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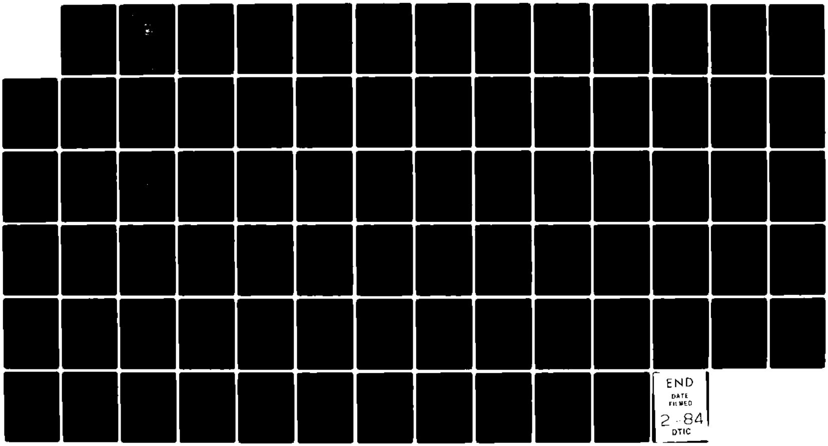

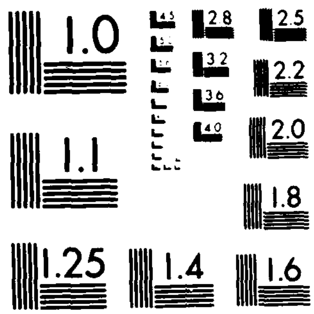

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Monterey, California

THESIS

DESCRIPTION AND ANALYSIS OF PACAM V (PILOTED AIR COMBAT ANALYSIS MODEL) AS A TACTICAL DECISION AID WITH A USER'S GUIDE FOR OPERATION AT NPS

by

Douglas Michael Kelly

September 1983

Thesis Advisor: R. E. Ball

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Description and Analysis of PACAM V (Piloted Air Combat Analysis Model) as a Tactical Decision Aid with a Users Guide for Operation at the Naval Postgraduate School

by

Douglas Michael Kelly
Lieutenant, United States Navy
B.A., State University of New York at Geneseo, 1975

Submitted in partial fulfillment of the requirements for the degree of

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Author: Douglas M. Kelly

Approved by: ______________________ Thesis Advisor

______________________ Second Reader

______________________ Chairman, Department of Administrative Sciences

K. T. Marshall
Dean of Information and Policy Sciences

ABSTRACT

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. PURPOSE

The development of effective and survivable fighter air-to-air tactics has been a difficult problem faced by the Navy's decision makers through out the history of Naval Aviation. With the high cost of replacing aircraft and aircrew and the numerical disadvantage the Carrier Airwing can expect to encounter, a solution to this problem has become even more pertinent today. We can no longer rely solely on past experience, intuition, or a "gut feeling" to develop tactics. All of these do have a place in the decision making process, but they must be substantiated by some hard analysis.

This study will examine one tool that could be used in this decision making process. PACAM V (Piloted Air Combat Analysis Model) is a computer model developed by A. T. Kearney Inc. Caywood-Schiller Div. for the Air Force to assist in the evaluation of aircraft, armaments, and tactics by simulating the performance of multiple aircraft and weapons in combat.

The model was obtained by the author from the Flight Dynamics Laboratory (AFWAL/FIMB), Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB. It was adapted for use on the IBM-3033 computer at the Naval Postgraduate

School (NPS). The model was then converted from a batch mode of operation to a user-friendly interactive mode. This was done so that the model could be easily used by tactical decision makers at NPS with a minimal knowledge of computers and computer simulations.

The model will be described in this thesis and the advantages and disadvantages will be discussed. The limiting assumptions of the model will be outlined and commented upon. The model's handling of the damage process itself, that is, how it simulates damage caused to an aircraft by a damage mechanism, will be described and critiqued. Then an overall critique of the model will be presented by comparing it to other models available for use at this time. A step-by-step user's manual has been developed by the author enabling an individual with no previous experience with either computers or simulations to sit down at a terminal at NPS and in a reasonable amount of time be able to use this model for tactical analysis.

B. BACKGROUND

The survivability of the aircraft that they fly has always been a primary concern of the operators of fighter aircraft. For all practical purposes, the only effect an aircrew can have on this survivability is through the tactics they employ when confronted with a specific threat. The aircraft they are flying have already been designed with a given amount of survivability built in, including a given ECM (Electronic Counter Measures) and ECCM (Electronic Counter Counter-Measures) capability.

The question, then, is "what is the best tactic for my aircraft against a given threat." There will be as many answers to this question as there are fighter aircrews and therein lies the problem. Perhaps the more pertinent question would be "how do I evaluate the different tactics in an air-to-air environment to determine what is the most effective tactic to accomplish the goal of my mission?" The obvious answer is to go out and fly the tactics and see which works the best. This is the solution that has been used in the past at facilities like the Naval Fighter Weapons School, VX-4 and in the Air Force's Red Flag exercises. In peacetime this method of evaluation is slow, costly, and inefficient. In time of war, it can be fatal. Most of the fighter tactics used today were developed through hard experience in Vietnam or are based on intelligence from Israeli encounters in the Mideast. We must develop realistic and effective tactics during peace time to counter the expected threat. The major problems with trying to develop these tactics through flight tests only are discussed below.

Monetary: The high cost of fuel and maintenance make it prohibitively costly to thoroughly flight test all tactics. Does succes in 1, or 3, or even 10 engagements with a given amount of survivability built in, including a given ECM (Electronic Counter Measures) and ECCM (Electronic Counter Counter-Measures) capability.

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Monetary: The high cost of fuel and maintenance make it prohibitively costly to thoroughly flight test all tactics. Does succes in 1, or 3, or even 10 engagements imply the tactic is successful? Furthermore since no actual bullets or missiles are fired, how is success defined and determined?

Aircrew Performance: The varying abilities of the aircrews involved in the evaluation injects a degree of uncertainty into the results of any test.

Threat Simulation: How are we simulating the threat we wish to counter? Are the aircraft and pilots we use to model the threat a reasonable facsimile?

When the above shortcomings are considered, relying solely on flight test to evaluate new tactics can become a very qualitative and sometimes even arbitrary process. That is why a model such as PACAM can be so valuable. Many of the proposed tactics can be inexpensively examined and possibly eliminated through the use of a model.

C. HISTORY OF THE MODEL

The model PACAM V has been developed from a series of earlier versions through an evolutionary process. A brief summary of that development is a good way to introduce the model [Ref. 1]. PACAM I was originally prepared for the Aeronautical Systems Divisions/Research (ASD/XR) starting in 1968. It was designed to simulate one-versus-one aerial combat in three-dimensional space. Both sides used the same tactics and a limited maneuver suite. Each aircraft fought unaware of weapons usage by his foe. The flight path data resulting from the simulation was stored on tape to allow the later evaluation of weapons firing opportunities. Under the auspices of the Air Development Test Center/Research (ADTC/XR), the evaluation program was expanded to include air-to-air missiles. The missile flyout was analyzed against the previously stored flight path of the target aircraft. PACAM I was actually a system of three separate models: Model B (duel); Model E (weapons); and Model D (end game).

PACAM II was developed to overcome some of the limitations in PACAM I. The major changes were made in the area of tactics. Asymmetrical tactics were permitted; the two sides were allowed to make different decisions under various conditions. A "level of aggressiveness" factor was incorporated. Nonaggressive (escape) tactics were included for poor position and low fuel situations. The decision process was based on user-supplied tables which facilitated the incorporation of additional tactics. More significantly, PACAM II was designed to permit multi-aircraft combat. Several tactical routines were developed for this purpose.

PACAM II continued to use the partitioned model concept (B, E, D), which implied that manuvering, both offensively and defensively, was independent of weapons firing. This limitation lead to the development of PACAM IV.

The major tactical goal of PACAM IV was to permit dynamic reaction to weapons firing, with all the concomitant effects. It was necessary to merge the three models (duel, weapons, and end game) into a single program and to provide additional subroutines to allow their interaction. First, a screening program was incorporated into the duel program, so that firing opportunities for each of four weapons types (two types of missiles, guns, and lasers) on each aircraft could be evaluated at each time pulse. Optional firing doctrines then allowed the choice of firing at the first opportunity, or, if conditions are predicted to be improving, waiting. Up to ten vehicles (aircraft and missiles) may be handled simultaneously.

The dynamics weapons portion of the simulation begins when a missile is entered into a list of active vehicles by the launch routine. Weight and drag are then decremented from the launching aircraft. The missile's path is integrated, as long as the missile remains viable. If the missile is detected, the target aircraft may choose to evade it, which changes the subsequent course of the battle. The missile evaluation routine checks, at each time pulse, for break lock and closest point of approach to the target. The end game routine determines whether or not a kill has been made given the closest point of approach and the particular weapon involved. If so, the (killed) target is removed, aircraft roles are reassigned, and combat among the remaining aircraft continues. Similar dynamic evaluation is provided for gun and laser weapons, if they are present on the aircraft.

These dynamic weapons provisions, plus the desire by the Laser Engineering and Application for Prototype Systems (LEAPS) office at Kirkland AFB to use PACAM for bomber defense evaluation, led to another series of changes in PACAM IV. Vehicle sizes vary from B-52 aircraft down to AIM-9 missiles. This variation required that the detection range be made a function of the target size and aspect, as well as of the type of sensor.

An optional Monte Carlo routine provides a stochastic determination of the kill evaluation and missile detection variables. Bomber penetration and defense tactics are available, as are tail defense weapon screening, firing, and evaluation.

The evaluation of PACAM IV to handle bomber penetration and defense tactics against fighters led to the next major modification, PACAM V. The inclusion of ground-launched, surface-to-air missiles (SAM), which support the fighters, has given PACAM V a unique capability for evaluation. PACAM V also incorporates improved handling of sensor characteristics, target description, and kill evaluation. The ability to handle one-versus-one combat is retained completely.

The next modification of the model, which will be called PACAM VIII, is currently under development. It will significantly increase the size and complexity of the problem that can be analyzed and will be described more fully later in the section on the future of the model.

D. DEFINITIONS

Considerable misunderstanding of the concepts of survivability can occur when different conceptual definitions for survivability, vulnerability, and susceptibility are used. The following definitions are presented to clarify the use of these terms in this report [Ref. 2].

1. Survivability

Survivability is defined as the capability of the aircraft to avoid and/or withstand a man-made hostile environment during ingress, weapons delivery, and egress from the hostile area. It is dependent on the vulnerability and the susceptibility of the aircraft to the enemy weapon systems. Probability of kill (P_K) is a probability measure associated with survivability. It represents the unconditional probability of "losing" the aircraft due to hostile action. Survival of an aircraft is the complement of the event that it is killed, thus

$$P_S = 1 - P_K$$

2. Susceptibility

Susceptibility is the likelihood of the aircraft being hit by enemy fire. Exposure time to enemy defenses is one major factor that determines how easily an aircraft can be hit, aircraft performance is another. It is not a function of how tough or hard the aircraft is and does not consider how damaging such a hit may be. The more susceptibile an aircraft is, the more likely it will sustain a hit.

The unconditional probability of a hit (P_H) is the probability measure associated with susceptibility.

