A DESCRIPTION OF AN AAW MODEL AND ITS CLASSROOM USES.

Alvin F. Andrus

Naval Postgraduate School

Monterey, California

Abstract

A probabilistic event store computer simulation of the interactions between surface-to-air missile systems and aircraft in a non-jamming environment and over flat terrain is presented. The purpose of the model is to test the general disposition of the missile areas and the associated missile system reaction times against an aircraft attack. The model is used as text material in a simulation course. Several model applications are included.

1. INTRODUCTION

The model presented in this paper is an event store computer simulation of the interactions between surface-to-air missile systems and aircraft in a non-jamming environment and over flat terrain. The model is programmed in FORTRAN. The purpose of the model is to test the general disposition of missile areas and the associated missile system reaction times against an aircraft attack. The model is a probabilistic monte carlo simulation. That is, the success or failure of a probabilistic event is determined in the model by comparing the numerical value assigned to the probability of success or failure to a program generated random number. The model was constructed as a classroom aid to be used in a graduate course on system simulation as applied to military conflict situations. The motivation behind the construction was to provide a model that would be complex enough to be interesting for the student to use and at the same time simple enough to illustrate the programming techniques of computer simulation model building.

2. PLAYING AREA

The playing area for the model is a pie slice portion of a circle. The center and radius of the circle and the central angle defining the pie slice are inputs. The numerical restrictions within the computer program are such that the central angle and radius must be less than 180 degrees and 1000 miles respectively.

3. OFFENSE

The offense consists of as many as twenty aircraft. These aircraft fly through the playing area in an attempt to penetrate a set of missile defenses. The entry points into the playing area for the aircraft are generated uniformly over the arc of the circle defined by the playing area. The flight path for each aircraft after it enters the playing area is to fly straight toward the center, (GX,GY). The spacing time between aircraft and the speeds and altitudes of aircraft are generated uniformly between their respective minimum and maximum values. These minimum and maximum values are inputs to the model.

The aircraft in the model play a passive role and serve only as the set of stimuli needed to cause the missile systems to act. These aircraft do not defend themselves against missile attack nor do they attack the missile areas.

4. DEFENSE

The defense consists of as many as three missile areas with their associated missile systems. These missile areas need not be located within the playing area; however, since only the results of interactions occurring within the playing area are considered in the model, the sphere of influence of the missile area must include some portion of the playing area in order for the missile areas to exert any effect on the simulation results.

Associated with each missile area are the parameters needed to describe its missile system. The values of these parameters are inputs to the model, and the parameters are:

(1) Search radar maximum range.

(2) Missile maximum range.

(3) Missile average speed.

(4) The number of tracking radars.

(5) The number of missile launchers.

(6) Maximum and minimum time required to reload a launcher.

(7) Maximum and minimum time required to assess a target after missile intercept.

(9) Missile single-salvo kill probability.

The significant time delays inherent to the missile systems included in the model are:

(1) Reload time: The amount of time required to reload a missile launcher.

(2) Acquisition time: The amount of time required, once an aircraft is observed on the search radar, to transfer the aircraft as a target to an available tracking radar.

(3) Assessment time: The amount of time the tracking radar must remain trained

on the target after missile intercept in order for the result of the intercept to be observed.

In the model all of these times are assumed to be uniformly distributed between their maximum and minimum values, which are inputs to the model.

5. ASSUMPTIONS

It is an assumption of the model that all aircraft are observed by all missile areas subject to the aircraft radar horizon and the missile area search radar maximum range. It is also the case that in order to fire a missile, or salvo, at an aircraft:

(1) The aircraft must be observed at the time of fire.

(2) A missile launcher must be loaded.

(3) A tracking radar must be free in order to be used for full course missile guidance.

(4) The intercept point must be within the missile maximum range circle.

(5) The aircraft must not be past the point of closest approach to the missile area at the time of fire.

The firing doctrine for a missile system is shoot-look-shoot at all available aircraft. That is, when a missile area has launched a salvo against a target no new salvos against that target will be launched from that missile area until that salvo has intercepted the target and the results of the intercept have been assessed. The aircraft are selected as targets, within the missile launcher and tracking radar numerical restrictions, on a first-come first-served basis. The model does not include altitude or minimum range restrictions on the missile.

An illustration of the playing area with a typical missile area and aircraft flight path is included as Figure 1.

6. GAME DOCTRINE

With the input parameter values assigned the model considers the interactions that occur in the playing area between the missile systems and aircraft. For the given set of defensive and offensive parameters the required number of aircraft will enter the playing area at points, times, speeds and altitudes generated by the computer program. This set of aircraft will then proceed directly toward the center, (GX,GY), passing through the missile defenses.

One complete pass through the computer simulation with one set of aircraft is referred to as a replication. To generate data for statistical purposes, at the completion of a replication the computer program will generate a new set of aircraft and using the same set of input values will produce another replication. The desired number of replications is an input value and must be less than twenty-one. An entire set of replications for a given number of aircraft is referred to as a run. For each run the model output consists of any of the following forms of output:

(1) Battle History: An event history of each replication containing the generated events of the battle in the

order in which the events occur and are generated.

(2) Standard: A compilation of each replication containing all aircraft initial conditions and the number of salvos fired by each missile area at each aircraft and the identification of the missile area responsible for killing each aircraft.

(3) Summary: A summary of information, by totals with respect to replication, for each run including the sample mean, variance and standard deviation of all totals presented.

The computer program will make as many runs as desired with an increased number of aircraft for each run. The number of aircraft in the first run, the increment for the number of aircraft in each new run, and the number of runs are input values. Each new run is considered by the model to be an extension of the previous run, that is, if run three contained seven aircraft and run four is to contain nine aircraft, then for all replications in run four the first seven aircraft will have entry points, altitudes, speeds and times identical to those replications in run three, etc. The random numbers used in the replications of a run in order to determine the outcome of probabilistic events are used again in the replications of a new run. In this manner it is hoped that any changes in the results between runs can be attributed to the increase in the number of aircraft rather than to the deviations of the sets of random numbers used. The model contains two missile firing procedures. These procedures are referred to as uncoordinated and coordinated and the procedure used is determined by the user as an input to the model. The uncoordinated missile firing procedure allows all missile areas in the simulation to fire missiles at all aircraft that can possibly be fired upon while the coordinated missile firing procedure allows a missile area to fire missiles at an aircraft only if no other missile area is currently engaging that aircraft. When the user elects to employ both procedures, they are not intermixed in the simulation but are run separately and the same sets of aircraft and sequences of random numbers are used in the corresponding replications and runs of the simulation so that differences in the results can be attributed to the procedure used.

7. EVENTS

As mentioned earlier the model is an event store computer simulation, i.e., all actions that are to occur in the simulation are dynamically generated by the computer program as a result of previous simulation actions and are listed chronologically in an Event Store List. Each of the actions included in the simulation assumes the form of a computer program subroutine, called an event, and the information pertaining to the action on the Event Store List is the information needed to execute the proper subroutine. There are only four major actions included in the model as events and these events are:.

(1) Fire Missile Salvo.

(2) Missile Intercept.

(3) Reload Missile Launcher.

(4) Free the Tracking Radar from an Intercepted Target.

Each of the computer program subroutines representing these events uses as input parameters the following information:

(1) Time event is to occur.

(2) Identification of Event.

(3) Identification of Aircraft.

(4) Identification of Missile Area.

The dynamic process of simulating one air battle from start to finish forms the executive routine for the computer simulation. This executive routine consists of two program subroutines referred to as SNE and TNE. SNE, Store Next Event, is the subroutine that takes the generated information pertaining to an interaction and properly places this information on the Event Store List. TNE, Take Next Event, is the subroutine that, at the completion of any of the four events, interrogates the information on the Event Store List and transfers control of the computer program to the proper subroutine.

General flow charts describing the logic included in each event of the simulation plus the interrelationship of events are included as Figure 2 through Figure 6.

