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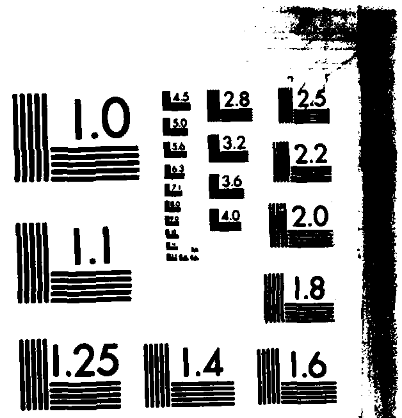
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Monterey, California

THESIS

AN EXPECTED VALUE AIR COMBAT MODEL SIMULATION ALGORITHM TO PREDICT MISSIONS PERFORMANCE IN TACTICAL AIR OPERATIONS

by

Efstratios Skliris

September 1983

Thesis Advisor: James K. Hartman

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Initially the reader will be introduced to the concepts, methods and present constraints of Modeling and Simulation focused on Air Operations. Then the thesis will demonstrate a

Block 20 continued:

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The model developed in this study is a highly aggregated Theater-Level model which utilizes the allocation of aircraft in various missions on a daily basis to obtain the outcome of an offensive versus defensive systems engagement.

The simulation algorithm which supports the model consists of an air portion including a limited number of factors of accomplish the main objective--to give insight capabilities to a non-expert reader.

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An Expected Value Air Combat Model Simulation Algorithm to Predict Mission Performance in Tactical Air Operations

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I. INTRODUCTION

A. GENERAL

During a Tactical Air Campaign, the commanders (decision makers) on each side are faced with many decisions which affect the outcome of the campaign. They make decisions such as how many sorties should be flown in offensive, defensive or support roles, specific targets to be hit, mission profiles, and the mix of aircraft to be sent against each target.

Two of the most important and basic decisions in a Tactical Air Ware are: a) the apportionment of sorties among the various air tasks and b) the allocation of aircraft to be sent against each target.

> A Tactical Air Operation involves the employment of tactical air power to gain and maintain air superiority, inhibit movement of enemy forces, seek out and destroy enemy forces and their supporting installations ... (and) directly assist ground or naval forces to achieve their immediate operational objectives... [Ref. 1:p.1-1]

The mission of tactical air power is:

> "To deter the enemy from attacking, and should deterence fail, to conduct war at the level of intensity and effectiveness needed to win." [Ref. 1:p.1].

This mission demands the right forces effectively employed. When faced with an enemy offensive air threat, a priority mission of tactical air forces is to defeat the enemy air effort. At the same time, engaged surface forces must be provided close air support at a level commensurate with the pace of their operation and the pressure exerted by enemy ground forces. The relative weight and timing of the effort committed to these tasks will vary according to the nature of the threat and degree of success achieved by friendly air and surface forces.

The above formidable task of apportioning sorties among offensive defensive, or support roles and of allocating aircraft within the different air roles (air base attack, close air support, tactical maritime operations) in a multi-strike campaign requires reliable, demanding training and realistic exercises. [Ref. 1:p.1-2]. The latter have to stress the tactics that will be used in combat and can be achieved by simulation using a computer war game. [Ref. 2:p.16]. The decision process employed by a commander can be characterized as a two-sided war game in which the successive decisions which are made each day are based upon the resources available and the status of enemy forces. [Ref. 3:p.4].

Many detailed simulation models have been developed to study the employment of tactical air forces and to practice different force mixes, but these models are constructed to represented a large scale of operations and attempt to approach an exact model of the real life situation. The problem with many of these models is their enormous size.

The data bases are huge, and the computer storage space required to run these models severely limits where they can be operated.

For example the IDA TACWAR model (a comprehensive theater level model developed for the Joint Chiefs of Staff) requires 10,000 data items to be input for model operation. [Ref. 4].

B. PROBLEM SETTING

Consequently, there is a need for a small scale model which allows a student analyst of tactical air operations to create his own battles and to test his own strategies with a program which is simple to use and inexpensive to run on a computer.

Such an Air Combat Model Simulation would deal with the apportionment and allocation decisions and will be used as a preparation step for student analysts to participate in one of the more complex war models used in the level of Tactical Air Force, General Staff, or National Defense General Staff (DOD), [Ref. 5]. The level of detail in the model would be such that participants could readily observe the impact of their allocation decisions, note where they have made mistakes, and formulate new strategies.

C. OBJECTIVES OF THE THESIS

The objectives of this thesis are twofold:

1. To find a progressive overview of fundamental principles met in Air Combat Modeling Simulation.
2. To determine an informal, two-sided air combat model in which the participants make decisions and supply input data.

D. OVERVIEW

The thesis is structured such that the reader can progressively develop background. In Chapter II the conceptual setting of the nature of the System's Modeling is presented along with its types and their processes. Furthermore some distinct concepts of system simulation are presented. Chapter III deals with Modeling in Theater Level of Operations, the associated problems and the main elements of consideration. Chapter IV focuses directly on the Air Combat Model Simulation and the elements of constructing similar models.

Finally, Chapter V demonstrates an air combat model simulation namely "ICARUS" which is presented in the analytic phase-demonstration to give a basic picture of an air model construction process.

Throughout the thesis, it is assumed that the reader is generally familiar with computer programming techniques and is very willing to support this basic study with extra reading or study of the reference books.

II. CONCEPTUAL SETTING

A. SYSTEMS

Trying to understand or predict the behavior of a very large and complex organization like an Air Force, one realizes that there are a lot of variables and combinations of them which make it impossible. Keeping track of all the interactions while being able to make decisions based on the interactions of such a complex system is outside the capabilities of the human mind.

Consequently, there is a need for a way to study similar problems and today the answer is System Simulation. In other words by following a scientific process and using the digital computer, one can make predictions and make decisions.

The above paragraphs express efforts of many decades, if not centuries, of the research and scientific community. Therefore, a stepwise detailed analysis of the included notions will be presented in this section with the following sequence:

1. System
2. Model
3. System Simulation

The ways of expressing the acieved effectiveness of a complex system with applications oriented to the Air Force will be presented as a conclusion to this section.

1. What is a System

Gordon in [Ref. 16:p.1] defines a system as:

> "An aggregation or assemblage of objects, in some regular interaction or interdependence."

For the purpose of this thesis a more specific and operational definition will be used, given by Fitzgerald [Ref. 6].

> "A system can be defined as a network to interrelated procedures that are joined together to perform an activity or to accomplish a specific objective. It is in effect, all the ingredients which make up the whole."

The above definition is broad enough to include "static systems," but the principal interest of this thesis will be in "dynamic systems," where interactions cause changes over time.

Mil-std 499 (USAF) defines also the system as it is considered in the combat modeling environment as:

> "A system is a composite of equipment, skills, and techniques capable of performing and/or supporting an operational role. A complete system includes all equipment, related facilities, material, software, services, and personnel required for its operation and support to the degree that it can be considered a self-sufficient unit in its intended operational environment." [Ref. 7: p.75].

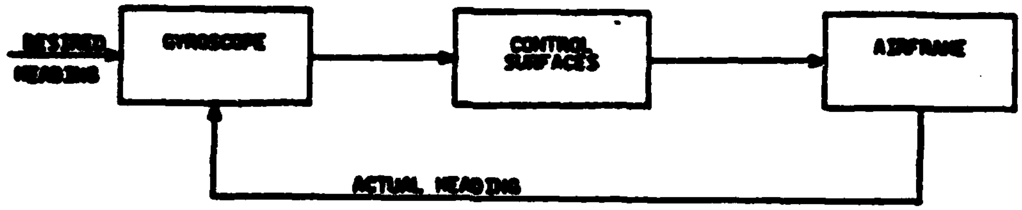

Figure 2.1 Aircraft Under AUTOPILOT Control

For an example of a conceptually simple system, consider an aircraft flying under the control of an auto-pilot, Figure 2.1. A gyroscope in the autopilot detects the difference between the actual heading and the desired heading. It sends a signal to move the control surfaces. In response to control surface movement, the airframe steers toward the desired heading.

As a second example, consider a factory that makes

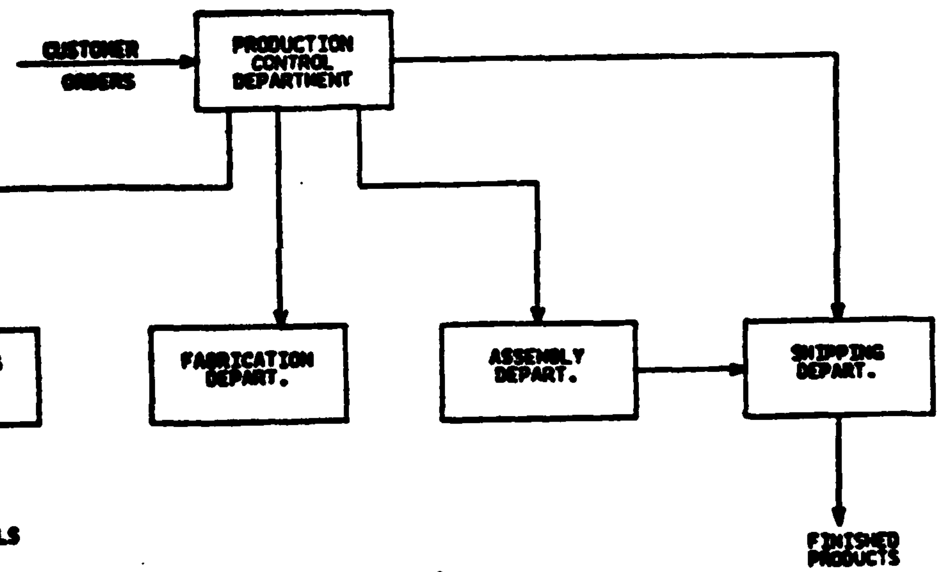

Figure 2.2 A Factory System

and assembles parts into a product, see figure 2.2. Two major components of the system are the fabrication department making the parts and the assembly department producing the products. A purchasing department dispatches receives finished products. A production control department receives orders and assigns work to the other department.

In looking at these systems, one sees that there are certain distinct objects, each of which possesses properties of interest. There are also certain interactions occuring in the system that cause changes in the system.

2. Terms of a System

Entity: is an object of interest in a system [Ref. 16:p.2] or an entity is each of the elements of the system.

Attribute: is a property of an entity. Consequently, each entity has one or more attributes.

Activity: is any process that causes changes in the system.

State of the System: is a description of all the entities, attributes and activities as they exist at one point in time.

The progress of the system is studied by following the changes in the state of the system.

In the description of the aircraft system, the entities of the system are the airframe, the control surfaces, and the gyroscope. Their attributes are such factors as speed, control surface angle, and the gyroscope setting. The activities are the driving of the control surfaces and the response of the airframe to the control surface movements. In the factory system, the entities are the departments, orders, parts, and products. The activities are the manufacturing processes of the department. Attributes are such factors as the quantities for each order, type or part, or number of machines in a department.

Every system has three basic features. It has an environment in which it exists. It has a set of boundaries which distinguish the system from the result of its environment. And it has a set of subsystems which are its component parts. [Ref. 15].

A system is consequently often affected by changes in the system's environment occuring outside the system. Some system activities may also produce changes that do not react on the system. An important step in modeling systems is to decide upon the boundary between the system and its environment.

"Endogenous" is a term used to describe activities occuring within the system and the term "exogenous" is used to describe activities in the environment that affect the system.

A system for which there is no exogenous activity is said to be a "closed" system in contrast to an open system which does have exogenous activities [Ref. 16:p.4].

Another distinction that needs to be drawn between activities depends upon the manner in which they can be described. Where the outcome of an activity can be described completely in terms of its input, the activity is said to be "deterministic". In other words the output of a deterministic system can be predicted completely if the input and the initial state of the system are known. That is, for a particular state of the system, a given input always leads to the same output. On the contrary, where the effects of the activity vary randomly over various possible outcomes, the activity is said to be "stochastic". [Ref. 16:p.4]. That is, a stochastic system in a given state may respond to a given input with anyone among a range or distribution of outputs. For a stochastic system-given the input and the state of the system- it is possible to predict only the range within which the output will fall and the frequency with which various particular outputs will be obtained over many repetitions of the observation. It is impossible to predict the particular output of a single observation of the system. [Ref. 19:p.14].

A very basic distinction in a system's classification is the way a system changes from one state to another. The previous examples, aircraft/factory, respond to environmental changes in different ways. The movement of the aircraft occurs smoothly, whereas the changes in the factory occur discontinously, i.e. the ordering of raw materials or the completion of a product, occurs at specific points in time.

Systems such as the aircraft, in which the changes are predominantly smooth, are called "continous systems". Systems like the factory, in which changes are predominantly discontinous, will be called "discrete systems". Because the distinction of continous vs discret is a very important step with serious consequences on how the system will be represented, the author will insist on some more supporting classifications of the issue continous vs discrete.

In the same examples, the complete aircraft system might even be regarded as a discrete system. If the purpose of studying the aircraft were to follow its progress along its scheduled route, with a view to study air traffic problems, there would be no point in following precisely "how" the aircraft turns. It would be sufficiently accurate to treat changes of heading at scheduled turning points (check points) as being made instantaneously, and so regard the system as being descrete.

In addition, in the factory system, if the number of parts is sufficiently large, there may be no point in treating the number as a discrete variable. Instead, the number of parts might be represented by a continuous variable with the machining activity controlling the rate at which parts flow from one state to another. The later approach is called Systems Dynamics. [Ref. 13:p.5].

This ambiguity in how a system might be represented illustrates an important point. The description of a system, rather than the nature of the system itself, determines what type of model will be used. A distinction needs to be made because the general programming methods used to simulate continuous or discrete systems differ.

3. Why we Analyze a System

The objectives in studying system behavior are "to learn how the state transitions occur, to predict transitions in state, and to control state transitions". [Ref. 19:p.16].

In general, the objective of a system study is to predict how a system will perform before it is built. Clearly, it is not feasible to experiment with a system while it is in this hypothetical form. An alternate that is sometimes used is to construct a number of prototypes and test them, but this can be very expensive and time-consuming. Even with an existing system, it is likely to be impossible or impractical to experiment with the actual system. For example, it is not feasible to test the results of a thermonuclear bomb or to ditch an airplane in order to predict its behavior in water landings.

Consequently, system studies are generally conducted with a "model" (substitute-simplification) of the system.

B. MODELS

Up to this point the reader has been oriented in the area of investigation (the system) and the basic terminology.

As mentioned previously, the initial step in analyzing a system is to build a "model" of the system.

In this section the notion of "model" and "modeling" will be implicitly and explicitly presented since they constitute the basic framework and purpose for this study, i.e. to study the modeling of Air Operations.

1. The Nature of Modeling

The process by which the analyst arrives at a model of the phenomanon he is studying is probably best described as "intuitive". If one grants the modeling is an intuitive process for the analyst then the interesting question is how to develop this intuition. [Ref. 8:p.B-707]. What can be done for the inexperienced person who wishes to progress as quickly as he can toward a high level of intuitive effectiveness? Can one answer only, "Get more experience, for it is the chief source of intuitive development?"

Military organizations have been the source of much of the development of modern, sophisticated modeling techniques, but the concept of models and modeling is neither new nor specific to military applications.

The Greeks had highly abstract models of the nature of the universe, e.g. the earth-fire-water-air and the atomic models of the substance of things; the Euclidian geometry, the axioms of which were generally accepted as consistent with the real world; and the Ptolemaic geometric model of the universe. Every artistic, scientific or commercial endeavor is based on an implicit if not explicit model, including an objective, the means to be used, and the environment within which it will be carried out.

Each theoretical or scientific study of a situation centers around a "model," that is, something that mimics relevant features of the situation being studied. For example, a road map, a geological map, and a plant collection are all models that mimic different aspects of a portion of the earth's surface.

The concept of a model is then very broad and general, and alway subject to constraints.

Hartman in [Ref. 24] defined a model as "a representation of some aspects of a subject of interest," which is potentially useful to analysts and decision makers because it represents the real world but does not replicate it. The latter probably confuses the reader but one has to keep in mind that the effort is to simplify particular aspects of the real world to help us solve particular problems. It is not the intent to represent everything in an all purpose model that tells everyone everything, solve nothing, and takes forever doing so.

"Forever" may sound overstated, but any length of time longer than that which is available, because of the nature of orders from superios, is effectively forever.

Thus, to the first constraint of limiting the scope of the models to be considered on military (primarily Air

Force) applications one must add a constraint on the complexity and length of time required for solutions and "computer runs." However, reducing complexity always involves a trade off with realism and the risk of omitting a factor that is important. This is particularly likely for factors that are not quantifiable or not readily quantifiable.

The art of modeling is becoming increasingly sophisticated in methods for introducing nonquantifiable, judgemental factors. One such method is the introduction of a "man-in-the-loop," a man-computer interaction. Nevertheless, the analyst must be enternally vigilant against overemphasis on the numbers and must always seek to define the limits and omissions of the model as well as what they do to assist the analysis. He must make the limits and omissions of his analysis clear to the decision-maker he seeks to aid. [Ref. 9:p.I-5].

For the purpose of this theses the following definition of the "model" will be utilized. [Ref. 24].

> "A model is the process of developing an internal representation and set of rules which can be used to predict the behavior and relationship between the set of entities composing the system when a realistic range of inputs is provided."

2. The Purpose of Modeling

If models are not all-purpose and cannot do everything, what can they do? Models can attack many specific kind of problems but one must note that models cannot always solve problems, particularly in the military field in which answers can only be determined in real war.

Although the models cannot always provide solutions, they may "shed light" in several ways: [Ref. 9:p.I-63].

Constructing and using a model increases the understanding, by both the analyst and his "client," of the problem being studied. The purpose is not just to educate the modeler. The learning must be transfered to the user or decision-maker.

Models can also aid in making choices. They can assist in comparing alternative weapons systems, tactics, environments, routings, training methods, and so on. They may sometimes give answers, in the sense that the absolute numbers are taken as valid. For example, a limited logistics model may be able to give valid estimates of absolute quantities of fuel consumed, or vehicles in given circumstances. On the other hand a bomber penetration model may give 70 percent bomber survival, or 70 percent of targets hit. However, one cannot know that 70 percent would be the real number unless it was in real combat.

One should always seek first to learn from a model. [Ref. 9:p.73]. In the process of learning one can often use a model to assist in making choices while caution and skepticism are always in order. One should seldom, if ever, accept absolute results of applying models, at least in the highly uncertain world of military affairs.

The purpose of a model should always be subsidiary to the purpose of the modeler or the decision-maker he serves. Analysts analyze, and the models can assist them in their taks. Models should always come after the definition of the problem. Modeling is one, but not the sole aid to analysis. It is never clear that a numerical mathematical or computer model should be used, or that a particular type of model should be used.

The above may sound obvious, however it frequently occurs that analysts apply a model they know and like, but this may not be the best approach to the problem. [Ref. 9: p.3].

3. Types of Models

Models can be classified in a variety of ways and can take many forms. Taylor stresses the following three basic types of models: [Ref. 10:p.4].

a. Iconic Models

An iconic model is a large or small-scale representation of states-objects, or events. For example a scale model airplance resembles the system under the study. They "look-like" what they are supposed to represent with only a transformation of scale. More examples of inconic models are a flow chart, road map (or any picture or diagram that looks like the real thing), or a wind tunnel. In each case only the scale of the system or operation has been changed.

b. Analog Models

In this model a property of the real system is represented by a "substituted property" which often behaves in a similar way. For example, an electric circuit that behaves like a mechanical system is an analog model.

c. Symbolic Models

This model uses a symbol rather than a physical device to represent an entity of the system. Verbal description of processes or systems qualify also as symbolic models.

When symbols represent quantities the model is usually called a Mathematical model, for example a set of equations. Later the focus will be on mathematical models of combat, in particular, combat attrition and therefore an indepth analysis of the mathematical model will follow.

Hartman gives the definition of mathematical model as follows: [Ref. 24].

> "A mathematical model is an abstract, simplified, mathematical construct related to a part of reality and created for a particular purpose."

As far as a model is concerned, the world can be divided into three parts:

1. Things whose effects are neglected.

2. Things that effect the model but whose behavior the model is not designed to study.

3. Things the model is designed to study the behavior of.

The model completely ignores item (a). The constants, functions, and so on, that appear in item (b) are external and are referred to as "exogenous variables" (also called parameters, input, or independent variables). The things the model seeks to explain are "endogenous variables" (also called output or dependent variables).

The exogenous-endogenous terminology is frequently used in economic modeling. The input-output terminology is used in areas of modeling where the model is viewed as a box (computer) into which one feeds information and from which obtains information. The parameter-independent-dependent terminology is the standard mathematical usage.

Definitions of the variables and their inerrelations constitute the "assumptions" of the model. One then uses the model to "draw conclusions" i.e. to make predictions. This is a deductive process: If the assumptions are true the conclusions must be also true, [Ref. 24].

4. Thoughts on Mathematical Modeling

When one tries to construct a mathematical model one may face a variety of conditions which can cause the abandonment of the effort as hopeless.

The mathematics involved may be so complex that there is little hope for analyzing or solving the model. This complexity can occur when using a system or partial differential equations or the problem may be so large (factors involved) that it is impossible to capture all the necessary information into a single mathematical model. A military confrontation (combat model) is an example. In such cases one attempts to replicate the behavior directly in some manner by partitioning from the collection of these data and then reach conclusions.

On the other hand one may attepmt to replicate the behavior "indirectly" by using, (mainly), the digital computer.

Mathematical models can be distinguished according to their characteristics into four classification schemes as follows:

a. Analytical vs Numerical

In an analytical model it is possible to deduce the behavior of the system, directly from the system's mathematical representation. Kirchoff's law (electricity) is an example of an analytical model. A numerical model implies that an exact deduction of the system's behavior is not feasible but numerical methods can provide descriptions of the behavior for certain system aspects as are defined in the numerical model. Numerical integration is an example of a numerical model.

b. Continuous vs Discrete

Continuous-change models are used to represent systems that consist of a continuous flow of information or material (e.g. Flow of gas in a pipeline). Continuous models are usually represented by differential equations which describe "rate of chage of the variables over time." Discrete-change models represent systems in which "changes in the state of the system are discrete" (e.g. messages arriving at a node of a network). Discrete models are usually represented using queueing theory and stochastic processes.

c. Static vs Dynamic

A static model either does not take into consideration the passage of time or describes the states of a system at a specific point in time. On the other hand, a dynamic model explicitly recognizes the passage of time. A dynamic model may specify also the relationships between the various system states at different points in time.

d. Deterministic vs Stochastic

In a deterministic system's model, all the entities of the system modeled have fixed mathematical or logical relationships to each other and the behavior of the system is completely determined by these relationships. Hence, its output is uniquely determined by its input in the sense that the same input always produces the same output.

A Stochastic model contains an element of chance (called also uncertainty) so that its output is not uniquely determined by input, but rather one must talk about the chances of observing various outputs for a given input. In other words, one must consider the Probability Distribution over the set of possible outcomes for a given set of inputs.

5. The Modeling Process

In previous sections the notion of model and modeling was presented as well as their common distinctions according to characterists.

Now a closer examination of the process of mathematical modeling will be demonstrated. [Ref. 11:p.ch-2]

Suppose one wants to understand some behavior or phenomenon in the real world, or may wish to make predictions about the behavior in the future and analyze the effects various situations have on that behavior.

One procedure which can be followed is to conduct some real world trails or experiments and observe their effect on the real world behavior. This is depicted in the left side of Figure 2.3.

While this procedure might seem ideal, one would not want to follow such a course of action. For instance, the cost of conducting even a single experiment may be prohibitive, such as detonating a 50 kiloton nuclear weapon over New York City to study its effects. Or one may not be

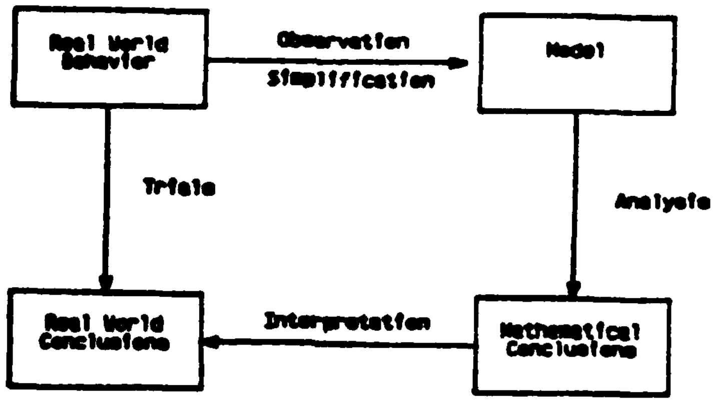

Figure 2.3 Reaching Conclusions about Real World Behavior

willing to accept even a single experimental failure, such as investigating different designs for a heat shield for a manned spacecraft.

The preceeding analysis underlines the need of developing an indirect method for studying real world phenomena.

Looking again at Figure 2.3 (right side) suggests an alternative way of reaching conclusions about the real world. First, make some specific observations about the behavior being studied and identify the factors that seem to be involved. Usually one cannot consider, or even identify, all the factors involved in the behavior, so make simplifying assumptions that eliminate some factors.

Next, conjecture tentative relationships amongst the factors being selected, and create a rough "model" of the behavior.

6. The Methodology of Model Construction

Having developed the required background from the previous sections attention is directed to the construction of Mathematical models. The outline of the procedure will be presented as is given by Weir and Giordano. [Ref. 11:p. C2-17].

The various steps are:

STEP 1. Identify the problem: What is it that you want to do or find out? Typically this is a very difficult step because people often have great difficulty in deciding what must be done. In real life situations, no one is given a simple mathematical problem to solve. Usually it is sorted from large amounts of data to identify some particular aspects of the situation for study.

STEP 2. Make assumptions: Generally you cannot hope to capture into a mathematical model all of the factors influencing the problem that has been identified. The task is simplified by reducing the number of factors under consideration. Then relationships between the remaining variables must be determined.

a. Classification of the variables: What things influence the behavior you identified in STEP 1? List things as variables. The variables the model seeks to explain are the dependent variables and there may be several of these. The remaining variables are the independent variables.

Each variable is classified as either dependent or independent, or you may choose to neglect it altogether.

b. <u>You may choose to neglect some of the independent variables for either of two reasons</u>:

1. First, the effect of the variable may be relatively small compared to other factors involved in the behavior.
2. You may also neglect a factor that affects the various alternatives in about the same way, even though it may have a very important influence on the behavior under investigation.

c. <u>Determination of the interrelationships among the variables selected for study</u>: Before you can hypothesize a relationship between the variables, you generally must make some additional simplifications. The problem may be sufficiently complex so that you cannot see a relationship among all the variables initially. In such cases it may be possible to study <u>submodels</u>. That is, you study one or more of the independent variables separately. Eventually you will connect the submodels together.

STEP 3. <u>Solve or interpret the model</u>: Now put together all the submodels to see what the model is telling you. In some cases the model may consist of mathematical equations that must be solved in order to find out the information you are seeking. Often a problem statement requires a best of optimal solution to the model, called Optimization Models, (the study of optimization constitutes a large and interesting field of Operations Research/Mathematics in which extensive research is currently conducted). Or you may end up with a model so unwieldy you cannot solve or interpret it. In such situations you might return to STEP 2 and make additional simplifications. Sometimes you will even want to return to STEP 1 to redefine the problem.

STEP 4. Verify the model: Before you use the model you must test it out. There are several questions you should ask before designing these tests and collecting data, a process which can be expensive and time comsuming.

1. Does the model answer the problem you identified in STEP 1, or did you stray from the key issue as you constructed the model?

2. Is the model usable in a practical sense, that is, can you really gather the necessary data to operate the model?

3. Does the model make common sense?

Once the common sense tests are passed, you will want to test many models using actual data obtained from empirical observations. You need to be careful to design the test in such a way as to include observations over the "same range" of values of the various "independent variables" you expect to encounter when usually using the model. The assumptions you made in STEP 2 may be reasonable over a restricted range of the independent variables, but very poor outside of those values.

Be very careful about the conclusions you draw from any tests. Just as you cannot prove a theorem simply by demonstrating many cases in which the theorem does hold, likewise, you cannot extrapolate broad generalizations from the particular evidence you gather about your model.

STEP 5. Implement the model: Of course your model is no use just sitting in a filing cabinet. You will want to explain your model in terms that the decisions makers and users can understand if it is ever to be of use to anyone. Further, unless the model is placed in a "user friendly" mode it will quickly fall into disuse. Expensive computer programs sometime suffer such a demise. Often the inclusion of an additional step to facilitate the collection and input of the data necessary to operate the model determine its success or failure.

STEP 6. Maintain the model: Remember that your model is derived from the specific problem you identified in STEP 1 and form the assumptions you made in STEP 2. Has the original problem changed in anyway, or have some previously neglected factors become important? Does one of the submodels need to be adjusted?

7. Critique of the Modeling Methodology

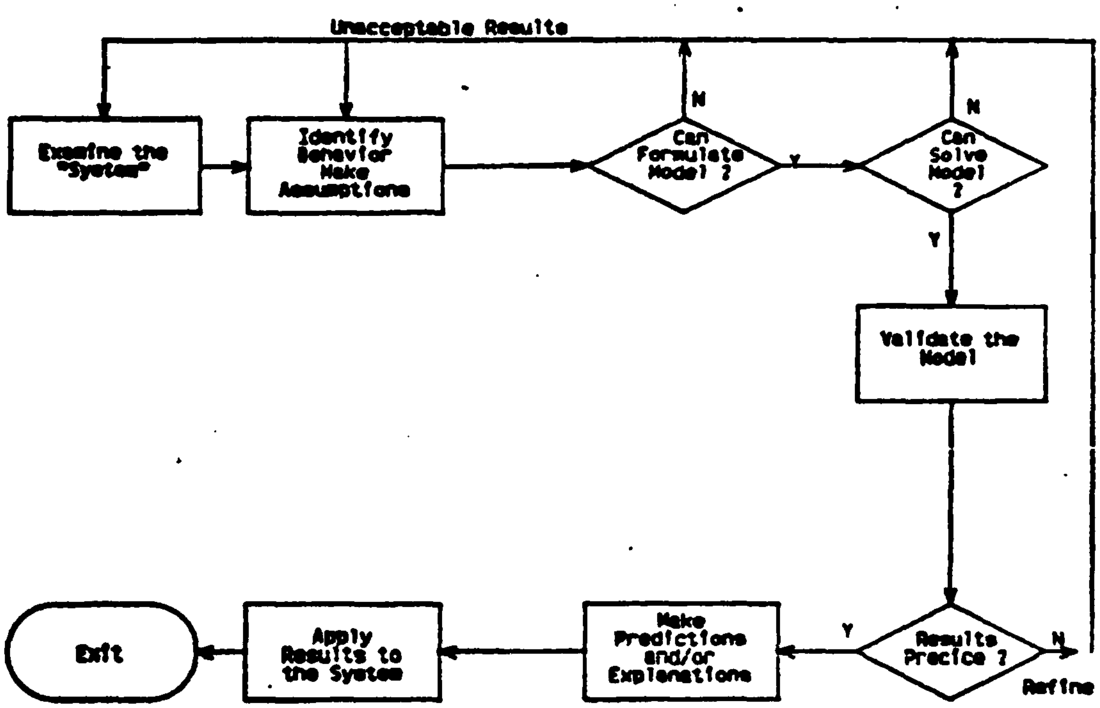

Figure 2.4 The Iterative Nature of Model Construction

Figure 2.4 amplifies the above ideas in viewing the modeling process, and attempts to display graphically its iterative nature. One begins by examining some system and identifying the particular behavior to be predicted or explained. Next identify the variables and simplify the assumptions, and then generate a model. Finally, attempt to validate the model with appropriate tests. If the results of the tests are satisfactory the model can be used for its intended purpose.