3. <u>Vulnerability</u>

Vulnerability is the liability of an aircraft to damage or attrition when hit by hostile fire. It does not consider how likely is a hit by hostile fire. The more vulnerable an aircraft is, the more likely it will be "lost" when hit. A probability measure associated with vulnerability is the conditional probability of a kill given a hit ($P_{K/H}$). Another measure of vulnerability is vulnerable area. It represents a statistical area which, if hit, results in a kill of the aircraft. Vulnerable area, A_V, and $P_{K/H}$ are related by the equation

$$P_{K/H} = A_V \div A_P$$

where A_P is the presented area of the aircraft. Note that A_V and $P_{K/H}$ are dependent upon the aspect of the threat to the aircraft, as well as aircraft and weapon characteristics.

The probability of kill of an aircraft is the product of the probability of a hit and the probability of a kill given a hit;

$$P_K = P_H \times P_{K/H}$$

II. MATHMATICAL MODEL PACAM V

A. INPUT PARAMETERS

There are eight categories of input for PACAM V which will be briefly described below. The ninth input parameter, Tactical Inputs, is the analytical heart of the model, so a separate section will be used to describe it in detail. The inputs must be provided as punched cards or card images. A detailed description of each of these inputs is available in [Ref. 1] and [Ref. 3].

1. Control and Scenario Parameters

The Control and Scenario Parameters represent all of the descriptive input data required to run PACAM V with the exception of battle geometry (i.e. initial conditions and SAM site locations). Examples of these inputs are the number of aircraft on each side, the tactics to be employed, and the maximum duration of the engagement.

2. Aircraft Type

The aircraft type inputs are all of the data concerning the aircraft needed during a PACAM run. One set of data is required for each type of aircraft. This data includes information regarding the aerodynamics of the aircraft, guns on board, various performance maxima and minima, pilot G restrictions, and the aircraft power plant specifications.

3. Missile Input

The missile input describes all of the missile aerodynamic, propulsion, and guidance data for both air-to-air and surface-to-air missiles. One set of data is required for each type of missile. This data includes information such as the fully fueled weight, the structural G limit, the nominal lethal radius, and the nominal thrust.

4. Sam Site Inputs

Sam Site Inputs deal with the parameters of the SAM launch sites and their location. All other SAM data falls into the category of missile inputs. One set of data is required for each missile. It includes such items as minimum time between successive launches, the maximum elevation angle of the radar, and the maximum number allowed in the air from one site at any time.

5. Firing Screen Inputs

The Firing Screen Inputs define the conditions under which weapons may be fired within the program. The screening parameters delineate the requirements necessary for weapons release, whether or not a firing occurs depends on firing policy specified by the tactical inputs. The firing screen inputs deal with the type of sensors, lock-on requirements, geometric constraints, and the restrictions arising from launching aircraft.

6. Detection Contours

The effects of target aspect, sensor characteristics and countermeasures are partially accounted for by means of a set of user-supplied nominal detection range contours.

7. Laser Inputs

Each aircraft in the engagement may use a laser weapon, but all laser weapons have the same characteristics. Such information as the laser wave length, the intensity required to open fire, and the aperture diameter must be provided.

8. Initial Conditions

These inputs establish the starting positions of the aircraft relative to each other. The weapons load out of each aircraft is also included in this category.

B. OUTPUT

There are seven categories of output generated by PACAM. Each of these is briefly discussed here. Detailed descriptions are available in [Ref. 3].

1. Reflected Input

PACAM V has the capability of printing out all of the input data at the start of each run for run identification and error checking.

2. Standard Aircraft Report

A report of aircraft position, orientation, maneuver state, and information state is produced at each major time pulse. In addition, when weapons are on board the aircraft a line of output is printed for each weapon at each minor time pulse.

3. Firing Screen Output

This output presents the time, the identification number of each aircraft, it's potential target, the status of each weapon type, and the type of weapon actually fired, at each major time pulse.

4. Special Reports

Information useful for detailed inspection of any set of parameters computed by PACAM V can be made available through minor modification to the output routines.

5. Narrative Output

As an alternative to, or in addition to, the detailed output described above, PACAM V has the ability to list only the significant events occuring during the engagement. The narrative output includes, the reaction to other aircraft and missiles, the firing of weapons, and the killing of targets.

6. Graphics Interface

Two PACAM V subroutines have been written to provide input to the graphics programs at Eglin AFB and Kirkland AFB. Both graphics packages present output in the form of movies and still pictures. The graphics capability is not currently installed at NPS.

C. TACTICAL

1. Tactical Inputs

All PACAM V inputs, except those discussed here, are of a control, scenario, or engineering nature. Almost without exception they can be defined in a context external to PACAM and can be chosen or developed without regard to their ultimate usage as PACAM V inputs.

The tactical inputs, however, are quite different. PACAM V is a fully dynamic battle simulation with aircraft reacting to their partners as well as to their opponents; missiles are evaded, and both aircraft and missiles can be killed. The basis for all these actions is a series of posture delineations, priority lists, and decision tables utilized to fulfill the tactical doctrines desired.

In order to fully understand the capabilities of the model a fairly detailed description of logic used to describe the tactics to the computer is given here. A even more detailed description along with examples and input tables is available in [Ref. 1].

The first and primary concept the user must be familiar with is that of the tracking angle plot. The tracking angle of one aircraft with respect to another is defined to be the angle (between 0 and 180 degrees) between the velocity vector of the reference aircraft and the line-of-sight vector to the other aircraft, as illustrated in Figure 2.1 for any pair of aircraft, then, there is a pair

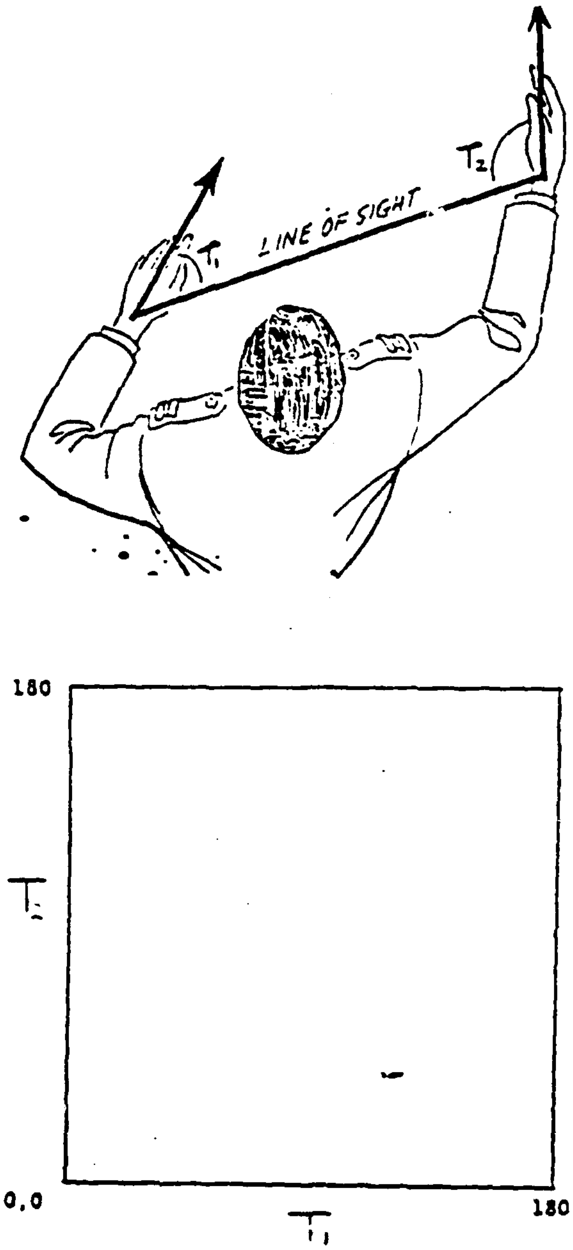


Figure 2.1 Tracking Angle Plot

of tracking angles (T1, T2) which, together with the range, can be used to describe their relative positions in space. This concept is often used intuitively when aerial engagements are discussed.

In Figure 2.1, a simplified tracking angle plot is shown. On this plot, T1 represents the tracking angle of aircraft 1, and T2 is the tracking angle of aircraft 2. Note that the square:

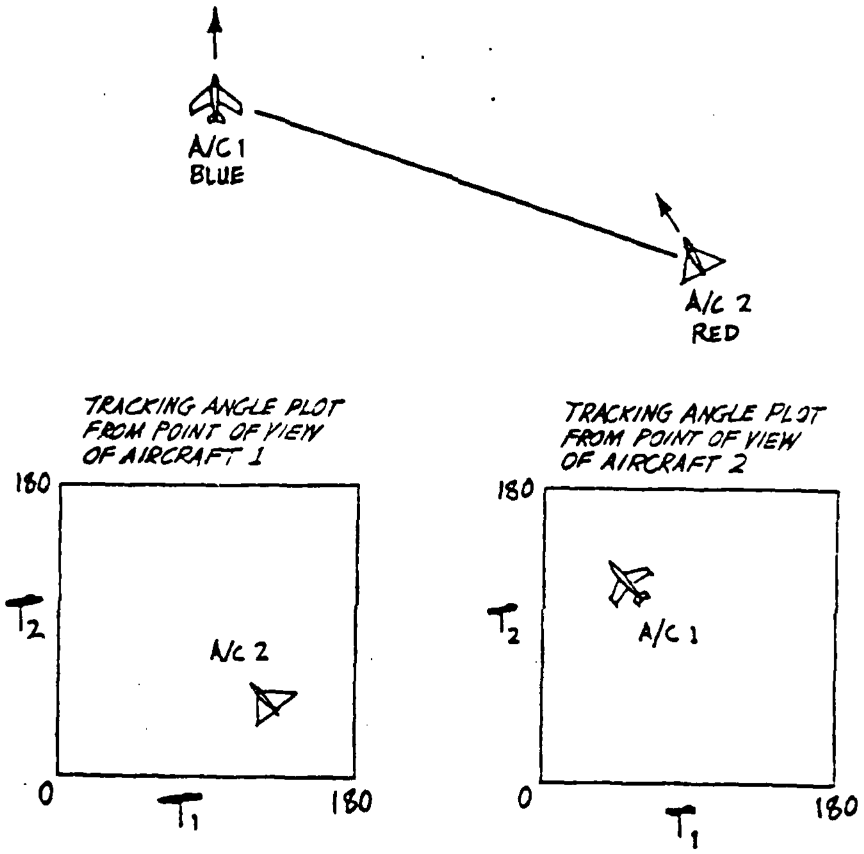
$$0 \leq T1 \leq 180$$

$$0 \leq T2 \leq 180$$

is a boundary of the region of interest, as no other values for the tracking angle may occur.

When several aircraft are involved, a tracking angle plot can be constructed from the point of view of each aircraft in the engagement, as shown in Figure 2.2. If the plot is from the point of view of an aircraft which has more than one opponent, then all opponents appear on the plot as shown in Figure 2.3. In these plots, the T1 axis measures the tracking angle of the aircraft from whose point of view we are looking, not necessirily aircraft 1, with respect to its opponent, and the T2 axis measures the tracking angle of the opponent with respect to that aircraft.

This tactical state or posture of an aircraft may be defined easily only in extreme cases. As we can see from Figure 2.4, the two corners shown represent the ultimate offensive and defensive positions for a forward-firing



Note: Orientation of A/C symbol in plot is not significant.

