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SABER: AIRLAND COMBAT TRAINING MODEL

Credibility Assessment and Methodology

THESIS

David L. Scagliola
Captain, USAF

AFIT/GST/ENS/92M-06

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This thesis focuses on the progress made towards generating the Saber training model, its ability to meet the objectives specified by the Wargaming Center, and its ability to represent actual combat. Specifically, this thesis is directed towards characterizing, establishing a credibility assessment, and developing a methodology for the Saber model, reflecting its present stage of development.

This thesis develops an understanding of the potential of the Saber model, provides documentation needed for future verification and validation efforts, and provides an airland methodology that explains how Saber could be integrated into an airpower employment training exercise at the Air Force Wargaming Center. This thesis also provides a structured approach for accomplishing a credibility assessment, on combat models used for training and education.

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SABER: AIRLAND COMBAT TRAINING MODEL

Credibility Assessment and Methodology

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

Masters of Science in Operations Research

David L. Scagliola B.A

Captain, USAF

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Preface

The goal of this thesis was to determine the status of the first version of the Saber AirLand Combat Training Model being developed for and sponsored by the Air Force Wargaming Center, Maxwell AFB, AL. The development of Saber is the result of at least five previous thesis efforts and this thesis effort concentrated on consolidating the previous individual efforts into a single document.

This thesis also accomplished a credibility assessment of the Saber model and described an airland methodology. The credibility assessment was accomplished to determine if Saber could realistically model a theater-level combat environment, and the airland methodology explained how Saber could be integrated into a tactical employment training seminar. Hopefully, the documentation and effort that went into this thesis will be of considerable benefit to the Air Force Wargaming Center and the United States Air Force.

I would like to thank my thesis advisors, Major Mike Garrambone and Major Mark Roth for their assistance and demonstrated expertise in the areas of combat modeling and computer simulation. Thanks is also given to my reader Colonel Thomas Schuppe for shedding some light on the big picture. Special thanks is also extended towards Lt Col Paul Butalla and Major Roger Wolczek for their assistance in providing answers to the many questions asked about the role and responsibilities of the Air Force Wargaming Center.

Most of all I want to thank my family who have been so very supportive for the past 18 months and especially during the development of this thesis. My wife Maria showed great patience and understanding with regards to the mess I made in "her" house and accomplished a disproportionate number of the household duties, so I could devote more time to my studies. My daughter Meghan was also wonderful and quickly learned that daddy's blank stare was a result of thinking too hard and not a genetic flaw, she also accepted that when daddy was at the computer he was about as responsive as a brick wall.

SABER: AIRLAND COMBAT TRAINING MODEL

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Abstract

Saber is a theater-level, two-sided, multiple scenario, airland combat training model, being designed by a number of computer and engineering students and faculty at the Air Force Institute of Technology (AFIT). The Saber program is intended to replace the Agile model, which is currently used at the Air Force Wargaming Center, Maxwell AFB, Alabama for Theater Warfare Exercise (TWX) training purposes.

This thesis effort focuses on the progress made towards generating the Saber airland combat training model, its ability to meet the objectives specified by the Wargaming Center, and its ability to represent actual combat. Specifically, this thesis is directed towards characterizing, establishing a credibility assessment, and developing a methodology for the Saber model consistent with its present stage of development.

This thesis develops an understanding of the potential of the Saber model, providing documentation needed for any future verification and validation efforts, and providing an airland methodology that explains how Saber could be integrated into an airpower employment exercise to train senior Air Force and allied officers at the Air Force Wargaming Center. This thesis also provides a structured approach for accomplishing a credibility assessment on combat models used for training and education.

SABER: AIRLAND COMBAT TRAINING MODEL

I Introduction

Saber is a theater-level, two-sided, multiple scenario, Airland combat training model, being designed by a number of computer and engineering students and faculty at the Air Force Institute of Technology (AFIT). The Saber program is intended to replace the current airpower employment training model, called Agile, that is used during the Theater Warfare Exercise (TWX) at the Air Force Wargaming Center, Maxwell AF. . abama. This thesis effort focuses on the progress made towards generating the Saber AirLand combat training model, its ability to meet the objectives specified by the Wargaming Center and its ability to represent actual combat. Specifically, this thesis is directed towards establishing an assessment and methodology of the Saber model in its present stage of development.

1.1 Background

The Theater War Exercise (TWX)/Agile is a computer generated combat training scenario that was created in compliance with a directive from 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" (Mann:3). The Wargaming Center at Maxwell AFB, is responsible for the design, development and maintenance of a number of computerized wargames, including TWX/Agile. The TWX/Agile wargame was designed specifically to introduce and educating senior Air Force officers to the decision making processes required in applying the principles of airpower towards the arts of operations, warfare and planning.

The original model, written in 1977 and programmed in FORTRAN, did not provide much flexibility in the areas of scenario development or interpretation of results. At the end of the exercise, instead of having consolidated output, the students were presented with reams of data to decipher. The need to sift through this mound of paperwork was time consuming, and often lead to both student frustration, and questions relating to the validity or worth of the exercise; although, some would argue that it was meant to be a massive paper war. In 1987 the TWX was modified to run on PC based computers. The conversion to PCs also led to changing the name of the exercise from TWX to Agile. Agile proved to be more user friendly than the original TWX, but the basic design and concepts remained the same.

An update of the TWX was made in 1990, which incorporated a new land battle, programmed in Ada. Switching the land battle to the Ada language provided the players with multiple scenario options, a program that is almost self-documenting and a program that is easier to maintain (Ness:81). Unfortunately, the potential of this update could not be fully exploited because it was linked with the older air battle module and this version has never been used.

In 1991, work was done to create the conceptual framework for an air module based on current Air Force doctrine, and to include this module in the wargame. The concept of integrating the air and land aspects led to the development of the Saber AirLand Combat model (Mann:5). To date, there have been no fewer than five thesis efforts dedicated to the conceptual design and development of the Saber AirLand Combat Training Model.

At this time the Saber model is not complete; although a good deal of effort has been devoted to developing the framework and eventual structure of the model. Previous efforts have been devoted to 1) the conceptual design of the model, 2) the software design for the system simulation, 3) the user interface programs, 4) the database design, 5) a graphics package, and 6) an animation program.

1.2 <u>The Problem</u>

Although the concepts of the AirLand battle, along with its conceptual design and algorithms, have been documented, the computer model has not been integrated or tested. The purpose of this thesis is to determine the present status of this first version of the Saber model, to characterize and develop an assessment of the model, perform verification and validation on its completed sections, identify its strengths and weaknesses, recommend changes to enhance the model if needed, document the model operation, and record or recommend changes to the computer code as necessary.

1.3 Objectives

There were three major objectives to this thesis effort. The first objective was to characterize the model, i.e. to identify, document, and define the scope and intentions of the Saber model. The second objective involved developing an assessment of the Saber model. This assessment is accomplished by examining the Saber model's fundamental concepts and determining if they are consistent with present military doctrine. By having a model that is doctrinally sound, a credible foundation will be available upon which to work. The third objective of this thesis involved combining the previous five thesis efforts that have lead to the development of the Saber model into one comprehensive document. Combining these theses generated the Saber AirLand Battle Methodology and provides a better understanding of the model and explains how Saber attempts to reflect the true nature of combat using airland battle doctrine.

The accomplishment of these three objectives, in most cases, occurred simultaneously. To accomplish these objectives the following actions were taken:

1. Identify the assumptions driving the model, and document their source.
2. Identify the desires, needs and requirements established by the Wargaming Center in relation to model operation.
3. Determine if the scenario is adequate and appropriate.
4. Ensure the model documentation, operating instructions and manuals are 1) available; 2) complete; and 3) understandable at the user level.
5. Examine the database structure as well as its content.
6. Ensure the model coding and algorithms are correct or can be justified.
7. Make sure the simulation decision and logic routines have a rational flow.

1.4 Assumptions

Four major assumptions were identified and accepted as part of this thesis effort. The first assumption is that the coding of the simulation is consistent with current programming practices of the Ada language, i.e. the structure, design, and programming style are 'optimal'. The second assumption is that the database is structured and designed in accordance with the requirements of the simulation. The third assumption is that formal testing, or follow-on verification and validation, will be accomplished at the Wargaming Center. The forth assumption is that the material presented in past theses efforts, devoted to the development of Saber, has been reviewed and is an accurate representation of the intent, goal, present status and other specifications of the Saber AirLand Combat model.

1.5 Scope and Limitations

Figure 1 is an illustrations that identifies the components needed in the construction of a 'typical combat model' and has been used to divide the efforts that have been devoted to the development, concept and design of the Saber model.

The Wargaming Center is the sponsor of the Saber model and provided the purpose, a need, the environment, and the proposed scenario data. Horton designed the database management system (DBMS), which structures the initial scenario, weapons, unit, and terrain data into a format that can be used by the simulation. He also designed the screens for the graphical user interface to accept player inputs (Horton).

Developing the present simulation required the efforts of three individuals. Ness created the Land Battle that was intended to be an improved version of Agile (Ness). Mann suggested changes to Ness' effort and developed a conceptual framework for an AirLand Battle (Mann). Sherry integrated the ideas of Mann and Ness and started the design of an object-oriented simulation. Sherry also enhanced some of Ness' design in an effort to more closely model an airland battle. Some of the specific changes included 1) the

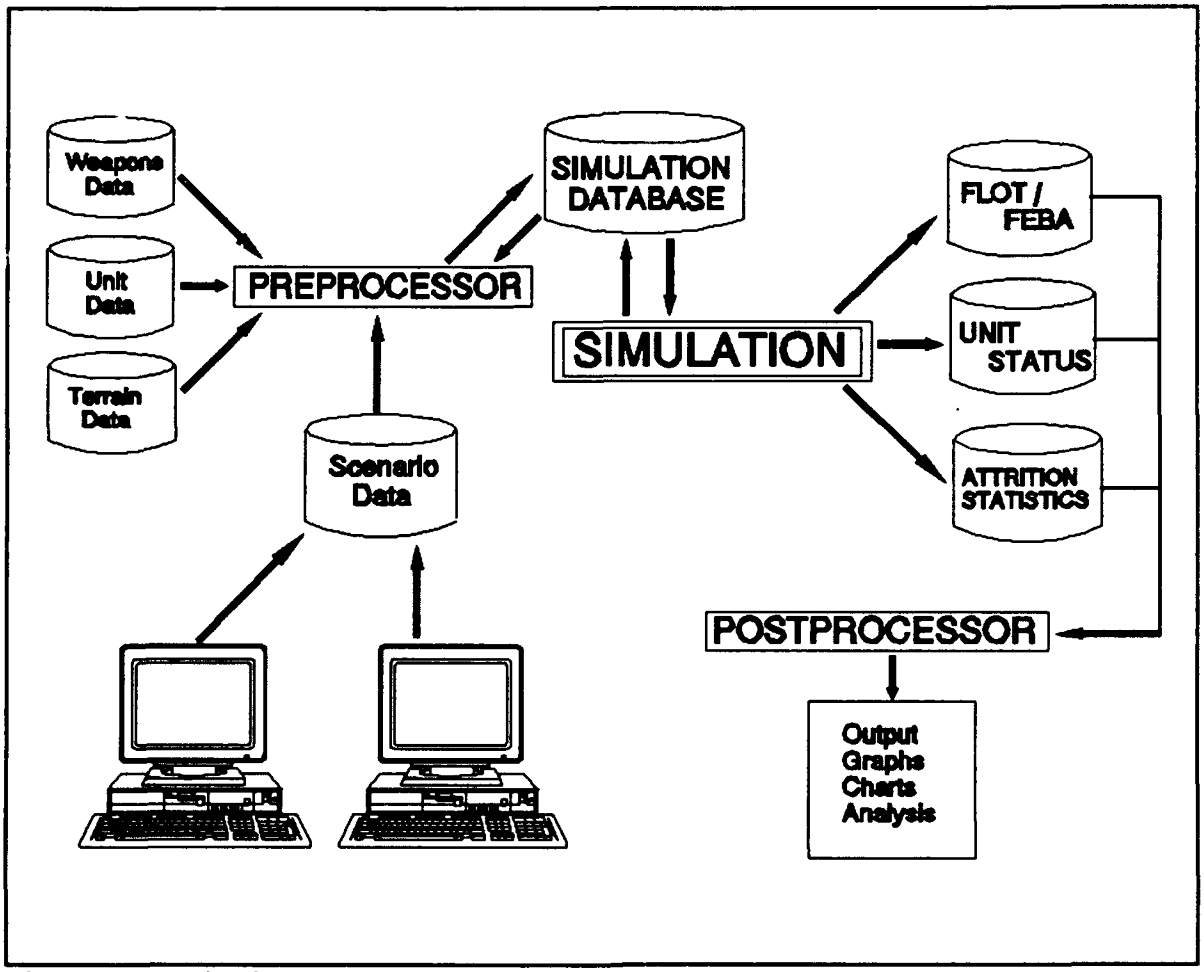

Figure 1 Typical Combat Model (Mann)

addition of a history file, 2) the capability to have more than one obstacle in a hex, 3) the ability to target obstacles, such as a bridge, road, railroad, or pipeline, and 4) the ability of a unit to target more than one other unit (Sherry). Unfortunately, there was not sufficient time available to complete all of the coding required for the simulation.

Klabunde designed the graphical post processor that provides a visual interpretation of the wargame. The graphics package provides access to Horton's user interfaces design screens and allows end of day reports to be viewed on screen. The graphics package also includes an animation feature that allows the players to view combat interactions as the wargame unfolds (Klabunde).

There are portions of the Saber model that still need to be completed. Specifically, the two items that will require follow-on efforts are 1) the completion of the model simulation, 2) the development of a post processor to generate output reports, charts, and analysis information.

The scope of this thesis is to combine the information contained in the previous theses effort into a comprehensive document that characterizes the Saber model. This thesis will not develop any Ada code or attempt to complete any sections of the model; although suggestions and recommendations will be included in an effort to enhance the model and/or explain how to complete those sections requiring additional attention.

1.6 Intentions

The Wargaming Center at Maxwell AFB, is the sponsor of the Saber AirLand Combat Model and will be its primary user. The Wargaming center is very much interested in receiving a theater level model that is fast (four hours maximum between input and analysis); contains sufficient detail to be representative of theater level warfare; is not difficult to use; and is flexible enough to provide for future developments and improvements in weapons systems and tactics.

It is the intention of this thesis effort to examine the present status of the Saber model and to determine if Saber is capable (or has the potential) to provide the needs and meet the goals established by the Air Force Wargaming Center.

1.7 Thesis Overview

Chapter II is a literature review that provides an understanding of the individual and aggregated aspects of an airland combat model and the generation of computerized wargames. Chapter III outlines the methodology used to assess the credibility of the Saber model. Chapters IV, V, and VI, respectively examine the three primary areas of concern when assessing the credibility of a model. Chapter VII is devoted to the development of the airland methodology. And finally, Chapter VIII contains recommendation for the improvement and/or enhancement of the Saber model, as well as a summary and the conclusions of this thesis effort.

II Literature Review

2.1 Introduction

The purpose of this chapter is to identify and describe some of the literature available concerning an airland combat model and the development of wargaming models in general.

The specific topics to be discussed are 1) model credibility and accreditation, 2) Airland battle and military doctrine 3) force allocation, strategy and tactics, 4) scenario development, 5) building wargames, 6) mathematical models, 7) theater level warfare models, and 8) problems with theater models.

2.2 Model Credibility and Accreditation

"Accreditation is convincing those in authority that you built the right model right" (Harrison:6). Credibility is a measure of the confidence the user has in the model, that it is able to provide answers to the questions asked. Both of these concepts are dependent on verification and validation.

Verification and validation can have different meanings, depending on the reference source. For the purpose of this thesis, the meaning and scope of verification and validation are being established as follows:

2.2.1 Verification. Verification is ensuring the following items are consistent with current Air Force and Army doctrine, concerning an airland battle (Garrambone):

- assumptions;
- scenario development;
- documentation and operating manuals;
- database design;
- computer coding, logic and algorithms;
- simulation flow.

The intent of verification, to ensure the model is properly constructed, is considered a two part process. The first part, called logical verification, is the process of reviewing the individual mathematical equations and algorithms to ensure they are correct. The second part, code verification, is an examination of the code to ensure the equations, algorithms and overall flow of logic are implemented correctly in the computer program (Williams:4).

2.2.2 Validation. The objective of validation is to test the model to determine if the output is consistent with established concepts of combat, based on (Garrambone):

- historical data;
- field experiments and tests;
- comparison with other models;
- empirical judgement;
- expert opinion.

Validation can be considered the process of determining if the right model was built. The purpose of validation is to ensure that the model is able to accurately represent the actual environment within the constraints of not actually being there. In other words, validation is used to ensure there are no gaping holes between the model and the real world it is intended to represent.

Validation is important in every phase of model development, from the initial assumptions and documentation to comparisons with laboratory data, field exercises and independent review.

Documentation and model configuration are an integral part of the accreditation, verification and validation process and the credibility issue as well. Without documentation and an understandable model layout, attempts at verification and validation are generally confounded, and the credibility of results may be suspect. Additionally, all attempts at verification and validation need to be included in the documentation as an aid in further analysis (Williams:5).

2.3 AirLand Battle and Military Doctrine

The philosophy of the AirLand Battle concept continues to evolve. Until recently the Army directed most of its effort into defeating the enemy in and around the small area of actual conflict called the Forward Edge of the Battle Area (FEBA). Traditionally, the Army's primary area of concern was with progress being achieved by their Forward Line of Own Troops (FLOT). The Army of today is developing a doctrine that envisions a "target rich but asset limited" battlefield that extends far beyond the FEBA and FLOT (Schoenstadt:1). The Army, and the other services, recognize that conflicts of the future will involve the efforts of joint and, probably, combined armies. The traditional massed firepower and maneuver of the Army combined with the fluid, punishing effectiveness of airpower will be the cornerstone of future military engagements and the projection of power. The joint interface between the Army and Air Force needs--and continues--to evolve along with this new concept of AirLand Operations (LeGare:3-8).

AirLand Battle operations can be effectively modeled at the theater level of interaction by conducting exercises or by using wargames. Wargaming at the theater level usually involves two forces--respectively called blue and red. Typically the doctrine of the blue force resembles that of the US military, while the red force is modeled after the--former--Soviet military.

There is no single source or document which specifies the airland doctrine of the US military and the interaction of forces in combat; although general concepts are available when the different sources are combined. General Curtis E. LeMay stated the importance of doctrine and its relation to other aspects of warfare by writing,

> At the very heart of warfare lies doctrine. It represents the central beliefs for waging war in order to achieve victory. Doctrine is of the mind, a network of faith and knowledge reinforced by experience which lays the pattern for the utilization of men, equipment, and tactics. It is the building material for strategy. It is fundamental to sound judgement.

The basic doctrine of air warfare is to achieve freedom of action and control of the air environment; this intent implies that gaining air superiority is the primary goal of the air forces. Gaining air superiority is essential in accomplishing the overall mission of protecting ground forces and ensuring unincumbered surface operations (Ness:13).

US Army Field Manual (FM) 100-5 is the primary manual for describing Army doctrine. Unfortunately, this manual is not complete, and it concentrates primarily on an airland battle associated with a conventional conflict in Europe (Metz:32).

Offensively, Soviet doctrine is similar to that of the US in that its primary objective is to achieve air superiority. Defensively, Soviet doctrine emphasizes an overlapping defense in depth concept, provided by a variety of long, medium and short range surface-to-air missile (SAM) and anti-aircraft-artillery (AAA) systems. Although US defensive systems are assessed to be better overall than those of the Soviets, any lack in capability is made up for by the variety and number of weapon systems fielded.

2.4 Force Allocation Strategy and Tactics

Historically the analysis and modeling of strategic and tactical fighter forces has been woefully inadequate (Goodson:2). The primary deficiency in theater-level modeling is caused by not taking into account, ignoring, over or underestimating, or viewing as a constant the reactions of a rational, cognizant, and relatively intelligent opponent to changes in the combat environment. In reality, the reactions of an opponent determine the two most critical components of any battle - Force Allocation Strategy and Tactics Selection (Goodson:2-8).

Force Allocation Strategy is the allocation of each unit to the tasks that need to be accomplished throughout the engagement. Tactics involves using your forces to their full advantage while denying the enemy the chance of exploiting your weaknesses in accomplishing a military objective.

The relationship between strategy and tactics is best explained by the following quote.

> If one knows the total future military potential of the aircraft and the worth of the target in the same units, then one can readily make a correct choice in tactics. Unfortunately, the future military potentials of the aircraft and the worth of the targets are not values which can be simply made up. They depend most strongly on how the forces are used -- on the allocation strategy! One simply cannot make a rational choice of tactics in a vacuum. (Goodson:6)

With the concepts of force allocation strategy and tactics in mind, a concerted effort will be made to ensure the strategy and tactics incorporated into the Saber model are appropriate to the situation and scenario development.

2.5 Scenario Development

TRADOC Regulation 71-4 is used to establish general guidelines for the use and development of scenarios and scenario related material in support of studies and analysis. The TRADOC regulation gives a formal definition of scenario by stating

> a) A scenario is a graphic and narrative description of the area, environment (geographic setting, means (political, economic, social and military), and events of a hypothetical conflict during a future time frame.
> b) It reflects currently approved assumptions; the red, blue and unaligned force structures; terrain; weather; operational art; and tactics...[and]
> c) A scenario portrays approved doctrinal and operational concepts in selected situations under simulated conditions. (TRADOC:3)

The purpose of a scenario is to define the "setting and scope of player decisions". The components of a wargame scenario include "[relevant] background information, the objectives [and/] or [assigned] missions, [available] resources, command relationships [and], planned modifications to any of the above". A scenario should not contain information that is not relevant to the current situation or environment (Perla:29).

The TWX was designed as a conventional battle centered in Europe. The recent disintegration of the Soviet Union and the deterioration of the Warsaw Pact have made the probability of a massive, high intensity conflict in Europe very unlikely. Events such as those in Iraq and Panama that required the rapid deployment of forces will probably be more typical of the types of conflicts the US is likely to face in the future (Rozman:74). Due to the decreased likelihood of a major conflict in Europe, the developers of the Saber model have chosen Korea as the scenario for the initial development, testing and play; although the red forces will still be modeled using Soviet equipment, doctrine and tactics.

2.6 Building Wargames

James Dunnigan is a recognized authority in commercial wargame development and design. His two basic rules for designing a wargame are to 1) keep it simple and 2) to plagiarize (Dunnigan:235-236). Dunnigan does not use the word plagiarize to mean steal the ideas of someone else but rather to use what is known and build a new wargame based on generally available and tested information. In essence, Dunnigan sees little sense in reinventing the wheel. He recommends keeping the wargame simple as a method of keeping the process understandable. An overly complicated model often clouds the important issues with unnecessary clutter, or distractions. Dunnigan recommends a ten step process for the development of a wargame (Dunnigan:236-239). These steps are

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

Although this list is intended as a guide to the commercial development of a wargame, the steps are equally valid for the single production of the Saber model.

2.7 Mathematical Models

This section discusses the difference between deterministic and stochastic computations, and the need to keep equations simple.

When there is relatively little uncertainty in a problem, a deterministic (previously determined, average or expected) value is often used to compute the outcome of an event. The advantages of using a specific value are that only one iteration of the function is required to get an answer, the answer will be the same every time, and the algorithm can be simplified, which usually results in less computer time and associated computer costs. Stochastic techniques (such as Monte Carlo random draws), on the other hand, are ideally suited for situations in which there is considerable uncertainty or variability in the outcome of an event. The primary advantage of a stochastic simulation is that "the variability of the parameters [is taken] directly into account, thereby achieving a measure of the resulting uncertainty in the output" (Bouton:267). Although stochastics techniques increase the complexity of a model, they are able to give a better representation of real life events. For example, suppose it usually takes between 1/2 and 1 1/2 hours to refuel an aircraft. Using a deterministic model, a value representing one hour would be used for the refueling time. In a stochastic model, assuming a uniform distribution, any value between 1/2 and 1 1/2 is equally likely. If a simulation or model is run many times, the average or expected value will be nearly the same for both the deterministic and stochastic models. However, the variability between refueling times is much more apparent, and more representative of real life, when a stochastic technique is used.

One of the primary reasons a wargame is computerized is to relieve players from the tedium of mathematical manipulation, so they can concentrate on the important issues of the game. The Saber model, like most other wargames, uses many mathematical equations and algorithms to compute probabilities and expected values within its submodules. A good deal of emphasis will, therefore, be placed on ensuring the equations, formulas and algorithms used within the model are rational (used in the correct context) and are as accurate as possible.

Keeping the mathematical equations and algorithms simple and understandable will greatly facilitate the validation process. The following quote supports the notion and identifies the benefits of keeping the model simple.

> While there are dangers in oversimplifying the model, in a general sense it is better to be simple. Complicated formulas, or relationships so involved that it is impractical to reduce them to a single expression, are likely to convey no meaning at all, while a simple, though possibly approximate, relation may be easily understood. A major error may invalidate the more complicated expression and, yet in the general complexity of the formulation pass unnoticed. In uncomplicated expressions, [on the other hand], serious error is apt to become

> obvious long before computation is completed, because the relationship may be simple enough to reveal whether or not the behavior of the model is going to be reasonably in accord with intuition. The most convincing analysis is one which the nontechnician can think through. (Quade:353-354)

In other words, even if an equation is eloquent and quite precise it may not be the best equation to used if it can be replaced by one that is far more simple and nearly as accurate. There are not many things worse than being absolutely wrong with great precision (Meyer:3).

2.8 Theater Warfare Models

The Headquarters US Air Force Wargaming Review Group was established in 1984 and assigned the task of ensuring,

> a cohesive Air Force approach [was being taken] in satisfying operational wargaming systems requirements. As a result of the group's findings that year the Directorate of Operations for the Air Force Deputy Chief of Staff was made the executive agent for Air Force war-gaming policy, requirements, concepts of operation, and budgets. The same year saw the creation of the Air Force Wargaming Center, at Maxwell AFB Alabama, whose mission is to plan and conduct war games in support of USAF educational and operational requirements. (Lee:44)

The Theater Warfare Exercise (TWX), is one of many wargames the Wargaming Center is chartered to maintain.

Simulated warfare models are usually designed to operate in one of three combinations of geographic location and levels of warfare. These three categories include local/tactical, theater/operational and global/strategic (Perla:7).

> Theater/operational games are usually designed to explore specific issues and identify strategic, operational, and tactical problem in the theater. Often they point out areas in need of further study.
>
> Theater/operational games may be the level of game most usefully and most frequently employed for many research areas. They are used to "preplay" or test plans, from exercise plans to fleet [or combined army] war plans.
>
> When well designed, such games force participants to deal with the same situations they might face in actual operation. They allow commanders and their staffs the chance to explore why and how their plans might be able to deal successfully with the problems they have perceived and also provide fertile ground for identifying unforseen difficulties and unexpected solutions. (Perla:8)

There are many advantages to theater warfare models and wargames in general. Some of the advantages of wargames include

1. their ability to make people think about warfare;
2. they provide a (nonlethal) threat environment to test decision and planning abilities;
3. new ideas can be tried without risking lives;
4. they can be much less expensive than an actual field exercise;
5. their ability to compress, or expand, time so the players can focus on important events;
6. they are not restricted by international boarders, safety of flight rules or environmental constraints (Lee:44-45).

