pilots

would want to fly along a path that has the least enemy

resistance.   This path is the sequence of air hexes with the

least number of enemy action potentials.   Therefore, if a

path travels through 15 air hexes at the 2 level and has 34

enemy sightings, and the other levels have more sightings,

120
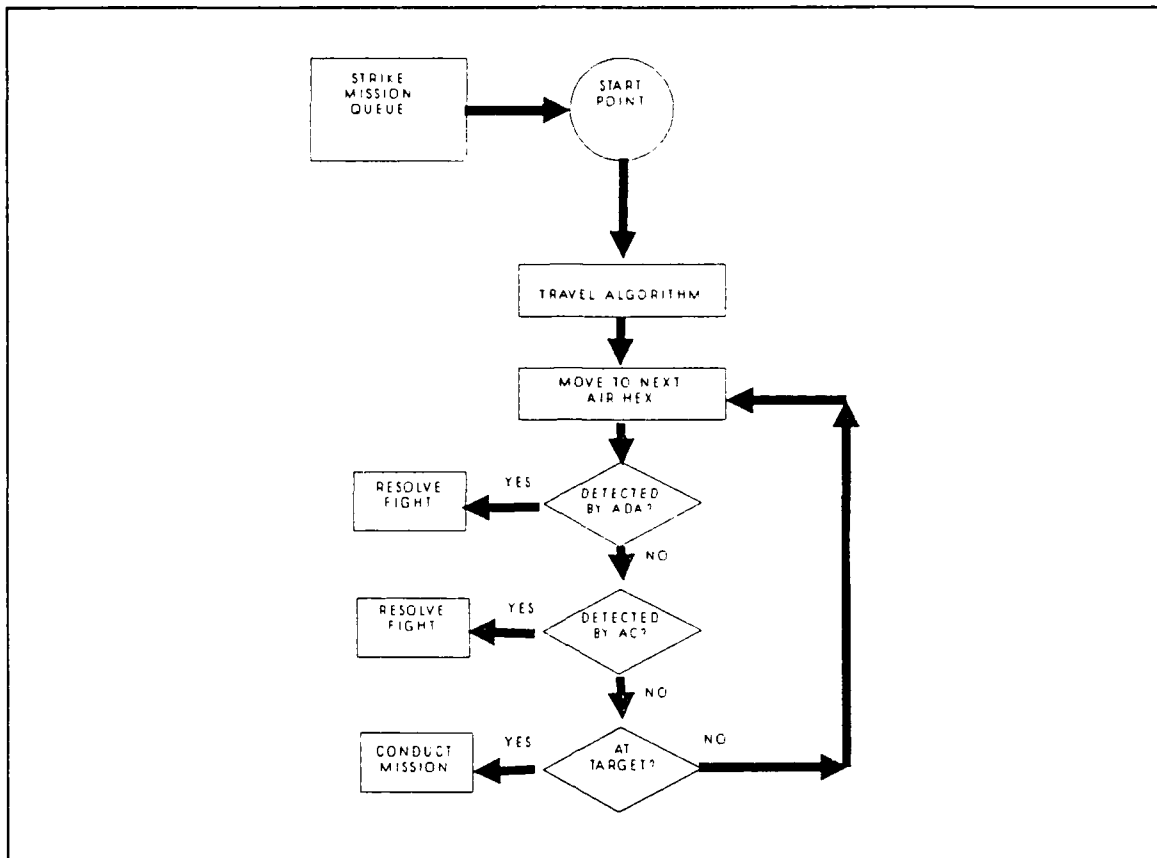
Figure 15. Aircraft Mission

then the aircraft package chooses the level 2 path as the

present optimal path. Sightings are also based on known

enemy ADA units. If the enemy ADA unit's intel index is

very low, then this unit is not included in the optimal path

calculations. The travel algorithm then checks the straight

line paths to the air hexes to the left and right of the

straight line path. Each time a lower enemy presence is

detected, that path is designated as the optimal path. Upon

ending the search, the optimal path is taken, and the

aircraft package moves along this path until the package

encounters a hostile air defense unit, hostile aircraft, or

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reaches its target. Upon accomplishing its mission or being forced to turn back, the package can either retrace its steps or determine a new return path.

6.4   Transportation

The transportation and distribution of supplies is the primary worry of the logistician. These supplies need to be delivered in some manner and there is a time lag imposed by some types of delivery. Using cargo aircraft would be the quickest means of delivery for the supplies are transported the same day. Unfortunately, cargo aircraft are also the most constrained. Pipelines, trains, and trucks are considered quick means. Barges and ships are the slowest. In this model, user defined transportation time holds the supplies in transit for X number of time periods or days for each supply movement. Each mode of transportation asset has a maximum capacity in tons of the amount of supplies that can be moved in a time period or day.

When the players assign a mission to a mover of supplies, a "supply train" is formed. See Figure 16. The amount of supplies is subtracted from the sender base along with the amount of transportation from the overall transportation pool. The supply train is then held in the queue until the required amount of time has passed. The supplies are delivered to the receiving base and the base
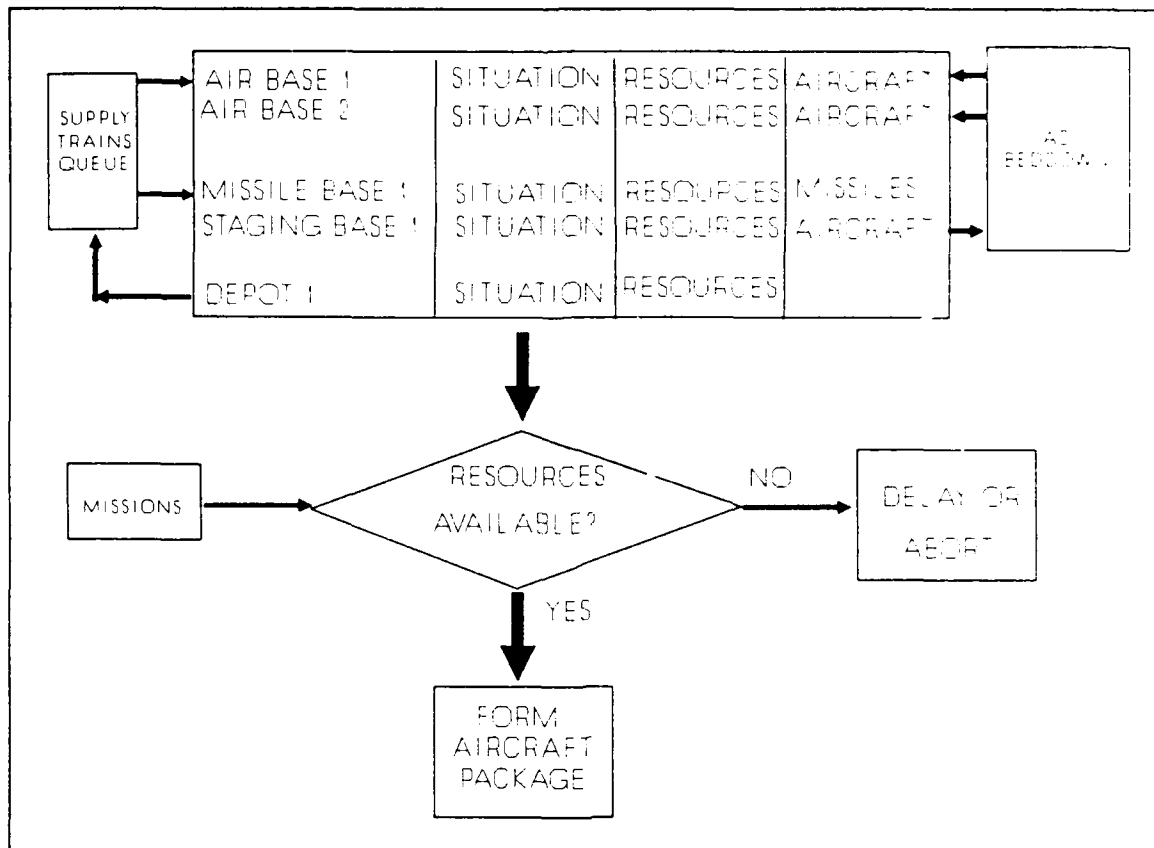
Figure 16.   Air Bases and Logistics

resources are increased.

While in transit, these supply trains are subject to
air interdiction.   When this interdiction occurs, some
supplies and transports may be destroyed.

A report of the status of all supply trains and bases'
resources needs to be available every day.

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6.5   Aircraft Beddown

Aircraft beddown is the process of distributing new aircraft squadrons to the forward bases. Each day, the database inserts new aircraft into the staging areas. These aircraft represent reinforcements flying in.   The players decide where to place or beddown these new aircraft.   These aircraft come with a limited amount of spares and maintenance personnel that are flown along with the aircraft.

6.6   Airborne and Air Assault Operations

Some land forces need to be transported by aircraft or organic Army helicopters to conduct a vertical envelopment. These functions are coordinated by the Air Lift Control Center for the necessary cargo aircraft to transport the troops and equipment. On the tactical side, these operations must have the cargo aircraft protected as they bring troops into the enemy territory. Enemy air defenses not only destroy valuable cargo aircraft, but the troops within.

When airborne operations are directed, the ALCC needs to figure out the number of airlifts to support these operations and the troops to be transported must be near an air base. As a logistic function, the troops become

resources of that air base. The planes transport these
troops to the drop zone, where the troops paracnute in. The
program creates an empty unit at the drop zone. As the
aircraft reach the unit, the unit is increased by the
transferred resources.

6.7   Detection

There are two types of detection. Detection by early
warning systems and local detection by the aircraft packages
and the SAM sites.

6.7.1   Long Range Detection. Airborne early warning
aircraft and ground control intercept check the air hexes in
their range. When an aircraft package enters the air hex,
the early warning systems attempt to detect the aircraft.
If the aircraft package is not detected, the detection
indicator for the aircraft package is set to No. If the
aircraft package is detected and the detection indicator is
previously No, then the indicator is moved to Yes. If the
indicator is already at Yes, then the indicator is increased
to Positive Identification. When an aircraft package moves
into a new air hex, and is not detected, the indicator
decreases to the next lower level.

When an aircraft package is detected by early warning systems and there is an effective command and control system, then the enemy counter air assets can more readily identify the aircraft package. This early warning detection is perishable information. While a package might be detectable along the front lines, as the package moves into air hexes that are not covered by early warning systems, the information becomes more uncertain.

6.7.2   Local Search Algorithm   The detection of aircraft by enemy aircraft or radars, without help from GCI or AWAC aircraft, is done with the following equation.

$$P(t) = \left(\frac{1}{EC}\right) * \left(1 - e^{\left(\frac{-(wWt)}{A}\right)}\right) \qquad (1)$$

P(t) is the probability of detection at P(t),

EC is the Electronic Combat value of the target,

w is the target speed

W is the diameter of the sensor's detection area

t is the time the target was in the area, and

A is the size of the area of search.

This equation is modified from TAC Thunder (AFCSA, 1990b:14-3).

Because the air hex features in this model, these calculations can be assembled quite quickly. If the weather is bad or marginal in a number of air hexes, then the chances of detection is decreased proportionally by decreasing the sensor's detection range. The target aircraft package's speed is the maximum speed the slowest aircraft is capable. The area of search is exactly the size of the air hex. And to find the target's time in the area, is the distance of the hex (km) divided by the speed of the aircraft (km/hour). See the examples in Appendix A.

6.8   HIMAD Batteries

6.8.1   One Missile Versus One Aircraft.

According to Hartman, one of the most frequently used distributions for combat models is the Bernoulli distribution (Hartman, 1985:2-46 to 2-50). The Bernoulli distribution defines an event that has only two possible outcomes, that is a success (1) or a failure (0). This is demonstrated below by a sample from a uniform random number draw from 0.0 to 1.0

In Hartman's example, he uses the Bernoulli trial on the outcome of a surface-to-air missile's chances in hitting an aircraft. A success is the killing of the aircraft with the probability of "p" under certain conditions.
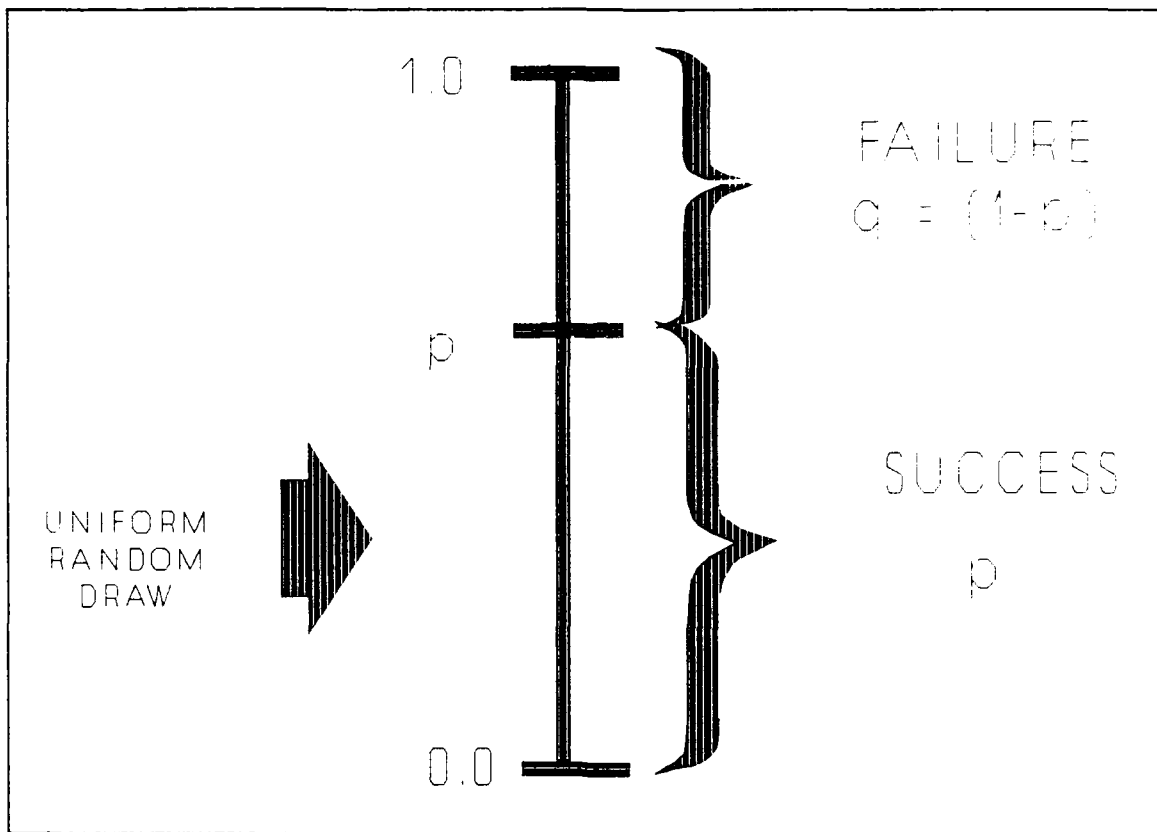
Figure 17.   Bernoulli Cumulative Function

6.8.2   Multiple Missiles Versus One Aircraft.   From a
number of rounds fired at a target the formula of the
probability of at least one hit is:

$$Pr(\text{at least one hit}) = 1 - (1-p)^n \qquad (2)$$

where p = the single shot probability of hit and n = the
number of rounds fired (DA, 1977:14-22).