The process depicted in Figure 2.4 not only emphasizes the iterative nature of model construction, but also introduces the tradeoffs between model simplication and model refinement. Start with a rather simple model, progress through the modeling process, and then refine the model as the results of your validation procedures dictate. If one cannot come up with a model treat some variables as constants, by neglecting or aggregating some variables, by assuming simple relationships (such as linearity) in any submodels, or restricting further the problem under investigation. On the other hand, if the results are not precise enough, then refine the model. Refinement of a model is generally achieved in the opposite way: Introduce additional variables, or assume more sophisticated relationships among the variables, or expand the scope of the problem. By trading-off between simplification and refinement you can determine the generality, realism, and precision of your model. This trade-off process cannot be overemphasized and constitutes the "art of modeling."

C. SYSTEM SIMULATION

By this point of the thesis the reader has achieved an intuitive picture of the main notions; (system, model). Now a modern and powereful method of solving complicated problems will be presented. This is the use of digital computers to simulate a system or model, and subsequently to make predictions of its behavior which is called Simulation.

1. What is Simulation

Simulation is one of the most powerful techniques available for solving problems. It is a very important and useful tool for analyzing the design and operation of complex processes or "systems". It involves the construction of a replica or "model" of the problem on which one experiments and tests alternative course of action. This gives greater insight into the problem and a better position from which to seek a solution. [Ref. 12:p.3].

Simulation is not new as an aid in solving problems. Engineers have always used mechanical models of ships, aircraft, and space vehicles to simulate full-scall prototypes under actual operating conditions in test tanks and wind tunnels. However the use of simulation as a decision making tool for Management is relatively new. [Ref. 13: p.35].

By using a digital computer, management can simulate the behavior of entire business and manufacturing systems in order to evaluate overall performance under the influence of interacting factors. Simulation as a management tool consists of representing the real world in terms of a mathematical model that will react similarly to the situation after which it is patterned. A simulation model can be very general or quite specific, depending on its intended use. [Ref. 13:p.35].

Among the many definitions offered by various authors, the most suitable one for the purpose of this thesis is the following given by Shannon. [Ref. 14].

> "Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understand the behavior of the system or of evaluating various strategies (within the limits impose by a criterion or set of criteria) for the operation of the system."

The simulation problem solving approach, can be conducted by experiments in a systematic way until either finding a satisfactory answer or terminating due to lack of progress. Starting from the point of present understanding of the problem, proceed according to ability and application to search for the best possible solution in the time available. This means that simulation can be very laborious and expensive and does not necessarily produce an acceptable answer, much less the optimum answer. Later a critique of the simulation approach will be illuminated.

Simulation forces one to observe and understand the behavior of the problem by identifying those factors which are important. This results in an appreciation of the dynamics of the total system under study.

2. <u>Simulation Process</u>

The process of any simulation model includes the

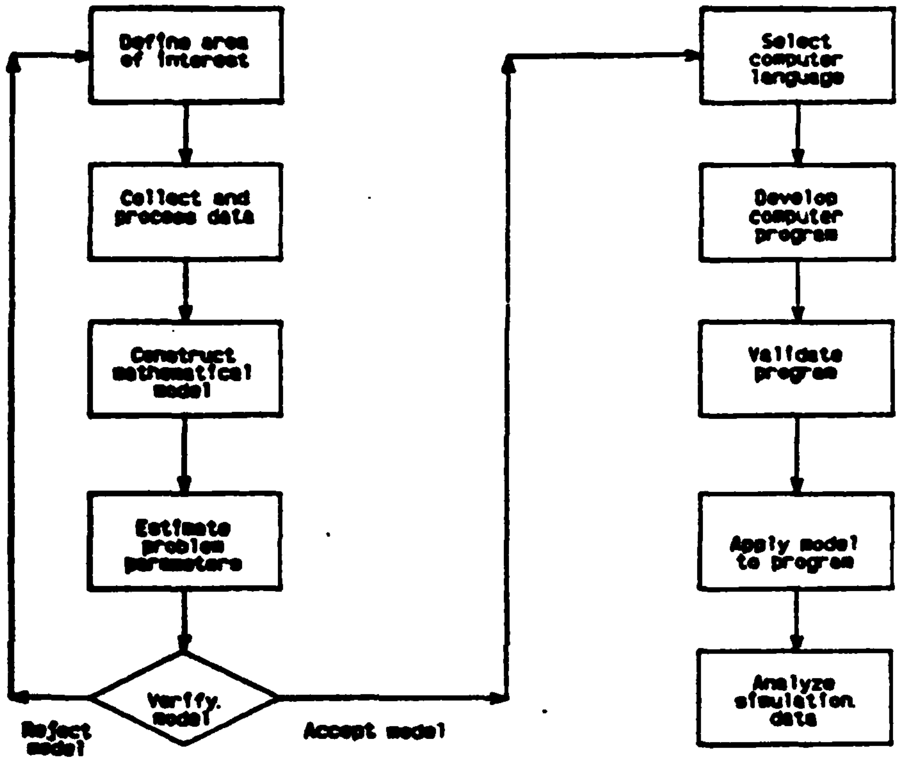

Figure 2.5 Steps in Developing a Simulation Model

steps depicted in Figure 2.5. [Ref. 13:p.38]. The author will not insist on the analytic clarification of all the notions and definitions presented in the flow chart, because many of the included terms coincide with the model's development and process of modeling which have already been presented in preceeding parts of this section.

However, some "technical" topics in simulation will be presented as necessary background.

3. <u>Selecting a Simulation Language</u>

Many special-purpose simulation languages have been developed, and all that have remained in use do provide an effective programming method for certain types of simulation problems. A list of 23 such languages will be found in [Ref. 15:p.276-278] see also [Ref. 16:p.3]. In choosing a computer language for simulation programs, familiarity should be one of the determining factors.

Each language also is based upon a set of concepts used for describing the system. The term "world-view" has come to be used to describe this aspect of simulation programs. [Ref. 16:p.194]. Payne comments in [Ref. 17: p.193] that learning a new programming language is not an easy task. It requires a careful study of the language, manuals and considerable practive in writing programs. It is not only programming convenience that justifies such an effort, often the major benefits result from learning the language's new simulation concepts and techniques contained in it as well as the ability to read programs written in the language.

Although there are many possible languages available, only FORTRAN, GPSS and SIMSCRIPT will be discussed.

1. FORTRAN

In the United States, FORTRAN is the most commonly used general purpose programming language. It also is one of the most commonly used languages for computer simulation. [Ref. 18:p.166].

However, FORTRAN is cumbersome to use in simulations. This language requires a large number of statements in programming. The net result is that the program becomes very complex for any simulation. [Ref. 13:p.39].

2. GPSS

General Purpose Simulation System (GPSS), was developed originally be G. Gordon at IBM and is one of the most popular discrete-event simulation languages. [Ref. 14:p. 197]. GPSS is "process" oriented, containing a supply of flow chart-like blocks. It also provides a large variety of autonomously generated measurements about the simulation model. Each block type represents a specific action that can occur in the system. The user constructs a logical model of the system using block diagram consisting of specific block types in which each block type represents some basic system action. This visual representation permits other peple to understand the structure of the model with a minimum effort.

GPSS elements are blocks, transactions, and equipment. Specific block types have a name, a characteristic symbol, and a block number. Each block has designated a block time that indicates the number of time units required for the action represented by the block. The block time is not constant, it may vary in a random or nonrandom manner. Transactions are basic units that move through the system. Equipment elements contain facilities and stores. Facilities can handle one transaction at time, whereas stores can handle many transactions simultaneously. [Ref. 19:p.66].

3. SIMSCRIPT

SIMSCRIPT was developed by H. Markowitz, G. Hanser and H. Karr at the RAND Corporation in early 1960s. [Ref. 17:p.134]. It is a very widely used language for simulating discrete systems. i.e. is based upon the notion that every model system is composed of elements with numerical values that are subject to periodic change. The state of a system is described in terms of entities, attributes, and sets. The status of a system is changed at discrete points in simulated time by the occurence of an event.

The occurence of these events is governed by a SIMSCRIPT provided timing routine. This timing routine automatically keeps track of simulated time and causes the various events to occur as they are scheduled by the simulation program. The different kinds of events are enumerated in an events list and a separate event subroutine has to be written for each event. A person with limited SIMSCRIPT experience can follow the words of a statement and usually comprehend the item. Compared to FORTRAN when the later is used to represent a specific real world activity, it may

Problem: To find item in inventory which has the greatest stock.

```
SIMSCRIPT
FIND NSTOCK = MAX OF STOCK
      (ITEM),
   FOR EACH ITEM

FORTRAN
MAX = NSTOCK(1)
DO 10 I = 2,N
IF (MAX-NSTOCK(I))
     20,10,10
20 MAX = NSTOCK(1)
10 CONTINUE
```

Figure 2.6 Comparison of Statements FORTRAN vs SIMSCRIPT

require 10 to 20 statements. SIMSCRIPT can do the same job with only two or four statements. See Figure 2.6 [Ref. 13: p.40].

4. Verification and Validation

In the development of a simulation model, two of the most important stages the builder must accomplish are verification and validation. Without them the model formulation, preparation, and translation into an acceptable computer language are meaningless. This part of the thesis will present an introduction to the issues of verification and validation. Differentiation between verification and validation is difficult since they are not independent processes.

"Verification" is generally viewed as insuring that the model behaves the way it was designed.

"Validation" consists of testing the agreement between the behavior of the model and the real system. [Ref. 14:p.30].

An important distinction between verification and validation is that models can be completely verified, while complete validation is impossible. Van Horn [Ref. 20:pp. 247-257] suggests that a model may be considered valid when it has achieved an "acceptable level of confidence." Only the model builder and user can determine what is an acceptable level of confidence.

There are four views concerning the problem of model verification and validation: Rationalism, empiricism, pragmatism, and utilitarianism [Ref. 14:p.213]. Each of these philosophies will be discussed briefly.

a. Rationalism

Rationalism is closely associated with mathematics and logic. Rationalism contends that a model is simply a system of logical deductions derived from a set of unquestionable truths. Immanual Kant used the term "synthetic a priory" to describe these premises of unquestionable truth, [Ref. 21:p.B92-B101]. (see also [Ref. 13:p.143]). Kant and his followers argued that if one accepts the basic premises about a model (which tey considered unquestionable) and the formal logic used to deduce the consequences, then one accepts the validity of the model. The problem of verification has then been reduced to the problem of stating the basic assumptions underlying the behavior of the system being modeled.

b. Empiricism

In direct contrast to rationalism, empiricism refuses to accept any assumption that cannot be verified by experiment or analysis of statistical data. [Ref. 14:p.214]. Empiricists insist that model verification must begin with facts not assumptions. Hence, they regard empirical science, and not the mathematics, as the ideal form of knowledge. "A sentence the truth of which cannot be determined from possible observation is meaningless" [Ref. 22: p.256]. Empiricists often emply formal statistical "tests of hypothesis", based on historical data, to validate a model. Rationalists argue that historical data often does not show that a hypothesis can be accepted, only whether or not it can be rejected. Aless extreme point of view is held by the third group, the pragmatists.

c. Pragmatism

While both the rationalist and the empiricist are primarily concerned with the internal structure of the model, they disagree over the nature of the internal relationships that are valid. The pragmatist feels that the validity of a model depends upon its ability to properly transform inputs into outputs. If the model fulfills the purpose for which it was built, then it is a valid model. Proposing that the usefulness of the model be the key to its validation, pragmatists emphasize the question of whether errors in the model render it too weak to serve its intended purpose.

d. Utilitarianism

Perhaps the most practical approach to model verification and validation is taken by the utilitarian. Two important characteristics of this approach are:

The objective is to validate a specific set of insights not necessarily the mechanism that generated the insights.

> There is no such thing as "the" appropriate validation procedure. Validation is problem dependent. [Ref. 20: p.248].

Hence, this approach advocates the use of any of the verification and validation tests which might apply to the model being treated.

5. <u>Critique of the Simulation Approach</u>

The previous material of this chapter has presented different notions and techniques with one purpose: To study the behavior of a complex system or its substitute, "the model."

At the end of this chapter some more critique will be directed toward the simulation technique with the objective of making the reader aware of the capabilities and limitations of this problem solving method and of pointing out the nature of some basic ideas concerning simulation.

What problems should be solved with simulation technique, and what conditions are necessary to achieve successful results? These questions as to the proper use of simulation do not have will-defined answers. There have been many discussions of the appropriate use of simulation, but these opinions have changed over a period of time and are the subject of considerable controversy.

Payne in [Ref. 17:p.270] refers to use of the computer by the latest generation for the following motivations:

Primarily to achieve economy. The computer has been used to do what had previously been done by people, but faster, more accurately, and cheaper.

Secondly to do jobs which would not be feasible without computers. The computer characteristics that make it possible to do these operations are speed, accuracy, and reliability.

Thirdly to gain "computing for insight", which means to gain understand of a system by using computer models.

The latest category includes the notion of simulations. The goal is to increase understanding of the system and to be able to predict how the system will behave in the future and under altered conditions, and consequently to make decisions as a result of the predicted behavior as one of the inputs in the decision process.

However, and in spite of the above "good will" intentions of the scientists, there is quite a large criticism of simulation. The reader interested in modeling and simulation is suggested and encouraged to search the extensive and varied literature available in the subject. Also in two periodicals mainly devoted to the subject of simulation "Simulation" published by the Society for Computer Simulation and "Simuletter" published by the Special Interest Group in Simulation of the Association for Computing Machinery, one can find computer-related articles and commends from professional practitioners in the field.

D. MONTE CARLO SIMULATION TECHNIQUE

Systems-Models that exibit stochastic elements in their behavior can be simulated with the aid of the technique called "Monte Carlo" (named after the famout gambling resort town of Monaco). This technique involves sampling from those known probability distributions that represent each of the actual chance processes included in the system/model under study.

The element of chance (stochastic) is simulated by generating so called "pseudorandom numbers" used to determine the outcomes of random events, such as the outcome of firing at a target or the determination of the result in an air combat engagement.

By completing a system/model simulation run many times while keeping the nonstochastic inputs constant but allowing the chance elements to fluctuate according to their known probability distributions, a statistical average for run results can be determined.

Turban and Merendith, see [Ref. 23:p.31] have listed the steps necessary in building a Monte Carlo simulation as follows:

1. Describe the system/model and obtain the probability distributions of the relevant probabilistic elements of the system.
2. Define the appropriate measure(s) of performance.
3. Construct cumulative probability distributions for each of the stochastic elements.
4. Assign representative numbers in correspondence with the cumulative probability distributions.
5. Generate a random number for each of the independent stochastic elements and ... (determine) the measure of system performance.
6. Repeat step five until the measure of system performance stabilizes.

Thus, the distinguishing feature of the Monte Carlo method is the repetitive execution of an established experiment or simulation involving randomness.

Most combat simulations (our main interest) in Defense Planning are Monte-Carlo simulations.

The strong point of Monte Carlo simulations is that they may contain a lot of details and therefore may be more credible than a more abstract model. The large amount of details, however, causes a significant amount of computer time to be required for a single run.

Taylor in ref [Ref. 10:p.18] specifies a number of serious shortcomings to the use of Monte-Carlo simulation for Defense Analysis.

First such simulations are quite costly to build. It is not unreasonable to expect to spend 5 to 10 man-years of effort to develop a detailed simulation of Tactical combat.

Second, they are costly to run, with typically 10-20 minutes of computer time required per replication for equivalent battle time, and one needs 10-60 replications for statistical stability in the results.

Additionally, because of the amount of details involved the Data Base requirements are quite demanding. For example, it is not unheard of to have several analyst spend about three months preparing a new set of input data.

It is also costly to maintain a staff of highly trained personnel to insure that the computer program stays running and free of errors (debugged) as changes are continously implemented.

Finally the tremendous amount of detail (i.e. the large number of variables and other parameters) present in a simulation precludes the running of parametric studies to examine the sensitivity of the model to changes in assumptions and input data.

TABLE I

Disadvantages of Monte-Carlo Simulation

1. Costly to build
2. Costly to run
3. Costly to maintain
4. Lack of flexibility for change
5. Essentially impossible to perform sensitivity and other parametric studies

The disadvantages of Monte-Carlo simulation are summarized in Table I.

While electronic digital computers themselves are not necessary for the execution of simulation, they do offer tremendous speed and consistency of conditions for such models. Thus the computer is ideally suited to perform the large number of repetitions required by the Monte Carlo technique.

E. MEASURES OF EFFECTIVENESS (MOEs)

Within the Air Force and the rest of the DOD, the term "Measures of Effectiveness" (MOEs), is used in many different ways. Whenever, the term is used, the MOEs are seldom defined in such a way that the reader knows exactly what is being measured. [Ref. 7:p.73].

There is difficulty in communicating between decision levels since often there is no way for any decision maker to find out what is meant by the terms used. The main reason for having MOEs is to aid management in making decisions, therefore this communication difficulty needs correction. Confusion is further increased by having many MOEs for a single specific mission. While these MOEs may at times be somewhat similar it is seldom possible to go from one to the other without more information. This information is often lacking. [Ref. 7:p.73].

Hartman in [Ref. 24] defines MOE as:

> "A MOE is a quantitative indicator of the ability of a human/material, or material system to accomplish the task for which it was designed. For a military force, it is a measure of the ability of the Force to accomplish its combat mission."

In general, a MOE is any index which indicates the quality of a system. In the simplest case it may be a measured physical quantity, such as range or payload. On the other hand, it may be a calculated quantity based on a measurement, such as mean down time between maintenance actions. Lastly, it may be a predicted quantity based on measurement and/or simulation. For example, "the probability that a system can meet an operational demand at a random point in the time while under attack," will require prediction since there will be some uncertainty, about the attack environment. [Ref. 25:p.8-9].

MOEs serve to indicate what can be expected from the system, i.e. to measure the effectiveness of a system, since the MOEs used will address system effectiveness at the user level. At higher levels, other considerations besides MOEs are used to make management decisions. These considerations include, but not limited to, life cycle cost, urgency of the need, priorities and politics. Thus MOEs are one in a series of factors in the final decision process.

Before defining what will be meant by MOEs in the scope of this thesis, several other terms must be defined. While many of the definitions to be given are taken directly from

MIL-STDS they are here to be sure that there is no misunderstanding of what is being said.

AFM II-1, Volume I defines:

> "Mission is the task, together with the purpose, which clearly indicates the action to be taken and the reason therefore."

In other words, with identification of the prime mission of the system and alternate or secondary missions one answers the questions: What is the system to accomplish? How will the system accomplish its objectives? Consequently the mission may be defined though one or a set of scenarios.

Before a measure can be defined, the property being measured must be defined. Therefore, before MOE can defined, the meaning of "effectiveness" (a property) must be agreed upon.

Mil-std 499 (USAF) defines Systems Effectiveness as follows:

> "System Effectiveness is a measure of the degree to which a system achieves a set of specific mission requirements. It is a function of availability, dependability and capability."

Now, three more terms must be defined, namely "availability," and "capability." Mil-std 499 (USAF) refers to Mil-std 721B for these definitions. The later defines, see also [Ref. 26].

> "Availability is a measure of the degree to which an item is in the operable and commitable state at the start of the mission, when the mission is called for at an unknown (random) point in time."

it also defines:

> "Dependability is a measure of the item operating condition at one or more points during the mission, including the effects of Reliability, Maintainability, and Survivability, given the items condition(s) at the start an item will (a) enter or occupy any one of its required operational modes during a specified mission, (b) perform the functions associated with these operational modes."

and finally:

> "Capability is a measure of the ability of an item to achieve mission objectives given the conditions during the mission."

The problem still exists of deciding on the scale (units) to be used for availability, dependability and capability. Since Mil-std 721B states that dependability may be stated as a probability, logically it is desirable to state the other two as probabilities. [Ref. 25:p.77].

Hence:

Availability (A): Is the probability that an item is in operable and committable state at the start of a mission when the mission is called for at an unkown (random) point in time.

Dependability (D): Is the probability that an item will:

Enter or occupy anyone of its required operational modes during a specified mission.

Perform the functions associated with those operational modes given the item Availability, and

Capability (C): Is the probability that an item will achieve the mission objectives given the Dependability.

Thus D and C are conditional probabilities, also with these definitions, A, D. and C are "statistically independent."

With the above definitions, it follows that:

> "A Measure of Effectiveness (MOE) of an item is a parameter which evaluates the extent of the adequacy of the item to accomplish an intended mission under specific conditions. It is a function of Availability, Dependability, and Capability." [Ref. 25:p.77].

Thus, MOEs are expressed as probabilities since A, D, and C are probabilities.

1. Quantities for a Good MOE

USAF in [Ref. 7:p.77] suggests the following quantities which have to satisfied by a "good" MOE:

a. The MOE should be sensitive to all variables affecting the model.

b. The MOE should be precisely defined.

c. The MOE should not be overly broad.

d. The MOE's, as well as their input measures of performance, should be mutually exclusive. This prevents one aspect of the model from being counted several times and weighting the MOE heavily for this aspect.

e. The MOE should be relevant to the mission. This assures that the proper effectiveness is being measured.

f. The MOE should be express in terms meaningful to the decisions maker. Since the purpose of MOEs is to aid the decision maker.

g. The MOE should have inputs that are measurable. If the inputs are not measurable, the MOE cannot be evaluated.

h. The MOE and its inputs should be quantifiable if at all possible. Qualitative evaluations should be used only for aspects that cannot be measured. This is almost always correct only in the man-machine interface.

2. <u>Assumptions and Ground Rules for MOEs</u>

Following is a set of assumptions or ground rules, which must be made for MOEs and with the presented rationale. [Ref. 7:p.80]. No attempt has been made to put them in any particular order of importance.

a. Standards MOE's will be at the user level. Since these MOEs are inputs at all decision levels, it is only here that it is possible to start standardizing. It would be impossible to standardize MOEs at some other, higher level, if the inputs to the user level were not standardized.

b. There will be a separate MOE for each scenario for which a system has a mission capacity. If the MOEs were combined into some grand ensemble MOE, it would be impossible to separate the MOE for the most important mission from the least important one.

c. The mission for the system to be tested must be defined before the measurement is made. For example, the effectiveness of an aircraft will be different for an air-to-air engagement than for an air-to-ground engagement.

d. The scenario must be explicitly stated. The scenario includes the following information:

1. The mission to be executed.

2. A completed definition of the system whose MOE is to be determined.

3. For a test of one system against a second system (i.e. a two-sided test) a complete definition of the second side system including such things as "target aspect angle" for radar systems.

4. The tactics to be used in the test.

5. The level of the engagement. For example, one-on-one or N-on-M where N and M integers.

6. The use rate. For example, for an aircraft it might be one sortie a day or a maximum sortie rate.

7. The sequence of events in the mission profile. For an aircraft, this would be flight profile.

e. All quantifiable data elements and measures of performance (A, D, and C) are to be stated and measured as probabilities. Since the probabilities (data elements) are either independent or conditional, their product has the same meaning and value as obtaining by only determining the value of measures of performance (A, D and C).

f. There will be a single, well defined, scale for qualitative evaluations. Qualitative evaluations should be used for man-machine interface only.

g. The MOE, the measures of performance (A, D, and C), and the data elements should always be reported.

3. Demonstration of MOEs for Aircraft System

Since a system, by definition, is a self-sufficient unit for a mission the term "Aircraft System" will include cargo, bombs, missiles, pods, or whatever load the aircraft is carrying. For this reason, Aircraft Systems are very broad in their applications to missions as shown in Table 3.6 which lists the Air Force missions and Aircraft System missions. [Ref. 7:p.120].

It can be seen that there is no one-to-one correlation between the two. For example, using an Aircraft System for air-to-air combat can be a part of counter air, close support or combat air patrol (CAP), Air Force missions. Therefore, the analyst-modeler in the scenario should cover the Air Force mission be statements such as, "an A-7E/AIM-7E Aircraft System, during CAP, engages a MIG-19..."

There is a close time tie between Availability (A), Dependability (D), Capability (C), and the sortie profile for Aircraft Systems. For instance, Availability will address all operations executed up to the time the engines are to started. Dependability will cover all operations executed from engine start to engine shut down including post flight aircrew and maintenance checks of the system. After postflight checks, the Aircraft System is in the Availability portion of the cycle again. Capability addresses those periods of the sortie during which the

TABLE II

Air Force vs Aircraft Missions

Aircraft Systems Missions	Corresponding AF Missions
1. Air-to-Air Engagements	1, 2, 5
2. Air-to-Ground Engagements	1, 2, 3, 4, 5
3. Search and Rescue/Recovery	5, 8
4. Airlift	2, 11
5. Command and Control	1, 5, 10, 13
6. Reconnaissance	3, 6, 7, 10, 15
7. Electronic Warfare	1, 3, 4, 5, 6
8. Airborne Atmospheric Sampling	15
9. Training	14
10. Airborne Test Bed	16
11. Refueling	9
12. Battlefield Illumination	2, 12
13. Demonstration Team	17

Air Force Missions	Corresponding Aircraft Missions
1. Counter air	1, 2, 5, 7
2. Close Air Support	1, 2, 4, 12
3. Air Interdiction	2, 6, 7
4. Fire Suppression	2, 7
5. Combat Air Patrol	1, 2, 3, 5, 7
6. Electronic Warfare	6, 7
7. Reconnaissance	6
8. Search and Rescue/Recovery	3
9. Refueling	11
10. Forward Air Control	5, 6
11. Airlift	4
12. Battlefield Illumination	12
13. Command and Control	5
14. Training	9
15. Weather	6, 8
16. Research-Develop/Test-Eval	10
17. Demonstration Team	13

aircraft missions shown in Table II are actually being executed.

Following only the measures of performance (A, D, and C) which make up the MOE's for an Aircraft System will be shown in Figure 2.7, and the subsequent Figures. The reader who is interested in the detailed process for any aircraft system (piston or jet, single or multiengined,

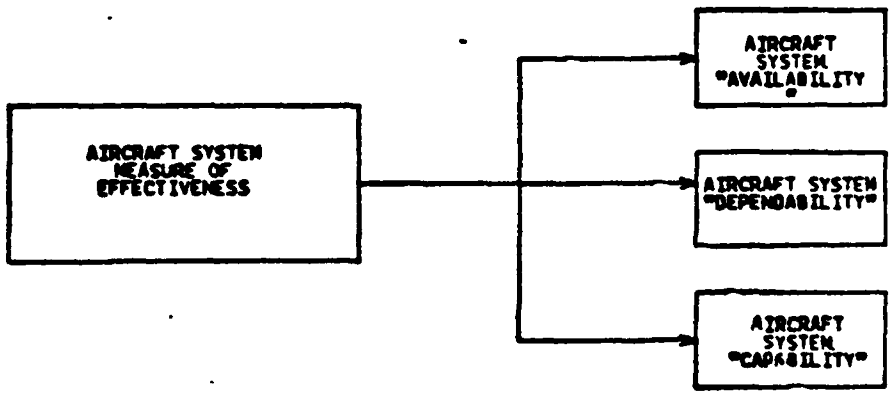

Figure 2.7 Aircraft System MOEs

bomber, fighter, helicopter, transport or trainer and with variations of armament loads will find in [Ref. 7:p.120-127] a complete presentation of the MOEs selection and estimation.

In Figure 2.7 the Aircraft System MOE are presented. It is assumed that the analyst has been given, or has stated, the scenario for the system. The scenario includes the system's mission. With this in mind the analyst can proceed to those data elements that address the Aircraft System's Availability (A), as in Figure 2.8.

The aircrew is considered equipped when they have the proper required personnel equipment such as oxygen masks, helmets, earphones, microphones, etc. The other data elements are self explanatory.

Given the Aircraft System's availability, the Aircraft System's dependability can be addressed. The dependability data elements are taken during different portions of the sortie as shown in Figure 2.9. These portions (time-sequence) are broken into sortie phases in the same manner as a usual Technical Order (T.O) check-list for the aircrew.

Having already indicated the availability and dependability of the Aircraft System, the only part of the MOE left is capability. The data elements for A and D are fairly mission independent for a given set of items that make up the Aircraft System. Capability on the other hand, addresses the Aircraft System's specific mission. As shown previously in Table II, Aircraft Systems have certain missions. A given Aircraft System will have a certain capability for each of these missions. Figure 2.10 shows how the capability of an Aircraft System is stated as that system's capability for a specific aircraft mission.

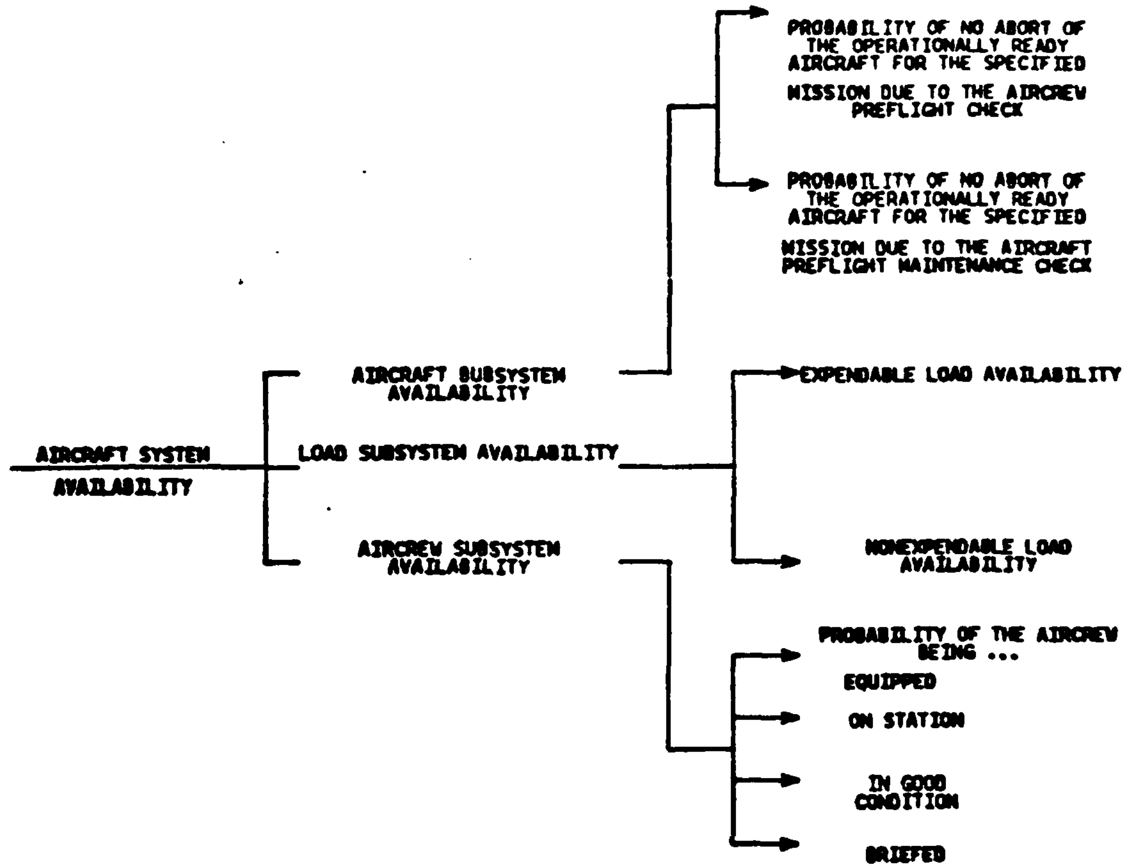

Figure 2.8 Aircraft System Availability

4. System Attributes Other than Effectiveness

There are many system attributes other than system effectiveness that are of interest to the operational commanders. These other attributes of a system are not measured directly. Only their effect on A, D, and/or C will be measured by MOE's. The author will only name some of them. The interested reader is encouraged for further study of [Ref. 7] and [Ref. 27] for detailed explanations.

