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FEASIBILITY OF A REALISTIC AIR DEFENSE EXPERIMENTATION SYSTEM FOR EVALUATING SHORT-RANGE AND MAN-PORTABLE WEAPON SYSTEMS OPERATORS

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To determine the feasibility of using a simulation of the real world for developing a data base for SHORAD/MANPAD system operator performance, a rational analysis was made of the SHORAD/MANPAD engagement environment and the air defense man/machine system performance requirements. The products of the analysis were (1) a list of critical factors that must be represented in a simulation of the actual engagement environment and (2) a guide for developing specific air defense weapon system engagement scenarios for obtaining operator performance capabilities data. →(continued)

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The critical factor list was used to evaluate various simulation approaches, facilities, devices, and materials, leading to the selection of a reduced-scale iconic form of simulation for this project. The primary focus in describing the simulation was the target presentation system. The target presentation system adopted was a visually guided radio-controlled model aircraft. The visual image and flight characteristics of the reduced-scale aircraft targets presented a high fidelity target that also provided adequate infrared and radar sources for tracking and aiming requirements.

~~The~~ instrumentation ~~that would be~~ required to support the simulation measurement bed operation was identified generically. A general description of the simulation facility physical layout was provided, along with a description of validation tests that should be conducted prior to the final decision as to whether the facility is operationally feasible.

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FOREWORD

The U.S. Army Research Institute for the Behavioral and Social Sciences executes human performance research under the New System Design thrust of the Manned Systems Integration domain. The exploratory research effort, "Development of Realistic Air Defense Experimentation," is aimed at generating a data bank of information concerning operator performance in forward area air defense systems.

The research described in this report had the objective of determining the feasibility of a simulation facility for evaluating short-range and man-portable air defense operators.

This research was performed under Army Project 2Q162717A790 and is responsive to the needs of the Directorate of Combat Developments, U.S. Army Air Defense School, Fort Bliss, TX.

Edgar M. Johnson

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Technical Director

FEASIBILITY OF A REALISTIC AIR DEFENSE EXPERIMENTATION SYSTEM FOR EVALUATING SHORT-RANGE AND MAN-PORTABLE WEAPON SYSTEMS OPERATORS

EXECUTIVE SUMMARY

Requirement:

To determine the feasibility of using a simulation of the real-world engagement environment for developing a data base of short-range (SHORAD) and man-portable (MANPAD) air defense weapon systems operator performance. Specifically, the technical objective was to determine the feasibility of using off-the-shelf simulation techniques for forward area air defense missions.

Procedure:

Mission and engagement environment analyses were performed for four SHORAD weapon systems (Vulcan, Chaparral, ROLAND, and SGT York) and two MANPAD systems (REDEYE and STINGER). A general systems theory orientation was taken for identifying the input, operation function, and output variables that are critical to the air defense mission and systems operation.

Variables were categorized as (1) physical environment, (2) atmospheric, (3) target, (4) command and control, (5) perceptual, and (6) equipment input. A group of experts scaled 18 variables from these categories in terms of their importance for being represented in the SHORAD/MANPAD engagement environment. Instrumentation, along with a scenario generation guide, was identified and developed for evaluating operator performance and conducting research in the simulation. Methods for validating the simulation were described.

Findings:

The results of the SHORAD/MANPAD mission and engagement environment analyses produced a list of 52 variables that were used to create a matrix of input by system operation variables. Thirteen of the variables were system operation variables and 39 were input variables.

All environmental simulations except the reduced-scale representation of the real world failed to meet critical system operation input requirements. As currently configured, none of the dome or cockpit simulators can provide for the radar return signal required for three of the weapons. The only environmental simulation to meet the technical feasibility requirement was the reduced scale representation.

Eight instrumentation systems were identified for collecting and recording data from the simulation. The developed scenario generation guide consists of four sections: (1) description, (2) specifications sheet, (3) generator, and (4) system crew response procedure. Five methods, three empirical and two rational, were proposed for validating the simulation.

Utilization of Findings:

The results of the research will be used first to decide whether it is feasible to collect operator performance data in a reduced-scale simulation of the SHORAD/MANPAD engagement environments. Second, the results will aid in the decision to implement the simulation approach. Third, the general guidelines for simulations derived from the research will be used to fabricate the facility.