2.9 Problems with Theater Wargames

Although there are many advantages to using wargames and combat models, there are also some limitations, problems and pitfalls to be aware of. This section provides some insight into the disadvantages of combat models and wargames.

At the user, student or instructor level of game interaction, there are some dangers to become aware of. The following are some of the dangers of wargaming:

1. Wargames are designed to give the illusion of reality. Generally, the better the wargame is, the better it represents reality. The fact is, however, there are many variables and unknowns that are estimated or ignored when a model is put together that contribute to the outcome on a particular event. The danger in believing a model is an exact representation of reality is that the student will tend to believe the output is factual and discount any of the underlying assumptions.
2. There is no threat of death in a wargame. The objective of most wargames is to win, usually without regard to the price of victory. In an actual combat environment, however, decisions might be quite different when it is realized that a bad decision could lead to the loss of life.
3. The weaknesses of the computer model can be exploited. If the inherent idiosyncracies of a model are discovered, events can be manipulated to the advantage of the player. The danger in exploiting the model is that a good deal of effort is then directed towards beating the machine, while the value of the game, as a learning tool, is lost.
4. Wargames are often designer dependent and create mindsets. Most wargames are designed with a limited set of objectives to concentrate on. The danger in developing mindsets is that, when confronted with

the actual problem, the player might limit the range and scope of the problem and ignore some important issues.

5. Wargames can be taken too seriously or not seriously enough. Ideally, a wargame should be used as a learning tool - to gain insight. If a wargame is taken too seriously players get the impression that outcomes are predictive and there are strict bounds on right and wrong. If the game is taken too lightly, they usually end up being little more than a waste of time and effort (Perla:14,Lee:44-45).

For the developer and designer of wargames there are also some pitfalls to be aware of. There are three specific pitfalls that will be discussed next --"Underemphasis on problem formulation", "Parochialism", "Excessive attention to detail" (Quade:348).

Underemphasis on problem formulation is the case when not enough time, money or effort is directed towards finding out what the problem is. The pitfall occurs with the tendency to "get started" before the problem is well defined (Quade:349). A lot of time and effort is lost when an answer is found to the wrong question.

The idea behind parochialism is that the organization that developed the system is only as good as the system (Quade:352). Therefore, efforts are taken to protect the integrity of the system, and any attempt to criticize the system is considered an attack on the organization and defensive barriers are constructed. Even if the system has severe limitations, and the organization knows what these limitations are, it is considered inappropriate for anyone outside the organization to mention them. The pitfall of parochialism is that a system, which could be fixed by outside experts, stands little chance of being fixed.

Paying excessive attention to detail is related to both the individual components of a model and its overall scope. The individual components include the mathematical equations, formulas and algorithms in the computer model. Excessive attention to detail, relating to these individual components, usually leads to a more complex and cumbersome model while adding little to the accuracy of the model (Quade:354). Excessive detail relating to the overall scope of the model often results in expecting the model to accomplish too much. The problem with trying to do too much is that a number of things will probably be done poorly. However, if the scope of the problem is reduced or divided among different agencies more effort could be placed into doing a few things very well.

2.10 Summary

The purpose of this literature review was to identify and describe some of the information available concerning the basic components involved in constructing an airland combat model and wargames in general. The specific topics discussed were, model credibility and accreditation, the Airland Battle and military doctrine, force allocation strategy and tactics, scenario development, building wargames, mathematical models, theater level warfare models, and problems with theater models.

This literature review formed the foundation for understanding the individual and aggregated aspects of an airland battle. This literature review was also helpful in identifying the methods available for performing a credibility assessment on the Saber AirLand Combat Model.

III Methodology

3.1 Introduction

There are, unfortunately, no specific step-by-step procedures available for performing an overall assessment of a combat model or any other type of computerized model. There are, however, a number of sources available that discuss the need and importance of accomplishing such an assessment, that identify areas of special interest, and provide guidance in the verification and validation process (GAO, Sargent).

Of specific interest to this thesis effort is a General Accounting Office (GAO) report assessing the credibility of Department of Defense (DOD) simulations. This report recognizes that, "although simulations are useful tools, they are always approximations to reality and, therefore, their credibility--the level of confidence that a decisionmaker [or user] should have in their results--is open to question" (GAO:2). The GAO developed an assessment framework of 14 factors, that should be considered when determining the credibility of a simulation. These 14 factors are divided into three main areas of concern--"theory, model design and input data; the correspondence between the model and the real world; and management, documentation, and reporting" (GAO:3-4).

On the next page Table 1 identifies the factors in assessing the credibility of a simulation. It should be noted, however, that this table was developed for evaluating the credibility of a model used for analysis and not necessarily a combat training model.

As can be seen from Table 1, the framework is a reflection of the scope and intent of the first part of this thesis, developing an assessment of the Saber model, and also involves combining a good deal of information from all of the theses used in the development of Saber. Because of the similarity between this credibility assessment framework and the intent of this thesis effort, this framework was used as the foundation in evaluating the credibility of the Saber AirLand Combat Model.

Area of Concern	Factor
Theory,model design, and input data	1. Match between theoretical approach and real events being simulated. 2. Choice of Measures of Effectiveness. 3. Portrayal of immediate combat environment. 4. Representation of operational performance. 5. Depiction of critical aspects of broad-scale battle environment. 6. Appropriateness of mathematical and logical representations. 7. Selection of input data.
The correspondence between the model and the real world	8. Verification effort. 9. Attention to statistical quality of results. 10. Sensitivity testing effort. 11. Validation effort.
Management Issues	12. Organizational Support. 13. Documentation 14. Full disclosure of results.

Table 1. Assessment Framework (GAO:3)

Using this framework as guidance proved to be very beneficial in providing documentation relating to the appropriateness of using Saber as a theater level training model, the verification and validation process, and as an aid in future improvements to the Saber model.

Table 1 is a generic outline for determining the credibility of a model. The remainder of this chapter is dedicated to identifying the specific factors and methodologies, related to the three areas of concern, which are used to evaluate the Saber combat model.

3.2 Theory, Model Design, and Input Data

The first area of concern involves the underlying theory, design and input data of the Saber model (GAO:18). The factors considered under this heading are outlined as follows.

3.2.1 <u>1. Match Between the Theoretical and Actual Intent of the Model (GAO:29,30).</u> This factor looks at the intended purpose or function of the Saber model. The GAO report states that "a simulation quite credible in the abstract may not meet the specific needs of its user, depending on the model's theoretical approach" (GAO:29).

Saber is being designed as a theater level combat training model. With this in mind, specific questions need to be asked, to include: Is this the type of model the Wargaming Center wants?; Is it the model it needs?; Is the model capable of performing at the theater-level of abstraction? Answering these questions requires close coordination and communication with the intended users.

3.2.2 <u>2. Measures of Effectiveness (MOE).</u> MOEs are specified criteria or values that indicate success or failure and can be classified by type--internal or external. Internal MOEs consider issues such as missions flown, turnaround time, enemy aircraft destroyed, land occupied, attrition rates etc. External MOEs address issues such as how long the student took to plan the engagement, or if all the learning objectives were met. Again, close coordination with the user is required to identify the MOEs.

3.2.3 <u>3. Portrayal of the Combat Environment.</u> Portraying the combat environment involves looking at the scope and range of the combat model. The GAO report focussed on five attributes to consider for a typical scenario--"the size of the battle, the duration of the battle, the nature and behavior of enemy targets, the deployment...[of assets], and the terrain over which the battle might take place" (GAO:31). These attributes are defined as follows:

3.2.3.1 Size of the Battle. As mentioned earlier, Saber is a theater level model, it would, therefore, be inappropriate to model or keep track of individual entities (such as by aircraft tail number) at the squadron or battalion level.

3.2.3.2 Duration or Battle Length. This attribute identifies the amount of time allocated to the conflict. If the battle is too short, cumulative effects and interactions such as attrition rates, air defense measures, resupply and logistics, or intelligence gathering may be ignored.

3.2.3.3 The Nature and Behavior of Enemy Targets. This attribute looks at the types of targets and their effect on the scenario. The nature of targets will also identify sanctuaries (targets that are immune to attack), and how targets change after an attack or as the conflict progresses.

3.2.3.4 The Deployment of Assets. This attribute identifies the resources the commanders have at their disposal. It identifies what assets are available, how they are to be used, where they will be used and when.

3.2.3.5 The Terrain. This attribute identifies how the terrain is depicted in the model--is it real?, or a statistical representation?, and to what degree is it modeled?. Identifying the type of terrain and its portrayal and use is important in determining the portability of the model from one area to another.

3.2.3.6 Scenario Development. Another aspect of the combat environment is the scenario development. Questions related to the scenario include: What are the events leading to this situation?; Is such a situation realistic or pure fabrication? and; Could the model accommodate the play of an alternate scenario and how flexible is the model with respect to revisions?

These questions are answered by examining the documentation generated by the individual theses, the data bases and their structure, the computer algorithms, discussions with the computer programmers, and other proponents of the Saber model.

3.2.4 <u>4. Operational Performance.</u> For this thesis the operational performance factors considered were those factors or areas within the model that the blue or red commander has little or no control over, but are needed to add a sense of realism to the model. For the Saber model five performance factors were considered--1) the IFF/Fratricide issue, 2) Weather, 3) Command, Control and Communications (C^3), 4) Intelligence, and 5) Logistics. These factors are briefly defined or described as follows:

3.2.4.1 IFF/Fratricide. This factor determines how the model handles the issues of friendly vs threat detection, identification and targeting. It should be noted that during Desert Storm a large percentage of combat related deaths were a result of 'friendly' fire--which was made more evident by the low number of total casualties.

3.2.4.2 Weather. Weather can have a profound effect on planning factors such as mission type--influencing mission aborts, number of sorties flown, speed of advancing units, and the overall effectiveness of weapon systems.

3.2.4.3 Command, Control, Communications (C^3). C^3 involves, among other things, what the blue or red commander knows and how well--or if--he is able to use what is known to his advantage. Suppose, for example, the blue commander learns that red intends to attack in sector X, at Y hours with Z units. A number of questions could be asked relating to such an event, including: What is the source of the information--is it reliable?, Could the commander pass this information to lower levels?--If so, how?, Can C^3 assets be targeted?, If a C^3 net is destroyed, how will this affect further actions?

3.2.4.4 Intelligence. Intelligence is closely related to C^3. While C^3 involves disseminating information, intelligence is essential in determining what information should be sent. Passing bad information might be worse than passing no information. Specific questions include: Where did the information come from?, Is it reliable and can it be verified?, How can information be obtained and at what cost?

3.2.4.5 Logistics - and resupply are important considerations in long engagement combat models. Questions related to logistics include: Where are the supply units located?, Who makes the decisions about what is needed?, How are they notified of needs?, How is resupply accomplished?, How will shortages affect the war effort?, Are logistic and supply activities subject to attrition? (Hartman,b:22).

The operational performance factors are an integral part of the model and are directly related to the degree of realism the model provides. An examination of the algorithms and the related documentation provided answers to most of the questions related to these operational performance factors.

3.2.5 5. The Broad-Scale Battle Environment. Portraying the broad-scale battle environment involves developing the 'big picture'. This factor looks at the individual elements of the aggregated model to include the air war, the land battle and their interaction. Questions related to this factor included: What units are involved?, How well defined are the air and ground elements?, What level of detail is used to model weapons, attrition, maintenance?, Do the air and ground aspects complement each other?, What is the allocation process? (Hartman:21).

Answers to these questions will be useful in describing the scope of the combat environment and were available by sifting through the information related to doctrine and force employment.

3.2.6 6. Logical Representation of Model Design and Mathematical Algorithms. One of the primary purposes of using a computer for a simulation is to relieve users from the computational grind or what is called number crunching. Designing the model to follow a logical sequence should ensure the numbers are crunched when they are supposed to be, i.e. event B follows A, and C follows B etc. Otherwise, a situation such as computing attrition before the units have engaged in battle could occur. Therefore, part of the task for this factor was to identify the sequence of events within the Saber model.

Another area examined was the algorithms used in the simulation portion of the model; to ensure the formulas and variables are used correctly and make sense. It is expected that a theater level combat model will use many mathematical algorithms and logic routines. The TWX air battle alone had eight separate mission submodules dedicated to movement, attrition, damage assessment, support and control of air assets, which represents over 100 algorithms, some requiring many individual calculations. Imbedded within these algorithms were parameters designed to account for changes in strategy, and other qualitative or quantitative interactions--logic factors (Ciola:1-44). It is not expected that the Saber model will have any fewer algorithms considering it is designed to model the air and land battle.

One of the primary problems with the TWX algorithms was that,

> in this model, the values selected for constants/scaling factors are arbitrary and contextually may be interpreted as expedients which provide reasonable answers to some difficult analytical problems. (Ciola:3)

Every effort will be made to ensure this problem is not duplicated in the Saber model. It is understood that scaling factors are often needed in order to calibrate the model in order to account for factors omitted from the equation. However, whenever such scaling factors are used, their context and relevancy must be identified. Documentation is the best way to identify these scaling factors or constants and to determine if their use is required and credible.

3.2.7 7. Selection of Input Data (GAO:37). The credibility of a models' results are usually directly related to the quality of the input data. Inappropriate data or data that has been tailored to fit the situation diminishes the credibility of the results (GAO:37). The data bases and algorithms used in the Saber model were intentionally drawn from unclassified sources--as were those for the TWX model (AFWC,1987:2). Therefore, the sources of this data are readily available without the fear of divulging classified information.

Although there is a wealth of information available for putting together a combat model, questions are often raised concerning the goodness or validity of the data. These questions include:

- What is the source?;
- Who developed the information and what are his qualifications?;
- How current is the information?;

- For what purpose was it developed?;
- Does the data reflect parochial interest (Battillega:537)?;
- Is the data based on historical data, field testing, expert opinion, intuition or an educated guess?;
- Can the data be duplicated?;
- Is it rigorous (does it only apply in certain situations)?;
- Is the value absolute or is there a measure of uncertainty? (Battillega:538);
- Is it presented in an understandable format?

If the answers to these questions are available, and acceptable, the source and value of the data is less likely to be suspect. Once again, documentation is the primary method available to access the quality and appropriateness of data sources.

3.3 The Correspondence Between the Model and the Real World (GAO:40).

The following four factors are included in the credibility framework in an effort to demonstrate that the model is a good representation of the real world or would be a good depiction of reality if the situation modelled ever occurred (GAO:40). Specifically these factors are included to provide evidence that

(1) the computer program operates as the simulation model's designers wanted,
(2) the output of the simulation represents the model's average output over many runs,

(3) the results take into account sensitive parameters and alternative scenarios, and
(4) a model's results bear sufficient resemblance to real world results or results from other models or methods (GAO:40).

Factors 8-11 conform respectively to the items listed in 1-4 above and are discussed as follows.

3.3.1 8. Evidence of a Verification Effort (GAO:40). The process of determining if the computer programming, logic, algorithms and other aspects of verification are correct is often performed as part of the initial checkout in the development of a simulation. Unfortunately, much of this work is not documented, so no history is developed and no evidence exists that any verification attempts were ever made (GAO:40). The credibility of a combat model can be questioned due to a lack of a well documented verification effort.

This thesis will stand as proof of the initial checkout of the Saber model. A good portion of this checkout will be accomplished by answering the myriad of questions posed in section 1--items 1-7. The documentation provided by this thesis will assist in the development of the Saber model, and should prove beneficial as an aid to future verification efforts.

3.3.2 9. Evidence that the Results are Statistically Representative (GAO:40-43). As discussed earlier, models can be deterministic, stochastic, or a combination of the two, in nature. Introducing stochastic processes into a model adds variability to the output which is more characteristic of real events. However, excessive variability in the output of a simulation is generally not welcome and could indicate there is something wrong with the model. The results from one run to another should be reasonably close to some expected (average) value for similar situations, if the simulation were duplicated a sufficient number of times.

The Saber model--like many theater level models--is being designed with mostly deterministic methodologies; although some stochastic processes will be incorporated. Using largely deterministic equations it is expected that the output can be fairly well determined, with only slight variation due to randomness.

An examination of the random density functions incorporated into the mathematical algorithms, provides insight into the nature, appropriateness, extent and expected variability of any stochastic influence.

3.3.3 10. Evidence of Sensitivity Testing (GAO:40-43). Sensitivity testing (or sensitivity analysis) is used to identify those parameters which are most sensitive to change or fluctuation and to determine the amount of variability or uncertainty introduced into a model due to slight changes in these critical parameters. If the output of a simulation changes significantly with a small change in the value of one of these critical parameters, then it is vital to the credibility of the simulation that the parameter be correct.

The input parameters as well as the algorithms and their internal stochastic processes were examined concurrent with a number of the factors mentioned previously. Other parameters, such as the effects of the weather, terrain, and other changes in the simulation environment should be examined after the integration of the model is complete. Section 5.3 discusses the specific parameters that were identified and explains how testing of these parameters should or could be accomplished.

3.3.4 11. Evidence of a Validation Effort. The GAO Report provides a general definition of how the results of a model can be validated.

> Validation, in a narrow sense, is the comparison of simulation results to results from other methods, such as operational testing and evaluation or historical experience, or from models for estimating a weapon's performance that are believed to be substantially credible. (GAO:44)

This general definition is, unfortunately, too narrow for the purpose of validating the Saber model. The scope of Saber makes validation of its ability to model performance factors inappropriate. Saber is intended to represent warfare at the theater level. At the theater level, individual units are aggregated (grouped) into larger units--to save computer space and time. As a result of this grouping, the actions of the individual entities are lost and replaced by an average behavior value (Hartman:3).

It would be equally impractical to validate Saber based on historical events. There have not been any events--recently--that match the magnitude and scope of the Saber model. There are a number of exercises that attempt to bring attention to warfare at the theater level, such as REFORGER (Return of Forces to Germany) and Team Spirit (a training exercise centered in Korea). However, these exercises concentrate more on logistics and planning than on the engagement of forces, and the aircraft that fly missions are concerned more with making their 'time over target' then with coping with the stresses of war or the possibility of attrition. Therefore, even with these theater level training exercises there are very few established criteria to model Saber against.

As for validating Saber against another model, the only model that could be considered similar would be the TWX/Agile. Unfortunately, the TWX model was never officially validated; so again there are no strong criteria or measures of merit established. However, TWX/Agile was used for a number of years--with apparently good results--and is, therefore, used as the base line model for comparison purposes.

Determining the validity of the Saber model requires a different approach than the models discussed in the GAO Report. Sargent's tutorial on simulation model verification and validation suggests that, as a minimum, the following steps be performed when considering the validity of a model (Sargent:38).

1. An agreement be made between (i) the modeling team and (ii) the model sponsors and users (if possible) on the basic validation approaches and on a minimum set of specific validation techniques to be used in the validation process *prior* to developing the model.

2. The assumptions and theories underlying the model be tested, when possible.

3. In each model iteration, at least face validity be performed on the conceptual model.

4. In each model iteration, exploration of the model's behavior be made using the computerized model.

5. In at least the last model iteration, comparisons be made between the model and system (output) data for at *least* two sets of experimental conditions, when possible.

6. Validation be discussed in the model documentation.

Steps one, two and three of this outline were accomplished commensurate with the evaluation of factors previously discussed. The evaluation of the final three steps could not be accomplished because the model simulation is not complete. However, it was determined that the Wargaming Center was most qualified to accomplish the last three steps when the model is completely integrated and running.

3.4 <u>Model Credibility Based on its Support Structure, Documentation and Reporting.</u> Simulation models can have extended lifetimes; although, rarely in their original form. The TWX, for example, has been in use since 1977. Over the years models are--generally--enhanced, made more complicated, updated, or modified to meet the needs of the users and often there are several versions of a model in use. Because there is potential for the abuse or misuse of a model, it is important to establish a point of contact (POC) for maintaining the subject simulation. This POC would be responsible for understanding the inner workings of the model, its inherent strengths and weaknesses, and ensuring the intent of the model is not compromised. The POC would also be responsible for maintaining the documentation related to both user and computer interfaces, and other operational requirements. Documentation and a functional support structure alone "will not create credibility where the underlying theory, computer representation, or validation procedures are weak, but it will help prospective users judge the applicability of a simulation to their needs and will add further credibility if the simulation is relatively strong" (GAO:47). The GAO Report recommends "the support structure, documentation, and reporting" area of concern be divided into the following three factors--items 12 - 14 (GAO:47).

3.4.1 <u>12. Establishment of Support Structures to Manage the Simulation's Design, Data, and Operating Requirements.</u> This factor seeks to identify the group or organization responsible for managing the simulated model. Specific questions to be answered include:

- Who is the primary user of the model?;
- What is the responsible agency?;
- Where is this agency located?;
- By what authority is the responsible agency or POC designated?;
- How does this authority manifest itself, i.e. what are the bounds of authority?;
- What is the relationship between the user and the POC?;
- Can a model be modified to suit the needs of another organization?,
    -- Who must be notified if changes are made?
    -- Who controls the documentation of changes?;
- How are studies and analysis conducted?;
- How are changes disseminated to users?;

Answering these question will provide insight into the underlying support structure of the Saber model. The existing support structure for the TWX is well defined and documented, and it would not be unreasonable to assume that this support structure would carry over for the Saber model. Therefore, specifying the support structure turned out to be a fairly simple matter of documentation.

3.4.2 13. Development of Documentation to Support the Information Needs of Persons Using the Simulation (GAO:47-51). The importance of understandable and complete documentation has been mentioned numerous times in this section. A well documented model clearly specifies the intent of the model, instills confidence that the model is able to answer the questions posed, and provides guidance on how to use the model correctly. At the very least, documentation should be provided on the following items:

> the program listing;...[program structure]; variable listings; definitions, and sources;...comments and caveats about operating quirks and special library of input/output routines; the operator's manual; the players manual...[of the] MSG [Model, Simulation and Game]; the pertinent analysis routines used to reduce data generated by the MSG and to estimate input parameter values for the MSG; appropriate data reflecting what the MSG cost to construct, update, and run; and the register of critical personnel involved in MSG initiation--who wanted it built, for what reasons; production--the identities of the master modeler and the model team and what validation procedures they used; operations--the history of professional review by persons external to the builder-user; and use--who used it, when, and with what purpose and outcome. (Battillega:519)

Although this looks like an exhaustive--and exhausting--list of items, most of the material will be acquired while seeking answers to questions posed during the examination of factors previously mentioned. Most of this information will be available--in one form or another--in the literature and theses reports being put together by the students constructing and implementing the Saber program. The remaining items were obtained through coordination with the Wargaming Center, the designated sponsor.

3.4.3 14. Disclosure of the Simulations Strengths and Weaknesses (GAO:47-52). It has often been said that a chain is no stronger than its weakest link. However, the same can not--in most cases--be said about a simulation model. In many cases a simulation can be very good in spite of some inherent limitations or weaknesses. In the terminology of simulation, correcting or explaining these weaknesses is often referred to as making 'model accommodations' that require a 'work around'. It could be said--referring back to the analogy of the chain--that a simulation is no stronger than its most significant undocumented weakness. Free disclosure of a model's weaknesses, as well as its strengths, is viewed as a positive contribution to the credibility of a model (GAO:51).

Many of the strengths and weaknesses of the Saber model should be made obvious when the other factors in this framework are examined. Additional items will be listed in an attempt to advise potential users of the limitations of Saber when used as a theater warfare model. The correction of some of these weaknesses or limitations might be considered in later enhancements.

3.5 Assessment Framework Table 2 is very similar to the table used in the GAO report to organize the different areas of concern. The format is beneficial in that it provides an abbreviated assessment framework that should be an explicit means of identifying the strengths, weaknesses, limitations and other comments concerning the Saber model. In addition to the GAO format, a value will be included to rate the overall area of concern and the individual factors. This rating should be made clear after the item is explained and justified in the documentation, and will range from G-good, A-adequate, P-poor, to INC-incomplete.

Area of Concern:	
Factor: Attribute:	Comments, Strength, Limitation/Weakness Rating:

Table 2. Assessment Framework Display Format

3.6 Summary

The evaluation of the Saber AirLand combat training model will require analysis from at least five different perspectives--1) as an operations research (OR) analyst evaluating the model design and function, 2) a purely subjective verification and validation agency, 3) a possible Air University (AU) instructor required to use this model to achieve established learning objectives, 4) a systems analyst of AUCADRE controller required to maintain the program, and 5) a possible user in the form of an AWC or AFCSC student. The challenge lies in maintaining an open and unbiased attitude while performing these different functions.

The next three chapters will examine the three primary areas of concern and their associated factors. Theory, model design and input will be discussed in Chapter 4, the correspondence between the model and the real world will be looked at in Chapter 5, and Chapter 6 will be devoted to management issues.

IV Credibility based on Theory, Model Design, and Input Data

This chapter discusses the first areas of concern when assessing the credibility of a model--credibility based on theory, model design and input data. The specific factors and attributes are discussed and limitations and weaknesses are presented where appropriate. Refer to Table 3, located in Appendix A, for a condensed version of this chapter.

4.1 Match Between the Theoretical and Actual Intent of the Model. This section answers the questions asked concerning the theory and actual intent of the Saber model.

4.1.1 *Is Saber the type of model the Wargaming Center wants?* For two reasons the answer to this question is yes. The first reason deals with the changing view of what the next war will be like. With the disintegration of the Soviet Union and the Warsaw Pact the likelihood of an all out thermal nuclear holocaust is greatly diminished (Rozman:74). It is anticipated that wars of the future will be much smaller in scale and farther away from well supplied main operating bases. Wars of the future will involve getting the right forces at the right place at the right time. In keeping with the changing view of future wars the Wargaming Center wants a wargame that is 1) instructive in the areas of employment, allocation, allotment and apportionment, 2) can provide insight into the operational art, 3) forces an understanding of sustainment, and 4) has a duration of at least ten days. Because Saber was conceptually developed in coordination with the Air Force Wargaming Center, it was specifically designed to accomplish these objectives.

The second reason the Wargaming Center wants the Saber model is because of its programming language. An Air Force policy letter has established "Ada as the single implementation language for all new and upgraded software systems in the Air Force" (DAF,1991). Ada is the primary language used in the Saber model; although there are some built in applications linking Ada with 'C' (primarily for graphics programming). Saber not only satisfies the Air

Force mandate, but it also has the potential to be very useful as a learning tool and test model for future Ada implementations.