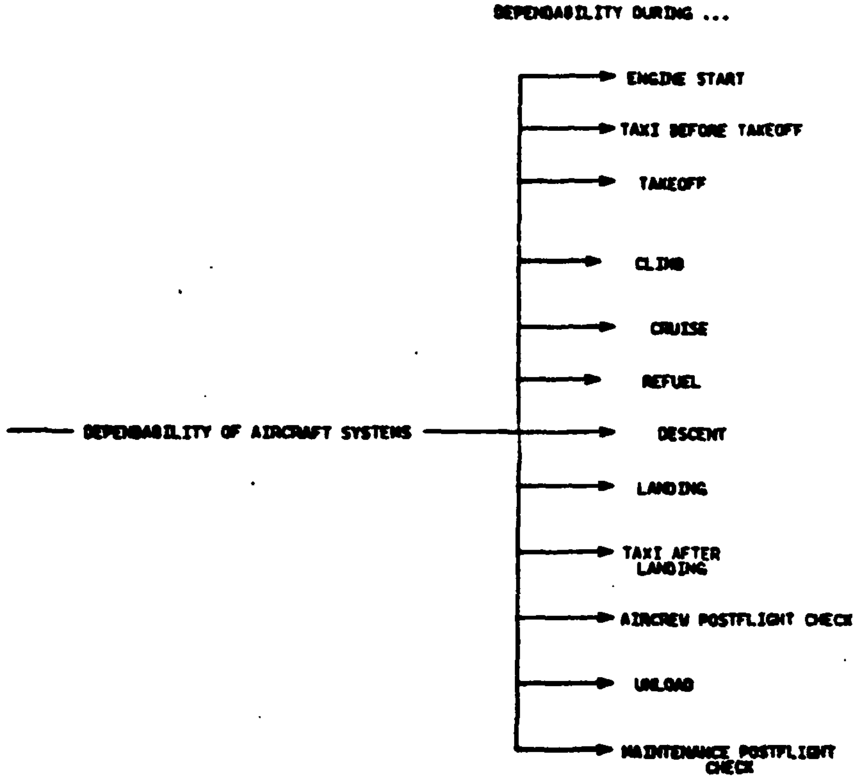

Figure 2.9 Dependability of Aircraft System

a. Reliability

b. Maintainability

c. Interoperability

d. Survivability

e. Combatibility

Also other aspects of a system (e.g. doctrine, organization, operational techniques, tactics, and training of operator and maintenance personnel) can be examined only

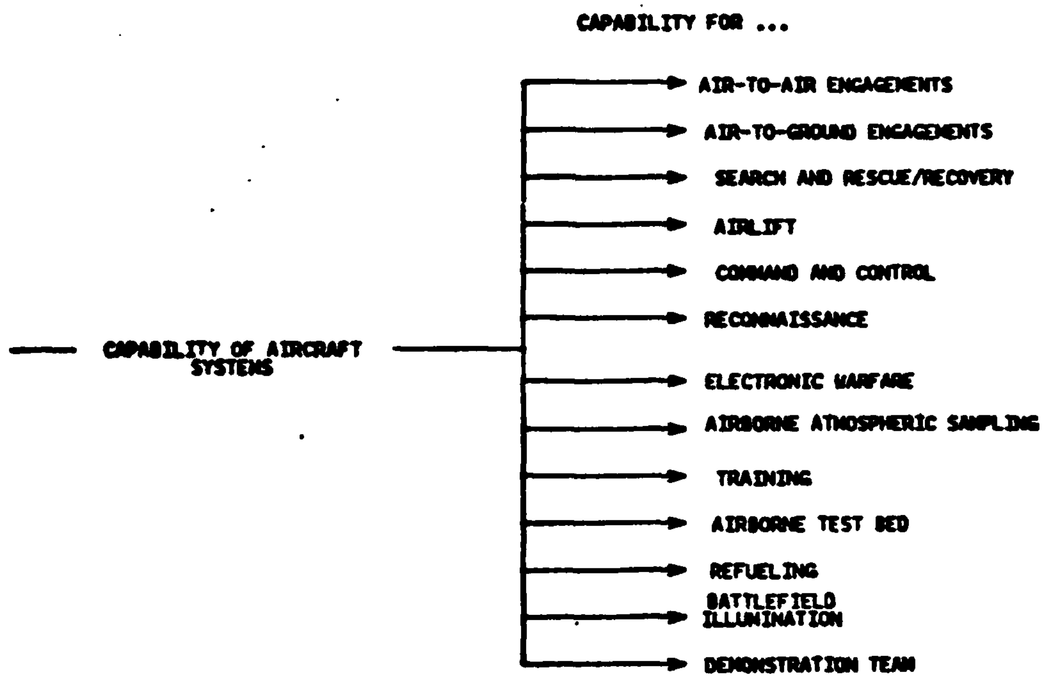

Figure 2.10 Capability of Aircraft Systems

by how these various aspects affect the System Effectiveness. It is in no way a measure of these aspects when they are varied and the effect on the MOE is noted. The effect on the MOE is only one of the many important features of these aspects. For example, one consideration in deciding between two tactics should be the systems effectiveness for each tactic. This can be determined by the MOE using each tactic. Other aspects of the tactics must also be examined. Some of these are the vulnerability of the system using each tactic, the ease of using each, the training required for each, the affect on interoperability with other systems, etc.

From the author's view it cannot be stressed too highly that MOE's only measure effectiveness as defined presently by the previous mentioned documents. Other attributes of systems must also be evaluated by some other means.

5. <u>Some MOE Examples</u>

The U.S. Navy in the manual for MOEs, [Ref. 28.p.33] presents some examples of operational selection of MOEs which demonstrate the use of MOE.

CASE I

1. System evaluation of the air fire support capabilities and limitation of the V/STOL A-8A aircraft in close air support mission.

<u>MOEs Selected</u>

(a) Aircraft availability, which is defined as the ratio of the number of aircraft available for the mission to the number of aircraft for the mission.

(b) Timelines of aircraft's response, which is defined as the ration of aircraft response to target "shelf fire."

(c) Ratio of weapon load carried by the aircraft to the weapon load needed for mission.

(d) Ratio of aircraft ordnance delivery mode to delivery capability needed.

(e) Average number of sorties per aircraft per day.

CASE II

1. Evaluation of aircraft ordnance carrying capability in Close Air Support (CAS).

MOE Selected

(a) Percent of CAS attack sorties for which an expected target kill is achieved at or below a specified weapon weight.

2. Determination of aircraft utilization.

MOE Selected

(a) Average utilization per aircraft per month.

3. Evaluation of aircraft performance in a rescue mission.

MOE Selected

(a) Survival probability of seriously wounded personnel in enemy territory as a function of the distance rescue aircraft must fly.

CASE III

1. Evaluation of reconnaissance system performance in identifying and locating targets.

MOEs Selected

(a) Average probability that the system or sensor is capable of detecting targets of interest.

(b). Average probability that the system or sensor is capable of both detecting and correctly identifying targets of interest.

(c) System or sensor's ability to localize targets once the targets have been identified.

(d) System or sensor's time late, which is defined as the time between detection by the system or sensor and the first avaiability of this information for operational use.

2. Evaluation of the contribution of reconnaissance system performance to strike aircraft penetration of a SAM barrier.

MOEs Selected

(a) Total attrition due to SAMs that is prevented by the information provided by the reconnaissance sortie.

(b) Total attrition due to hostile interceptions that is prevented by information provided by the reconnaissance sortie.

3. Evaluation of the value of reconnaissance information for the interdiction mission in which strikes are made at enemy truck traffic.

MOE Selected

(a) Expected number of trucks destroyed per convoy as a function of reconnaissance system localization accuracy.

4. Evaluation of the influence and effect or reconnaissance system performance on sortie requirements.

MOE Selected

(a) Number of reconnaissance sorties needed to support an operational situation.

(b) Probability that the operationally useful information about a particular target is on hand.

(c) Number (or percentage) of targets about which "live" information of acceptable quality and quantity is in hand.

(d) Number of reconnaissance sorties saved as a function of the time delay between the gathering of and the using of information from a reconnaissance sortie.

(e) Reduction in the strike effort (required to perform a specific task) which is made possible by the use of information gathered by reconnaissance.

(f) Number of strike sorties not wasted.

6. Conclusions on Systems Performance

In general, there are two ways to observe or predict the behavior of a system, [Ref. 29].

a. Control or record the external and internal variables and observe actual System performance, however, it is often not feasible because:

The cost of operating the system through enough trails may be prohibitive.

The desired tests may be destructive in nature to the system.

It may be desired to estimate the performance of the system before it is built.

b. Construct a model of the System which captures the essence of the system's performance rather than the actual performance of the system itself.

III. THEATER LEVEL COMBAT MODELS

In the preceeding chapters the reader was introduced to the main elements, concepts and notions of System, Model and Systems Simulation which apply to studying complex systems.

In this chapter the study will be focused on the military applications of modeling and will try to answer questions like:

Why an analyst is interested in combat models, Which are the main elements of concern in a combat model, and How the decision makers use combat models as aids to emply their strategy.

> Strategy: The art and science of employing the armed forces of a nation to secure the objectives of national policy by the application of force, or the threat of force. [Ref. 30:p.1].

A. THEATER-LEVEL COMBAT MODELS AND UTILITY

Trying to trace and analyze the different interactions between two (or more) opposing forces, in other words to study the "combat processes", defines a combat model.

Hence, combat models are the tools or the means, and not the end objective in themselves, to study or analyze something. The primary purpose is to gain an understanding of the very complex phenomena which take place in a military conflict.

At this point lets make a brief review of the fundamentals of combat. Figure 3.1 shows the basic concept of combat. Simply stated, all combat involves the interaction between opposing forces, designated RED and BLUE. These

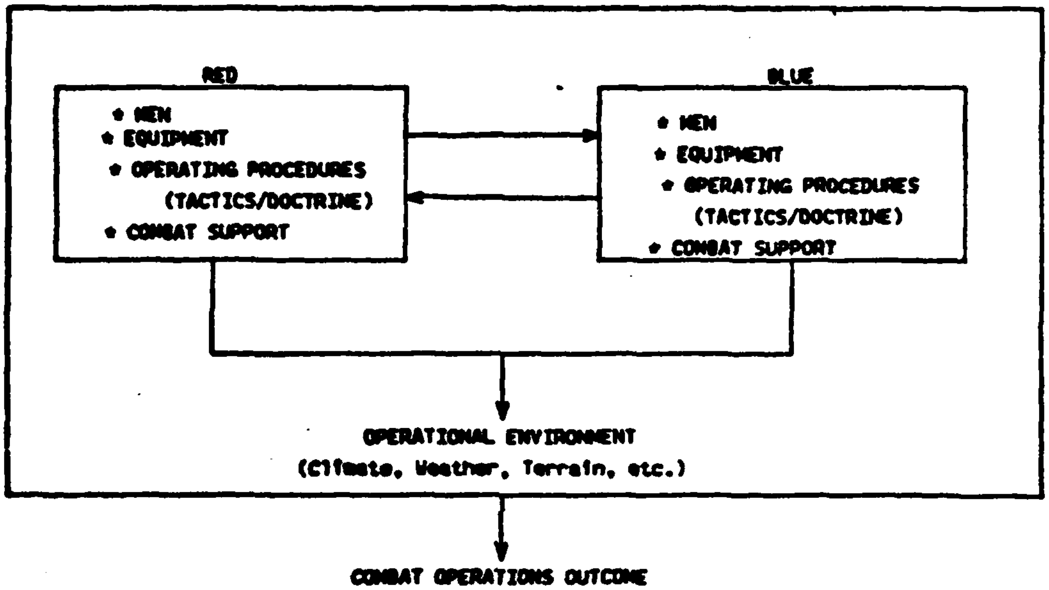

Figure 3.1 A Concept of Combat

forces are composed of men and equipment, are governed by operating procedures, and involve some measure of combat support. Both forces function in an operational environment which is composed of natural factors such as weather and terrain. The interaction between RED and BLUE results in a combat operational outcome, which can be measured in a variety of ways:

a. Annihilation: The forces of one side are destroyed virtually en toto on the battlefield by those of the other side. Vanquished force remnants are routed, captured or surrender to the enemy.

b. Territorial conquest: The seizure (capture and occupation of all of one side's territorial objectives, hostilities are terminated by the route, capture, or surrender of opposing force.

c. Stalemate: The achievement of objectives and/or the number of causalties suffered lead to a protracted conflict or a negotiated settlement.

Now let us go back to the initial question: What are typical Defense-Planning problems? Stockfish states them as follows: [Ref. 31].

a. How to assess a possible opponent's military capability, and how large should our military forces be to meet the perceived threat?

b. How should the total force be structured between major services, such as Land Forces and Tactical Air Forces?

c. How should the total forces be structured with respect to (1) combat branches, such as infantry and tanks, and (2) service specialties that provide logistic and personnel support?

d. What should be the technical performance and physical specifications of new weapons that will be the object of engineering development programs? Given the availability of new weapons, what should be their tactical usage, How many of them should be procured, and in what organizational and command context should they be employed?

Such issues concern the evaluation of weapons-systems and force-level planning alternatives in future time frames. In order to determine the benefits from a particular alternative one must be able to predict the effectiveness of specified military forces in possible future military engagements. Since such forces and/or weapon systems only exist "on paper," the combat models are used to study them.

Bonder states that in order to make predictions of combat results one must carefully consider the following characteristics: [Ref. 32.p.75].

a. Weapons Systems Characteristics: Firing maneuver capability, reliability, accuracy, lethality, acquisition capability.

b. Organization Structure: The number of different types of weapons systems in the organization.

c. Doctrine and Tactics: The behavioral decision processes which drive much of the combat activities. On a broad scale these include the choice of battle type (attack a fixed defensive position, delay, chance meeting, withdrawal, etc.) and the choice of defensive position. On a more microscopic scale these include the weapon-to-target fire allocation decisions, route selection, assault speeds, and the decisions to initiate and end the firing activity.

d. Terrain-environmental Effects: These include effects such as the interaction of the line-of-sight process on acquisition capabilities, agility of weapon platoforms, and the effect of meteorological conditions on acquisition.

In summary the combat models are valuable in many aspects of Defense Planning such as:

1. To design specifications and select new weapons.
2. To allocate recources between air and land and, within land forces between infantry and artillery.
3. To allocate tactical air capability among diverse missions.
4. To specify the amount of logistic support that the combat elements of field forces should have.
5. To estimate the rate at which forces might be mobilized and deployed, and:
6. To decide how large the forces should be.

Before closing this section on combat models and their utility, it is necessary to emphasize that there are almost no empirically verified models of most combat processes.

The major difficulty is that the empirical data base is too poor. (see [Ref. 10:p.8]) In other words, since nations fight wars for other reasons than to collect combat data, there is not a data base rich enough in detail to permit the classic scientific verification of combat models.

This shortage of historical and other empirical data for combat models and analysis is apparently not as widely acknowledged, articulated, or appreciated by the policy-making community as it should be.

Karl von Clausewitz in the same spirit stated many years ago in his classic work "on war" that:

> "if theory caused a more critical study of war, then it had achieved its purpose."

B. TYPES OF COMBAT MODELS

In the preceeding sections the evolution and notion of combat models was presented. Now an indepth research will follow on the types and structure of combat models and how the human factor is involved in those combat processes.

1. Simulations

Simulation which runs completely without human intervetion is perhaps the most widely used type of combat model technique in military systems analysis, which runs completely without human intervation. In order to obtain predictions of outputs such as causalties, resources expended, etc., in this type of combat model one arranges the events and activities of the different combat processes in a specific sequence. The decisions involved are based on predetermined rules which are programmed into the automated evaluation proceedure.

Most simulations used in military planning contain a significant number of stochastic events and activities in an attempt to capture the chance element (uncertainty) associated with many combat processes. In such a stochastic simulation the model is solved by the Monte-Carlo method.

2. Analytic Models

Analytic models are like simulations in the sense that they also have no human involvement. As in the development of simulations, the process is studied and decomposed into its basic events and activities. A mathematical description of all the basic events and activities is developed, and these events and activity descriptions are integrated into a mathematical structure of the process.

3. War Games

Webster defines a Game as:

> "A situation involving opposing interests given specific information and allowed a choice of moves with the object of maximizing their wins and minimizing their losses."

The above definition most certainly applies, in general, to warfare.

According to [Ref. 33:p.185] and [Ref. 34] a War Game is:

> "A simulation, by whatever means of military operations involving two ore more opposing forces, using rules, data, and procedures designed to depict an actual or assumed real life situation."

More specific for the thesis topic is the definition given by Paxson [Ref. 35].

> "A War Game is a model of military reality set up by a judicious process of selection and aggregation, yielding the results of the interactions of opponents with

conflicting objectives as these results are developed under more or less definite rules enforced by a control or umpire group."

The distiguishing feature of war games in relation to simulations and analytical models is that actual human beings are used to simulate decision processes by having people play the role of decision makers and use their own judgment in making decisions.

Finally as a general comment one realizes that "analytic models, machine simulations and games" are often used to classify the analytic techniques in solving two-sided military problems.

Models and simulations are techniques while games are related to simulations and behavior; the latter is a viable mechanism to train decision makers.

Taylor in [Ref. 10:p.12] classifies war games as either "rigid" or "free", depending on whether or not the assessment rules are rigidly prescribed and completely cover all possibilities. The rigid war games are somewhat similar to simulations in that combat interactions are considered in detail. On the other hand, in "free" war games the assessment of combat outcomes is judgmentally determined by umpires.

C. OBSERVATIONS ON MODELING

A morphological matrix can be postulated for all modeling activities constructed around three basic dimensions TECHNIQUE, SCOPE, and APPLICATION as shown in Figure 3.2.

These three dimensional cateogries are further expanded as follows: [Ref. 36:p.7].

1. <u>MODELING TECHNIQUE</u>

a. Military exercises (Field, Fleet, Air, Joint)

b. Manual War Games

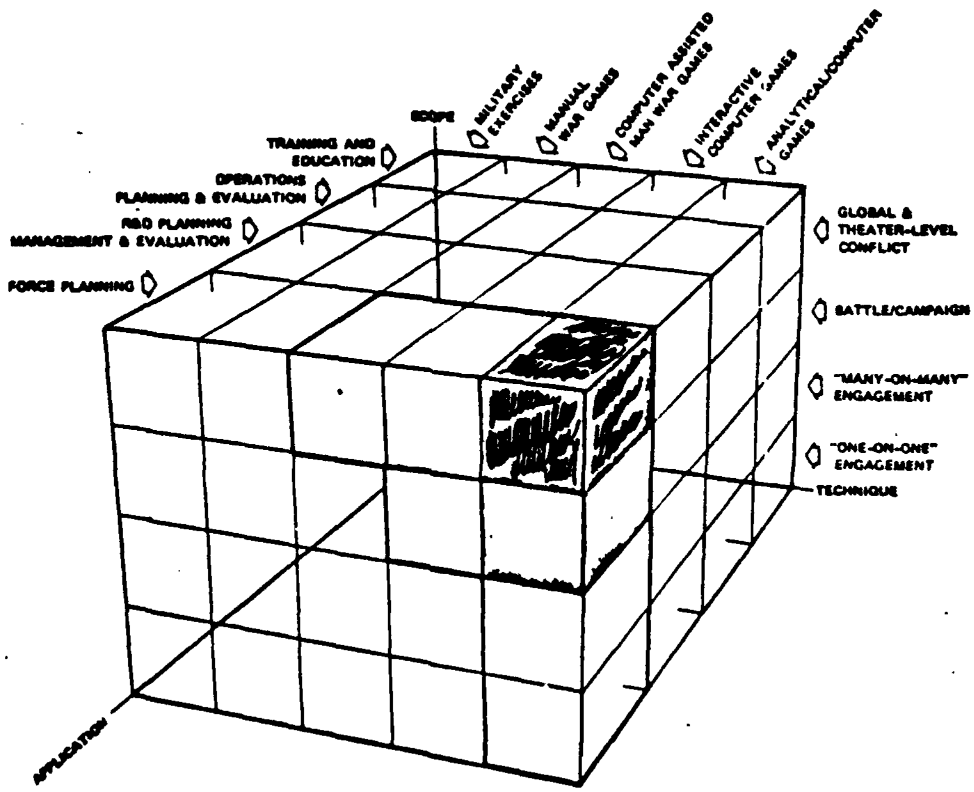

Figure 3.2 Modeling Classification Matrix

c. Computer assisted manual war games

d. Interactive computer games

e. Analytic/Computer games (analytic models, simulations, optimization)

2. MODELING SCOPE

a. Theater-level conflict

b. Major general engagement or battle (in-theater)

c. Local engagement "many-on-many units"

d. Local engagement "one-on-one/many units"

3. MODELING APPLICATION

a. Force planning

b. R/D planning, management, and evaluation

c. Operational planning and evaluation

d. Training and Education

The matrix shows that any modeling research performed in models must be selective and focused on particular elements of this matrix if the effort is not to become untenable in its proportions. If one, for example, selects force planning as the APPLICATION topic to focus attention, then the two other dimensions of the matrix indicate analytic/ computer games for the TECHNIQUE and theater level conflict for SCOPE.

1. Combat Model Spectrum and Characteristic Trends

In the analysis of models it was stressed that models are representations of reality. With respect to combat operations the combat models can take a variety of forms like:

a. Real Combat

b. Field Exercises

c. Command Post Exercises (CPX)

d. Wargames (Board)

e. Computer Assisted (interactive) Wargames

f. Computer Simulation (including decisions)

The spectrum of combat models forms is presented in Figure 3.3, along with the associated trends in model characteristics in areas like Human Decision, Impact and Operational Realism, Degree of Abstraction, Time-Money-Details of Information, Outcome Reproducibility, and Convenience and Accessibility.

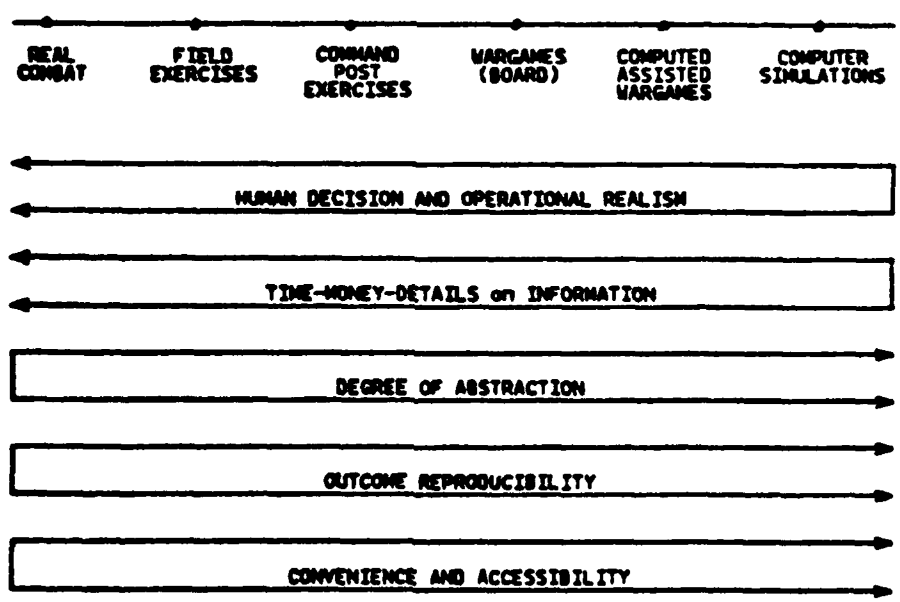

Figure 3.3 Combat Model Trends and Characteristics

2. <u>An Algorithmic Development of a Theater-Level Combat Model</u>

Following a basic guideline an algorithm will be presented concerning the route of combat model development. Starting with a need to model a large scale model the following steps, each taking about a year, are necessary: [Ref. 9:p.VI-17].

a. Develop overall architecture and design specifications.

b. Develop or adapt algorithms for individual routines.

c. Research, adapt, or develop input data requirements.

d. Program and debug (correct) individual routines and major sub-models.

e. Make first non-trial runs with user input and make major modifications to control input and output.

f. Modify to incorporate user-directed changes in weapons systems, doctrine, tactics, etc.

The above sequence reflects the general pattern that has been observed in model development and a more detailed discussion is necessary, according to the author's view, for a better assimilation of the significance of the steps.

The overall architecture and design specifications are usually in the form of flow charts to guide the programmer. At this state, the architecture is guided by relatively broad and simply stated objectives that, in principle, meet all the sponsor's requirements, and at the same time, make the model fast and easy to operate. This is usually interpreted to mean simple and quick changes in inputs rather than computer running time. Often the sponsor also specifies modularity, i.e., the ability to use more than one set of routines, especially some that have already been developed. This is easy to do at the flow chart level, but is much more difficult to program.

The programming stage often produces several problems. First, the broad compass of theater-level models and their cost usually result in a fairly large number of agencies being represented at the progress meetings. The people at these meetings discover for the first time that the military functions for which they are responsible are not represented in enough detail for the model to be of much use to them. The original sponsoring agency and the developer then face a dilemma. If the criticisms are ignored, they lose the support of that angency. If they try to meet a significant number of these criticisms, the model quickly becomes difficult to control, and the input requirements escalate in number and complexity.

The development and debugging of the master program is a longer process that most developers recognize or are willing to predict. Some theater-level models (IDA, TACWAR, CEM, etc.) contain between 20000 and 50000 FORTRAN statements. Early runs of a complex, debugged model often produce an overall pattern of warfare that everyone would consider "unrealistic."

Most theater-level models require about three years before they can be run for the record. During that period, many changes will occur in programs, priorities, and knowledge about enemy forces and systems. It is almost certain that a change in the model will be required very quickly to deal with a new program. This begins a process that, in practice, is unending. The result is a constant struggle to keep the program and its documentation up to date. If, as frequently happens, their is a significant personnel turnover in the agency operating the model, the result can critically affect the future of the model.

3. <u>Theoretical View of Aggregation</u>

Now let turn the focus in the systematic process of combat modeling to the topic of aggregation. If one cannot model the individual combatants in detail then it is necessary to use "Aggregation." The characteristics which will be considered as appropriate to aggregate are:

a. Force Size: What level of unit it is required to model? i.e. Theater, Tactical Air Force, Group, Combat wing, Squadron, One to one

b. Functions Being Modelled: Mainly they concentrate on Attrition, Maneuvers, Command and Control, Interbranche (Air Force-Army-Navy) coordination, Logistics, Intelligence.

c. Environmental Factors: At this level very extended areas are modelled and the main problem is to represent terrain and weather.

d. Decision Processes: Between individual weapons (who is to shoot at whom). There are Manual Processes, Human/ Computer Interactions or Automated Decisions.

e. Randomness: Use "stochastic" processes up to Combat Wing level and "deterministic" in some higher level of modeling.

f. Intended Use of Model: Decide how the model will be used. For example, for analysis or strategic/tactical investigation or simulating Decisions Simulations.

Let us suppose one is trying to build a combat model where E = (Combat Entities) and S = Scenario Description, then the mapping

$$E \times S \xrightarrow{\quad f \quad} Re \qquad \text{(eqn 3.1)}$$

gives the aggregation results Re. In that case f is a <u>"combat model"</u> so as given E, and S it computes the combat results Re, (e.g. number of aircrafts, target destroyed, attritions, etc).

If one cannot represent the model f then must aggregate. In that case the set (E) is aggregated into the

$$U \times S \xrightarrow{\quad g \quad} Ru \qquad \text{(eqn 3.2)}$$

much smaller set (u) of units (e.g. Battalion, Combat Wing), then g is an "Aggregated Combat Model."

An example of aggregation is the case when one has several units representing Divisions and presents their attrition as a percentage.

Division Strength = (1% causalties) *Division Strength (End-Start of day).

Bode in [Ref. 36:p.61] explains aggregation as:

The "lumping together" of several individual things into a composite thing which is then used to collectively represent the individuals. Similarly aggregation can be viewed as:

* A transition from individual (or micro) properties to ensemble (or macro) properties (Natural sciences).

* Selective encoding of key information which "summarizes" a group of individuals (Communications science).

* A many-to-one representation of individuals in the system by individuals in a coarser and less complex system (Systems science).

The key point is that, aggregation loses information about the identities since it combines elements into units and individual processes into rates of attrition.

4. Validity and Theater-Level Combat Models

As has been shown, no theater-level models contain all the elements of a theater war. It follows that the "historical method of validating" a model is a shaky one at best, in the following sense: "We have calibrated many of the existing models to the results of the 1973 Arab-Israeli War and we can reproduce the results." [Ref. 9:p.VI-21].

There are two reasons why the historical method should be used with caution.

First, the environment and force structure on the two sides may not be typical of those the model is designed to investigate. In practice, in case of similar modifications, the required changes would be so extensive that the result would be a "new model."

Second, a major factor in past war may not be explicitly incorporated in the model. One example is the critical importance of electronic warfare in the 1973 Arab-Israeli War which many models did not consider.

There is a large literature on the validation of models in general and theater level models in particular. This thesis will present the issue of combat model validation along the lines of [Ref. 9:p.vi-22] is which four types of validity are treated:

a. Input Validity: The accuracy, currency, consistency, and authority of the force structure and the system performance data base.

b. Design Validity: The degree to which the logical structure of the model and its algorithms are internally consistent and reflect the dynamics of combat in a reasonable fashion.

c. Output Validity: The degree to which the model's output enables the user to rank alternative inputs in terms of specified criteria. To have output validity, the model's output must be sensitive to input variations that the user intends to make.

d. Face Validity: The willingness of the decision-maker to make decisions based (at least in part) on the model because he believes that it makes sense.

5. Conceptual Structure of Combat Models

There exist two principal ways to structure models for analysis:

(a) Bottom-up. This way takes technical data of weapon systems, physical constants and mathematical principles and aggregates them through different levels of analysis to a final result. This is the way how, for example, the outcome of an engagement of an aircraft versus an antiaircraft missile is modeled. Taking the time necessary to detect and identify the aircraft as a threatening target and the time to aim (lock on) and launch the missile, as well as trajectory-directional data of the SAM, the probability of hitting the target can be calculated. Taking a (pseudo-) random number, the model can actually predict if the aircraft is killed or not. Manual wargames and stochastic or deterministic simulations are examples of this kind of modeling [Ref. 37:p.12]. The important aspect is that the model is connected to the reality through the use of technical or physical data.