FEASIBILITY OF A REALISTIC AIR DEFENSE EXPERIMENTATION SYSTEM FOR EVALUATING SHORT-RANGE AND MAN-PORTABLE WEAPON SYSTEMS OPERATORS

CONTENTS

LIST OF TABLES

LIST OF FIGURES

FEASIBILITY OF A REALISTIC AIR DEFENSE EXPERIMENTATION SYSTEM FOR EVALUATING SHORT-RANGE AND MAN-PORTABLE WEAPON SYSTEMS OPERATORS

INTRODUCTION

Short-Range and Man-Portable Weapon Systems

The deployment doctrine of the U.S. Army's air defense branch integrates a set of forward area short-range (SHORAD) and man-portable (MANPAD) air defense weapons with the more complex, long-range, fixed location weapon systems (IHAWK, Nike-Hercules, and PATRIOT) to form the entire air defense network. Currently, the SHORAD and MANPAD systems include the short-range, mobile Chaparral missile weapon, the short-range, self-propelled (SP) and towed Vulcan gun weapons, and the man-portable REDEYE missile weapon. The respective follow-on systems are the ROLAND, SGT York, and STINGER systems. A brief description of the six weapon systems is provided below.

Chaparral. The Chaparral weapon system is a highly mobile surface-to-air, infrared (IR) homing guided missile system designed to counter the high-speed, low-altitude threat to organizations and critical assets in the forward areas. Chaparral is fielded in the self-propelled configuration only; however, the launching station is a complete, self-contained weapon system and may be separated from the carrier and operated in a ground-emplaced mode. Effective employment of the system depends on visual target detection, tracking, and recognition. Chaparral is considered to be a fair weather system capable of operation only during periods of good visibility. The system is composed of three major elements: the launching station, carrier, and Chaparral missiles.

ROLAND. ROLAND is an all weather, short-range air defense missile system designed to limit the damage inflicted by low-altitude enemy air attack under the Nike-Hercules/IHAWK and/or PATRIOT umbrella. The fire unit module is mounted on a chassis and has a search-on-the-move capability. ROLAND contains two radars: surveillance and tracking. These radars operate effectively during all weather conditions and are capable of operating with severe ground clutter and in active and passive electronic countermeasure (ECM) environments. To enhance ROLAND's flexibility, an electro-optical sighting system can be used during favorable weather and/or in intense ECM environments to provide a more accurate alternative to radar tracking. This sight may be used independently or in conjunction with the tracking radar. The ROLAND command-to-the-line-of-sight guided missile is a certified round that is contained in a sealed launch tube from which it is fired. The fire unit has the capability for a full, on-board load of 10 missiles, 1 on each of the launch beams and 4 in each of the 2 magazines. Reloading of the launch beams can be done automatically.

Vulcan. The self-propelled Vulcan weapon system is a surface-to-air gun system with a surface-to-surface capability. It is deployed in forward areas of the field Army to protect against hostile aircraft operating at low altitudes.

Since visual target detection, tracking, and identification are required to engage hostile aircraft, the system is capable of air defense operation only during periods of good visibility. The Vulcan system can be used in the ground role for perimeter or area defense in daylight or darkness. It can be used to deliver a high rate of fire during assault. The SP Vulcan weapon system consists of a six-barrel, 20mm, automatic cannon with a fire control system mounted on a full tracked armored chassis. It is capable of high-speed travel on improved roads, extended travel over rough terrain, and amphibious operation on streams and small lakes. The system is equipped for on-vehicle intercommunications between crew members and voice radio communications.

The towed Vulcan air defense artillery weapon system consists of a six-barrel, 20mm cannon and a fire control system mounted on a two-wheel trailer carriage. The system is capable of being towed at high speeds over improved roads, traveling over rough terrain, and fording streams to a depth of 30 inches. The towed Vulcan has essentially the same target engagement capability as the SP Vulcan. The cannon characteristics, fire control system, and modes of operation are the same as those of the SP Vulcan; the primary difference is that the towed Vulcan uses a linked feed system and is mounted on a trailer. The system is designed to be towed by a 1-3/4-ton truck; however, an adapter permits the system to be towed by a 2-1/2-ton truck. The system is air portable by cargo aircraft and helicopter and can be air dropped.

SGT York. The SGT York system is a 40mm gun system that can be used in a point and area defense. The system is track mounted and self-propelled. The system is also equipped with identification friend or foe (IFF) capabilities for target identification. The system is equipped with a target-tracking radar and computer system that can automatically control the tracking system of the weapon. Target detection, acquisition, and identification occur visually and electronically. Radar detection, acquisition, and identification are followed by visual confirmation. The gunner monitors an optical sight with a 5° field of view and the squad leader uses a periscope with a 20° field of view. Both can control target tracking.