This formula is used in a number of models (DA,
1977:20-5; AFCSA, 1990b; Hartman, 1985a:9-6).   An example
and proof follows.

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Assume that if a SAM hits a plane, that the plane is killed. Also assume that under certain conditions that the probability of a missile hitting an aircraft is p and the probability of not hitting the aircraft is q = (1-p). Then for one aircraft and three independent missile launches, the outcomes are:

      3 hits   p*p*p,

      2 hits   p*p*q + q*p*p + p*q*p,

      1 hit   p*q*q + q*p*q + q*q*p, or

      0 hits   q*q*q.

In all the outcomes, except the last case, the plane is killed. The actual probability of kill can be represented by:

$$Pr(kill) = 1 - Pr(0 \text{ hits}), \qquad (3)$$

or
$$Pr(kill) = 1 - (q*q*q). \qquad (4)$$

This equation can be reduced to

$$Pr(kill) = 1 - q^n. \qquad (5)$$

Remembering that q = (1-p),

$$Pr(kill) = 1 - (1-p)^n. \qquad (6)$$

6.8.3   Multiple Missiles Versus Multiple Aircraft.

TAC Thunder uses a variation of this equation (AFCSA, 1990b:12-3). The equation is:

$$Pr(kill) = 1 - (1-SSPK)^{(\# \text{ of missiles fired}/\# \text{ of targets})} \tag{7}$$

where SSPK is the single shot probability of kill.

This equation assumes that the missiles are uniformly distributed among all the targets. Therefore, if there are 10 weapons fired at 5 aircraft, the equation calculates the aggregated probability of kill for 2 weapons on a single aircraft.

This probability of kill (Pk) is the aggregate Pk taking into account the number of weapons fired and the number of targets available. If there are more weapons than targets, the Pk reflects a higher probability of destroying each of the aircraft. If there are more aircraft then weapons fired, then the Pk reflects a lower probability of destroying each aircraft.

6.8.4   Determination of the Number of Missiles Fired.

The number of missiles fired by the anti-aircraft battery is an important input to the above formulas. To determine this, a number of assumptions need to be made. The first

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assumption is that each TEL/radar pair will evoke a shoot-look-shoot philosophy. This is due to the missiles need for the fire acquisition radar to paint the target. The second assumption is that the battery will attempt to engage all targets and aircraft packages with the same priority. The last assumption is that an individual battery must detect the flight to fire the weapons. If target detection does not occur, then the missiles are not launched.

Each operational TEL/radar pair will fire at the flight package. The number of missiles fired per TEL/radar pair is:

Missiles = 1 or INTEGER [(Time of AC package to cross the air hex/the time it takes to reload or reacquire the AC package)]

The total missiles is equal to the TEL/radar pairs * the missiles each fired * a probability that the TEL/radar pair and the missiles were able to fire * an early warning command and control function. The probability of the TEL/radar pair and missile ability to fire is a subjective fraction entered into the data base or can be a random number from 0.0 to 1.0. The early warning command and control is a variable that is established by the condition of the air defense headquarters. If the air defense

headquarters are operational and the early warning radars are working, then the value is 1.0. Early warning Command and control is degraded as the early warning radars and the air defense headquarters are destroyed.

6.8.5 _Random Number Draws_. Once the aggregated Pk is calculated, the attrition takes place. There are two methods for doing this process. The first method is a random number draw for each pair of one plane versus the aggregated Pk. The alternative is a single random number draw compared to a cumulative binomial distribution.

6.8.5.1 _Bernoulli Random Number Draws_. For the aircraft and Pk pair, the computer draws that number of uniform random numbers from 0 to 1. The program gives a kill if the random number is lower than the PK. The simulation then tallies the kills and subtracts the aircraft from the aircraft package. Care must be used to ensure that the number of planes destroyed does not exceed the number of missiles fired. This can occur if the random numbers are particularly low.

6.8.5.2 _Binomial Random Number Draws_. The binomial distribution determines the probabilities of two discrete outcome combinations. By using the number of target

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aircraft and the Pk, the binomial can determine the discrete probability of no aircraft kills all the way up to the total package being killed (AFSCA, 1990a:11-14). Using these probabilities, a computer can form the cumulative distribution. A single random number is drawn and compared to the cumulative distribution. The range that the random number falls into determines the number of aircraft lost.

To show that the binomial and bernoulli distributions are similar, the following discussion is offered by Przemieniecki (Przemieniecki, 1990:21-25).

If n is the number of planes, p is the aggregated probability of kill of each plane individually, then q is the probability of an individual plane's survival where q = (1-p). Therefore the probability of one of the planes being killed out of n planes is:

$$Pn(1) = n * p * q^{(n-1)}. \tag{8}$$

To consider the total combinations of r planes being killed out of n planes (with r = 0, 1, 2, . . . ,n) then one can use a combinatorial formula:

$$\binom{n}{r} = \frac{n!}{r! * (n-r)!} \tag{9}$$

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Therefore, the probability of r aircraft being killed out of n aircraft is equal to:

$$Pn(r) = \binom{n}{r} * p^r * q^{(n-r)} \qquad (10)$$

or

$$Pn(r) = \frac{n!}{r! * (n-r)!} * p^r * q^{(n-r)} \qquad (11)$$

When all possible events are considered, the summation of all events from 0 planes to n planes killed is equal to 1.0. Therefore, given the aggregated probability of kill for each aircraft, the binomial distribution is used to determine the probability for each case of r planes killed. See Figure 18. The probabilities are then used in a cumulative probability array with given ranges for the probabilities of r planes killed. A single random number draw is then necessary to determine the number of planes killed.

One must insure that there is a check that the number of planes killed does not exceed the number of missiles fired. Using these formulas and a favorable random number draw could result in more kills than missiles fired. (See

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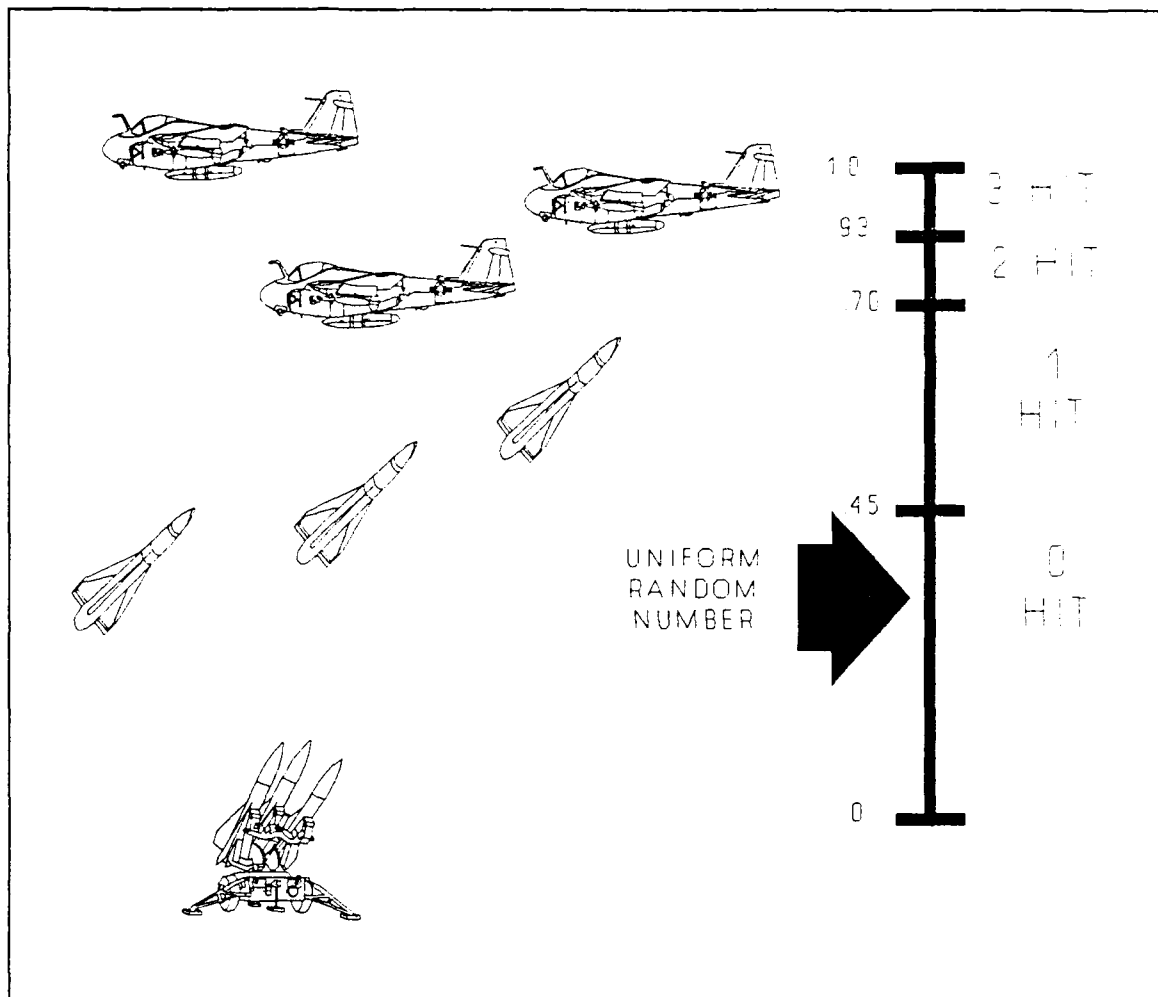
Figure 18. Binomial Random Number Draw

Appendix B for a demonstration of the algorithm).

6.9   SHORAD

The US Army's National Training Center (NTC) at Fort Irwin, California uses a simplified method of determining ground fire and SHORAD against attacking aircraft (DA, 1988: II-B-10 to II-B-15). The present system in both Agile and Ness' land model uses a surface-to-air index (SAI) that is

not explained. The following is the air defense resolution method done in the field at NTC. The Senior ADA Controller and the Senior Air Force Controller at the NTC jointly developed this method (Cowen, 1990). While this algorithm may be subjective and based on the controllers expert opinion, it does take in account types of aircraft, tactics used by the aircraft, and the contributions of the different ADA weapons in shooting down the attacking aircraft.

Engagements are evaluated using an ADA Defend Value Table based on the level of air defense against the appropriate attacking aircraft. Each aircraft engagement is based on the cumulative air defense value for a HIGH or LOW probability. HIGH and LOW probability is determined on the amount of evasive maneuvers an aircraft makes. A HIGH probability of hit is given if the aircraft take no evasive actions. A LOW probability of hit is assigned if the aircraft take evasive maneuvers, uses flares, and/or use ECM. The Air Defense Value total is divided by among the attacking aircraft.

The umpires determined the number of aircraft destroyed by the value per aircraft, three dice, and a look up table.

SLOW MOVING ATTACK AIRCRAFT

WEAPON	RANGE	HIGH PROBABILITY	LOW PROBABILITY
SA-6/8	12,000 m	9	4
CHAPARRAL, SA-9/13)	5,000 m	7	3
STINGER, SA-14 (1-3)	5,000 m	6	2
(4-5)	5,000 m	8	4
(6 OR MORE)	5,000 m	9	5
VULCAN, ZSU 23-4	1,500 m	7	3
SMALL ARMS (1/2 CO+)	750 m	5	1

Table 5. ADA Values for Slow Moving Aircraft

FAST MOVING ATTACK AIRCRAFT

WEAPON	RANGE	HIGH PROBABILITY	LOW PROBABILITY
SA-6/8	12,000 m	9	2
CHAPARRAL, SA-9/13	5,000 m	7	3
STINGER, SA-14 (1-3)	5,000 m	4	1
(4-5)	5,00C m	5	3
(6 OR MORE)	5,000 m	6	4
VULCAN, ZSU 23-4	1,500 m	5	2
SMALL ARMS (1/2 CO+)	750 m	3	1

Table 6. ADA Values for Fast Moving Aircraft

SUMMARY OF LOOK UP TABLE

ADA DEFEND VALUE/NUMBER OF AIRCRAFT	PROBABILITY OF KILL	
1	3/16 OR	.1875
2	4/16	.25
3	5/16	.3125
4	6/16	.6875
5	7/16	.4375
6	7/16	.4375
7	8/16	.5
8	9/16	.5625
9	10/16	.625
10	11/16	.6875
11	12/16	.75
12	12/16	.75
13(+)	13/16	.8125

Table 7. Summary Table for ADA Values Losing

By using this system, the players get a better feel for SAI. The new SAI carried by units and bases is a vector. This vector gives the number of each type of weapons possessed by the unit. An additional algorithm is necessary to determine the air defense value for that engagement, the

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number of aircraft destroyed, and the increase of CEP error

caused by the SAI against the incoming planes.   The

flights' electronic combat number determines which

probability class to use.

One advantage of using this system is being able to tie

the SAI and the number of air defense vehicles together.

Each unit carries a characteristic of how many air defense

vehicles it owns.   The SAI vector can be broken out using

proportions of the unit's vehicles.   By using the TOEs, the

SAI vector can be calculated.   An assumption that has to be

made is whether all a division's vehicles or only part of

the vehicles weapons can be employed.   If one assumes that a

battalion is being attacked at one time, then only that

proportion of the division's SAI is used.

The SAI algorithm is not very detailed.   Since only the

primary aircraft attack the target, the compute_ must

consider relative range to determine how close the aircraft

get to the target to deliver their ordinance.   If the

aircraft must approach the target within certain ranges, the

SAI are applied.   The type of aircraft and the flights' EC

number determine the ADA probability column to use.   The

separate ADA Defend Values are summed and the total is

divided by the strike aircraft.   The look up tables are then

used to determine the probability of kill for the aircraft.

As each aircraft begins their own run against the target, a

uniform random number from 0 to 1 is drawn. This number is compared to the probability of kill. All random numbers less than the PK destroy the aircraft. After each engagement, a new SAI is computed to account for damage to ADA vehicles and a decrease in the amount of available ammunition.

If the aircraft is not destroyed, there is still a chance that the pilot may be spooked. When this happens, the CEP will increase. While this is only addressed in the US Army ADA mission, it is an important factor for consideration. The Army ADA mission is to destroy aircraft and to deter their attack. Near misses or the knowledge of the anti-aircraft fire being accurately fired would ruin a pilot's aim. If the aircraft is not destroyed, but the random number is close to the PK, then the CEP should be increased by some percentage factor, e.g., 50%. Both the amount close to the PK and the percentage of increase of the CEP may be a user defined number or an additional random number draw.

The above algorithm needs to be tempered by the weather, and day/night conditions. An additional probability should be included to decrease the probability of kill during night and adverse weather. This probability will be tied to the weather and cycle indicator and the percentage needs to be supplied in the database.

6.10   Air-to-Air Combat

Aircraft attrition from air-to-air engagements is a function of many factors. First, there must be detection. Detection can be aided by GCI or AWACs or may occur by a chance occurrence between CAP and a hostile flight. Weather, altitude, electronic combat, and detection by ADA sites are also factors of detection.

If detection occurs on an incoming hostile flight, then aircraft may be intercepted by ADA sites, CAP, or DCA. The priorities of engagement are those listed above: (1) the theater air defense sites, (2) any CAP missions flying in that area, and (3) by the DCA missions.