(b) Top-down. This approach is different in the way that it uses mathematical representation of the effects of sets of weapons systems instead of representing the physical

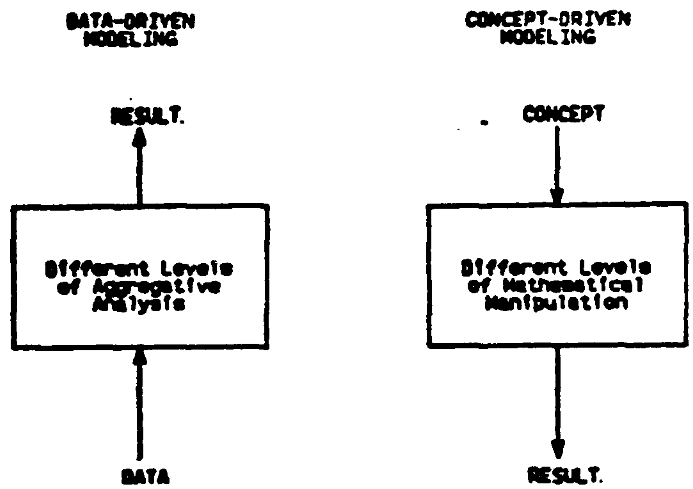

Figure 3.4 Data-Driven vs Concept-Driven for Aggregation

attributes of each individual weapon. The outcomes of military encounters can be determined by manipulating mathematical expressions rather than simulating physical interactions. The principal differences between data-driven and concept-driven analysis is depicted in Figure 3.4.

After the tracing of several combat models an ideal structure for the modeling of combat has been derived, [Ref. 38:p.20]. That is implicit in all the models although

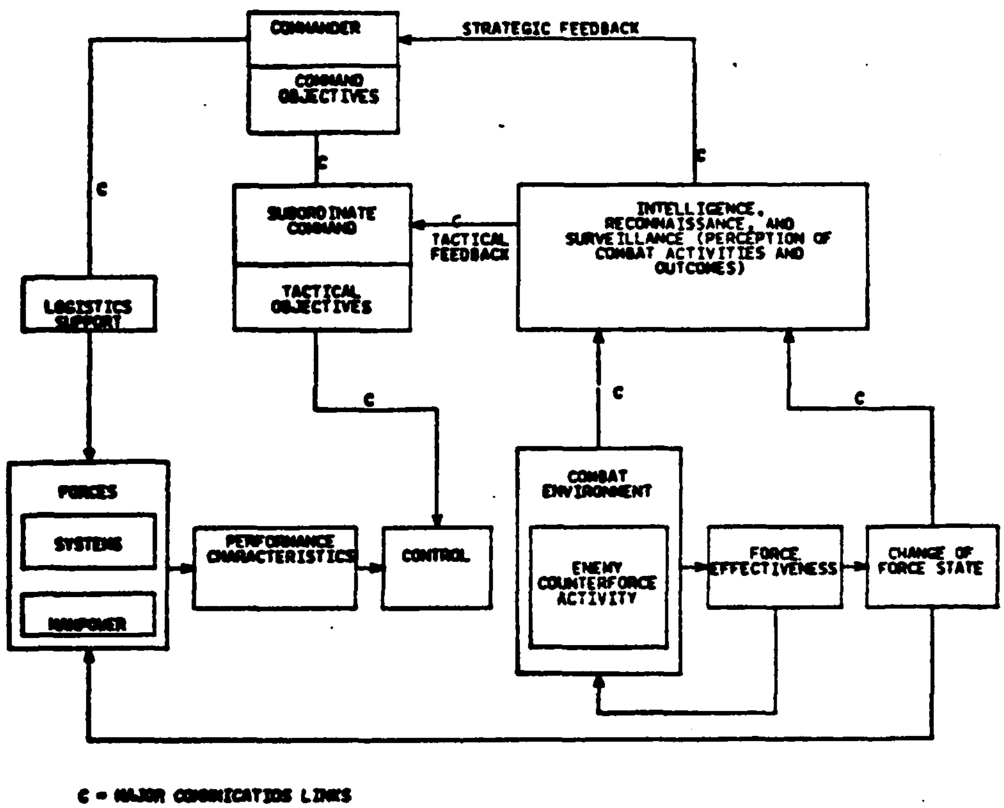

Figure 3.5 Structural Concept of Combat

it is not satisfied entirely by anyone model.

In brief, Figure 3.5 consists of a dynamic combat loop concerned with friendly force vs enemy counterforce activity coupled to a command control loop though intelligence, reconnaissance and surveillance means by which friendly perceptions of combat activities are generated. Logistics support is an important function (often negleted in modeling), since the system is also vulnarable to enemy attack of supply lines.

A similar block can be constructed for the enemy forces, around the "counter force activity" block presenting the dynamic behavior of the system.

Theater models, if indeed they are to be reasonably faithful abstractions, must address the "givens" in a problem. They can be listed as shown in Table III [Ref. 38:p.53-70].

In modeling warfare situations, one essentially feeds the combat elements (as inputs) into mathematical formulations of the combat processes that are tied together by appropiate logic to derive outputs which are, in effect, the outcomes of the encounter between the opposite forces.

Applying the concept of the elements, processes and outcomes mentioned above one can structure the combat model into a series of cause and effect loops that are, to a large measure, interactive, see Figure 3.6 [Ref. 38:p.69.].

But whatever approaches are taken, they will be constrained by data that are or cannot be made available. The possible sources for data to the analysis of combat are:

a. National archieves

b. Official military histories

c. Field/fleet/air exercises

d. Combat experiments

e. War games, models, and simulations

f. Operational test and evaluation (OT & E)

g. Proof tests

h. Engineering laboratory tests and design studies

As noted by Taylor in [Ref. 39]. (a) and (b) are sources of real combat data while (c), (d) and (f) are sources of simulated combat data. Data for the "technical" characteristics and performance of military equipment are represented in (g) and (h).

Reviewing the issues and problems associated with model design development and application, an attempt has been made to structure a graphical depiction of their interrelationships.

Modeling issues are organized into two major interdependent groups. One group concerns MODEL and GAMING STRUCTURES in the broad sense of model concept and design, and the other concerns COMBAT OPERATIONS and PROCESS MODELING.

At this point the forcus will be diverted to Figure 3.7 which shows factors that directly affect modeling. Although it is not the intent of the author to trace the

AD-A137 651 AN EXPECTED VALUE AIR COMBAT MODEL SIMULATION ALGORITHM 2/3
TO PREDICT MISSIO..(U) NAVAL POSTGRADUATE SCHOOL
MONTEREY CA E SKLIRIS SEP 83

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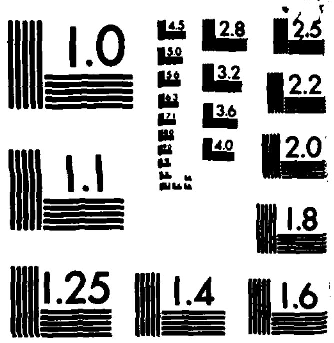

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

TABLE III

Elements and Process of Combat

ELEMENTS

(1) Combat circumstances, initial objectives and missions (both sides)

(2) Natural and man-made environments in the area of operations

(3) Human resources, numbers and characteristics

(4) Material resources, numbers and characteristics

(5) Organization and structure of opposing forces

(6) Tactics, doctrine, and operational concepts

PROCESSES

(A) Attrition

(B) Suppression

(C) Movement

(D) Command, Control, Communications, and Intelligence (C I)

(E) Combat support

(F) Combat service support

whole scheme of Figure 3.7 a run through route will be followed.

At the top of the figure is an abbreviated representation of the spectrun of armed conflict as it is observed to occur in the real world. One must recognize the need for some form of analysis of the real world as the enabling

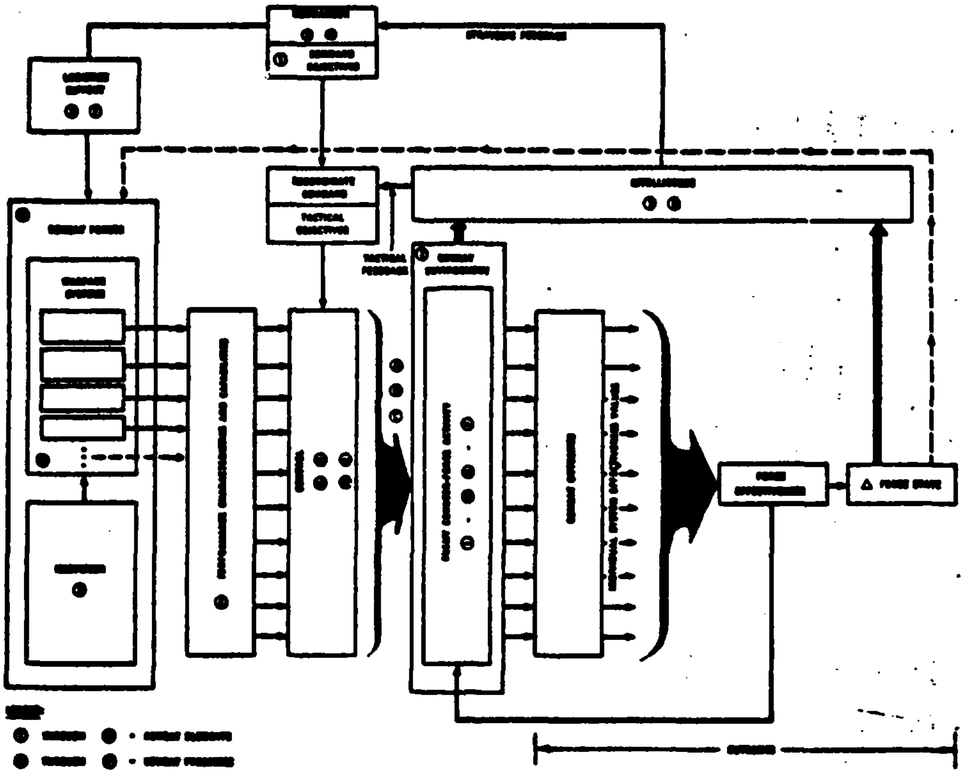

Figure 3.6 Structural Elements, Processes, Outcomes

adjunct to planning. This analysis must be shaped and constrained by existing or anticipated world conditions (political, economic, military), national and military objectives, budgetary considerations, etc. The analysis can be qualitative or quantitative.

In pursuing the quantitative methodology, one enters the realm of conflict abstraction. Following the route of quantitative analysis, it is the activity of gaming that dominates all of the efforts in conflict abstraction.

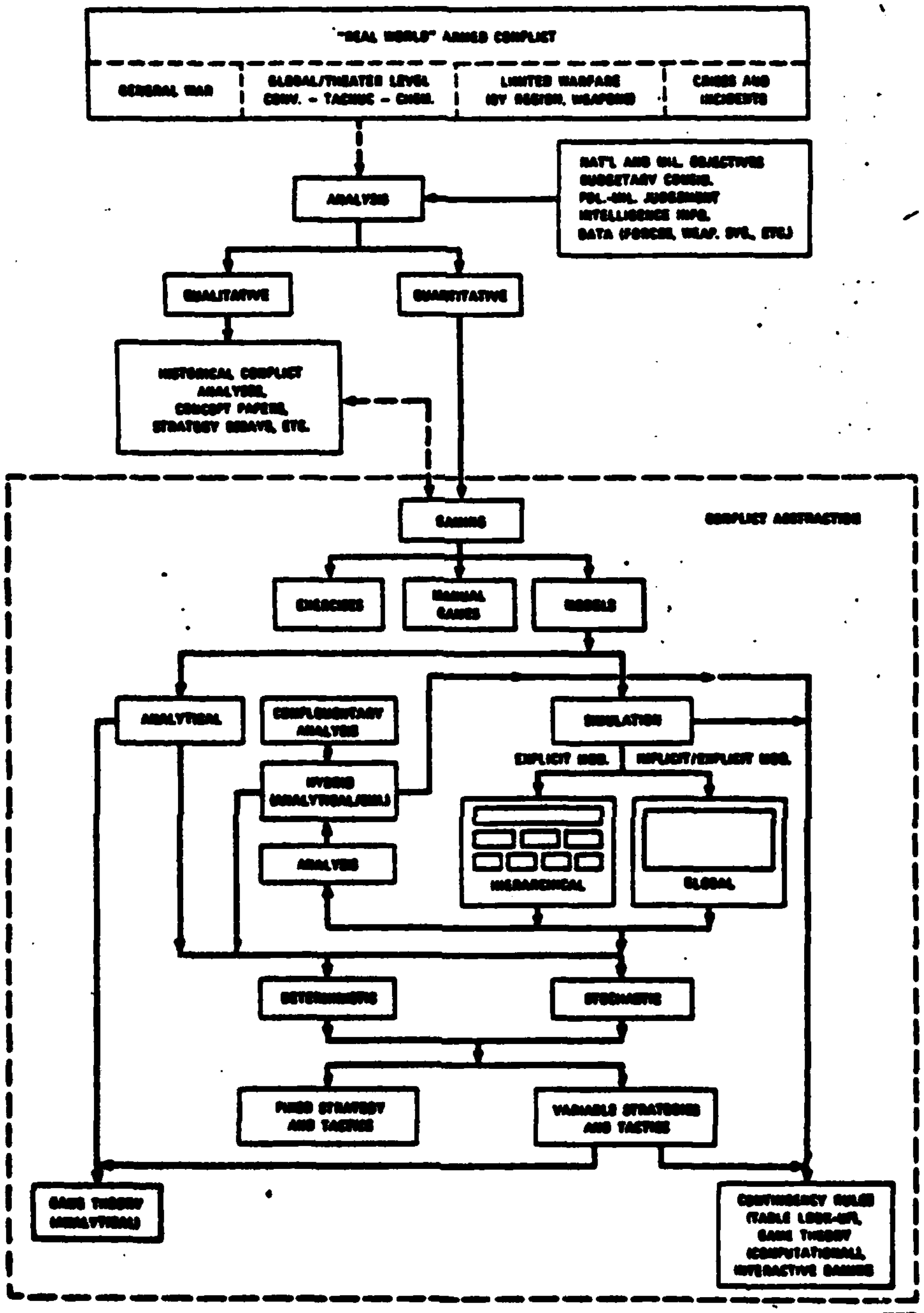

Figure 3.7 Theater-Level Modeling: Gaming Structures

From the two fundamental forms of modeling, analytical and simulation, shown in the figure, simulation will be followed. As technique, simulation dominates virtually all efforts to model combat, and around simulation technique two fundamental modeling structures are built, namely hierachical and global.

The hierarchical approach involved a "stepping-stone" build-up of information from "one-on-one" models up to "force-on-force" ones. The structure of global simulation, by contrast, incorporates complete hierarchical states of combat activities and operations in a single model. The next issue is deterministic versus stochastic modeling, as shown in the same Figure 3.7. Ideally the stochastic modeling oc combat should be preferred, as natural choice. However, the two major difficulties; a) absence of suitable statistical data and b) the complexities associated with combat have to be considered.

The modeling of strategy and tactics. This area encompasses the human "behavior" in operational decision making and weapons employment into models of combat. In Figure 3.7 a dichotomy is implied in model structures by the boxes labeled Fixed/Variable Strategies and Tactics.

With fixed strategy models, the attack and defense objectives and plans, the weapons to be used, and the allocations of manpower and weapons to specific roles are decided before and became a matter of input to the model. "What if" questions can be answered by repeated runs with the model and appropriate variations of the input. On the other hand in treating variable strategies and tactics as a part of game structure, three basic techniques have been advanced:

* Contingency rules (table look-up)
* Game theory (analytic and computational)
* Man-machine interactive or player-assisted gaming

The above concludes the discussion based on Figure 3.7 which was restricted to factors that directly affect gaming structure, its form, size, and complexity.

Next to be considered is the modeling of combat operations and functions. This hierarchical view of relationships is reflected in Figure 3.8, in which the upper part repeats some of the classification material of Figure 3.7, indicating that the structure of the model selected (a simulation for example) should depend on the nature of the required degree of resolution to be provided by the model.

Tracing down the Figure 3.8, one deals with the issues of modeling tactics, doctrine, and command and control of Ground and Air warfare. The figure emphasizes the importance of command, control, communications and intelligence. The combat missions shown are the classical ones, while air and ground activities are closely interrelated in actual combat, an attempt is made to dissociate the combat missions into activities that are primarily ground (solid lines) and air/anti-air (dashed lines). It may be inferred

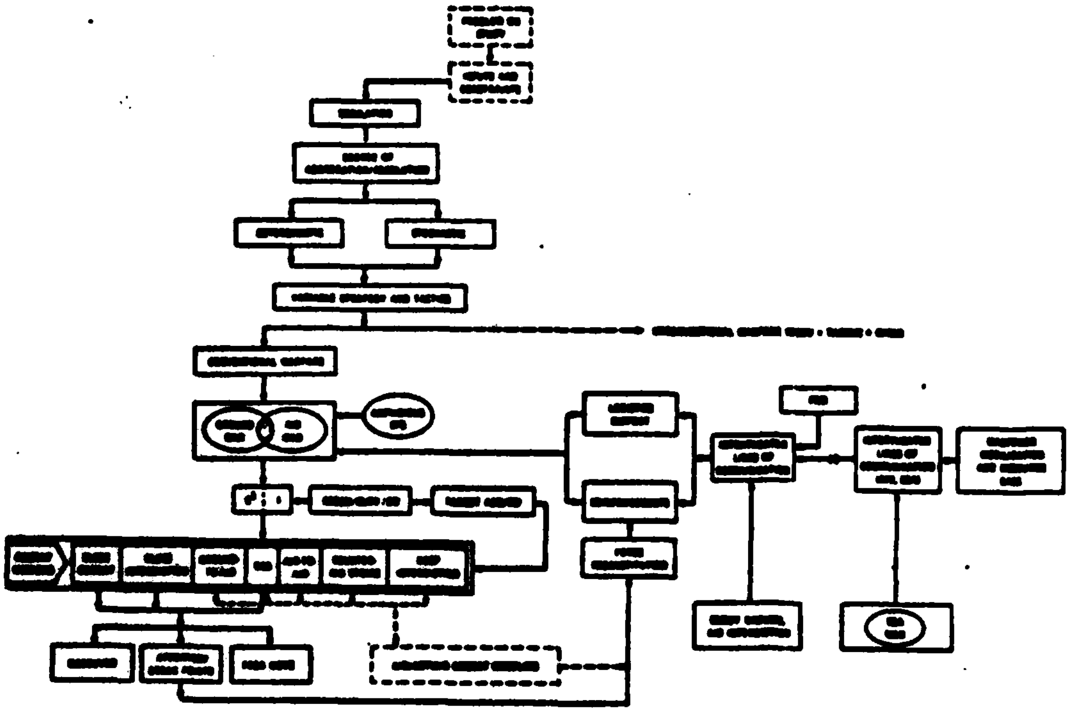

Figure 3.8 Theater-Level Modeling: Combat Modeling

from the Figure 3.8, that these problems suggest a specific issue and difficulty in theater level combat models.

D. DECISION MAKING AND COMBAT MODELS

The notion of decision making process as a function of mental activities is a complicated one and specifically under the situation of uncertainty, stress, fear, threat and time restrictions.

Trying to model these reactions in a combat model simulation is one of the most difficult issues ever addressed in the combat model community.

In this section the author will focus the study in the fundamental process and role of judgment in the decision theory perspectives and the latest available methods of modeling decisions in air combat models.

1. Decision Process a Judgmental Approach

The effectiveness of any military system is the extend to which the system achieves a set of objectives. The quantitative expresssion of the extent to which specific missions requirements are attained by the system is referred to as a measure of effectivenss (MOE).

In the Operations Research community, it is important to distinguish between the performance (e.g. rounds fired per minute, single shot kill probability, etc) of a weapon system and its effectiveness or military worth. Failure to choose appropriate MOEs can lead to completely wrong conclusions as to preferred alternatives.

Although, as stated previously, performance data for a weapon system may be collected in "Operational tests," a combat model is usually required to "put it all together" against an enemy threat in an operating environment to estimate systems effectiveness. In other words, the combat model transforms performance measures into effectiveness measures.

Now comes the main decision. What specific "measures of effectiveness" or what specific "outcome measures" one ought to use?

Some of the specific measures which are going to be presented are "outcome measures," that are really concerned with our judgements on which of a number of possible outcomes for a simulation is preferred. Here is the main source of difficulty for the decision maker in trying to select satisfactory measures.

Following is a brief presentation of the various kinds of measures within a decision theory perspective.

The first of the measures, namely outcome measures are concerned with judgments about which of the possible outcomes are preferred.

The second type of measure called decision criteria are concerned with courses of action preferred among a number of alternatives and:

The third type of measure, known as, measure of effectiveness (MOE) concerns measures like which system or which combination of systems is best.

Obviously, the fundamental purpose of the above measures is to assist the overall decision process. In each case, the measure serves essentially as "value criteria" in making decisions. Actually, most people are quite good in using intuitive value judgments to make decisions. The problem arises when one tries to deal with such "judgmental values" within the comtext of a formal analysis, like in proofs through combat model simulations.

In the above case the scientifc training suggests that one should address the problem objectively and not by resorting to subjective judgmental criteria. Consequently there is a conflict between the intuitive way of approaching the problem and the way one thinks he ought to try to approach it from a schientific perspective.

Decision theory suggests to use values in common sense reasoning and that is justified by some fundamental principles of "cybernetic" efficiency. (Greek word "cyber-netis" meaning the control of process of information transfering with a system under the mathematical or computer assisted method).

A better understanding will be acquired by learning how to use those principles about "judgmental values" within the combat model analysis and simulation process itself.

Today it is well understood that one can incorporate some of the "subjective value" criteria in a model's construction and in doing so can build models that are considerably more flexible and more efficient. The only reservation is that if one is going to include subjective value criteria these value criteria must be explicit so the model user can understand the outcome within the context of the value criteria that have been used.

Pugh states that the traditional benefits of "values" within "value criteria" is that they make it possible to decentralize the decision process and still get a reasonable sensible result. [Ref. 40:p.72]. Consequently it is helpful to make decisions in terms of intermediate outcomes when one is unable to project the outcome of the decision all the way to an ultimate outcome. Values also serve in a very practical way as a tool of command.

One of the things that a commander does in giving commands to his subordinates is to define value priorities or priorities for his course of action. The commander's action specifies the value priorities by which the subordinates will make their decisions.

At this point a formal definition of value should be helpful to the reader.

Pugh defines

> "Value is a scalar quantity, associated with outcomes for the purpose of making decisions." [Ref. 40:p.73].

To make decisions among a number of alternatives a "value function" is needed.

> "Value function is a scaler function defined over the space of possible outcomes for the purpose of making decisions." [Ref. 40:p.73].

In other words a value function assigns values to the various outcomes and makes choices between them.

A typical form of a value is essentially a summation over a number of considerations of a series of values that are somehow functions of the outcome. It generally takes the form of a weighted sum of the number of considerations, all

$$V = Sfi\ (u_1\ u_2\ u_3\ \ldots,\ u_n) \quad \text{(eqn 3.3)}$$

of which are relevant to the decision.

One of the lessons that comes out of looking at this formally is "do not omit any important consideration from the definition of value criteria."

The next point needed to be clarified is how the values really are used within a decision process, given that one is willing to program a decision system on a computer process.

The simplest form would look like the following shown in Figure 3.9.

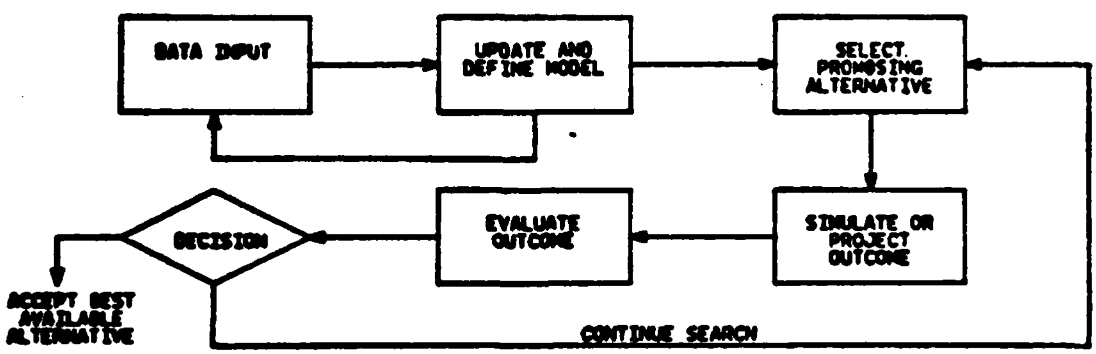

Figure 3.9 The Human Decision Process

An initial loop inputs data and fundamentally updates the model of the information about the environment within which decisions are to be made. The next step is to consider a series of alternative, and for each alternative, to simulate or project the outcome. Finally, value criteria are used to assess the outcome. So, in order to be able to apply the value criteria, a way to calculate the value of each of a number of possible outcomes is needed.

In projecting, predicting outcomes the question which arises is, what it is defined as an "outcome." If one tries to think too far ahead, the process becomes very complex. So almost all practical military decisions are made in terms of outcomes that are projected for only a relatively short time ahead.

On the other hand, people typically use "rule-of-thumb criteria." They do not think ahead at all, but given a particular state of the environment, they make some specific decision. To make good decisions that way, a complex network of decision rules is needed, or in our terms a very complex value function. Most of the practical decisions that are made every day are made by thinking a little way ahead and using judgmental value criteria to evaluate the projected outcomes.

But lets see now how the values are generated in a military environment where the value decision process is very complex. In Figure 3.10, starting with long-range national goals and objectives, the military objectives are specified as a kind of subsystem. At the highest level of military goals and objectives one probably comes to long-range criteria. (i.e. the objective of winning the war). But as soon as one moves from that to how he is going to fight the war on an intermediate basis, then he wants a good exchange ratio with the opponent. As one proceeds downward he begins to become involved in situations where the objective

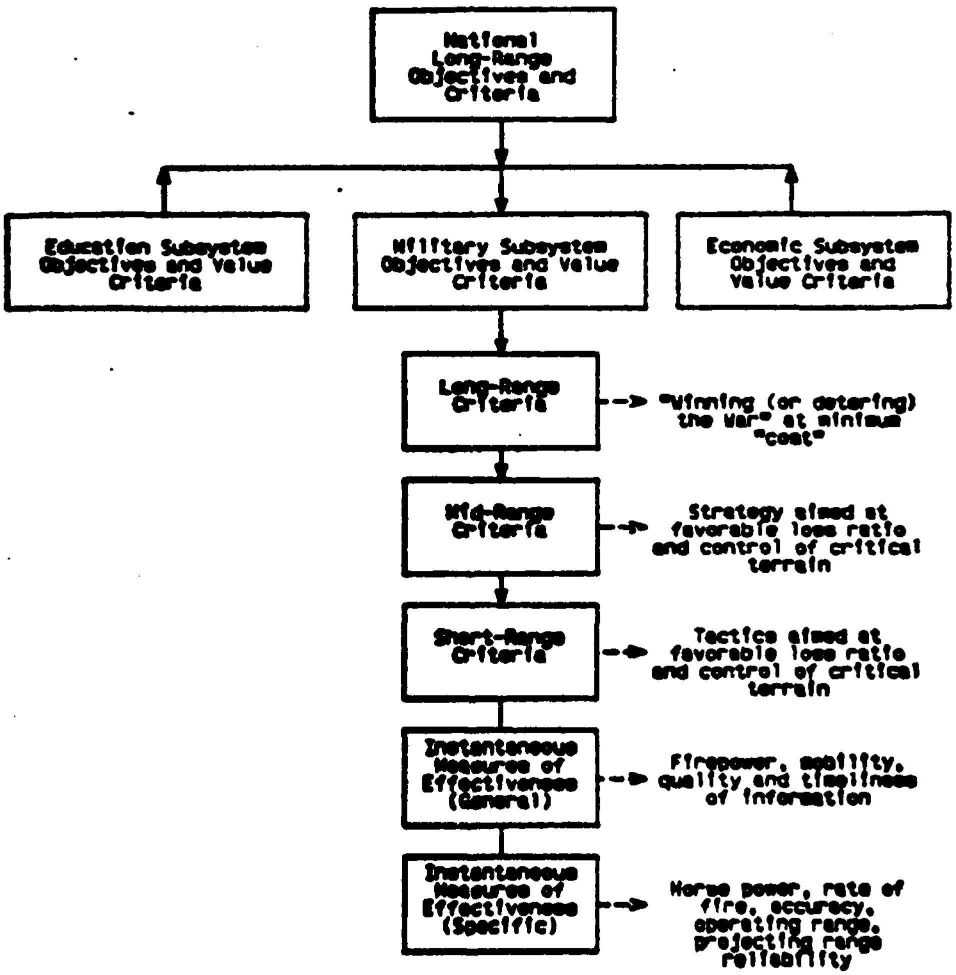

Figure 3.10 Hierarchy of Military Value Criteria

has to do with short-range tactical objectives on particular pieces of terrain, which have to do with exchange rations.

It is noticeable that as one moves down this chain he is moving from value criteria that are useful in terms of looking a long distance ahead to judgmental value criteria that are useful in terms of short-range decisions.

Finally at the bottom of this chain one comes to what is called "instantaneous measures of effectiveness." These are the MOE's that tell what the "firepower score" is for an aircraft or what the combat effectiveness of the airplane is vs a frigate.

Value measures have to be deduced from experience in military matters, at the short-range level, perhaps at the mid-range level, and theoretically even at the top level.

E. VALUE-DRIVEN DECISION THEORY

The proper modeling of Command-Control and Intelligence, as it affects combat performance, has been one of the most difficult problems confronting the combat situation designer.

The combat effectiveness assessment is critically dependent on availability of timely and relevant information, but the lack of procedures for quantifying the implications of improved information flow has made it extremely difficult to assess the combat performance of new weapon systems. For example, improved information has no effect on the maneuverability of a particular aircraft or the rate of fire of a particular gun, however, it can profoundly influence combat outcomes by changing the choice of missions for the aircraft or the aimpoints for the gun.

To represent the effect of information quality on combat outcomes, it is necessary to model the way that combat decisions are influenced by the availability of information. Recent theoretical developments in the understand of human decision processes, appear to offer the possibility of realistically simulating command-and-control processes. The new approach that is used to model the effects of C2I is described as an information-oriented and value driven simulation. This type of combat model simulates not only the physical interactions between combatants, but also the effects of information that is used by combatants to make decisions in response to a changing combat environment.

In [Ref. 41] the development and associated theory is explicitly presented with its applications to Air Force efforts to model pilot's decisional behavior, in models like TAC COMMANDER, TAC FIGHT, and TAC BRAWLER.

1. The Value-Driven Approach

The Value-Driven decision approach to the modeling of C3 in combat simulations comprises both a formal structure and a body of guidelines and techniques for use in applying the approach to combat simulations."

The essential element of the value-driven approach is the "decision element." The formal structure of the decision element is shown in Figure 3.11.

The decision elements includes the capability to receive and interpret sensor and communication data to form an internal mental model of the external world, to generate possible courses of action and to project their consequences, and to select and direct the implementation of a particular course of action.