8. MODEL RESULTS

In this section a typical application of the model is presented. Basic to this discussion are the set of model inputs contained in Table 1. The position of the missile sites is illustrated in Figure 7. The measure of effectiveness used in this presentation is missile system effectiveness defined as the percent of aircraft killed averaged over the replications. Using this basic input as a starting scenerio we shall use the model to investigate trade offs in the values of the missile system parameters in an effort to maintain missile system effectiveness at a minimum value of .95.

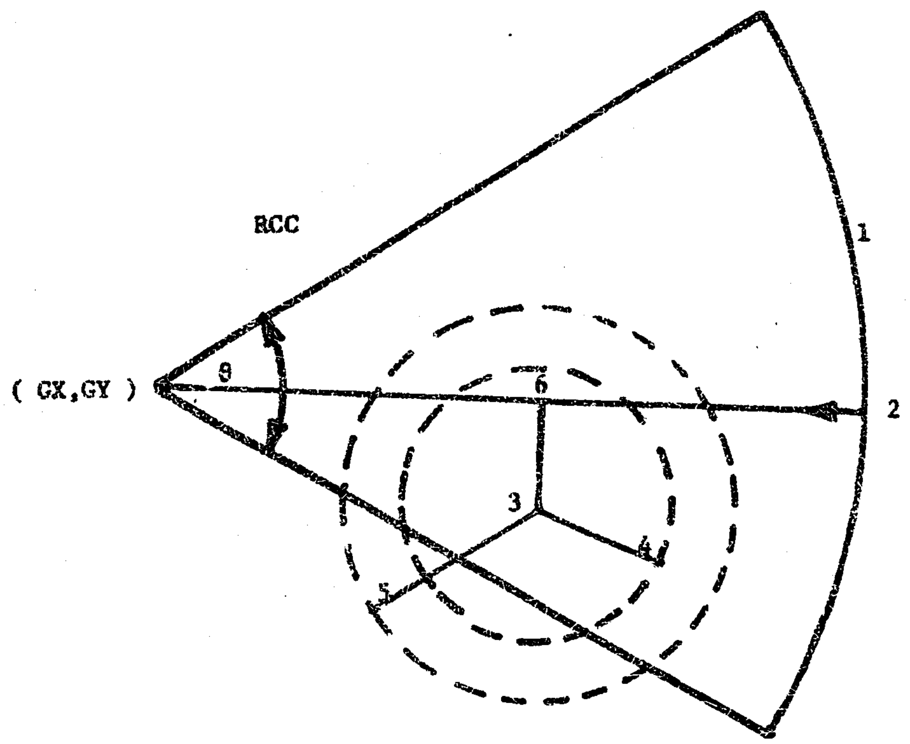
8.1 Missile Kill Probability: In order to determine an effective minimum acceptable missile kill probability for the missile system the missile kill probability was varied from 35 to 95 percent while all other parameters were held constant. The results of the model, i.e. the percent of aircraft killed as a function of missile kill probability for four raid sizes, are displayed in Figure 8. As expected, the percent of aircraft killed increases with increasing missile kill probability.

In Figure 9 is the graph of the percent of aircraft killed as a function of raid size for the missile kill probabilities of 35, 65 and 95 percent. From the graph it can be seen that for each of these missile kill probabilities the saturation raid size for the missile system appears to be between 10 and 15 aircraft, i.e. the percentage of aircraft killed seems to begin decreasing in this range indicating the missile system begins to lose effectiveness for raid sizes larger than 10. It can also be seen that there isn't much difference between the coordinated and uncoordinated firing modes. This is due to the position of the missile sites and the range of the missile in the scenario, i.e. these constraints are such that very few aircraft are simultaneously considered as targets by more than one missile site. It should be noted that for the 65 percent missile kill probability that missile system effectiveness is not at the desired level of 95 percent. Maintaining the missile kill probability at 65 percent, we shall now look at other parameters of the system to determine their effect on missile system effectiveness.

8.2 Missile Speed: The missile average speed was then varied from 600 to 1300 miles per hour. The effect on missile system effectiveness for the four raid sizes is graphed in Figure 10. The results indicate, again as expected, that the percent of aircraft killed increases as missile speed increases but is still below 95 for the raid size of 20. Figure 11 contains the graph of missile system effectiveness as a function of raid size for the selected missile speeds 600, 900 and 1300 miles per hour.

8.3 Aircraft Speed: Employing a missile speed of 1300 miles per hour and a missile kill probability of 65 percent the sensitivity of the system was tested against aircraft speed. The model was run varying aircraft speed from 350 to 1050 miles per hour. The results are graphed in Figure 12. Figure 13 contains the graph of missile system effectiveness as a function of raid size for the selected aircraft speeds 350, 750 and 1050 miles per hour. It can be seen from these graphs that missile system effectiveness decreases as aircraft speed increases and that for the aircraft speed of 750 miles per hour the missile system effectiveness has decreased below 90 percent for all raid sizes tested.

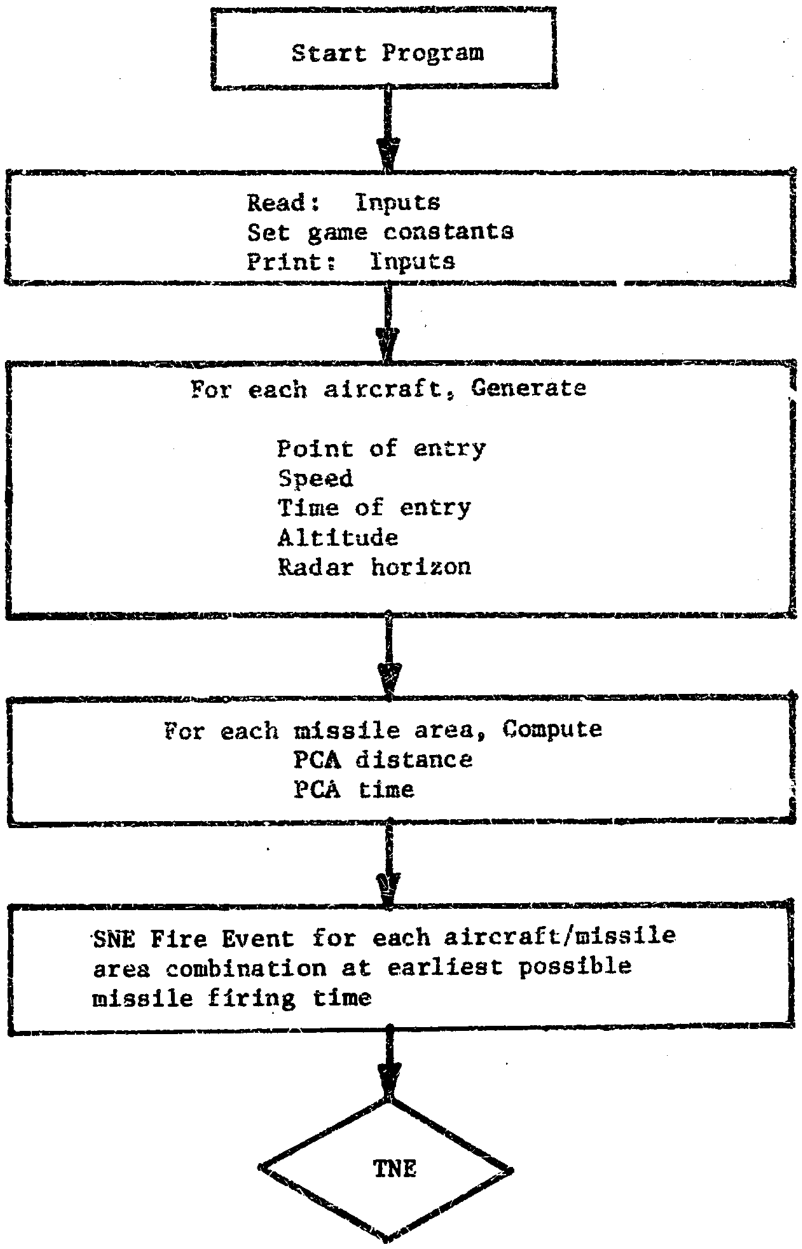
8.4 Tracking Radars and Launchers: Using the same scenario as that used above for the sensitivity of the system with respect to aircraft speed, the basic missile system was changed from one launcher and two tracking radars to two launchers and four tracking radars at each site. The results are graphed in Figure 14. This increase in missile system capability provides an increase across the board in missile system effectiveness. Figure 15 contains the graph of missile system effectiveness as a function of raid size for the selected aircraft speeds of 350, 750 and 1050 miles per hour. When comparing these results to those contained in Figure 11 it should be noted that the "doubling" of missile system capability does not in fact double missile system effectiveness. At an aircraft speed of 750 miles per hour for instance, the maximum increase in missile system effectiveness caused by the increase in missile system capability is 45 percent. The overall maximum increase in missile system effectiveness is 73 percent and occurs at an aircraft speed of 1050 miles per hour with a raid size of 20.