4.1.2 *Is Saber the type of model the Wargaming Center needs?* The answer to this question is again yes. The Wargaming Center is chartered to maintain wargaming models at many different levels. For example, CAMPEX is an employment exercise, Arrow and Agile are theater level exercises and ACES is an intensive simulation designed to play at a level up to global. Agile is expected to be discontinued shortly, which will leave a niche in the theater level area. Saber is designed to fill that niche. Saber will be an enhanced and improved version of Agile that is more user friendly, exportable, fully documented, and able to play multiple scenarios. Saber is also more robust than Arrow but not as intensive or restrictive, in terms of hardware, as Aces. Therefore, the need for the Saber model has been established due to its ability to fill the niche at the theater level.

4.1.3 *Is the model capable of performing at the theater level?* As mentioned previously, Saber is being designed as an enhanced version of Agile and the Wargaming Center was confident that Agile was an effective theater level model (AFWC:a). Therefore, it stands to reason that an updated version of Agile would be equally capable and the answer to the question posed is yes. It should be noted, however, that the enhancements designed into Saber involve more than merely updating Agile. Saber was specifically designed to represent the concept of an AirLand battle and associated doctrine at the theater level and is quite an improvement over the separate Air and Land battle concepts modeled by Agile.

4.2 Measures of Effectiveness (MOE). This section discusses the type of MOE, internal or external, best suited for the Saber combat training model when evaluating the performance of players. Internal MOEs should be considered inappropriate for evaluating student performance! Recall internal MOEs involve attributes such as the number and type of missions flown, enemy aircraft destroyed, land occupied, staying power, attrition rates and killervictim-scoreboards, etc. The problems with internal MOEs are that 1) they are often scenario dependent, 2) in a stochastic model it would be difficult to obtain and justify objective standards, and 3) the long term effects of a decision might be ignored if the simulation is not played out long enough. Consider, for example, the decisions of four students on how best to use an aircraft strike package. The first decides to strike the enemy Headquarters Command and Control network, the second attacks an advanced surface-to-air (SAM) site, the third attacks a bridge, and the fourth student decides to attack the enemy front line troops. The initial casualties and collateral damage from the first three missions would probably be minimal, while attacking the enemy troops would result in measurable statistics. However, looking into the future we might find that taking out the SAM site allowed a second sortie to penetrate and strike a critical munitions depot, leaving enemy troops at the front without weapons; destroying the bridge delayed enemy troop reinforcements and the army was overrun; and destroying the C^3 net created confusion and denied vital intelligence at the enemy front and friendly forces were able to outmaneuver their entrenched foe. Who made the better decision? This example--could be complicated further if an aircraft was randomly shot down. The controversy explained illustrates the difficulty of applying internal MOEs to a limited training exercise.

It was decided that external MOEs would be a better means of evaluating the performance of players (Butalla, Wolczek). External MOEs involve, among other things, how well the players grasped the educational objectives of the combat exercise. These objectives would include an understanding of Air Force doctrine and missions, the principles of war, and the ability to make decisions in a stressful environment. It was also decided that the educational objectives of the Agile model, discussed in more detail in chapter 8, are quite specific and would be equally appropriate for the Saber model.

4.3 Portrayal of the Combat Environment. This factor focusses on the scope, range and domain of combat and is defined in terms of six attributes--

1) the size of the battle, 2) the battle duration, 3) the nature and behavior of enemy targets, 4) the deployment of assets, 5) the terrain, and 6) scenario development. These six factors are discussed next.

4.3.1 Size of the Battle. The size of the battle involves both the overall theater of operation and individual combat units. Saber is a theater level combat training model currently being constructed to represent a Korea scenario. The theater represented in the graphical display is approximately 1250 X 1080 km^2. This size is sufficient to display the land mass of North and South Korea and a large portion of China--which is neutral. A large expanse of ocean is also represented that could be used to model maritime operations. A limitation exists, however, in interfacing this theater with the outside world. A scheme has been developed to provide staging bases and control points for entities entering the theater of operation, but this scheme still needs to be implemented.

Land combat units are aggregated at the division level and fighting occurs between adjacent area hexes (in the Saber model a hex is a symmetric six sided figure that is 25 km across the flats). Aircraft sorties can be flown with a single aircraft or in a package. A package consists of the primary mission aircraft and a number of other aircraft that provide support functions. These support functions include air refueling, electronic countermeasures, combat air patrol, etc. The resolution of combat units is limited to components such as different types of aircraft, tanks, anti-personnel vehicles (APV), anti-aircraft and anti-armor weapons, etc. Accounting for individual aircraft by tail numbers and single soldiers are below the level of resolution of this model.

4.3.2 Duration or Battle Length. The smallest unit of time represented is a two hour cycle. There are 12 two hour cycles per game day. A two hour cycle was chosen to represent the average time needed to complete all aircraft sortie packages.

The information needed for each day is provided by information resulting from the previous days' activities. There is, therefore, no technical limit, other than storage capacity of the computer, to the number of game days capable of being played. The Wargaming Center would like a model that could support a duration of at least ten days (Wolczęk). Saber should be able to accommodate that desire.

4.3.3 The Nature and Behavior of Enemy Targets. Targets can be struck by either air or ground assets. Air assets are able to acquire or strike 1) other aircraft, depending on the assigned mission, 2) air bases and depots and missile platforms, 3) ground units, 4) ground hexes, used for reconnaissance or mine laying missions 5) obstacles, such as bridges, pipelines, mine fields and rail lines. Although the need has been identified to enable aircraft to strike supply trains and caravans moving equipment, munitions and other supplies, this ability is not integrated into the model. Striking targets should result in direct attrition, force a change in posture, create delays in enemy movement, reduced capability of enemy assets, or any combination of the above.

Sanctuaries are defined as targets or entities that are immune to attack. Higher Headquarters Command and Control assets must be considered sanctuaries because they are not explicitly modelled. Additionally, when the interface between the theater and the rest of the 'real world' is complete, there will be a number of hexes dedicated to outside staging bases and depots that will also be immune to attack. Assigning sanctuary status to these staging bases is justified due to their distance from the actual combat environment.

4.3.4 The Deployment of Assets. Assets include both air and ground combat and non-combat units. Asset descriptions include aircraft type, capability, missions and location; land unit location, strength and posture, and; the movement of supplies or reinforcements. Movement is based on an assessment of the tactical situation, resources available, planned objectives, perceived intentions of the enemy, or other extenuating circumstances. The concepts of apportionment, allocation and allotment are an integral part of the training seminar. Game players are directly responsible for the movement of assets under their control. They determine what resources are available and make decisions in an attempt to maximize their effective use. Although these concepts are an integral part of the game they are not internal to the model design. Saber is designed to provide a list of resources and their attributes, a method to manipulate these assets, and a means of displaying the results of such manipulation. Saber plays no direct part in the employment or deployment of assets; although it does create air packages and coordinates ground actions based on player input instructions.

4.3.5 The Terrain. The theater land map was generated by overlaying a hexagonal grid over a Jet Navigational Chart (JNC). JNC charts are used routinely by aircrew members for route planning and are detailed enough to show the elevation and location of terrain features and obstacles used in the terrain file. Hexes that are entirely water are colored blue. A hex that is part land and part water will take on the attribute of the larger portion. Land hexes are varying shades of green, black or red based on ease of ground travel or trafficability. The hex is sub-divided into six pie cut sections and each pie section is evaluated to determine its own trafficability value. There are six possible values, ranging from excellent to very poor, that can be assigned to each pie section. For example, a mountain pass or a swamp might be rated poor or very poor, but a road could upgrade the section to fair, good, very good or excellent. The hex color is based on the average trafficability within the hex. Other features included in the terrain graphics are cities, roads, pipelines, rail lines, rivers and borders. Roads, pipelines and rail lines connect from the center of one hex to the center of adjacent hex(es) and are identified by different colors and shapes. Rivers and borders follow the outline of hexes and are also identified by a specific color and pattern.

Portability of the planned scenario from one area to another is possible because the terrain map is not 'hard-wired', i.e. the terrain data is located in separate files and is isolated from model execution functions. A changing of the theater of operation would require overlaying the 100 by 100 hex grid over the desired new land area and updating the data files. Although this sounds simple, and technically speaking there are no obstructions, it would be a long and tedious process. The main chore would be to take every hex (up to 10,000 in all), and divide them into six pie sections determining a trafficability value for its 60,000 sections. After the trafficability values are determined there are other hex-side files to consider in order to include obstacles, neighbor hex identity relationships, and the location of borders, coasts, the FEBA, and rivers.

The limitations of the terrain map are listed below. These limitations are not considered significant, because they are typical of the limitations found in similar low resolution combat models. Hartman wrote that "the purpose of the terrain model in a large scale aggregated combat simulation is to represent trafficability for the movement process model (Hartman,b:23)", and the Saber terrain model is capable of accomplishing that task. Limitations to the terrain map include the following,

1. The color of a hex may not be a true representation of movement when the hex is entered from different directions.
2. One color represents trafficability for about 500 km^2 of surface area.
3. All terrain attributes, including: ruggedness, forestation, urbanization and other features are aggregated into a single trafficability value.
4. Terrain depiction is basically two dimensional.
5. Bridges and mine fields are not displayed on the terrain map even though they can be targeted and the graphics display will not identify obstacles that are destroyed.
6. Movement from one hex to another is restricted to six directions--N, NE, SE, S, SW, and NW. Moving due east, for example, would require moving into the adjacent NE hex and from there moving into the adjacent SE hex. Although, the model compensates (increases the relative ground speed) for units moving a number of hexes due east or west.

4.3.6 Scenario Development. It is expected that scenario development will proceed along the same lines as the Agile wargame. Both the user and the operations section at the Wargaming Center are actively involved in developing the scenario. Developing the scenario is consistent with Section 2.5 of this thesis. The Wargaming Center uses a specific manual to aid them in scenario development (DAF,1988b). It is obvious from examining the Agile series Blue and Red players handbooks that a good deal of effort is put into scenario development and the resulting product is quite comprehensive. The scenario developed added a sense of realism to the Agile wargame and the same effort should be expected for Saber.

4.4 Operational Performance factors. Operational performance factors were defined as those factors that commanders have little or no initial control over but add a sense of realism to the model simulation. The following section identifies and discusses five of these factors--1) IFF/Fratricide, 2) Weather, 3) Command, Control and Communications (C^3), 4) Intelligence, and 5) Logistics.

4.4.1 IFF/Fratricide. IFF is an acronym for Identify Friend or Foe. Most aircraft are equipped with transponders that can automatically identify an aircraft by call sign, type, mission number, altitude, airspeed, and heading, whenever the aircraft is interrogated (a specific radio signal sent from a ground controller or airborne platform requesting identification). It is, therefore, not a good idea to keep this transponder turned on when flying over enemy territory in a wartime environment.

Destroying a friendly target is called fratricide. At first it may seem improbable that anyone would make the mistake of firing at a friendly target, but mistakes happen; especially when you consider the speed of modern aircraft, the similarity in design and the fact that the decision to fire is often made within seconds of detection.

Air to ground attacks are also prone to fratricide and are potentially more serious than ground to air or air to air; because of the destructive power of modern weapons. A good deal of coordination and communication is required between forward air and ground controllers and allied attacking forces. Unfortunately, even with exceptional preparation and training, accidents still occur.

How does Saber handle the IFF/Fratricide issue? Basically, it does not! The IFF/Fratricide issue is considered below the level of resolution in this theater-level model. Several assumptions are made to circumvent the issue: 1) aircraft pilots and tactics are optimal, they do not make mistakes, 2) an aircraft package or ground unit is not allowed to strike a target unless the target is identified as a threat, this feature is coded in the simulation, and, 3) safe passage procedures are in effect. Safe passage procedures are used when ingressing and egressing enemy/friendly airspace to keep from being shot down by friendly forces. Safe passage procedures include assigning designated corridors, altitudes and/or airspeeds that will identify an aircraft that transitions from enemy to friendly territory. Safe passage procedures are assumed because the players do not choose ingress and egress routes or the time of FEBA or FLOT penetration. Consideration has been given to including 'free fire zones', (areas where aircraft do not belong and are subject to being shot at without warning) into the simulation, but no specific coding has been developed.

4.4.2 Weather. Weather is divided into three categories and affects a number of operations in the Saber model. The three types of weather are good, VFR conditions (visual flight rules); fair, MVFR (marginal VFR), and; poor, IFR conditions (instrument flight rules). Every hex contains one of the three categories of weather that can be selectively displayed on the visual graphics terrain map if desired.

Weather can affect which types of aircraft can fly, the optimum weapons load, the probability of penetrating a defensive area, and the probability of finding a target and/or destroying it. Finding or hitting a target is complicated further by a stochastic process designed to determine the actual weather at the target. For example, the capability of an aircraft equipped with a weapons load designed for fair weather might not be as effective if poor weather is encountered at the target area, but more effective if the weather is good. Weather conditions at the main operating base (MOB) and post strike base will also determine if the aircraft can take off and where it can land. Although the use of all weather aircraft reduces the effects of weather at the target area and (MOB), not all aircraft are all weather capable and some will be grounded in poor weather. Attributes are assigned to all aircraft designating whether it is all weather capable and under what conditions it is allowed to take off and land. In addition to weather restrictions, some aircraft are also restricted to day operations.

Some of the limitations identified in representing weather include:

1. Seasonal conditions are not explicitly played, there are no extremes of hot or cold, wet (monsoon) or dry conditions.
2. Winds, at altitude or on the surface, are not shown.
3. Extremes of hot and cold do not affect unit efficiency.
4. Weather for the different zones in the model must be loaded into the weather database, but daily updates are generated randomly in the model; which may be a duplication of effort.
5. Presently, weather is a ground mapped phenomenon and does not extend into the air hex environment.
6. The weather generating algorithm and actual weather determination is complicated and could probably be simplified without loss of fidelity.
7. Weather has no impact on ground movements.

The last two limitations, i.e. the complicated weather algorithm and weather having no impart on ground movement, will be discussed further a later section--Chapter 8, Section 8.3.

4.4.3 Command, Control and Communications (C^3). Command, Control and Communication is a part of the exercise but is external to the simulation itself. Using Agile-Falcon '91 as an example, there are four levels of command and control within the planned exercise structure (AFWC:7). The Combined Forces Command (CFC) is the overall command in theater headed by the Commander-in-Chief (CINC). CINCCFC represents the command above the level of resolution, i.e. Higher Headquarters (HHQ) and the National Command Authority (NCA). The CINCCFC facilitates game play by providing guidance to the players, helping to coordinate their plans, interjecting political and military changes, ensuring educational objectives are met, and act as a link down to the next level of command (AFWC, 1991:7). The second level is composed of the Combined Air and Component Command (CACC) and the Combined Ground Component Command. The responsibility of "the CACC Commander and staff [is to] develop the air [and ground] strategy that is implemented during the Execution phase (AFWC, 1991:7)". The strategy developed is passed to the next level of command in the form of an Air Directive (AD). The third level is the Tactical Air Control Center (TACC), which is also referred to as the game execution phase. At this level the plans and guidance of the CACC are implemented by developing an Air Operations Order (AOO), more commonly referred to as a 'frag', which is entered into the computer. The computer provides the fourth level in the command and control structure. The computer plays the role of all subordinate commanders and diligently performs all tasks and functions directed by the AOO.

Communications, getting information from one level to the next, is not a problem in the command and control structure. The players are all located in the same building and all of the players have roles at each level of interaction. Therefore, it would not be uncommon for decisions made at the highest level, to be input to the computer at the lowest level, by the same person. This short distance from implementation to execution implies that the chain of command has--only--one link, which presents some limitations. The likelihood of a misunderstanding or receiving a garbled or incoherent message is almost eliminated. Conflicts of interest are eliminated below the TACC level, and; individual unit commanders can not have a 'better idea' on how to use their forces because the 'obedient' computer plays this level. There is also very little chance of important information being delayed, mislayed, or otherwise disrupted and there is no chance of the information being intercepted or compromised. Additionally, there are no inter theater communications required, and targeting a C^3 network if any existed, would have little effect on information flowing up or down the chain.

4.4.4 <u>Intelligence.</u> In contrast to communications, Saber portrays intelligence, both internally and externally, much better. External to the simulation there are three stages organized in the CACC staff planning phase. Intelligence is one of these stages--the other two are operations and logistics. Operational factors were discussed in Section 4.3 and logistics will be discussed in Section 4.5. The job of the intelligence staff is to gather and assess the wealth of information available on enemy actions to select targets or provide support to friendly units (AFWC:8). Internal to the simulation, each unit and target has its own intelligence and visibility index. "Visibility to the enemy...describes whether an asset will appear on the computer [screen or printed report] of a player that is not the player which owns the particular asset (Horton:129)."

The intelligence index is a numerical value representing a measure of how much of the unit or target is known. There are three levels of awareness represented using the intelligence index value. At the lowest level there is the indication of a suspected unit and its location, the next level will identify the unit by class, such as armor or infantry, and the third level includes unit class, name, branch of service and combat strength. Knowledge of the combat strength of a unit is also dependent on the intelligence index. There can be either no information on the target, an underestimation of the target, perfect intelligence, or an overestimation of target capability (Mann:74). This range acts as a filter intending to account for the 'fog of war' inherent in most intelligence gathering operations.

The intelligence index of a unit can be improved by use of a number of intelligence gathering techniques. Intelligence gathering techniques include using reconnaissance aircraft, possible satellite missions--although this ability does not presently exist in the model, engaging or being in contact with a unit, or by using special operations forces (Ness:71). The intelligence index of a unit will decrease over time if the information gathering process is not continued, i.e., over time the intelligence information becomes less accurate.

Intelligence information is also provided by the graphical displays. Some of the information available includes: the theater map, countries and sanctuaries; the trafficability of hexes and obstacles; a weather overlay, and; general unit locations and status. All of this information can be made clearly visible with the movement and click of a mouse attachment.

4.4.5 Logistics. Logistics is also given a great deal of consideration in the Saber model; although, many features are incomplete. The primary focus of the exercise is to make decisions to ensure the right forces get to the right place at the right time with the right 'stuff', all of which implies logistics.

The planning phase begins with the forces and supplies that might be available, given a limited buildup time and notification of impending hostilities, in the theater of operation. From this initial stockpile, and intermediate supplies and reinforcement brought to the staging bases, the Logistics Division on the CACC staff is responsible for ensuring there is adequate support for proposed plans and operations. Specifically these duties include the coordination of aircraft beddown and rerolling, and the distribution of supplies. Outlined in the Blue Players Handbook of Agile-Falcon '91 is an entire chapter dedicated to the responsibilities and duties required of the Deputy Chief of Staff Logistics (AFWC:'91:29). In addition, there are a number of reports discussed that should be included in the Saber output. In addition to being mentioned here these reports should be included as part of the output reports discussed in section 8.1. The reports needed include (AFWC,'91:37):

1. Base Capacity, Storage and Ramp space available.
2. Logistics Calculator, to determine support requirements for expected aircraft.
3. Logistics Inventory, to show the types of aircraft and munitions available.
4. Logistics Overages, to show where there are too many supplies.
5. Logistics Shortfall, where supplies are needed to support the planned missions.
6. Predirected Rates and Analysis. The predirected rate of supplies is used to simulate the "replenishing of supplies which is accomplished as a normal part of a base or ground unit's operations (Sherry:27)".

In addition to the external representation of logistics, Saber is also designed to keep track of logistic and supply statistics within the simulation. Internal to the simulation the computer is designed to perform the function of a giant bookkeeper. The simulation should indicate when supplies and munitions are too low to accomplish scheduled missions and cancel or abort missions if required. The computer should also keep track of supply train movement and the flow of oil (POL) through the pipelines. The computer should also keep track of munitions, supply trains and other assets lost to combat actions.

4.5 The Broad-Scale Combat Environment. This factor looks at the combat potential and representation of troops and units, the range of conflict and the interaction of ground and air assets.

An assessment of the battle environment should begin with an understanding of the combat, and other, units involved and how their combat fighting strength is determined. Mann did a thorough job of defining the aggregation, disaggregation and proposed composition of units in this model (Mann:85-100). He begins by explaining that US Army higher headquarters usually monitor the progress of troops two levels down. For the Saber theater level model this involves keeping track of armies, corps, and the next level down, divisions. The divisions modeled include: mechanized infantry, armored, airborne infantry, air assault, marine and light infantry, separate brigades, and additional support units. The Red side consists of motorized rifle and tank divisions, (using BTR fighting infantry vehicles or newer BMP wheeled armored personnel carriers equipped with anti-tank systems), and tactical air armies.

One of the problems with an aggregated model, such as Saber, is trying to standardize the value of individual components and their ability to inflict damage or attrition. For example, how does an attack helicopter compare to a TOW (Tube-launched, Optically-tracked, Wire-guided) antitank missile? There are two basic types of aggregated attrition models, homogeneous and heterogeneous. In a homogeneous model the components of a unit are grouped together into one scaler value and a force ratio is determined by comparing attacker to defender strength. This force ratio is also used as a measure of FEBA (Forward Edge of the Battle Area) movement when forces are engaged in battle; a force ratio greater than one means you 'outnumber' the enemy and are able to project power and gain ground. In a heterogeneous model weapon classes are assessed against weapon classes in a matrix format. Both types of models address the quantity vs quality issue, but heterogeneous models also provide insigh into the shooter vs target relationship. A homogeneous attrition model, while perhaps not as precise or eloquent as a heterogeneous model, is more understandable and easier to implement (Hartman,b:38). Saber uses a homogeneous attrition process and defines units based on "battalion equivalents" (BE) and the J-series tables of organization and equipment (TOE) provided at the US Army Command and General Staff College to determine a scaler firepower value (Mann:86). Using a scaled variant of this system, a Soviet motorized rifle battalion (MRB) is given a value of 1.0 and other systems are related to this standardized MRB. The combat capability of a unit is a function of its firepower and combat power. The firepower of a unit is a function of its direct fire weapons, tanks, armored-personnel vehicles (APVs), infantry, and attack helicopters. Another aspect that is considered is the quality of troops. The troop quality is a value used to represent some human factors including moral, training, fatigue and resolve. If one knows how many vehicles and other equipment a unit has then "using the TOEs and the battalion equivalents, one can aggregate up to division level and disaggregate down to the vehicle level" (Mann:87). For example, a typical armored division with over 7000 vehicles, 172 aircraft and 17,000 soldiers has a firepower score of 315; or 315 time the fighting strength of a Soviet MRB. This value is determined by adding the battalion equivalent values of the components making up an armored division. According to Mann these components include 348 tanks, 216 Bradleys, 144 infantry squads, and 29 attack helicopters along with 72 tubes of artillery and 9 multiple launched rocket systems (MLRS) (Mann:89).

The actual calculations and value of the individual combat components, for Blue and Red, are given by (Mann:176):

US Firepower = Quality of Unit [assumed initially to be 1] * (.5 tanks + .3 Bradleys + .1 Mech Infantry Squads + 1.9 Apache + .15 Light Infantry Squads + .1 HUMMV TOWs).

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

Using firepower scores has some inherent limitations (proficiency and training, command and control, superior leadership, synergistic effects, and tactics for example, are lost in the aggregation), but some system is needed to relate combat fighting capability to the units involved and using BE and TOE values provides a standardized unit of reference.

The Combat power of a unit is a measure of how well the unit is able to project its strength, by itself or with assistance, in actual combat. Combat power is a function of the units firepower, and other assets including, supporting artillery, its defensive posture, close air support and terrain (Mann:176).

In addition to ground-to-ground combat, aircraft also interact with ground units, causing attrition and creating possible movement delays. Aircraft and their weapons systems are identified with a destructive index, which is a measure of how much damage they can inflict against ground or other air targets. Aircraft and ground units also have survival indexes that measure their ability to defend themselves.

Saber is designed, primarily, to represent a conventional theater-level campaign. However, nuclear, biological and chemical (NBC) weapons, and aircraft or ground units capable of delivering these munitions, are included in the model as well. Including NBC weapons in the model is intended to increase the realism and represent the full range of weapon employment options. The first strike use of NBC weapons is definitely not recommended, but using them is possible--even though their use would be a violation of the Geneva Convention. NBC weapons are targeted against hexes or combat units and their use would result in attrition, movement delays and have lingering effects. These lingering effects are modeled by use of an attribute called 'persistence-time', which reflects the time remaining, after weapons release, that a hex will be subject to the effects of the attack (Horton:118). The use of NBC weapons would probably create more questions than answers involving support, decon teams, specific location of units, training, and in determining the variables used for validation.

Another aspect of the broad scale combat environment involves the degree to which land and air assets interact. One of the reasons Ness developed, or enhanced, the land battle of Agile was that it modeled the land portion so poorly (Ness:5). Often the movement of land units was preprogrammed and progress was a reflection of the air campaign alone. However, the limited interaction between land and air assets was not viewed as a serious limitation because Agile was after all, an air power employment exercise. Mann combined Ness' improved land methodology with the concept of an airland battle so that Saber could represent an airland campaign requiring greater interaction of ground and air forces. External to the simulation, during the planning phase discussed in section 4.3.3, the air and ground component commanders (CACC and CGCC) should be considered equals in the generation and execution of the airland campaign and in the selection of targets. Therefore, the judgement and decisions of both commanders would determine the progress made during the game. Even though progress or movement on the battlefield should not be used as an MOE, coordination and the effective use of men and materiel is a valid learning objective.

Internally, Saber allows the closer interaction of ground and air forces. Close air support (CAS) sorties need to be requested, by the CGCC who represents the individual unit commanders, and scheduled in support of ground units. CAS strike missions contribute directly to the combat power of the unit supported, resulting in direct attrition and can be used to slow an enemy's advance. Ground units can also defend against air attacks by using their anti-aircraft artillery or with surface-to-air missile systems. The movement of supplies is also a coordinated effort between ground and air assets.

Some limitations still exist between the interaction of the land and air forces due largely to the computer processing involved. Saber is event driven and does not use parallel processing. The event sequence establishes the air battle to be fought first, followed by the land battle. Parallel processing would allow both battles to occur simultaneously. For example, there is no way of modeling an aircraft that is destroyed after its mission is completed. The simulation will compute a certain percentage of aircraft lost and the assumption is that these losses occurred prior to the attack. Another example where parallel processing would be beneficial is during the attack sequence. The enemy would, probably, find it very difficult to concentrate on firing at a target when its head is being kept down by an airborne attack. It should be understood, however, that the lack of parallel processing is not a weakness in the design concept or a lack of proficiency on the part of the Saber designers, but rather a limitation imposed by the existing computer technology.

4.6 Logical Representation of Model Design and Mathematical Algorithms. The model design was examined for its logical representation for two reasons. The first reason is that the model design and flow was not explicitly developed in any of the previous thesis efforts. Previous efforts concentrated on individual sections of the model and not the overall design. The model design and flow provided in this section was developed by combining relevant information from the other theses and should be beneficial in the documentation process. The second reason the model design is being examined is to ensure it is understandable, and the sequence of events are presented with a logical flow. The mathematical algorithms were examined to determine their source, relevance and function.