If early detection is made by the defensive aircraft, the defending aircraft may have the advantage of surprise. This surprise enables the defending aircraft to fire the first missile volley undetected. After the first volley has hit, then it is assumed that both sides will have detected each other. See Figure 19.

When opposing groups of aircraft detect each other then the form of combat is extremely complex, but there does exist entire large computer models to simulate this situation, e.g., TAC Brawler. Does one side have long range weapons that enable them to engage the enemy for the first shot without the enemy able to respond with his missiles? Do the planes have special defensive gear to fool the
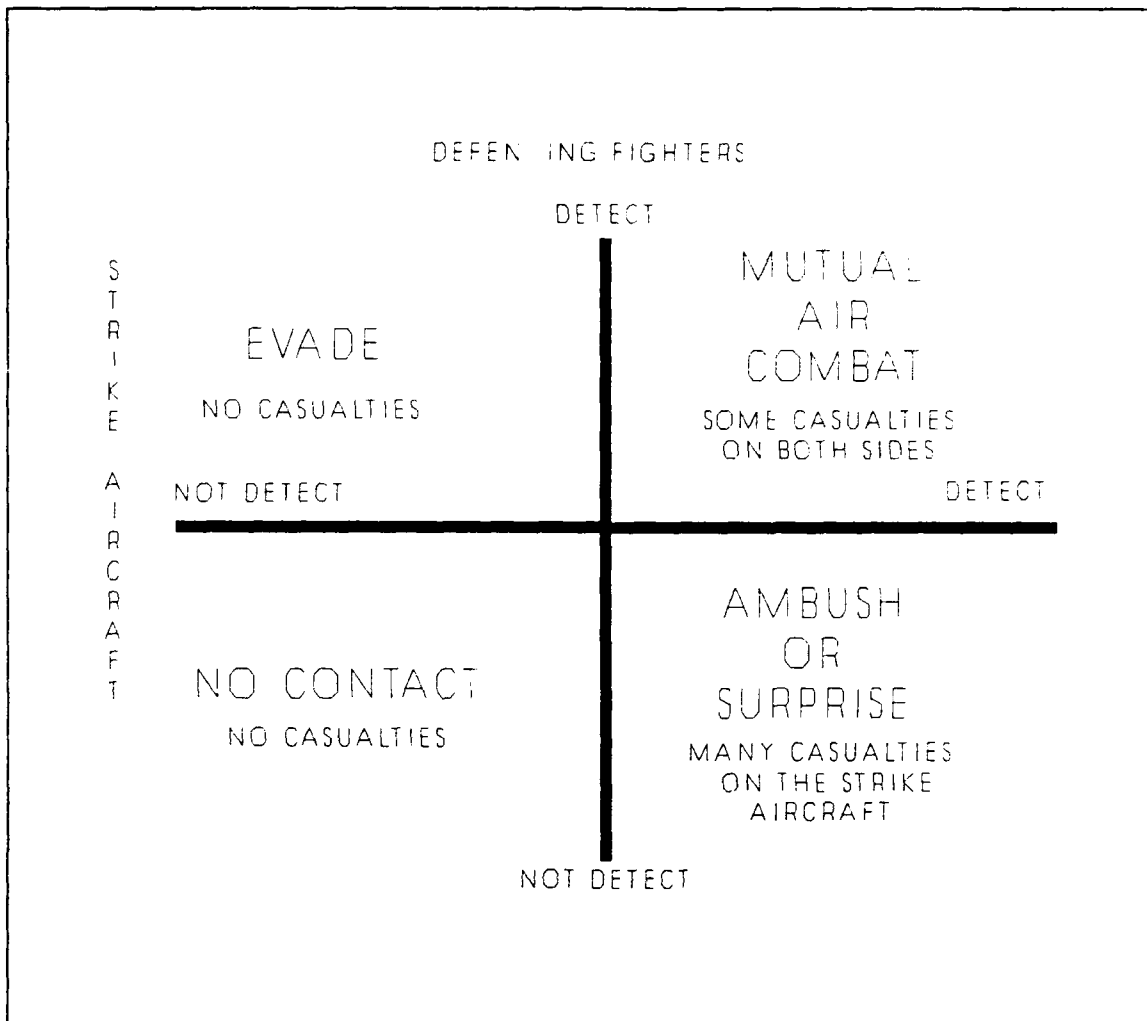
Figure 19.   Air-to-Air Fight

enemy's missile?   In a dogfight, who has the advantage?   How

long does a fight last?   How many missiles are fired per

side?

To make the problem manageable and to keep the

computing time down, some bold assumptions must be made.

First, there is a shoot-look-shoot doctrine, that is, planes

await the outcome of their missiles before they shoot again.

Next, each plane can fire only a certain number of missiles

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at a time. This can be a user defined number, and should be either 1 or 2. And lastly, the fight will last the maximum of each side firing a user defined number of full volleys before the survivors are far enough apart, and that a continued fight is no longer possible. From a fighter pilot interview, it is felt that three volleys are the largest number of possible releases before the aircraft become too far apart to engage (Towe,1990).

In the actual fight, there are many determining factors such as: the combat ability of the aircraft, the number of aircraft, the number of weapons used, and the capability of the missiles. The aircraft have to maneuver into an advantage position and be able to maneuver away from the enemy so as not to give the enemy a favorable shot. The ability to maneuver one aircraft into position versus another aircraft can be expressed as a probability. The missiles' probability of kill can be multiplied together to get an aggregated single shot probability of kill (SSPK). TAC Thunder does this process with the SSPK(shooter versus defender) equal to the Probability of Launch(shooter) times the PK(shooter weapon versus defender) (AFCSA, 1990b:14-16). This SSPK can be used in a binomial distribution to determine the number of aircraft destroyed per volley (AFCSA, 1990a). TAC Thunder uses this binomial method for

aircraft losses, except that it uses look up tables for the one versus one attrition and aggregates upward.

To simplify the probability of launch, aircraft can be rated as to their air combat ability. The SOTOCA model uses a pairwise comparison for this process. While this is a easily used value that simplifies calculations in the attrition process, it is a very involved sequence of data entry. Jim Dunnigan has also established a defining air combat rating.

Using the air combat rating, one can use Markov chain theory to determine the two sides' probability of launch (DA, 1977:17-4). The ratios of the linear air combat capabilities determine the probabilities. For example, assume that a Blue F-15 has the combat capability (CMBT) of 12 (per Dunnigan) and the Red Flanker has a CMBT of 10 and the Red Flogger C has a CMBT of 6. In a four versus four engagement of 4 F-15s versus 2 Flankers and 2 Floggers, the linear weighted combat power would be 48 versus 32. By using the ratios of (the individual side's combat power) / (the total combat power of both sides) one gets the Blue probability of launch on Red (Blue PL) as 48/80 or .6. Red's probability of launch on Blue (Red PL) is 32/80 or .4.

The Pk of multiple weapon systems are then aggregated for a single Pk. The mean Pk and the number of weapons fired is then used in the computation of SSPK.

$$SSPK_{br} = \text{Blue PL} * \text{mean(Pk of Blue weapons fired)}. \quad (12)$$

So this aggregated single shot probability of kill is the number of aircraft and their combat ability to get into a firing position times the average mean probability of kill of their weapons. Using the missile formula from section 6.8.3, equation 7, the computer can determine the overall probability of kill of Blue shooting at Red in the form of:

$$PK_{br} = 1 - (1\ SSPK_{br})^{\text{(Weapons Fired/Red Aircraft)}}. \quad (13)$$

This PK_{br} is the aggregated Pk taking into account the number of weapons fired and the number of targets available. If there are more weapons than targets, the PK_{br} reflects a higher probability of kill that is higher than the SSPK. If there are more targets than weapons fired, than the PK_{br} reflects a lower probability of kill per target than the SSPK. See example in Appendix B.

Once PK_{br} and PK_{rb} are calculated, the attrition process can take place. Again, the computer can do either a Bernoulli or binomial random number draw as covered in sections 6.8.6 and 6.8.7. The missiles from the fight are subtracted along with the killed planes and the fight goes per Figure 20.
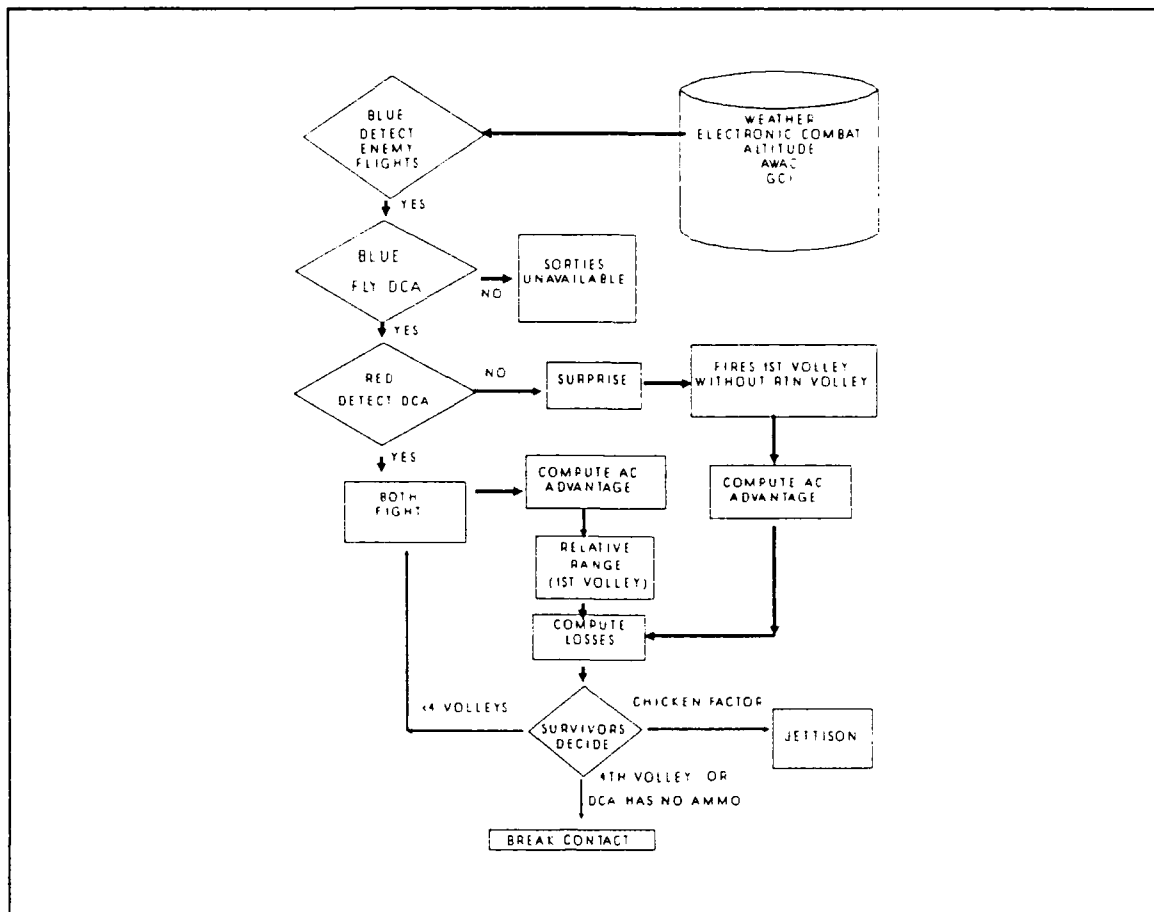
Figure 20. Air-to-Air Combat

6.11   Strike Missions

CAS, BAI, AI, and OCA involve aircraft attacking a
ground target, where some portion of the ground target is
destroyed. A topic that is frequently overlooked is
collateral damage. This can be represented by changing the
ground hex's terrain and borders mobility factor to a slower
factor representing the craters, burning vehicles, and
unexploded munitions that are left behind after such an
attack. The ground target may have a SHORAD self-defense

against such attack. This defense is to interfere with the aircraft's attack and possibly shoot the aircraft down.

6.11.1   Ground Targets. There are several entities that aircraft can effect. These are units, bases, supply trains, and the terrain hexes themselves. Units that can be attacked are air defense units, ground combat units, and support units. Aircraft can attack air bases, depots, and missile bases. Staging bases can not be attacked. Supply trains are the barges, ships, trains, pipelines, trucks, and cargo aircraft that are transporting the logistics to the bases. The terrain hexes and their borders have a movement capability that can be degraded and cause units to slow down. Attacks by aircraft can change terrain movement values to those of rough terrain with poor mobility, or place mine fields along the their borders. A hex side that represents a bridge over a river can be changed as the bridge is destroyed.

The mathematics of an air attack on ground forces is most involved. Factors that influence the air attack are weather, time of day, terminal air defenses, attack ability of aircraft, type of ordinance, stand off range of munitions, types of sub targets at the site, and the degree of effectiveness of the munitions on those types of targets.

The first step is to identify the system components an attack would aim at.

An air defense unit has four major components. These are the acquisition radar, the fire control radar, the transporter-erector-launchers (TELs), and the missiles on hand. Each component is an important part of the system.

A ground combat unit has vehicles or infantry squads that make up the types of combat power inherent in a unit. The air defense vehicles give the SAI. The tanks, fighting vehicles, attack helicopters, and infantry squads give the firepower score. The artillery field pieces generate the artillery support, and finally the trucks carry the supplies needed for the sustainment of the battle.

Bases have a generic format. They have an amount of resources and a number of different planes or missiles that delivery the ordinance. The purpose of the attack is to decrement the enemy's resources and destroy his planes/missiles. The planes may be provided shelters, which decrease the attackers' ability to destroy the planes.

Because a hex has an interdiction value and six trafficability borders, its mobility factors can be decreased when the hex is under direct or indirect attack.

6.11.2 A Detailed Scenario Example. The aircraft package arrives at the target and the planes lost to enemy air defense have been stripped off. The first item to be considered is the weather at the site and the type of planes remaining. Poor weather or inappropriate plane type will decrease the probability of hit for munitions. The next factor under consideration is SAI. A high SAI will decrease the effectiveness of the planes in making their pass, and will destroy some of the planes making their runs. The next thoughts are for the munitions to be paired up with their targets.

The planes will attempt to hit the priority targets first. The data base assigns a weight to the available targets. Each plane is then evaluated on its bombing run. The air-to-ground munitions is compared to the SAI effectiveness range to see if the aircraft has the relative advantage.

There are two main types of weapons. These are point weapons and area weapon. Area weapons are most effective against soft targets, such as infantry squads, aircraft, fuel, trucks, TELs, radars, ADA missiles, and all supply trains. Point targets are hardened targets that require direct hits to be destroyed. These targets are tanks, aircraft shelters, runways, bridges, and harden storage areas. The in between class, or firm targets, contain

infantry fighting vehicles, air defense guns, and artillery.

6.11.3 Mathematics of Hitting and Destroying a Target.

The probability of killing a target is represented by (DA, 1977: 14-2):

$$Pk = Pr(kill) = p(hit) * p(kill\ if\ hit) \qquad (14)$$

or
$$Pk = p(h) * p(k \mid h). \qquad (15)$$

Therefore, the first, and hardest part, is determining if the bomb, missile, or warhead hit the target.