1: Entry arc for aircraft
2: Typical aircraft entry point and flight path
3: Location of missile site
4: Missile maximum range circle
5: Search radar maximum range circle
6: Point of closest approach
GX,GY: Center of circle defining playing area
RCC: Playing area radius
θ: Central angle

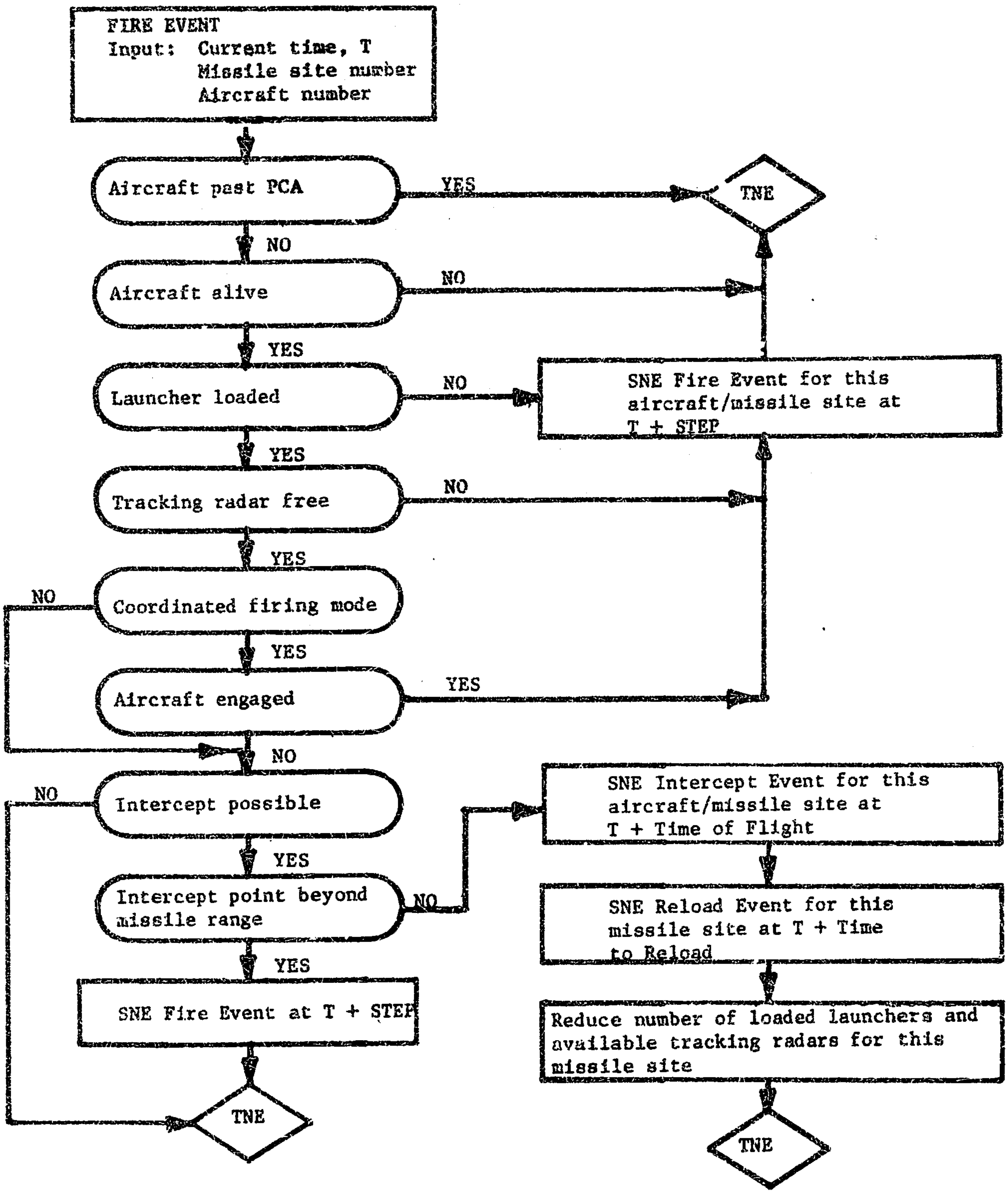
Playing Area Illustrating Missile Site and Aircraft Flight Path

Figure 1



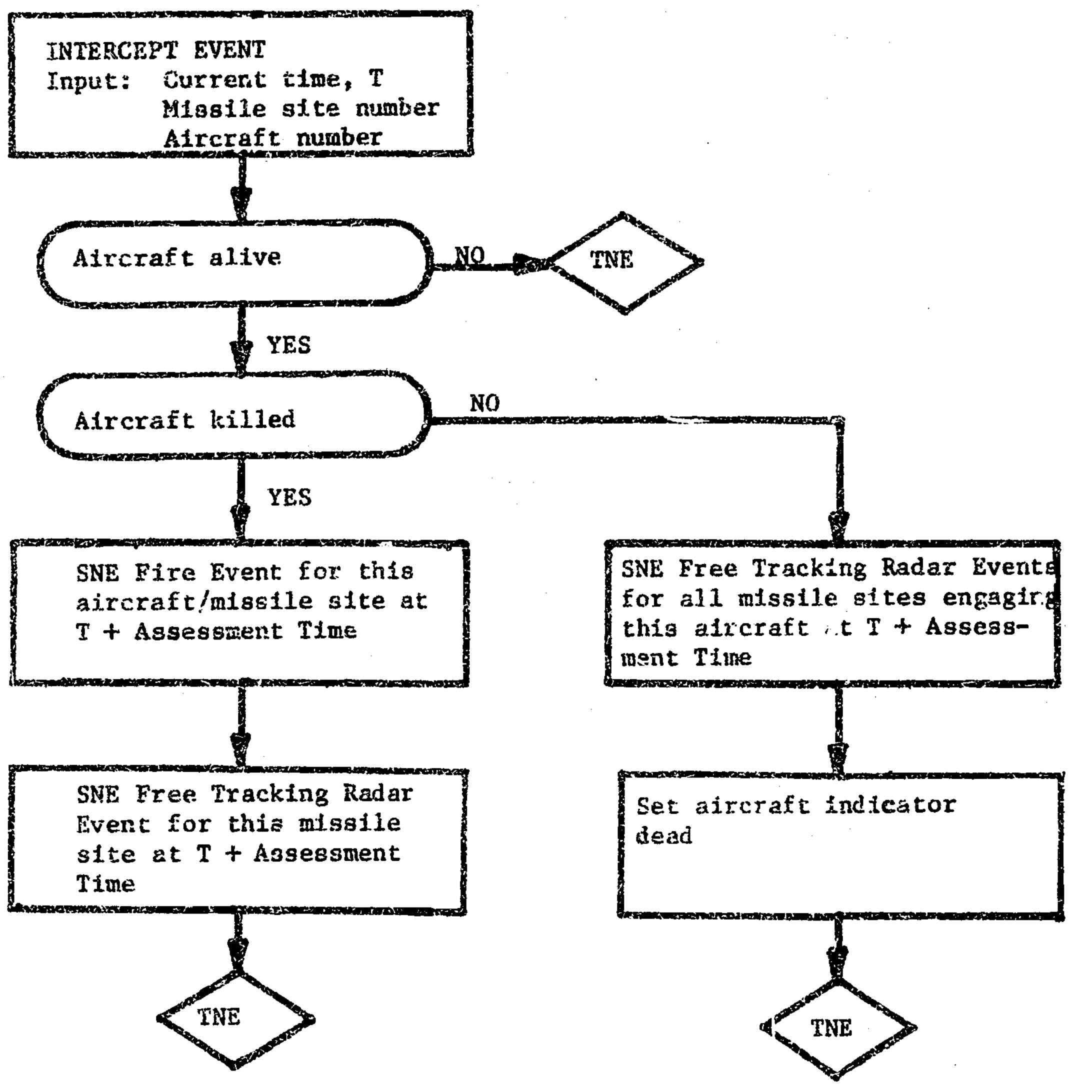
Simulation Logic for Model Initialization