4.6.1 Model Design. Figure 1 (Section 1.5) shows the layout and flow of a 'typical' simulation model. The Saber model differs from this typical sequencing in one important area: the relationship between the pre and post processors. Normally, the post processor is used after the processing--hence the name post--or execution of the simulation. In the Saber model, on the other hand, a good deal of what are considered post processor functions, e.g. graphics displays, status reports, charts, graphs, analysis information, and other output, are accomplished prior to model execution. The reason for this is that the information needed by the post processor is located in the flat files generated by the preprocessor. The simulation functions as a book-keeper; keeping track of internal objects, crunching numbers and then generating output in the form of updates to the simulation database. The post processor is only dependent on the simulation to show changes in the combat environment; to generate output, analysis files and charts, and; to generate the simulation animation. The justification for structuring the model with the pre and post processor so closely linked is due to the seminar nature of the wargame. During the preparation and planning phase of play, that could last a week, the students need access to the material relevant to the game.

A good deal of the information needed is provided by Day 0--the baseline scenario--output reports, and by the graphics display. Therefore, the graphics display would need to be available throughout the entire planning phase. Additionally, the player/simulation interface is accessed through the graphics programs; instead of through a separate 'stand alone' program. In a typical model, the simulation would have to be run--first--in order to get all of the wargame information. With the Saber model the initial scenario is pre-canned and is provided soon after the computers are turned on. Figure 2, on the next page, is more representative of the way the Saber model is structured.

Figure 2 outlines the flow of the Saber program beginning after the pregame preparation. Following the initial planning phase, after the player have gotten acquainted with the Saber model, the players are ready to input their missions, including: air and land unit movements, aircraft strike and support packages, and logistics support. When all of the missions are

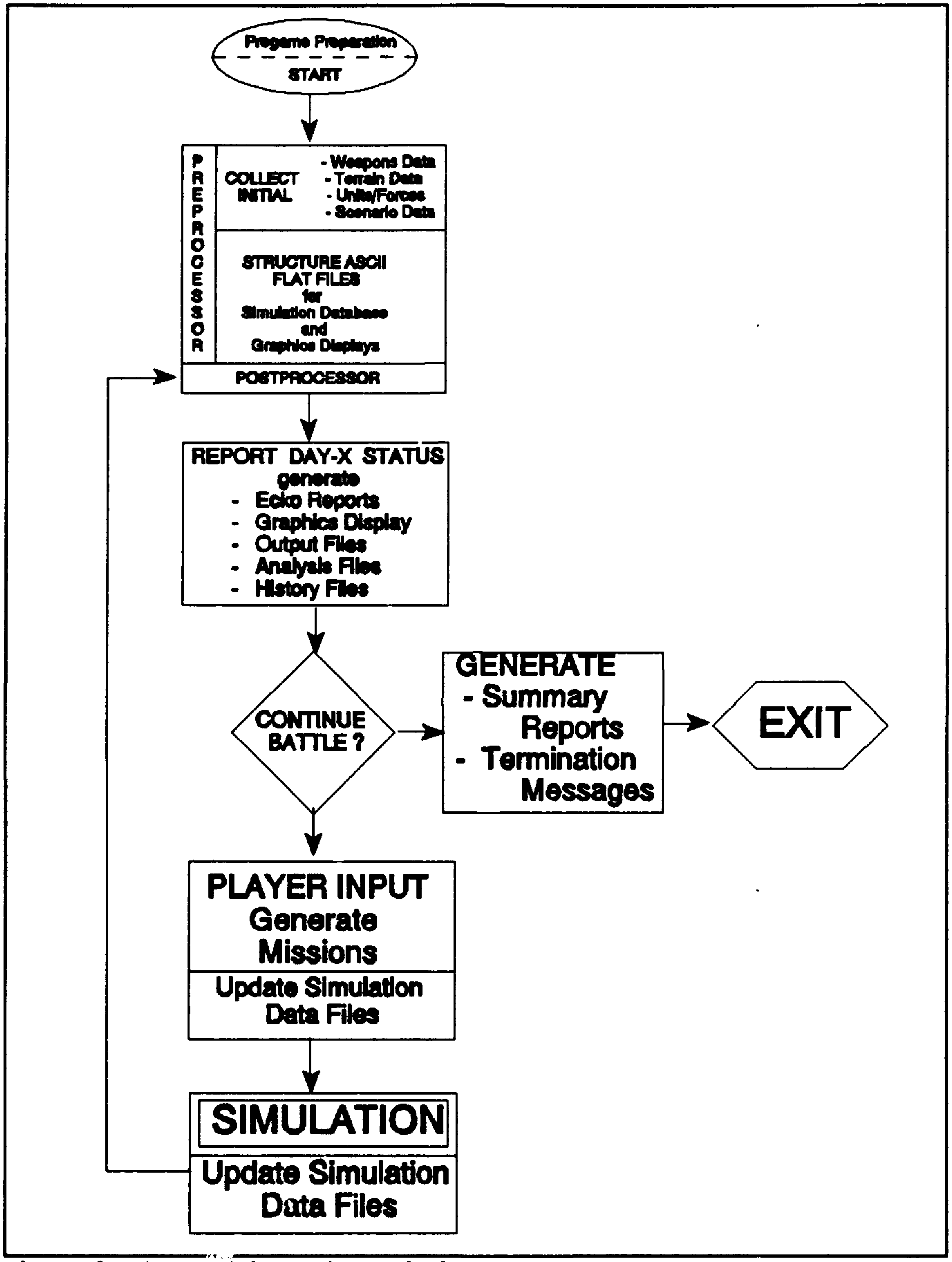

Figure 2 Saber Model: Design and Flow

generated the simulation files are updated and the execution, or simulation, process begins. After the simulation is completed the data files are again updated and passed to the pre and post processor functions where the output, in various forms, is provided to the players--which completes the cycle. In between the output from one day's activity to the generating of new missions, a mechanism should be provided--as yet there is none--that would specify when the wargame is terminated. This mechanism could be as simple as a "Do You Want To Continue? Y/N" message. By pressing "N" the simulation would terminate and provide summary reports and/or termination messages. The generation of summary and other output status reports, is being examined as a proposed follow-on thesis effort and the mechanism--such as the one mentioned above--should be included in that effort.

4.6.2 Mathematical Algorithms. The mathematical algorithms, functions and equations used in the Saber model were examined for their logical presentation and documentation as part of this section. The attrition, posture and movement algorithms for land forces are based on Lanchester equations. Lanchester ascertained that the ratio of an opposing unit's combat power is directly related to combat losses, forward movement and the projection of power, and changes in a unit's posture. Ness adapted the equations used in the Agile model when he developed his land battle. In his thesis, Ness provides good documentation related to the use, development and rational of equations used (Ness:66-71).

Sherry concentrated on the air portion of the simulation, but also modified some of land movement algorithms to reflect the changes made in the orientation of the hexagonal grid coordinate system. The aircraft attrition, movement, and effectiveness algorithms contain a number of stochastic processes and were outlined by Mann (Mann:116,177). Sherry coded the algorithms developed by Mann, and; because Ada does not contain intrinsic probability functions, wrote code for a number of probability distribution functions. The probability distribution functions written include: the Uniform, Poisson, Normal, Binomial, and Bernoulli. Coding these distribution functions did not present much of a problem; because the equations are readily available in many probability or statistics books (Mendenhall:749,750). Mann, in addition to providing the types of algorithms and functions needed, also documented, and gave an indepth review, rational development, and examples for the equations, functions, and algorithms presented.

Overall, the equations, functions and algorithms used in the Saber model were found to be understandable, rational, and most important, well documented; with the exception of the attrition formula (discussed in Section 5.3.6) that was found to be in error.

4.7 Selection of Input Data. One of the primary constraints of the data base construction was that it come from readily available unclassified sources. The requirement that information come from unclassified sources was imposed in an effort to make the simulation accessible to a larger number of potential users. The information obtained from, credible, unclassified sources should not be considered bad or inaccurate, but rather generic in nature or characteristic of a particular class of weapons. Using generic information can also reduce the need to track the individual characteristics of a number of similar weapons system.

The are a number of ways to declassify a source, such as giving ranges to the systems operating limits instead of actual values. Suppose, for example, an aircraft had a flight envelope extending up to 58,000 feet, with a range of 1550 miles and a maximum airspeed of 1.27 mach. An unclassified version of this aircraft might list its altitude limit as 'high' (which could be defined from 40,000 - 60,000 feet), its combat range as 'long' (defined as > 1200 miles), and its airspeed as 'supersonic'. These figures, while generic, would allow the essence of the aircraft to be characterized.

Horton was assigned the task of developing the database and determining the type of information needed for the simulation. He was also required to structure the database to allow for ease of information input and retrieval.

The type of data included: information on the terrain, used for the graphical map display and movement algorithms; weapons data, both air and ground direct fire weapons, and; unit data, consisting of the force structure, composition and components.

Information on the theater and ground map was extracted from Jet Navigation Charts (JNC) and Operational Navigation Charts (ONC). A JNC chart is scaled 1:3,000,000 which means that one inch represents about 41 NM; an ONC chart is scaled 1:1,000,000 so each inch represents about 14 NM (or 25 km which is the size of the hexes used in the terrain map). These charts are readily available from nearly any base intelligence shop, base operations, and most flying squadrons. Information on bases, such as number of runways, runway length, runway surface, and fuel types, is available from an assortment of Flight Information Publications (FLIP) published by the Defense Mapping Agency Aerospace Center (DMAAC). Some specific publications that are useful include VFR and IFR Supplements and Standard Instrument Departure (SIDS) booklets.

Horton realized the importance of collecting information from reliable sources: as an aid in verification, validation and realistically representing the combat environment. He, therefore, collected his weapons systems data from recognized sources--recognized in the sense that they have been subject to, and accepted, by the defense department and other members of the military community. Most of the aircraft information came from Dunnigan's book *How to Make War, 1988*. An alternative sources for aircraft information including weapon capabilities, payloads and performance factors was found in an assortment of Jane's Information Group publications called *Jane's All the Worlds Aircraft*. Information on predominantly ground systems was also found in some of Janes' publications including *Jane's Military Vehicles and Ground Support Equipment*, by Taylor, and; *Jane's Weapon Systems*, by Blake. Sources other than Jane's included: *The US War Machine*, by Dornan, and specific information on surface-to-air missile systems was found in *The World's Missile Systems*, by Korb. Overall, there was a good deal of information/data collection involved in developing the weapons database (Horton:59). Unfortunately, some of this information is outdated or incomplete and a complete review and possible culling of the weapons systems database should be accomplished before the game is exercised.

Information on land units involves their identification, classification (type of unit), position and strength. Most of this information was provided by the Wargaming Center or adapted from the Agile-Dragon wargame. The Wargaming Center uses a number of unclassified sources containing information on the Korean theater of operation, from which to develop the type of information needed in the Saber simulation (Buttala).

Collecting data for the simulation was only part of Horton's thesis effort. Developing a method to import and retrieve this data was another challenge. Horton designed the database with the goal of allowing "Saber to be executed on as many different hardware platforms as possible by not tieing it to any specific application package" (Horton:54). Saber uses, what is known as, the Oracle RDBMS as a repository for data, but operates on data stored in ASCII flat files using dynamic storage techniques. Uploading and downloading data and files into Oracle is accomplished using Oracle Structured Query Language (SQL) commands.

Although, it took only a few paragraphs to describe the database and its structure, it should not be assumed that there was not much involved in its development. Actually, the development of the database and the collection of data was a considerable task and occupied a great deal of Hortons total thesis effort.

V Credibility Based on the Correspondence Between the Model and the Real World

This chapter discusses the credibility of Saber based on its ability to model possible real world events. Saber is designed to capture the essence of theater-level conflict and the following four sections examine the efforts devoted to ensuring the model provides a good representation of theater-level warfare.

5.1 Evidence of a Verification Effort. One of the purposes of this thesis was to provide evidence that an initial review of the Saber model was made and to develop the documentation necessary to identify the extent of that verification effort. Accomplishing this purpose was simplified by the verification efforts of all of the contributors to the development of the Saber model. Because it was understood that Saber would develop in a continuous process and that documentation would be vital to follow-on efforts, each previous thesis write-up or supporting document contains one or more sections on the verification efforts made during the development phase.

The definition of verification was provided in section 2.2.1 and involves ensuring the 1) assumptions, 2) scenario development, 3) documentation, 4) database design, 5) computer coding, logic and algorithms, and 6) simulation flow, are consistent with accepted military doctrine and reflect the intentions of the model designers. Each of these six areas have been examined, and written about, either in the previous chapter or in Chapter 6 to follow. Based on the documentation provided on these six areas, there is no reason to suspect that Saber will be unable to function as intended by the designers and within the constraints of sound military judgement and doctrine.

5.2 Evidence that the Results are Statistically Representative. Because the Saber simulation was not operational at the time this report was written, it was not possible to gather any quantifiable evidence that the results are statistically representative. However, the mathematical models and algorithms used in the model were examined and there is no reason to expect that the results will not be statistically representative when the simulation model is completed. One of the algorithms that could be examined in detail was the random number generator. The random number generator is important; because many of the stochastic processes require a value from a random draw (a random statistic taken from a uniform distribution between the values of 0 and 1). Because Ada does not have an intrinsic random number generator, Sherry had to code a uniform distribution that could be used for the random draws. Appendix B contains a number of computer programs and the analysis conducted in an attempt to show that the random number generator coded by Sherry is representative of a uniform distribution.

Movement and the attrition of air and ground objects were the primary areas of concern for determining if output from the model was statistically representative. The mathematical equations used for the movement and attrition of land units are, in almost all cases, deterministic. Attrition is based on force ratios, terrain characteristics, unit posture and engagement type, all of which are constants for a given scenario. Land movement should be based on the type of unit, engagement status, mission, trafficability and weather. The only random variable in the equation is the value for weather; however, "weather has the least effect on movement (Ness:61)" and was not included when Ness' movement equation was modified for the Saber model. Therefore, concerning the movement and attrition of land units, for a given scenario the outcome is predictable with no variability expected.

Although the land battle is largely deterministic, there are a number of stochastic processes involved with air assets. The movement and attrition of aircraft (and the attrition of land units caused by attacking aircraft) are based primarily on probability functions. In order for an aircraft to fly a mission it must first be mission capable, and part of being mission capable is the completion of required maintenance. Maintenance times are computed using one of three, controller selected, probability distribution functions: normal, poisson or uniform. Using these distribution functions could add considerable variability to the model by affecting the number or types of aircraft available to fly missions; although, such variability should not be considered unrealistic.

The ability of an aircraft to get to the target is also conditional on random events. For example, some aircraft will be forced to 'weather abort' and others will be forced to abort due to maintenance problems. In addition, an aircraft strike package enroute to the target is subject to being intercepted and/or killed by enemy CAP or DCA aircraft or by area defense SAM systems. In the target area, the strike aircraft are also subject to point defense SAM and anti-aircraft artillery. The effectiveness of an aircraft strike package is, therefore, dependent on 1) the probability of the aircraft to penetrate the enemy defenses, 2) the probability of finding the target, 3) the probability of a given aircraft to hit the target based on the weapons' CEP (the Circular Error Probable is the distance from a target inside of which 50% of the weapons' strikes will fall, and is used as a measure of weapons effectiveness) and the size of the target, and 4) the probability that the target is destroyed given that it was hit. Each of these movement and attrition processes are dependent on either probability distributions and/or random draws.

Mann did a good job of defining the probability distributions and the stochastic processes used in the model, explaining the algorithms, and providing examples of how the algorithms work (Mann:116,177). Sherry was responsible for coding the algorithms, but, unfortunately, did not have time to complete the coding of all of the algorithms. Completing the coding of these algorithms should be accomplished by follow-on efforts. The correct coding and individual testing of these algorithms should be given considerable attention; because it would probably be difficult to track or identify problems once the algorithms are integrated into the model. For example, Mann warns that when using the binomial distribution along with a random draw to computing aircraft air-to-air and ground-to-air attrition, it may be possible that the number of aircraft killed exceeds the number of missiles fired;

thereby raising serious questions as to the credibility of the model (Mann:134).

In order to test the algorithms before and after they are integrated into the model there should be a mechanism that would turn off the stochastic processes. Turning off the stochastic features and using deterministic values in the attrition and movement algorithms could provide a baseline test case for further testing. Once the baseline is available it would be much easier to determine the variability induced by using stochastic methodologies. In addition to being used for testing, using the deterministic or stochastic algorithms should be included as an optional feature of the model. Suppose, for example, two seminar groups wanted to compete or just compare their performance. Using the deterministic option would allow results to be compared with random influences kept to a minimum. However, the use of the deterministic or stochastic option should be left to the discretion of the game director or controller, so that the training objectives of the game are not compromised.

5.3 Evidence of Sensitivity Testing. Sensitivity testing is another area that must be left until the simulation model is complete. At that time there are a number of factors that should be examined to ensure the model operates in a consistent manner; without excessive variability or other unrealistic results. In order to accomplish sensitivity analysis a baseline model should be developed. One of the features of the baseline model would require that the stochastic processes be turned off. It might also be beneficial to use a scaled down version of the theater-level scenario in order to allow tracking of entities. The proposed prototype design, discussed in Section 8.1, might be helpful as a start in developing the scaled version of the baseline theater-level model. Sensitivity testing would then involve running a number of iterations using different variable values, such as a high, low and average value. After the iterations are complete, comparisons could be made to determine what factors are most affected and an expected range could be determined. However, if variables are changed or calibrated, additional iterations would be required to determine synergistic relationships. The following six factors were identified as having the most impact on the model or the simulation and should be considered for testing with this baseline model.

5.3.1 Weather. There are a number of processes that are dependent on weather, including: movement rates, intelligence collection, the ability of an aircraft to take-off and land, and attrition. One method of checking the effects of weather is to run four iterations of the baseline simulation. The first iteration should assume good weather; the second fair; the third poor, and; the fourth iteration should use the variable weather patterns. The results using variable weather patterns should fall between the high (good) and low (poor) weather results.

5.3.2 Terrain. The processes that are dependent on terrain include: movement rates, and attrition. Terrain features can also be used as targets that will tie up resources that could be used elsewhere. The effects of terrain could be tested by running one iteration with a bald earth (the topography is devoid of terrain features) and comparing that with the results obtained when using the programmed terrain features. The lack of terrain should result in faster movement rates and higher attrition.

5.3.3 Movement Rates. The are a number of different units modelled in the wargame including: armored, infantry, light infantry, etc. It should not be expected that each of these units would travel at the same speed. The ground speed of these units is determined by controller input and a consensus should be reached as to what values are most appropriate for different division or unit types.

5.3.4 Chicken-factor. The chicken-factor, also called breakpoint by combat modelers, is defined as a threshold point at which time a commander will breaks contact, withdraw, or retreat, from combat. The decision by a commander to change posture from attack to defend or from defend to withdrawal is often dependent on many factors including: tactics, firepower or combined combat power, resolve, or attrition. Although there is considerable controversy involved with using attrition as the sole predictor of the breakpoint, there is additional evidence "that percent casualties may still be the best criteria to use" when determining the breakpoint (DA:28-37). The typical range for breakpoint is between a 5% and 50% reduction in starting firepower, with 30% the value most often used, and the breakpoint figure is often lower for an attacking versus defending troop status (Ness:27, DA:28-37). The chicken-factor/breakpoint is a user defined value in the Saber model. The allowed range should be from 10% to 40% and the suggested values are 20% for attacking and 30% for defending forces. Sensitivity testing should be conducted to determine the amount of variability present when other values are used.

5.3.5 Breakdown point. For this thesis the breakdown point of a model has two meanings defined by scope. The first definition of breakdown is that point at which a unit is no longer able to engage in combat and is considered destroyed. The breakdown/destroy value was assigned a numeric value in Ness' model, but has been redefined to be a reduction, from the original firepower of a unit. Although a value of 80% is currently used, like in the Agile model, the actual value is determined by controller input. Sensitivity testing could be accomplished to see how critical the selected value is to the outcome of battle engagements.

On a larger scale, another meaning for breakdown is the point at which the simulation is no longer able to realistically model the combat environment. Saber is designed to model attrition, i.e. the destruction of individual component, not damage to the unit. If, for example, a unit contains ten tanks and suffers 40% attrition, Saber considers that the unit has lost four tanks. Another way to look at the loss would be to assume that each tank lost 40% of its combat potential. The question could then be asked, "Is a unit with six good tanks better than a unit with ten tanks that are operating at 60% efficiency?". In other words, there has to be a point where the damage to an asset is so high that it is no longer operational--consider an aircraft that is airworthy but not combat capable. And, there has to come a time when the unit is no longer able to function with the resources available--for an individual unit this is the destroyed point discussed in the previous paragraph. There must also be a time when the model is no longer able to predict the attrition caused by equipment that should no longer be operational and the simulation results become unrealistic, and the credibility of the model becomes suspect. Sensitivity testing should be conducted to determine when the results of the simulation are outside of a specific range of operation and are no longer realistic or credible.

There is very little guidance on what the precise values are for many of the variables, so the values selected will have to be based on expert opinion, professional expertise, an educated guess or intuition. Morris writes that "modeling is and, for greatest effectiveness, probably ought to be, an intuitive process for the experienced..." (Morris:707). Therefore, providing a 'best guess' should not be considered inappropriate and in most cases should not distract from the credibility of the model, provided the reasons are logical and documentation is provided.

5.3.6 Attrition Formula. Ness based the attrition of land units on Lanchester equations and a comparison of the relative combat power of opposing forces. The formula for computing attrition is given as (Ness:67):

$$ATR(\mathit{blue}) = \frac{CP(\mathit{red})}{CP(blue)} \times .01 \times CRA$$

where the factor ".01" is used to change the attrition value to a percentage, and CRA is a "Combat power adjustment" factor that ranges from 1.0 to 9.0 based on the combat power ratio of Red/Blue forces, such that,

$$CR(\mathit{blue}) = \frac{CP(\mathit{red})}{CP(blue)} \quad \text{and,}$$

$$CRA = \begin{cases} 1.0, & CR(\mathit{blue}) < 1.0 \\ CR(\mathit{blue}), & 1.0 <= CR(\mathit{blue}) <= 9.0 \\ 9.0, & CR(\mathit{blue}) > 9.0 \end{cases}$$

The same calculation is then performed for Red forces by switching *red* for *blue* and *blue* for *red*.

Taking an extreme case, where Red forces are outnumbered ten to one, a range can be determined for the attrition equations. Using the above equation for this example results in a 90% attrition rate for Red and a .01% attrition rate for Blue. However, an attrition rate greater than 80% results in the destruction of the unit, so in this case the extra 10% would be overkill; also, a blue rate of nearly zero might appear overly optimistic in this situation. Therefore, there is a controller supplied minimum and maximum attrition value used for engaged forces per period. It is the values selected for the minimum and maximum attrition level that should be examined to ensure they fall within a reasonable range.

Before the attrition equation is used in the Saber model it should also be recognized that the equation represents attrition for a 12 hour period. Therefore, because Saber is a higher resolution model than Agile (the equation was developed for the Agile land battle), and uses a minimum period of two hours, the results of <u>the attrition equation must be divided by six</u>.

5.4 <u>Evidence of a Validation Effort.</u> Sargent's tutorial states that "a model should be developed for a specific purpose or use and its validity determined with respect to that purpose" (Sargent:33). The purpose and intended use of the Saber model have been clearly described in previous sections of this thesis. What needs to be determined is the ability of Saber to achieve the desired objectives and produce valid results. The Wargaming Center, as the intended user, has provided guidance on what is expected from a combat model. The Wargaming Center explicitly states that "for the purpose of providing support to the decision making environment of a wargame, our metric is that the model produce credible results" (Lavoie). The ability of Saber to produce credible results is one of the primary purposes of this thesis effort, and there is no reason, at this time, to suspect the results from Saber will be anything but credible. However, final judgement must be reserved until the simulation is complete and all the pieces of the model are integrated.

The final judgement, as to the credibility of the Saber model, should be left to the Wargaming Center for three important reasons. The first reason is the excessive time required to accomplish a comprehensive validation process. There is very little chance of completing a thorough verification and validation process in the time provided to complete an individual thesis effort. The second reason the Wargaming Center is most suited to perform the validation involves the resources available. The validation of a model often relies on the opinions of 'experts' and the Wargaming Center is staffed with personnel deemed proficient in all matters of model development and construction as well as individuals with expertise in the application of combat power and the war fighting arena. The third reason the Wargaming Center should accomplish the validation process is that procedures are already established that require the testing of models before they are used. The procedures referred to are located in (DAF,1988b:5) and require that "rigorous evaluations to examine all components of the exercise (support software, equipment, written material, procedures, personnel, etc.) as an integrated whole to ensure the components are compatible and meet the exercise objectives."

Although the final validation process should rest with the Wargaming Center, it is understood that the developers of Saber are not exempt from ensuring the individual contributions to the model are credible and documented. As mentioned many times, documentation is critical to establishing the credibility of a model and in simplifying the enormous task of model validation.

VI Credibility based on Model Support Structure, Documentation and Reporting

This chapter discusses the last of the three primary areas of concern when considering the credibility of a model, credibility based on Saber's support structure, documentation and reporting of strengths and weaknesses. An abridged version of this section can be found in Table 3, Appendix A.

6.1 Establishment of Support Structures to Manage the Simulation's Design, Data, and Operating Requirements. The purpose of this factor is to identify the agency responsible, and the depth of responsibility within that agency, for ensuring the Saber model is maintained--as opposed to laying fallow on a shelf collecting dust. A number of questions were asked concerning this factor that are answered in the following sections.

6.1.1 *Who is the responsible agency for the Saber model?* The Wargaming Center at Maxwell AFB, AL is the sponsor of the Saber AirLand Combat model and will accept responsibility for the model once it is completed. The Wargaming Center follows the guidance in AU Regulation 53-7 when developing and conducting wargames and exercises.

> [AU Regulation 53-7] defines responsibilities and establishes procedures for scheduling and conducting computer-assisted wargames and exercises. The primary purpose of this regulation is to define the relationship between the Air Force Wargaming Center (AFWC) and Air University (AU) exercise sponsors in the development and conduct of computer-assisted wargames and exercises. (DAF 1990:1)

Two operating instructions (OIs), AFWC OI 55-1 and AFWC OI 55-3, expand on the requirements of AUR 53-7 and are beneficial in answering questions related, respectively, to the exercise design team construction and the wargame development process (DAF,1988a,1988b).

6.1.2 *What are the responsibilities of the Wargaming Center?* The Air Force Wargaming Center "designs, develops, and maintains computer-assisted wargames to support AU sponsors and the educational objectives of the sponsor's programs" (DAF:90:2). This responsibility extends through all of the phases of the wargames' "life cycle" as outlined in AFWC OI 55-3--from inception to retirement.

Identifying the key 'players' in the development and execution of a computer wargame or exercise will answer many of the management and support questions raised in this section. The key players include: AU Exercise Sponsors, the Exercise Coordinator, the Exercise Director, and the Exercise Design Team.