Figure 2.2 Tracking Angle Plot for Two Aircraft

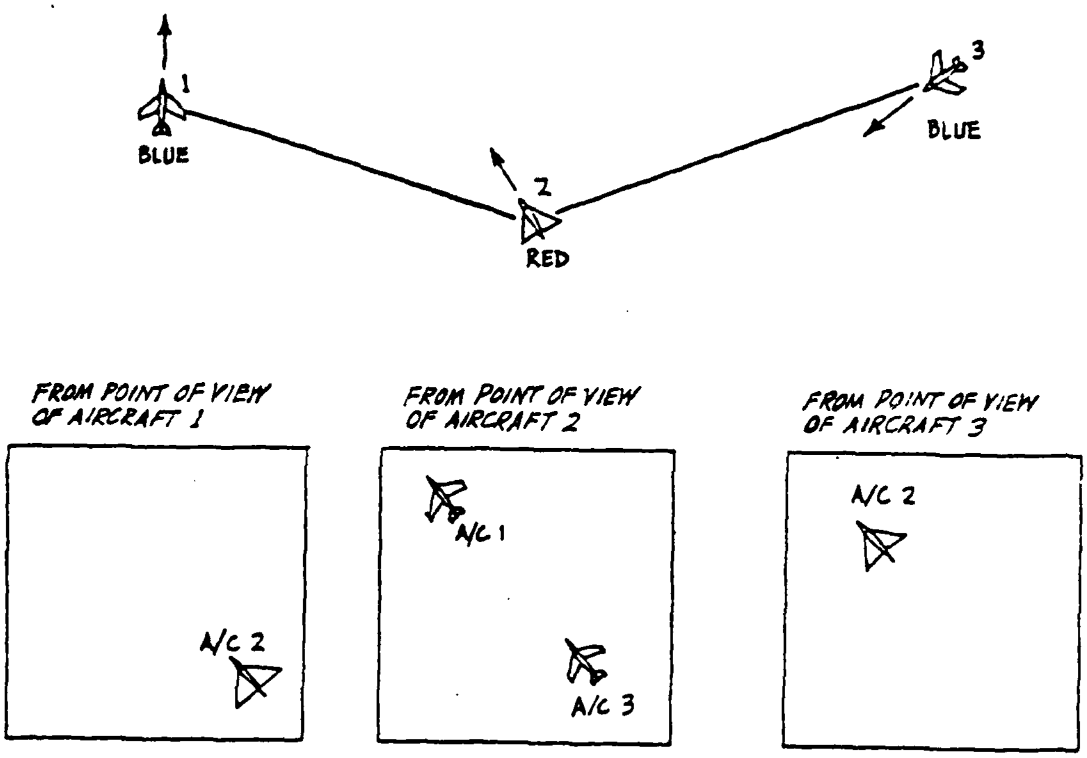


Figure 2.3 Tracking Angle Plot for Three Aircraft

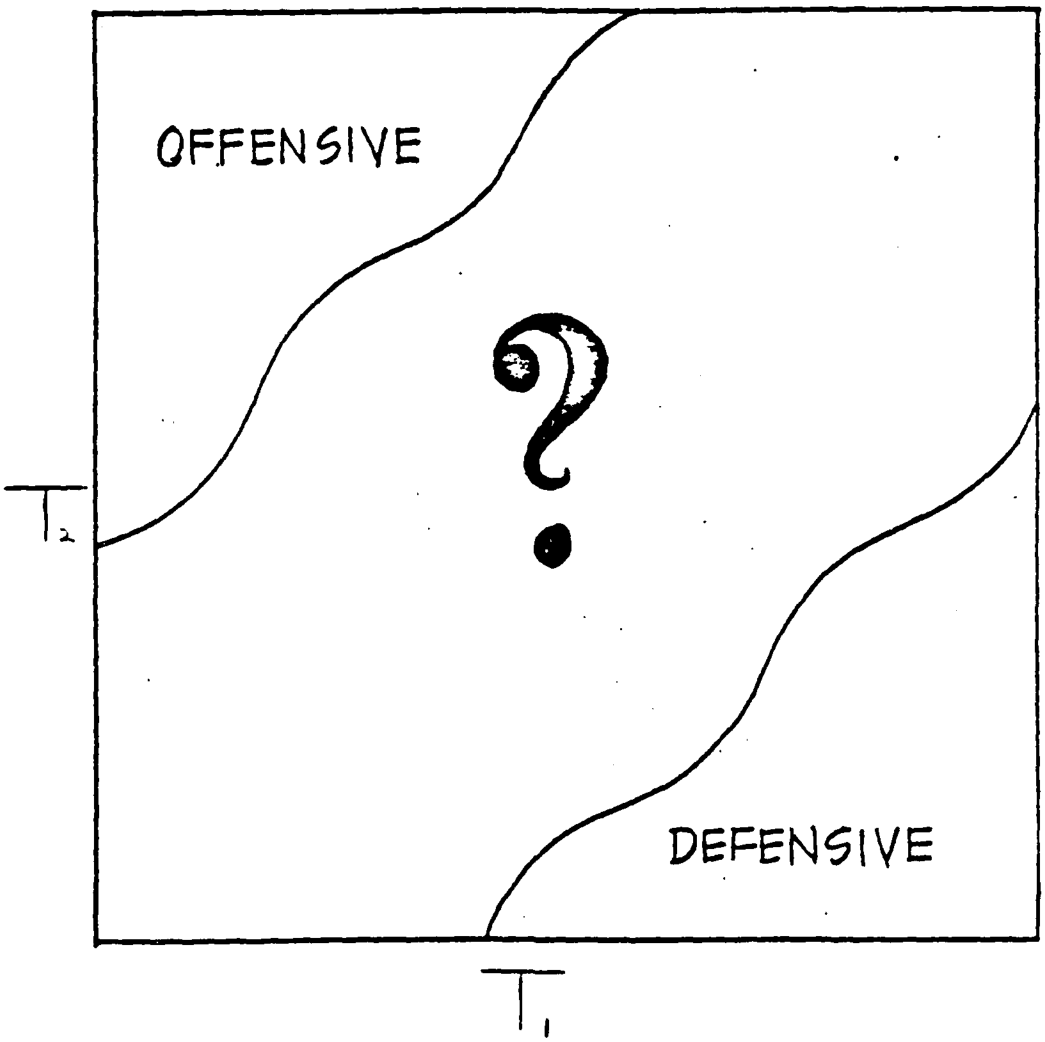


Figure 2.4 Region of Uncertainty

aircraft, provided the range is close enough. A large grey area of uncertainty exists as one move from these corners, and the resolution is dependent on the perceived maneuverability advantages and degree of agressiveness of each pilot.

PACAM V partitions the tracking angle plot into offensive and defensive regions as shown in Figure 2.5. When an aircraft has a T1, T2 point in the offensive region this aircraft has the advantage. Conversly, when T1, T2 falls in the defensive region the aircraft is now a target. Note that the four defensive regions are nested within one another in terms of the limiting values of T1 and T2 which define them. The four regions also have maximum and minimum range restrictions. The offensive zones are defined in a similar manner. It should be emphasized that Figure 2.5 is just a typical partitioning of the tracking angle plot. The user can partition it any way he chooses by inputing the appropriate values of T1, T2 and the range restrictions for each zone. The model is restricted to six zones.

An aircraft's maneuver is defined by the path it is attempting to fly. In reality an aircraft could choose from any of several maneuvers as a response to a particular situation. In PACAM V, however, an aircraft only has an option in its maneuver when it is in a offensive situation. When an aircraft has an opponent in the offensive region of Figure 2.5, it can choose from any number of maneuvers,

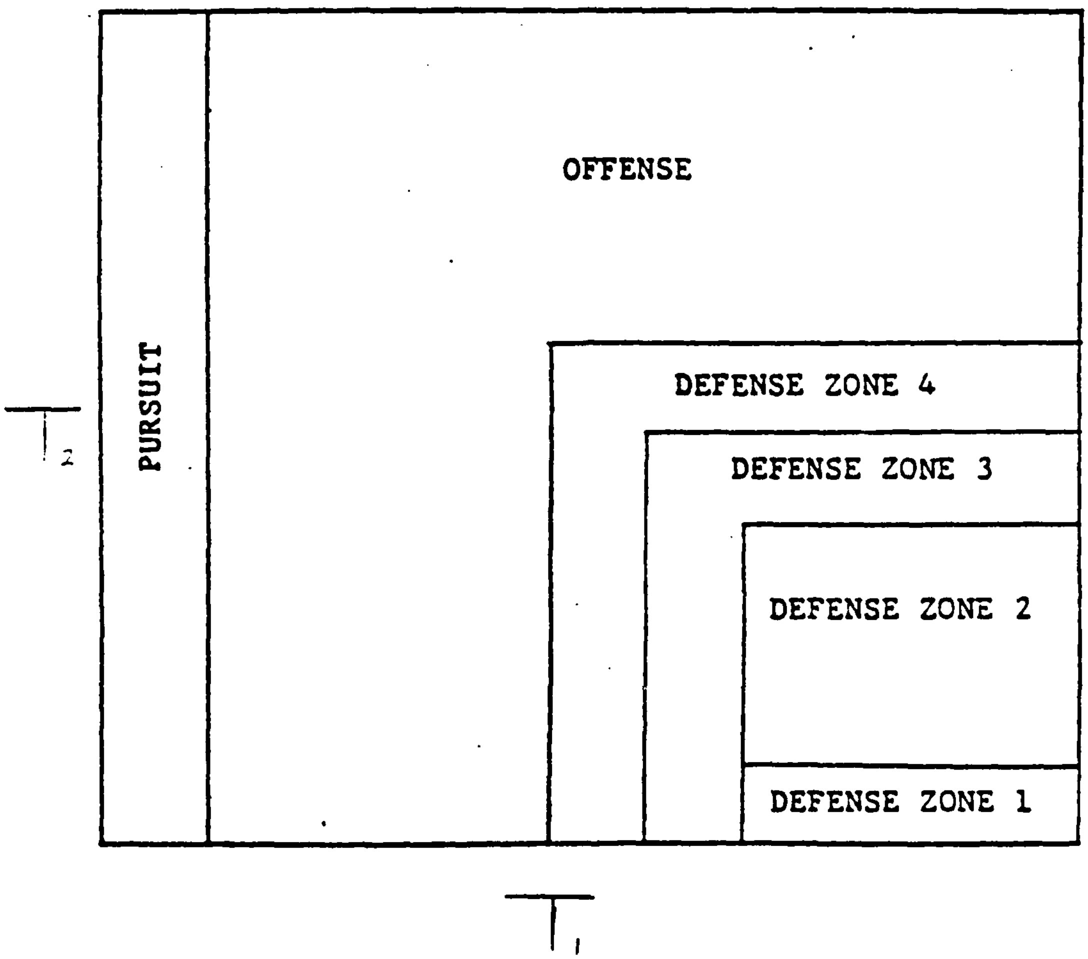


Figure 2.5 Offensive and Defensive Zones

depending on where within the offensive region the opponent lies. If the opponent is in any of the defensive regions or in the pursuit region, the aircraft must utilize a single maneuver input by the user.

The second concept we must be familar with to understand the model is the distinction between "posture" and "maneuver." An aircraft's posture is its perceived combat relationship against a single opponent. This is defined in terms of the opponent's position on the aircraft's tracking angle plot. For a fighter aircraft, the posture is designated by a letter from A to F; for a bomber it is G or H. The meanings for these eight single-letter designations are listed in Table I.

TABLE I

PACAM V Postures

CODE	POSTURE
A	Attack
B	Convert
C	Defense-Zone 1
D	Defense-Zone 2
E	Defense-Zone 3
F	Defense-Zone 4
G	Bomber Attack
H	Bomber Defense

Along with the opponents position on the tracking angle plot, the posture of the aircraft's partner influences the aircraft's choice of maneuver. In addition, factors such as being shot down, running out of fuel or ammunition, or being unaware of an opponent can affect the maneuver. The maneuvers which are possible in PACAM V are listed in Table II.