Figure 2



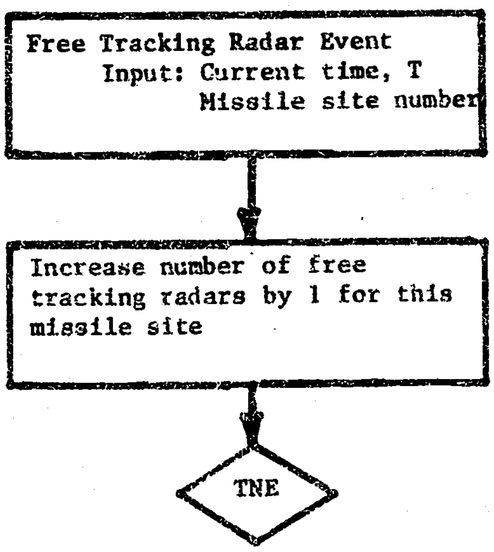
Fire Event Logic

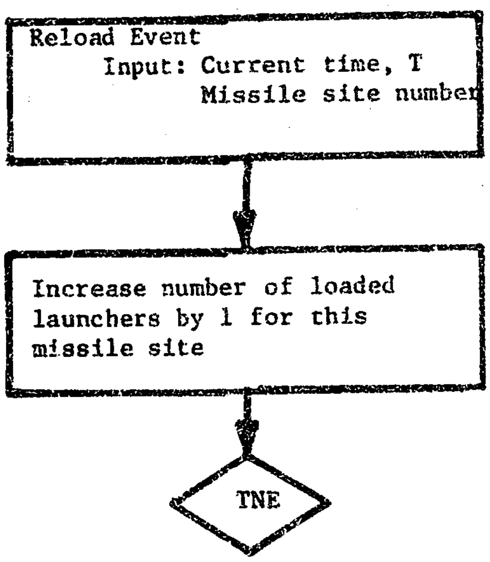
Figure 3



Intercept Event Logic

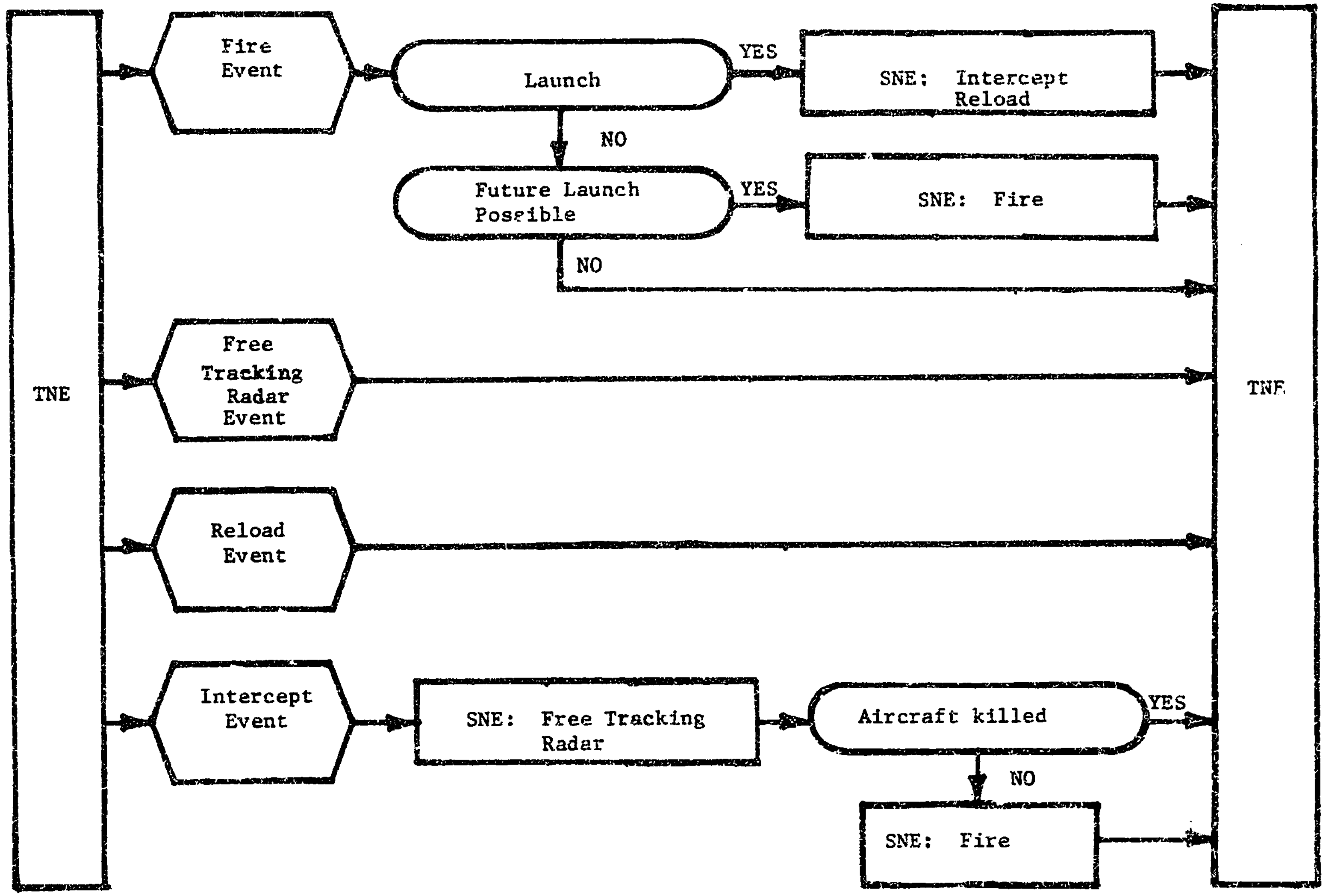
Figure 4





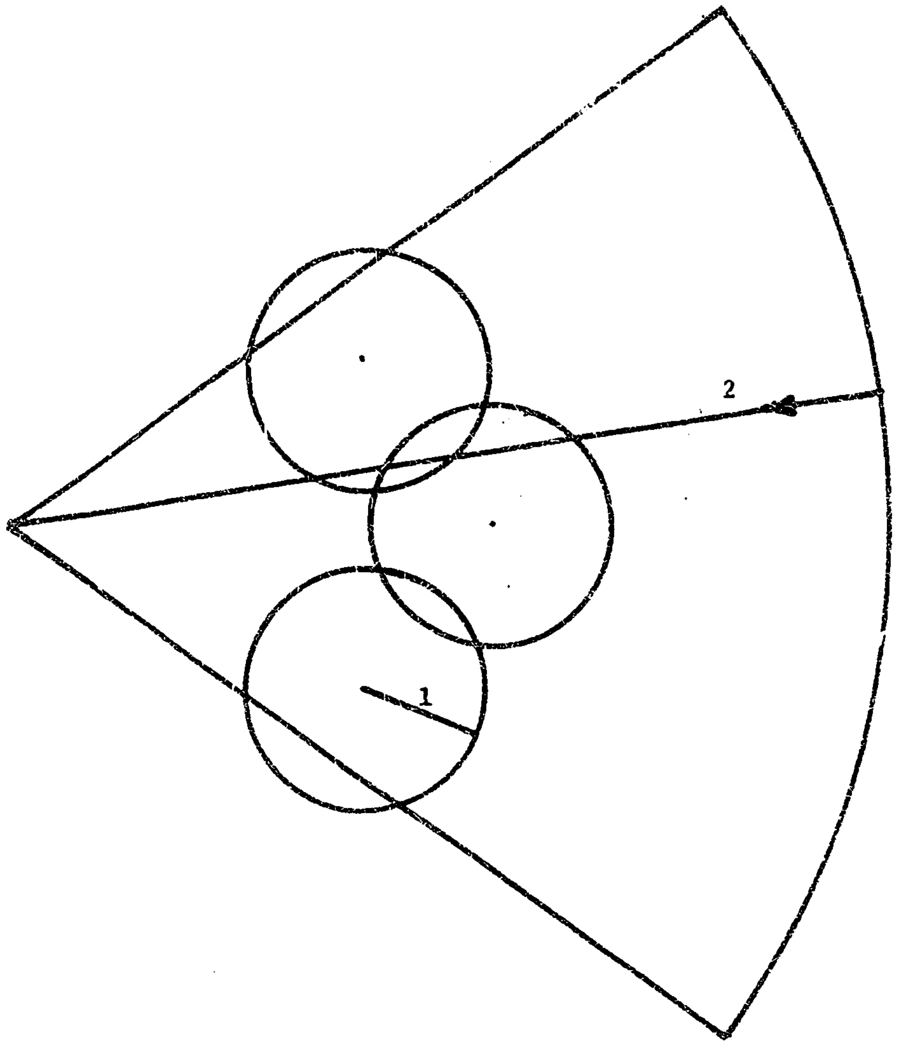
Free Tracking Radar Event Logic
Reload Event Logic

Figure 5



Interrelationship of Events

Figure 6



1: Missile maximum range, 50 miles
2: Typical aircraft flight path

Disposition of Missile Sites for Application Scenario

Figure 7

INPUT DATA A.F. ANDRUS

GAME PARAMETERS

XCOORDINATE OF CENTER	(GX) =	0.0	MILES
YCOORDINATE OF CENTER	(GY) =	500.00	MILES
RADIUS OF CIRCLE	(RCC) =	500.00	MILES
CENTRAL PLAYING ANGLE	(CPA) =	90.00	DEGREES

MISSILE AREA INFORMATION

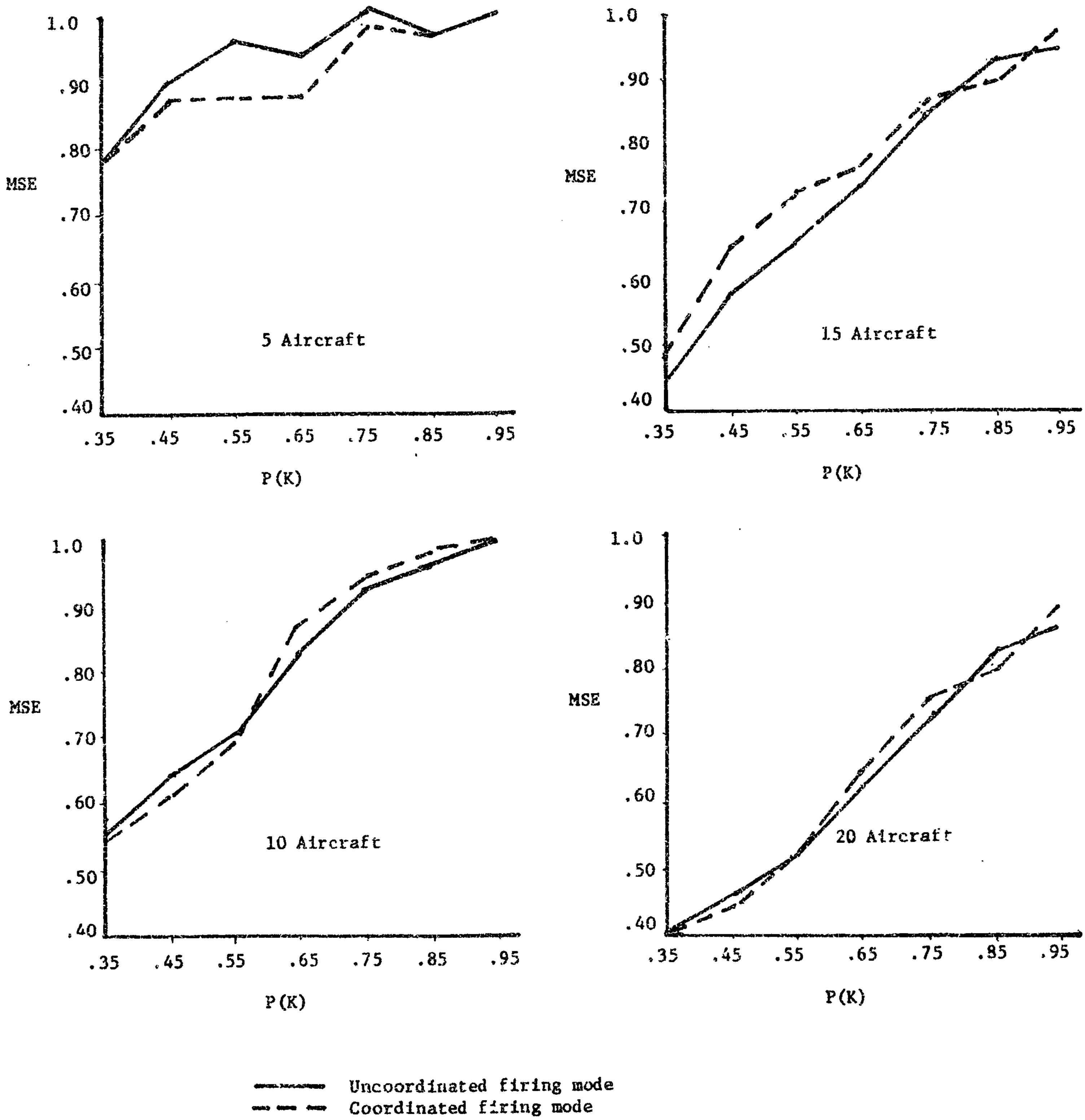