6.1.2.1 <u>AU Exercise Sponsors.</u> Exercise sponsors are the intended users, such as the Air Command and Staff College (ACSC) or the Air War College (AWC), of the wargame or exercise that is supported and maintained by the Wargaming Center. Together the exercise sponsor and the Wargaming Center develop an exercise requirements document "detailing the objectives, purpose, requirements, and responsibilities for each wargame or exercise. The exercise requirement document is the contract between the AFWC and the AU exercise sponsor (DAF,90:1)." Based on the requirements of the exercise sponsor the AFWC will decide the type of wargame best suited for the proposed exercise. It is understood that the exercise sponsor will not develop independent wargames requiring the support or assistance of AFWC personnel or equipment (DAF,90:2).

6.1.2.2 <u>The Exercise Coordinator.</u> The Exercise coordinator is "the individual designated by the sponsoring organization to be the principle point of contact (POC) between the AU exercise sponsor and AFWC (DAF,90:1)." According to AUR 53-7 the exercise coordinator:

a) Works directly with the AFWC exercise director to develop the exercise requirements document.
b) Is an active participant in the exercise design team.
c) Works directly with the AFWC exercise director to ensure the exercise meets educational objectives as stated in the exercise requirements document.
d) During game execution, is the final authority for decisions affecting attainment of educational objectives or the sponsor's curriculum or schedule.
e) Certifies that the exercise is ready for use.
f) Provides a critique of the exercise to include recommended improvement areas, if appropriate.

6.1.2.3 The Exercise Director. The exercise director is an individual, designated by the AFWC, responsible for conducting the exercise. The Wargaming Center assigns an exercise director to each wargame and AUR 53-7 states that the exercise director:

a) Works with the exercise coordinator to develop the exercise requirements document.
b) Works closely with the exercise coordinator to ensure the exercise meets the requirements of the sponsoring agency as stated in the exercise requirements document.
c) Is the final authority for decisions regarding the model/simulation or computer support during exercise or wargame execution.

6.1.2.4 Exercise Design Team. AFWC OI 55-1 specifies the composition and function of the exercise design team. The director of the Air Force Wargaming Center determines which exercises and wargames, (that are identified in the exercise requirements documents for the year), the Wargaming Center is able to support. Once the wargames/exercises are identified, the Deputy Director for Operations designates an Exercise Director for each wargame to be supported and asks the different AFWC divisions to provide names so exercise design teams can be developed. Design teams are composed of individuals from the following divisions: intelligence; operations support; operations analysis; applications software; a Navy representative, if the wargame involves naval assets, and; an Army representative, if ground forces are employed. It is realized that the design team is instrumental to the effectiveness of the wargame, so measures are taken to enhance the coordination and cooperation of team members. For instance, in the areas of exercise development and execution, team members are responsible first to the exercise director and then to their division chief. Every effort is also made to keep the integrity of the design team intact. Prior coordination is required in order to remove or replace any design team member. (DAF,1988b)

According to AUR 53-7, the design team, with assistance provided by the sponsor, if needed:

a) Prepares exercise instructions and scripts.
b) Builds the exercise control database.
c) Develops scenario.

d) Establishes command, control, and communications procedures for the exercise.
e) Develops or modifies computer software appropriate for the exercise.

It should be obvious, from reviewing this section, that the Air Force Wargaming Center is more than able to provide the support structure required to manage the Saber model.

6.2 Development of Documentation to Support the Information Needs of Persons Using the Simulation. The previous section identified two 'users' of the wargame simulation--1) the exercise director along with the exercise design team, and 2) the exercise coordinator. The next sections identify the specific information needs of the model users and explains how the information needs of these users are met.

6.2.1 Information needs of the Exercise Director and the Exercise Design Team. It is important to note that Chapter 7, outlining the AirLand Methodology, is intended to support the needs of the exercise director and the design team, by explaining the principle concepts and scope of the Saber model. In addition, a document has been developed, as part of this thesis effort, that contains 1) the program and variable listings, 2) the design structure, 3) a list of input data and routines needed to run the simulation, and 4) a library of definitions.

As discussed in the last section, it is expected that the exercise director and design team will be able to generate the necessary operators', players' and analysis manuals using the expertise and talent of the individual team members. Operating 'quirks' and weaknesses or limitations of the Saber model should be made evident by reading through the next section (6.3) of this thesis.

6.2.2 Information needs of Exercise Sponsor/Users. The Catalog of Wargaming and Military Simulation Models is a good reference for determining if a model is suited to the needs of a potential user (FSRPD). The catalog contains the descriptions of many models, simulations, wargames, and exercises used within the military community. Simulations are classified based on a

SIMTAX taxonomy developed by the Military Operations Research Society (MORS) and the J-8. The SIMTAX Taxonomy Worksheet is fairly standard for all models and provides valuable information about the models' function, purpose, and design. A sample version of the Saber Taxonomy Worksheet, very similar to the TWX/Agile worksheet, is provided below. It should be remembered that this worksheet reflects the status of the Saber model as of 15 February 1992. Because some parts of the Saber model are not complete, they are listed in the worksheet as INC-incomplete or UNK-unknown.

SABER TAXONOMY WORKSHEET

TITLE: **SABER**

MODEL TYPE: Training and Education.

PROPONENT: Air Force Wargaming Center (AFWC), Maxwell AFB, AL 36112.

Points of Contact: Col M. Heenan, AUCADRE/WG, MAFB, AL 36112
(205) 293-6618, AV 493-6618.
Lt Col Buttalla, Exercise Director X6336
Maj Wolczek, Analysis X6528
Maj Sachs, Systems X7926

PURPOSE: Saber is a seminar exercise driver for the Theater Warfare Exercise. The intent is to expose players to the high-level decision making process required to plan and execute a theater-level airland campaign.

DESCRIPTION:

Domain: Land and Air (some Naval carrier air and satellite operations).

Span: Theater level (Korean theater for the first available scenario).

Environment: Day and night operations, includes weather and terrain factors.

Force Composition: Combined forces BLUE (allied forces), and RED (North Korean/Soviet) operational control of air and ground assets.

Scope of Conflict: Conventional preferred. Authorization is required to schedule and load nuclear, biological and chemical (NBC) munitions.

Mission Area: All conventional air and land missions at the theater level--air-air, air-ground, suppression of enemy air defense sites, ground-air, and ground-ground.

Level of Detail of Processes and Entities: Saber extends control down to aircraft sorties and sortie packages--not to tail numbers. Land forces are aggregated at the division level.

CONSTRUCTION:

Human Participation: Required for decisions and processes.

Time Processing: Dynamic, event-step driven. Within the events the game is broken into 12 two hour cycles--eight day and four night. A game period is controller specified and can range from a single two hour cycle to a number of days. The order of battle for the next game period is determined by the completion of both Red and Blue player inputs and output provided by the simulation.

Treatment of Randomness: Deterministic with some stochastic (random) processes included for: actual weather, aircraft maintenance, turnaround times, probability of kill, and movement.

Sidedness: Two-sided, asymmetric, reactive. Red side played by one or more sponsor/user faculty members or members of the AU Intelligence Division.

INPUT: The Blue side has two phases of play. The first phase is coordinated by the air and ground component command staffs. In this phase apportionment and game plans are addressed. Input includes: aircraft mission inter and intra-theater air and surface movement of logistics, aircraft beddown locations, and ground movement. The second phase involves play at the next level down--the air control centers. Input at this level consist of target identification and the designation of aircraft strike and support packages.

OUTPUT: Graphical display of theater map, unit locations and status. Animation of unit movement provided. The generation of printed reports is INC...[but should be automatically generated at the end of each game day (day and night cycle or selected cycle length). Reporting should be provided on virtually every aspect of game play. Selective on screen viewing of any output report should also be provided. Saber should provide reports in three primary areas: 1) operations, 2) intelligence, and 3) logistics. In addition some analysis information should be available to help players analyze their overall plan for the next game period.]

HARDWARE AND SOFTWARE:

Computer (Operating System): Operates on a *Sun 4*, or compatible work station.

Storage: UNK...[approximately .5 megabytes for execution and 3 MB for disk work space.]

Peripherals: Terminal, printer and monitor (color optional).

Language: Verdix Ada, Version 6.

Documentation: INC...[Overview, Operator, User, Data Base, Software, Model Code, Programming, Utility, Analysis, and Instructional manuals should be made available.]

SECURITY CLASSIFICATION: Unclassified to include the Korean scenario and the database structure and content.

GENERAL DATA:

Date Implemented: UNK...[expected by Jan 93]

Data Base: Over 55 files in nearly 1.2 MB of storage. About two man months would be required to research and replace the data base.

CPU time per Cycle: UNK

Data Output Analysis: Monitor program and backup files of each game cycle to recover from errors and develop the animation. Formal analysis is accomplished by the Exercise Design Team as a validation step. Analysis of output, during play, is accomplished as part of the academic exercise.

Frequency of Use: At least once a year by each user.

USERS: UNK... [users that might be interested in Saber include the: Air War College (AWC), Air Command and Staff College (ACSC)]

COMMENTS: Managed through the review and configuration control board at the Air Force Wargaming Center, Maxwell AFB, AL.

6.3 Disclosure of the Simulation's Strengths and Weaknesses. The primary strengths of a model lie in its ability to capture or represent the situation it was designed to model. Secondary considerations related to the strength of a model involve 1) the ease of operation, 2) user friendliness, 3) having an understandable design, 4) the ability to easily update and improve the model, and characteristics of 5) accessibility, flexibility, and portability. Saber is designed to capture the essence of theater level conflict and its strength in this respect, has been discussed throughout this assessment framework, as have its operational factors. This next section, therefore, concentrates on the limitations and weaknesses of the Saber model.

6.3.1 Limitations and Weaknesses. An aggregated, low resolution, theater level educational/training combat model, such as Saber, is designed to capture the essential nature of large scale, combined arms conflict. Because there are too many factors and individual entities to reasonably consider in a large scale battle, many aspects of combat are grouped/combined, simplified, modified or ignored. Unfortunately, individual differences and some "basic combat processes" are often lost in an aggregated model (Hartman,b:2). Most of the time this lost information is not overly important to the model--if it was that important it probably would not be excluded, unless it was beyond the control of the designer. Lost information is, however, considered a limitation in representing the 'big picture'.

Some of the limitations listed below might seem trivial, unimportant or 'nit-picky', requiring little more than a safe assumption to be made. However, the position taken for this section is that, at least some thought and consideration has been given to all of the limitations and weaknesses listed and the likelihood of questions such as: "But have you considered [this]...? or Does it do [that]...?" should be reduced to a minimum. The limitations identified in previous sections will be included in this section in order to have a consolidated listing. The following list is not--probably could not be--all inclusive, but it manages to highlight most of the limitations or weaknesses found while sifting through the compilation of information provided on the Saber model.

6.3.1.1 Limitations and Weaknesses from Previous Sections. The following list was developed from limitations identified in Chapters 4, 5 and 6 and are identified by section.

1. Internal MOEs would be difficult to develop due to the unclassified nature of data, proposed battle duration, and the stochastic nature of the model (Section 4.2).

2. Interface between the theater campaign and the 'real world' is not explicitly modeled (Section 4.3.1).

3. Combat units are aggregated at the division level and firepower is defined by direct fire components, neglecting many other factors (Sections 4.3.1, 4.5).

4. Limitations in terrain representation include: color scheme, two-dimensional landscape, obstacles not annotated, and only six directions of movement (Section 4.3.5).

5. IFF/Fratricide issue is not addressed (Section 4.4.1).

6. Limitations with weather include: no seasons, extremes in hot or cold; no weather movements fronts; limited effect on air and ground assets, and; the weather generating algorithm is complicated (Section 4.4.2).

7. C^3 is mostly external to the model, poor internal representation--assets can not be targeted or destroyed (Section 4.4.3).

8. Interaction of air and ground is restricted due to a lack of parallel processing (Section 4.5).

9. Proposed use of NBC munitions is poorly developed (Section 4.5).

10. Comprehensive verification and validation of the model is not possible because the simulation is not complete (Chapter 5).

11. The attrition equation used to model the losses sustained by opposing ground forces must be reduced by a factor of six, to reflect the change in minimum period length from 12 to two hours (Section 5.3.6).

6.3.1.2 Other Model Limitations and Weaknesses. The following list of limitations and weaknesses have not been specifically identified in any of the previous sections.

1. Conventional War only - NBC capable aircraft are available but loading would not be authorized. Technically this is an imposed limitation; however, even if NBC munitions were authorized, the results of their uses would be suspect because of a lack of validated information pertaining to their use.

2. Aerial refueling is assumed complete if an AR aircraft is assigned to the sortie package.

3. Tactics are computer generated and assumed to be optimal.
   - Aircraft strategy and tactics.
   - Ground employment, strategy and tactics.

4. Computer controls ground-based air defense employment.
   - Assume enemy area defenses are avoided during ingress/egress.

5. Staging Base (SB) aircraft must first be moved into theater to fly missions, (even the long range strategic bombers).

6. Aircraft from SBs bring their own war reserve spare kits (WRSK) and maintenance personnel--space is assumed available for both.

7. Staging Bases provide supplies but are not targets.

8. Aircraft damage is not modeled; surviving aircraft require spare parts and 'normal' maintenance after each mission. It is planned, however, to increase the maintenance times of surviving aircraft that have been intercepted or engaged by the enemy.

9. A land unit is "destroyed" when its combat strength is reduced to 20% of its beginning strength; although the value can be changed by controller input.
   - Posture changes based on attrition (Breakpoint) only.

10. Recurrent resupply of units is provided by the computer.
    - Currently supply caravans can not be targeted.

11. Reroling (changing the mission of a multi-role aircraft) can be accomplished without penalty, which assumes:
    - No time lost in reconfiguring the aircraft.
    - Crews and support personnel are trained for rerole.
    - Crew is available whenever aircraft is ready to fly.

12. An aircraft accomplishes its assigned mission or fails to. There are no secondary targets or targets of opportunity.

13. Beddown is limited based on ramp space and cross-servicing capability. There are no 'in-flight-emergency' (IFE) beddown procedures.

14. A limitation of the wargame--not the model itself--is that a 10 day battle neglects or limits the development of:
    - adaptive strategy and tactics,
    - significant logistics shortages, and
    - neglects possible effectiveness of economic blockades.

15. Another wargame limitation is that there can be no preemptive attack by Blue forces.

16. No Special Operations.
    - clandestine, spying, terrorist actions,
    - psychological warfare,
    - deception campaigns, or
    - space operations--other than possible satellite use.

17. No Political/International relations - change or addition of allies is not considered.

18. Because unit are aggregated within a hex, combat is 'head-to-head' i.e advancement is made in the opposite direction of the enemy advance and there is no lateral movement; thereby limiting the ability to outmaneuver, outflank or 'divide and conquer' enemy units.
    - synergistic effects are lost (only a linear improvement in combat capability) when two units merge.

19. Quality of troops, human factors, is difficult to define.
    - assume personnel feel 100%, unless what?;
    - assume no malingerers, psychotics episodes.

20. No Hospitals, Casualties, that could slow down movement.
    - a hospital about to be overrun would require the redirection of assets.

21. No POWs to hinder forward movement.

22. No ground sensors or forward observers used to gather intelligence.

23. No Battle Field obscurant to affect TGT acquisition or tracking.

24. Insufficient munitions cancels the sortie; aircraft will not take off with a partial load--except for 'gun only' missions.

25. Range of aircraft does not limit mission type.

26. Time Over Target (TOT), or rather time period over target, can be selected but with little impact on the sequence of play; because missions are completed within a two hour time cycle.

27. Can not choose aircraft ingress or egress routes.

28. Some aircraft and missile systems modeled are obsolete, and the newest aircraft are not included; requiring a complete review and culling of the weapons database.

29. Saber is a war of attrition vs precision.
    - superior leadership is not modeled.
    - the use of precision guided munitions to disrupt and destroy the leadership infrastructure would have little effect on game progress.

30. The user interface input screens have been designed but not coded. Although there are four areas--five types of reports identified by (Horton:134)--for player input, there is only one report format that is coded and can be accessed through the graphics package.

31. There are no post processor functions to provide output reports, charts or analysis data.

32. The Saber's most serious limitation is that the simulation portion does not work. The structure and proposed design of the simulation is available, but there are many submodules that are not completely coded.

6.4 Summary of the Credibility Assessment Framework. The previous three chapters have been devoted to assessing the credibility of the Saber model. Chapter 4 discussed the theory, design, and input structure of the model. Chapter 5 looked at Saber and its ability to model the real world and identified areas where more work is required. Chapter 6 examined the support structure, documentation and reporting of strengths and weaknesses.

At this time there is not sufficient evidence to question the credibility of the Saber Model. The primary strengths of Saber include: a well defined purpose to fill a need; the enormous amount of talent that has gone into its development; a programming style that is understandable and, nearly, self documenting; an understandable simulation structure and database design; the graphics package is quite impressive; the use of a user-friendly interface concept, topped off with; a well defined support structure to be provided by the Air Force Wargaming Center. Although there were a number of limitations documented, the limitations should not be serious enough to distract from the overall robustness and capabilities of the model. However, final judgement must be reserved until after the model is rigorously tested; using a structured verification and validation process, or a simulated command exercise, or with a follow-on thesis effort.

VII Saber AirLand Methodology: a model description

This chapter outlines a proposed AirLand Methodology for the Saber Model. TWX/Agile had two such methodologies--one for the Air Campaign and another for Ground. The AirLand concept of Saber allows for a single methodology. This methodology is designed, not only to outline the internal characteristics of Saber, but also to develop an exterior framework and explain how Saber could interface with a seminar environment. External to the simulation, a good deal of the following information was adapted form the Agile wargame; because, the exercise concept and audience--intended users--are the same. However, internal to the model, more emphasis is placed on how the air and ground components interact than was available in Agile. This methodology is written with the specific intention of providing the Exercise Director with a consolidated version of Saber; although, the information should be equally valuable to anyone interested in learning more about the Saber AirLand Combat Training Model.

7.1 Introduction

Saber is a seminar exercise driver for a theater-level warfare exercise. Saber uses an object-oriented design and is programmed predominantly in Ada; the graphics are generated by X-Window C routines that are incorporated into the Ada language through bindings. Saber uses two "top-level simulation objects" called the Air Force Simulation (AFSim) and the Army Simulation (ArmySim), (Sherry:38). Consistent with their names, the AFSim focusses on airpower employment and the ArmySim controls ground actions. The simulation is divided into the AFSim and the ArmySim in an effort to provide structure and flexibility to the simulation design. The AFSim and ArmySim coordinate/compliment each other and can call procedures and functions common to both. The simulation will execute on a *Sun 4* or compatible work station.

The intent of Saber is to assist in exposing players to the high-level decision making process required to plan and execute a theater airland campaign. It is not expected that participants, (e.g. students at the senior service schools), arrive with a full appreciation or understanding of all the factors influencing airpower and its employment. Therefore, prior to play, academic instruction should be provided on: airpower strategy and doctrine, principles of warfare, command arrangements, the nature of combined and joint operations, enemy intention and threat assessment, friendly vs. enemy force capability and a host of other subjects related to theater-level warfare. With this academic preparation, Saber is designed to support and reinforce the educational objectives of an 'employment' phase of training. The computer and the Saber simulation are used as additional training aides and do not provide the final word, book answer or gospel, relating to the subject of airpower employment.

Saber should be viewed as the computerized simulation of a board game, designed to support and reinforce educational objectives. These objectives include the ability to (AFWC,1987:2):

1. Apply US/Allied air force doctrine in a theater-level war exercise.

2. Apply the principles of war in a combined air/land campaign.

3. Comprehend logistical factors in supporting and sustaining air operations and the importance of planning and coordination.

4. Comprehend the AF roles and missions and their use in supporting a joint/combined theater commander.

5. Comprehend the complexity of the decision making process involved in airpower employment including logistics, intelligence and political factors.

6. Comprehend the importance of staff coordination.

7. Comprehend the difficulty of determining what information is needed to support rational and timely decisions and how to derive that information from raw data.

The databases and algorithms used in Saber come from unclassified sources. Some of the specific sources include 1) Dunnigan's How to Make War, 2) a number of Jane's Information Group publications, including: Jane's All the Worlds Aircraft, Jane's Military Vehicles and Ground Support Equipment, and Jane's Weapon Systems, additional information can be found in 4) Doran's The

US War Machine, and 5) The World's Missile Systems, by Korb, and; a number of other military journals.

To date, there have been six thesis efforts--including this one--originating at the Air Force Institute of Technology's Operational Science, Electrical Engineering, and Computer Science departments devoted to the development and enhancement of the Saber model.

7.2 Organization and Play

There are three major categories of participants in Saber--the control team (white), the player teams (Blue and Red) and the computer. White is composed of the exercise sponsor's coordinator, a Wargaming Center game director and design team, and other data processing personnel, responsible for: conducting the exercise, ensuring academic objectives are met, issuing materials, presenting the scenario, and providing Higher Headquarters (HHQ) guidance and messages above the simulated theater-level interaction. The Blue side (US and allied forces) is played by a group of students and is played at two levels. Red can be played by faculty or staff members, intelligence personnel, or other students, preferably with expertise and knowledge of North Korean (Soviet or Chinese) doctrine, strategy, and tactics. The role of the computer is to accept player inputs, execute the simulation, crunch the numbers, do bookkeeping, and produce the reports needed by the players to determine the outcome of their decisions. The computer interfaces are designed for players with limited computer training (SAC checklist mentality).

There are two levels of player involvement. Headquarters Combined Forces Command (CFC) oversees control of the two subordinate command levels--the Combined Air/Ground Component Commands (CACC and CGCC) and the Tactical Air Control Center (TACC). The Commanders of CACC/CGCC and the TACC are assigned by the faculty. The role of the CACC/CGCC and their staff, representative of a number of Allied and US senior (O-5 and higher) officers, is to develop an air (and ground) strategy to support and prioritize the objectives of the Commander in Chief, Combined Forces Command (CINCCFC). This strategy is implemented by issuing an Air Directive (AD), which provides guidance to lower command levels. The CACC/CGCC staffs concentrate on apportionment (the number or percentage of aircraft dedicated to the TACC missions), setting the priority of targets, and; the inter/intra-theater movement of equipment and materiel, i.e. Logistics. Scheduling and tactics (Wing functions) are not a concern at this level. The job at the TACC level is allocation; to implement the AD by making decisions to ensure the optimum use of available resources and to generate force packages against assigned targets. Players have a role at each level and switch roles periodically within the cycle of play.

Saber has two phases of play--prehostilities and hostilities. The prehostile phase includes academic study, and an introduction to the scenario, which should include pre-warning or a prehostilities build-up, that leads to a limited warning, preemptive attack on Blue forces. Time should then be allowed for players to read the handbooks, organize teams and develop strategies at the CACC/CGCC and TACC levels and input these plans and decisions. Time should also be permitted for players to get acquainted with the Saber screens, help functions or utilities, user interface input menus, output graphics and reports. The hostilities phase would begin with the execution of the computer simulation, representing the first day of battle, and continues until the exercise is terminated.

7.2.1 Model Operation Each day's war operations are divided into two phases-- planning and execution. During the planning phase; a sequence of events called 'Daily Events' are followed. During this phase enemy actions over the past day are evaluated, the status of friendly forces is determined, the CINC is briefed and guidance is received from HHQ, previously established objectives are reviewed and modified as necessary, Blue's strategy is developed and coordinated with other team members, logistics are ordered and transported, and; other daily tasks are performed.

Part of these 'other daily tasks' is understanding the "Principles of War" as outlined in AFM 1-1. These fundamental principles are based on the writings of Sun Tzu, Clausewitz, Napoleon and other masters in the art of war.

The players need to consider these concepts in developing and implementing their strategy and plans; because the simulation coding is not specifically designed to. These concepts include:

1. Know Yourself - What is your strategy, plan of attack and objectives and how, when, where and by whom will they be achieved?

2. Know the Enemy - be the enemy air commander; what would you do?

3. Objective - what do you want your actions to accomplish?

4. Offensive - actions to seize, retain or exploit the initiative.

5. Mass - concentration at a critical time and place.

6. Economy of Force - no more and no less than needed to accomplish the objective.

7. Surprise - act or react in a manner the enemy does not expect.

8. Security - deny useful information to the enemy but obtain and exploit information about enemy activities.

9. Unity of Command [Centralized Control] - one responsible commander to specify a common objective.

10. Unity of Command [Decentralized Execution] - accomplishment of objectives by commanders in the field using their best judgement and available resources.

11. Maneuver - maintains initiative, dictate terms of the engagement and conduct operations at the right place and time.

12. Timing and Tempo - maintain a faster tempo of action and reaction than the enemy; dominate, be unpredictable and create confusion.

13. Simplicity - quick, clear and concise effort towards a common goal.

14. Logistics - are sufficient men and materiel available for the missions; where is it?; where does it need to be?; how will it get there and when?
    - Resource Allocation - what resources are needed, where, when?
    - Apportionment - distribution of resources by priority or percentage to meet objectives and ensuring they last throughout the campaign.
    - Allotment - dividing of forces between bases. Acquiring new forces from staging bases (SB) outside of theater, or from movement within theater.
    - Posturing Forces - consider beddown and tasking of aircraft, people which are constrained by special servicing needs, enemy damage to facilities and munitions, lack of trained specialists.

15. Cohesion - fighting spirit that holds a unit together.

16. Have a backup plan - remember Clausewitz's "friction" in war.

In the execution phase, sorties are tasked against specific targets, identified in intelligence reports, and land units are given their orders.

While Blue players are accomplishing the actions listed in the above two phases, Red players are doing the same.

7.3 Saber AirLand Battle Methodology: Introduction

As the AirLand Battle concept evolves, the interface between joint Army and Air Force operations and plans must also evolve (ALB:8). Saber is a theater-level, two-sided, airland combat training/educational model, designed to increase the awareness of senior military officers in the areas of: combined/joint military actions; airpower and its employment, and; the command level decision-making processes required in a, hopefully credible and realistic, simulated combat environment. Players are required to develop objectives, based on certain constraints, and then create tactical air and ground mission to accomplish these objectives. Sample objectives might be: to destroy or neutralize a certain percentage of enemy air bases; establish air superiority within X hours; maintain a high level of intelligence data collection; deny enemy resupply access routes; cut off enemy advancement routes, and/or; surround or capture key enemy positions. Intelligence, logistics and operations are modelled along with all phases of joint operations in a US/Allied tactical airland battle environment.

Saber is divided into 12 two hour cycles--eight daytime and four night. After players have input their desired missions, for the predetermined period length, the Saber simulation phase begins. The sequence within the Saber simulation specifies that the air battle--called the Air Force Simulation (AFSim)--is executed first. Accomplishing the AFSim first is consistent with the airpower philosophy used during the Iraqi war 'Desert Storm'. The computer attempts to accomplish each mission as directed; although some sorties will be lost due to abort for maintenance or weather, attacks prior to launch, lack of munitions, inability to locate the target etc. These non-effective aircraft represent Saber's attempt to inject a dose of reality into the wargame. A blanket order--default condition--can be given to all land forces to hold their position. Land forces in a prepared defensive posture are subject to much less attrition than units on the offensive and a defensive posture allows more protection from enemy airborne attack. Furthermore, fewer air assets are required to protect well entrenched ground units, so more assets can be devoted to gaining control of the sky e.g. air superiority.