TABLE II

PACAM V Maneuvers

CODE	MANEUVER
1	Lead pursuit for gun firing
2	Offensive turn to pursuit
3	Defensive jink
4	Defensive turn
5	Escape, low
6	Escape, high
7	Continue unaware
8	Fly formation with partner
9	Attempt to bracket opponent
10	Out of combat, shot down
11	Evade missile
12	Disengage due to bingo fuel
13	Disengage
14	Chandelle
15	Split-S
16	Immelman
17	High speed yo-yo
18	Barrel roll
19	Bomber penetration
20	Bomber defensive action

A typical partitioning of the tracking angle plot is shown in Figure 2.6. The posture of the aircraft is determined by using these regions in the following manner. First, regions C, D, E, and F are checked, in that order. If the aircraft sees an opponent in any one of these regions, and if the range limits are satisfied, the process is terminated and this determines the posture of that aircraft with respect to that opponent. If the posture is not C, D, E, or F, then region A is checked. If region A is also negative, then the posture defaults to B.

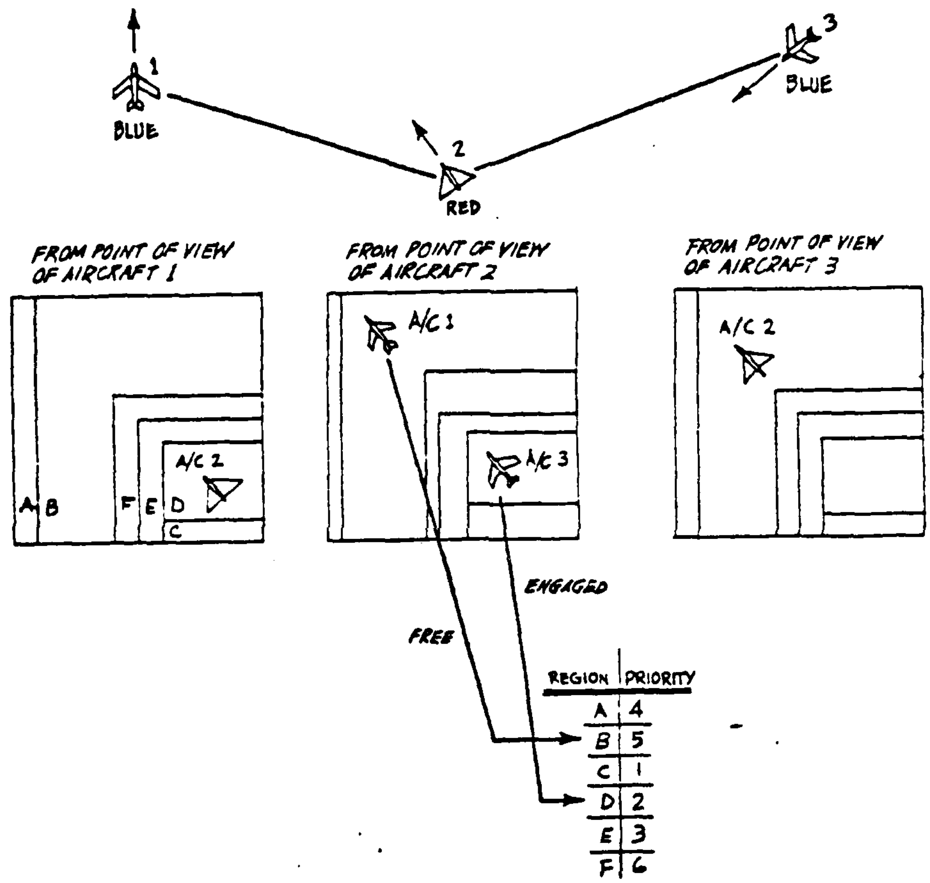


Figure 2.6 Typical Tracking Angle Plot

In the case of a single aircraft which has two opponents, the single aircraft must decide to which of the two opponents to react. The user accomplishes this by assigning priorities to each of the six postures (i.e. attack, convert, and the four defensive posture). The single aircraft reacts to the opponent having the higher priority posture. If both opponents are in the same priority region, the single aircraft reacts to the closer.

At this point it is necessary to decribe the tactical doctrines that are available when two aircraft are on one side. There are three different options that are available. First, there is the option to use Welded Wing tactics. In this tactic, the lead fighter acts as a single fighter against either one or two aircraft. The wing man attempts to fly formation on his leader. He makes no independent maneuver decisions. However, he does make his leader aware of any aircraft he detects, and, he does fire missiles against any opponent meeting lauch requirements. If the leader is killed, the wing man continues the battle as a single fighter. This is a common tactic used by Soviet Bloc air forces when one of the pilots in the flight has limited experience.

The second tactic available for flights of two aircraft is the Free/Engaged Fighters tactic. In this tactic, when a single fighter (or welded wing leader) chooses which opponent he will react to, that opponent (under this doctrine) becomes the engaged fighter. The engaged fighter's maneuver will be the same as if he were alone with his opponent. The engaged fighter's partner, however, is now labelled free, and, he chooses his action from a decision table, based upon his posture and that of his partner. At each major time pulse, roles and actions may be changes as a function of newly determined posture relations.

Figure 2.7 displays a typical Free-engaged maneuver table for two versus one and can be interpreted as follows. The first row is all 9s. This means that if the engaged fighter has posture A (i.e. Attack), he is close to a pursuit course, and the free fighter will perform maneuver number 9. That is, he will attempt to come around and bracket the opponent, even if the current geometry of the situation is such that the free fighter is in a defensive position with respect to some other threat. The fifth row spells out the maneuvers followed by the free fighter, given that the engaged fighter has a posture of E, which corresponds to seeing the opponent in defensive zone 3. The entry 1 in column A means that if the free fighter is already on a gun-firing pursuit course, it will continue that maneuver. The 2 in column B specifies that if the free fighter is in an offensive situation and is striving to get to a pursuit course, it will continue that course. The entries in columns C and D, however, mean that because the opponent is

ENGAGED ↓ / FREE → (POSTURES)	A	B	C	D	E	F
A	9	9	9	9	9	9
B	9	9	9	9	9	9
C	1	2	2	2	2	2
D	1	2	2	2	2	2
E	1	2	2	2	5	6
F	1	2	2	2	5	6

Figure 2.7 Free Fighter Maneuver Table

concentrating on the offensive against the engaged fighter, the free fighter will attempt to come about and "sandwich" the opponent. The fifth and sixth columns say that the free fighter will remain in its defensive position, since maneuver 5 is to attempt to escape at a low altitude. Figure 2.8 represents the complete tactical logic of the three aircraft at each point in time. An instantaneous picture is also shown.

The final tactic available for sections of fighters is called the Double Attack Doctrine. Under this doctrine, two fighters make action decisions based upon their joint posture, independent of their opponent's decision regarding to whom he will react. The doctrine is implemented by a double entry decision table referred to at each major time pulse. Because there is no distinction drawn between free and engaged fighters if a side is using Double Attack tactics, the fighters are labeled "Lead fighter" and "Wingman." There are two numbers entered for each location in the table. These entries represent the maneuvers to be taken by the two fighters based on their joint posture; the first number represents the lead fighter and the second wingman. An example of a Double Attack maneuver table is shown in Figure 2.9.

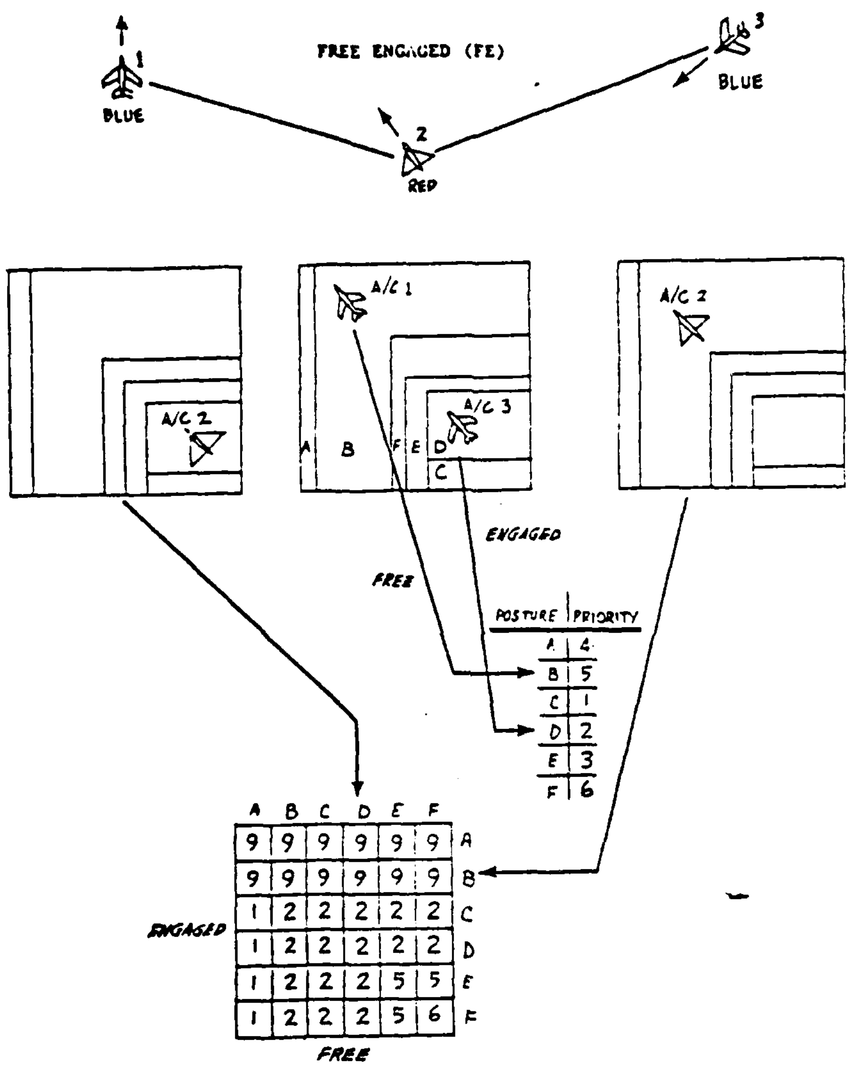


Figure 2.8 Tactical Logic for Free Engaged Tactics

WINGMAN'S POSTURE

LEAD FIGHTER'S POSTURE	A	B	C	D	E	F
A	1 / 1	1 / 2	1 / 3	1 / 2	1 / 2	1 / 6
B	2 / 1	2 / 2	2 / 3	2 / 2	2 / 5	12 / 6
C	3 / 1	3 / 2	3 / 3	3 / 4	3 / 5	3 / 6
D	2 / 1	2 / 2	4 / 3	2 / 2	2 / 2	4 / 6
E	2 / 1	5 / 2	5 / 3	2 / 2	2 / 2	5 / 6
F	6 / 1	6 / 12	6 / 3	6 / 4	6 / 5	6 / 6

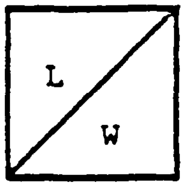


Figure 2.9 Double Attack Maneuver Table

D. ASSUMPTIONS AND LIMITATIONS

The major assumptions made for the PACAM V model are:

1. The model begins at initial conditions established by the user. An engagement is initiated at the time either side detects the other. Once detection occurs, the model traces through the ensuing sequence of events by means of a deterministic, time-step simulation.

2. Partners share information; that is, detection by one aircraft on a side is the same as simultaneous detection by all aircraft on the side.