MISSILE AREA NR	1	2	3			
	150.00	160.00	130.00	MILES	AX	= XCOORDINATE
	~~570.00~~	~~500.00~~	~~430.00~~	~~MILES~~	~~AY~~	~~= YCOORDINATE~~
	1	1	1		MAL	= NR OF LAUNCHERS
	2	2	2		MTRF	= NR OF T RADARS
	200.00	200.00	700.00	MILES	RMR	= SEARCH RADAR MAX RANGE
	50.00	50.00	50.00	MILES	RMAX	= MISSILE MAX RANGE
	600.00	600.00	600.00	MI/HR	AVS	= MISSILE AVG SPEED
	0.17	0.17	0.17	MINS	ATM	= ACQUISITION TIME MINIMUM
	0.75	0.75	0.75	MINS	ATX	= ACQUISITION TIME MAXIMUM
	~~0.17~~	~~0.17~~	~~0.17~~	~~MINS~~	~~ASM~~	~~= ASSESSMENT TIME MINIMUM~~
	0.33	0.33	0.33	MINS	ASX	= ASSESSMENT TIME MAXIMUM
	0.17	0.17	0.17	MINS	RTM	= RELOAD TIME MINIMUM
	0.50	0.50	0.50	MINS	RTX	= RELOAD TIME MAXIMUM
	65.00	65.00	65.00	PER.	PK	= KILL PROBABILITY PER SALVO