7.4 Planning the AirLand Campaign

The preparation of the airland campaign, external to the simulation, should be considered a three step process: 1) developing the basic Scenario, 2) Translation of the scenario into tactical plans, and 3) conversion of those plans into instructions understandable by the simulation.

7.4.1 Scenario. The scenario need not be elaborate but should at least, 1) identify the antagonist and the location of opposing forces; 2) define the theater area of operation including: location, terrain, and weather, and; 3) establish the objectives of both sides. Scenario development requires coordination between the user and the program designers. Analysis should be accomplished, after a scenario draft is developed, to ensure the scenario is consistent with the AirLand Order of Battle, and changes should be made to the scenario as required.

7.4.2 Tactical Plans. Planning proceeds, as in real life, with an assessment of the terrain, using scale maps and computer graphics, a list of forces and support assets, an estimate of the situation from both sides, and the establishment of force posture and positions.

7.4.3 Translation of plans for input. Translating plans is a two phase process. Initial inputs to the preprocessor for use in the simulation database include: 1) the initializing of all constant values, i.e. the unit casualty break-point, movement rates, fixed target locations, weapons parameters, etc., 2) the terrain, weather and defense quality for each quad, and 3) unit data--components, firepower and combat power, location, type and posture. The second phase involves preparing orders to accomplish the objectives established in the scenario.

7.5 Missions Modelled. The following strike and area missions are included in the Saber model (AFM 1-1, provides detailed mission definitions):

Mission Type	Abbreviation
Suppression of Enemy Air Defenses	SEAD
Combat Air Patrol	CAP
Close Air Support	CAS
Offensive Counter Air	OCA
Air Interdiction	AI
Battlefield Air Interdiction	BAI
Defensive Counter Air	DCA
Electronic Combat	EC
Reconnaissance	RECCE

Other missions include: Missiles, Satellites, Reserve [Augmentation], and Airlift.

Air Force missions use specialized aircraft (some aircraft are multi-role) which are subject to degradation and loss from enemy air attack, ground defenses, weather, and aborts. Certain mission types (e.g. CAS, OCA), in addition to causing damage, can also gather intelligence, to be used in future planning. Multi-role aircraft can change mission profiles, for example, from an attack to a defensive role.

The Saber aircraft database contains characteristics or attributes for each aircraft type including: sortie rate, fuel consumption, standard weapons loads, performance factors, maintenance distribution, effectiveness in poor weather conditions, destructive index, survival index etc.

Saber simulates the close coordination necessary between air and ground forces on the modern battlefield. The survivability of aircraft, on strike missions against defended ground positions, is dependent on the aircrafts' ability to penetrate or outmaneuver: 1) enemy area surface-to-air missile (SAM) sites, 2) enemy point defense SAM and AAA sites, 3) combat air patrol (CAP), and 4) defensive counter air (DCA). The effectiveness of land units is enhanced by support from air assets provided by offensive air strikes (CAS & BAI), interdiction (IND) and by gathering intelligence information with reconnaissance missions. The following sections should be helpful in characterizing the major internal features of the Saber model.

7.6 Combat Units. Combat units are aggregated at the division level of resolution and Saber is designed to represent the interaction of forces given a theater-level scenario. The theater battle area is overlaid by a hexagonal grid that provides a positional reference for: unit location, type, and posture; terrain; and weather zones. Land units aggregated within a hex and can move from one hex to another or attach themselves to other units. Hexes are also used as reference in assigning action orders to land units. Land forces can execute or accomplish six types of action orders--discussed later.

The movement of land forces is related to terrain, enemy encounters, delays caused by air attack or artillery, and posture. Ground combat occurs when opposing units occupy adjacent hexes. Movement and combat casualty (attrition) rates are proportional to the relative combat power ratios of the engaged units, terrain, unit posture, and the engagement type. Casualties resulting from air attacks are directly related to the number of sorties flown, the dimensions of the target, and a destructive index or air-to-ground (a2g) capability of the aircraft. The sum of attacks on a unit determines the overall damage, in the form of attrition, sustained.

7.7 Grid System. The six sided hexes are 25 km across, i.e. from flat side to flat side. The sides of each hex are approximately 14 km long, meaning a unit within a hex must defend a perimeter of, roughly, 85 km and an area of about 525 km^2, which is consider appropriate for division-level assets. Individual hexes are identified using a zz-xx-yy coordinate system: zz indicates the elevation, that identifies the hex as ground or air, xx defines the x-axis position, and yy defines the y-axis. The values of xx and yy range from 0 - 99; which limits the size of the theater map to 100 X 100 hexes. For the Korean scenario a 50 X 50 grid is used, representing an area of 1250 X 1050 (1,312,500) km^2.

Air hexes consist of seven underlying ground hexes, making them 75 km across the flats, and are identified by the coordinate location of the central ground hex. Air hexes can also be broken into altitude blocks by assigning a value to the z-axis. For example, a hex coded 01-xx-yy (zz = 1) would identify a ground hex, 02-xx-yy would represent tree top or nap of the earth flying, and so on up to the airspace used by satellites. There are currently seven layers of air hexes.

7.8 Weather. Theater-level weather and forecasts are located in a separate database. Weather updates are pre-scripted to represent changing weather patterns. Weather in target areas is randomly generated based on conditional probabilities. There are three categories of weather--good, fair and poor. Weather conditions are used to determine what aircraft can fly (some aircraft are all-weather capable, others are not), the munitions load, and the ability to locate and strike the target. The categories good, fair and poor represent VFR, MVFR and IFR flight conditions respectively. Darkness can be thought of as an attribute of weather, that would restrict some air operations and reduce the effectiveness of anti-aircraft systems, but is associated more with the day/night cycle than with weather.

7.9 Terrain and Trafficability. Each hex, 525 square km, contains a value that is used to indicate ease/difficulty of movement. There are five possible values (ranging from Excellent to Very Poor) with a color assigned to each for use with the graphical display. The color value for each hex was chosen by: 1) overlaying the hex grid on a 1:50,000 chart of the theater, 2) dividing the hex into six pie sections, 3) examining each pie section for trafficability characteristics, 4) assigning one of the five values to the pie section, and 5) averaging the pie section color values to determine the color value of the hex for display. Terrain ruggedness, rivers, mountains, roads, cities, rail lines, bridges, and other obstacles are considered when deciding what value to give to the pie section.

7.10 Ground Forces and Unit Types Individual land units can be modelled at any desired force level, but divisions are used to define the specific level of aggregation. Divisions modelled include: mechanized, armor, airborne infantry, air assault, marine infantry, light infantry, and some separate brigades that provide additional support. Blue combat units are called Corps, Red units are Armies. The data structure does not restrict the number of corps or armies a force may have; computer memory and storage capacity is the only limitation. Unit size, strength and combat capability are all related to combat power (CP), which is a measure of a unit's firepower potential and support from other units. The firepower of a unit is determined by aggregating all of the direct fire weapons (tanks, anti-personnel vehicles, infantry and attack helicopters) into a single value. The CP can be computed as a function of the unit's firepower and other assets including: time in the hex, support artillery, its defensive posture, terrain, support from air assets, and the quality of the troops. The quality of troops is a value intended to represent: command and control; leadership; service support equipment; human factors such as morale, training or experience and fighting skill, fatigue, and resolve, and; other less tangible assets.

Units can be divided into five types:

Type	Description
Fixed	Air Base, Missile Base, or Depot
Combat	Can engage opposing forces
Support	Units that follow the combat unit
Overrun	Captured Immovable or Support units
Destroyed	Land units that have lost 80% or more of their CP from ground or air attack.

7.10.1 Defensive Postures. The defensive capability of a combat unit is based on the amount of time the unit remains in the same hex. The assumption is that, the longer a unit is in a given location, then more elaborate the unit's defenses become. For example, the defensive ability of a unit just entering a hex might be limited to a hastily dug foxhole; whereas, a unit that has occupied the same hex for a period of time will make use of the available resources, natural or man-made, and develop defenses that provide more significant protection to men, weapons, and materiel. More significant defenses would also imply more extensive fire control and communications ability.

7.10.2 Battle Engagements. Ground combat occurs at the hex level. The assumption is that opposing units in adjacent hexes engage in combat. Because of the hex size and configuration, units involved in a one-on-one engagement would protect a 'front' that is about 14 km across. When two or more units attack an enemy unit, the combat potentials are added and applied against the enemy; there are no synergistic effects--improvement, other than linear, in the combat capability of the additional units--included in the model. Theoretically, a unit could be attacked on all six fronts. If a unit is engaged on more than one front, the combat power dedicated to each front is based on the proportionate strength of the attacking units.

7.10.3 Action Orders. Action orders specify the mission a land unit is to perform during the specified periods of the day and night cycle, orders may go unfulfilled due to uncontrollable circumstances such as an engagement with an enemy unit, the enemy is no longer in its expected location, air attack, and/or overambitious orders. The are three general mission types or unit action orders--Attack, Defend, and Withdraw. An "attack" order specifies that a unit will move to a designated hex and attack an enemy position in an adjacent hex. Forward movement is dependent on the unit's 'effectiveness' in battle. A unit given a "defend" order will proceed to a designated hex, if it is not already there, and protect its position. Opposing forces in adjacent hexes will not engage in battle if both have "defend" orders. The longer a unit remains in the hex, the stronger its defenses become. A "withdraw" order specifies that the unit will break contact with the enemy, with all or a portion of the unit, and proceed to a designated hex. A "withdraw" order is considered voluntary and a unit withdrawing will proceed without hinderance, unless it encounters another engaged unit, to its assigned rear location. In addition to directed orders, significant attrition of engaged units can cause a change in posture. In other words, in the absence of orders actions may be forced on a unit. For example, an attacking army may be forced to defend, and a defending army may be forced to withdraw or be destroyed if the battle is going badly.

7.11 Aircraft Packages and Maintenance. An aircraft package is formed by taking aircraft from one or more bases. A package can contain strike, support, or both types of aircraft. In order to fly as a package the simulation checks to ensure: the necessary runway length is available for the aircraft to take-off; the aircraft is not in a maintenance status; the base contains sufficient fuel and weapons load, the aircraft is capable of flying in the weather expected at the target area, and the target is within aircraft range or air refueling (AR) aircraft are included in the package. The simulation assumes AR will be accomplished if the package contains AR aircraft. After aircraft are launched the munitions and fuel are decreased from base supply. Aircraft from different bases meet at a designated rendezvous hex from where the mission begins. After the mission is complete, aircraft return to their main operating base (MOB) or an alternate if the MOB is overrun or under attack. After each mission the aircraft returning to base require maintenance. Maintenance times are random and determined by an assigned distribution, mean, and standard distribution. Aircraft are not considered mission ready until the maintenance time is complete.

Attack helicopters are a special type of airborne platform. Attack helicopters are assigned to combat units and are aggregated into the firepower value. The assumption is that helicopters are self sustaining, with respect to maintenance and support, and only constrained by shortages of fuel and ammunition.

7.12 Movement Rates. Land units that are not engaged in battle move at a constant rate called 'groundspeed', that is a characteristic of the unit involved. Aircraft fly at a rate called 'airspeed' and is characteristic of the aircraft (Horton:93). Groundspeed represents the maximum speed that a unit can move with 'Excellent' trafficability conditions. Units move from the center of the hex they are located in, to the side of the hex, to the center of an adjacent hex. A unit may reach its destination without interruption, or it could be attacked enroute and have to defend its position until the combat situation is resolved. Headquarters, corps artillery, and combat support units are considered non-combatants that are located behind combat units and are not allowed to over-take the combat forces. The movement of a unit/aircraft through a ground/air hex is controlled by a simulation movement algorithm that is designed to 'look-ahead' to deconflict the route, i.e. the algorithm would not, intentionally, put the unit/aircraft in the direct path of an advancing threat.

Movement of units engaged in combat is largely dependent on the combat power ratio of the opposing forces; although, trafficability of the assigned hex, unit type, and posture are also factors used to determine the advancement rate. The movement algorithm is based on the assumption that attrition is inversely proportional to forward movement, i.e. the unit suffering the least attrition is able to advance and push the enemy back. Hence, the rate at which a unit advances increases with an increasing Combat Power Ratio as long as it maintains its offensive posture. Obviously, a unit with orders to "defend" will not gain ground regardless of the battle outcome; although it could be forced to withdraw.

7.13 Close Air Support Close air support aids land units by directly destroying enemy assets and by increasing the combat power potential of any unit CAS is assigned to. CAS missions are assigned to a specified Corps and will support the division or unit that needs the most support. The computer polls the units in contact with the enemy and assigns the CAS mission support to the unit that faces the strongest, determined by firepower value, enemy position. If CAS missions are assigned to a Corps that has no divisions or units engaged in combat, the sorties return to their MOB without losing their resources. Although the aircraft return with their weapons, the sorties are considered ineffective and contributed nothing to the war effort. Therefore, it is important for planners to assign CAS missions where they are needed, but to use the aircraft for other missions when CAS support is not required.

7.14 Intelligence. An intelligence index is assigned to all units to represent the fog of war. The index ranges from zero to two. The number 1.0 represents perfect awareness, unit name, location and strength. Values above and below 1.0 represent over and under estimations. During each cycle the intel-index of each unit is degraded, resulting in less accurate information until eventually no information is provided at all. The intel index on a unit can be improved by flying reconnaissance aircraft, using BAI or IND aircraft to attack or by engaging the unit.

7.14.1 Reconnaissance. Reconnaissance (RECCE) improves intelligence estimates. The capability of an aircraft to gather data is listed in the Aircraft type. A RECCE mission can be assigned to collect information within a specified hex or designated to report on any enemy units within a given area. The intel index of a unit is always degraded prior to a RECCE mission. Weather is the primary factor influencing the ability of an aircraft to gather data. A random draw determines the actual weather over the target. Bad weather decreases the probability that an aircraft will find the target and complete its mission.

7.15 Attrition Functions. There are four types of attrition functions used to model 1) air-to-ground (a2g), 2) ground-to-air, 3) air-to-air (a2a), and 4) ground-to-ground engagements.

7.15.1 Air-to-Ground (a2g). Air-to-ground engagements involve an aircraft or strike package attacking an enemy unit or other fixed target. Attrition of ground units is a function of 1) the capability of the attacking aircraft, that is specified by a destructive index labelled 'a2g rating', 2) the probability of hitting a target of specified dimension, determined using a normal distribution function, 3) the munitions load and its effectiveness against the 4) hardness of the target. Additionally, weather in the target area will determine if the aircraft is able to find the target.

7.15.2 Ground-to-Air. Ground-to-air represents the ability of a ground unit to kill aircraft. In order to kill an aircraft it must first be found.

Finding an aircraft is dependent on the area searched by the radar, the amount of time the aircraft is in the detection area, and any electronic countermeasures (EC) used. An aircraft using EC or being provided with EC support would be much harder to find than an aircraft without EC assets. If the aircraft is found, attrition is based on the number and type of defense system(s) used and a probability-of-kill (Pk) or 'quality' value. A Binomial distribution, with variables of Pk and the number of aircraft in the strike package, is used to determine the discrete probability for a given number of aircraft killed. A random number is drawn to indicate the actual number of aircraft lost (Mann:133).

7.15.3 Air-to-Air. Air-to-air combat is also known as a 'dog fight'. Detection must occur before a dog fight can occur. Once the opposing aircraft detect each other they engage in combat. A Cumulative Binomial distribution is, again, used to determine the number of aircraft killed. Pk for Red and Blue aircraft is determined by comparing the combat rating ratios of the aircraft times the average number and value of missiles fired (Mann:142).

7.15.4 Ground-to-Ground. Ground-to-ground engagements occur between opposing armies and is probably the easiest attrition algorithm to understand. Attrition among ground units "is based on force ratios [a ratio of combat power], engagement type, unit posture (attacker or defender), and terrain characteristics (Ness:38,67)." Ground-to-ground actions also involve the use of artillery and surface-to-surface (s2s) missile systems. Artillery and s2s assets increase the combat power of units they are assigned to support.

7.16 Input/Output Reports and Data. There are a number of data files needed for the simulation as well as a number of reports and updated files generated after the simulation. This section discusses the input requirements and the model output. Figure 3 is an illustration of the model design showing the relationship between input, simulation, and output data.

7.16.1 Model Input. The computers are normally initialized by Wargaming personnel--involves little more than turning them on. After the planning phase is complete players input their plans in preparation for the execution of the wargame. There are four areas of player input. These areas include: the beddown location of aircraft, the movement or transportation of supplies, orders assigned to land units, and the designation of aircraft and missile missions with their specified targets.

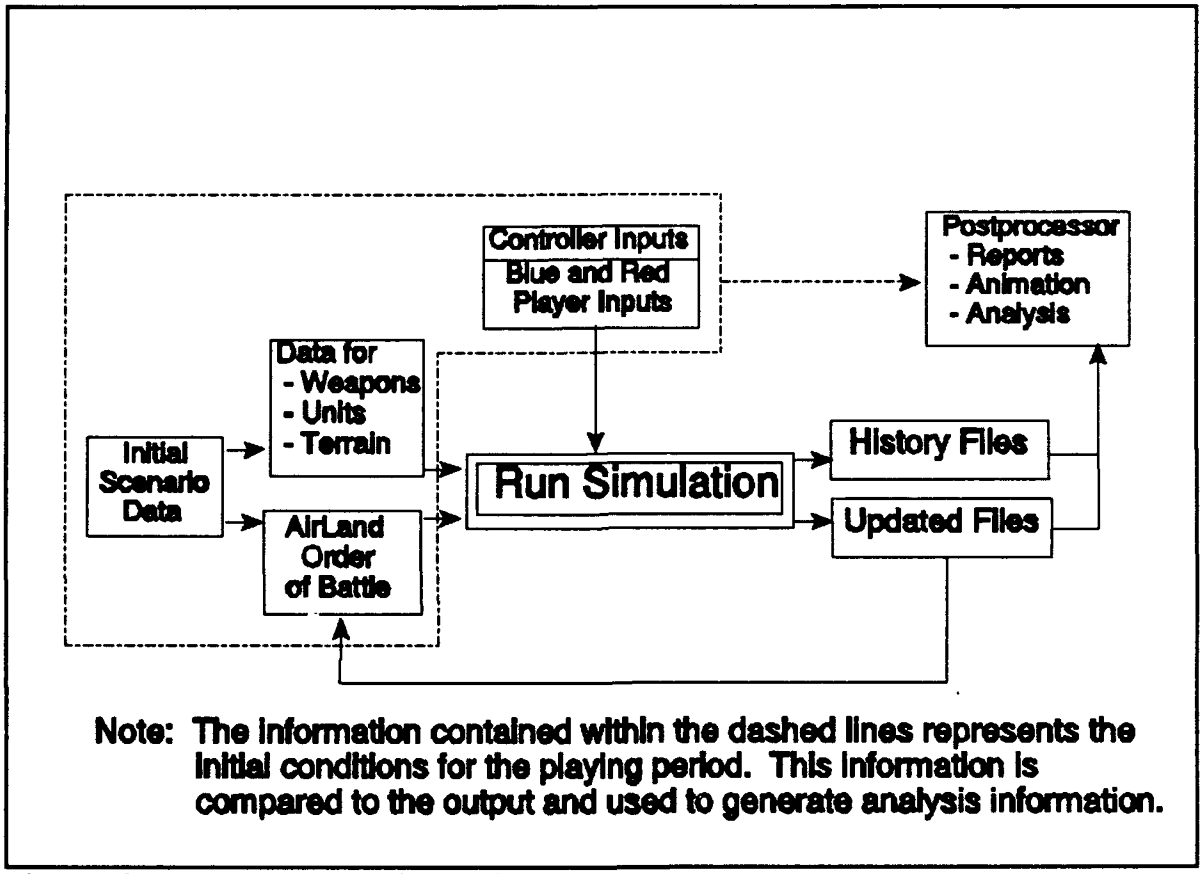

Figure 3 Saber: Input, Simulation, and Output Process.

Input is made through the graphics player interphace and is accessed by using pull-down menus. The player input process is designed to be user-friendly, so it can be used by individuals with limited computer experience. The input interface allows for fast data entry; contains error checking and correcting procedures; uses consistent formats for each input screen, and if all else fails; provides some user "help" functions and/or warnings (Horton:61-79)

7.16.2 Model Output. Presently, output is limited to that shown by the graphics display. The on-screen graphics provides an opportunity to see how well, or poorly, many phases of the battle are progressing. However, even though the graphic displays are quite impressive, written reports are also needed for comprehensive game planning, study, and analysis. A follow-on thesis effort has been initiated at the Air Force Institute of Technology to develop post processor output reports. Output reports for the Saber model should be very similar to the information provided in the TWX/Agile model; although some reports would have to be deleted or changed and others added to reflect the differences between Agile and Saber. Mann discussed the types of reports Saber should provide, based mostly on output from Agile, and gave a short description of their content (Mann:193-196). A summary of the types of reports needed include:

1. Mission Input and echo reports,
2. Mission Summary,
3. Friendly AirLand Order of Battle,
4. Enemy AirLand Order of Battle,
5. Aircraft basing, servicing capability and maintenance status,
6. Total sorties flown,
7. Summary of total aircraft lost,
8. Summary of enemy OCA missions,
9. Summary of friendly aircraft lost,
10. Summary of base and depot logistics,
11. Summary of aircraft cargo shipped,
12. Logistics analysis such as aircraft usage rates,
13. Intelligence listing of all known units,
14. Friendly and enemy units overrun or destroyed,
15. RECCE missions and results,
16. Combat power ratios of engaged units,
17. Friendly and enemy SAM unit locations and effectiveness ratings,
18. Weather forecasts,
19. Bombing Encyclopedia (BE) and target locations,
20. Satellite reports.

7.17 Summary.

As previously mentioned the Saber model was not completed at the time of this writing; although efforts are underway that should lead to its completion in the near future. As items of interest are completed or modified, documentation should be provided describing the progress made. As changes are made, this methodology will also need to be updated in order to provide the best information available on the Saber AirLand Training Combat Model.

VIII Recommendations for Model Enhancement, Summary, and Conclusion

The intent of this chapter is to suggest changes to the present version of the Saber model. The changes recommended were developed in an effort to provide a better understanding of the model process; to streamline some of the model design, and/or; to enhance certain portions of the model to account for some model weaknesses. It should be perfectly clear--by reading the volumes of literature devoted to the Saber model--that a good deal of effort and creativity was put into each phase of development. Although, some of the effort put into the model was out of sequence or misdirected, very little was wasted or inappropriate to the task. In essence, this chapter attempts to enhance the Saber model without dwelling on its deficiencies.

8.1 Developing a Prototype Design. The development of the Saber model began with Ness' Land Battle, originally designed as a follow-on to the TWX/Agile wargame. Ness' model was complete in that it was self contained, and a wargame--involving only land forces--could be enacted without relying on any other external software. Sherry took Ness' code and modified it to accommodate some Saber design and concept changes. After these changes were made the simulation should have been tested to ensure it still worked. The simulation may have been tested at this point; however, there is no documentation available to prove that it was, or to indicate the results. Instead, it appears work continued on coding and integrating the ideas developed by Mann in order to develop the 'full blown' airland battle.

An accepted procedure for developing a complicated computerized project is to use of a top-down design and a bottom-up coding scheme. Apparently this methodology wa abandoned in favor of getting as much of the model completed, as possible, in the time available--which is reasonable considering the grading criteria of a thesis project. Unfortunately, streamlining the development process did not produce the expected results, i.e. when all the pieces of the model were put together the program would not compile. It has been written that in the "...unpredictable programming process; it would be nicer to think we can get it right the first time than to pay for the error in trial-and-error methods..."; unfortunately, it is often discovered that many things are not done right the first time (Tingley:44). Tingley recommends using a prototype design in the development of complicated/unpredictable systems. He states that, "Prototypes are models; [designed so that] each successive version is a progressively refined and corrected representation of the goal [established by the] production system." (Tingley:45). Therefore, after examining the difficulties inherent in the Saber model, it is recommended that a prototype design be developed for the Saber model.

The initial version of the prototype should be Ness' modified design, but with fewer objects to manipulate. Figure 3 is an illustration of a possible prototype scenario developed as part of this thesis effort. The battle environment is restricted as follows:

1. two forces, Red and Blue, are used;
2. the battle area is laid out in a ten by ten grid;
3. the FEBA/Flot divides the two armies
4. only the ground level is initially represented;
5. the terrain is 'bald', i.e. no terrain features;
6. two air bases on each side;
7. a security force protects each air base;
8. a minimum number of aircraft are kept at each air base;
9. two infantry divisions are modelled on each side;
10. each side has a depot;

The rationale for providing this scenario is that the areas of player input, specifically those involving the movement of assets, can be tested; which should be the first step in the prototype development process. By using a limited number of entities, it should be easier to track the interaction and movement of forces. Using a limited number of entities should also be beneficial in verifying any output reports generated by input instructions. The next step in development should be to include terrain and air hex features and to test the interaction of land and air forces when strike packages are created and land forces are given instructions. A further refinement would involve including weather effects into the model. The object-oriented design of Saber should make it easier to test each object as they are added to the prototype until all of the objects needed for the simulation are included.