The decision element is composed of three structural element and a series of activities that are controlled by or used in the construction or processing of the elements. [Ref. 41], and [Ref. 9:p.v-7,v-8].

a. The executive control program: This master program performs the supervisory and control functions for major decision elements. It oversees the execution of each of the major activities, including those concerned with the information and updating of the mental model and the generation, projection, evaluation and selection of courses of action.

b. The prior knowledge library: To realistically and satisfactorily perform the decision-making function in a combat simulation model, a decision model must have access to information not accessible exclusively via sensor and communication links with other decision elements. This information is contained in the prior-knowledge library.

The types of prior knowledge required here takes three forms:

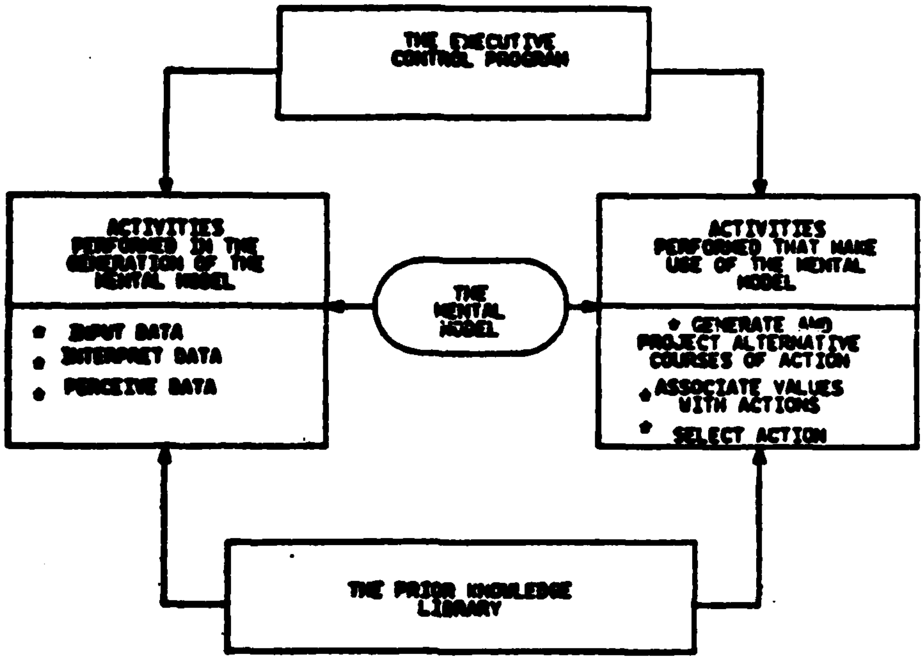

Figure 3.11 Logical Structure of the Decision Element

The first is simply the knowledge of the rules or laws of action which permit the decision element to project the consequences of pursuing a given course of action.

The second concerns the set of alternative courses of action that are generated as candidates for implementation.

The third conerns the evaluation of the courses of action for the purpose of the selection of an alternative for implementation.

c. <u>The mental model</u>: For a decision element to contemplate possible courses of action, to project their outcomes and to evaluate their utility requires a "mental picture" or a "mental model" of the current state of the external world. This mental model then serves as the basis for all activities of the decision element.

The series of information processing activities engaged in by the decision entity can be divided into:

(a) Activities involved in the generation of the mental model as:

1. Input data
2. Interpret data
3. Perceive situation

(b) Activities that use the mental model in the generation, evaluation, and selection of courses of action like:

1. Generate and project alternative course of action
2. Associate values with alternative courses of action
3. Select alternatives

2. <u>Value-Driven Method vs Other Methods</u>

In this section a perspective of the value-driven decision approach is developed that allows comparison to other methods of treating command and control in combat simulation. Comparison of the method with the methods of "artificial intelligence" will be suggested as an individual study topic to the reader.

The most common procedure for treating command and control in combat (Air and Ground) models is the "decision-rule approach." A brief description and further comparison to the "value-driven approach" is following.

The "decision-rule" or the closely related decision table approach provides the simplest method for representing dynamic decision processes in combat simulations. In a representative scenario, two opposing commanders must determine the posture, e.g. attack, hold, and delay, which their respective forces should assume during the next time period. The determination is made by comparing the ratio of some measure of the strength of each force, most commonly "firepower scores," with a set of prespecified thresholds which serve as break points for selecting postures for the forces. For example, a three-to-one force ration might serve as the breakpoint for the stronger force initiating an attack and and eight-to-one ratio would cause the weaker force to adopt a delay posture.

The significant features of the "decision-rule" approach in comparison with the "value-driven" method are: [Ref. 41:p.39].

All decisions are based solely on the current state of the forces. No projections of the consequences of adopting a particular course of action are made in the simulation. Moreover, the courses of action that are considered, such as the attack, hold, and delay postures are "hardwired" into the software. No capability is available for dynamically generating courses of actions.

All decisions are made by comparing selected measures, such as the "firepower scores," to predefined, generally inputted threshold values.

The decision-rule approach, thus, lacks the richness of the value-driven approach in terms of not allowing for the dynamic generation, projection, and evaluation of alternative courses of action.

Other features of the value-driven approach, such as the dat interpretation and situation perception function while formally permitted in the decision-rule structure are generally not developed in the form or with the degree or richness of the value-driven method.

Finally, the value driven command language for representing the flow of information among decision elements in the command-and-control system is not present in the decision-rule approach.

Thus, in spite of its desirable simplicity, the decision-rule approach does not possess the versatility that is needed to adequately represent command and control in most combat simulations.

The principal advantages of the value-driven method are:

a. <u>Realism of representation</u>: Each decision entity identified as playing a crucial role in the representation of command and control is represented in the simulation by a distinct decision element.

b. Power of the approach: The dynamic generation of alternatives in response to changing combat conditions gives the approach the power to generate realistic courses of action either to exploit a developing situation or to prepare a suitable defense.

c. Flexibility of the approach: The use of values also permits the user to easily modify tactics for play in the simulation without modification of the software. The user need only vary the value weights associated with actions consistent with the desired tactics. New tactics can be introduced into the simulation through the addition of tactics but without modifcation the basic software.

The principal disadvantage of the method is its complexity, "more straight forward" decision-rule methods would seem to offer a simpler approach for representing command and control in combat simulations. However, the difficulty in generating suitable courses of action based solely on the current state of the simulation and the lack of flexibility to dynamically generate and evaluate alternative courses of action usually makes the "practical" application of the simpler method more difficult, [Ref. 41:p.50].

F. MODELING OF ATTRITION PROCESSES

As one considers the entire field of ground and air combat modeling and traces its development, one realizes that attrition (causalties inflicted by either side on the other) is regarded as the functional ne plus ultra for the engaged forces.

The focus of interest on attrition apparently stems from a preoccupation with "wars of attrition" such as occured during WW I and most of WW II. In conflicts of this type, the forces of the opposing sides are in contact and engaged. There is generally ressistance to the movement of forces in either direction, therefore, a FEBA (Forward Edge of Battle Area), can be drawn, or "bomb lines" can be defined, showing the line of area of contact between opposing forces.

In the world of modeling, it is the attrition process, expressed either implicitly or explicitly, that causes the force ratio to change. It is the prevailing force ratios that in many models cause the movement of the FEBA, thus controlling the winner or loser of the conflict.

With the importance of attrition so established, the routes of attrition modeling presented by Law in [Ref. 42:p.9] and shown in Figure 3.12 will follow:

1. Aggregated Differential Equation Approach

Taylor in [Ref. 10] in his work presents a two volume analysis of the so called LANCHESTER-type models and the willing reader will find a detailed clarification of the methods of predicting attrition rates, in particular, the coefficients that portray these rates. [Ref. 43:p.24].

Let us consider a combat between two homogeneous forces, Figure 3.13, a homogeneous X force (tanks) opposed

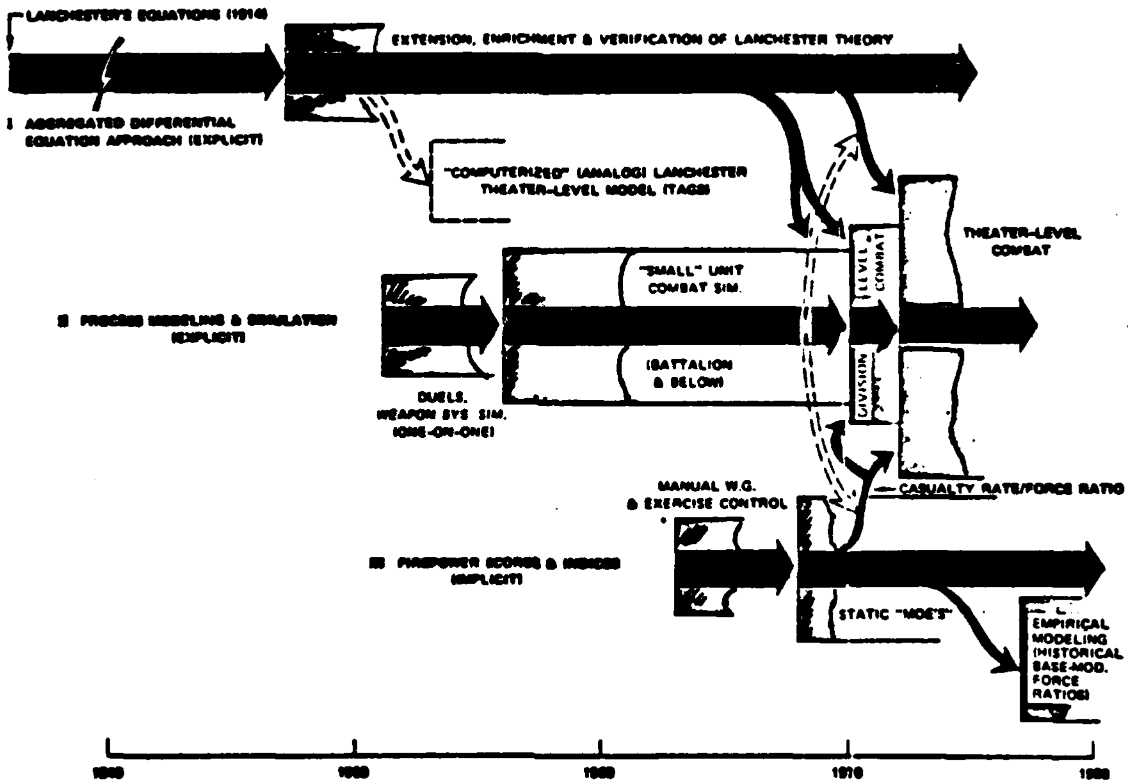

Figure 3.12 Basic Approaches to Attrition Modeling

by a homogeneous Y force (antitank) assumes that the casualty rate of such a homogeneous force is equal to the product of the single weapon system-type kill rate and the number of enemy firers.

The above method of attrition coefficient estimation systems from early work of Lanchester.

The quantities A and B are called Lanchester attrition rate coefficients. The coefficient A denotes the rate at which one Y firer kills X targets, at time t.

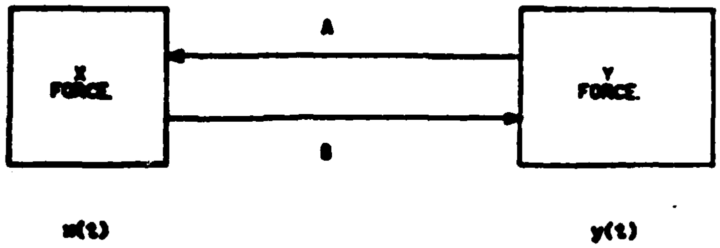

Figure 3.13 Combat Between Two Homogeneous Forces

$$\frac{dx}{dt} = -\,Ay \text{ with } X(o) = Xo,$$

$$\frac{dy}{dt} = -\,Bx \text{ with } Y(o) = Yo \qquad \text{(eqn 3.4)}$$

The above equations are known in the literature, see [Ref. 43:p.12] as constant-coefficient Lanchester equations for "Modern" warfare.

In the simplest case A and B are constants (equ. 3.4), independent of the number of combatants and other changes

$$A = a \text{ and } B = b \qquad \text{(eqn 3.5)}$$

in engagement condition. In this simple case it is easy to analytically and very explicitly extract information about the dynamics of combat from our constant-coefficient

$$\frac{dx}{dt} = -\,ay \text{ with } X(o) = Xo,$$

$$\frac{dy}{dt} = -\,bx \text{ with } Y(o) = Yo. \qquad \text{(eqn 3.6)}$$

Lanchester-type model and one readily deduces Lanchester's

$$b\ (Xo^2 - X^2) = a\ (Yo^2 - Y^2) \qquad \text{(eqn 3.7)}$$

famous "SQUARE LAW", (equ. 3.7).

The dimensions of A are (number of X casualties)/(time * number of Y firers). Thus, A is indeed a rate and has the dimension of reciprocal time.

The coefficients a, b assume the basic operational assumption that both sides use "aimed" fire. That is each combatant on one side aims and fires at a live combatant on the other. All combatants on either side are within firing range of each other.

In a similar way when a weapon system employs "area" fire, that is fire delivered over a fixed area over time rather than aimed fire against individual targets, the corresponding Lanchester attrtion-rate coefficients depend on the number of tragets and hence the combat is modeled by (equ. 3.8) where the area-fire attrition rate coefficients A

$$A = A(t) \text{ and } B = B(t) \qquad \text{(eqn 3.8)}$$

and B do depend on the force levels. Such a coefficient depends both on the vulnerable area of the target and also on the lethal area of the projectile fired by the firer's weapon system.

Assuming now that the single-weapon-system-type kill rate, for example, A depends not only on time t but also on the number of targets x (e.g. target detection depends on the number of targets), then one is led to the further enriched fundamental Lanchester-type paradigm for homogeneous force combat in which the attrition-rate coefficients are:

$$A = A(t,x) \text{ and } B = B(t,x) \qquad \text{(eqn 3.9)}$$

When a weapon system employs "area" fire and enemy targets defend a constant area, the corresponding Lanchester attrition-rate coefficient depends on the number of targets

$$A(t,x) = a_A x \text{ and } B\ (t,y) = b_A y \qquad \text{(eqn 3.10)}$$

$$\frac{dx}{dt} = -\ a_A xy \text{ with } x(o) = xo,$$

$$\frac{dy}{dt} = -\ b_A xy \text{ with } y(o) = yo. \qquad \text{(eqn 3.11)}$$

and hence the combat is modeled by equation 3.11 where the area-fire attrition rate coefficients aA and bA do not depend on the force levels.

Again, for the case of <u>constant coefficients aA and bA</u> analytical results are readily obtained, and one readily

$$b_A\ (xo-x) - a_A\ (yo-y) \qquad \text{(eqn 3.12)}$$

deduces Lanchester's famous "LINEAR LAW."

An excellent overview of the developments in Lanchester attrition is presented by Taylor in [Ref. 10] and [Ref. 44] relating them to the broader aspects of combat modeling and gaming.

As a closing comment, attrition coefficients for Lanchester's equations have been modified to incorporate new parameters. Time-dependent variable attrition-rate coefficients depend on the rate of closure between the firing combatants and their targets, thus bringing battle dynamics into the attrition process. Finally, the Lanchester formulations have been modified to accomodate the heterogeneous force mixes that reflect the "combined arms" nature of warfare.

2. Process Modeling and Simulation

The second approach to attrition modeling Figure 3.12 is embedded in modeling the broader combat process of "shoot, move and communicate." This type of modeling began in "one-on-one" and "one-on-several" weapon system duels, employing either analytical or simulation technique.

In the development of this approach the firer-target pairings are treated more or less discretely. The engagements are modeled stochastically round by round, explicitly considering the functional steps, which start with target acquisition and end with the delivery of munitions and the assessment of weapons effects. Along with this enrichment of attrition modeling, afforded by Monte-Carlo simulation, came the opportunity to model many other important combat functions and variables such as weapons and sensor mixes, movement, terrain, communications, doctrine and intelligence.

The concept of a measure of effectiveness for each of the systems in the friendly force emerges from the combined interaction of these systems with the enemy forces in the battlefield environment. The MOEs for these systems combine in some manner to produce an overall MOE for the friendly forces. This measure encompasses the effects of weapon system combat performance relative to that of specific enemy units in a specific geographical and climatical environment, the behavior of the human beings involved, the differences in command objectives, the differences in the nature and degree of control for both sides, and the ability of the logistics-support system (which may well be subject to enemy attrition) to meet the force demands. The force effectiveness, in effect, operates on the states of both the enemy and friendly forces, influencing whatever changes in state (time, space, composition, and configuration) that may occur. From these changes in state, one can determine whether the friendly force advances, retreats, or is in a stand-off condition with respect to the enemy force.

Before shifting to the last approach it is necessary to discuss simulation of the Air War. As the scope of combat activities treated by simulation broadened, the importance of putting air support into modeling became increasingly apparent. This resulted ultimately, in air-to-air, air-to-ground, and ground-to-air combat modules.

The initial pattern was somewhat different when viewing the combined-arms modeling problem from the Tactical Air Force side. Here, there appeared an early appreciation for the fact that tactical air war was a supporting arm and that its effectiveness could only be properly measured by its influence on ground activities.

An important spin-off of the program of model development by the Air Force was the early recognition of the problem of air resource allocation in those instance in which aircraft were used multifunctionally. In that case the problem is to allocate multipurpose aircraft optimally among the various missions. To this end the use of game theory and the multistage game (two-person, zero-sum) was introduced.

3. Firepower Scores and Indices

A third approach to attrition modeling is the firepower scores method. Much as been written about firepower scored and indices and there are many variations of the concept. For the purpose of this thesis a brief description will suffice. It can generally be stated that there are three fundamental approaches to the problem of developing an understanding or relationship among the many variables in combat.

These are:

a. Historical approach (based on the study of historical combat records).

b. The judgmental approach based on field experience in combat and military exercises, and

c. Experimental/Analytical approach based on the use of physical and formal models, from controlled field experiments to highly abstract models and simulations.

The use of fire-power indices in determining combat attrition can be characterized as a method that, in some way, involves all three of these approaches. [Ref. 42].

As figure 3.12 shows the origin of fire-power scores can be traced back to their use as an evaluation and control mechanism in the conduct of manual war games and map exercises. The concept of the score envolved from a necessity to place some value on each of the many different types of weapons that might appear in a game.

At the very least, while still providing some measure of utility, the value could be based on the relative potential contribution afforded by each type or class of weapon in inflicting causalties on opposing forces. In effect, these weapon value ratings were somewhat gross estimates of relative weapon effectiveness by officers experienced in combat arms.

This thesis will cover four approaches to developing indices of effectiveness as presented by Lester and Robinson see [Ref. 45:p.9].

a. Firepower Scores

Indices of the relative value of weapons, based on weapon firepower, have been employed by military modelers and force-planners for many years. These indices, referred as firepower scores (FPS) are also known as firepower potential (FPP). When summed to form the score for a unit, they are called indices of combat effectiveness (ICE), unit firepower potential (UFP), etc. Indices of the "firepower" category are essentially expressions on single round lethality multiplied by an expected expenditure of ammunition (EEA) during a fixed period of time. Depending on how the lethalities and EEA are calculated, FPS can be said to represent a more general kind of effectiveness than just firepower.

Firepower scores are frequently criticized as representing only firepower, and not, for example, mobility, target acquisition, capability, and vulnerability.

b. Weapon Effectiveness Indices

The term weapon effectiveness indices or WEI are used to reflect the firepower potential of a nonhomogeneous combat force. The force has at its disposal a wide variety of weapon types. To compute the firepower index, one simply finds the products of firepower scores and adds these products over all weapons types employed by the force.

This simple mathematical operation does indeed produce some sort of indication, which reflects the capability or potential of a force to inflict causalties on an enemy. The formula and weights for different weapon and characteristics can be found in STAG's report on Selected Analysis Task I, June 1971.

The WEI consider many more weapon characteristics than the FPP's, but unlike the FPP's they do not explictly consider relative opportunity for engagement, nor relative amounts of ammunition available.

c. Army War College Combat Power Scores

In 1970 the Army War College developed factors for estimating the outcome of brigade level engagements. These values represented the relative value of US and USSR armor, infantry, and artillery units in seven different postures. However, they can be aggregated into a signle set of scores by averaging them over an appropriate distribution of postures. [Ref. 45:p.16-19].

d. Quantified Judgment Method (QJM)

The basic approach in this method is to define a set of "potential" capability scores for weapons, namely Theoretical Weapons Lethality Indices (TLI) and Operational Lethality Indices (OLI), then develop a number of weapons and forces modifiers which will bring predicted outcomes into reasonable agreement with the observed outcomes of a large number of historical battles.

Body in [Ref. 46:p.34-35] follows another approach trying to quantify aggregated capabilities and express them in suitable form. Such aggregates are referred as Military Effectiveness Indices (MEI) and following is a brief discussion of them.

"Static" or potential MEI assess starting conditions only, and relate to what could happen, not what does happen in the real world of a model.

On the other hand a "dynamic" MEI is employed in models such that the number of participants, locations, and perhaps effectiveness, are changing over time. That means that a "game" can be played.

Some applications of "static" and "dynamic" indices will be presented.

STATIC

a. Inventory count: The indices are simple sums of numbers of items.

b. Index of Combat Effectiveness and Firepower Potential:

A number that suports to indicate the worth of a combat unit in comparison to some standard unit. In the ATLAS model, for example, the ICE are derived from FPS by knowing the lethal area of a type of round of ammunition and multiplying by an assumed daily expenditure rate for this type of ammunition resulting in a Firepower Potential Score.

c. Based Aircraft Attriting Potentials: The potential of an air force to destroy an opposing air force's aircraft that are on the ground. It is the potential fraction of the opposition's aircraft on the ground that are destroyed beyond repair (K-Kill) in one day when one air force, unopposed by air defense, strikes the opposition's air fields. It is measured in aircraft killed per day by the total number of the oppositions aircraft in theater. The detailed calculations of the index are classified. [Ref. 46:p.39].

DYNAMIC

a. Global Level Models: Global applications of the above notions are conceptualized through, for example, specification of the strategy alternatives in terms of military force size, composition, and world-wide deployment, and political-economics instruments of power such as treaties and trade agreements. The payoff (MEI) must be specific in terms of global national objectives.

b. Theater Level and Battle Level Models: The trade-off variables of interest are total force size, composition of the forces, and deployment and employment of the force composition including the mix lf land, sea, and air forces, and components of these factors such as units of armor, infantry, air superiority fighters, ground attack aircraft, etc. The analysis evaluates the capability of each opponent to achieve selected objectives under varying (dynamic) assumptions relative to the trade-off variables. A NATO-Warsaw Pact military capability consideration is in the above area of discussion.

Can a static MEI approximate the results of a detailed dynamic model? The answer is perhaps, but none has been generally demonstrated with sufficient credibility to justify the index as a sole comparison. On the other hand, static MEI can be useful adjuncts to the dynamic model.

Can a static index serve as a "rule of thumb"? The answer is that no single index to date can be trusted as the sole indicator, [Ref. 46:p.55] but a comparison of several indices can help the analyst and decision-maker develop insight.

At the present time judgement and experience remain by far the most important tools for estimating the relative effectiveness of military forces and the expected attritions.

Cordesman in [Ref. 47:p.201] states:

"Reality tells us that number and quality of personnel dominate the outcome of war. MOEs tells us that time differences in technology dominate computerized sand boxes."

Most high-level decision makers have beeter intuitive judgments about systems effecitveness that most traditional static MEI/MOE designers.

IV. AIR COMBAT MODELS SIMULATION

The purpose of this chapter is to describe the state of the art of air battle models in such a way as to indicate what should be built into, or expected to be available from, a particular air combat model.

However, before starting a detailed discussion of air combat models it will be useful to discuss the ways in which air combat differs from surface combat and, hence, ways in which air combat models can differ from surface combat models.

A. UNIQUE CHARACTERISTICS OF AIR COMBAT MODELS

Surface combat (LAND-SEA) takes place in an environment that is much less homogeneous than is the air environment. For example consider a campaign of moving ground forces located at point "A" to combat point "B". This process could depend on factors such as:

1. The transportation means assigned or available to the moving unit.
2. The intervening terrain.
3. The condition of the road net connecting point "A" and point "B".
4. The season of the year.
5. The climate and or weather.

6. The distance between point "A" and point "B".

7. The amount and type of traffic recently using the road net.

Although some of the factors may have some influence on operating air forces located at point "A" to combat at point "B", in general air forces are much less dependent on this kind of environmental information. One way to characterize this difference is to say that the air as a medium is much less variable and, hence, much more homogeneous.

Another way in which ground battle models are more complex is in the number of elements to be considered. A conventional war in NATO involves only several thousand aircraft and SAMs on each side. For the sake of comparison, the number of crew served ground weapons that would be employed in a ground war in Europe could easily approach one hundred thousand weapons on each side.

A third way in which land combat is more complex than air combat is the degree of inter-engagement dependence. The status of a ground unit at the start of a given engagement is very dependent on the nature and outcome of its previous engagement. The number and type of surviving personnel, weapons, and supplies were determined in the previous engagement. The opportunity to reconstitute these resources depends on the outcome of the previous engagement. Although the posture of a combat unit is a function of the orders it receives from the higher headquarters, the range of possible orders is largely determined by the outcome of the previous engagement. Finally, the terrain on which a unit is currently engaged is determined principally by the location, the nature and the outcome of the unit's previous engagement.

Although some of these factors from a previous engagement may influence the way in which a subsequent air engagement takes place, in general, the air combat process is much less dependent on this kind of prior engagement information.

Another difference in an air battle is the nature of the way in which weapons are employed. Ground forces tend to fight in organizational groups, i.e. a battalion engages a battalion, or a brigade engages a division. So it is appropriate to consider a battalion level combat model or a brigade or division level combat model. This is, in general, not true in case of air combat.

An F-15 wing might be simultaneously engaged in three different parts of Europe in three different kinds of air superiority missions against elements from different enemy air organizations. An A-10 squadron might have one group of aircraft engaged over Northern Germany and another operating in the Southern part. In general it does not make sense in an air combat model to think in terms of wing versus wing or squadron versus squadron.

Another distinction between air battle models and surface battle models is the firing process. Air battles tend to have "point" firing processes rather than "area" firing processes. An aircraft uses its gun by pointing at or leading a target. This is true in air-to-air combat and also in air-to-ground attacks. Contrast this with the surface employment of a minefield, the field-of-fire responsibility of a machine gun, or the area of an artillery barrage. The increasing employment of guided munitions in both air-to-air and air-to-ground missions is consistent with the notion of "point" rather than "area" fire. Furthermore, in surface-to-air engagements, radar and IR-guided surface-to-air missiles (SAMs) and radar-directed gunfire are rapidly replacing anti aircraft barrage fire.

The final aspect of air combat models that is different from surface models is the way in which the major elements are attrited. An infantry company can exhibit substantially different effectiveness characteristics depending on which 10% of its officers and men are killed. A ship may sustain a fatal hit and yet fight on for a substantial period of time. The death process for aircraft is considerably more discrete. The fate of an aircraft hit by a SAM, an air-to-air missile, or a burst of gunfire is much more likely to be two valued, that is alive or dead, than would that of a ship hit by a missile or an infantry company hit by an artillery salvo.

Each of the characteristics discussed, the homogeneous environment, the small number of fire and maneuver elements, the iner-engagement independence, the point fire engagements process, and the two valued kill mechanism tends to make air combat earier to understand than ground combat and, therefore easier to model to an equivalent level of detail.

It has been argued [Ref. 9:p.32] that in contrast to land campaign modeling where an hierarchical structure is required, it is unreasonable for air combat models to map organizational structure into model structure, so another frame work must be introduced. The framework most often used for air combat models involves a structure of an ascending order of complexity and potential learning about the processes involved, namely "one-versus-one", "few-versus-few" and "force-versus-force" models.

1. <u>One-Versus-One Air Combat Models</u>

The most detailed physical representations of the weapon systems in air combat are found at the one-versus-one level. At this level the physics of the aircraft, SAMS, radars, anti-aircraft guns, air-to-air, and air-to-ground missiles are explicitly treated, see [Ref. 48].

In an aircraft, effects such as lift, thrust, drag, angle of attack, airspeed, acceleration and how they all change as the aircraft maneuvers can be explicitly captured. Detection processes can be modeled as a function of on-board avionics, cockpit masking, size of the opponents, radar cross section and IR signature. Often a number of different radar cross sections and IR signatures are modeled as a function of the spatial relationship between the two adversaries. [Ref. 49:p.5-14].

This level of model has its maximum utility in addressing questions of engineering trade-offs. For example, when contemplating the addition of "leading edge" slats to an air-to-air fighter aircraft, one has to consider the disadvantage of the extra weight and drag which is experienced by the aircraft through an entire fight versus the advantage of improved low speed, instantaneous turn rate. This turn rate advantage occurs only in the later stages of the fight when the speeds have decreased considerably. Another example of engineering tradeoffs that can be examined at the one-on-one level is a question of the benefit associated with carrying extra ordnance on an aircraft. Here it is a question of the effect of the extra weight and drag versus the benefit of the extra firepower. It must be considered that in a one-on-one engagement, the additional firepower may not show up to its full advantage as it would in a few-on-few engagement where there are more targets available on which to expend the ordnance.

Care must be taken in one-on-one modeling when treating a single combat element employed alone versus a combat element that is intended to function as part of a system. For example, a strategic bomber may be employed in combat as a single entity whereas a given SAM, that may engage it, is part of a larger air defense system. The element intended for single employment, the bomber, typically has all the faculties available that the military planner felt were necessary to carry out the mission. On the other hand, since the element that is merely a part of the system was conceivably intended to contribute to some synergistic effect of the total system, its effectiveness is understated if it is considered to engage by itself.

A similar situation can be encountered when using one-versus-one models in quantity versus quality comparisons. The "quality" aircraft has more on board capability in general. The "quantity" aircraft may be dependent on the existence of other capabilities inherent in some larger system. In addition, the larger numbers and usually higher sortie rate of the "quantity" aircraft are not captured in one-versus-one models. In general, one-versus-one based analysis will favor the "quality" candidate.

Another area that must be treated with considerable care when using one-on-one models is the way in which the decision-maker in the system is modeled. For example, consider the case of an air-to-air combat where decisions regarding maneuvers against an intelligent enemy are made by a simulated pilot. Similarly, the simulated enemy pilot must also be free to maneuver in such a way so as to adapt his behavior to the combat situation as it develops.

This caveat is often violated in models of surface-to-air missiles versus an aircraft. [Ref. 50]. Typically, the aircraft is constrained to perform a series of pre-programmed maneuvers and is not capalbe of reacting to the maneuvers of the missile. On the other hand, the missile's behavior is modeled so that it can adapt its flight path to the behavior of the maneuvering target. This can lead to inappropriate conclusions. The reason for having a pilot in the aircraft is to get adaptive behavior into the decision making, as opposed to the programmed decision making that limits a surface-to-air missile, regardless of its sophistication.

As stated earlier in this thesis, models can be used to compare one system with another, but difficulty can arise when trying to compute adsolute effectiveness. This is the case when a one-versus-one model is used for computing values for use in higher level few-on-few or force-on-force models. It is essential that the one-on-one model be used in a way that is consistent with the details of the scenario under consideration in the few-on-few or force-on-force models. One factor that must be given careful consideration is the duration of time for which the one-on-one conflict is allowed to continue. Often, the one-on-one simulation is used for longer durations of combat than would be realistic considering the number of aircraft involved in a large scale conventional air war.