AIRCRAFT INFORMATION

MAXIMUM SPEED	(DSX) =	350.0	MILES/HR
MINIMUM SPEED	(DSM) =	350.0	MILES/HR
MAXIMUM ALTITUDE	(AMAX) =	2000.0	FEET
MINIMUM ALTITUDE	(AMIN) =	2000.0	FEET
MAXIMUM SEPARATION TIME	(STX) =	0.02	MINS.
MINIMUM SEPARATION TIME	(STM) =	0.0	~~MINS.~~

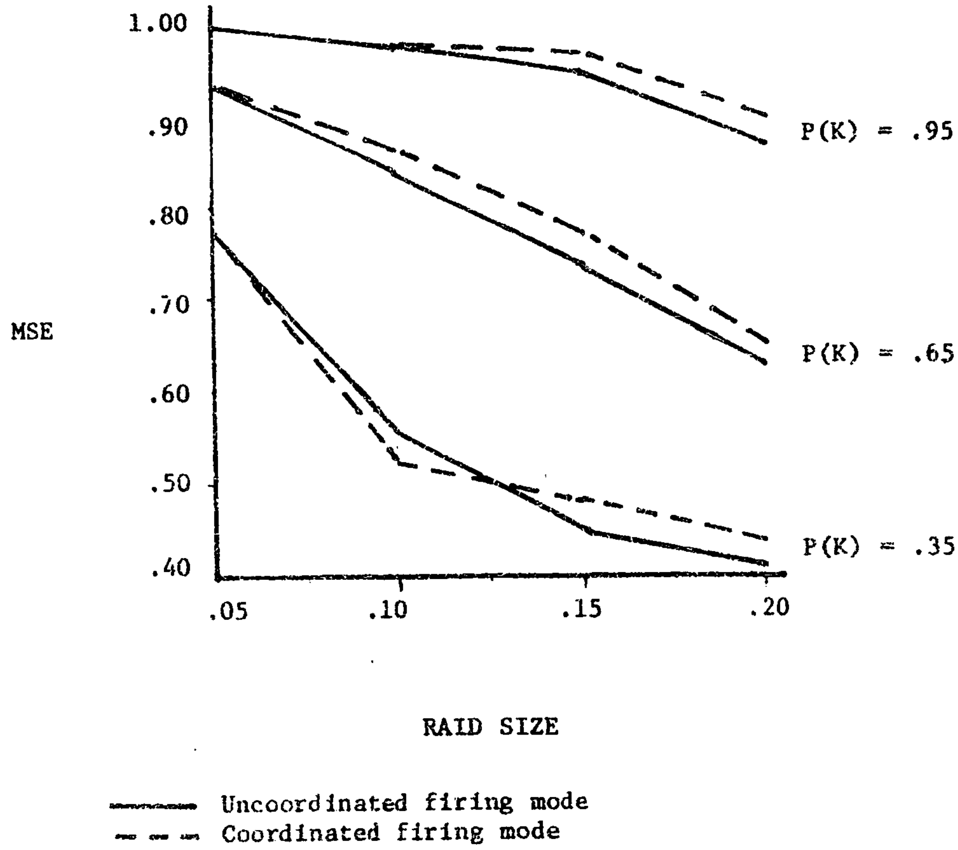
Input Information for Application Scenario

Table 1



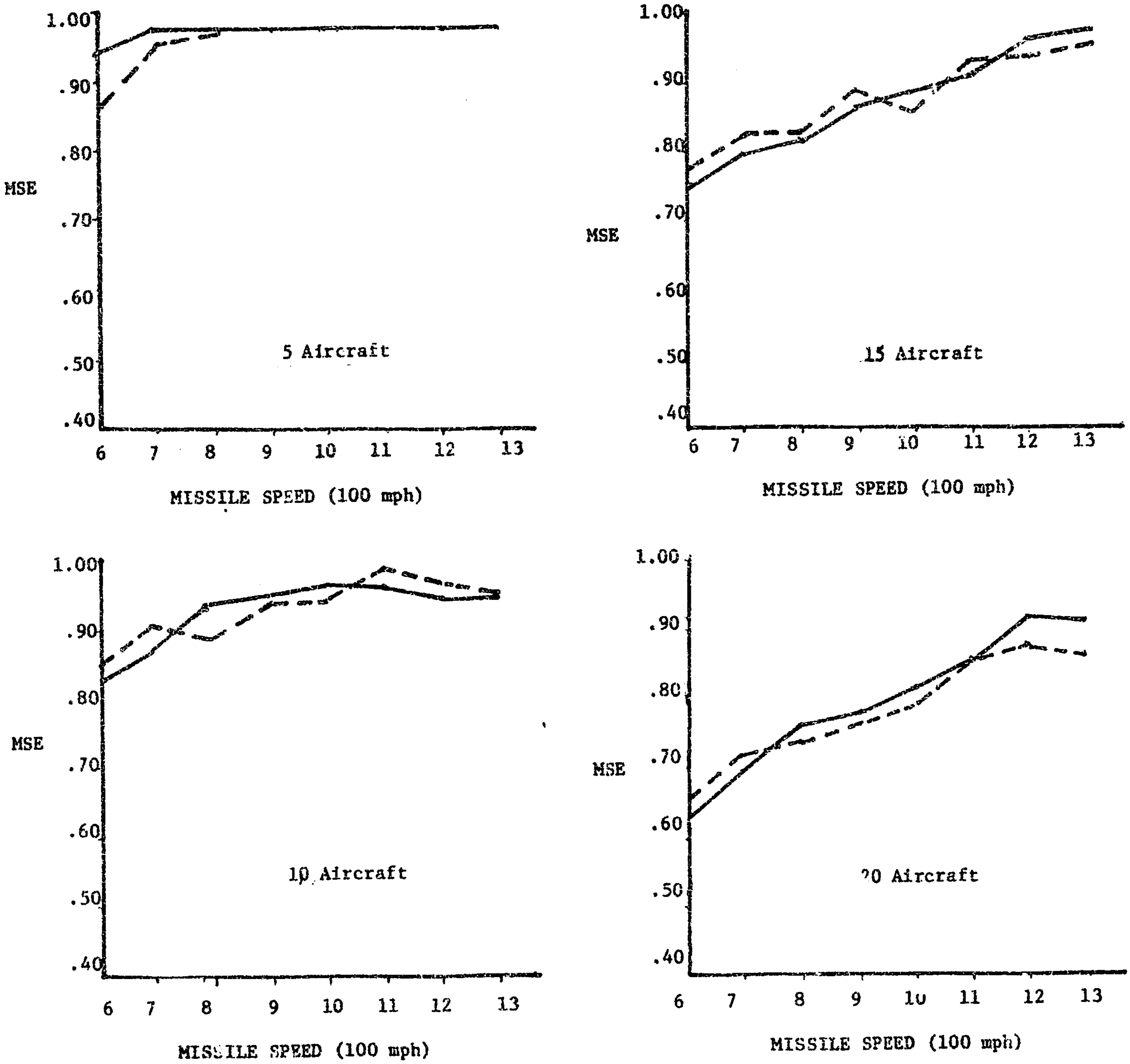
Missile System Effectiveness (MSE) vs Missile Probability of Kill (P(K))