6.11.3.1 Circular Error of Probability.

A measure of the dispersion of a round to describe the accuracy of a weapon is the circular error of probability (CEP) (DA, 1977: 13-7). The CEP is the circle in which 50% of the rounds fired will land. The DARCOM-P 706-101 derives the CEP from a circular normal distribution. The circular normal distribution is:

$$f(x,y) = \frac{1}{2\pi\sigma^2} e^{\left(\frac{-(x^2+y^2)}{(2\sigma^2)}\right)} \qquad (16)$$

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Here one needs to assume the center of impact at the origin and that there is no errors in aim, or that the errors are accounted for in the CEP. To get the CEP, one needs to integrate the above function and find the area where the probability of hit is equal to one-half, that is,

$$\int\int_{x^2+y^2 \leq R^2} f(x,y)\,dxdy=0.5 \qquad (17)$$

By changing the x and y variables into polar coordinates, we can get the coordinates into a single variable R which represents the radius in which 50% of the hits occur. Therefore:

$$x=r*\cos(\theta) \qquad (18)$$

and

$$y^-r*\cos(\theta) \qquad (19)$$

where

$$0 \leq (\theta) \leq 2\pi \qquad (20)$$

Substituting into the above equation one gets:

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$$\frac{1}{2\pi\sigma^2}\int_0^{2\pi} d(\theta)\, e^{\left(\frac{-r^2}{2\sigma^2}\right)} r\, dr = 0.5 \tag{21}$$

$$1 - e^{\left(\frac{-R^2}{2\sigma^2}\right)} = .05 \tag{22}$$

$$e^{\left(\frac{-R^2}{2\sigma^2}\right)} = 0.5 \tag{23}$$

or

$$CEP = R = \sqrt{2\ln 2} * \sigma = 1.1774\sigma \tag{24}$$

Here CEP represents round-to-round standard deviation in a single direction, with the radius equivalent to 50% of the rounds within this radius.

6.11.3.2   Probability of Hitting a Circular Target.

If the computer needs to calculate the probability of a hit by using the above equations, it may let a circular

target have a radius $\underline{r}$ and assume a circular normal distribution for the weapon deliver syster with its

$$CEP=1.1774\sigma,$$

then

$$p(hit) = 1 - e^{\left(\frac{-r^2}{2\sigma^2}\right)}. \tag{25}$$

6.11.3.4 Probability of Hitting a Rectangular or Square Target.

If the target is rectangular, the probability of hit becomes an integration of:

$$p(hit) = \frac{1}{2\pi\sigma^2} \int_{-a}^{a} \int_{-b}^{b} e^{\left(\frac{-(x^2+y^2)}{2\sigma^2}\right)} dxdy. \tag{26}$$

While this equation gives the exact probability, it is computationally intensive. A reasonable assumption is the chance of hitting a rectangular target is actually a probability content cutoff of the normal distribution in the x and y directions (DA, 1977:14-5 to 14-6). In that case, the exponential function can be substituted for the normal distribution. This is called the Polya-Williams

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approximation which compares the probability of hitting a square target to a circular target.

Using this approximation, the probability of hitting a square target of the dimension 2a by 2a is:

$$p(hit) = 1 - e^{\left(\frac{-2a^2}{\pi\sigma^2}\right)}. \tag{27}$$

For a rectangular target of 2a by 2b the Polya-Williams approximations is:

$$p(hit) = \left[\left(1 - e^{\left(\frac{-2a^2}{\pi\sigma^2}\right)}\right)\left(1 - e^{\left(\frac{-2b^2}{\pi\sigma^2}\right)}\right)\right]^{0.5} \tag{28}$$

6.11.4   Mechanism for Determining Hits. Given that the computer can determine the probability of hits, the computer needs to determine the number of hits made. The aircraft unloads its n bombs with a CEP against a target with measurements of 2a by 2b. The computer calculates the probability of hit and then uses the binomial distribution from Section 6.8.7 to determine the number of hits. Based on this number of hits, the computer determines the amount of damage that has been caused.

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6.11.5 Probability of Kill. Given the number of hits, the computer determines if the target was an area or point target, where again point targets are tanks, bunkers, and aircraft shelters. Given there was a hit on a point target, the computer looks up the probability of kill on that target with that munitions. The probability of kill is then evaluated using a Bernoulli random number draw for single targets or a binomial draw for a class of targets. For example, a Bernoulli draw may be necessary for a single aircraft after a single target such as a Stealth fighter versus an air defense headquarters bunker. A binomial distribution may be more appropriate for a flight of A-10s against a tank division.

Area targets are single entities that represent a large area. Examples are a runway or a depot. Bombs that hit a area target destroy x square meters of targets area. Therefore, if a depot has 1000 square meters of area and is hit by 5 bombs that destroy 75 square meters each of depot, than the depot has 625 meters left and 62.5% of its supplies remaining.

6.11.6 Targeting Algorithm. When the aircraft begins its bombing/strafing run on the entity, there are a plethora of targets to chose from, which target is the pilot going to chose? Is he going after a high value item, or is he going

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to chose the first target he can find and quickly return home? A solution to these questions can be a little bit of both.

The ground entity has so many targets in various amounts. An example is a full strength Motorized Rifle Division that is moving towards the FLOT that has 220 tanks, 111 BMPs, 232 BTRs, 8 attack helicopters, 20 SA-6s, 16 SA-9s, 16 ZSU-23-4s, 90 artillery pieces, 236 fuel trucks, and 1525 cargo trucks for a total of 2,474 vehicles (DA, 1984b, 4-34 to 4-36). Assume that the infantry squads are traveling in their vehicles so that the squads do not appear as targets. Quick calculations show that less than 9% of the MRD is made up of tanks and over 61% is made up of cargo trucks. Therefore, it is difficult for a pilot to attack an MRD and always find tanks to shoot at.

One assumption is that the leadership of the TAF will have a priority of targets for the pilots to hit. These targets can be assigned a subjective weight by the players either at the beginning of the wargame or each day. For example the command has deemed that tanks, fuel trucks, and ADA vehicles are important, followed by artillery, BMPs, and cargo trucks, and finally infantry squads and BTRs are the lowest priority on the target list.

Using the percentage makeup of the ground entity, and the players' assigned weight of individual targets, the

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computer can calculate a target score by multiplying the two numbers together. The individual target scores are normalized by dividing the scores by the summation of all the scores, building a target score probability list. By forming the cumulative distribution of these target score probabilities, the computer compares a random number draw for each plane to the cumulative probabilities and assigns each plane to a particular class of targets.

In the case demonstrated by Table 8, a random number of .5 would have the aircraft attack the fuel trucks; the second plane draws a .8 and attacks the cargo trucks.

TARGET	NUMBERS	PERCENT	WGT	WGT*%	Pr (TGT)	CUM PROB
TANKS	220	.088	40	3.55	.221	.221
BMP	111	.044	20	.897	.055	.277
BTR	232	.093	5	.468	.029	.306
INF SQUADS	0	.0	5	.0	.0	.306
ATK HELO	8	.003	30	.097	.006	.312
SA-6	20	.008	30	.242	.015	.327
SA-9	16	.006	30	.194	.012	.339
ZSU-23-4	16	.006	30	.194	.012	.351
ARTY	90	.036	25	.909	.056	.408
FUEL	236	.095	35	3.33	.207	.616
CARGO	1525	.616	10	6.14	.383	1
TOTAL	2474	1		16.06	1	

Table 8. Targeting Example

There are ground entities other than combat units. There are four different types of bases, HIMAD units, hexes and their borders, and supply trains. How are these entities targeted?

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Hexes and boundaries are targeted by their hex number with an additional identifier if one of the 6 edges are targeted. A hex's center region can be changed by massive bombing, the use of air droppable mines, or the use of unconventional weapons. Hex edges which represent bridges over a river, can only be changed by bombing these bridges. A non-river edge can be mined to slow traffic.

HIMAD units can have their two types of radars, TELs, missiles, or SAI vehicles destroyed. The process for targeting can be the same as the process described for the MRD.

While the units represent vehicles, bases occupy square footage on the ground. Each of the base's targets can be represented by some area. By using this area instead of the vehicles, the targeting algorithm can work. For example, an air base has runways, aircraft on the ground, aircraft/shelter pairs, SAI vehicles, POL, maintenance facilities, spare parts, and some ammunition. The percentage area for each target is multiplied by the player supplied weights to get a target score. After the normalization, the score is used in a cumulative distribution with a random number draw.

Ground supply trains are assumed to be a linear target of identical vehicles. If an entire supply train is calculated as 10 meters by 100 meters, then this represents

the total target. An attack that destroys 60% of this train
would destroy 60% of the weight of each resource being
carried and 60% of the transportation asset. There should
also be an additional delay in transporting the remaining
supplies.

6.12   Nuclear Weapons Effects

Nuclear weapons have four major effects (DAF, 1978:6-1
to 6-8). They are blast, radiation, thermal, and
electromagnetic pulse (EMP). Blast is the most widely
known effect of the higher yield bombs and radiation is the
primary killer in small yield weapons. While chemical
weapons effect only ground targets, nuclear weapons can be
used for counter air, close air support, and air
interdiction.

Nuclear weapons for counter air operations are
difficult to use except if the target is a satellite or an
area mission that is constantly flying. The effect of the
EMP is to increase the randomness in the detection and
would decrease the ability of kill for most weapons.

Nuclear weapons against ground targets are treated as
munitions with a very high effectiveness and a very small
CEP. There are two basic types of weapons. The high yield
weapon destroys all entities in the target zone, renders

hexes impassable, and kills any entering entities. A low yield weapon destroys or creates causalities of many of the personnel of ground units within the hex. There would also be collateral damage to the equipment and to the hex land forms. Entities remain in an inoperable phase until decontamination takes place, care on the wounded is accomplished, and the reestablishment of the chain of command is in effect. In actuality, the loss of personnel is severe for the blast, and then losses continue for some time afterwards as radiation sickness continues.

Due to the effect of the radiation, units have their quality of troops decreased which could be represented by the degradation of the unit and having a direct impact on the unit's Firepower Score.

6.12.1 Assumptions. To simplify the weapons effects, the Firepower Score can be decreased by the quality index and the hexes can be altered. For nonpersistent and enhanced nuclear radiation weapons, the entities lose a percentage of its personnel. Subsequent non-persistent attacks on following days have less of a percentage of kills as the troops expect the attacks. Persistent chemical and high yield nuclear attacks result in a high percentage of the entities being destroyed and the hexes mobility index increasing to a large level.

For the use of nuclear weapons, there are a number of simplified assumptions. The height of burst is considered optimal. Weather, soil type, and air density are considered normal or standard. Nuclear weapons are of many types; tactical, enhanced radiation, fission, fusion, etc. In this wargame it is assumed that all the weapons are tactical warheads. Due to the short duration of the game, fallout will only occur in the ground hex that the device was set off in. The effects of long term radiation and EMP are not considered.

There are two main immediate killers in nuclear weapons. They are overpressure and immediate radiation. Overpressure is the crushing force. Five pounds per square inch (psi) will knock down buildings and destroy aircraft on the ground. Forty pounds per square inch is the threshold for lethality for killing people (Glasstone, 1977:552). For radiation, the unit of measure is a REM (roentgen equivalent man). REM is the biological dose of radiation absorbed by a human. The REM is the amount of rads absorbed multiplied by the relative biological effectiveness (RBE) of the particular radiation. The RBE for gamma radiation is 1 and the RBE for neutron radiation has been upgraded to 20 (Beller, 1990). An amount of 600 REMs or greater brings about incapacitation and death. Between 150 to 600 REMs is varying amounts of death. REMs

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of 150 will result in only 5% of the personnel becoming incapacitate, with the recovery period being from 0 to several weeks (Glasstone, 1977:580).

There are other effects of nuclear explosions that are not considered: dynamic pressure, thermal and light radiation, fallout, and electromagnetic pulse (EMP). Dynamic pressure is the high-velocity wind that throws, drags, or tumbles targets. While these can be a casualty producer, overpressure is a more reliable killer. Thermal and light energy is immediate, but with little penetrating power. Nuclear radiation has an initial and residual effect. Ground bursts cause fallout. Initial radiation is the radiation that occurs in the first minute. The major significant radiation is the gamma and neutron radiation. This radiation cause the most penetrating radiation. Electromagnetic pulse is an intense electromagnetic field that can cause electronic component failures or system degradations to computers, radios, transistors, and power systems. And example of the effects of EMP is during the 1962 high altitude nuclear bomb test at Johnston Atoll, there were 30 simultaneous failures of series connected street lights and hundred of burglar alarms set off at Oahu, Hawaii. What is more remarkable, is that Oahu is over 800 miles away from ground zero.

6.12.2 <u>Formulas</u>. The formulas for nuclear weapons

are based on ratios with the yield of the weapons

(Glasstone, 1977). In other words,

$$d/d_o = W^{(1/3)},$$ (29)

where W is the yield of the weapon, d_o is the distance in

meters of the effects of a 1 kiloton bomb, and d is the

radius of the effects in meters. In this example, the

distance from ground zero to a given overpressure extends

scale as the cube root of the yield (Glasstone, 1977:110).

Therefore for a given overpressure, d_o is the distance from

ground zero for 1 KT and d is the corresponding distance

for W KT. For a 1 KT weapon, there is a 40 psi for 525

feet and for 5 psi there is a radius of 2,500 feet.

Distances for the radiuses of effect can be calculated

using the Nuclear Bomb Effects Computer software that

accompanies Glasstone's book.

Using this convention, the formulas are :
for 40 psi to kill all humans,

$$d1 \text{ meters} = (160 \text{ meters}) * YIELD^{(1/3)},$$ (30)

for 5 psi to destroy buildings and aircraft on the ground,

$$d2 \text{ meters} = (762 \text{ meters}) * YIELD^{(1/3)},$$ (31)

for 600 REMs to kill all humans,

$$d3 \text{ meters} = (710 \text{ meters}) * \text{YIELD}^{(1/4)}, \qquad (32)$$

and for 150 REMs to kill only 5% of a units's humans,

$$d4 \text{ meters} = (1054 \text{ meters}) * \text{YIELD}^{(.15)}. \qquad (33)$$

Armed with these formulas, the computer can now calculate the effects of nuclear weapons. The first step is to determine ground zero for the bomb. From the yield of the weapon, the computer calculates the four distances, and uses the distances for radiuses of circles. Every entity within the radius of d1 is destroyed by overpressure. All bases within the radius of d2 have all their resources destroyed except for their hardened targets. All entities within the circle prescribed by d3 are destroyed. All ground units that are between the circles of d3 and d4 have radiation casualties. Here either a linear or exponential interpolation program must be used. The distance d4 represent 5% of the unit's destroyed and d3 represents 100% of the unit destroyed, so any unit in between these distances should have losses corresponding to the closeness to one of these rings.

6.13   Chemical Effects

Chemical weapons will be the most difficult to integrate with Ness' land battle. Chemicals weapons kill personnel and leave equipment intact. Unfortunately, although Ness covers many areas in his model his entities do not include personnel. Neither does the Agile model for that matter.

More problems also exist. Chemical decontamination requires vast amounts of water and special supplies. The exchange of MOPP (mission oriented protective posture) suits is necessary. The wearing of chemical MOPP suits has other effects and that is its degradation of the amount of work that troops can do. The use of either chemical or nuclear weapons also heightens the political stakes of the model to beyond a theater-level wargame.