In addition to being able to explicitly capture the physics of the situation, another advantage of the one-versus-one model is that it requires less sophisticated intelligence information. The intelligence requirements at the one-on-one level typically involve considerations of physical capabilities of the system employed, rather than considerations of employment doctrine, tactics, training, intentions, and the like. This in itself gives the one-on-one level model a sounder basis from an intelligence standpoint.

Finally, one-versus-one is also the level of modeling where the maximum amount of test data is available for model verification. Often the ability to validate a model against actual system performance in the air is much greater at this level than at any other level of modeling. Because of the restrictive nature of one-versus-one models the kind of questions that can be addressed is somewhat limited. To broaden the nature of the insight that can be gained, it is necessary to utilize the few-versus-few level of modeling.

2. Few-Versus-Few Air Combat Models

As one would expect, the few-vs-few level of modeling is more complicated than the one-on-one level. The basic question that must be answered in the consideration of few-vs-few modeling is how many systems constitutes a few. There are a number of factors influencing this problem. In the case of air-to-air combat, the basic question can be the air-to-air employment concept of each adversary. For example, if the enemy "tactical employment concept" is to use a flight of four aircraft, whereas the "friendly concept" is to use an element of two aircraft then perhaps the few-on-few, air-to-air model should be capable of handling a flight of four aircraft versus two elements of two aircraft each.

It is somewhat different in the air-to-ground role. Whether that role be air-to-ground in strategic or theater level conflict, it is basically the disposition of the ground forces that determines the size of the few-on-few engagement. Consider a flight of four A-10 aircraft attempting to attack targets in a battalion deployed on the ground. The number of the targets that the A-10s can engage in the ground force is influenced by the way in which the targets are dispersed over the terrain. The way in which the ground forces can engage the A-10s is determined by the range, capability, and location of their various surface-to-air defenses. Also how many defenses can engage the attacking aircraft depends upon the tactics employed by the attacking aircraft. If they are able to ingress to the target area and egress at very low altitudes, or if they are able to maneuver sharply, (jinking), in the target area, then fewer of the surface-to-air defenses will be able to engage them or even detect them.

Another way to consider the problem of using the few-vs-few model is to consider the questionof edge effects. For example, suppose the analyst desires to use a model in which four A-10s engage a company of armored vehicles. If the deployment of the ground forces is such that surface defenses from other compaines of armored vehicles are able to engage the A-10s when they are attacking, then the results can be biased considerably by the fact that the analyst ignores the contribution of the defenses of the surrounding companies.

It should be recognized that it is at the few-on-few level that one can first model the synergistic effects that evolve from a well-planned, well-structured defensive system. For example, at the one-on-one level, the tactics that might protect attacking aircraft from being engaged by an SA-6 surface-to-air missile could very well place the attacking aircraft in the heart of the engagement envelope of some other systems in the defensive array of the ground forces. One gets a considerably different view of the effectiveness of the air defense system when one considers it performing as a system.

It is equally true that one gets a different impression of the effectiveness of air-to-ground aircraft when they are abole to engage a system of defenses in a way that is mutually supporting. As the first aircraft "rolls in" to engage the target, the second aircraft may very well follow to engage any defenses that attempt to engage the first aircraft. The synergistics that exist in both attacking and defending forces become apparent in well done few-on-few models.

The intelligence information required to successfully use a few-on-few model is substantially more extensive than that needed for use of a one-on-one model. For example, does an adversary commit his aircraft in flights of two or in flights of four, or in even larger groups? When enemy fighter bombers are attacked, do they jettison their ordnance and run, do they jettison their ordnance and fight back, or do they retain ordnance and attempt to press on to the target regardless of the attackers?

How are surface-to-air missile systems dispersed throughout the ground organization, and how do they engage attacking aircraft? Does the firing doctrine call for firing more than one SAM at the same aircraft? Does it allow for firing a number of different types of SAMs simultaneously at the same aircraft? How do the surface-to-air missile systems and the antiaircraft artillery systems interact in the engagement of attacking aircraft? In short, where the one-on-one level merely required knowledge of engineering details of the systems, the few-on-few level requires knowledge of engagement policy, training, employment doctrine and other more sophisticated intelligence information.

The question of command and control becomes relevant at the few-on-few level. How are defenses internetted? For example, how many Transporter Erector Launchers (TEL) are assigned to each acquisition radar? Does each TEL have its own tracking radar? How is the C3 system connected? How are orders passed along the communications net? How does the C3 system degrade as part of it is destroyed or if communications are jammed? All of these questions become important when one is considering modeling at the few-on-few level. As a practical matter, it is beneficial to design the model so that whatever connection scheme is used among the elements in the ground forces, it can be represented by entering the appropriate data into the model.

Once one introduces the notion of command, control, and communication, then the entire question of countermeasures becomes important. For example, the use of electronic countermeasures to jam radars, the use of missiles to destroy acquisition or tracking radars, the use of communications jamming to force the SAMs and other defenses to behave autonomously all become a consideration at the few-on-few level.

The decision process, although present at the one-on-one level, is particularly complex at the few-on-few level. [Ref. 51]. In the case of air-to-air combat, the simulated pilots must react based on information from preflight instructions, from flight and element leaders, and from their own sensors. In addition, it is reasonable to expect they would process this information in accordance with how the fight was going. For example, if the fight started out with four aircraft on each side and one side is down by two aircraft because two have already been destroyed, it would be reasonable to expect the decision making of the two surviving pilots to be considerably different than it was when things were equal.

Another complexity that is introduced for the first time in the modeling process at the few-on-few level is the question of what is the appropriate MOE. In air-to-air combat, one could consider the number of friendly aircraft lost, the number of enemy aircraft lost, the fraction of friendly or enemy aircraft lost, the ratio of friendly to enemy aircraft lost, etc.

The problem of MOE is also complex when one considers modeling few-on-few air-to-ground combat. Should the MOE be the number of tanks killed, or the number of armored fighting vehicles, which includes not only tanks but also other vehicles? Should the number of surface-to-air defenses that are destroyed be part of the MOE? In addition, if some subset of the vehicles assigned to the organization is to be construed as the MOE, then one must consider the degree to which the attacking aircraft can ascertain the difference between a tank and an armored personnel carrier and a truck or a SAM at the range which their weapons are employed. Care must be always be exercised in considering the way in which the MOE chosen influences the conclusions that one can draw from using the model to produce an analysis.

The final aspect of the discussion of the few-on-few modeling is the question of how the model can be validated. Model validation for few-on-few is considerably more difficult than it is for one-on-one because of the shortage of data. However, in recent years, the use of instrumented ranges and realistic scenarios in training and testing exercises by the Air Force (USAF) has generated considerable data. Exercises like RED FLAG have generated data that can be used to validate models and to promote their use in gaining insight into processes involved in few-on-few combat.

3. Force-Versus-Force Air Combat

Force-versus-force, or as they are sometimes called, campaign level models, represent the upper level of a hierarchically structured group of models. The force-on-force model typically depends for its fidelity on the detail captured in the supporting one-on-one and few-on-few models. As a result of this fidelity, there are a number of questions that can be examined using the force-on-force model. The first of these questions is the quantity/quality question. Since one-on-one and few-on-few models typically involve equal numbers of aircraft systems, it is difficult to gain insight into the quantity/quality question where quantity predominates because it is cheaper. In addition, the implication is that the "quantity" airplane has fewer subsystems and, hence, can be employed at a higher daily sortie rate. As a minimum, the force-on-force level model should have sufficient fidelity to capture the essence of the quantity/quality question.

Another form of question that can be examined using force-on-force models is the appropriate force mix once you have decided upon the individual elements. In a strategic strike force, how many B-52 penetrating bombers, B-52 stand-off cruise missile carriers, and B-1 bombers should be included? Typically, this is studied by defining the force mix to be considered and then comparing the effectiveness of that force mix with some other equal cost mix. In the theater force situation similar analysis using force-on-force models is done to determine the mix of air-to-air specialized, air-to-ground and general purpose systems.

The reason that these questions can be examined using force-on-force models is that the question can be addressed using results that have relative rather than absolute validity. Furthermore, it is well to remember that force-versus-force models cannot be legitimately used to gain insight into question of how much is enough because of the absence of absolute validity not only at this level in the hierarchy but also at the one-on-one and few-on-few levels.

Although a number of important insights can be gained by analysis using force-on-force models, there are some serious problems associated with their use. The first of these problems is the amount of intelligence information that their use requires. Considerable detail concerning the scenario is required beyond the traditional questions of numbers of weapon systems and initial location of military organizations. Whereas the one-on-one level and the few-on-few are basically involved with questions of physical and tactical intelligence data the force-on-forece level requires insight into the strategic philosophy and strategy of the opponent. These very "esoteric" considerations do not appear in the intelligence literature with any consensus in the community.

Another problem involved with the use of models at this level is that regarding the duration of the combat to be modeled. The longer the period considered by the model, the harder it is to retain thefidelity of the model. For example, as a war progresses adaptive tactics evolve. Pilots on both sides attempt to deal with the realities of the combat they are experiencing by adaptive behavior. In short, they learn. This is a difficult characteristic to model. In addition, in a longer duration combat there is the question of changing the role of the forces. After the initial three or four days in a conventional war, the general purpose fighters may be removed from the air-to-air role and reemployed in the air-to-ground role. The ability to perfrom this reassignment in real life is quite a bit more complex than is typically captured in the modeling.

Duration of combat also has a strong influence on the amount of detail required in the air base, supply, and maintenance systems of the force-on-force model. For example if only a few hours of the war are to be modeled, then on the average not more than one sortie can be flown per aircraft, and details of the supply and maintenance systems are not required. However, the aircraft shelters and revetments and the air base runway must be modeled. Since the airfield's ability to generate sorties will be a function of how well these facilities survie the attack.

If the combat is to last more than a few hours but less than about four or five days, then much more of the air base detail must be modeled. This includes at a minimum, aircraft and maintenance shelters, runways, maintenance hangars, fuel, ammunition and spare parts. Once again, these resources should be put at risk to enemy attacks. The ability of an airfield to generate sorties should be a function of how successful the attacks are. The upper limit of four or five days depends on how many spare parts and how much consumables are assumed to be on the air base at the time of the attack, together with the consumption rate of these resources.

If the combat duration is to last more than four or five days, then the amount of logistics infrastructure modeling required increases "exponentially". Ammo and fuel dumps, supply depots, maintenance and battle damage repair facilities, transportation nets and even computer facilities on which supply systems are so heavily dependent could all have a major effect on sortie rate. Logistics pipelines must be at risk to enemy attacks, and the ability of the e.g. NATO system to generate combat ready sorties must depend on success of those attacks. Very few, if any existing force-on-force battle models include these considerations.

Arguments concerning duration of combat have been couched in terms of theater force scenarios. Obviously they also hold for models involving strategic missile and bomber forces, although the time constraints for which more infrastructure detail is required are likely to be different.

Another important aspect of force-versus-force or campaign level modeling is homogeneity of detail. In the modeling process, the model builder decides which elements of the process are important and includes them, while excluding those elements that are construed to be unimportant. Once an element is included for consideration in the model, it is important that it be treated at the appropriate level of detail, so as to not gloss over its true impact on the combat process. This question of homogeneous level of detail is very judgemental, as is the question of which characteristics of the combat process are important enough to be included in the model and which are not.

At the few-on-few level, the idea was introduced that the decision concerning the MOE is a complicated one.

This problem is an overwhelming problem at the force-on-force level. Consider the question of the effectiveness of strategic nuclear forces employed against the Soviet Union. There are a number of MOEs available such as hard target potential, equivalent megatons on target, or fractions of target base destroyed that could be used as the measure of evaluation. Each of these MOEs has associated specific shortcomings and advantages. The problem is to understand the way in which the MOE biases the outcome obtained using the model.

The same problem is there when analyzing force structure at the theater level of conflict. One traditional MOE is the number of aircraft killed on each side, or the number of armored fighting vehicles destroyed on each side. It may be considerably more important in conventional theater conflict to consider the degree to which the adversary's ability to deliver nuclear weapons has been reduced. This addresses his ability to escalate to the nuclear level, and indeed his propensity to cross the nuclear threshold in the first place.

Although this section is devoted to considerations of air combat models at the force-on-force level, it is often necessary to combine an air combat model with a ground combat model to capture the constribution of air to the ultimate measure of that contribution, the prosecution of the ground war. All of the difficulties that have been addressed previously concerning the greater complexity of ground combat, should be considered. In addition, the analyst must be concerned with the sensitivity of the gound battle model to timing and maneuver, not just to fire power. For example, a tactical fighter force can be employed in the morning in the North German front and in the afternoon in the South German front. Such an employment flexibility can only be captured in a combat model that correctly treats the maneuver of forces as a function of time.

The problem arising from the marriage of air and ground models at the theater level is most severe for the close air support (CAS) and battlefield interdiction (BI) missions. These missions represent an important linkage between the air and ground battles and as such require careful consideration by the modeler. This is particularly true in the situation where two battle models which were developed separately are then joined at some later date. The linkage question can also be a problem when a model was built as either an air or ground model, and then the other portion was added later.

Timing problems can arise from the linkage of air and ground battle models. The time constants that characterize ground force movement, engagement of ground forces, and reconstitution of ground forces tend to be longer than the time constants that describe these same processess for air forces. If a ground battle model is built to account for the slower ground processess, it may not be able to reflect adequately the fact that during the course of one ground engagement the air forces may have engaged, reconstituted and reengaged three times.

In one ground battle model that has been used for some time, the targets destroyed by CAS and BI sorties were removed from the ground order of battle once every 24 hours, at midnight. Targets destroyed by ground forces were removed at the time the destruction took place. This approach severely understates the responsiveness of theater air forces. The approach was used as a simple modeling solution to the problem of double killing of targets, i.e. having a CAS sortie attack targets killed by ground fire (which may occur to some degree), or ground forces attack targets killed by CAS sorties (which may occur to some degree). This highlights the tendency to model some of these complex command and control processes with convenient but overly simple modeling techniques.

A further complication along these lines concerns the question of allocation of CAS and BI sorties to various locations across the theater. The linkage between ground and air combat models usually requires the development of some set of rules for allocating CAS and BI sorties to various parts of the battle. In general, it is best to avoid allocation rules that are based on planning factors. It may be appropriate to plan to provide a certain number of CAS sorties for each engaged division, or for each kilometer of front line. However, to use these planning factors for allocation decisions seriously understates the ability of air forces to mass in the air battle model in order to respond to developments occuring in the ground battle model. It is much more realistic to have the air resources allocated as a function of the progress of the ground battle.

4. Very Aggregated Air Battle Models

It is true that proceeding from one-on-one to few-on-few to many-on-many has inherent in it an aggregation process, i.e. as one goes up the hierarchy, one sacrifices a level of detail in order to consider broader aspects of the process. There is often a tendency to want to go one level above the force-on-force or many-on-many level to what can be considered very aggregated air battle models. Often this process is accompanied by the use of some optimization algorithm that varies the employment decisions in such a way as to optimize some MOE. This may be done in a static way or it may be done over a period of time as in the dynamic programming approaches that are used at this very aggregated level of modeling. Often the entire theater war, including air and ground battle, will be reduced to three or four variables describing each side. This would appear to be too high a level of aggregation to give any insight into the process.

Another example of overaggragation at the high level of modeling concerns use of Lanchester equations to describe campaign level combat. The difficulty is that the form of the model drives the results in a way that, often, does not reflect the reality of the combat situation. For example, those conditions that must be satisfied to use the "linear law" are generally not satisfied in the air-to-air combat. Those hypotheses necessary to use the Lanchester "square law" are, typically not set in air-to-air combat either with the possible exception of beyond-visual-range engagements among aircraft that have radar missile capabilities.

Yet Lanchester-type models in this very aggregated way will probably determine the outcome. For example, in a quantity/quality comparison the "linear law" favors the quality system, whereas the "square law" favors the quantity system. Even though neither choice reflects the realities of the combat situation and the hypotheses necessary to derive the model, the outcome follows predictably and automatically.

Perhaps 10 or 15 years ago substantial insights could be gained by using these very aggregated models. But air combat-modeling has progressed beyond the stage where new insights are to be gained from modeling the attrition process in this elementary way. It is conceivable that processes and models that were less well studied, such as command and control processes, reconnaissance processes, and decision-making processes, may benefit from some highly aggregated study. This suggests that the appropriate role for these highly aggregated models is diagnostic: i.e., to guide the analyst and model builder toward the proper construction and employment of force-on-force level models, rather than to an analytical product which is credible in itself.

B. AIR WARFARE

1. Doctrine of Tactical Air Operations

In the first paragraph of this thesis the doctrinal mission of the Tactical Air Operations is stated. A broader approach will be attempted in the present section to orient the future modeller-analyst in understanding and modeling the problems of Tactical Air Campaigns.

The air campaign involves many missions that go far beyond air combat to include those of aircraft in ground support and attack and of ground weapons opposing them.

Surface operations depend upon friendly air operations to create and maintain a favorable environment for land and sea forces to exploit their mobility.

The flexibility and firepower of tactical air readily enhance not only land forces but also naval forces. Tactical air may be employed in concert with, or act independently of, friendly naval units to secure and maintain sea lines of communication and to deny the use of the sea to the enemy.

2. The Missions

For continuous operations, air superiority is essential. Sea operations conducted adjacent to areas dominated by enemy air forces require action to gain control of air.

Success in any armed conflict may require tactical air forces to perform operations of:

1. counter air
2. close air support and
3. interdiction operation

simultaneously with limited assets. Intelligence, derived from reconnaissance, surveillance and other sources, must provide warning, permitting decision makers to apply tactical air power in the most efficient manner. Aerial refueling, electronic warfare, defense suppression, special operations, tactical airlift, airborne warning and control, and search and rescue operations are capabilities that enhance the flexibility and survivability of tactical air power [Ref. 1:p.3].

How these forces are integrated and employed will determine the effectiveness of tactical air power. Command, control, communications, intelligence and interoperability will provide the essential mechanism to integrate and employ the forces.

Figure 4.1 from [Ref. 1] presents the existing doctrinal integration of US Tactical Air Forces. The author points out the omission from the chart of the Tactical Support Maritime Operations (TASMO), but that is due to different organizational structure of the US Armed Forces, planned to operate in a "global" environment, in comparison to other Air Forces which are called to operate in smaller scale environments.

Analyzing the above doctrine of employment of the Tactical Air Force we see that it involves many missions. Trying to design models to aid in making weapons choices and force structure decisions, as well as force employment concepts for a given force structure is a highly complicated process.

However, it must not be lost sight of that, while aircraft must attack each other and defend themselves, their primary reason for being (in theater warfare) is to support the ground forces, and the ultimate measure of effectiveness is ground attrition, especially of tanks and other vehicles killed in CAS and battlefield interdiction.

This is incidentially, institutionally difficult, in the Air Force pilots become aces for shooting down planes, not shooting up tanks. Nevertheless, aircraft do not take and hold territory.

If the basic objective of Tactical Air Force is to support the ground forces, the above comments suggest the extensive complex of roles played by TAF in achieving this objective.

Clearly, the struggle for air superiority is a dominant theme. Douhet [Ref. 9:p.v-2] perceived almost 65 years ago that if "command of the air" could be achieved, the Air

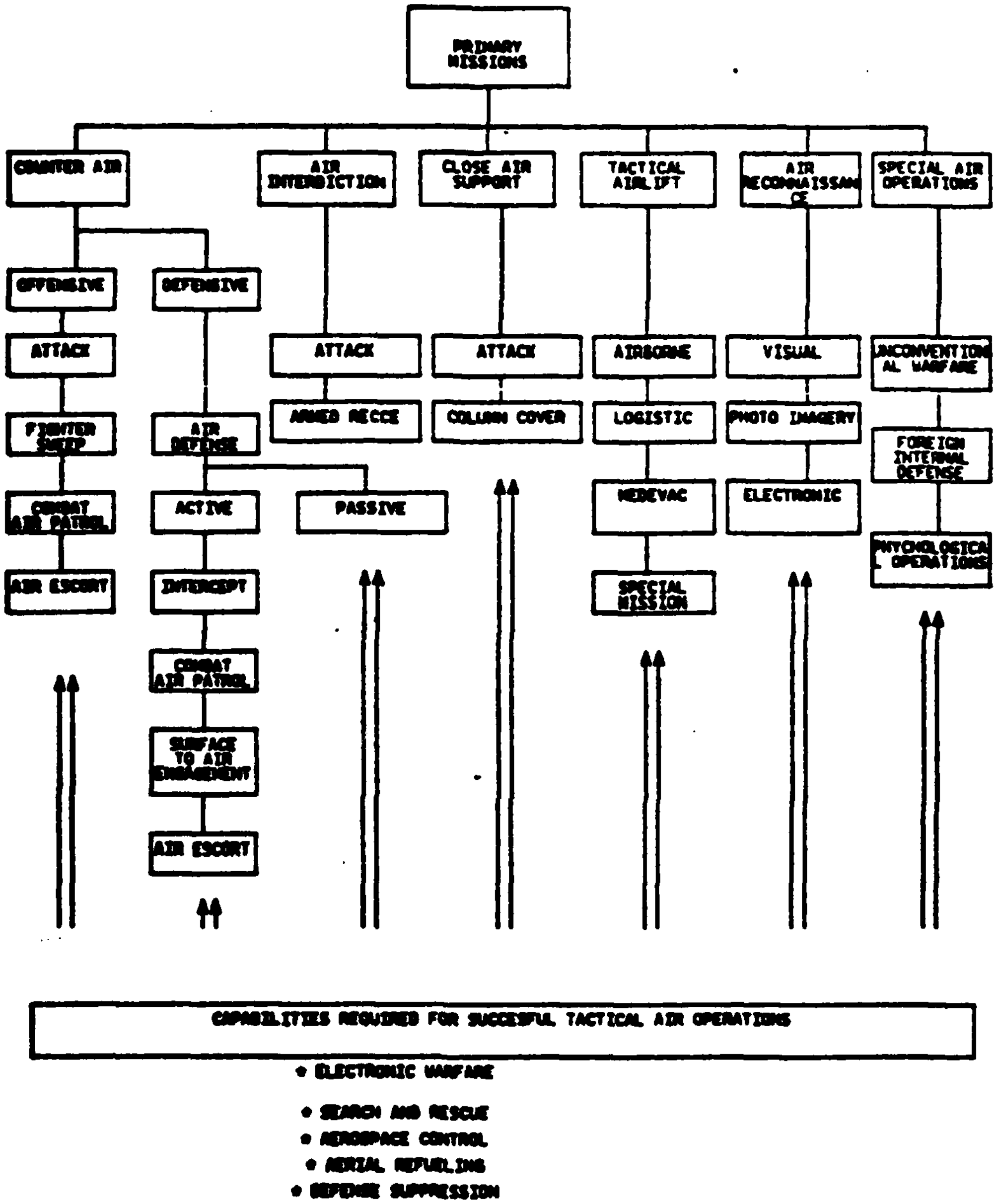

Figure 4.1. The Integration of Tactical Air Operations

Force would then be free to attack ground targets unimpeded. At that time, his scenario was understood by one side which prepared to achieve command of the air, while the other side did not. One assumes today a mutual perception of the problem in a similar way by all the sides.

In the first place, ground support may mean CAS at the FEBA or combat area (since the FEBA is likely in the future not to be of the classic linear and well-defined form) as well as to the rear. The above includes water territory in the notion of ground support.

How far in the rear is a good question. For a few tens of kilometers back, the flow of new material toward the front provides a potential class of targets that will affect the battle in hours or days. Farther back, staging areas, ammo dumps, dispersed vehicles, repair depots, bridges and other transportation nodes, etc. are targets the destruction of which can affect the battle in days to weeks. Deeper interdiction can attempt to prevent longer-term reinforcement and indeed to destroy the base of both support and morale on which any army ultimately depends.

The menu of ground targets is, then rich. But the choices cannot be made solely in terms of predicted impact on the ground battle, a difficult and uncertain enough task in itself.

Given that resources are scarce, and virtually fixed from the point of view of the commander of a battle, every use of an aircraft is at the expense of some alternative use. CAS means less interdiction to the rear. Both mean less defense versus enemy CAS and interdiction, less suppression of his defenses (destruction of ground defenses, C3, and air bases, and less resources with which to defeat his aircraft in combat.

This is an opportunity-cost view of the trade-offs. These trade-offs can also be looked at in terms of their synergistic effects. The more successful the defense suppression and achievement of air superiority, the easier and more successful will be the CAS and interdiction missions, and the less successful will be the enemy in these misssions.

Every planner and commander assumes that the answer to the choices above is a MIX, of missions and equipment [Ref. 9:p.v-4].

C. SQUADRON'S PERFORMANCE SIMULATION

The following clarifications and mainly the associated flow chart in Appendix "A", presents very briefly a simulation logic of how a combat squadron may be simulated or evaluated during its mission interactions, and as a result of this evaluation one may conclude about the overall performance of that type of weapon system.

The flow of logic focuses on how one will predict a manned aircraft's weapons systems performance in the level of an attack squadron under a variety of mission conditions.

Figure 4.2 presents the possible interactions in a similar modeling process according to a scenario. The scenario has to establish the time and sequence of the

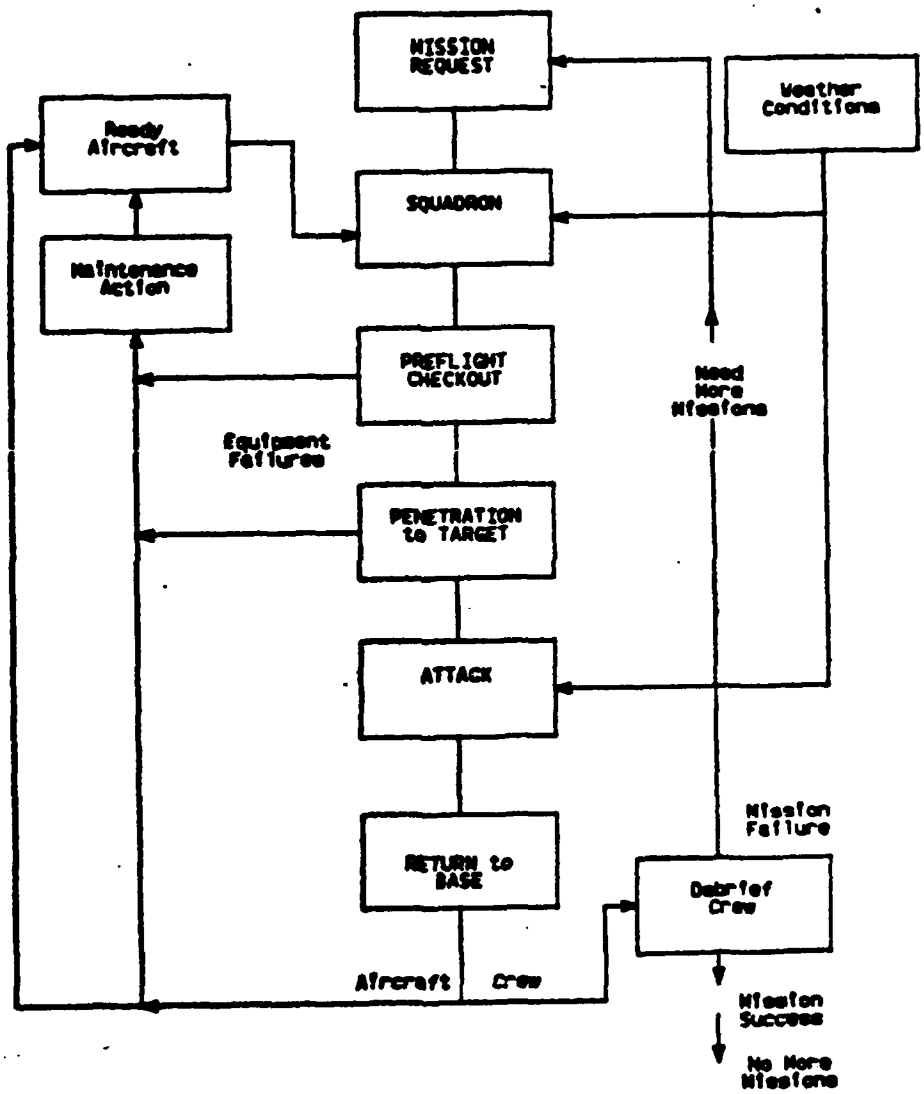

Figure 4.2. Overall Logic of Interactions

targets to be attacked. The performance of a manned tactical-attack aircraft varies considerably with the nature of the targets, the surrounding terrain, enemy defenses, weather and operational techniques, just to rename some of the factors.

The fundamental parts a modeler can consider in this kind of modeling-simulation are:

1. Operational Regime: The intended mission types for the specific weapon system, considering target characteristics and enemy defenses, mission frequency, number of aircraft deployed, and aircraft characteristics.
2. Effectiveness measure: The criteria to measure the performance of the system, the number of targets eliminated, and the cost in men and material.
3. Support concept: The support activities, ranging from those directly tied to the aircraft rearming, refueling, and servicing, to the logistics pipeline with associated costs and time factors.
4. Limited resources: Solutions to problems like this are obtained much more readily if the system is assumed to have everything necessary when needed. Unfortunately this is not true in almost any case. The number of aircraft in the squadron, number and skill of support personnel, spares, and amount of support activities are all limited.

5. Tie-in with Existing Systems: These could range from the skill of the flight crew, based on their level of training, to the logistics support concept employed and repair at the squadron level versus replacement.

The interlocking "submodels" as a general guideline are shown in Figure 4.2 also and are the following:

1. Targets to be eliminated in the form of mission requests with the characteristics of anticipated mission profiles.
2. Maintenance of the aircraft by the squadron environment with replenishment activities and support resources.
3. The individual aircraft flights composed of penetration to the target, attack, and return to base.
4. Evaluation of mission-either elimination of target or the requirement for another mission to continue the attack.

These five fundamental parts as well as their interactions can be combined in an almost infinite number of ways. This is why a scenario is necessary. The scenario will establish the time and the sequence the squadron will eliminate the targets. Furthermore a control will be maintained to output characteristics of important situations.

The overall performance will be measured in terms of availability, dependability, and capability.

The mission may be subdivided into phases of the mission like: Preflight, Penetration, Attack, Return, Landing, and Mission Evaluation. In turn each of these mission phases can be remodeled and reevaluated in accordance to system analysis needs.

Appendix "A" provides an overall view of the suggested simulation process.

V. ICARUS AIR COMBAT MODEL

In this part of the thesis a demonstration model, named ICARUS, will be described. The purpose of the model is not to solve any real world situation or to be an example of an "ideal" model but to give some insight to the beginning analyst concerned in air combat modeling.

A. GENERAL MODEL DESCRIPTION

ICARUS is a highly aggregated two-sided deterministic simulation algorithm comprised of interaction equations which utilize the allocation of aircraft to various missions (MIX) to obtain the outcome of offensive vs defensive Air Force engagements. The algorithm is based on study of more than 20 Theater-Level models but specifically on the LULUJIAN-I, general non-nuclear warfare model developed by WSEG, see [Ref. 52]. It can be used as a basis for a computer simulation program to train student analysts in air combat modeling and the associated issues.