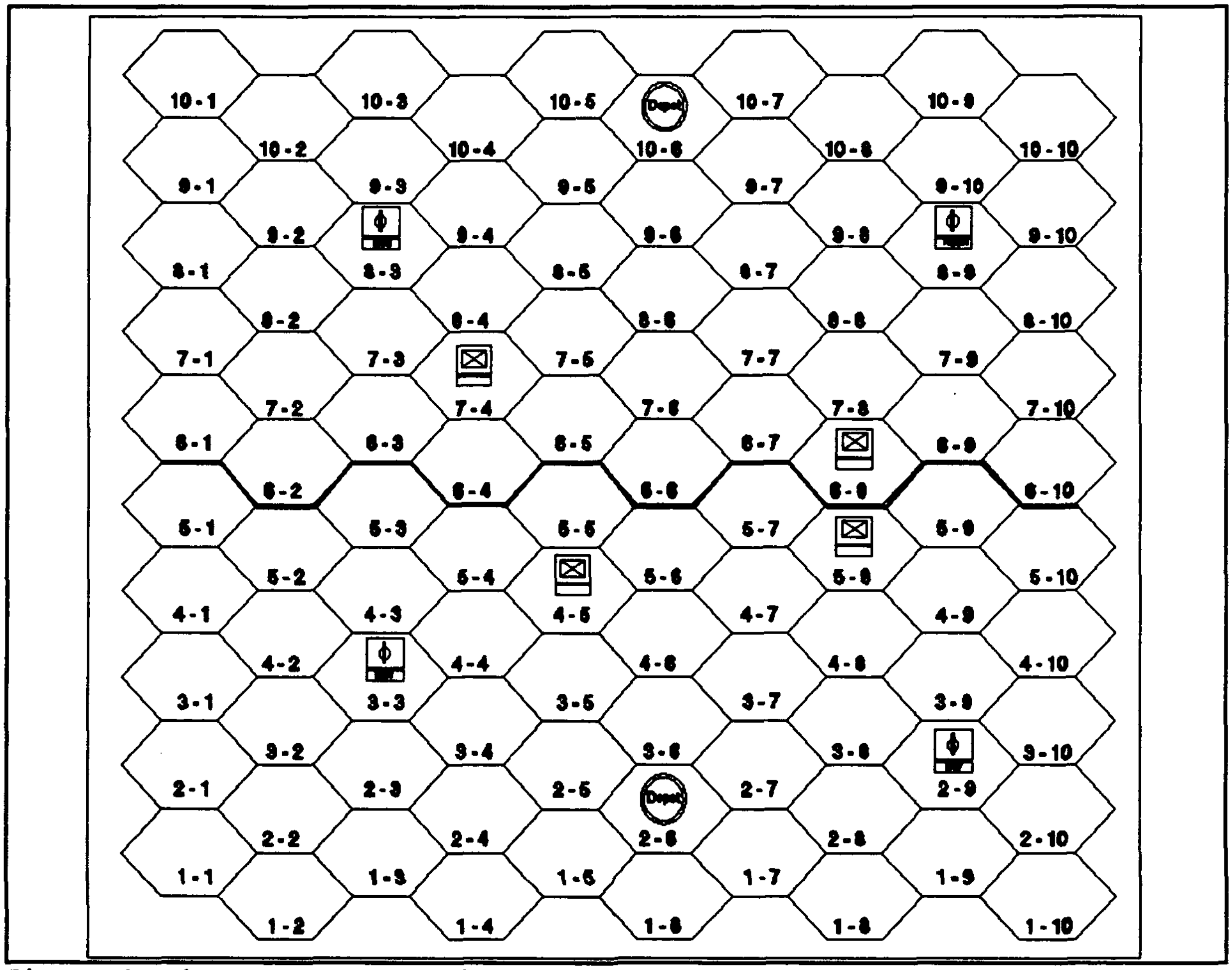

Figure 4 Saber Prototype Design

However, throughout this process the stochastic features of the model should not be used; because, introducing randomness could confuse the results. Adding the stochastic features should be the final step in the design process.

Undoubtedly developing and testing a prototype will require a good deal of time and effort. However, the time and effort devoted to the systematic and structured development of a continually refined prototype designs should provide better documentation of the development process and a better understanding of the overall model integration.

8.2 Movement Delay Algorithm. In addition to attrition, air attacks on land units by BAI, IND or CAS can also cause delays that affect unit movement and ability to use support assets. The Agile model had a number of ways to represent the slow down and delay of enemy units that were under attack. There were two types of movement delay that could be included in the Saber model. The first type of delay is an 'Attack Delay' that would not allow movement during the attack. The second type of delay would be a 'Damage Delay' that would require repairs be made before the unit is up to its operational capability.

An attack delay would be simple enough to compute based on a few assumptions. The first assumption is that a unit under attack will stop, as soon as it is notified of an imminent attack, and defend itself. A second assumption is that on average an attacking aircraft will stay in the area for about 15 minutes, i.e. the attack may only take five or ten minutes, but the enemy would probably remain in position and weary for about 15 min. The attack delay imposed on a unit would be: Attack Delay = (Number of strike aircraft in the package X 15 minutes). Admittedly 15 minutes is an arbitrary value, but it is a simple concept and intuitively seems about right; although it should not be hard-coded into the simulation. Whatever value is used could be labeled 'Attack_delay_constant' and be included in the Constants.dat file and subject to change if deemed inappropriate based on subsequent testing.

During the attack the attrition functions are concerned with the number of assets that are destroyed. The Damage Delay attribute would account for the number of assets that are damaged and the time required to make these damaged assets fully operational. It is assumed that repairs could be made while the unit is advancing, but if the unit is attacked before all repairs are made the firepower of the unit is reduced by a 'Damage_factor'. This scheme would require keeping track of another variable 'Baseline_firepower, that should represent the maximum potential firepower of a unit and is computed after the attack. A simple algorithm that would model the reduction in firepower is:

Damage_factor = 1 - x[EXP(-x)], such that the

Actual Firepower = Baseline_firepower X Damage_factor where x is the number of cycles since the unit was last attacked or zero if the unit was never attacked.

If a unit is in a defensive posture but must be moved, Saber has a move_lnlt (leave no later than time) order that can be given to land units. A penalty for using this order could be that the firepower of the unit, if it has been attacked, would be reduced to the firepower value at the departure time. The reduced firepower at the time of departure would reflect the damaged assets that had to be left behind--at the departure time it would be necessary to set the value of 'x' to zero.

Introducing the two damage variables should be considered enhancements to the model and should be implemented only after the prototype designs are tested and accepted.

8.3 Weather Generating Algorithm. The algorithm for generating weather is confusing and should be changed. The present algorithm starts with a given type of weather (good, fair or poor) forecast in each hex to be used for planning purposes. If an aircraft is assigned to strike a target, the weather in the target hex must be calculated to determine what the actual weather is. Determining the actual weather in the target area is based on conditional probabilities. For example, if good weather is forecast in a given hex there might be a 65% chance that the actual weather is good, a 30% chance that it is fair, and a five percent chance that the weather will be poor. The problem with this process is that each weather zone has its own weather forecast and a different set of conditional probability percentage values; making the process much more complicated than it needs to be. A simpler procedure would be to base the actual weather on a 70-20-10 split. For example, if the weather is forecast good there is a 70% chance that it is good, a 20% chance it is fair, and a 10% chance of it being poor. For weather that is forecast poor the chances would be 70% poor, 20% fair, and 10% good, and; for fair weather the breakdown would be 70% fair, 30% good, and 10% poor. This scheme could be used to create the weather pattern for the next day; the actual weather today could be the forecast weather for tomorrow. Using the computed actual weather for today as the forecast weather for the next day would be possible because most of the weather generating process is hidden from the players. There are three readily apparent benefits to using this scheme, 1) less storage space is needed, 2) interesting weather patterns could still be created, and 3) the weather patterns would not have to be hand generated and placed in the weather files.

8.4 Impact of Environmental Conditions on Unit Movement and Attrition. The movement of ground units is dependent primarily on terrain and unit posture. Two more variables, weather and night-time conditions, should be included in the ground movement algorithm. During weather conditions such as good or fair the movement of ground units should not be limited. However, in poor conditions, representative of rain or snow--in varying degrees of intensity--the movement of units is bound to be slowed down. An observation was made, recently, while driving in some heavy snow. Normally cars on the highway average about 65 mph. On this day, however, the average speed was closer to 45 or 50--representing a slowdown of about 25%. The observation was not scientific in any sense, but the results point to a relationship between weather and movement--at least with automobile traffic--that is closely related to troop movement in the Saber model. It would not be unreasonable to assume that the movement of a land unit would be slowed by at least 15% during poor weather.

Another aspect of the environment to consider is operating in a night-time condition. The Agile model degraded the day movement rates by 10% for night movement operations--which seems to be a reasonable value--that would not be inappropriate to use in the Saber model.

The relationship that weather and night operations have on unit movement rates can also be extended to include the attrition rate. In the Saber model the movement of forces is inversely proportional to the amount of attrition sustained, i.e. the more attrition the slower the movement. In a sense the model depicts trading enemy lives for land. Therefore, the attrition of units during bad weather and night operations should be reduced by the same factors that are used in the movement algorithms. For example, a unit attacked at night in poor weather would have its movement rate and its attrition rate decreased by 25%.

8.5 Number of Air Levels. Saber is designed to have seven levels of air as identified by Mann, these levels are (Mann:59,60):

1. ground terrain hex, also called base hex;
2. tree top level, 0 - 200 feet;
3. low altitude, 200 - 2,000 feet;
4. medium altitude, 2,000 - 10,000 feet;
5. high altitude, 10,000 - 30,000 feet;
6. very high altitude, 30,000 - 100,000 feet, and;
7. space, 100,000 - up.

The number of air levels is excessive, contributing little more than cluttering to the database, and should be limited to four. The first level would be the ground hex that could be used for both ground movement and nap of the earth, terrain following, aircraft and helicopters. The second level would be low altitude extending up to 5,000 feet. Medium altitude, level three, would extend up to 20,000 feet, and; the fourth level, high altitude, would extend up to space. During the normal sequence of play aircraft such as AWACs, tankers and EC platforms would occupy the same air hex as a satellite, but the distinction between a satellite and an aircraft should be fairly obvious.

8.6 Ground Hex Trafficability. The trafficability of each hex is given one of the following values: excellent (EXC), very good (VG), good, fair, poor, or very poor (VP). The meaning of these values were explained in section 4.3.5. Another value, called impassible (IMP), should be added to the list. Impassible is already used as a border attribute to restrict land units from moving into a water hex and could also be used to restrict land units from entering a ground hex. Some uses of an IMP value would be to restrict land units from entering an area contaminated with chemical weapons or nuclear fall-out until the area is safe--as indicated by the variable persistence_time. It should be assumed that units would impose this restriction on themselves if they were in control of their actions. Another use of IMP would be to model the total destruction of a bridge; also there should be an icon available to show the bridge and the fact that it was targeted and hit. Consider, for example, the case where a road leading to the destroyed bridge is rated EXC. Once the unit gets to the bridge there are not a lot of options available in trying to cross the bridge--unless the unit has an armored vehicle launch bridge (AVLB)--and the players should be aware that the bridge can not be used.

In real life the most feasible option is to repair the damaged bridge or build a new bridge, but building a bridge takes time. It would not be unreasonable to assume that a unit would need at least one day to upgrade the status of the bridge from IMP to whatever trafficability value the hex's pie section originally had. The need to repair a bridge would show the important relationship between combat and support units and add a sense of reality to the combat simulation.

8.7 Aircraft Maintenance Distributions. When an aircraft returns from a mission it is automatically scheduled for maintenance and is not ready to fly again until its required maintenance is complete. Each aircraft is provided with a statistical distribution along with a mean and standard deviation to compute the maintenance time. There are three possible distributions allowed: normal, poisson, and uniform (Sherry:34). However, the rational for using three different distributions can not be determined. Therefore, it is recommended that only one maintenance distribution be used for all of the aircraft. In the absence of quantifiable data concerning the exact nature of a distribution, one heuristic approach favors using a triangular distribution (Law:205). A triangular distribution has three input variables: a denotes the least amount of time needed to complete the task; b represents the expected maximum time to complete the job, and; m is the most likely time. It is then necessary to find 'experts' who are able to provide estimates for the values of *a*, *b*, and *m*. Once estimates are obtained, a probability density function can be placed on the interval [*a*,*b*]. The actual time of maintenance is determined by comparing a random number draw with the cumulative density function. An algorithm for generating a triangular distribution and relating it to a random draw is described in (Law:261). Additionally, the algorithm has been coded in BASIC and is included in Appendix C, along with some test trials.

Using a triangular distribution would reduce the number of distributions that had to be computed and relieve the need to 'guess' means and standard deviation values--concepts that are foreign to most people. A triangular distribution may not provide an exact answer, but it will provide a reasonable approximation and will not fool others into believing more is known about the maintenance process than actually is. Very accurate approximations for *a*, *b*, and *m* could be obtained from aircraft maintenance shops; although the difference between actual data and best guess values would probably be insignificant, it would be good to have a documented source for the purpose of validation.

8.8 Generating History Files. The design team analysts, and possibly players, should have the ability to go back in the battle a few days, change some missions and continue play. Being able to back up a few days would require the generation of history or back-up files. The need to generate history files has been addressed (Klabunde:111), but no specific procedures have been developed to determine how they should be constructed. A base-line history file is available in the form of the Day-0 database, but additional files would be needed after each game day. There are three possible approaches to generating future history files: 1) reproduce the entire simulation database after each day's play, 2) only keep track of the items that have changed, or 3) replace any files that contain changed data. Approach number one from above would waste a lot of storage space because of the sheer number of files that would need to be reproduced and many entries would probably not change from day to day. Approach two would require much less space, but the distinction between the variable and the data file it belongs to might not be obvious. Approach three, changing the files that have changed variables, is a compromise between one and two and appears to be the better of the three options. Only updating the files that have changed should reduce the total space required for storage of history files and allow the individual variable to be tracked. The procedure required to go back to game day X, would be to initialize the game at Day-0 and then run all of the history files up to day X. It would be interesting to find out how long it takes to go through all of the history files to initialize day X; although, it would probably take less time than expected given the speed of the Sun computers.

When Saber is played in a seminar setting there could be many groups accessing the same files. Therefore, it will be necessary to provide a distinction between the different games in progress and the history files generated. The easiest way to keep the files separate would be to use separate directories. Using separate directories is a simple solution, but very necessary if the files are to be kept from getting mixed up.

8.9 Aircraft Strike Mission. The status and beddown of returning aircraft needs to be clarified. An aircraft package is formed by grouping one or more aircraft from one or more bases. A package would normally contain the strike aircraft and a variety of support aircraft, i.e. tankers, EC, SEAD, and escort. The strike mission starts at a designated rendezvous hex. If a strike package is intercepted on the way to the target the escort aircraft will defend the package while the strike aircraft continues the mission. If the strike package does not find the target the aircraft should return to their main operating base (MOB) with their weapons still available for future use. Sherry wrote that, "When the aircraft package returns from a mission, the aircraft are randomly distributed back to the basses. (Sherry:35)" This statement is somewhat misleading. Aircraft returning from a mission should return to their MOB unless the air base is under attacked or over-run. Each air base specifies two alternate bases where returning aircraft can land if the MOB is under attack, if runway length is not sufficient for the aircraft to land, or if the base is no longer operational.

An aircraft strike package departs the MOB at the start of the cycle, so they are not on the ground subject to attrition if the base is attacked during the cycle. However, because all of the air missions are completed before ground actions are simulated, it may not be known if the aircraft are returning to an air base that was targeted and/or destroyed during the mission. Therefore, a list should be made of all of the air bases that will be struck during the cycle. After the strike package completes its mission, any aircraft that departed from an air base that was attacked should be held in a queue until the operational status of the airfield is known. After the status of the airfield is known, i.e. at the end of the cycle, the aircraft would be allowed to either land at the MOB or at a designated alternate airfield.

8.10 Repairs to Damaged Assets. Other than locating rapid runway repair (RRR) crews at air bases and depots, there is no specific explanation on how repairs are made to assets that have been damaged by air attack or ground assault. A simple solution would be to allow the repair of damaged assets to be made at some constant rate. The restriction would be that, in order to repair an asset, a unit must be located in the hex where the damage occurred; for example, a bridge would not automatically repair itself. Upgrading the status of a damaged bridge has already been discussed in Section 8.6 and the same concept could be used for repairing rail and pipe lines.

Because aircraft are dependent on having an active runway of sufficient length in order to take-off, repairs to an air base would center around improving the condition of the damaged runways. Agile used an improvement statistic of 10% per day to model airfield repairs. For example, if a 10,000 foot long runway was completely destroyed, it would not be unreasonable to expect a repair team to restore at least 1,000 feet of the runway per day, provided the air base is not under constant attack. Therefore, it is recommended that repairs to runways facilities be provided at a rate of 10% per day. Although a repair rate of 10% is not supported, or rejected, by any statistical data, it does appear to be, at least, reasonable based on an understanding of airfield operations.

8.11 Status of an Over-run Airfield. If an airfield is attacked and eventually over-run, it should not be assumed that all of the assets of the airfield are destroyed by the attacking or withdrawing forces, i.e. a good deal of supplies, POL and munitions would probably be left behind. Most of these supplies could be used by the occupying army; an exception would be ground to air (SAM) missile systems. It should be assumed that the effectiveness of a SAM is determined by the proficiency of the launch team, and; although a missile could be fired, in the absence of a qualified technician the effectiveness of the system would be questionable. However, other supply assets, especially POL, would be available to the occupying army. Many Soviet aircraft are equipped with connections that are compatible with the refueling systems of allied aircraft.

In addition to using the supplies and runway facilities of an over-run air base, the status of the air base should change to reflect the new ownership. In other words, the database would have to be changed to reflect control of the air base by the occupying force. Changing the designation of the country that controls the air base would allow aircraft to use the newly acquired installation and the air base would be included in the list of places supplies could be transported. Changing the status of an air base, perhaps a number of times during a game, would not be inconsistent with the ebb and flow of a fluid battle field environment and should be included in the Saber model.

8.12 What about the Navy? One of the assumptions made in Mann's thesis was that naval operations would not be included "at this time" (Mann:6). Therefore, naval assets are not well defined in any of the documentation. At this time, however, it is considered that the Navy could play a big part in an AirLand Battle and should be included.

The Navy views itself as an autonomous self sufficient institution capable of performing many functions (Builder:29). The Navy has the ability to project power over land, sea and in the air. Some of the missions the Navy is capable of include: enforcing a blockade; the projection of airpower; self protection from enemy attack; transporting land forces, such as marine amphibious assault units; projecting firepower from sea to land with artillery; the destruction of land targets with sea launched cruise missiles (SLCMs) such as the Tomahawk. The Navy has a long tradition and has proven its ability to project power many times and in many parts of the world, some notable examples are the Spanish American War, The Cuban Missile Crisis, and incidents in Libya and the Persian Gulf. Considering the many uses of a strong naval presence it would not be realistic to omit the Navy from the Saber wargame. A scheme is needed, therefore, to define naval assets and include them in the Saber model.

There are four primary types of bases defined in the Saber model: air bases, depots, staging bases, and missile bases (Sherry:69). Mann defined the function of bases and the attributes associated with bases: identity, situational awareness, resources, and assets (Mann:102). A carrier task force could be considered a combination of all four of these bases that are located on a floating platform. The only thing that would separate a carrier group from a land base would be the ability of the naval combatants to move in the water. Sherry discusses a mission called "deploy" in relation to moving an air base from one location to another (Sherry:35). The deploy mission could be used for moving the carrier task force from one location to another. Klabunde managed to model the movement of a naval unit during the animation demonstration as part of his thesis defense, so the ability to move naval combatants is possible. All that is needed is a better description of the deploy mission and to allow the defined naval assets to move in the ocean.

A final concern with naval assets involves their command and control. In lieu of creating a CINC Navy position at the component command level, operational control of the Navy should be turned over to the existing air and ground component commanders. The ground commander should exercise operational control of the movement of the carrier group and be given control of any land assets, i.e. marine forces, that are a part of the naval assets. In addition the ground commander should be in charge of the sea-to-land artillery and be responsible for the use of cruise missiles. The air component commander should exercise control of air assets in the carrier group. At the tactical level aircraft could accomplish the same missions, strike and support, that land based aircraft perform. If necessary, aircraft from a carrier could use the facilities of an air base; although the reverse should not be allowed.

There are no technical reasons preventing naval assets from being included in the Saber model. The involvement of naval forces could range from a simple show of force to combined/joint military operations involving many aircraft on assorted missions. The pieces were already in place to incorporate naval assets, the only thing needed was a little structure and, hopefully, this section provided the needed structure. If further guidance on naval force employment is needed, the Wargaming Center can provide personnel with expertise in naval operations and planning.

8.13 Summary. The previous sections discussed some enhancements to the current version of the Saber model. Some of the ideas are provided in an attempt to clarify issues that were not included in other theses and others were included to improve the model structure and flow. The most important section was 8.1, where the development of a prototype model was discussed. Before any of the recommendations or enhancements are introduced the prototype model should be built, refined and tested. Building the prototype model should be given top priority in continuing the development of Saber.

Dunnigan's ten steps of model development were discussed in section 2.6. Unfortunately, Dunnigan's steps were not followed in the development of Saber. In the rush to get as much accomplished in as short a time as possible, Saber was being forced from conceptual development, research, and a rough prototype design to something very close to a production or operational model. Forcing Saber to conform proved to be as effective as pushing on a rope and led to a good deal of frustration and misdirected effort. It must be realize that Saber is not as advanced in its development process as might be deduced from reading this or previous thesis write-ups. The fact is that the Saber simulation does not work, and without a simulation that works the rest of the model is just fluff. Based on the analysis of this thesis, Saber is no further advanced than development step 3, referred to as the integration of ideas into a prototype. It has been said that a building can be no stronger than its foundation. This thesis effort--in combination with all the others--has provided Saber with a strong foundation. Follow-on efforts will be required to continue the process of making Saber a strong combat model that reflects the efforts dedicated to its development.

8.14 Conclusion. This thesis started with the intention of providing verification and validation to the first version of the Saber model. However, after reviewing the documentation and observing the features of the model it was determined that Saber was not ready for a verification and validation check. What Saber needed was a sanity check, not because the concept of the model was inherently flawed, but because the model lacked substance. Even though a Saber development work group was formed, had periodic meetings, and shared ideas, Saber was largely a collection of individual efforts, which provided very little integration or cohesion. Saber did not have a strong foundation or a sense of unity. The purpose of this thesis was to provide Saber with a unique identity and to define its role as a combat training model.

The need to identify and/or characterize the Saber model was the reason for using the credibility assessment framework inspired by the GAO report discussed in Section 3.1. The credibility assessment framework provided a structured means to identify the character of Saber in three important areas: theory, model design, and input data; the correspondence between the model and the real world, and; management issues. The strengths of the Saber model were listed in section 6.4 but are worth repeating. The specific strengths include: a well defined purpose and need; the amount of effort devoted; an understandable programming style; the straight-forward simulation database design; the impressive graphics; the proposed user-friendly interface design, and; a well defined support structure. In addition to the strengths identified through the use of the credibility assessment framework, a number of model and/or design limitations and weaknesses were discovered. Most of the weaknesses were minor and should not distract from the ability of Saber to capture the essence of theater-level combat; however, the incomplete nature of the simulation, and the user input interface will need to be corrected before the model can be considered operational.

In addition to characterizing the Saber model the second intent of this thesis was to define Saber's role as a combat training model. Defining Saber's role was the reason for including Chapter 7, Saber AirLand Methodology, into this written report. The Saber AirLand methodology not only serves to describe the feature of the model, but also provides a means for incorporating Saber into a seminar environment. Overall, Saber appears to be on the right track; although there are some obstacles to overcome. The major hurdles, in order of importance, are the completion of the simulation; the completion of the user input interface, and; the design of a post processor capable of providing output reports, charts, and other analysis data. The development of the Saber model is continuing with the addition of two individuals to the Saber implementation design work group. These individuals have accepted the responsibility of completing the Saber model as part of their required thesis effort. The development of a prototype model, discussed in Section 8.1, should be very beneficial to these individuals, and to the eventual completion of the Saber AirLand Combat Training Model--Good Luck!

Appendix A. Credibility Assessment Summary

This appendix summarizes the credibility assessment framework developed in Chapters 4, 5, and 6. The table identifies 1) the primary area of concern when determining the credibility of a model, and the specific chapter, 2) the associated factors and attributes of the particular area of concern, and 3) a summary of the features of the factor or attribute considered, to include: comments, strengths, limitations and/or weaknesses. In addition, a relative measure of merit rating is given to each factor or attribute to better identify the model's strengths and weaknesses. The ratings are: G - good, A - adequate, P - poor, and INC - incomplete.

Table 3: Saber's Credibility Assessment Summary

Area of Concern: Theory, Model Design, and Input Data (Chapter 4)	
Factors and Attributes:	**Comments, Strength, Limitation/Weakness**
1. Match between the Theoretical and Actual Intent of the Model	Saber was designed to satisfy the *want*, *need*, and *performance* requirements established by the Wargaming Center. The *want* includes: a wargame that focusses on employment, allocation, allotment, the operational art, sustainment, and has a duration of at least 10 days. The *need* for Saber has been provided by Saber's ability to fill a niche at the theater level of play. The *performance* criteria is met by Saber's ability to represent an AirLand battle. Rating: G
2. Measures of Effectiveness	Internal vs External MOEs discussed. External MOEs, (i.e. accomplishment of educational objectives), can be more objectively determined than internal measures of effectiveness and should be deemed most appropriate for the Saber model. Rating: G

3. Portrayal of the Combat Environment	This factor examines the scope, range and domain of the combat environment.
1) Size of Battle Area	Saber models theater level operations and combat units are aggregated at the division level. Saber does not track individual aircraft or combat soldiers. Rating: G
2) Duration of Battle	The game period is a controller defined value that can range from a two hour cycle to a number of days. At the end of the period Saber is designed to provide 1) an updated order of battle, and 2) output reports, charts and analysis information, for planning the next period. Rating: G
3) Nature and Behavior of Enemy Targets	Except for designated sanctuaries, nearly any object identified by intelligence reports can be targeted. Striking a target can result in direct attrition, a change in unit posture, create delays, and/or reduce the capability of enemy assets. Rating: G
4) Deployment of Assets	The concepts of apportionment, allocation, and allotment are integral parts of the training seminars. Game players are responsible for the movement of assets under their control. Movement is based on an assessment of the tactical situation, resources available, planned objectives, perceived intentions of the enemy, or other extenuating circumstances. Rating: G
5) Terrain	Saber provides a colored graphics display of the theater land map. Nearly all of the features needed for players to evaluate the location, and movement of assets is provided on the graphics display. Although there were some limitations identified with the terrain map, the limitations were characteristic of a low resolution combat model and did not distract from the overall design. Rating: G
6) Scenario Development	Scenario development is important to add a sense of realism to the wargame and is given a good deal of attention. Procedures are established that combine the needs of the user with the expertise of the personnel in the Wargaming Center to provide realistic scenario development. Rating: G

4. Operational Performance Factors	For this thesis, the operational performance factors discussed are those that the players have little or no control over, but are important in adding a sense of realism to the wargame.
1) IFF/Fratricide	Saber does not model the IFF/Fratricide issue. Several assumptions are made to circumvent the issue. Rating: P
2) Weather	Weather plays a factor in many aspects of the wargame, including: the types of aircraft that can fly, the weapons loads, the probability to penetrate area defenses, and intelligence collecting. Weather does not have an affect on the movement of assets or attrition. Additionally, the weather generating algorithm is complicated. Rating: A
3) Command, Control and Communications (C^3)	C^3 is handled external to the simulation and the chain of command and operational responsibilities are well established. However, internal--to the simulation--representation of C^3 is not modelled. Rating: (external)-G, (internal)-P
4) Intelligence	Intelligence is modelled externally and internally very well. During the wargame planning phase an intelligence officer is assigned staff and is responsible for gathering and assessing the wealth of information made available. Internal to the simulation, Saber keeps track of entities and provides ways of improving or obtaining intelligence information. Rating: G
5) Logistics	Logistics is also given a great deal of consideration both internal and external to the model simulation. The primary focus of the exercise is to make decisions and to ensure the right forces get to the right place at the right time with the right equipment, all of which implies logistics. The simulation is designed to assists the logistics effort by performing the function of a book-keeper. The simulation should also provide a means of transporting equipment and provide some analysis information indicating areas of expected shortage or overages. Rating: (external)-G, (internal)-INC