REDEYE. REDEYE is a man-portable, shoulder-fired, infrared homing guided missile system designed to provide combat units with the capability of destroying low-altitude hostile aircraft. Because it is man-portable, it can be deployed easily and flexibly throughout the forward area. The REDEYE weapon can be employed to provide protection for battalion maneuvers and artillery assets. REDEYE can destroy a wide variety of aerial targets, including jet and propeller aircraft, helicopters, and reconnaissance drones. Effective employment of the system depends on visual target detection, tracking, and recognition. To successfully destroy the target, the system's infrared sensing tracking head must maintain lock-on to the target's heat source. REDEYE is considered to be a fair weather system capable of operation only during periods of good visibility.

STINGER. STINGER is also a man-portable, shoulder-fired, infrared homing guided missile system. STINGER provides air defense to combat arms battalions and selected combat support units. STINGER is designed to counter high-speed, low-level, ground-attack aircraft. Also, it is a lethal weapon against helicopter, observation, and transport aircraft. The STINGER weapon system has the capability of electronically identifying whether the target is friend or foe. When the IFF interrogator is used with the weapon, it helps identify friendly aircraft. Effective employment of the system depends on visual target detection, tracking, and recognition. STINGER is considered to be a fair weather system capable of operation only during periods of good visibility. The STINGER must also maintain IR lock-on.

In each of the SHORAD/MANPAD systems, the human operator must perform a sequence of tasks in order to engage enemy targets. When a crew is on alert status, all members of the crew first visually search for aerial targets. When a target has been detected, the operational mode shifts to the recognize/identify task. The identification of the target as friend or foe is the responsibility of the squad leader or crew chief. The next task is for the operator to acquire the target in the system sight. When the target has been acquired, the operator begins to track the target using the manual or automatic mode. Tracking continues until the target is determined to be within the proper envelope for engagement. The REDEYE, STINGER, and Chaparral systems require that, before launch, the operator attain infrared acquisition while continuing to track. The ROLAND system requires radar acquisition before firing. The Vulcan and SGT York systems have both manual and radar options for tracking and engaging the targets. Slew rate signals are provided to the gunner to indicate whether system capabilities have or have not been exceeded. Once these engagement criteria have been met, the operator fires the weapon, while maintaining track for a few seconds. After the firing event the operator monitors for effect to assess target damage, or to decide to reengage the same target, or to engage a new target, depending on the engagement command.

Background

Beginning in 1964, the Human Resources Research Organization (HumRRO) initiated a series of studies to investigate the perceptual performances required of forward area air defense crewmen. The first study (Wright, 1966) involved a combination of visual target detection, recognition, and range estimation, with and without binoculars. This study was requested by U.S. Army Air Defense School (USAADS) personnel who were preparing the training program for the REDEYE operators. The data were also to be used in engagement war gaming to evaluate air defense weapon effectiveness. Performance envelopes were developed for scenarios in which target altitude, direction, speed, and crossing angle were varied.

The research continued in connection with joint services studies carried out by Joint Task Force Two (JTF-2) (Frederickson, Follettie, & Baldwin, 1967; Baldwin, Frederickson, Kubala, McCluskey, & Wright, 1968) in which both offensive and defensive capabilities were evaluated for air defense weapon systems and military aircraft. The JTF-2 studies also included the evaluation of foreign weapon systems. For most of the air defense weapon systems, target detection and identification data were obtained under a wide variety of conditions. The critical detection parameters identified in these studies were atmospheric conditions (humidity and dust), target/background contrast ratio, early warning, and search area. During the conduct of these studies, similar work was also being carried out in Germany (Doetsch & Hoffman, 1966). Conclusions from these studies were essentially the same as the American studies, except their detection ranges were much shorter because of the high humidity in Germany compared to the desert environment where most of the HumRRO studies were conducted. In a subsequent publication, Wirstad (1967) compared the results of the two HumRRO studies with the results of a Swedish research program. The complex operator problem of detection-recognition-range estimation was the focus of this comparison. A particular emphasis in that discussion was the relationship between aircraft recognition accuracy and range at recognition. Where aircraft have recognition features that consist of fine detail, recognition distance is quite short. If the recognition features are gross, recognition distances are greater.

Several research directions grew out of the initial HumRRO work. One was the detailed study of aircraft recognition (Vicory, 1968; Whitmore, Cox, & Friel, 1968; Vicory, 1969; Miller & Vicory, 1971; Whitmore, Rankin, Baldwin, & Garcia, 1972). This effort led to the development of the aircraft recognition training program and materials currently being used in forward area weapons training. This research provided input to the development of the ground observer aircraft recognition (GOAR) training slides and the printed materials.