The theater of operations involves two sides with their respective air forces. Figure 5.1 provides a general representation of the forces and the types of interactions included in this model.

Each side has four forward operating bases which are vulnerable to attack by the opponent. Aircraft replacement and supplies are generated from a sanctuary base located in

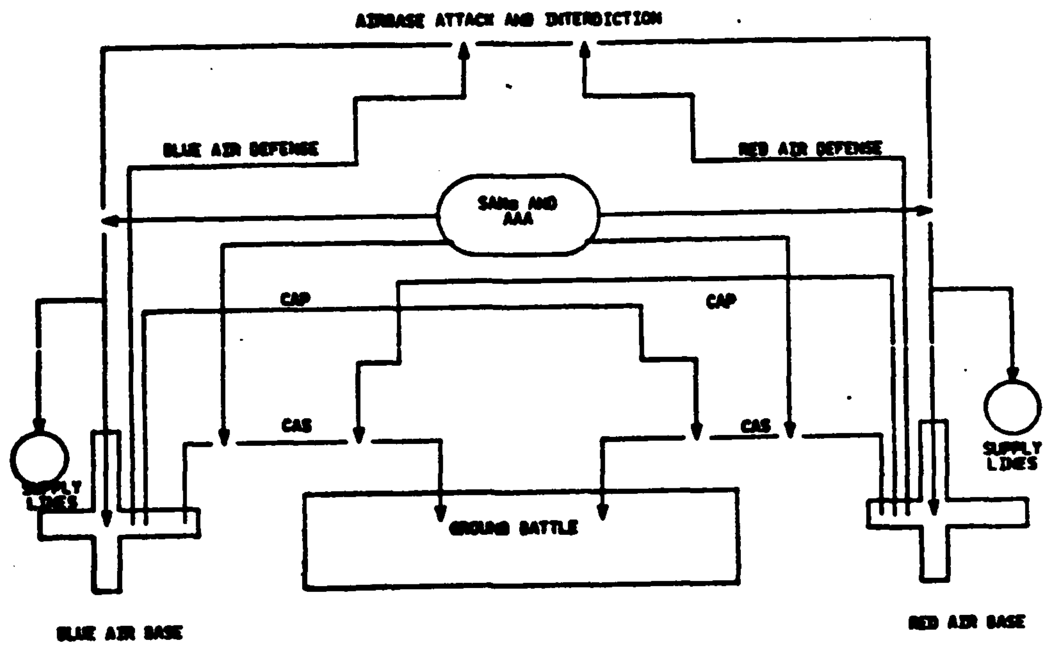

Figure 5.1. Depiction of ICARUS Air Operations

the rear of the sector. The sanctuary base is assumed to be invulnerable to attack.

The theater of operations is divided into two well defined territories by a line called FEBA (Forward Edge of Battle Area).

For the most part, ICARUS is a "pure" Air Operations model which excludes interactions with the other branches (Army-Navy) not because that is "tactically real" but in order to simplify the model. A reference to the FEBA will indicate interactions with enemy ground forces.

The ground forces are defined in terms of homogeneous divisions with no distinction between armored, infantry, or tank division. The primary purpose of the RED side is to occupy territory while BLUE's goal is to slow the rate of movement of the FEBA as much as possible.

The direction and rate of movement of FEBA depends upon the relative strength of the opposing forces.

The supply system initiating from the sanctuary area is modeled as pipeline running toward the FEBA. This supply line is under the influence of enemy interdiction attacks which would reduce the rate of "spare supplies" on the specific day.

The ground forces defend against attacking aircraft by AAA, and SAMs.

The Air Forces consist of four types per side as follows:

A multi-purpose fighter

A restricted attack aircraft

A special close air support aircraft

A special mission aircraft

The multi-purpose fighter is able to perform most of the tactical air operations missions while the rest are limited to a particular role (bomber or attack). The special mission aircraft is capable of sophisticated reconnaissance.

The decision makers, users RED and BLUE, can allocate eight (8) air missions provided for in the model:

1. Air Base Attack (ABA)
2. Interdiction (INTD)
3. Reconnaissance (RECCE)
4. Combat Air Patrol (CAP)
5. Close Air Support (CAS)
6. Air Defense (AIRDEF)
7. Defense Suppression (DEFSP)
8. Escort (ESCORT)

A brief discussion will be given concerning the notion of the missions mentioned above and a detailed analysis will be presented in the Air War section.

In the ABA mission, see Figure 5.1, offensive strikes are aimed at enemy air bases to destroy enemy aircraft on the ground, patroleum (POL), munitions, and to disrupt operations of the airbases.

The purpose of the INTD mission is to damage, destroy, or delay logistics support for enemy ground units engaged in battle. Successful INTD missions will create a delay in arrival of resupplies and will also reduce their quantity.

The RECCE mission improves the accuracy of information about enemy airfields and ground forces. Flying RECCE missions against a target will give information about the status of supplies and logistics located at the target.

CAP missions attempt to gain and maintain air superiority over the main battle area. These missions will tend to increase the effectiveness and reduce the losses of CAS.

The CAS missions attack enemy ground units engaged in combat with friendly forces. They have two principal effects. First, they produce causalties among ground units, and second they influence the movement of the FEBA by causing causalties, disrupting coordination, and slowing troop movement.

The AIRDEF missions are aircraft on alert at designated bases and are used to protect that airbase from attack. In addition, they protect territory behind the forward defenses from enemy aircraft which have penetrated the missile defense zone.

DEFSP missions are designed to destroy or suppress enemy ground-to-air defenses by clearing corridors for subsequent penetrations by aircraft on INTD or ABA missions.

Escort missions accompany primary mission aircraft, such as ABA, and engage enemy interceptors. These missions are part of a "mission package" concept or the so called "Joint Combined Raids" (JCR) used by the United States Air Force (USAF) in which attack aircraft (strike) are accompanied by properly configured escort and defense suppression aircraft. These escorts will reduce the losses to the primary mission aircraft from enemy interceptors and ground defenses.

However, the "cost" is in terms of what one must sacrifice to provide the escort package.

a. Assumptions

The following assumptions are made in this model:

(a) The conflict is a conventional war. Nuclear or chemical weapons are not modeled.

(b) Intangible quantities such as leadership and training are equal for each side and are not treated.

(c) Weather is not treated.

(d) Different types of munitions are not considered.

(e) Command, control, and communications are not a factor.

(f) Air refueling, search and rescue, and aircrew training are not modeled.

(g) No distinction is made between a daylight cycle or a nightime cycle.

b. Limitations

This model is intended to be an educational tool, and is not meant to give real world results. Data contained in the model are either fictitious or from unclassified published models. Many of the details of war gamming are deliberately suppressed in ICARUS since it is not meant to be an explicit representation of real-world events. However, the model should allow the reader to gain insights into the critical elements which must be considered in an effective air campaign.

1. Tactical Air War Module (TAWM)

The TAWM consists of logic and engagement equations describing the various missions and allocations of tactical combat aircraft in theater operations. The features of the TAWM are:

*Four aircraft types

*Four mission bases

*Air-to-air interactions modeled as "many-on-many"

*Penetration of barrier, area, and point SAMs and AAA

*Interdiction of aircraft in shelters and in the open

*Attrition of aircraft

*Effective sorties by type and mission

A standard force is assumed built into the model to provide each side with four different types of aircraft. Each type possesses its own performance characteristics and capabilities reflected in a "destructive index" for that type. In general the BLUE side possesses more effective aircraft systems which can counter the numerical advantage of RED's ground forces if they are employed effectively. The user may change the standard numbers to his will.

The four types of aircraft are distributed at four airbases lying 300 kilometers behind the FEBA. Prior to the start of each day's activities, there is an opportunity to rearange the "order of battle" by allocating the aircraft available from one base to another.

One major decision is the percentage of support for the ground forces to be allocated; the user can do that according to his own estimate of the situation.

Aircraft may be allocated only to missions they are capable of. Table IV list the mission capabilities for each aircraft for each side.

The air defense of a particular base must be performed by aircraft located at the base. For example if BLUE has 20 F-4 aircraft at base 2, he can not allocate more than 20. If he decides to allocate more, he has to deploy aircraft from other bases before or at the start of the operations. Once both sides have finished allocating forces the model will calculate the losses and provide a quantitative assessment of the air missions.

Although it is desirable that the model's outcome is credible, primary emphasis is given on the effect of strategy and employment tactics on the total outcome of the battle.

B. THE ANALYTIC METHODOLOGY AND LOGIC

Now a more detailed presentation of the included tactical air missions of the ICARUS model will be given.

1. Air Base Attack (ABA)

The air base attack sorties have been one of the most effective methods of countering enemy air forces. They impact upon an opponent's air field by destroying aircraft

TABLE IV

Aircraft Capabilities

BLUE AIRCRAFT

TYPE OF AIRCRAFT	SPECIFIC MISSIONS	BUILT IN STANDARD FORCE SIZE
B1	INTD CAS	130
B2	ABA RECCE INTD CAP CAS AIRDEF DEFSP ESCORT	381
B3	ABA INTD CAS	89
B4	RECCE	73

RED Aircraft

TYPE OF AIRCRAFT	SPECIFIC MISSIONS	BUILT IN STANDARD FORCE SIZE
R1	ABA INTD CAS DEFSP	123
R2	ABA RECCE INTD CAP CAS AIRDEF	112
R3	ABA RECCE INTD CAP CAS AIRDEF DEFSP ESCORT	140
R4	RECCE	19

on the ground and disrupting base support facilities such as runways, taxiways, or maintenance facilities. All of these actions serve to reduce the enemy's ability to generate sorties. However, several defensive measures are employed to minimize the impact of air base attack. Aircraft shelters and revetments protect aircraft on the ground. Improved surface-to-air missiles (SAMs) and a effective deployment of anti-aircraft artillery (AAA) have posed a serious attrition threat to air base attack aircraft. As a result of these defenses, a complex set of strategies is available to the attacker in terms of "mission package", protecting the main strike force with escort and/or defense suppression aircraft. The ICARUS air model is designed to reflect the impact of "mission package" on the outcome of the battle.

The treatment of the air base attack mission in the ICARUS model is oversimplified. The computations are based on highly aggregated interactions between the two opposing forces. Aircraft shelters and revetments are not treated in the model. However, AAA, SAMs, and attrition due to AAA, SAMs, and air defenders is calculated. A general flow of the attack mission is depicted in Figure 5.2.

Treatment of the attrition from AAA and SAMs embodies a relative static and predictable array of defenses. AAA loss rate are considered to be the same for all aircraft, and all aircraft must penetrate the coverage of these weapons. SAM units are deployed in two locations, along the FEBA and in the area between the FEBA and the airbases.

Suppression aircraft reduce the number of SAM sites available to fire missiles at the attack force.

Attrition due to air defenders is dynamic (stochastic) since the probability of kill depends upon the size of the opposing forces.

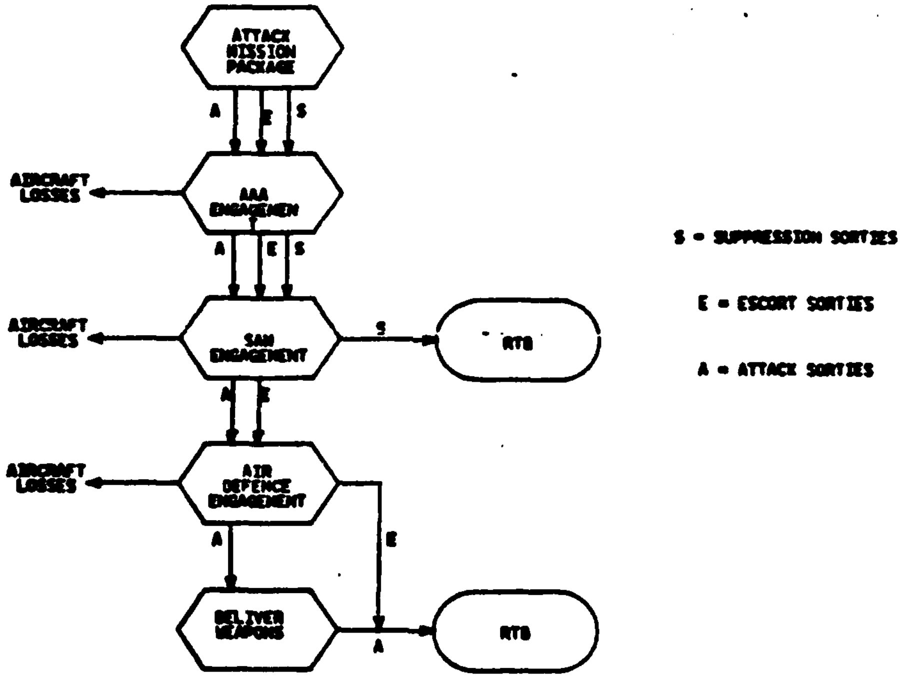

Figure 5.2 Mission Package Flow Sequence

The maximum number of aircraft which each airbase can support is initially input as data. As the base status is reduced by repeated airbase attack sorties, the number of aircraft which the base can support is proportionately reduced. The amount of reduction is a function of:

The "Effective Sorties" which can reach the bases and the "Operational Index" for the types of aircraft which attack the base.

"Effective Sorties" are defined as those attackers which survive the AAA and SAM threats and are not detected and engaged by the defenders. Attackers who are detected and engaged by air defense aircraft are assumed to "jettison" (drop) their bomb load. Those attackers detected and engaged have some probability that they will be shot down by the defenders.

The "Operational index" is defined as a figure which expresses the amount of contribution per aircraft type, sortie numbers, and mission type (CAS-ABA) to reduction of the functional ability of the target (Base) to support further. In Table V, the data presented are arbitrarily assigned and the analyst may adjust them to different values if desired.

a. Interdiction (INTD)

Interdiction missions attempt to damage, destroy, or neutralize support and logistics received by enemy ground units. Destruction of POL and munitions in the logistics pipelines has more immediate effect on the level of intensity of the conflict than the destruction of command and control facilities.

In the model the interdiction sorties may be split into two components: those that attack air base supply routes and those that attack army supply lines. Interdiction sorties are subject to the same threats experienced by the air base attack sorties. The model will react to successful interdiction sorties against a logistics line by reducing the number of spare parts which the base can receive from the sanctuary depot.

In a similar manner, the model will react to successful interdiction missions against the ground forces by either slowing or accelerating the "rate of advance" or the FEBA.

TABLE V

Operational Index for Aircrafts vs Missions

"OI" for CAS MISSION

TYPE	INDEX
B1	.0003
B2	.00015
B3	.0003
R1	.00015
R2	.0001
R3	.00015

"OI" for ABA MISSION

TYPE	INDEX
B2	.002
B3	.003
R1	.0015
R2	.001
R3	.002

b. Reconnaissance (RECCE)

Accurage intelligence is essential in the successful conduct of an air war especially since resources are limited and attrition is high. Maximum efficiency from limited capability can only be achieved if the information on which decisions are based is timely and accurate.

In ICARUS, information about the status of enemy air bases and ground forces may be obtained through the use of reconnaissance missions. These sorties have no damaging effect on enemy status but are capable of defending themselves if attacked. In order to obtain RECCE information about a particular target, at least one RECCE sortie must survive. For example, if 4 RECCE aircraft were sent against an airbase, and none of them survived, no intelligence information would be available for the status of that base. However, if even one of them returns, the status of the target would be available.

c. Defense Suppression (DEFSP)

Defense suppression missions suppress and destroy enemy ground-to-air defensive in the vicinity of the ground combat zone and the area between the FEBA and the air bases. Aircraft allocated to this mission will reduce ground-to-air losses of other mission aircraft. Employment of suppression aircraft will open a corridor for the attack aircraft to penetrate ground defenses. However, by allocating aircraft to the suppression mission, a commander is using aircraft which might be used for one of the other missions (CAS, ABA, etc).

The model views the suppression aircraft as preceeding the main attack force to clear a corridor for these aircraft (see Figure 5.2). The number of SAM sites encountered by the main attack force is less than the original deployment of SAM sites because of SAM site suppression. This is calculated by the model by modifying the expected number of SAMs shot at each aircraft by the fraction of SAM sites surviving suppression.

d. Escort (ESCORT)

Escort sorties accompany the primary mission aircraft to the target and engage enemy interceptors. Escorts are used as part of a mission package along with defense suppression in an attempt to counter enemy defenses. The cost is in terms of what one must sacrifice to provide the escort package.

Allocating aircraft to the escort missions in ICARUS will reduce attacker losses due to air defense aircraft. Escort missions can be assigned to accompany the deep penetrators (ABA or INTD) an the interdiction of the Army's supply lines. Each escort sortie reduces the effective number of enemy air defense sorties according to a simple subtractive rule. The use of escort sorties is examined more closely in the section on aircraft losses.

e. Air Defense (AIRDEF)

Air defense sorties may be split into two components: Those that are deployed forward near the FEBA (CAP) and Those that are used for defense of the rear areas (AIRDEF).

CAP missions attempt to gain and maintain air superiority by attacking enemy aircraft which enter the forward combat zone surrouding the FEBA. They are used primarily to protect friendly ground forces from enemy CAS sorties and army logistics lines from enemy interdiction. AIRDEF missions are normally on alert. When early warning radar detects an incoming hostile force, the air defenders are "scrambled" (quick take-off) to intercept the air threat. Air defense also protects friendly air bases and supply lines in the rear of the battle area from enemy air attacks. Air defense aircraft attack enemy interdiction, air base attack, and reconnaissance aircraft and their escorts. Additionally they reduce the effectiveness of those attackers that survive by forcing some pilots to jettison their ammunitions.

The effectiveness of an air defense sortie is modeled in ICARUS probabilisticaly. The likelihood that an air defense aircraft detects an intruder is heavily dependent on the assistance the defensive aircraft receives regarding the location of intruder aircraft. The model attempts to capture the situation in which the air defense search process is essentially autonomous and the probability of detection (Pd) is sensitive to the number of intruders in the friendly air space. Hence, Pd is proportional to the number of opportunities for making a detection. The model also assumes that intruders who are detected and engaged but not shot down will jettison their ammunitions and return to base.

f. Close Air Support (CAS)

The Army depends on CAS to assist in countering large concentrations of enemy forces. CAS missions attack enemy ground units in actual combat with friendly forces. Air power provides the fastest means of significantly affecting the ground battle. Since most CAS sorties require visual acquisition of ground forces, weather and darkness are significant factors. Normally CAS would be allocated to units faced with a distinct force disadvantage.

Since the model considers only one section of the FEBA, there is no decision on where to allocate the CAS sorties. Weather and darkness are not treated in the model resulting in uniform effectiveness for CAS. Of course addition of weather or a night cycle will improve the model's treatment of the CAS mission.

2. <u>Aircraft Losses</u>

Aircraft allocated to attack enemy air bases will supper attrition due to anit-aircraft artillery (AAA) or surface-to-air missiles (SAMs) which are located along the FEBA and between the FEBA and the air bases.

The aircraft which survive up to that point may then be engaged with enemy air defense aircraft in air battle where a loss may be sustained on both sides. Attack aircraft which survive the air defense then proceed to their designated targets.

The ability of the SAM defense to kill attack aircraft may be reduced by allocating (assigning) SAM suppression missions. These aircraft precede the main attack force to "clear" a corridor for the attackers and mainly to allow them to penetrate the enemy defense. Also by allocating aircraft to escort attackers will reduce attack losses due to air interceptions. The escorts will engage the air defenders first and consequently will reduce the number of air defenders which can engage in interceptions with attack aircraft. So SAM suppression and escort missions are critical elements in the air warfare scenario.

Air-to-air losses will be calculated in terms of "probability of survival of an attack sortie" using the

$$P_{SA} = e^{-a/b} \qquad \text{(eqn 5.1)}$$

exponential form: where,

P_{SA} = The Probability an offensive sortie survives

a = Function of number of air defense sorties

b = Function of number of offensive sorties

a/b = engagement ratio

This exponential form is derived from the Poisson probability distribution and expresses the concept of "diminishing returns" per weapon. The effects in this case are multiple or overlapping. Thus, the expected number of attackers or defenders killed is not simple proportional to the number of aircraft used. Figure 3.5 depicts the concept presented. Once the defender has achieved about a two-to-one ratio i.e. engagement ration = 2, over the

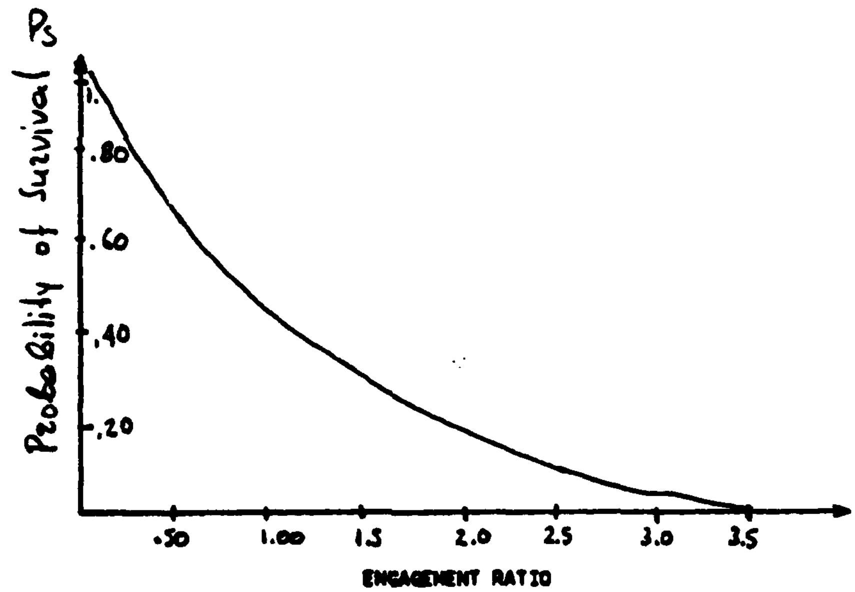

Figure 5.3 The Engagement Ratio on Attackers Survivability

attacker, vary little is gained in terms of decreasing the attacker's probability of survival. In that case the attacker should attempt to concentrate his forces as much as possible.

One way to do this concentration is with the use of escort sorties. The model assumes that each escort sortie will reduce the number of air defenders available to detect and engage a bomber sortie by a specific number according to a simple subtractive rule. Thus, if a mission A contains 50 bombers and 20 escorts against 30 defenders, only 10 defenders would be "eligible" to detect and engage the 50 bombers. The other 20 defenders would be occupied by the escorts. Now suppose another mission B which contains 70 bombers and no escorts against 30 defenders. All of the defenders would be available to detect and engage the bombers. On mission A the engagement ratio of defenders to bombers is 10/50 (.20), and on mission B the ratio is 30/70 (.43). In Figure 5.3 it is indicated that the probability of survival for bombers on mission A is (.82) and the probability for bombers on mission B is (.65). Hence, the use of escorts increases the probability of survival of mission A bombers by (.17) over mission B bombers.

3. Movement of FEBA

In this part of the thesis a very aggregated indication of the air war interactions and the influence in the total assessment will be demonstrated through the ICARUS model to show the effects of air support to the ground battle. However, it is stressed that the model will not concentrate in that area (land combat) since as explained in previous text land warfare is more complicated than the whole air war module of any associated theater level model.

Since we assume that the RED forces (army) start the battle with larger number of forces than the BLUE (army), RED consequently will advance and the FEBA will always start moving in a forward direction (as seen by RED). The RED side is always advancing, and BLUE is attempting to slow the movement. The rate of FEBA movement will depend on the relative strengths of the opposing forces.

As was mentioned in mission analysis, "effective close air support" will influence the rate of FEBA movement. CAS sorties produce causalties in proportion to the "Operational Index (OI)" of the aircraft involved. The "index" accounts for damage due to disrupting troop coordination, slowing troop movements, and creating an adverse psychological effect on the opponent, [Ref. 55:p.30]. As mentioned in the previous sections, a shortage of spares will produce a slowdown of an army's ability to move the FEBA.

A rather simple mathematical expression developed by RAND Corporation [Ref. 56:p.25] indicates that the average motion of the FEBA may be described using the "effective force ration", F, defined as:

$$F = \frac{M\ (slow) + SCAS\ (OI)}{M\ (d)\ slow + SCAS\ (d) \times OI\ (d)} \qquad \text{(eqn 5.2)}$$

where

M = the number of attacking division equivalents

slow = The logistics slowdown factor of the attacker

SCAS = The number of the attacker's effective CAS sorties,

OI = The operational index of the attacker's CAS aircraft, and

M(d)slow, SCAS(d), OI(d) are the defender's factors.

The daily movement of the FEBA is then expressed as a function of the effective force ration (see next section for a detailed explanation of the functions).

C. THE ANALYTICAL FORMULATIONS OF AIR COMBAT

The interaction equations for the offensive and defensive engagements in the air combat model are presented below. Many of the approaches used in the air model ICARUS were adopted from the routines in the LULEJIAN-I modifications, [Ref. 52]. Following a brief presentation of ground interaction equations will be presented which were adopted from the Rand Model TAGS [Ref. 56].

a. SAM Suppression and AAA

The following assumptions apply:

(a) Suppression aircraft precede attack aircraft.

(b) Sites being suppressed get first shot at attackers.

(c) SAM sites are suppressed for one day only. A specific fraction of those sites suppressed are assumed destroyed where:

$$\text{Expected Number of SAMS shot at Suppression Aircraft} = \text{Fraction of FEBA Barrier covered By SAM Sites} \times \text{Probability of SAM Site aquires a Penetrator} \times \text{Simultaneous Missile firing capability of the SAM Site} \times \frac{1}{4}$$

$$\text{Fraction of FEBA Barrier covered by SAM Sites} = 1 - \exp^{-\frac{(\text{\# of Barrier Sam Sites})(2)(\text{SAM sites Poidius})}{(\text{Length of Barrier SAM Deployment}}}$$

$$\text{Number of Aircraft Surviving SAM Site Suppression Mission} = \text{Number of Aircraft that survive to perform SAM Suppression} \times 1 - \text{PSSP a SAM kills a SUPP.}^{(\text{Expected II of SAM Shot})}$$

$$\text{Number of Aircraft that Survive to Perform SAM Suppression} = \text{Number of AC Allocated to Suppression} \times \text{Probability of Surviving Deployed AAA}$$

$$\text{Number of SAM Sites Suppressed by Suppression AC} = \text{Number of SAM Sites} \times 1 - \exp^{-\frac{\text{Number of Suppressions}}{(\text{Number of SAM Sites})}}$$

$$\text{Number os SAM Sites Destroyed by Suppression AC} = .3 \times \text{Number SAM Sites Suppressed}$$

$$\text{Number of ATTACK Aircraft Surviving SAM Fire} = \text{Number of Attack AC Entering SAM Area} \times 1\text{-PSSP or SAM kills an Attacker}^{(\text{Expected II of SAM Shot})}$$

where:

$$\text{Expected No. of SAMS Shot} = \text{Expected No. of SAMs Shot at Supp. AC} \times 1 - \text{Fraction of SAM Sites Suppressed}$$

b. Air Defense

$$\text{Defending AC Engagement Potential} = \text{Number of Defending AC} \times \text{Potential of an Defending AC to Detect and Engage an Offensive AC}$$

$$\text{Number of Attackers Detected and Engaged} = \text{Number of Attackers Surviving Ground Defenses} \times \text{Probability are Attacked is Detected and Engaged by a Defender}$$

$$\text{Probability an Attacker is Detected and Engaged} = 1\text{-exp}\ -\frac{\text{(Defending AC Engagement Potential)}}{\text{Number of Attackers Surviving}}$$

$$\text{Probability an Attacker is killed by a Defender} = 1\text{-exp}\ \frac{(\text{Defender } P_K)(\text{No. of Defenders Engaged})}{(\text{Number of Attackers Engaged})}$$

$$\text{Probability a Defender is killed by our Attacker} = 1\text{-exp}\ \frac{(\text{Attacker } P_K)(\text{No. of Attackers Engaged}}{(\text{Number of Defenders Engaged})}$$

c. Aircraft Losses

The model may use the Monte-Carlo method (subroutine RANDOM) to determine the number of aircraft killed given the number of aircraft engaged and the probability an aircraft is killed. RANDOM calculates kills using a binomial criterion. Each encounter is treated as an independent Bernoulli trail. For each encounter a random number can be drawn, if the random number is less than the Pk of the Attacker, the aircraft is considered killed. Otherwise the aircraft survives but is assumed to have jettisoned its ordnance load. The attacking aircraft which survive the ground-to-air defense and are not engaged by the air defenders are sent against the opposing air base for final computations. For the air base attack mission, base, status, STAT, is reduced in the following manner:

$$STAT = STAT - \sum_{i=\lambda}^{4} (fin_i) \quad \text{(eqn 5.4)}$$

where,

STAT = base status

fi = Operational Index for the type i aircraft

ni = Number of type i aircraft

The number of sorties an airbase can support is then computed:

$$NSORT = MAX \times STAT \quad \text{(eqn 5.5)}$$

where,

NSORT = Number of sorties an airbase can support

MAX = maximum number of sorties an airbase can support if fully operational

STAT = base status

Interdiction sorties reduce the number of spares received by an opponent in the following manner:

$$SPARES_i = SUPPLY \times (.995)^{INTDi} \quad \text{(eqn 5.6)}$$

where,

SPARES = Number of spares received daily by base i,

SUPPLY = Maximum supply capability of the logistics network,

INTD = Number of effective interdection sorties against base i (i.e. 1 = for 1, 2 - for base 2,...).

d. Ground Equations

The daily movement of the FEBA, called FDME, can be expressed as a function of the effective force ratio, F, in the form:

$$FVEL = VMAX \left[SIN \left[\frac{\Pi}{2} \left(\frac{F-X1}{X_2-X_1} \right) \right] \right]^{2X_3} \qquad \text{(eqn 5.7)}$$

where,

VMAX = Maximum velocity of the FEBA against negligible opposition X1, X2, X3,...Xs are constant INPUT by the analyst [Ref. 56:p.11].

Figure 5.4 indicates how the movement rate is affected by selection of the constants. The value of the constants X1, X2, X3, and X4 have been adapted from the Rand model TAGS.

Daily troop casualties inflicted by CAS are a function of the number and type of aircraft involved. The total casualties per day produce by CAS sorties, Ccas, is given by:

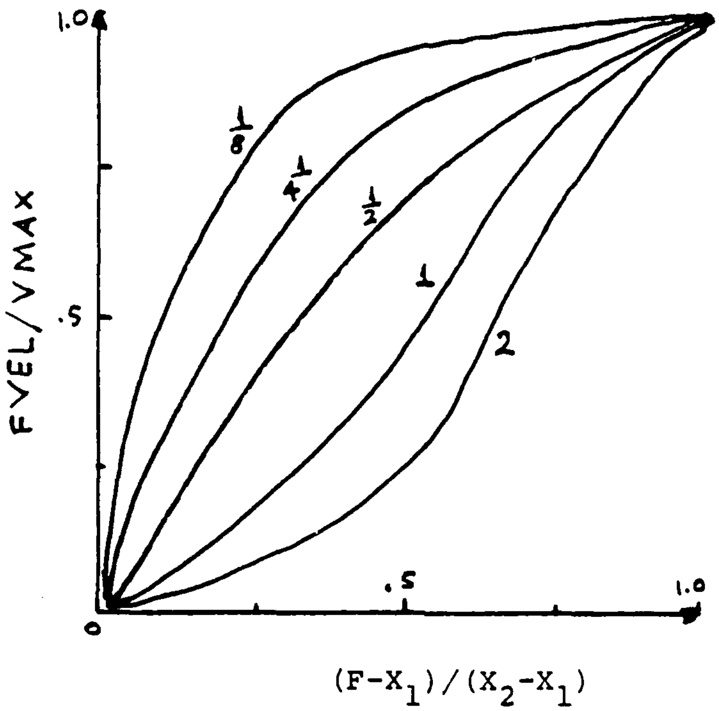

Figure 5.4 Effect of Selected Constants of FEBA Movement Rate

$$CCAS = M \quad 1-\exp \sum_{i=1}^{4} D_iS_i/M \qquad \text{(eqn 5.8)}$$

where, M = Number of enemy divisions

Di = Operational index for type i aircraft

Si = Number of successful friendly CAS sorties of type i aircraft.