5. Broad Scale Battle Environment	This factor looked at the combat potential and representation of troops and units, the scope or range of conflict, and the interaction of ground and air assets. The firepower of a unit is a function of the number and types of direct fire components [based on a "battalion equivalent" (BE) system] and the quality of the troops. Combat power is a function of a unit's firepower, support assets, terrain, and unit posture. Saber is designed to represent a conventional theater level campaign; although nuclear, biological and chemical (NBC) weapons are included as possible weapons loads. The interaction of ground and air assets is enhanced due to the airland battle doctrine that the model was designed to represent. Rating: G
6. Logical Representation of Model Design and Mathematical Algorithms.	This factor looked at the layout of the model design and the mathematical algorithms, functions and equations used in the model. The model design and flow were examined with specific attention given to the functions of the pre and post processor, player input, the model simulation, and output reports. The mathematical portions of the model were found to be clear, understandable, and well documented. Rating: G
7. Selection of Input Data	This factor looked at the sources of information used in the simulation database and in the development of other exercise materials. The information used to develop the weapons, units, terrain and scenario data files 1) come from readily available, reliable, and unclassified sources, and 2) are well documented. Rating: G

Area of Concern: Credibility Based on the Correspondence Between the Model and the Real World (Chapter 5)	
Factors and Attributes:	**Comments, Strength, Limitation/Weakness**
8. Evidence of a Verification Effort	For the purpose of this thesis, the initial verification effort focussed on the 1) assumptions, 2) scenario development, 3) documentation, 4) database design, 5) computer coding, logic and algorithms, and 6) design or flow of the model and wargame. Each of these factors were found to be consistent with accepted military doctrine and/or reflected the intentions of the model designers. Rating: G
9. Evidence that the Results are Statistically Representative	Because Saber is not operational, there is no quantifiable evidence that results are statistically representative. This factor specifically examined the stochastic processes used to model the movement and attrition of air and ground assets. Based on an examination of the above two attributes, there is evidence to expect the output results will be statistically representative; although the final determination must be reserved until the model is complete. Rating: INC
10. Evidence of Sensitivity Testing	Again, because the model is not complete, there was no way to test the factors that should have the greatest impact of output results. Therefore, this section identified areas that should be examined when the simulation portion of the model is complete. These areas included: 1) Weather, 2) Terrain, 3) Movement Rates, 4) The "chicken-factor"/breakpoint, and 5) The model breakdown point. Rating: INC
11. Evidence of a Validation Effort	Validity can be determined with respect to the ability of a model to accomplish a specific purpose or use. The Wargaming Center's desire is to have a model that produces credible results in simulating an airland battle, and Saber should provide this capability. The Wargaming Center was judged most capable of completing the validation effort; because of 1) time requirements, 2) the resources and expertise required, and 3) the procedures that have already been developed for this purpose. Rating: INC

Area of Concern: Credibility Based on Model Support Structure, Documentation and Reporting (Chapter 6)	
Factors and Attributes:	**Comments, Strength, Limitation/Weakness**
12. Establishment of Support Structures to Manage the Simulations Design, Data, and Operating Requirements	This factor sought to identify the agency responsible for ensuring Saber would be maintained, and to identify the users and their responsibilities. The Wargaming Center was identified as the responsible agency for the Saber model--through every phase of Saber's life cycle. Key players involved in the use or development of wargames were also identified and their purpose and functions were explained. These players include, 1) AU Exercise Sponsors, 2) the Exercise Coordinator, 3) the Exercise Director, and the 4) Exercise Design Team. The Wargaming Center was determined to be more than capable of providing the support structure required to manage the Saber model. Rating: G
13. Development of Documentation to Support the Information Needs of Persons Using the Simulation	This factor identified what the information needs of the users are and how these needs can be met. Chapter 7, Saber AirLand Methodology (and additional information in a separate manual) was written to provide the information needs of the exercise director and design team members, The information needs of possible sponsors was provided by developing a SIMTAX taxonomy worksheet. Rating: G
14. Disclosure of the Simulation's Strengths and Weaknesses	This factor concentrated on the limitations and weaknesses of the Saber model. A number of limitations and weaknesses were identified during the review of the Saber documentation. Most of these limitations and weaknesses were typical of low resolution combat models and were not deemed sufficient to cast doubts on the credibility of the model or its ability to simulate a theater level combat environment. The most significant limitation to this current version of the Saber model is that it does not work, i.e. the simulation is not complete. And, until the model is operational the potential strengths and weaknesses of the model can not be determined. Rating: INC

Appendix B

This appendix outlines the analysis conducted on the random number generator, a uniform distribution coded by Sherry, that was discussed in Section 5.2.

The two properties of a list of pseudo random numbers--uniformity and independence--were examined with a variety of statistical tests. A test of uniformity was accomplished by writing a FORTRAN program that provided histograms of a list of random numbers (provided by Sherry's algorithm). A chi-square test for goodness of fit was then accomplished comparing the results of the FORTRAN program to the expected results of a uniform distribution. (The format uses MathCAD software from MathSoft Inc.)

Four Runs tests were accomplished to test (a sequence of 100 random numbers generated by Sherry's algorithm) for independence. The runs tests included: 1) Runs Up and Down, 2) Runs Above and Below the Mean, and 3) Runs test: length of runs for Runs Up and Down, and 4) Runs test: length of runs for Runs Above and Below the Mean (Banks:257 - 281). Based on the result of these tests there is no evidence to reject the hypothesis that these numbers are the result of a random process.

Other tests could (and probably should) be conducted on the random number generator and the sequence of numbers used for the following tests, such as an autocorrelation test, a gap test, and a Poker test. However, it should be realized that by conducting a number of tests, "the probability of rejecting the null hypothesis on at least one test, by chance alone [i.e., making a Type I error], increases" (Banks:268).

```
**  David L. Scagliola                                      Oct 91      **
**************************************************************************
**  THIS PROGRAM WILL DEVELOP A DISTRIBUTION HISTOGRAM FOR A            **
**             SEQUENCE OF RANDOM NUMBERS                               **
**************************************************************************

       INTEGER I,J,K,N,S(10)
       CHARACTER*40 STAR
       REAL X(5000),PERCENT
       READ*,(X(N),N=1,5000)        : Read in Random Numbers
       J = 5                        : Initial Sample Size
5      PRINT*,' '
       DO 10 K = 1,10               :
       S(K) = 0                     : Initialize Sums to Zero
10     CONTINUE                     :
       PRINT 400,J                  : Print Header and Sample Size
       PRINT 600
       DO 20 I=1,J                  :
          K=INT(10*X(I))+1          : Partition Random Numbers
          S(K) = S(K) + 1           :         Into Cells
 20    CONTINUE                     :
       DO 50 K=1,10
       PERCENT = 100*(S(K)/REAL(J)): Calculate Percentage in Cell
       STAR = ' '
       DO 40 L = 1,INT(PERCENT)      :
          STAR(L:L) = '*'           : Create Pattern for Histogram
40     CONTINUE                     :
       PRINT 500,K-1,K,S(K),PERCENT,STAR  : Print Statement
50     CONTINUE
       PRINT 600
       IF(J.LT.5000) THEN            :
                J = J*10             : Increase Sample Size
                GO TO 5              : Repeat Process
       END IF                        :
 400   FORMAT(1X,'RANGE',2X,'TIMES CHOSEN',2X,'PERCENT',3X,
     1           ' DISTRUBITION With N =',I5)
 500   FORMAT(1X,I2,'-',I2,5X,I5,5X,F7.2,5X,'+',A40)
 600   FORMAT(1X,'________________________________________',
     1           '_______________________')
       END
```

OUTPUT FOR RANDOM NUMBER GENERATOR TEST

RANGE	TIMES CHOSEN	PERCENT	DISTRUBITION With N = 5
0- 1	0	0.00	+
1- 2	0	0.00	+
2- 3	0	0.00	+
3- 4	0	0.00	+
4- 5	1	20.00	+********************
5- 6	2	40.00	+**
6- 7	0	0.00	+
7- 8	1	20.00	+********************
8- 9	1	20.00	+********************
9-10	0	0.00	+

RANGE	TIMES CHOSEN	PERCENT	DISTRUBITION With N = 50
0- 1	8	16.00	+****************
1- 2	7	14.00	+**************
2- 3	1	2.00	+**
3- 4	5	10.00	+**********
4- 5	6	12.00	+************
5- 6	6	12.00	+************
6- 7	2	4.00	+****
7- 8	5	10.00	+**********
8- 9	7	14.00	+**************
9-10	3	6.00	+******

RANGE	TIMES CHOSEN	PERCENT	DISTRUBITION With N = 200
0- 1	20	10.00	+**********
1- 2	22	11.00	+***********
2- 3	10	5.00	+*****
3- 4	17	8.50	+********
4- 5	26	13.00	+*************
5- 6	16	8.00	+********
6- 7	17	8.50	+********
7- 8	21	10.50	+**********
8- 9	31	15.50	+***************
9-10	20	10.00	+**********

RANGE	TIMES CHOSEN	PERCENT	DISTRUBITION With N = 500
0- 1	45	9.00	+*********
1- 2	51	10.20	+**********
2- 3	50	10.00	+**********
3- 4	33	6.60	+******
4- 5	66	13.20	+*************
5- 6	38	7.60	+*******
6- 7	51	10.20	+**********
7- 8	49	9.80	+*********
8- 9	62	12.40	+************
9-10	55	11.00	+***********

RANGE	TIMES CHOSEN	PERCENT	DISTRUBITION With N = 1000
0- 1	100	10.00	+**********
1- 2	103	10.30	+**********
2- 3	101	10.10	+**********
3- 4	69	6.90	+******
4- 5	120	12.00	+************
5- 6	89	8.90	+********
6- 7	106	10.60	+**********
7- 8	108	10.80	+**********
8- 9	106	10.60	+**********
9-10	98	9.80	+*********

RANGE	TIMES CHOSEN	PERCENT	DISTRUBITION With N = 2000
0- 1	191	9.55	+*********
1- 2	196	9.80	+*********
2- 3	211	10.55	+**********
3- 4	169	8.45	+********
4- 5	228	11.40	+***********
5- 6	183	9.15	+*********
6- 7	208	10.40	+**********
7- 8	209	10.45	+**********
8- 9	204	10.20	+**********
9-10	201	10.05	+**********

RANGE	TIMES CHOSEN	PERCENT	DISTRUBITION With N = 4000
0- 1	384	9.60	+*********
1- 2	400	10.00	+**********
2- 3	420	10.50	+**********
3- 4	367	9.18	+*********
4- 5	414	10.35	+**********
5- 6	380	9.50	+*********
6- 7	392	9.80	+*********
7- 8	413	10.32	+**********
8- 9	414	10.35	+**********
9-10	416	10.40	+**********

RANGE	TIMES CHOSEN	PERCENT	DISTRUBITION With N = 5000
0- 1	491	9.82	+*********
1- 2	502	10.04	+**********
2- 3	516	10.32	+**********
3- 4	476	9.52	+*********
4- 5	525	10.50	+**********
5- 6	459	9.18	+*********
6- 7	486	9.72	+*********
7- 8	502	10.04	+**********
8- 9	523	10.46	+**********
9-10	520	10.40	+**********

Chi-square test for goodness-of-fit (Using MathCAD software)

Chi-square test is conducted as follows,

1) partition random numbers into k intervals
2) determine (based on the distribution) the probability p of the random number falling in the interval
3) select a large enough sample size
4) compute the Chi-square statistic
5) compare with a Chi-square value at α, and (k-1) df
6) reject if calculated value is greater than Table value.

p = .1 ... Uniform distribution between 0 and 10
n_j = number of random numbers chosen in jth trial
k = 10 intervals in the histogram
N_k = number of observations in interval k
α = .05
(k-1) = 9 degrees of freedom

$p := .1 \qquad j := 1 ..7 \qquad k := 1 ..9$

n = 50 200 500 1000 2000 4000 5000

$$N := \begin{bmatrix} 8 & 20 & 45 & 100 & 191 & 384 & 491 \\ 7 & 22 & 51 & 103 & 196 & 400 & 502 \\ 1 & 10 & 50 & 101 & 211 & 420 & 516 \\ 5 & 17 & 33 & 69 & 169 & 367 & 476 \\ 6 & 26 & 66 & 120 & 228 & 414 & 525 \\ 6 & 16 & 38 & 89 & 183 & 380 & 459 \\ 2 & 17 & 51 & 106 & 208 & 392 & 486 \\ 5 & 21 & 49 & 108 & 209 & 413 & 502 \\ 7 & 31 & 62 & 106 & 204 & 414 & 523 \\ 3 & 20 & 55 & 98 & 201 & 416 & 520 \end{bmatrix} \qquad n := \begin{bmatrix} 50 \\ 200 \\ 500 \\ 1000 \\ 2000 \\ 4000 \\ 5000 \end{bmatrix}$$

$$Chi\_square_j := \sum_k \frac{\left[N_{k,j} - n_j \cdot p\right]^2}{n_j \cdot p} \qquad Chi\_square = \begin{bmatrix} 8.8 \\ 14.8 \\ 17.22 \\ 16.28 \\ 12.065 \\ 6.925 \\ 7.904 \end{bmatrix} \begin{matrix} \text{<-- n = 50} \\ \text{<-- n = 200} \\ \text{<-- n = 500} \\ \text{<-- n = 1000} \\ \text{<-- n = 2000} \\ \text{<-- n = 4000} \\ \text{<-- n = 5000} \end{matrix}$$

Chi-square(α=.05,9df) = 16.92

For values of n >= 1000 there is no evidence to reject the hypothesis that these random numbers are generated from a Uniform Distribution.

NOTE: Chi-square test is only valid for large values of n.

```
10 REM:              RUNS Testing Program
20 REM:         Written by: David L. Scagliola   3 March 1992
30 REM:
40 REM:         This program can be used to test the Independence
50 REM:         of a sequence of pseudo random numbers using two
60 REM:         Runs Tests: 1) Runs Up and Down and 2) Runs Above
70 REM:         and Below the Mean
80 REM:
90 REM:         Variables and I/O data:
100 REM:            rnd.dat = file random numbers are located in
110 REM:         result.dat = output results
120 REM:                NUM = number in the sequence
130 REM:                  A = random number read from rnd.dat file
140 REM:              COUNT = counter
150 REM:           X(COUNT) = array of random numbers
160 REM:           C(COUNT) = array of + and - in the sequence: Test 1
170 REM:          CC(COUNT) = array of + and - in the sequence: Test 2
180 REM:                PP$ = place holder for + or - value
190 REM:            PM$/PM$ = string of + or - in the sequence: Test 1,2
200 REM:                 N1 = number of +s
210 REM:                 N2 = number of -s
220 REM                   N = N1 + N2
230 REM:          MUE1/MUEB = computed mean value: Test 1/Test 2
240 REM:          VAR1/VARB = computed variance value: Test 1/Test 2
250 REM:              Z1/ZB = computed z statistic: Test 1/Test 2
260 REM:                  B = number of runs in the sequence
270 REM:
280 REM:
290 DIM X(100), C(100), CC(100)
300 OPEN "a:rnd.dat" FOR INPUT AS #1
310 OPEN "a:result.dat" FOR OUTPUT AS #2
320 INPUT "Numbers in the sequence = ";NUM
330 PRINT#2, "The Stream of Random Numbers is..."
340 REM:  Read in the sequence of random numbers
350 FOR COUNT = 1 TO NUM
360 INPUT #1,A
370 PRINT#2, USING ".### ";A;
380 X(COUNT) = A
390 NEXT COUNT
400 PRINT#2,"                   Analysis of Runs"
410 FOR COUNT = 2 TO NUM
420 REM:  Assign + or - to the random variable
430 IF X(COUNT - 1) < X(COUNT) THEN PP$ = "+":C(COUNT) = 1
440 IF X(COUNT - 1)>= X(COUNT) THEN PP$ = "-":C(COUNT) = 0
450 PS$ = PS$+PP$
460 NEXT COUNT
470 PRINT#2,PS$
480 C(1) = -1
490 REM:  Determine number of runs
500 FOR COUNT = 2 TO NUM
510 IF C(COUNT - 1)<> C(COUNT) THEN RUNS = RUNS + 1
520 NEXT COUNT
530 PRINT#2, "                    Runs = ";RUNS
```

```
540 REM:  Compute statistics
550 MUE1 = (2*NUM - 1)/3
560 VAR1 = (16*NUM - 29)/90
570 Z1 = (RUNS - MUE1)/VAR1^.5
580 PRINT#2,"mean = "MUE1;"  Variance =";VAR1;"  and Z statistic =";Z1
590 PRINT#2, "         Analysis of Runs above and below the mean"
600 REM: Accomplish Test 2, identity sequence of + and -s
610 FOR COUNT = 1 TO NUM
620 IF .5 < X(COUNT) THEN PP$ = "+":PLUS = PLUS + 1:CC(COUNT) = 1
630 IF .5>= X(COUNT) THEN PP$ = "-":MINUS = MINUS + 1:CC(COUNT) = 0
640 PM$ = PM$+PP$
650 NEXT COUNT
660 PRINT#2, PM$
670 REM: Determine number of Runs
680 RUN2 = 1
690 FOR COUNT = 2 TO NUM
700 IF CC(COUNT - 1) <> CC(COUNT) THEN RUN2 = RUN2 + 1
710 NEXT COUNT
720 PRINT#2, "         Runs above and below the mean = ";RUN2
730 REM: Compute Statistics
740 N1 = PLUS
750 N2 = MINUS
760 N = N1 + N2
770 B = RUN2
780 PRINT RUN2
790 PRINT N1,N2,N
800 MUEB = (2*(N1*N2))/N + 1/2
810 VARB = (2*N1*N2*(2*N1*N2 - N))/(N^2*(N - 1))
820 ZB = (B - MUEB)/VARB^.5
830 PRINT#2, "Meanb =";MUEB;" Varianceb =";VARB;" and Zb statistic = ";ZB
840 END
```

Analysis of the Runs Tests

This page reports on the results of the BASIC program that tested the hypothesis for independence using the 1) Runs up a..d down test, and the 2) Runs above and below the mean test (Banks:273 - 278).

The Stream of Random Numbers is...

```
.707 .586 .558 .458 .745 .185 .840 .930 .536 .709 .156 .319 .124 .973 .088
.900 .700 .611 .772 .007 .095 .543 .127 .025 .876 .267 .426 .451 .049 .857
.336 .034 .488 .671 .128 .911 .041 .478 .413 .074 .350 .343 .331 .600 .552
.897 .130 .850 .106 .778 .192 .483 .357 .949 .813 .417 .651 .032 .895 .920
.360 .467 .673 .992 .086 .148 .248 .571 .949 .279 .489 .859 .742 .171 .997
.159 .814 .995 .446 .307 .551 .627 .705 .511 .781 .988 .803 .880 .138 .523
.444 .180 .872 .066 .970 .420 .371 .461 .225 .100
```

1) Analysis of Runs: Up and Down

```
---+-++-+-+-+-+--+-++--+-++-+--++-+-+--+--+-+-+-+
-+-+--+-++-+++-++++-++--+-++--+++-++-+-+--+-+--+--
```

Runs = 71

Mean = 66.33334 Variance = 17.45556 $Z_{statistic}$ = 1.11696

$Z_{.025} = 1.96 > Z_{statistic} = 1.116$

Therefore we can not reject (based on this test) the independence of this stream of random numbers.

2) Analysis of Runs: Above and Below the Mean

```
+++-+-++++---+-++++--+--+----+---+-+-------+++-+-+
---++-+-++--++---++--++-+-++--++++++++-+--+-+------
```

Runs above and below the mean = 51

Meanb = 50.42 Varianceb = 24.66754 and $Zb_{statistic}$ = -.085

$Z_{.025} = 1.96 > Zb_{statistic} = -.085$

Therefore we can not reject (based on this test either) the independence of this stream of random numbers.

The next page outlines the analysis conducted to determine if the "length of runs" for the 1) runs up and down or 2) runs above and below the mean would result in rejecting the hypothesis of independence (Banks: 278 - 281).

1) Length of Runs: Runs up and Down

The expected number of runs Y_i in the sequence of numbers N is:

$$E(Y_i) = 2/(i + 3)! * [N(i^2 + 3i + 1) - (i^3 + 3i^2 - i - 4)]$$

$$E(Y_1) = 2/4! * [100(1 + 3 + 1) - (1 + 3 - 1 - 4)] = 41.75$$

$$E(Y_2) = 2/5! * [100(4 + 6 + 1) - (8 + 12 - 2 - 4)] = 18.1$$

$$E(Y_3) = 2/6! * [100(9 + 9 + 1) - (27 + 27 - 3 - 4)] = 5.14$$

$$E(Y_4) = 2/7! * [100(16 + 12 + 1) - (64 + 48 - 4 - 4)] = 1.11$$

Table B.1 Length of Runs Up and Down: X^2 test

Run Length, i	Observed Runs, O_i	Expected Number of Runs, $E(Y_i)$	X^2 Statistic $\frac{[O_i - E(Y_i)]^2}{E(Y_i)}$
1	48	41.75	.935
2	19	18.1	.045
3	3	5.14	.891
≥ 4	1	1.11	.011
	71	66.1	1.88

The $X^2(0.05,2) = 5.99$ > X^2 statistic = 1.88

Therefore we can not reject (based on this test) the independence of this stream of random numbers.

2) Length of Runs: Runs above and below the mean

The expected number of runs Y_i in the sequence of numbers N is:

$$E(Y_i) = Nw_i/E(I), \quad \text{where } w_i = (n_1/N)^i(n_2/N) + (n_1/N)(n_2/N)^i$$

$$\text{and } E(I) = (n_1/n_2) + (n_2/n_1),$$

$$\text{given } n_1 = 48, \text{ and } n_2 = 52$$

$$w_1 = (.48)^1(.52) + (.48)(.52)^1 = .4992$$
$$w_2 = (.48)^2(.52) + (.48)(.52)^2 = .2496$$
$$w_3 = (.48)^3(.52) + (.48)(.52)^3 = .1250$$
$$w_4 = (.48)^4(.52) + (.48)(.52)^4 = .0627$$

$$E(I) = (48/52) + (52/48) = 2.006$$

$$E(Y_1) = 100(.4992)/2.006 = 24.89$$
$$E(Y_2) = 100(.2496)/2.006 = 12.44$$
$$E(Y_3) = 100(.1250)/2.006 = 6.23$$
$$E(Y_4) = 100(.0627)/2.006 = 3.13$$

Table B.1 Length of Runs Above and Below the Mean: X^2 test

Run Length, i	Observed Runs, O_i	Expected Number of Runs, $E(Y_i)$	X^2 Statistic $\frac{[O_i - E(Y_i)]^2}{E(Y_i)}$
1	26	24.89	.05
2	12	12.44	.016
3	6	6.23	.009
$\geq$ 4	6	3.13	2.63
	50	46.69	2.707

The $X^2(0.05,2) = 5.99 \quad > \quad X^2$ statistic = 2.707

Therefore we can not reject (based on this test) the independence of this stream of random numbers.

Appendix C

This appendix contains a BASIC program designed to determine aircraft maintenance times using a triangular distribution. Following the program are results from two sample runs.

```
10 REM:             Triangular Distribution Algorithm
20 REM:         Written by: David L. Scagliola   5 February 1992
30 REM
40 REM:       This algorithm can be used to find maintenance times
50 REM:       for an aircraft returning from a mission, given the
60 REM:       following information:
70 REM
80 REM:            a = expected minimum time required for maintenance
90 REM:            b = expected maximum time required for maintenance
100 REM:           m = mode or most likely time required for maintenance
110 REM:           c = the normalized mean for the triangular distribution
120 REM:           X = computed X-statistic
130 REM:          MX = computed maintenance time
140 REM: Input variables a,b, and m.  In Saber these values would be
150 REM: attributes of the aircraft.
160 OPEN "a:triangle.dat" FOR OUTPUT AS #1
170 READ A,B,M:DATA 3,8,5
180 REM: Compute c
190 C = (M - A)/(B - A)
200 FOR COUNT = 1 TO 2
210 PRINT#1,"               Test Results for 10 trials"
220 PRINT#1, "Triangular distribution with variables a =";A
230 PRINT#1, "                                       b =";B
240 PRINT#1, "                          and m, where a<m<b =";M
250 PRINT#1, " is normalized to triang("0;",";1;",";C;")"
260 PRINT#1, "Trial#  Random Number  X-statistic  Maintenance time (hrs)"
270 FOR TRIAL = 1 TO 10
280 U = RND(1)
290 IF U <= C THEN X = (C*U)^.5
300 IF U  > C THEN X = 1 - ((1-C)*(1-U))^.5
310 REM:  Compute actual Maintenance Time
320 MX = A + (B - A) * X
330 PRINT#1, USING "##.##        ";TRIAL,U,X,MX
340 NEXT TRIAL
350 A=4:B=11:M=7
360 NEXT COUNT
370 END
```

The sample runs are provided on the next page.

Sample Test #1

Test Results for 10 trials

Triangular distribution with variables a = 3
b = 8
and m, where a<m<b = 5
is normalized to triang(0 , 1 , .4)

Trial#	Random Number	X-statistic	Maintenance time (hrs)
1	0.12	0.22	4.10
2	0.65	0.54	5.71
3	0.87	0.72	6.60
4	0.73	0.60	5.99
5	0.80	0.65	6.26
6	0.07	0.17	3.86
7	0.49	0.45	5.23
8	0.45	0.43	5.14
9	0.11	0.21	4.04
10	0.95	0.83	7.14

Sample Test #2

Test Results for 10 trials

Triangular distribution with variables a = 4
b = 11
and m, where a<m<b = 7
is normalized to triang(0 , 1 , .4)

Trial#	Random Number	X-statistic	Maintenance time (hrs)
1	0.70	0.58	8.05
2	0.53	0.47	7.29
3	0.97	0.87	10.08
4	0.32	0.36	6.51
5	0.96	0.84	9.86
6	0.93	0.80	9.61
7	0.53	0.47	7.30
8	0.56	0.49	7.42
9	0.67	0.56	7.89
10	0.70	0.58	8.04

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Vita

Captain David L. Scagliola was born 26 August 1956 in New Britain, Connecticut. He graduated from New Britain High School in June 1974. In 1976 after a year and a half of studies at the University of Connecticut, West Hartford Branch, he enlisted in the Air Force. After completing basic and technical training, his first assignment was to the USAF Clinic, Rhein Main AB, Germany as a Veterinary Technician. Following three years in Germany, he returned to the states for a short tour at Parris Island, SC. In 1980, he was given an Honorable Discharge from the Air Force and returned to school at Eastern Connecticut State College (ECSC), and attended ROTC training at the University of Connecticut. He graduated suma cum laude from ECSC with a B.A. in Mathematics and received his commission in May 1982. His first assignment was to undergraduate navigator training at Mather, AFB CA. After receiving his aeronautical rating he attended the undergraduate electronic warfare officer training (EWOT) school at Mather, AFB CA with a follow-on assignment to Castle AFB, CA for B-52 aircrew training and finally to Griffiss AFB, NY as a B-52 aircrew member. In August 1990, after six years at Griffiss and attaining the position of Chief, Aircrew Training Devices Branch (B-52 Weapons Systems Trainer), he was accepted to the School of Engineering, Air Force Institute of Technology, Wright-Patterson, AFB, OH.

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