Considering the inclusion of chemical and nuclear warfare, there are two ways to model this phenomena. The first is the addition of personnel and water to the entities as resources and to include fatigue and MOPP status of the ground units. The second method is to make a number of bold assumptions and make the weapons destroy and degrade an amount of the Firepower Score.

6.13.1   High Resolution. Each entity carries
additional personnel attributes. These characteristics

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portray the total number of personnel in the vehicle crews.
Further subdivision may be necessary at bases, as flight
crews are differentiated between maintenance personnel.
When a flight leaves on a mission, the required crew must be
available to conduct the mission. Entities need to be in a
MOPP status of which there are five:

0 is the MOPP su , is carried but not worn.

1 is the suit is worn, all other gear is carried.

? is the suit and booties are worn.

3 is the suit, booties, and mask are worn, but not the
gloves.

4 is the er ire outfit is worn (DA, 1984c:E-33).
With each increasing level, decreasing amounts of work are
accomplished. MOPP 3 and 4 are especially burdensome to
troops conductine an attack in warm weather or during night
time conditions.

The effectiveness of chemical strikes depends on many
factors. Weather and wind direction are of primary
importance. These two factors determine the persist   of
a chemical agent. Hot and windy conditions cause t.   gents
to dissipate faster and be lethal for a shorter period of
time.

Different agents have a variety of effects and degrees
of persistency. While there are many chemical agents, there
are just a few common types. Blister agents (mustard and

Lewisite) are incapacitating agents that are known to be quite persistent, days to a few weeks. Thicken Soman is a persistent nerve agent used to kill troops. Persistent nerve can last a few hours to a week. A nonpersistent nerve agent can dissipates and kills unprotected troops within a few minutes.

In addition to killing personnel, persistent agents contaminate equipment and terrain. To decontaminate the equipment is a very time consuming and resource intensive task. If a ground unit is hit, the unit has to move out of the contaminated hexes and spend time and water to decontaminate. Otherwise the effectiveness of the unit decreases almost exponentially with time as the unit remains in MOPP 4. The contaminated hexes are marked and units should plan to avoid this terrain. Any unit that does enter a contaminated area has a decreased movement rate, has to don MOPP 4, experiences causalities, and has to decontaminate after leaving the hex.

6.13.2 Simple Resolution. The description of the chemical attack above would entail a lot of modeling. An easier method is to assume that the unit is going to experience causalities of X%, experience a drop in the quality of troops based on an exponential function until the unit moves out of the hex or the agent has dissipated, and

once out of the chemical environment regains their quality
back in the time it takes to decontaminate.

    6.13.3   <u>Low Concentration Bombings</u>. While the above
methods are good for full scale chemical attacks, what about
small or local tactical use of chemical weapons? In this
case, the chemical weapons can be treated as area type
bombs, that have a large radius of lethality. It is when
these attacks go above a threshold value of X number of
chemical weapons in a hex then Sections 6.12.1 or 6.12.2
apply.

6.14   Close Air Support

    The combination of different weapon systems brings
about a synergism in their killing powers. This is the
basis for the concept of combined arms. An example is that
the use of tanks, artillery, attack helicopters, and Air
Force aircraft destroys the enemy more than each of the
systems individually. While this is difficult to prove,
this belief can be incorporated into the model.

    When CAS is assigned to a Corps, the aircraft hit the
enemy units that are in contact with that Corps' divisions.
Not only will the normal air-to-ground algorithm be used,
but the friendly division's combat power also increases in
the artillery category. This increase in Firepower stays in

effect for the time period the CAS assists the unit. This increase of Firepower represents the additional synergistic effect of the AirLand Battle.

CAS missions are assigned to a Corps whose ASOCs would direct to the units that need help. For target assignment, the CAS for a Corps is read in the strike mission queue, and the Corps' divisions in contact are polled. If there is no unit in contact, the CAS missions are assigned to a Corps in contact. If there are no Corps in contact, the CAS is not activated and returned to its bases without using the resources.

If the CAS missions are activated, the CAS missions are assigned to a division in contact. The CAS mission then selects the enemy unit that has the highest Firepower Score against that division and attacks that enemy unit. The air-to-ground attack uses the algorithm in Section 6.11 and the friendly division's Firepower Score is increased per section 6.17.

6.15   Satellites

The state of the satellite is akin to the airplane in World War I (Heier, 1987; 17 to 18). This being that the satellite is the newest and most expensive vehicle on the battlefield. Like the aircraft the initial roles of the satellite are reconnaissance and messenger. Satellites

though have a very diverse function and specialties. The

satellites conduct tasks as:

        Ocean Surveillance
        Navigation (GPS),
        Electronic Intelligence,
        Photographic Reconnaissance,
        Communication
        Weather Reporting
        Missile Warning
        Anti-Satellite (ASAT)
        Tracking & Data Relay (Bishop, 1988; 36).

Each of the above categories may have more than one

quality or generation of equipment. A single satellite

might have more than one type of task. Smaller packages may

piggyback off a common satellite payload.

        Due to the short nature of this game, most satellites

will already be in place. Only a limited number of assets

will be available to augment the force. To get additional

support the satellites must already be on hand in a

warehouse, and there must be a system available to get the

payload into the proper orbit. This is the difficult part

for the players.

        The players need to understand that satellites are a

long term item. Those satellites in place before the war

are the only real assets available. There is always the

possibility that one of these critical assets may become

suddenly inoperable. The only changes the players can have

is to request very limited "Lightsat" and ASAT missions.

A Lightsat is a lightweight satellite that has limited capabilities. These satellites are placed in orbit by a launch vehicle already in place at the national asset level or by a special air-launched system such as Pegasus. The Lightsat will only have a percentage of the capabilities of already orbiting satellites. The present US ASAT capabilities are few. The only weapon ever developed is a missile fired by a high flying F15. This weapon has been mothballed for several years, but is still available.

A possible teaching point for the players is the tremendous asset satellites are. Therefore, to reinforce this lesson, the players should have a wide range of assets at the beginning of the war and later in the war, allow a critical satellite to die. The information loss should be staggering. A Lightsat should be available, but can only be launched after a delay. The Lightsat is then only a percentage of the former satellite capabilities.

From the opposite viewpoint, suppose, the enemy is using an old weather satellite to get strategic information. A report of this is made to the players. The options to the players are:

1. to do nothing,

2. attempt a risky ASAT operation,

3. attempt to jam the satellite, which will cost a lot of EC assets,

4. attack numerous receiving stations on the ground,

5. or a combination of the above options.

While it is beyond the scope of this thesis to have a full blown satellite war, satellites may need to be modeled as hunter-killers between themselves, missiles, aircraft, and even ground units.

The process for achieving satellites again deals with air hexes. The satellite represents an area mission that is in a continuous mission. All satellites exist in the highest air hex. If the space and time is available, additional air hexes could be added to represent very low earth orbit, low earth orbit, high earth orbit, or a geosynchronous earth orbit.

The satellites either move across the air hexes on predetermined paths representing their orbits or stay stationary in one spot. As they move to or occupy an air hex, they conduct their mission. Photo reconnaissance satellites increase the intel index of the ground units. Communication satellites send messages. Once a satellite passes out of the playing board, it is rescheduled to enter at the next time it is to pass over the theater.

Photo reconnaissance satellites will have different resolution. The higher the resolution, the less targets it can service. The lower the resolution, the larger area the satellite will affect.

A high resolution satellite will be able to be given a specific number of hexes or targets it will check. As the satellite passes over these targets. the intel index and the intel filter will be increased. The targets with the increased intel index will be reported in the intelligence reports. A target that is out of range of the satellite will be not be affected. The range will be determined by deriving the formula of the line that represents the path of the satellite. The negative inverse of the slope of the line will then be computed. This slope represents the lines at right angle of the target to the satellite path. This line represents the shortest path between the target to the satellite path. If the distance of this line is less than the field of view. Then the targets intel index is increased. If the line is larger than the field of view, the target is not effected.

Weather may also effect the acquisition of a target. A line of sight calculation needs to be made between the satellite and the target. If there is the sufficient bad weather along this line of sight, acquisition will be denied or reduced. This must account for the weather in all the air hexes that are intercepted in the line of sight. If acquisition is made, then the intel index is increased.

6.16   Reconnaissance

Reconnaissance of ground units by aircraft is a simple mechanism. As the Recce aircraft moves along its route or to its intended target, it accumulates the target numbers of all the ground entities it can detect. Once the recce mission makes it back, all these targets' intel indexes are raised by .X. This .X is a subjective value that is based on the quality of the sensor. Obviously the detection by the JSTARS would be higher than the detection of a single A-10 returning from a combat mission.

6.17   Ground Battle Formulas

To properly add the air battle, there has to some changes to the ground battle. While Ness freed the land model to a hex system, this thesis is reinstating the idea of individual systems having weights for the Firepower (AFWC, undated:5). The main difference between the two systems is the reliance on the battalions equivalents versus an unknown rationale, and the need in this game to give the targets physical dimensions for the aircraft to hit.

When a ground unit has 23 tanks destroyed, the simulation can determine the amount of firepower destroyed. ADA vehicles in a ground unit contribute only to the SAI, not to the firepower. When these assets are stripped away, air power becomes more potent.

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For this wargame, the following Firepower Scores are recommended:

US Firepower = Quality of Unit * (.5 tanks + .3 Bradleys + .1 Mech Infantry Squad + 1.9 Apache + .15 Light Infantry Squads + .1 HUMMV TOWs).

Soviet Firepower = Quality of Unit * (.5 tanks + .2 BTRs + .34 BMPs + .1 squad).

Fuel = 3000 gallons * fuel trucks

Ammo = 5 tons * ammo trucks

Combat Power = Firepower + function of (artillery, posture, CAS, and terrain)

There is also a need for each side to have the dimensions of the targets. Table 9 is an example of the measurements needed.

VEHICLES	LENGTH	WIDTH	ARMOR	REMARKS
T-80	6.9	3.6	HEAVY	(TANK)
BTR-70	7.5	2.9	LIGHT	(INF FGT VEH)
BMP-1	6.74	2.94	LIGHT	(INF FGT VEH)
122mm	10.0	1.97	LIGHT	(ARTILLERY)
ZSU-23-4	6.5	3.0	LIGHT	(ADA)
Ural-375D	7.35	2.64	NONE	(TRUCK)
SQUAD	20	30	NONE	(7-8 MEN)

(DA, 1984b)

Table 9. Examples of Dimensions of Soviet Vehicles (Meters)

VII.   Logistics and User Interfaces

7.1   Introduction

Pseudo-reality is the objective of this model. If this model accepts player input in the same format as those issued in war and can give output that mirror the situation briefings at the TACC headquarters, then the model may be believable to the players. At the point when players begin applying what they learned in the Air War College system in meaningful ways to play this wargame and credible results are coming out, then this wargame has served its purpose. All the model algorithms are for naught, if the input and output are in a stilted unrealistic form. Therefore, it is of prime importance that the finishing touches of this computer program ensures that there is a smooth and easily understood user interface system between this wargame and the players. The designers must realize that the players of this game may have little or no computer experience, and therefore the packaging of this program is of prime importance.

7.2   Input

Input is the step between the player's idea and the world of simulation. This process of input must be simple, easy, and conform to what the players would do in real life.

Input entry and error checking is made easier using a preprocessor to filter out grossly incorrect commands, and various tools would be helpful to aid in the planning of the missions. For this model there are four areas that need player input. The first is the aircraft beddown, where the question of where are the new aircraft from the staging base going to fly to a forward base? The next input required is the transportation of supplies, that is, what resources need to be moved. The third requirement recognizes that the land units need instructions. The last input is the aircraft and missiles missions.

7.2.1 AC Beddown. Aircraft beddown is the moving of aircraft from the staging bases to forward deployed bases. Typical commands would move n number of aircraft from Staging Base X to air base Y. The staging base should always have enough supplies to move the planes. In addition, the planes should come with a "spares" kit and additional maintenance personnel as a total package.

At times it may be necessary to move planes from one air base to another. The same above process should be used. Again a portion of the spare parts and the maintenance assets should accompanythe aircraft, but not as much as when the aircraft is first transported from the staging base. Additional resources needed by the relocation will

have to be moved by supply trains.

7.2.2 Transportation Moves. At the beginning of the
game, logistical planners should know how much haul
capabilities are available. A transportation requirement is
defined by the type of transportation, the number of days it
takes to transport resources, and the total tonnage means it
has to deliver resources. The logistician will be able to
use any fraction of a type of transportation to deliver the
resources. In another words, out of a total truck capacity
of 300 tons, the player desires 4 tons of a certain ammo and
45 tons of fuel from air base W to Z. This amount is put in
transit for an average transit time. Every day, the
logistician gets a report of the status of his supply trains
and the amount of transportation assets he has free to
commit. Once the supplies have been delivered, the
transportation asset is rolled into the total available to
be reallocated for a new mission. Like Agile, the
capabilities for a predirected rate of supply should also be
available. With the predirected supplies, a constant amount
of supplies are sent from a depot to base everyday until the
predirect is stopped or the supplies run out.

7.2.3 Land Units. Land units follow the orders laid
out in Ness' thesis. The missions differ depending on the

entity. Ground combat units have three missions; attack,
defend, and withdraw. HIMAD units have three missions;
move, fire, and no activity. Supporting units can move and
need to be directed to which units to give support and how
much support.

7.2.4   Aircraft and Missiles Missions. The player
input should correspond to the level of warfare being
modeled. If the players are role modeling the TACC of a
TAF, then these players should be doing the apportionment
and allocation of the air tasking order. These taskings
consist of the assigning of missions to Wing Operations
Centers, CRCs, ALCC, GACC, and ASOCs. These subordinate
cells then do their own individual planning and conduct the
missions.

Because the subordinates are assumed to be very
resourceful, orders will define the number of aircraft to a
certain mission and let the subordinates do the rest of the
assignment work. In this situation, the computer will pool
all available assets and from the "total pool" to try to
accomplish the missions. The computer will start with the
highest priority area missions in time period 1 of cycle 1.
Both sides, Red and Blue will be able to get their area
missions for that time period airborne before combat can
begin. At that time any ADA, SEAD, or air combat will be

resolved. Area Electronic Combat will begin to affect the detection rates and C2 missions would begin their detection process with CAP and DCA aircraft being posed to intercept the enemy incoming flights. Next, the strike packages will be processed for both sides. These packages form in a queue and are processed in order of priority. The reason for this queue is if any airfield is hit during this time period, it is assumed that the package would have gotten off safely. The aircraft are then processed alternating between Blue then Red with the highest priority missions first.

At the end of the mission, the aircraft packages are formed in another queue and await the end of the period. The aircraft then try to return to their parent unit. If the field is closed, then the aircraft will try to land in the next two alternate bases designated by the parent base. If these bases are closed, the aircraft goes to the closest open base.