D. SCORING SYSTEM

The score which will be given to each side at the end of the run will be computed using two results:

a. The cumulative FEBA movement and

b. The aircraft exchange ratio for each side.

The future user may select different weights but as indication is given for the sake of estimation of a total score as follows:

AD-A137 651   AN EXPECTED VALUE AIR COMBAT MODEL SIMULATION ALGORITHM   3/3
TO PREDICT MISSIO..(U) NAVAL POSTGRADUATE SCHOOL
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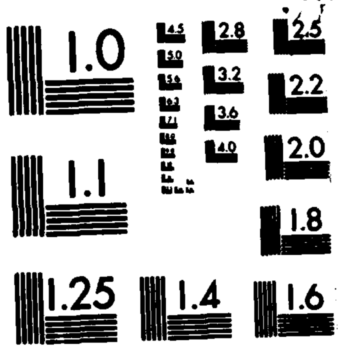


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

FEBA Movement weight is 50 percent

Exchange Ratio weight is 50 percent

The FEBA ratio, FRATIO can be calculated on the basis of cumulative FEBA movement to nominal FEBA movement.

FRATIO = TFEBA/NCM

where

TFEBA = The cumulative FEBA movement during the duraction of the simulation.

NOM = The nominal FEBA movement built in the model (Average constant).

Once the FEBA ratio is computed, a score can be given per side as follows:

RED Ground Score = FRATIO * 50

BLUE Ground Score = 1/FRATIO * 50

The Exchange Ratio can be calculated as follows:

Loss ratio for each side:

BRATIO = BLOST/BTOT

RRATIO = RLOST/RTOT

where BRATIO, RRATIO = Loss ratio for each side

BLOST, RLOST = Number of aircraft lost by each side

BTOT, RTOT = Original number of aircraft plus daily reinforcements for each side.

The Exchange Ratio, ERATIO, then can be calculated as the BLUE loss rate divided by the RED loss rate:

ERATIO = BRATIO/RRATIO

Exchange ratio has been traditionally used to express relative success in air-to-air combat in terms of enemy aircraft killed per friendly aircraft killed. Scores for the air portion can be computed as follows:

RED AIR SCORE = ERATIO * 50

BLUE AIR SCORE = 1/ERATIO * 50

The total score can be computed by summing the air and ground scores.

It should be noted that the measure of performance demonstrated in this model is one of many other choices, depending upon the situation and the utility of the commander, the use of other MOEs would be equally or more valid. For example rate of kill, force drawndown, and enemy causalties are some. The reader will review the section about MOEs for a more indepth discussion.

VI. CONCLUSIONS AND EXTENSIONS

The following conclusions are given as a final effort of the author to give some insight in Air Combat Models to interested analysts.

A. GENERAL

The problem of modeling a complex military function such as Air Force Systems is monumental. It is not a task which can be accomplished within a few weeks, but will take the combined efforts of several people for months.

The above facts are not starting but are added only so that the reader might be aware that the more specific conclusions presented are *applicable only* within the context of the assumptions made and are not offered as an exact answer to any real world problem. Rather, the conclusions are used to support technique and encourage further work in this area.

B. SPECIFIC

1. *Prospects for Theater-Level Models*

The usefulness and use of theater-level models have been steadily increasing in recent years. Theater-level models, despite their obvious and not so obvious limitations, are finding increasing acceptance at high levels. Theater-level models are almost the only alternative to intuition and organized judgment when examining a large scale war. The basis for intuition and judgment is rapidly disappearing as World War II recedes into the past and it becomes increasingly evident that Vietnam and the Arab-Israeli War in 1973 have only limited applicability to a war in Europe. One needs models that combine tactical and technological innovation.

The direction of development of theater-level models is primarily toward command, control, and communications. The C3 problem is closely related to intelligence, target acquisition, and electronic warfare. The next generation of theater-level models almost certainly will incorporate explicit decision-making (allocations) with incomplete, uncertain, and, perhaps, false information. Some models may provide explicit schemes for allocating intelligence, target acquisition, and electronic warfare resources as a function of the combat situation. Most of the technology involved in these processes is new and has never been in large-scale combat.

2. Validity of Theater-Level Air Models

There are three aspects to the problem of validating performance data in a theater-level model. The first is the technical validity of the measurements from which the data are obtained. Such performance data are: reliability (abort rates), probability of hit, probability of kill given a hit, CEP, fuel consumption, etc. Validity is determined by statistical sampling techniques. In principle, uncertainties can be reduced by increasing the sample size as long as the environmental conditions are precisely known and can be replicated. In practice however, that is rarely possible.

The second aspect of validity concerns the transfer of the tactical data from the test conditions to the combat environment that the model represents. The performance of most systems is affected by the skill and fatigue of the operator or pilot. The threat by the enemy fire encountered will affect most performance factors.

The third aspect of validation is how performance data are actually used in a model. The key point is the time period used (6 hours, 12 or one day). Detections, hit, and kill probabilities are difficult to use because of the fluctuation of the performance data over the period used.

3. Source of Data Collection

The best source of performance data is a recent war. Wartime data are particularly useful for theater-level models because many processes can be combined into a single value, such as the expected number of kills per sortie of a particular type of aircraft, weapon, and target. Thus, command-control, weather, variation in pilot skill, fire control hardware, and attack tactics are automatically taken into account.

A usual source of test data is the annual training tests, usually with a present scenario to insure that all essential elements are covered. Data from tests should be used with caution for two reasons: a) the goal is training, not realistic combat, and b) many pressures exist to make the reported data close to the performance goals stated by the agency controlling the training.

Field tests of equipment are an excellent source of one-on-one performance data, if allowance is subsequently made, as in Joint Munitions Effectiveness Manual (JMEM), for combat degradation factors.

Most available of all, but perhaps least useful, are manufacturers performance estimates. One method for simulating the performance of future system, thus acquiring combat data, is to run a highly detailed model of a few-on-few against various threats with a variety of performance specifications to determine how sensitive some overall MOEs, such as kills per sortie, are to variations of performance.

4. <u>Combat Theory</u>

Any indepth study of theater level combat modeling ends up in a key problem. There is a lack of coupling between existing models of combat (abstract world of modeling) and reality (real world). How does this one close the gap or forge the "missing link"? The answer is, a Theory of Combat of War. In other words the establishment of a link with "how does one want the model to behave."

The approaches which could serve as possible candidates to develop a combat theory are:

a. Historical and Military Theory Research.

b. Analytical Experimentation.

c. Behavioral Eperimentation.

d. Combat Experimentation.

C. ICARUS AIR MODEL

The model demonstrated in this study was designed to provide the individuals an opportunity to gain some insight in an air combat model.

Existing air combat models are quite large and contain so many factors that the main effects of a user's employment decisions are confounded by the interactive effects of the other factors.

ICARUS has a limited number of factors so that it is easier for a student analyst to determine the main effect of his strategy.

The idea of including details of only those factors that are of immediate interest in a particular model suggests the development of a family of models each appropriate for a specific level of detail.

Some of these areas are listed below:

(1) Inclusion of weather or night cycle, and precision munitions.

(2) Tactics variability, variable penetration altitudes, and speeds.

(3) Air Formations and Air Refueling.

(4) ECM/ECCM

(5) Survivability indices for the various aircraft types.

Using ICARUS as a starting point, one cound develop an even simpler model with one airbase on each side, or more complicated ones with more dynamic changes and stochastic features as well.

So ICARUS has the potential for being the basis for development of a family of air combat models to teach the principles of tactical air warfare.

The possibilities and opportunities in this area are almost unlimited.

APPENDIX A

FLIGHT

The provided flow chart follows a stepwise process to demonstrate a possible approach to model and simulate the performance of a Combat Squadron, in the following sequence of events:

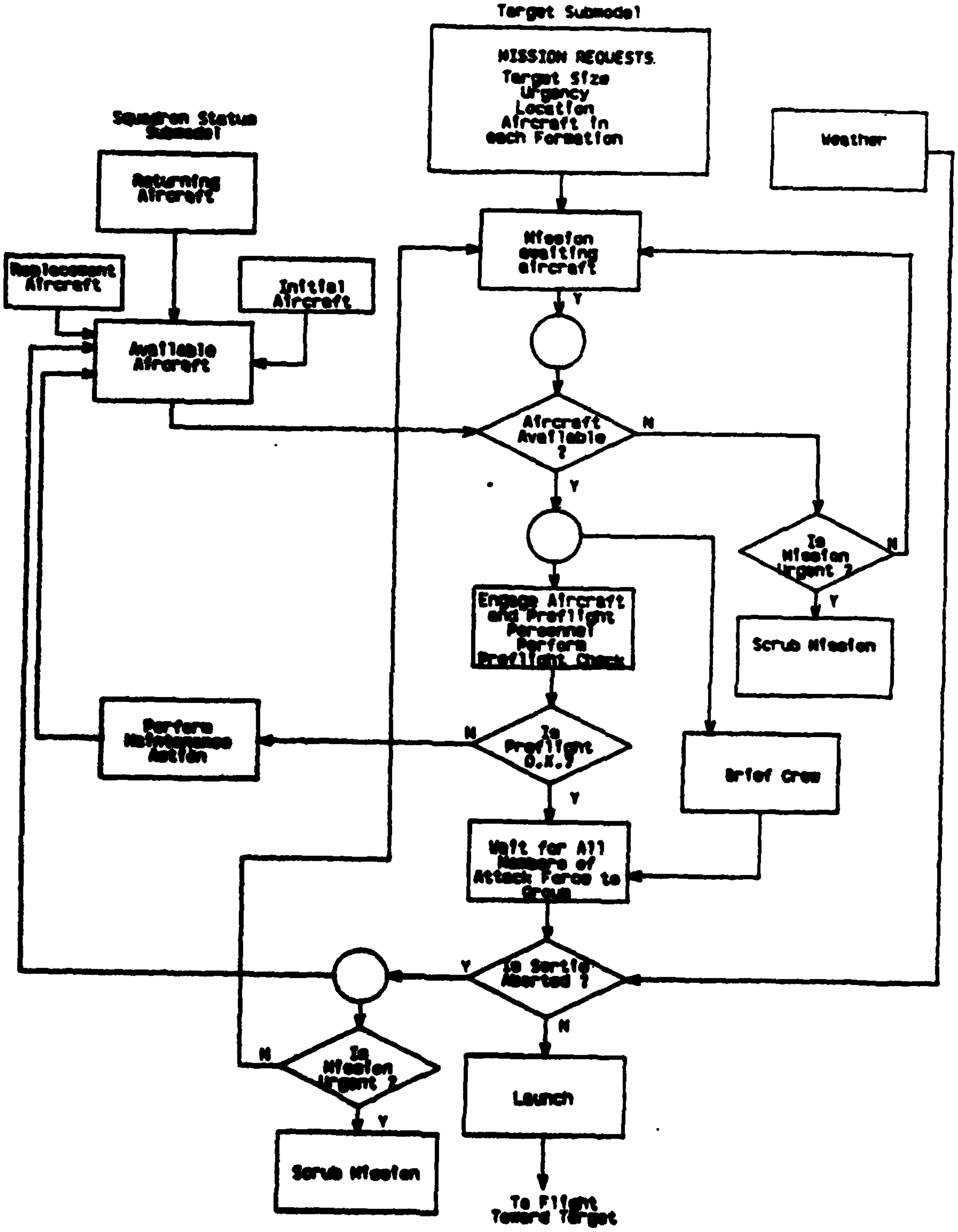
a. Mission and Squadron Interaction Prior to Take-off

b. Flight Toward the Target

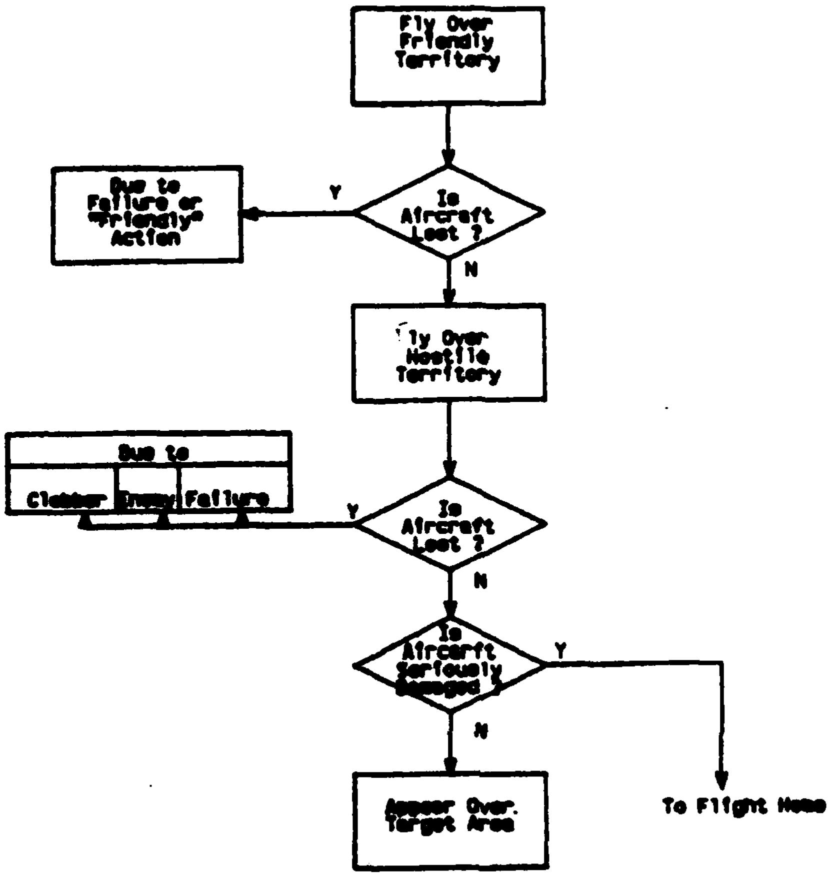
c. The Attack

d. Flight Home and Landing

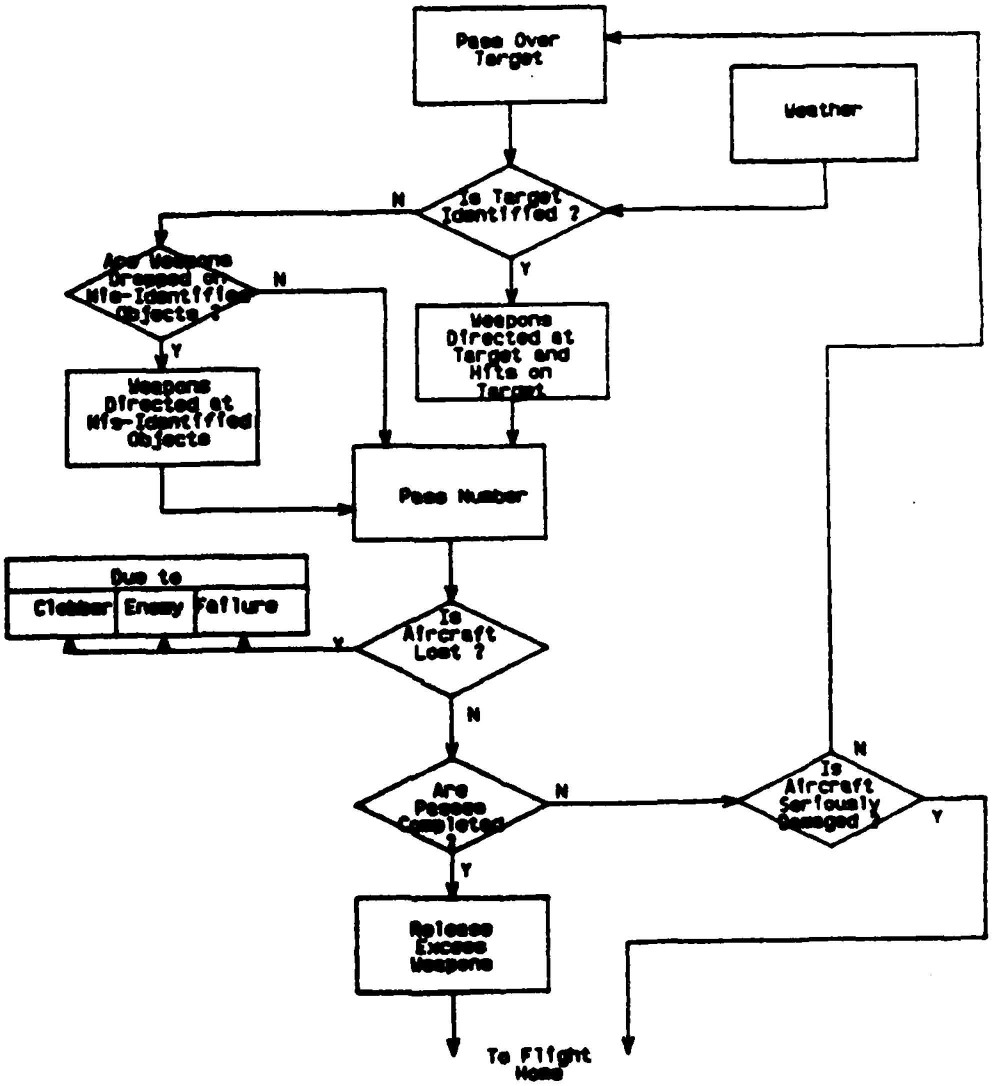
e. Postflight



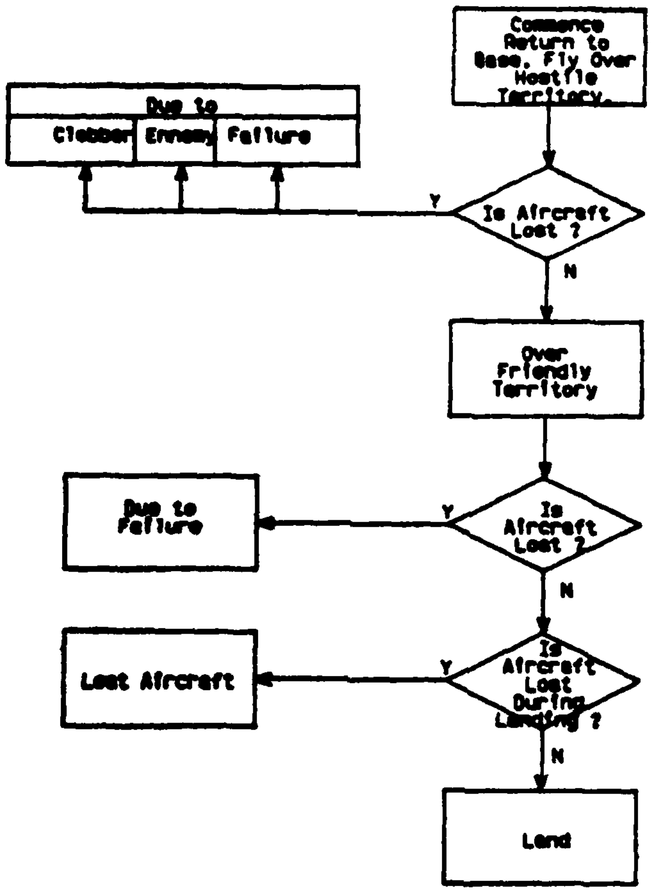
Mission and Squadron Interactions Prior to Take-off



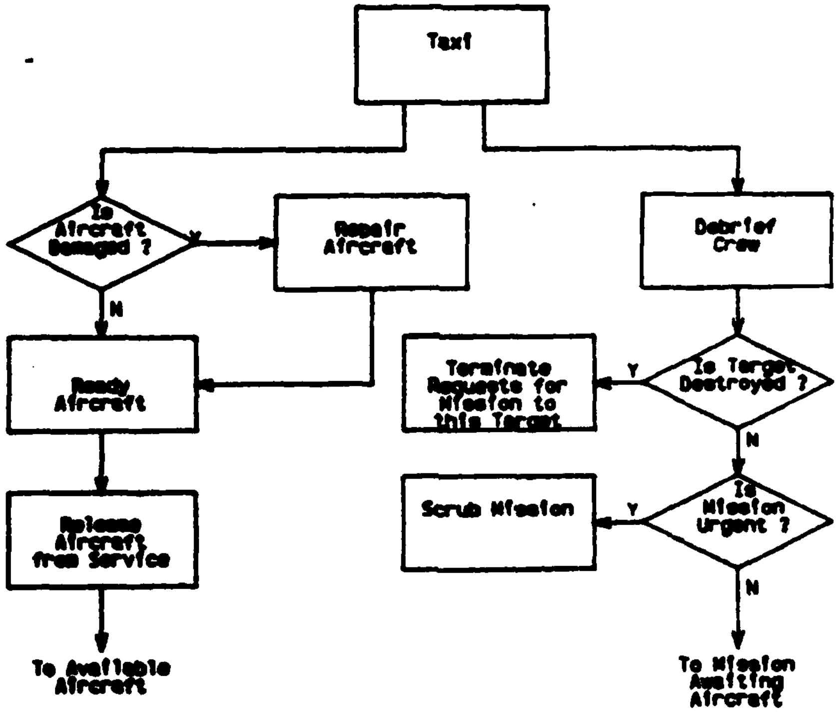
Flight Toward the Target


Pass Over Target
Weather
Is Target Identified ?
N
Y
Are Weapons Dressed on Mis-Identified Objects ?
N
Y
Weapons Directed at Target and Hits on Target
Weapons Directed at Mis-Identified Objects
Pass Number
Due to
Clobber
Enemy
Failure
Y
Is Aircraft Lost ?
N
Are Passes Completed ?
N
Is Aircraft Seriously Damaged ?
N
Y
Y
Release Excess Weapons
To Flight Home

Attack



Flight Home and Landing



Taxi
Is Aircraft Damaged ?
Y
Repair Aircraft
N
Ready Aircraft
Release Aircraft from Service
To Available Aircraft
Debrief Crew
Is Target Destroyed ?
Y
Terminate Requests for Mission to this Target
N
Is Mission Urgent ?
Y
Scrub Mission
N
To Mission Awaiting Aircraft

Postflight

LIST OF REFERENCES

1. USAF-TAC/Manual 2-1., Aerospace Operational Doctrine: TACTICAL AIR OPERATIONS, 15 April 1978.

2. Berkovitz, Leonard D. and Dresher, Melvin, Optimal Employment of Tactical Air Forces in Theater Air Tactics II: A Game Theoretic Analysis, RM-2137, Santa Monica, California, 28 March 1958.

3. Bercovitz, Leonard D. and Dresher, Melvin, A Game Theory of Tactical Air War, p-1592, Santa Monica, California, 13 January 1959.

4. Catalog of Wargaming and Military Simulations Models, 9th edition, SAGAM 120-82, May 1982.

5. White, F. J., Model for a Two-sided Tactical Air Employment Simulation, Air University: Maxwell AFB, Alabama, May 1976.

6. Fitzgerald J., Fitzegerald, A. F. and Stallings W. D., Fundamentals of Systems Analysis, 2nd Eidition, 1981.

7. Standard Procedures for Air Force Operational Test and Evaluation, RADC-TR-74-270-Final Report, October 1974, Rome ADC, AFSC, Griffis AFB, New York, 13441.

8. Morris, William T., On the Art of Modeling, Management Science, Vol 13, No 12, August 1967.

9. Hoeber, Francis P., Case Studies of Military Applications of Modeling, AFIT, Wright Patterson AFB, Ohio, May 1980.

10. Taylor, James G., Lanchester Models of Warfare Volume I. Naval Postgraduate School, Monterey, California, March 1983.

11. Weir, Maurice D. and Giordano, Frank R., Introduction to Mathematical Modeling, Brook/Cole Publishing Company, Monterey, California, 1984.

12. Poole, T. G. and Czymankiewicz, J. Z., Using Simulation to Solve Problems, McGraw-Hill Book Company (UK), n.d.

13. Chen, Gordon K. and Kaczka, Eugene K., Operations and Systems Analysis A Simulation Approach, Allyn and Bacon, Inc., Boston, n.d.

14. Shannon, R. E., Systems Simulation the Art and Science, Prentice-Hall 1975.

15. Fishman, George S., Concepts and Methods in Discrete Event Digital Simulations, New York, John Wiley and Sons, Inc., 1973.

16. Gordon, Geoffrey., Systems Simulation, Prentice-Hall, Inc., 1969.

17. Payne, James A., Introduction to Simulation Programming Techniques and Methods of Analysis, McGraw-Hill Book Company, 1982.

18. Maisel, Herbert and Gungnoli, Giuliano., Simulation of Discrete Stochastic Systems, SRA, 1972.

19. Mastrocostopoulos, Ioannis T., Specifications of a Simulation Model for a Local Area Network Design in Support of SPLICE, Thesis, Naval Postgraduate School, Monterey, California, September 1982.

20. Van Horn, Richard L., Validation of Simulation Results, Management Science, 17 January 1971.

21. Naylor, Thomas and Firger, J. M., Verification of Computer Simulation Models, Management Science, 14 October 1967.

22. Rechnbach, H., The Rise of Scientific Philosophy, Berkeley: University of California Press, 1951.

23. Meredith, J. R., and Turban E., Fundamental of Management Science, Business Publications, 1977.

24. Course Notes OA 4654 On Land Combat Models I, Professor J. Hartman, Naval Postgraduate School, Monterey, California, July 1982.

25. Weapons System Effectiveness Industry Advisory Committee Committee (WSEIAC) Final Report of Task Group II, DDC, Canereon Station, Alexandria, Virginia 22314, AD-458455.

26. Blanchard, Benjamin S., Logistics Engineering and Management, Virginia Polytechnic Institute and State University, Prentice-Hall, Inc.

27. Force Development Operational Testing and Evaluation Methology and Procedure Guide. 71-3 Department of the Army, October 1979.

28. A Study of Measures of Effectiveness Used in Naval Analysis Studies, ONR contract N00014-71-60247, Final Report, Volume 4, MOE's Reviews, 31 October 1972.

29. Course Notes OS-3103, Computer Simulations, Professor CDR Porter, Naval Postgraduate School, Monterey, California, July 1982.

30. Davis, Paul K. and William, Cindy., Improving the Military Content of Strategy Analysis Using Automated War Games: A Technical Approach and an Agenda for Research., RAND, N-1894-DNA, June 1982.

31. Stockfish, J., Models, Data, and War: A Critique of the Study of Conventional Forces, R-1526-PR, The RAND Corporation, Santa Monica, California, March 1975.

32. Bonder S., An Overview of Land Battle Modeling in the U.S. Proceeding 13th U.S. Army OR Symposium, November 1974.

33. Joint War Gaming Manual, JWGA-167-69, JCS, Joint War Games Agency, 1 July 1969.

34. Dictionary of United States Military Terms for Joint Usage, 1 August 1968.

35. Paxson, E. W., War Gaming, RM-3489-PR, The RAND Corporation, Santa Monica, California, February 1963.

36. Theater-Level Gaming and Analysis Workshop for Force Planning, Volume I, Proceedings, Office of Naval Research, Code 431, Arlington, Virginia 22217, 22-29 September 1977.

37. Bapistella., O. H., Concepts of Combat Modeling for Long-Range Air Armament Planning and their Implementation in the Tactical Air War Analysis Game, M.S. Thesis, Naval Postgraduate School, September 1981.

38. Low, Lawrance J., Theater-level Gaming and Analysis Workshop for Force Planning, Volume II, Summary, Discussion of Issues and Requirements for Research., Office of Naval Research, Arlington, Virginia, September 1977.

39. Taylor, J. G., Attrition Modeling Presentation at Third Systems Science Seminar, Hochshule der Bundeswehr Muchen, Naval Postgraduate School, Monterey, California, April 1978.

40. Pugh, George., Outcome, Effectiveness and Decision Criteria for Combat Gaming, Naval Research Center, Arlington, Virginia, September 1977.

41. Lucas, G. L., German G. F. and Pugh, G. E., Value-Driven Decision Theory, Application to Combat Simulations, Decision-Science Application, Inc., Arlington, Virginia, July 1978.

42. Low, L. J., A Description of the Evolution of War Game Models, SRI International, California, 1977.

43. Taylor, J. G., An Introduction to Lanchester-type models of Warfare, Department of Operations Research, Naval Postgraduate School, Monterey, California, unpublished.

44. Taylor, James G., Lanchester Models for Warfare Volume II, Naval Postgraduate School, Monterey, California, March 1983.

45. Lester, D. M. and Robinson, R. F., Review of Index Measure of Combat Effectiveness, Research Analysis Office, Deputy Under Secretary of the Army Operations Research, 1973.

46. Bode, J. R., Indices of Effectiveness in General Purpose Force Analysis, BDM Corporation, BDM/W-74-670-TR, Vienna, Virginia 22180, October 1974.

47. Cordensman, A. H., A concept Paper of War Games ARPA-TTO, 12 June 1974.

48. Simpson, W. R. and Oberle, R. E., The Numerical Analysis of Air Combat Engagements Dominated by Maneuvering Performance Naval Air Test Center, TM 77-2SA, Maryland, 20 June 1977.

49. Nunn, W. R. and Oberle, R. A., Evaluation Air Combat Maneuvering Engagements, Volume I, Methology, Center of Naval Analysis, Arlington, Virginia 22217, 28 February 1978.

50. Kelly, R. T., Greitzer, F. L. and Hershran, R. L., An Defense, A Computer Game for Research in Human Performance, n.d.

51. Baron, Sheldon., Chu, Kai-Chung., Ho, Yu-Chi., and Kleinman, David L., A New Approach to Aerial Combat Games, National Aeronautics and Space Administration, NASA CR-1626, Washington, D. C., October 1970.

52. Weapons Systems Evaluation Group., The LULEJIAN-I Theater Level Model, 400 Army-Navy Drive, Arlington, Virginia, 22204.

53. Nosenzo, L. V., Prototype of a Theater-Level Tactical Combat Model, Lulejian and Associates, Torrance, California, February 1974 (AD 92793).

54. Foley, J. M., A Two Person Simulated Tactical Air War Game, Thesis, Air Force Institute of Technology, Air University, March 1980.

55. Sisks, C. P., Giamboni, L. A. and Lind, J. R., Analytic Formulation of a Theater Air-Ground Warfare System (1953) Techniques, RM 1338., Santa Monica, California, 13 September 1954.

56. Emerson, D. E., The New TAGS Theater Air-Ground Warfare Model, R-1576-pr, Santa Monica, California, July 1973.

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