3. PACAM allows the user to select Monte Carlo options for two processes. They are: i) a Monte Carlo detection process, based on a function of the signal to noise ratio; and ii) a Monte Carlo kill determination process, in which aircraft are removed from combat when a sufficiently large random number is selected.

4. When there are two aircraft on each side, one side must fly welded wing tactics. Thus, maneuver decisions are not made independently for that side. The two aircraft do, however, make independent weapon firing decisions.

5. All aircraft enter combat flying straight and level.

6. The aircraft fly coordinated flight paths; that is, there is no yaw.

7. The detection capability of a sensor has well defined limits. For a given relative position of the aircraft, detection is either impossible or certain, unless the Monte Carlo option is selected.

8. Whatever information an aircraft has is perfect. There is no false information. An aircraft may, however, have incomplete information.

9. An aircraft's action is delayed by a set reaction time of one second.

10. An engagement ends under one of three conditions: i) all aircraft on one side have been killed; ii) the penetrator (bomber) has met its objective; or iii) the user-set time of flight has reached its maximum.

There are three limitations on the size of the problem which PACAM V can handle, two of which are significant:

1. Each side may consist of at most two aircraft, so the possible engagements are one vs one, one vs two, two vs one, and two vs two.

2. At most, six missiles may be in the air simultaneously.

3. Aircraft can fly no higher than 150,000 feet, since the air density equations do not hold above this level.

The limits on the number of aircraft and the number of missiles which can be airborne simultaneously are the major shortcomings of the model. There is currently a modification to the model being developed (PACAM VIII) that will expand the capability to eight aircraft and sixteen missiles.

III. DAMAGE AND DETECTION MODELS

Monte Carlo processes are used in two areas of PACAM V. First, if the Monte Carlo kill removal process is selected by the user, P_K is generated and compared to a random number to determine if a kill has taken place. Second, if the user selects the Monte Carlo detection option, the probability of detection (P_D) is generated and compared in a similar manner to determine if detection has taken place. In this Chapter, the models that are used to generate P_K and P_D, are examined and some possible imporvements to these models are suggested.

A. MODELING PHILOSOPHY

When mathematical models are constructed to simulate reality, the modeler must determine the degree of complexity that is necessary to achieve results that are considered usable. Earlier we defined P_K as:

$$P_K = P_H \times P_{K/H}$$

However, as explained in [Ref. 4], this equation can be broken down even further. The P_H can be divided into the smaller componelts of P_A, the probability of threat activity, P_{DT}, the probability of detection and tracking, and P_{LGD}, the probability of launch, guidance and warhead detonation. If desired, the model could even include the component reliability of each threat propagator. At some point in the analysis a decision has to be made as to what is the desired degree of detail that is necessary for the model.

PACAM V takes an approach that is a middle point between extensive complexity, which could make the model unmanageable and expensive, and simplicity, that could make it unrealistic. In PACAM V, the aircraft are there to fight, so P_A is not considered. The probability of detection can be included if the user wishes to have this as part of the scenario. In a fighter air-to-air scenario this is more of a tactical advantage consideration than a classic search and detection problem. The aircraft that detects his opponent first can commence a maneuver to obtain an offensive position before his oppenent. This is a very real advantage. As we will see in the Section on the detection model, because of the routine used and the sweep rates of modern sensors, detection will eventually take place as range decreases. The P_{LGD} is considered in a rudimentary sense. The missile flys out toward a target and if the target sees the missile it will react in a defensive manner to avoid the missile, if this option has been selected by the user. If the aircraft generates tracking angle rates or maneuver requirements that are beyond the capability of the missile, it will break lock. In PACAM V, the guidance system for each missile has a certain standard deviation, and if the missile does not guide within a specified radius of it's target it will not fuze. These parameters are input to the program when the missile data is read in. When the aircraft does not break lock and the missile reaches a position inside the fuzing radius, the warhead is detonated at its closest point of approach to the target. The detonation process always works. After the missile detonates, certain parameters are examined, and a single number P_K is generated. Thus, the concepts of P_H and $P_{K/H}$ are combined into this one number. A similar process takes place for gun firings.

It is the author's opinion that the level of complexity of the model is sufficient to produce usable results.

B. DAMAGE MODELS

1. Missile Kill P_K

The probability of kill is computed in PACAM V using two basic assumptions. These are:

1. The target is diffuse and each missile has a lethal radius R_L. This can be interpreted as meaning that the target is represented as a point in three dimensional space, and R_L is the distance from this point where the detonation of a perfectly reliable missile would kill a target one-half the time ($P_K = .5$).

2. The possible missile trajectories are characterized by a circular normal distribution centered about the ideal trajectory determined by PACAM V, with a circular error probable (CEP). CEP is by definition the radius of the circle that contains one-half the guidance errors.

The resulting expression used in PACAM V is:

$$P_K = \frac{{R_L}^2}{C^2} \times \exp\left(\frac{-{R_{CA}}^2}{C^2}\right)$$

where R_{CA} = distance of closest approach and

$$C^2 = \left[\frac{2}{\ln 2} \times CEP^2 \right] + \frac{{R_L}^2}{2}$$

This is known as the Bennett approximation to the circular normal distribution. Table III shows the P_K for several miss distances for the two missiles currently available in PACAM V. Each missile has an input value for R_L. This is an approximation determined by the warhead type and size.

TABLE III

P_K VS Miss Distance (Old Model)

R_{CA} (ft)	Long Range Missile	Short Range Missile
0	.517	.517
5	.513	.4516
10	.502	.2525
20	.459	.029
30	.397	.0008
40	.323	0.0
50	.24	0.0
60	.179	0.0
100	.027	0.0

It is the authors opinion that the use of an approximation to the circular normal distribution is unnecessary and actually produces erroneous results in this case. Based on personnal experience with live air-to-air missile firings, the P_K's in Table III are too small at the close ranges and too high at the exreme ranges.

An additional flaw in the approximation is that as CEP approachs 0, the P_K approachs two for small R_{CA}, which is unacceptable. If additional missiles were added to the model with more accurate guidance systems, then this expression would be unusable. The model does have a feature that truncates all values of P_K greater than one back to one. This is an unsatisfactory solution to the problem.

A solution to these problems would be to model using the Carlton Damage function [Ref. 5]. No additional assumptions are necessary, and a closed form solution to P_K is possible without an approximation. The Carlton Damage function combines nicely with the assumption of normal errors in guidance.

If the center of the error distribution is (μ_X, μ_Y), the location of the closest approach, and if the standard deviation of the X and Y errors are (σ_X, σ_Y), then the Carlton assumption states:

$$P_K = \frac{b^2}{\sqrt{b^2 + \sigma_X^2 \; (b^2 + \sigma_Y^2}} \exp\left[-\frac{1}{2} \left(\frac{\mu_X^2}{b^2 + \sigma_X^2} + \frac{\mu_Y^2}{b^2 + \sigma_Y^2} \right) \right]$$

where b is a scale parameter associated with the Carlton function. In this case, it would seem logical to use R_L as the scale factor. The assumption of circular normality of the guidance error allows use to say $\sigma_X = \sigma_Y = \sigma$. For a circular normal distribution, CEP is related to σ by CEP = $\sqrt{2 \ln 2}$. Since $\mu_X^2 + \mu_Y^2 = R_{CA}^2$, then the above expression for P_K reduces to:

$$P_K = \frac{R_L^2}{R_L^2 + \frac{CEP^2}{1.386}} \quad \exp\left[\frac{-R_{CA}^2}{R_L^2 + \frac{CEP^2}{1.386}}\right]$$

Table IV shows the P_K for the same missiles as Table III using this new model. The P_K's generated are higher at the close ranges and lower at the extreme ranges. The new model does not require an approximation, and as the CEP approachs 0, P_K goes to one, as it should. This new expression for missile has been adapted into the version of the PACAM V model as NPS.

2. Gun Kill P_K

In PACAM V, the P_K for gun kills is arrived at through the following expression:

$$P_K = 1 - \exp\left[a\left(\frac{TH}{BL}\right)^4\right]$$

where a = ln . ', and

TABLE IV

P_K VS Miss Distance for (New Model)

R_{CA} (ft)	Long Range Missile	Short Range Missile
0	.7362	.7352
5	.7285	.5702
10	.7061	.2657
20	.6231	.0125
30	.5057	.00007
40	.3777	0.0
50	.2592	0.0
60	.1640	0.0
100	.011	0.0

TH = cumulative hit time during a burst

BL = length of gun firing burst

This expression maximizes to P_K = .5 if the entire bust is on target.

A simple example will illustrate the weakness of this expression. Suppose the same gun is fired twice at a target. During the first firing, TH = 1 sec and BL = 3 sec. In the second firing, TH = 1 sec and BL = 1 sec. In both cases TH is equal, and therefore, assuming a constant rate of fire, the number of rounds on target should be equal. Therefore, the P_K's should be equal for both cases. Evaluating the expression with these given parameters, P_K = .008 the first firing run, and P_K = .5 for the second. There are two major errors in the logic that yields this expression. First, the burst length is totally irrelevent; the number of rounds on target should be the measure of effectiveness. Second, the rate of fire of the gun, which is readily available from the input data for each aircraft, is ignored.

A much better expression for P_K can be derived using the following line of thought. Considering the effectiveness of the modern 20mm (USA) or 23mm (USSR) HEI projectile, the assumption that 10 rounds on target would produce a P_K = .5 is a very conservative estimate. Using this assumption, the following expression can be developed:

$$P_K = 1 - \exp\left[-.069\left(\frac{TH}{\frac{1}{ROF}}\right)\right]$$

where TH = cumulative hit time during burst, and ROF = rate of fire. In this expression TH / (1/ROF) = rounds on target. Table V demonstrates how simple and well behaved this expression is.

TABLE V

P_K VS Rounds On Target

P_K	Rounds On Target
0.0	0
.066	1
.12	2
.29	5
.498	10
.644	15
.748	20
.8738	30
.936	40
.968	50
.984	60
.9989	100

This method of calculating P_K has been incorporated into the version of PACAM V available at NPS.

C. DETECTION MODEL

If the option to utilize Monte Carlo detection is selected by the user, then P_D, is calculated in the following manner. Range (R) is normalized with respect to a nominal range (RNOM) for the sensor being used. The probability of detection is determined using the exponential formulation:

$$P_D = \exp\left[a\left(\frac{R}{RNOM}\right)^4\right]$$

where a = ln .5.

Table VI illustrates the operation of this expression. It yields P_D = .5 when R = RNOM. If the user wished to alter this expression to produce a higher, or lower, P_D when R = RNOM, this is easily done by changing a. This is a common means of modeling and is adequate for the model as it stands.

TABLE VI

P_D VS (R/RNOM)

R/RNOM	P_D
3	0.0
2.5	.0000000000001
2	.000015258
1.75	.0015
1.5	.0299
1.25	.184
1	.5
.75	.803
.5	.9576
.25	.9972
.125	.9998

IV. CONCLUSIONS

A. USE OF THE MODEL

PACAM V presents an outstanding opportunity in the area of tactical weapons and aircraft performance evaluation. It's strength stems from two major design characteristics First of all, it has the capability to examine identical air-to-air engagements with only one variable changed. For example, if we wished to examine the effects of installing new engines in a fighter aircraft, such as an F-14, we could change the propulsion inputs to the model and run identical scenarios using identical tactics and see what, if any, change in the results occured. This leads us to the second strength of the model. Since items such as missile reliability and warhead performance have some randomness associated with them, it would not be desirable to draw conclusions from a single or even several engagements based upon these random results. This model allows us to run an unlimited number of repetitions on each of our scenarios so we can generate a very large data base from which we can make some credible conclusions.