7.2.5   Example of Mission Input For the Blue Side.

Example of input for a day cycle of a two hour block of time.

```
CLOSE AIR SUPPORT
#      AC     SP LAT LONG CORPS  CAP # CAP AC SEAD # SEAD AC EC # EC AC REFUEL
20     A10    32  46 10US        3   F15    1    F-4G              Y
7      A6     20  34 1MD         4   F18

OFFENSIVE COUNTER AIR
#      AC     SP LAT LONG TGT1 TGT2  ESC # ESC AC SEAD # SEAD AC EC # EC AC REFUEL
12     F111   32   46 RB32 RB45  2    F16    1    F-4G              Y
8      TORA   32   46 RB23


FIGHTER SWEEP
#      AC     SP LAT LONG     TGT     AREA LAT LONG  SEAD # SEAD AC EC # EC AC REFUEL
8      F15    32   46    MAINSTAY                     2      F-4G  1   EF111  Y
10     F16    32   46                45   46
```

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```
AIR INTERDICTION
#  AC  SP LAT LONG TGT AREA LAT LONG  ESC # ESC AC SEAD # SEAD AC EC # EC AC REFUEL
12 F111 32 46      RU22                2    F16   1     F-4G                  Y
8  TORA    32 46            28   45

BATTLEFIELD AIR INTERDICTION
#  AC  SP LAT LONG TGT AREA LAT LONG  ESC # ESC AC SEAD # SEAD AC EC # EC AC REFUEL
12 F111 32   46 RU33
6  JAGU 32   46            40   46

COMBAT AIR PATROL
#       AC       AREA LAT LONG  SEAD # SEAD AC EC # EC AC REFUEL
4       F1          32   46                             Y
2       F18         20   34

DEFENSIVE COUNTER AIR
#       AC    STANDBY #   AC
32      F15        12   F18
23      F16

RECONNAISSANCE
#  AC  SP LAT LONG TGT AREA LAT LONG  ESC # ESC AC SEAD # SEAD AC EC # EC AC REFUEL
1  RF4C 32   46            47   51
1  RF4C 32   46 RU12


SUPPRESSION OF ENEMY AIR DEFENSE
#  AC  SP LAT LONG   TGT   AREA LAT LONG ESC # ESC AC  EC # EC AC REFUEL
4  F-4G 32 36                40   36  2    F15                   Y
4  A10  32 36    RU12

ELECTRONIC COMBAT
#  AC  SP LAT LONG   TGT   AREA LAT LONG ESC #  ESC AC  SEAD #  SEAD AC  REFUEL
4  EF130 32 36              40   36  2    F15                            Y