Figure 8



Missile System Effectiveness (MSE) vs Raid Size

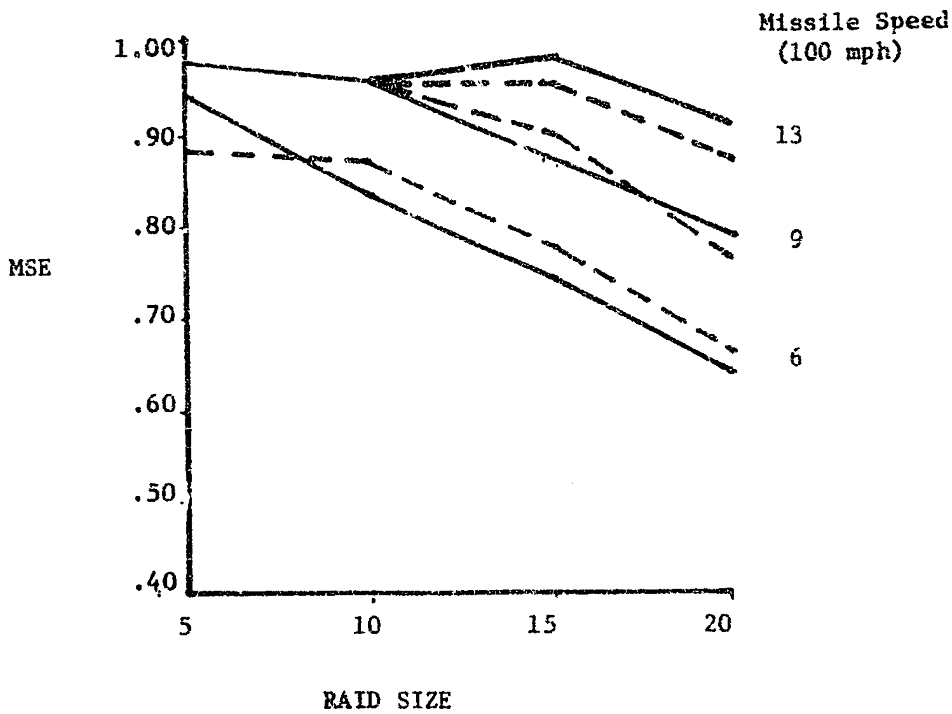
Figure 9



P(K) = .65
——— Uncoordinated firing mode
— — — Coordinated firing mode

Missile System Effectiveness (MSE) vs Missile Speed

Figure 10

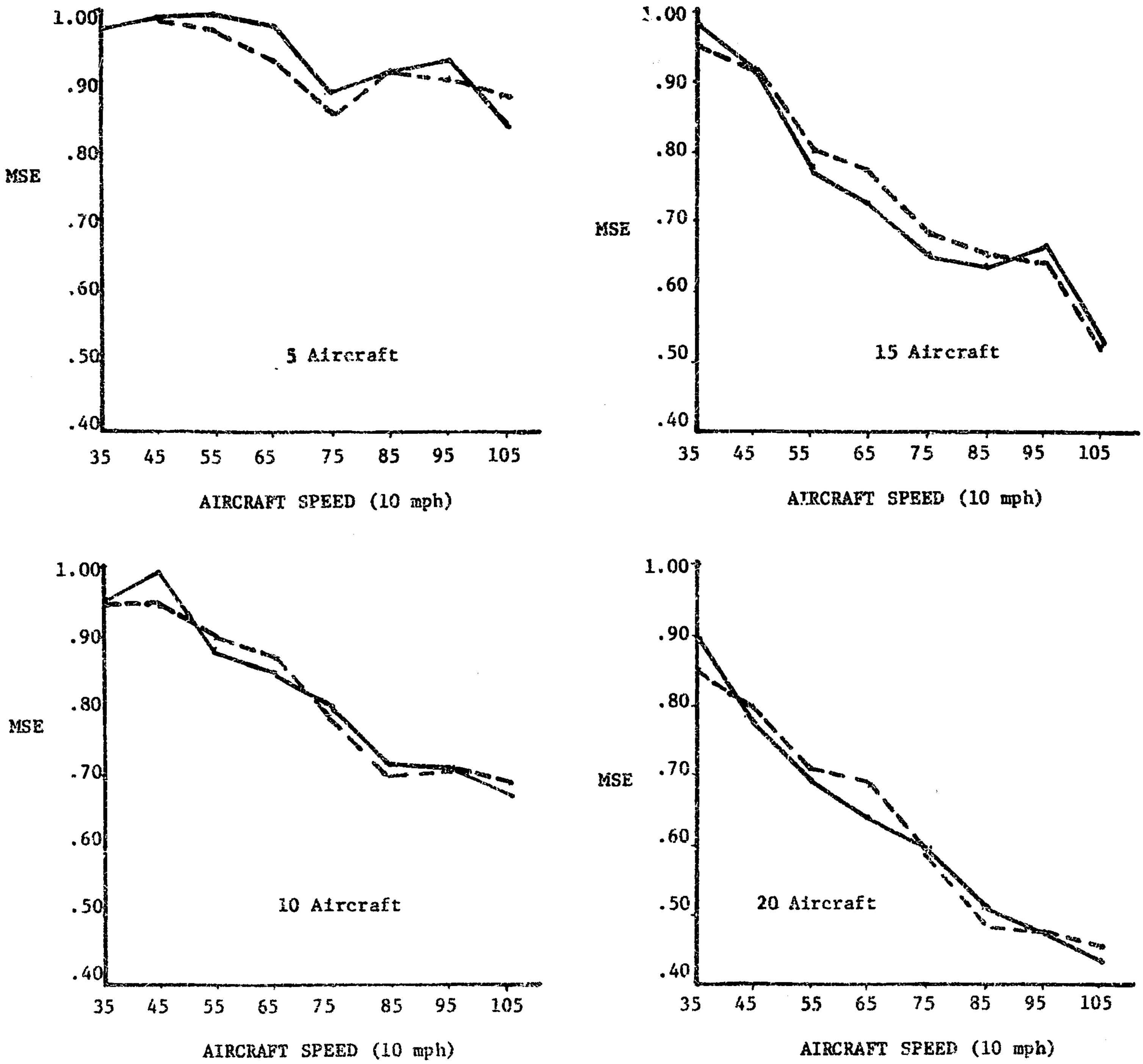


P(K) = .65

—— Uncoordinated firing mode
– – – Coordinated firing mode

Missile System Effectiveness (MSE) vs Raid Size

Figure 11



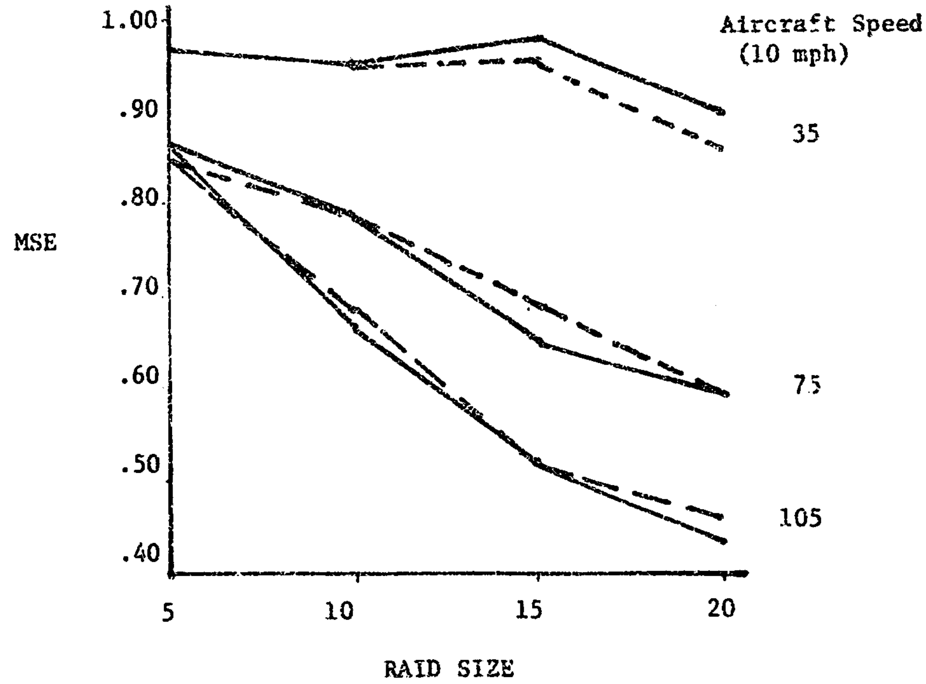
P(K) = .65

Missile Speed = 1300 mph

——— Uncoordinated firing mode
– – – Coordinated firing mode

Missile System Effectiveness (MSE) vs Aircraft Speed

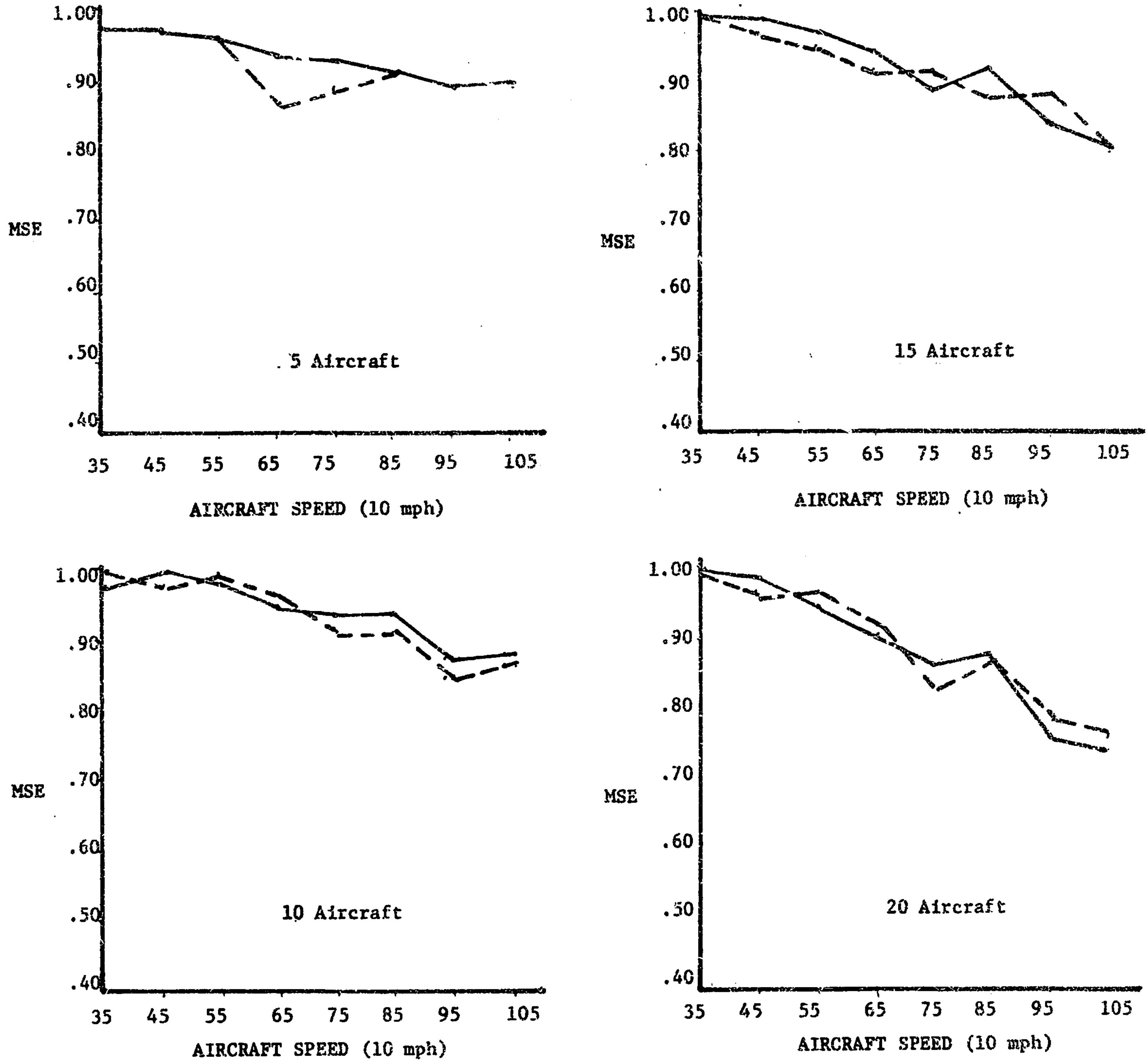
Figure 12



P(K) = .65
——— Uncoordinated firing mode
– – – Coordinated firing mode

Missile System Effectiveness (MSE) vs Raid Size

Figure 13



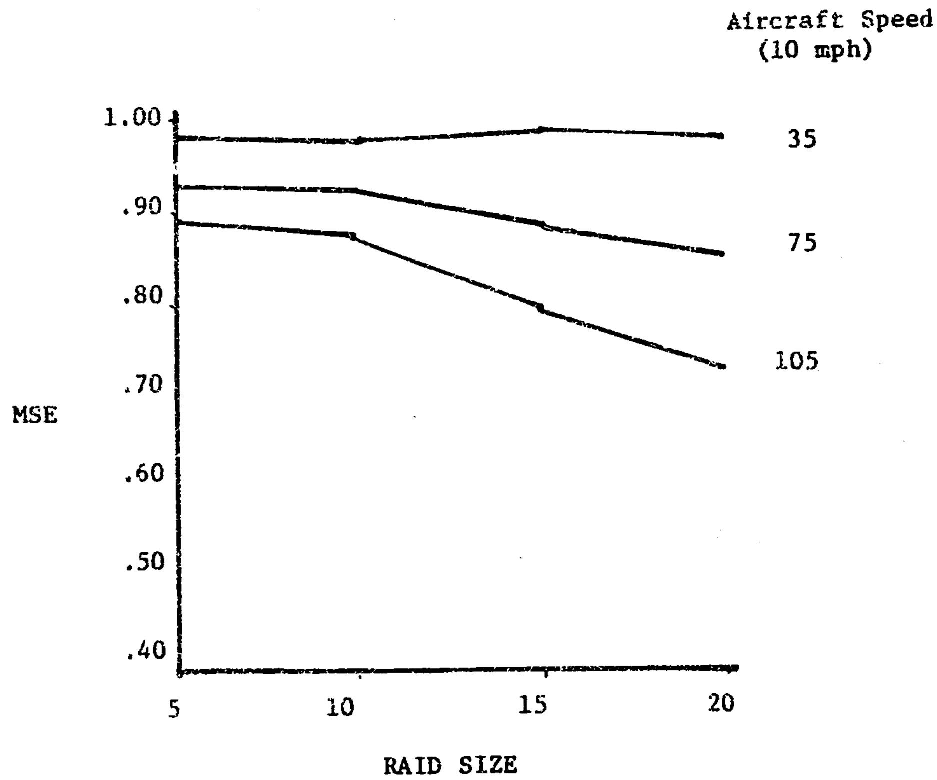
P(K) = .65
Missile Speed = 1300 mph

——— Uncoordinated firing mode
– – – Coordinated firing mode

Number of Tracking Radars per missile site = 4
Number of Launchers per site = 2

Missile System Effectiveness (MSE) vs Aircraft Speed

Figure 14



P(K) = .65
Missile Speed = 1300 mph

Number of Tracking Radars per missile site = 4
Number of Launchers per site = 2

Missile System Effectiveness (MSE) vs Raid Size

Figure 15

9. CONCLUSION

This paper has attempted to describe in minimum detail a missile system simulation and some typical applications. It has been assumed that the complexitv of the surface-to-air missile anti-air warfare situation is such that answers to the questions posed in the applications of Section 8 are not readily available by convenient analytical methods. If this is true then a model of this type can serve a useful purpose. The model has been used in several classes as an aid to solving several anti-air warfare problems. In the course in system simulation in which the model is used the student adapts the model to a problem of his own selection, creates the inputs, uses the model to generate data and then performs an appropriate analysis of the data. The simplicity of the model's structure has influenced the thinking of several students in the development of models for Master's Thesis in Operations Research at the Naval Postgraduate School.

BIBLIOGRAPHY

1. Andrus, A. F. A computer simulation to evaluate surface-to-air missile systems in a clear environment. Naval Postgraduate School. Technical Report/Research Paper No. 67. 1966.