The model can also be used to evaluate tactics in any given situation. We could compare two different tactics in identical situations and analyize the difference in results.

Suppose we wished to investigate an engagement between 2 F-14's and 2 MIG-23's. We decide we want to look at the effect of the MIG's using welded wing tactics as opposed to free/engaged fighter tactics. We could run the desired number of repetitions using each tactic, and then analyize the results.

The major weakness of the present model stems from the limitation on the size of the engagement that can be analyized. The restriction to 4 aircraft and a maximum of 6 missiles in the air does not allow for the development of some very desirable scenarios. A second shortcoming of the model is the restriction to welded wing tactics for one of the sections in a 2 vs 2 if the other section is using either free/engaged or double attack tactics.

The errors in the damage models, that were discussed in a previous section, have been corrected in the version of the program at NPS. With these corrections the damage models work realistically and accurately.

B. FUTURE OF THE MODEL

At present, an update and improvement to PACAM V, called PACAM VIII, is in development by VEDA, Inc., with a subcontract to Schiller Consulting. This new version of the model will correct all the above criticizisms. The major improvements in PACAM VIII will be:

1. The capability for up to 8 aircraft in an engagement (4 vs 4, 6 vs 2).

2. An increase in the number of missiles in flight simultaneously to 16.

3. The capability for IR background and radar clutter.

4. Upgrade of the missile simulations available (AIM-9M, AMRAAM, PHOENIX).

This version of the model will be available in late 1983.

C. AREAS FOR FUTURE STUDY

The possibilities for future study using the model are numerous. So far as improving the model itself, I think the next area that should be examined is the capability to incorporate Surface-To-Air (SAM) missiles and penetrating bombers into the scenarios. These capabilities are present in the model, but, an analyst with some operational experience in these areas should examine and critique them. Because of time constaints and the difficulty in inputing the initial conditions for these options, they were not made part of the interactive version of the model at NPS.

The laser capability of the model was not investigated because of the classification involved and the lack of any operational laser weapons available to fighter aircrews. This is an area of the model that is wide open to somebody with an interest in it.

The graphics capability of the model is another area that needs study. The Air Force has the graphics package running at two different bases where they have the ability to produce either still pictures or movies from the output.

This feature of the model would make evaluation of the output much easier and quicker.

The point of contact for anyone interested in any aspect of this model is Mr. Bob Mercer at AU 785-3428, Wright-Patterson AFB.

The use of PACAM V, or PACAM VIII, when it becomes available, to evaluate real fighter tactics was the primary purpose of this paper. It is the only model the author has seen that simulates dynamic air-to-air combat in a realistic and accurate manner. With the increased capability of PACAM VIII and the inclusion of penetrating bombers with a SAM defense, the model will become a valuable tool for the evaluation of fighter tactics and equipment.

APPENDIX A

USER'S MANUAL FOR PACAM V AT NPS

A. ACCESSING THE PROGRAM

To access the PACAM V program on the IBM-3033 computer at NPS the following procedure is required.

1. LOGON in the standard manner.

2. Type: CP LINK 2941P 191 192 RR

3. Enter the READ only password that can be obtained from Prof. R.E. Ball of the Aeronautical Engineering Dept. EXT 2885.

4. Type: ACC 192 B/A

How you have accessed all the TEXT, DATA and EXEC files required to run the program.

B. USING THE PROGRAM

Running the program is accomplished by answering a series of interactive questions at the computer terminal. In this section, each of the 34 questions that must be answered to run the program are presented. Some of these are self-explanatory, but others need a little more explanation than is provided at the terminal.

Before getting to the specifics of the questions, a couple of general guidelines need to be discussed. First, if the program asks for some kind of character input, that is some letter or string of letters, you must answer with one of the available options. If anything except one of these options is entered, the program will stop, and you will have to start over at the beginning. Second, when the program asks for some kind of numerical input, follow the last digit in the number by a period, except for questions 1 and 2. These two questions require just a single number as a response. This is done so the user will not have to worry about the distinction between real and integer numbers within the computer.

1. <u>Running PACAM V</u>

Initiating the program is very easy. Simply type the word "PACAM" and hit the enter key on the terminal. The program will ask the questions that are listed and discussed in the rest of this section.

QUESTION 1: AIRCRAFT TYPE ON RED SIDE, (1, 3, 4, 5, OR 6).

You may pick any of the five aircraft types to be on the Red side. The distinction of Red vs Blue sides is irrelevent and is provided only to make output and discussion easier. Information on the real world identities of the aircraft types is available to individuals with appropriate security clearances from Prof. R. Ball.

QUESTION 2: AIRCRAFT TYPE ON BLUE SIDE, (1, 3, 4, 5, OR 6).

You may also pick any of the five types of aircraft for the Blue side. It is not necessary to have different aircraft types on the two sides.

QUESTION 3: INPUT A UNIQUE IDENTIFIER FOR THIS RUN.

It can be any ten characters or numbers. If you make more than one run, this enables you to label the output for your convenience.

QUESTION 4: INPUT A SIX DIGIT SEED FOR THE RANDOM NUMBER GENERATOR.

The number input is used in the first call of the random number generator for the Monte Carlo processes selected by the user. A different seed should be used for each run if multiple runs are desired.

QUESTION 5: HOW MANY AIRCRAFT ON THE RED SIDE? MUST BE 1 OR 2.

Self-explanatory.

QUESTION 6: WHAT TACTIC IS THE RED SIDE USING? MUST BE ONE OF THE FOLLOWING: SN, WW, FE, OR DA.

Tactics are discussed extensively in Chapter II of the main body of the study. The tactical options available are as follows: SN, single fighter; WW, welded wing; FE free/engaged; DA, double attack. The allowable combinations of these tactics are illustrated in Table AI.

TABLE AI

Allowable Combinations of Tactics

		RED			
		SN	WW	FE	DA
BLUE	SN	X	X	X	X
	WW	X	X	X	X
	FE	X	X		
	DA	X	X		

QUESTION 7: HOW MANY AIRCRAFT ON BLUE SIDE? MUST BE 1 OR 2.

Self-explanatory.

QUESTION 8: WHAT TACTIC IS THE BLUE SIDE USING? MUST BE ONE OF THE FOLLOWING: SN, WW, FE, DA.

Same as question 6.

QUESTION 9: MAXIMUM TIME YOU WISH THE ENGAGEMENT TO LAST.

This sets an upper limit on the length of the engagement. If all the aircraft on one side are destroyed, or run out of fuel, the engagement will also end.

QUESTION 10: DO YOU WANT INITIAL DETECTION TO BE A MONTE CARLO PROCESS? (0 = NO, 1 = YES).

If you answer *no*, then the assumption is that both sides are aware of the location of the other side at the beginning of the engagement. An answer of yes will bring in the Monte Carlo detection routine described in Chapter III of the main body of the study.

QUESTION 11: DO YOU WANT THE INPUT DATA TO BE PRINTED AT THE BEGINNING OF THE RUN? (0 = NO, 1 = YES)

This option allows you to look at the input data for each aircraft in the engagement, if you are curious.

QUESTION 12: DO YOU WANT TARGET AIRCRAFT TO REACT TO A MISSILE FIRING? (0 = NO, 1 = YES)

A answer of no will result in the target aircraft continuing whatever maneuver it is executing when a missile is fired at it, even if it detects the missile. If you answer yes the target aircraft will execute a missile avoidance maneuver when it detects a missile that has been fired at it. This avoidance maneuver consists of a maximum G turn to place the missile 90 degrees off the nose of the aircraft.

QUESTION 13: WHAT TYPE OF KILL REMOVAL WOULD YOU LIKE TO USE? (0 = REMOVE AT A GIVEN THRESHOLD OF CUMULATIVE PROBABILITY OF SURVIVAL, 1 = REMOVE AS A RESULT OF A MONTE CARLO PROCESS AT EACH WEAPONS FIRING).

This option allows you to choose the type of kill removal you would like to use. If you choose the "0" option then aircraft will not be removed from the fight until their cumulative probability of survival has fallen below a threshold level that you provide. A selection of option "1" will result in a Monte Carlo determination of probability of kill after each missile that detonates or gun that is fired. This means that the calculated probability of kill will be compared to a random number to decide if the aircraft was killed. With option "1", it is possible for a high probability of kill shot not to kill the aircraft or for a low probability of kill shot to succeed.

QUESTION 14: IF YOU CHOOSE OPTION "0" IN QUESTION 13, WHAT THRESHOLD LEVEL WOULD YOU LIKE TO USE? ENTER ANY NUMBER BETWEEN 0 AND 1. IF YOU CHOOSE OPTION "1" IN QUESTION 13, ENTER 0 TO KEEP THE COMPUTER HAPPY.

Self-explanatory.

QUESTION 15: WHAT IS THE TOTAL NUMBER OF AIRCRAFT IN THE ENGAGEMENT? SUM OF RED AND BLUE. MUST BE 1, 2, 3, OR 4.

Self-explanatory.

TABLE AII

Initial Allowable Weights

Type	Min	Max
1	14607	18740
3	23998	29378
4	38303	49837
5	31692	54897
6	18548	25520

QUESTION 16: HOW MAY DIFFERENT AIRCRAFT TYPES ARE INVOLVED IN THE ENGAGEMENT? MUST BE 1 OR 2.

Self-explanatory.

QUESTION 17: DO YOU WISH THE RED A/C TO PERFORM 30 DEGREE CLEARING TURNS RANDOMLY DURING BUGOUT MANEUVERS? (0 = NO, 1 = YES)

This option allows you to use a tactic that is wildly regarded as an effective means of increasing survivibility. Bugout maneuver is the term used in fighter aviation for

TABLE AIII

Maximum Initial Altitudes

Type	Max Altitude
1	69000
3	62600
4	60000
5	65000
6	60000

TABLE AIV

Type 1 Max Initial Velocity

Altitude	Maximum Velocity (ft/sec)
0	1115
5000	1152
10000	1230
15000	1300
20000	1375
25000	1520
30000	1615
35000	1775
40000	1940
45000	2130
50000	2130
55000	2130
60000	2130
70000	2130

disengagement maneuvers. One of the most susceptible times for a fighter aircraft is when it is trying to extract itself from a prolonged engagement. A good tactic to employ during this segment of the fight is to be unpredictable

TABLE AV

Type 3 Max Initial Velocity

Altitude	Maximum Velocity (ft/sec)
0	1380
10000	1508
20000	1660
30000	1990
35000	2287
40000	2274
45000	2274
53000	2274
60000	2274
65000	2274

TABLE AVI

Type 4 Max Initial Velocity

Altitude	Maximum Velocity (ft/sec)
0	1306
5000	1393
10000	1476
15000	1618
20000	1742
25000	1850
30000	1890
35000	1945
40000	1935
45000	1935
50000	1935
55000	1935
60000	1935
65000	1935

in as far as your flight path is concerned. Random 30 degree hard turns make it difficult for a unseen opponent to

TABLE AVII

Type 5 Max Initial Velocity

Altitude	Maximum Velocity (ft/sec)
0	1340
10000	1515
20000	1720
30000	1990
40000	2300
50000	2420
60000	2420
70000	2420

TABLE AVIII

Type 6 Max Initial Velocity

Altitude	Maximum Velocity (ft/sec)
0	1340
10000	1530
20000	1740
30000	1940
40000	2110
50000	2110
60000	2110
70000	2100

acquire a firing solution. If this option is not selected, the aircraft will fly straight and level during bugout maneuvers.