COMMAND, CONTROL & DETECTION
#       AC       AREA LAT LONG  ESC #  ESC AC SEAD # SEAD AC EC # EC AC REFUEL
1       AWAC        28 36   2    F16                                 Y
```

Now the program would echo the inputs for the 2 hour block of time and ask the priorities, ranging from 1 to the total number of missions entered are correct. The priorities have been already established by default by mission type, but this gives the players a chance to override the defaults. The area missions that are ongoing, C2, DCA, CAP with refuel, electronic combat with an area mission and refuel, are carried into the next time period

and displayed before the players input the next time period's missions.

There is also a need for RESERVE mission for AWACs, DCA, and nuclear strike aircraft. These aircraft would be protected from missions until needed by the situation. These contingency missions would be loaded into the area mission queues, but they would not be activated until called upon. These planes have a dual personality, they have all the resources already allocated to them for flight, and are in the mission queues, but they do not consume these resources until activated. If these planes are not activated by the end of the day, they are returned to their bases and the resources are added back into the air bases' supplies.

7.2.6   Preprocessor. A preprocessor sorts information, checks the data for obvious errors, and formats the input file. Examples are the number of missions or aircraft assigned exceeding the number on hand. Another example is that a range consideration is being violated on the input. The preprocessor should have an override option for the exercise of certain instructor approved options. An example of the need for an override process, is if the missions are aborting due to a vast distance needed to be traveled, but some ingenious operational planning has

figured out how to extend the range in real life, e.g., Doolittle's Raid that launched Army Air Corps bombers off an aircraft carrier to conduct a one way bombing mission on Tokyo.

7.2.7 Planning Tool. The present Agile model has a planning tool. It uses the same algorithms as the actual model. This allows the students to test their options before entering their commands into the computer. This same process should be carried over into this simulation except that the algorithms would have to be expected value algorithms. The uses of stochastic planning tools might confuse the students more than help them.

7.2.8 Passwords. This wargame is a training tool, but many players are interested in beating their opponent than learning from the experience. Therefore, there needs to be special passwords on weapons like nuclear and chemical warheads. The procedures in the real world for the release of nuclear weapons are very strict and exacting; this should be the same in this game. A player trying to access the nuclear weapons module should be queried by the computer if the president has authorized nuclear release and what are the code instructions for the activation of the warheads. The incorrect response should lock the player out of the

nuclear module and raise a flag to the instructor.

7.3   Output

There are many different types of output that can
generated by a wargame. Some output is useful, but
traditionally most output is not. Usefulness depends on the
demands on the players and the goals of the exercise. In
keeping the model as flexible as possible, there should be a
plethora of data that is presented in both raw and processed
form for the players.

7.3.1   Raw data. The raw data begins with echo
reports. These reports tell the players what was entered
into the computer. Such reports must be established to
produce an audit trail for the players to keep track of
their original strategies.

The next raw data reports are the logistics reports.
These reports show the constraints placed on the players to
conduct war. The reports should show in detail the
resources on hand, used and the location of all committed
resources. There should also be a report of the estimated
supplies that will be coming into the theater. Examples of
the logistics reports are base logistic reports, depot
reports, tactical air lift reports, transportation assets
report, and refueling ability.

Another raw data output is after action mission reports by individual flights and missions. This also is an audit trail of the flight, attrition experienced by the mission, and a rough idea of the mission accomplishment. The players can construe this report as mission debrief information provided by the returning air crews. If the entire aircraft package is destroyed, the flight shows as missing in action and the players do not get a full report. A separate file accessible to the controllers should show the actual circumstances.

The raw data could not be complete without the land battle situation reports. The land units should report their locations, strengths, objectives, present situations, whether they are in contact with the enemy or not, and their battle results. The land units' logistics report should be reported here. This provides the players controlling the land units with their reports together in the same output medium.

The last raw data report, which should not be printed out unless required is a transaction file. This file should contain all individual transactions that a data base program and graphics programs can reference.

7.3.2   Processed Reports. There are many types of processed reports. One type may contain standard reports

assembled by aggregating the raw data. These type reports could contain killer/victim scoreboards, force ratios, and destruction rates. A second type report would be used to generate image data, such as charts, graphical representations, or animation.

A mission summary report can also be a very useful tool. This report reviews the past missions. It can provide the killer/victim scoreboard summaries, rates of aborted missions, and success of missions. A killer/victim scoreboard identifies different weapon system types and the objects by class that they killed. DARCOM-P 706-102, 1978, page 30-20 gives examples of such matrices. With this information, the player can determine the most dangerous weapon systems.

A reporting system could address aborted missions. There are many reasons for these aborted missions. Lack of maintenance, fuel, spare parts, and ammunition are the most obvious reasons. An aborted mission for bad weather is not an obvious answer nor are circumstances where planes may also have jettison their ordinance without engaging the target.

Intelligence reports are powerful tools to base future decisions. Incoming information comes from a variety of sources; satellites, air reconnaissance, returning sorties debrief, Special Forces units, ground units in contact, etc.

This information takes many well trained people a while to interpret. This game should give as a complete a picture as possible of unit locations, current strengths, recent losses, and incoming reinforcements as they would expect to obtain from standard sources. This process is already setup in Ness' program. What is needed is the ability to predict the enemy's future missions.

   7.3.3   Image Reports. The most important and most difficult to generate are image reports. Images portray raw information through graphics that can be quickly understood. This can be in two methods: charts of important measures of effectiveness, and map-like graphics.

   The chart process can serve as an important measure of progress. Examples are charts that reflect each days important results. The charts would show the Blue/Red aircraft loss ratio, the Red/Blue attack sortie rate, the Red/Blue defensive sortie rate, the Red base status, the Blue air base status, the Blue/Red ground combat ratio, and the amount of ground each side controls. A post processor can make these charts and add each day's data to the charts. A computer screen or paper copy can display these charts.

   Map-like graphics can display the general situation quickly. The U.S. Army's FM 101-5-1 Operational Terms and Symbols provides a standard visual system for the

development of military symbols.

These methods have been already incorporated into graphic programs at the Wargaming Center. New models should capitalize on the Wargaming Center's present accomplishments and add any additional necessary details. The present graphics program is using the standard symbols with the unit's name underneath as shown in Figure 21.

While the standard symbols are usually shown on maps, the computer game would have to display its own "simplified" map. The Wargaming Center's program displays the ground forces on the hexes corresponding to the units location. Hexes are also displayed along with symbols for terrain, boundaries, and roads. Their system can zoom to different areas and call up detailed information on individual units.

The only problem with the Wargame Center's program is that units are displayed without any quick idea of their capabilities. FM 101-5-1 recommends a solution to this very problem. The process is called decision graphics. The concept is for the graphic to display the overall combat effectiveness at a glance.

Decision graphics for combat effectiveness are represented by two circles (DA, 1985:3-2). The first circle is divided into thirds and displays the effectiveness of the unit. A clear circle represents no problems. One-third of the circle filled in represents mission accomplishment with
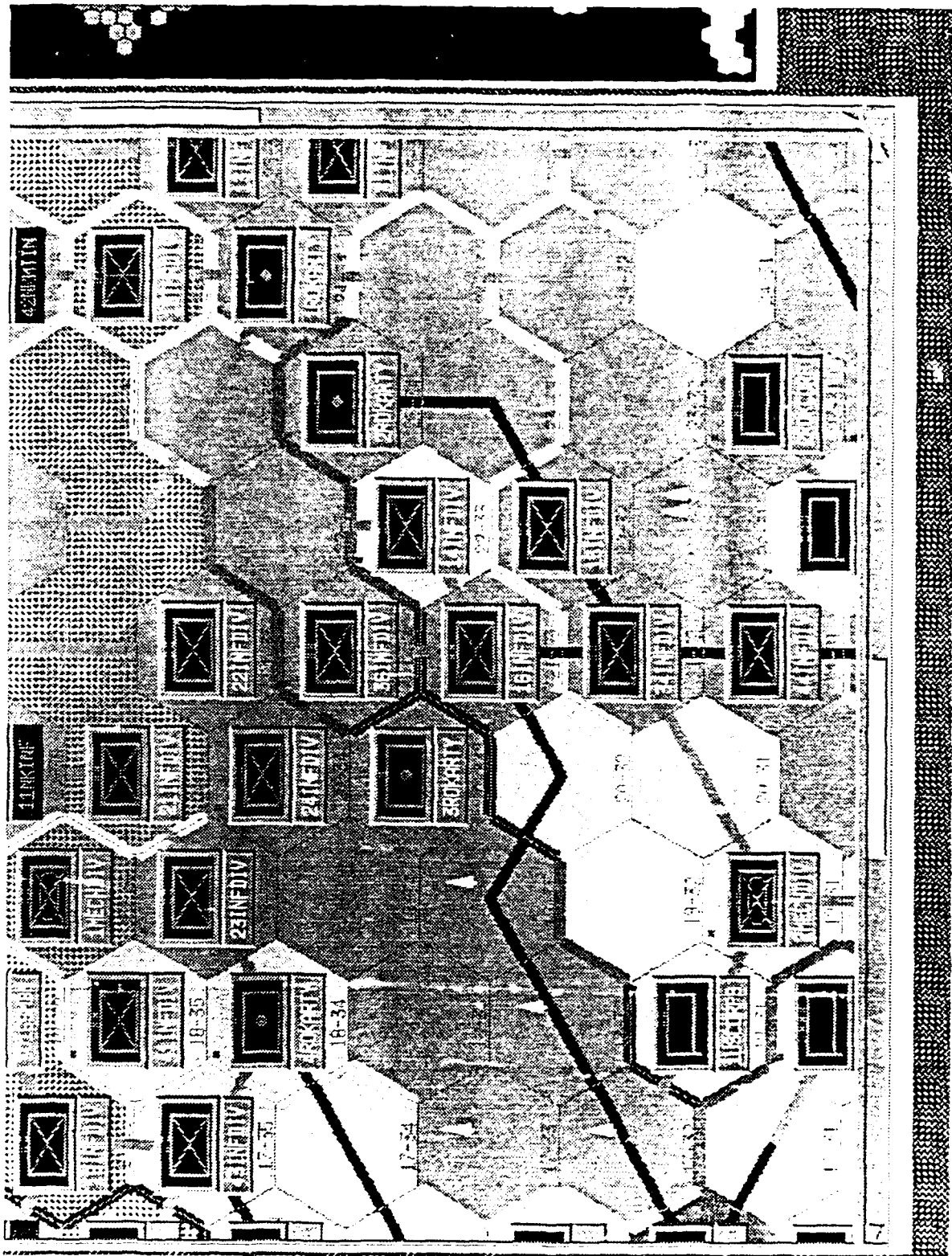
Figure 71. Present Graphics Program

some difficulty. A circle with two-thirds darkened represents major problems. A completely dark circle represents a unit that cannot perform its assigned mission. The second circle is usually divide into fourths. Each quarter represents a specific item of interest. Using Ness's land model, these quarters can represent a unit's combat power, surface to air index, ammo, and fuel. For an air base, the items could be runway, ammo, fuel, and maintenance.

The air battle could be animated to present a moving picture of the day's missions, although this may be to complex for the speed and size restrictions of some computers. If possible, the animation would read the transaction file and move the graphics across the screen. Air losses could be shown at their locations. This animation would lend credibility to operations and help the verification of the code and data bases. The students could actually see where they were losing planes and where they were succeeding. If animation is not feasible, then a graphical snap shot of the day's battle would suffice.

For planning purposes, the model needs to show the forecasted weather. This could be a snap shot of the next days weather. Cloud formations, prevalent winds, and storm fronts could be shown based on the hex system map. This

would help the planners in determining where they need to use their all weather aircraft versus fair weather aircraft.

7.3.4   Present Reports. A starting point for Saber's reports is the present Agile output. An Agile printout gives the following reports. Each side gets their own sets of reports.

- Mission Input- Basically an input echo report.

- Mission Summary- Reviews how the missions went.

- Air Order of Battle- Shows the air base status.

- Aircraft Basing/Cross-servicing Plan- Matrix match up of the aircraft with compatible maintenance assets.

- Total Sorties- The total projected sorties available for mission assignment for the next day.

- Enemy Air Order of Battle- Shows the effects of OCA on the enemy air bases.

- Aircraft Loss summary- Killer/victim scoreboard.

- Enemy OCA Summary- This report demonstrates the effectiveness of the recent enemy OCA campaign on the friendly air bases.

- Friendly OCA Summary

- Base Logistics Summary- Lists bases, aircraft, and resources.

- Depot Logistics Summary- The on hand depot stocks.

- Cargo Summary- List of the cargo aircraft summary.

- Logistic Analysis- Shows the aircraft usage rate at each base.

- Enemy Forces Land order of Battle- Results of the BAI, AI, and CAS missions of the enemy.

- Enemy Forces Army Summary- Reviews all known ground activity.

- Land Overruns- List of units and air bases overrun.

- Engagement Summary- Lists all units, their current locations, and missions.

- Friendly Forces Land Order of Battle- Enemy's impact on friendly units.

- Tactical Air Reconnaissance Summary- Reports reconnaissance activity, target identification, and level of reliability.

- Combat Power Ratio- Shows strengths of units now in contact.

- Enemy Surface-To-Air Defense Summary- Lists average SAI indices for a region.

- Friendly Surface-To-Air Defense Summary- Lists average SAI indices for a region.

- FEBA Plot- Graphic map of both sides forces, FEBA, and combat ratios for those units in contact.

- Zone Weather Forecast- Next day's weather.

- BE Directory- A bomb encyclopedia that gives a quick reference to target numbers and units.

7.3.5 <u>New Reports</u>. A satellite status report is needed. The capabilities of a satellite and the intelligence derived from satellites needs to be updated every day. Reconnaissance satellites give information on the enemy. A report should show how much of the intelligence reports are derived from an individual satellites. Communications satellites should also have a report on the worth of that satellite as a function of the command and control variable.

In the missile report, both sides capabilities should be listed. The range of the missile should be given in kilometers with a radius of range available on the computer graphics screen. The Blue forces should have listed the possible capabilities of the national assets to support space lift and more satellites.

A detailed air defense report is also needed. This report should also make available a graphical report of the range radius of the SAM sites. This report should be able at a glance to show the holes in the missile defense system of both the friendly and enemy ADA plans. This then becomes a valuable tool to determine one's own placement of CAP and where to send one's aircraft missions through any holes in the enemy's defense.

A controversial report is a feedback report. Given that this wargame is played many times, the results of these

runs should be stored to compare to the present players performance. Nothing is more frustrating then conducting an exercise, and then not getting any feedback. There are a multitude of performance measures that can be stored, e.g., aircraft force ratios, ground gained or lost, number of Red planes destroyed, number of Red vehicles destroyed, etc. Therefore, the computer can store the results of past games to give the players an idea how they compare to others.

7.4   Summary

User interface is probably the most important acceptability factor to players. Complicated input and output displays will disenchant any non-computer person. This wargame must be easy and user friendly. The best algorithms and the most realistic models are for naught if the computer does not have human factors considered from the start.