QUESTION 18: DO YOU WISH THE RED A/C TO FIRE AT THE FIRST OPPORTUNITY OR HOLD FIRE WHILE CONDITIONS SEEM TO BE IMPROVING? (0 = FIRE AT ONCE, 1 = HOLD)

This option allows you to dictate firing policy. If the "0" option is selected, the aircraft will fire any weapons it has loaded at the first time that a acceptable firing solution is reached. This will most likely not be the highest probability of kill shot. The "1" option will result in the program looking at the firing screen parameters and doing a trend analysis to determine if things look like they will get better. It will not fire until the firing solution looks like it is going to start to degrade.

QUESTION 19: DO YOU WISH THE BLUE A/C TO PERFORM 30 DEGREE CLEARING TURNS RANDOMLY DURING BUGOUT MANEUVERS? (0 = NO, 1 = YES)

The same as question 17, except this applies to Blue aircraft.

QUESTION 20: DO YOU WISH THE BLUE A/C TO FIRE AT THE FIRST OPPORTUNITY OR HOLD FIRE WHILE CONDITIONS SEEM TO BE IMPROVING? (0 = FIRE AT ONCE, 1 = HOLD)

The same as question 18, except this applies to Blue aircraft.

The questions up to this point have been of a general broad sense. The rest of the questions deal with the specific configuration of each aircraft and their initial positions. Questions 21 through 34 must be answered for each aircraft that is initialized, except the first one which only requires questions 21 through 30.

QUESTION 21: WHAT NUMBER WOULD YOU LIKE TO USE TO IDENTIFY THE FIRST A/C IN THE OUTPUT. YOUR CHOICES ARE 1, 2, 3, OR 4.

The easiest and least confusing thing to do is to number the first aircraft you initiate number 1, the second number 2, and so on until all the aircraft are initiated. However, the program will let you number them in any order you wish.

QUESTION 22: WHAT TYPE OF AIRCRAFT IS BEING INITIATED? THIS MUST BE ONE OF THE TYPES YOU PICKED IN QUESTION 1 OR 2.

Self-explanatory.

QUESTION 23: WHAT SIDE IS THIS A/C ON? THIS MUST ALSO AGREE WITH YOUR ANSWERS TO QUESTIONS 1 OR 2. PERMISSIBLE VALUES ARE R FOR RED AND B FOR BLUE.

Self-explanatory.

QUESTION 24: WHAT ROLE WILL THIS A/C TAKE? THIS MUST BE A SINGLE LETTER DENOTING L FOR LEADER OR W FOR WINGMAN.

It is important that this question be answered correctly. If there is only one aircraft on a side, either Red or Blue, then it must be given the role of leader. A side with two aircraft must have a leader and a wingman, there cannot be two leaders or two wingman on the same side.

QUESTION 25: WHAT IS THE INITIAL WEIGHT OF THIS A/C? SEE THE TABLE IN THE USER'S GUIDE FOR UPPER AND LOWER LIMITS FOR EACH A/C TYPE.

Table AII provides the necessary information. Keep in mind that what you are really inputing here is the fuel weight at the beginning of the engagement.

QUESTION 26: WHAT IS THE INITIAL ALTITUDE OF THIS A/C? SEE THE USER'S MANUAL FOR A TABLE OF MAXIMUM ALTITUDES FOR EACH A/C TYPE.

Table AIII provides the required information.

QUESTION 27: WHAT IS THE INITIAL VELOCITY IN FEET PER SECOND OF THIS A/C? SEE THE USER'S MANUAL FOR TABLES OF MAXIMUM VELOCITY VERSUS ALTITUDE FOR EACH A/C.

Table AIV, Table AV, Table AVI, Table AVII and Table AVIII provide the required information. It must be remembered that these maximum velocities are for a clean, that is, unarmed aircraft. As you load missiles and bullets on the aircraft, weight and drag indexes will be increased. The maximum velocity of a loaded aircraft will be considerably lower than those listed in the tables. Table AIX is provided to give the user some feeling for the relationships between true air speed in knots and velocity in feet per second, at various altitudes. If you should inadvertently enter an initial velocity that is too high for an aircraft in a given configuration, the program will stop and give you an error message on your output.

TABLE AIX

Velocity in Feet per Second

TAS (knots)	ALTITUDE (thousands of feet) 0	10	20	30	40
200	335	323	331	323	319
250	424	420	415	408	406
300	513	508	497	487	484
350	603	594	580	567	571
400	691	683	674	656	658
450	792	775	767	746	745
500	880	861	850	835	842
550	982	980	954	935	929
600	1082	1066	1057	1034	1026

QUESTION 28: HOW MANY LONG RANGE RADAR MISSILES DO YOU WANT TO LOAD ON THIS A/C?

The program does not put a limit on the number of missiles that can be loaded. It is up to the user to use realistic loads. Remember, the program can only have six missiles airborne at one time, so if you load a total of more than six missiles, it is possible that the program could stop if the seventh missile is launched before the first one detonates.

QUESTION 29: HOW MANY SHORT RANGE IR MISSILES DO YOU WANT TO LOAD ON THIS A/C?

The remarks following question 28 apply.

QUESTION 30: HOW MANY ROUNDS DO YOU WANT TO LOAD IN THE GUN OF THIS A/C?

The program will allow you to load as many rounds as you wish. They will not increase your drag index, but they will increase the weight.

At this point you have completed the initialization of the first aircraft. The program will now repeat questions 21 through 30 and also ask questions 31 through 34 for each additional aircraft involved. All the aircraft after the first must be references in space with respect to a previously initiated aircraft. Questions 31 through 34 accomplish this purpose.

QUESTION 31: WHAT IS THE IDENTIFICATION NUMBER OF THE A/C TO WHICH THIS A/C IS REFERENCED?

This must be the identification number, NOT the aircraft type, of a previously initiated aircraft. The identification number is the number you input in question 21.

QUESTION 32: WHAT IS THE INITIAL RANGE BETWEEN THIS A/C AND THE REFERENCE A/C? **NOTE** THIS MUST BE GREATER THAN THEIR DIFFERENCE IN ALTITUDE.

The range is in feet.

QUESTION 33: WHAT IS THE AZIMUTH OF THIS A/C AS SEEN BY THE REFERENCE A/C, IN DEGREES. THE ANGLE IS MEASURED FROM THE NOSE OF THE REFERENCE A/C TO THIS A/C. ANGLES RIGHT OF THE NOSE ARE NEGATIVE NUMBERS, ANGLES LEFT OF THE NOSE ARE POSITIVE NUMBERS.

Self-explanatory.

QUESTION 34: WHAT IS THE AZIMUTH OF THE REFERENCE A/C AS SEEN BY THIS A/C, IN DEGREES. THE ANGLE IS MEASURED FROM THE NOSE OF THIS A/C TO THE REFERENCE A/C. ANGLE RIGHT OF THE NOSE ARE NEGATIVE NUMBERS, ANGLES LEFT OF THE NOSE ARE POSITIVE NUMBERS.

When this question has been answered for the last aircraft, the program will be executed. It may take several minutes for it to run depending on the number of other users on the system and the length of the engagement you initiated. When execution is complete the following, and final, question will appear on the terminal;

ARE YOU READY TO SPOOL DATA TO PRINTER? (Y/N).

For a detailed discussion of the ouput available continue to the next section of the User's Guide.

C. OUTPUT

Two types of output are available for users of PACAM V at NPS. The first, Standard Aircraft and Missile Report is output directly to the IBM-3033 printer if you answer yes to the last question the computer asks. This report is a time-step by time-step record of all the events and parameters. The second output available is the Narrative Report. This report summarizes all the major events in an engagement and puts them in an easily read and understood format. An example of the Standard Aircraft Report is given in Figure A.1 and will be explained in the remainder of this section.

The Narrative Report is illustrated in Figure A.2 and discusses in Chapter II of the main body of this study. This report will automatically be written to a file on your A disk, called PAC9 OUT, every time the program is run.