Input needs to be in the same format as orders given to the real units in the field. While this is important, the entries in the computer must be simplified so that the players do not spend too much time punching in numbers. It is also important, that here is a way to override the default values when the wargame warrants changes.

Output needs to be consistent and helpful. New
graphics programs can much improve the "paper war" and give
the players better insight into the strategy of war.

VIII. Conclusion

8.1 Summary

This thesis provides the foundation to build a new theater wargame for the Air Force Wargaming Center, Maxwell AFB, Alabama. To restate the problem statement, given the recently developed land battle, this thesis' effort is to link US Air Force doctrine with a conceptual model's framework and develop the necessary mathematical formulation for a new air theater wargame. The goals were to provide the algorithms and the rationale for programmers to construct a computer simulation. This thesis has met these goals.

In the study matrix, I outlined the major areas that needed modeling. In Chapter II, the Air Force doctrine was explained along with the missions and the linkage to Army ADA. In Chapter III, a credible scenario was chosen to represent theater warfare. It was just a coincidence, that the actual war is taking place. In Chapter IV, the overall model begins to take shape, with the integration of intelligence. Chapter V is the development of the entities (aircraft packages, ground combat units, HIMAD units, and bases) along with a samples of the databases and the rationale and references for developing the entities.
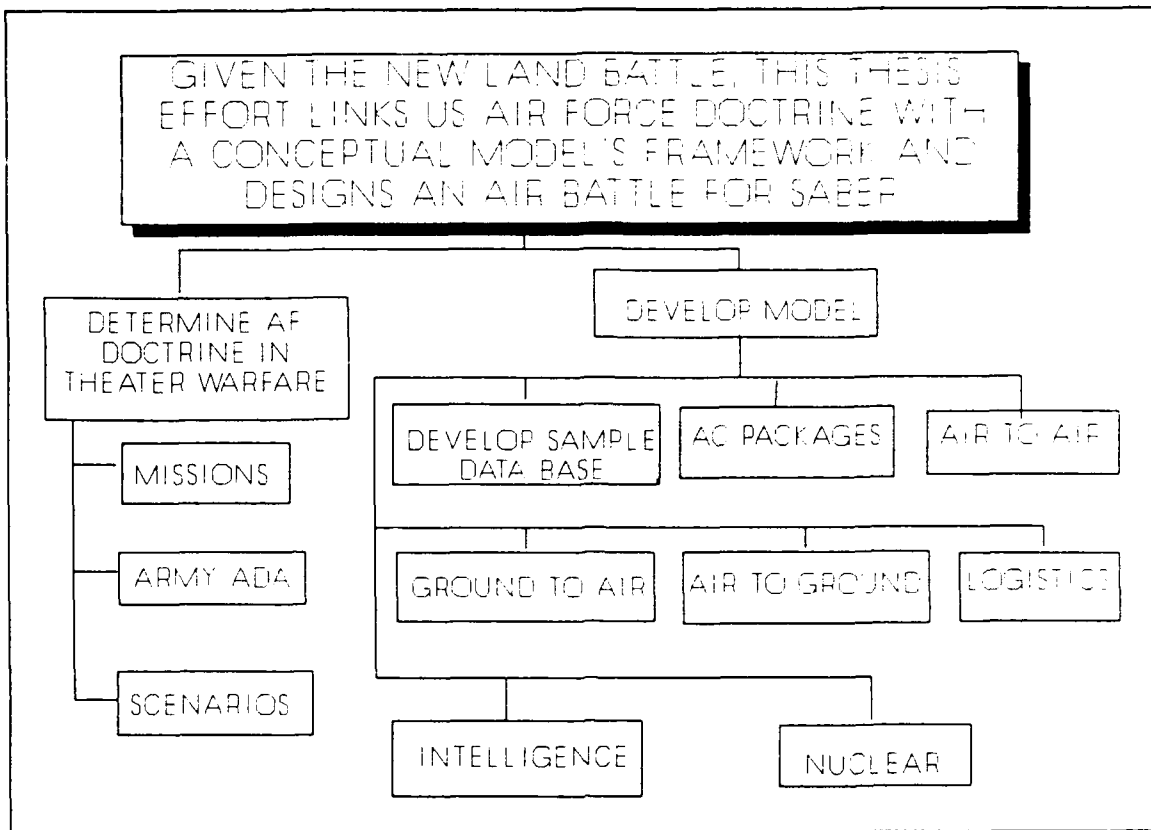
Figure 22. Study Matrix

Chapter VI describes the algorithms. The most important algorithms are the logistics, air-to-air combat, ground-to-air HIMAD and SHORAD processes, air-to-ground destruction of entities, and the effects of nuclear weapons. Chapter VII presents suggestions on the user interfaces, realizing that the packaging of the wargame is the most important part of player acceptability.

The algorithms provided are simple engineering models, readily available and unclassified. The extension of these models should not need major modifications.

8.2   Recommendations

A reminder from Dunnigan in his ten steps in developing a wargame (Dunnigan, 1980:236-239). These steps are:

1. Conceptual Development
2. Research
3. Integration of ideas into a prototype
4. Fleshing out the prototype (adding the chrome)
5. First draft of the rules
6. Game development
7. Blind-testing
8. Final Rules edit
9. Production
10. Feedback

Analyzing my work I am between steps 2 and 3. There is still a ways to go. Hopefully the Electrical and Computer Engineering Department will be able to develop the game.

The first areas of improvement are general ones brought out by James Taylor (Taylor, 1980:20). The process of enrichment of the details in order to better duplicate real-world combat can be done by:

1. making constants into variables,
2. adding more variables,
3. using more complicated (e.g., nonlinear) function relationships between variables,
4. Using weaker assumptions and restrictions, and
5. not suppressing randomness.

If the presented proposal is to difficult to model, then any of the above recommendations taken in reverse will simplify the model.

I only had 6 months, and it takes years to build a model.

So this is the start of the preliminary process. There are

several areas of concern that I wish to bring up from my research.

-There is no special school to teach how to conduct theater level warfare to the Air Force junior officers. How do they develop their skills? They seem to perform on the job training. This is opposite to the US Army training that teaches warfighting doctrine very early in the officer basic courses.

-There is a lack of material by the Air Force on their own warfighting doctrine. Some of the AF manuals date to 1978. There is also a dichotomy in their training system; the Air Force has a Warrior Prep program, and a lot of books on World War II, but this school has none of the Tactical Regulations on how the Air Force is supposed to fight. Even the Reserve Fighter Squadron on the base does not carry the tactical manuals.

Did I make a Type III error? That means did I solve the wrong problem? I talked to the Wargaming Center, but not to the teachers at the Air War College. Is this game fulfilling a need or has it been an academic exercise? What would have really helped in this thesis effort would be a paper from the Air War College on what they really desire from the Air Force Wargaming Center in terms of wargaming requirements.

-The last problem is the lack of information on the US

Air Force structure at the Wing and Squadron level. This information is very hard to get, and every unit seems to have an exception to the rule. There may be information available through the classified documents, but I did not pursue this direction in an attempt to keep this game unclassified. Making this thesis classified would have severely hampered the ability of the follow on thesis students to develop the computer simulation.

Additional thesis efforts are needed in :

Including naval warfare,

Adding an automated player support, especially for Red Players,

Developing measures of merit system to compare Blue players performance,

Making the land battle stochastic,

Adding the supply trains as entities that have to traverse the terrain, so that they can be fully affected by interdiction and terrain restrictions (i.e. mines and blown bridges),

Conducting sensitivity analysis on the prototype models,

Developing the full up data bases for this model.

Conducting in-depth research on the present Persian Gulf War to validate the warfighting doctrine applied in this thesis.

8.3 Conclusion

In conclusion, this thesis is the writing of the documentation before the writing of the computer code. It provides the hows and the whys to basic attrition warfare in a manner that future additions to the data base can be made with the basic understanding of how the entities' characteristics affect other entities. It is hoped that a credible and viable theater warfare computer wargame can be built from this foundation.

Appendix A.   Search Algorithm

ORIGIN $\equiv$ 1

w= Target Speed

W= The diameter of the searching sensor's detection area

t = Time of the target is the sensor's area

A = Area of search

U = Uniform random numbers from 0 to 1

$i := 1 \, .. 100$

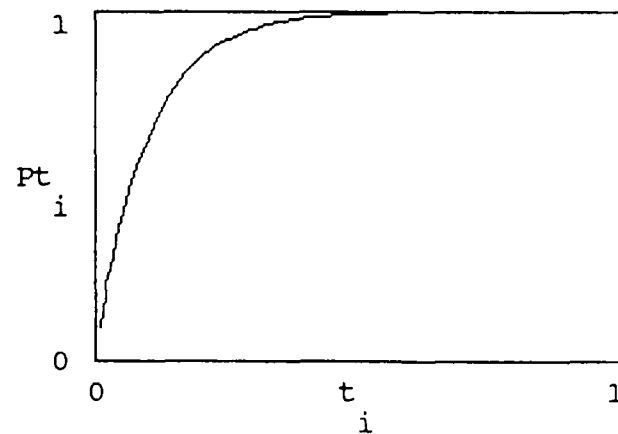|		
$w := 640$	kilometers/hour
$W := 60$	kilometers
$A := 541 \cdot 7$	Seven ground hexes at 25 km across
$t_i := .01 \cdot i$	Hours

$$C_i := \frac{-\left[w \cdot W \cdot t_i\right]}{A}$$

$$Pt_i := 1 - \exp\left[C_i\right]$$

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Now add Electronic Combat of a
 STEALTH FIGHTER which is assumed to be 10

EC := 10

$$Ptl_i := \left[\frac{1}{EC}\right] \cdot Pt_i$$
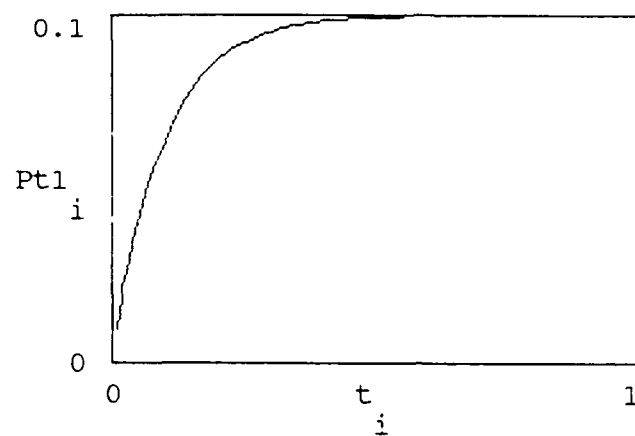
This is an example of trying to detect a
Fighter with an EC of 2

w = 640   kilometers/hour

t = 75 km at the point of the air hex
       divided by the speed of the aircraft

$$t := \frac{75}{640} \qquad t = 0.117188 \qquad Hours$$

W = 60   Sensor's detection area

A = 3787   Air hex's area in square kms

EC := 2   Electronic Combat

$$Pt := \left[\frac{1}{EC}\right] \cdot \left[1 - \exp\left[\frac{-w \cdot W \cdot t}{A}\right]\right]$$

Pt = 0.347627
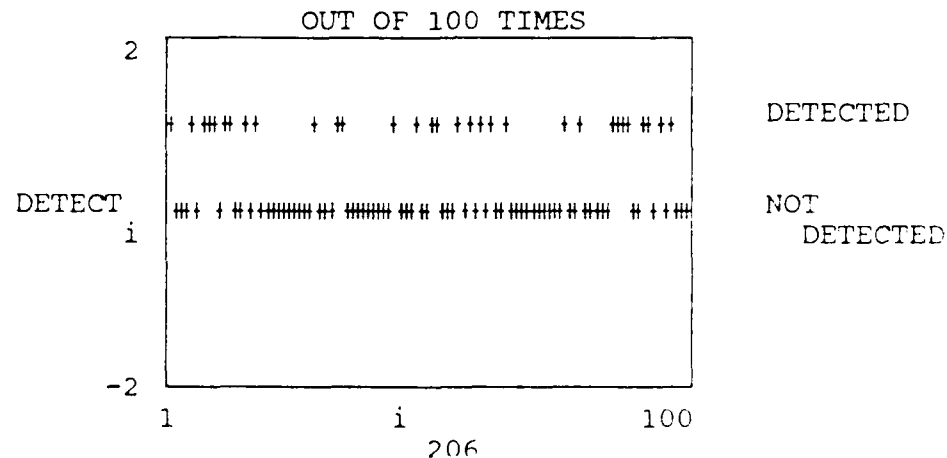
SO THE PROBABILITY
OF DETECTION IS .34

$U_i := rnd(1)$ 100 RANDOM NUMBERS

mean(U) = 0.505922

$$DETECT_i := \Phi\left[Pt - U_i\right]$$

$\Sigma DETECT = 32$

OUT OF 100 TIMES

ORIGIN ≡ 1

  SSPK = The single shot probability of
        kill for the missile
  AC = The number of target aircraft
  SHOOTERS = The number of TEL/Radar pairs
  MISSILES = The number of missiles fired
     per SHOOTER
  U = Uniform random numbers from 0 to 1

SSPK := .6   AC := 9   SHOOTERS := 6 MISSILES := 2

RDS := SHOOTERS·MISSILES
TOP := if(RDS ≤ AC,RDS,AC)   TOP = 9

i := 1 ..TOP U_i := rnd(1)

$$PK := 1 - (1 - SSPK)^{\frac{SHOOTERS \cdot MISSILES}{AC}}$$

PK = 0.705277

By Bernoulli trials we can find the
    number of hits and misses

$$U = \begin{bmatrix} 0.00126 \\ 0.193311 \\ 0.584999 \\ 0.350294 \\ 0.822826 \\ 0.174116 \\ 0.710488 \\ 0.303986 \\ 0.091406 \end{bmatrix} \quad \text{Random Numbers}$$

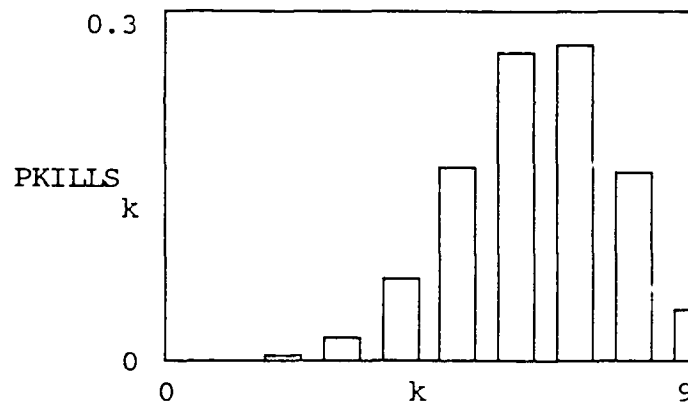$$HITS_i := \Phi[PK - U_i] \qquad MISS_i := \Phi[U_i - PK]$$

ΣHITS = 7   ΣMISS = 2

By the Binomial distribution, we can find
perform the same calculations

k := 0 ..TOP

ORIGIN ≡ 0

$$PKILLS_k := \frac{TOP!}{k! \cdot (TOP - k)!} \cdot PK^k \cdot (1 - PK)^{TOP-k}$$

$$PKILLS = \begin{bmatrix} 0.000017 \\ 0.000361 \\ 0.003459 \\ 0.019313 \\ 0.069323 \\ 0.165891 \\ 0.264655 \\ 0.271425 \\ 0.162381 \\ 0.043176 \end{bmatrix} \qquad \Sigma PKILLS = 1$$

$$U_1 = 0.193311$$

CUM_BINOMIAL$_k$:= 0   CUM_BINOMIAL$_0$:= PKILLS$_0$

CUM_BINOMIAL$_i$:= CUM_BINOMIAL$_{i-1}$ + PKILLS$_i$

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$$CUM\_BINOMIAL = \begin{bmatrix} 0.000017 \\ 0.000378 \\ 0.003837 \\ 0.023149 \\ 0.092472 \\ 0.258364 \\ 0.523018 \\ 0.794443 \\ 0.956824 \\ 1 \end{bmatrix}$$

$$BINOMIAL\_KILLS_k := \Phi \begin{bmatrix} U_1 - CUM\_BINOMIAL_k \end{bmatrix}$$

$$AIRCRAFT\_KILLED := \Sigma BINOMIAL\_KILLS$$

$$AIRCRAFT\_SURVIVED := AC - AIRCRAFT\_KILLED$$

$$AIRCRAFT\_KILLED = 5$$

$$AIRCRAFT\_SURVIVED = 4$$

ORIGIN ≡ 1

This example demonstrates that the probability
 of kill on aircraft by multiple missiles is
 greater than the SSPK when there are more
 miisiles than aircraft.

j := 1 ..10

$SSPK_j := .1 \cdot j$

AC := 60

SHOOTERS := 100   MISSILES := 2

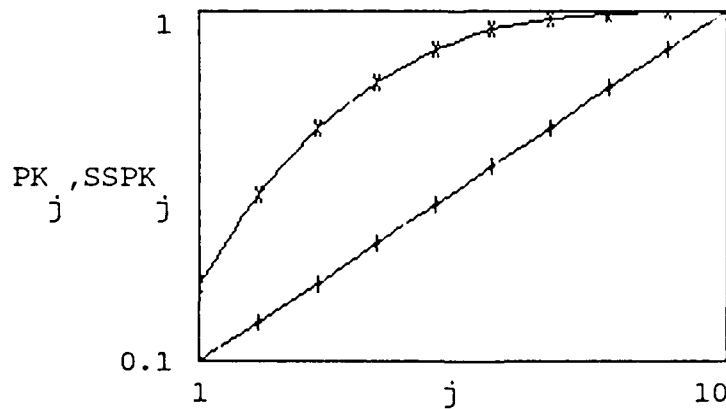RDS := SHOOTERS·MISSILES

TOP := if(RDS ≤ AC,RDS,AC)

TOP = 60   TOP keeps a cap on the maximum number of
            aircraft that can be killed.

i := 1 ..TOP

$$PK_j := 1 - \left[1 - SSPK_j\right]^{\frac{SHOOTERS \cdot MISSILES}{AC}}$$

PK is GREATER
than SSPK

This example shows that when there are less missiles than planes, the PK is less than the SSPK.

$$SSPK_j := .1 \cdot j$$

$$AC := 200$$

$$SHOOTERS := 30 \qquad MISSILES := 2$$

$$RDS := SHOOTERS \cdot MISSILES$$

$$TOP := if(RDS \leq AC, RDS, AC)$$

$$TOP = 60$$

$$i := 1 \text{ ..} TOP$$

$$PK_j := 1 - \left[1 - SSPK_j \right]^{\frac{SHOOTERS \cdot MISSILES}{AC}}$$
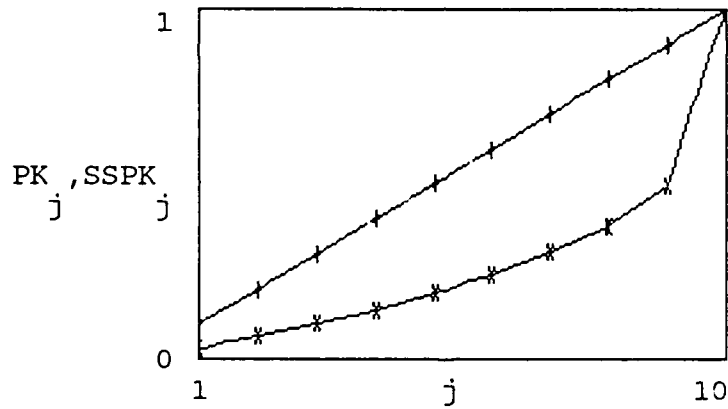
PK is LESS than SSPK

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Appendix C. Air-to-Air Combat

ORIGIN ≡ 1

4 BLUE AIRCRAFT VERSUS 4 RED AIRCRAFT

BLUEAC := 4   REDAC := 4

The combat ratings of the aircraft are listed below.

$$BLUE := \begin{bmatrix} 12 \\ 12 \\ 12 \\ 12 \end{bmatrix} \qquad RED := \begin{bmatrix} 10 \\ 10 \\ 6 \\ 6 \end{bmatrix}$$

BMANUEVER := ΣBLUE   BMANUEVER = 48

RMANUEVER := ΣRED   RMANUEVER = 32

$$BLUE\_PL := \frac{BMANUEVER}{BMANUEVER + RMANUEVER}$$

$$RED\_PL := \frac{RMANUEVER}{BMANUEVER + RMANUEVER}$$

BLUE_PL = 0.6

RED_PL = 0.4

BLUE AIRCRAFT FIRE 2 MISSILES EACH

$$BMISSILES := \begin{bmatrix} .8 \\ .8 \\ .8 \\ .7 \\ .7 \\ .8 \\ .8 \\ .8 \end{bmatrix}$$

mean(BMISSILES) = 0.775

BRANGE := 20   BMISSILE := 2

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RED AIRCRAFT FIRE 2 MISSILES EACH

$$RMISSILES := \begin{bmatrix} .6 \\ .6 \\ .4 \\ .4 \\ .5 \\ .5 \\ .4 \\ .6 \end{bmatrix}$$

mean(RMISSILES) = 0.5

RRANGE := 16   RMISSILE := 2

SSPKbr := BLUE_PL· mean(BMISSILES)   SSPKbr = 0.465

SPKrb := RED_PL· mean(RMISSILES)   SSPKrb = 0.2

$$PKbr := 1 - (1 - SSPKbr)^{\frac{BLUEAC \cdot BMISSILE}{REDAC}}$$

PKbr = 0.714

$$PKrb := 1 - (1 - SSPKrb)^{\frac{REDAC \cdot RMISSILE}{BLUEAC}}$$

PKrb = 0.36

Once the PKs are obtained, one can use
the Binomial distribution to determine
the number of kills.

i := 0 ..BLUEAC   j := 0 ..REDAC   ORIGIN ≡ 0
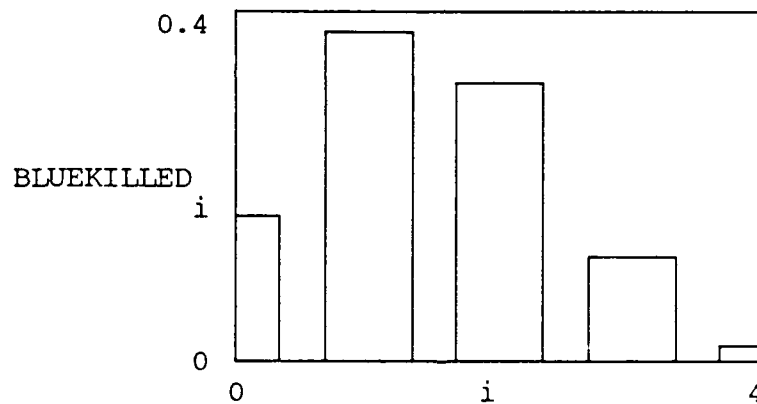
 BLUE AIRCRAFT

$$BLUEKILLED_i := \left[\frac{BLUEAC!}{i! \cdot (BLUEAC - i)!}\right] \cdot PKrb^i \cdot (1 - PKrb)^{BLUEAC-i}$$

$$BLUEKILLED = \begin{bmatrix} 0.168 \\ 0.377 \\ 0.319 \\ 0.119 \\ 0.017 \end{bmatrix}$$
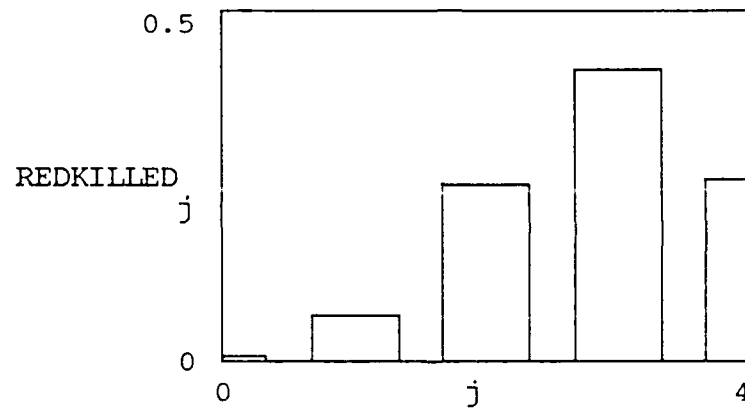
ΣBLUEKILLED = 1

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RED AIRCRAFT

$$\text{REDKILLED}_j := \left[\frac{\text{REDAC}!}{j! \cdot (\text{REDAC} - j)!}\right] \cdot \text{PKbr}^j \cdot (1 - \text{PKbr})^{\text{REDAC}-j}$$

$$\text{REDKILLED} = \begin{bmatrix} 0.007 \\ 0.067 \\ 0.25 \\ 0.416 \\ 0.26 \end{bmatrix}$$

$\Sigma\text{REDKILLED} = 1$

k := 1 ..BLUEAC

$CUM\_BINOMIAL\_BLUE_i := 0$ $CUM\_BINOMIAL\_BLUE_0 := BLUEKILLED_0$

$CUM\_BINOMIAL\_BLUE_k := CUM\_BINOMIAL\_BLUE_{k-1} + BLUEKILLED_k$

$$CUM\_BINOMIAL\_BLUE = \begin{bmatrix} 0.168 \\ 0.545 \\ 0.864 \\ 0.983 \\ 1 \end{bmatrix}$$

$CUM\_BINOMIAL\_RED_i := 0$ $CUM\_BINOMIAL\_RED_0 := REDKILLED_0$

$CUM\_BINOMIAL\_RED_k := CUM\_BINOMIAL\_RED_{k-1} + REDKILLED_k$

$$CUM\_BINOMIAL\_RED = \begin{bmatrix} 0.007 \\ 0.074 \\ 0.324 \\ 0.74 \\ 1 \end{bmatrix}$$

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Now draw two random numbers

$l := 1 .. 2$

$U_l := rnd(1)$ $\qquad U_1 = 0.001 \qquad U_2 = 0.193$

$BLUE\_KILLED_i := \Phi\left[U_1 - CUM\_BINOMIAL\_BLUE_i \right]$

$BLUE\_AC\_KILLED := \Sigma BLUE\_KILLED$

$BLUE\_AC\_SURVIVED := BLUEAC - BLUE\_AC\_KILLED$

$BLUE\_AC\_KILLED = 0$

$BLUE\_AC\_SURVIVED = 4$

$RED\_KILLED_i := \Phi\left[U_2 - CUM\_BINOMIAL\_RED_i \right]$

$RED\_AC\_KILLED := \Sigma RED\_KILLED$

$RED\_AC\_SURVIVED := REDAC - RED\_AC\_KILLED$

$RED\_AC\_KILLED = 2$

$RED\_AC\_SURVIVED = 2$

Appendix D. Air-to-Ground Attack
Using Circular Error of Probability (CEP)

ORIGIN $\equiv$ 1

CEP := 15 meters

$$\sigma := \frac{CEP}{1.1774}$$

σ = 12.74   meters

SQUARE TARGET   a := 10

Thw size of the target are 2a X 2a

$$PH := 1 - \exp\left[\frac{-2 \cdot a^2}{\pi \cdot \sigma^2}\right] \qquad PH = 0.324$$

RECTANGLE TARGET   a1 := 20   b1 := 20

The size of the target is 2(a1) X 2(b1)

$$PH1 := \left[\left[1 - \exp\left[\frac{-2 \cdot a1^2}{\pi \cdot \sigma^2}\right]\right] \cdot \left[1 - \exp\left[\frac{-2 \cdot b1^2}{\pi \cdot \sigma^2}\right]\right]\right]^{.5}$$

PH1 = 0.792

CIRCULAR TARGET   r := 22.5

The target has a radius of r

$$PH2 := 1 - \exp\left[\frac{-r^2}{2 \cdot \sigma^2}\right] \qquad PH2 = 0.79$$

Now compare the PH to random numbers
from a uniform random distribution to
determine the number of hits. This is
througha series of Bernoulli trials or
a Binomial distribution.

Once the number of hits are determined,
a fraction of the Area target is destroyed,
 (such as a DEPOT or RUNWAY) by using:

AREA OF EFFECTIVENESS: In square meters   AE := 20
     OR LETHALITY

AREA OF THE TARGET: In square meters   AT := 400

NUMBER OF HITS FROM BERNOULLI OR BINOMIAL   HITS := 3

$$\text{FRACTION\_NOT\_HIT} := \left[1 - \left[\frac{AE}{AT} \right] \right]^{\text{HITS}}$$

FRACTION_NOT_HIT = 0.857

FRACTION_DESTROYED := (1 - FRACTION_NOT_HIT)

FRACTION_DESTROYED = 0.143

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