1. Standard Aircraft Report with Weapons

A standard report of aircraft positions, orientation, maneuver state, and information state is produced for each PACAM V run. On this report, there is one line printed for each aircraft in the engagement, at each major time pulse. An explanation of the column headings of Figure A.1 follows:

```
                                           SPEED                                        ----RANGE----      ANG OFF     INFO     OPTIC
TIME  A/C   ALT    GAP  BETA (KNOTS)  MU   ALPH THROT  GEES TI-MS     1       2        1   2      STATE    CONTACT
                                                                                                          1 2       1 2

  0.0  1  30000     0       0    474     0      3  1.00  1.00  2- 2      0   20000      0  18      9 1       0 1
       2  25000     0    -160    444     0      5  1.00  1.00  1- 2  20000       0     18   0      1 9       1 0

 1.00  1  25514    -2       8    474    50     11  1.00  3.50  2- 2      0   18510      0  13      9 1       0 1
       2  25000     0    -165    444   -66     13  1.00  2.42  1- 2  18510       0     16   0      1 9       1 0
FR M5,IC 1,L2,F1,T4,PE1

 2.00  1  25883   -12      11    474   160     11  1.00  3.50  2- 2      0   17002      0   5      9 1       0 1
       2  25000     0    -171    444   -66     13  1.00  2.42  1- 2  17002       0     17   0      1 9       1 0
LN M5,IC 1,L2,F1,T4,PE2,F 16394.,V  749.,E  1.000
PN M6,IC 2,L1,F2,T4,PE1
PM M5,IC 1,L2,F1,T4,PE3,F 15419.,V 1004.,E  1.000,TM  0.6

 3.00  1  25654   -15       6    460   -80     11  1.00  3.60  2-11      0   15478      0   4      9 1       0 1
       2  25019     3    -171    443    33     13  1.00  2.44  1- 2  15478       0     15   0      1 9       1 0
KM K5,IC 1,L2,F1,T4,PE3,F 15239.,V 1054.,E  2.583,TM  0.7
FM K5,IC 1,L2,F1,T4,PE3,F 15055.,V 1105.,E  2.756,TM  0.8
FM K5,IC 1,L2,F1,T4,PE3,F 14866.,V 1155.,E  2.927,TM  0.9
LN M6,IC 2,L1,F2,T4,PE2,F 14866.,V  610.,E  1.000
FM K5,IC 1,L2,F1,T4,PE3,F 14672.,V 1205.,E  3.084,TM  1.0
FM M5,IC 1,L2,F1,T4,PE3,F 14474.,V 1255.,E  3.225,TM  1.1
KM K5,IC 1,L2,F1,T4,PE3,F 14271.,V 1304.,E  3.345,TM  1.2
KM M5,IC 1,L2,F1,T4,PE3,F 14064.,V 1354.,E  3.435,TM  1.3
FM M5,IC 1,L2,F1,T4,PE3,F 13853.,V 1404.,E  3.505,TM  1.4
KM K5,IC 1,L2,F1,T4,PE3,F 13637.,V 1454.,E  3.540,TM  1.5
FR M7,IC 3,L1,F2,T3,PE1
FR M8,IC 4,L2,F1,T3,PE1
KM K5,IC 1,L2,F1,T4,PE3,F 13417.,V 1503.,E  3.547,TM  1.6
FM M6,IC 2,L1,F2,T4,PE3,F 13084.,V 1071.,E  0.932,TM  0.6

 4.00  1  25338   -30       1    469   160     25  1.00  6.35  2-11      0   13958      0  15      9 1       0 1
       2  25065     6    -170    442     5     13  1.00  2.42  1-11  13958       0     12   0      1 9       1 0
KM K5,IC 1,L2,F1,T4,PE3,F 13193.,V 1553.,E  3.537,TM  1.7
FM K6,IC 2,L1,F2,T4,PE3,F 13702.,V 1123.,E  1.106,TM  0.7
FM K5,IC 1,L2,F1,T4,PE3,F 12965.,V 1603.,E  3.523,TM  1.8
FM K6,IC 2,L1,F2,T4,PE3,F 13516.,V 1175.,E  1.214,TM  0.8
FM M5,IC 1,L2,F1,T4,PE3,F 12732.,V 1652.,E  3.517,TM  1.9
KM K6,IC 2,L1,F2,T4,PE3,F 13324.,V 1227.,E  1.312,TM  0.9
LN M7,IC 3,L1,F2,T3,PE2,F 13365.,V  773.,E  1.000
LN M8,IC 4,L2,F1,T3,PE2,F 13365.,V  741.,E  1.000
KM M5,IC 1,L2,F1,T4,PE3,F 12495.,V 1702.,E  3.534,TM  2.0
FM K6,IC 2,L1,F2,T4,PE3,F 13127.,V 1278.,E  1.398,TM  1.0
FM K5,IC 1,L2,F1,T4,PE3,F 12253.,V 1751.,E  3.590,TM  2.1
KM K6,IC 2,L1,F2,T4,PE3,F 12926.,V 1330.,E  1.465,TM  1.1
FM K5,IC 1,L2,F1,T4,PE3,F 12007.,V 1800.,E  3.702,TM  2.2
KM K6,IC 2,L1,F2,T4,PE3,F 12719.,V 1382.,E  1.514,TM  1.2
FM K5,IC 1,L2,F1,T4,PE3,F 11756.,V 1850.,E  3.881,TM  2.3
FM K6,IC 2,L1,F2,T4,PE3,F 12508.,V 1434.,E  1.541,TM  1.3
KM K5,IC 1,L2,F1,T4,PE3,F 11500.,V 1899.,E  4.135,TM  2.4
FM K6,IC 2,L1,F2,T4,PE3,F 12291.,V 1485.,E  1.552,TM  1.4
FM K5,IC 1,L2,F1,T4,PE3,F 11240.,V 1948.,E  4.476,TM  2.5
KM K6,IC 2,L1,F2,T4,PE3,F 12071.,V 1537.,E  1.556,TM  1.5
KM K5,IC 1,L2,F1,T4,PE3,F 10975.,V 1996.,E  4.868,TM  2.6
KM K6,IC 2,L1,F2,T4,PE3,F 11845.,V 1589.,E  1.555,TM  1.6
FM K7,IC 3,L1,F2,T3,PE3,F 12447.,V  947.,E  0.825,TM  0.6
KM K8,IC 4,L2,F1,T3,PE5,F 12450.,V  901.,E  0.992,TM  0.6

 5.00  1  28913   -33      15    444    40     25  1.00  5.92  2-11      0   12497      0  16      9 1       0 1
       2  25157     5    -164    429   125     20  1.00  3.53  0-11  12497       0     13   0      7 9       0 0
KM K5,IC 1,L2,F1,T4,PE3,F 10705.,V 2045.,E  5.367,TM  2.7
FM K6,IC 2,L1,F2,T4,PE3,F 11615.,V 1641.,E  1.573,TM  1.7
FM M7,IC 3,L1,F2,T3,PE3,F 12265.,V  985.,E  1.613,TM  0.7
KM K8,IC 4,L2,F1,T3,PE5,F 12268.,V  936.,E  0.992,TM  0.7
FM M5,IC 1,L2,F1,T4,PE3,F 10430.,V 2093.,E  5.900,TM  2.8
KM K6,IC 2,L1,F2,T4,PE3,F 11381.,V 1692.,E  1.605,TM  1.8
FM K7,IC 3,L1,F2,T3,PE2,F 12120.,V 1022.,E  1.715,TM  0.8
FM M8,IC 4,L2,F1,T3,PE5,F 12122.,V  972.,E  0.992,TM  0.8
KM K5,IC 1,L2,F1,T4,PE3,F 10151.,V 2141.,E  6.474,TM  2.9
FM M6,IC 2,L1,F2,T4,PE3,F 11141.,V 1744.,E  1.678,TM  1.9
KM M7,IC 3,L1,F2,T3,PE3,F 11951.,V 1060.,E  1.755,TM  0.9
KM K8,IC 4,L2,F1,T3,PE5,F 11952.,V 1008.,E  0.992,TM  0.9
FM M5,IC 1,L2,F1,T4,PE3,F  9866.,V 2189.,E  7.074,TM  3.0
FM M6,IC 2,L1,F2,T4,PE3,F 10898.,V 1796.,E  1.789,TM  2.0
FM K7,IC 3,L1,F2,T3,PE3,F 11780.,V 1057.,E  1.782,TM  1.0
```

Figure A.1 Standard Aircraft Report with Weapons

```
FILE: PAC9     OUT      AT  NAVAL POSTGRADUATE SCHOOL                                          PAGE 001
1                                          TODAY              DAYTIM
 SUMMARY OF SIGNIFICANT EVENTS

     AIRCRAFT WILL BE REMOVED FROM THE FIGHT WHENEVER THEIR CUMULATIVE SURVIVAL PROBABILITIES DROP BELOW 0.250

        MSG
  TIME  NO.
  0.0    1      A/C- 1 CHANGE OF MVR-FROM  7 TO  2
  0.0    2      A/C- 2 CHANGE OF MVR-FROM  7 TO  2
  2.00   3      A/C- 2 LAUNCHES AAM  1 (TYPE 22) AT       A/C- 1, R=  17001 FT
  3.00   4      A/C- 1 LAUNCHES AAM  2 (TYPE 22) AT       A/C- 2, R=  15477 FT
  3.00   5      A/C- 1 REACTS TO MISSILE 1 (TYPE 22)
  3.00   6      A/C- 1 CHANGE OF MVR-FROM  2 TO 11
  4.00   7      A/C- 1 LAUNCHES AAM  3 (TYPE 21) AT       A/C- 2, R=  13557 FT
  4.00   8      A/C- 2 LAUNCHES AAM  4 (TYPE 21) AT       A/C- 1, R=  13557 FT
  4.00   9      A/C- 2 REACTS TO MISSILE 2 (TYPE 22)
  4.00  10      A/C- 2 CHANGE OF MVR-FROM  2 TO 11
  5.00  11      AAM  4 (TYPE 21) BREAKS LOCK ON       A/C- 1
  6.30  12      AAM  1 (TYPE 22) FUZES ON        A/C- 1, MISS DISTANCE=       4 FT
                 A/C- 1 SURVIVED, PK WAS 0.607
  8.90  13      AAM  2 (TYPE 22) FUZES ON        A/C- 2, MISS DISTANCE=       0 FT
                 A/C- 2 SURVIVED, PK WAS 0.735
  9.00  14      A/C- 1 REACTS TO MISSILE 4 (TYPE 21)
  9.00  15      A/C- 2 REACTS TO MISSILE 3 (TYPE 21)
 10.00  16      A/C- 1 LAUNCHES AAM  5 (TYPE 21) AT       A/C- 2, R=   6625 FT
 10.30  17      AAM  4 (TYPE 21) FAILS TO FUZE ON       A/C- 1, CLOSEST APPROACH=     781 FT
 10.40  18      AAM  3 (TYPE 21) FUZES ON        A/C- 2, MISS DISTANCE=      25 FT
                 A/C  2 REMOVED FROM FIGHT, PK WAS 0.566, CUMULATIVE PS WAS 0.206
                 AAM  5 (TYPE 21) LAUNCHED AT       A/C- 2 TERMINATED
 11.00  19      A/C- 1 NO LONGER REACTS TO MISSILE  4 (TYPE 21)
 11.00  20      A/C- 1 CHANGE OF MVR-FROM 11 TO  6
 60.00  21 FIGHT ENDS-MAX TIME LIMIT
1          SUMMARY PROBABILITIES OF SURVIVAL:

                    PROBABILITY
                         OF
               A/C    SURVIVAL

                1     0.392645
                2     0.206325
```

Figure A.2 Example of Narrative Output

TIME	-	The time in the engagement. (seconds)
A/C	-	The aircraft number that was input in question 21
ALT	-	The altitude of the aircraft. (feet)
GAM	-	The elevation of the aircraft's velocity vector. (degrees)
BETA	-	The azimuth of the aircraft's velocity vector. (degrees)
SPEED	-	The speed of the aircraft. (knots)
MU	-	The roll angle of the aircraft. (degrees)
ALPH	-	The pitch angle of the aircraft. (degrees)
THROT	-	The throttle setting: 0.0 - 0.5 military power 0.5 - 1.0 afterburner power
GEES	-	The acceleration normal to the longitudinal axis of the aircraft.
TI-MS	-	The tracking index and maneuver state of the aircraft. The tracking index = 0, if the aircraft is not tracking; = the number of the aircraft or missile being tracked, otherwise. The maneuver state of the aircraft is equivalent to its action. All possible values for the aircraft are listed in Table II in Chapter II of the main body of this study.
RANGE	-	The ranges from the aircraft to all other aircraft in the engagement (feet). An aircraft's range to itself is printed as 0.
INFO STATE	-	The information states of the aircraft with respect to all other aircraft in the engagement. This prints a 0 for any aircraft with itself or with any aircraft on its side. A value of 9 indicates unaware, other values are defined as follows:

	NO IFF	IFF
Tracking	1	2
Active	3	4
Passive	5	6
Aware	7	8

The output pertaining to the weapons in the engagement consists of an additional line of output printing a status report for each weapon active at the minor time pulse shown.

For missiles, the format of each line is described below. The first four variables represent:

The flight phase	PR	Prelaunch
	LN	Launch
	KW	Flight
	MK	End Game
The internal index	Ka	Where $5 \leq a \leq 10$
Missile ID	IDb	Where b is a unique internally assigned identification number
Launching aircraft	Lc	Where c is the launching aircraft number
Target aircraft	Rd	Where d is the target aircraft number
Weapons type	Te	Where e is the internal weapons type number
Maneuver state	Mf	Where f is the missile maneuver state:
		80 Dead
		81 AAM Prelaunch

82 AAM Guidance enable

83 AAM Proportional Nav R $\geq$ R*

84 AAM Proportional Nav R $\leq$ R*

85 AAM Pursuit course

86 AAM Beam guidance

98 Approach

99 Breack lock

Thus, the partial output line: KW, K5, ID4, L1, R3, T3, M84 represents a missile with internal index 5, launched 4th in this run, from aircraft 1 against 3. It is missile type 3, flying short-range proportional navigation.

Those six indentifiers are all that are printed at launch initiation (PR). At actual missile separation (LN) three more parameters are added:

R Range to target. (feet)

V Velocity of the missile. (feet per second).

E Missile "G" loading

After launch a fourth parameter is added:

TM Time of flight. (seconds)

At Endgame time, the type of missile, kill probability (P_K), closest approach distance in feet (RCAP) and results (KILL OR NO KILL) are shown.

For guns, the format of each line of output is as follows:

Identification	GQ	Identifies this as being a line of gun output
Firing aircraft	La	Where a is the firing aircraft number
Target aircraft	Rb	Where b is the target aircraft number
Time on	TON	Length of time the gun has been fired
Time of target	TGHIT	Total time for which the gun has been hitting the target
Aiming error	AIMERR	Angle between the Longitundinal axis of the firing aircraft and the line-of-sight to the desired lead point (degrees)
Range	R	Range to the target (feet)
Result	KRSLTc	Where c is a numerical code specifying the results of the gun firing 1. No kill, keep firing 2. No kill, cease firing 3. Target killed, cease firing

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4. Ball, R. E., The Fundamentals of Aircraft Combat Survivibility Analysis and Design, Naval Postgraduate School, 1983.

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