Another direction was the development of a training program to teach riflemen to detect, recognize, estimate range to, and engage aerial targets (McCluskey, Wright, & Frederickson, 1968; McCluskey, 1971). To make this training feasible, a scaled down training environment was established and evaluated. The validation studies involved whole task activities except for target identification.

One last research direction that evolved from these early studies was the investigation of the use of scale model aircraft as targets for detection, recognition, and tracking research (Baldwin, 1973; Baldwin, Cliborn, & Foskett, 1976). At first, static scale model aircraft were used, and later U.S. Army personnel used radio controlled models as part of the small arms aircraft engagement training.

Because of the introduction of the forward area alerting radar, several studies were included later that involved the introduction of early warning information and information hand-off (crewmen to crew chief) (Baldwin, Frederickson, & Hackerson, 1970). The information hand-off studies were planned because of the requirement for the crew chief to make the final identification of an aircraft.

Statement of the Problem

The studies described above answered questions that were relevant to the needs of the 1960s, but do not address a more important issue that is emerging with the introduction of new weapons. That issue relates to the capabilities of systems (man/machine) to accomplish mission objectives that depend on the successful performance of an interrelated and dependent series of system actions.

The earlier studies investigated operator capabilities for performing separate actions taken out of the context of the entire engagement sequence. They were "part task" studies. Those who used the research results for additional war gaming studies of weapon system capabilities assumed that full task performance could be determined as an additive function of the part task data.

The assumption was incorrect, however, since the separate events within the engagement sequence are not independent. In most task sequences, information is constantly being gathered, processed, and stored. Information gathered and used in the first task may also be needed in the fifth task, for example. If these tasks were studied independently, that information would have to be obtained separately, thereby lengthening the estimate of the real time required to perform the fifth task, and also the entire engagement.

Other kinds of interactions between the tasks can also be noted. When performing an event, an operator adopts a set (expectations, anticipations, etc.) relevant to the characteristics of the kind of action to be performed. Each time the kind of action changes, the set must be changed. This programing takes time, which is confounded with response times in a sequence of differing but continuing actions. When tasks are studied independently, the set is usually adopted or prepared for before the study begins.

A major problem in the design, development, and deployment of a weapon system could occur if the assumptions about human performance capabilities, based on data obtained in part task studies, proved invalid. A major problem here would be faulty allocation of functions to the operator and/or the equipment. For example, where independent studies of two separate actions may indicate each action was well within the performance capabilities of the specified segment of the population (extreme, 5th to 95th percentile, or average, 40th to 60th percentile), such actions would be allocated to the human operator. However, when the operator tries to perform the actions in succession, the interactions between behaviors may be such that the criteria for the second action cannot be met.

Another problem that might result from the use of part task rather than whole task data would concern the prediction of weapon system operational capabilities. The results of studies where engagement tasks are investigated independently of each other could lead to erroneous estimates of capabilities, and, subsequently, deployment and/or tactical doctrine decisions could be in error. Overestimates of capabilities might lead to significant underestimations of resources needed for either area or point defense. Underestimations of system capabilities could cause the opposite problem of a waste of resources in deployment decisions.

Where sufficient and valid system capability data exist, these design, development, and deployment issues would not necessarily be problems. A significant area of research that is needed is to assess empirically the performance of the air defense weapon systems operator during the entire engagement sequence to produce whole task performance data. In order to accomplish this objective, a performance experimentation system needs to be established.

The ideal situation for determining performance capability would be to use the real-world environment that would be expected to exist in combat. This would, however, be very costly, tie up tremendous amounts of resources, and logistically be very difficult to manage. The decision, then, was to determine if it would be feasible to use some representation of the real world to obtain valid performance data that would match or come close to that which would be obtained in the ideal situation. The major issues were those of determining which aspects of the real world need to be represented to produce valid estimates of operator performance and how this should be done. The two questions are interrelated in that the amount of information needed for answering the first question is related to the answer to the second. That is, some forms of real-world representation require a great deal of data to specify just how the fidelity must be achieved, whereas other forms of real-world representation need much less data.

A research project was designed to address these issues. The overall purpose of the study was to determine the feasibility of a realistic air defense experimentation system (RADES) for assessing the performance capabilities of operators of man-ascendant forward area air defense weapon systems. A man-ascendant system was defined as one that relies on human input to the control, operation, and decision-making functions of a system. These inputs were identified as being based upon perceptual, psychomotor, and cognitive processes in man's functioning as a systems operator. The processes occur simultaneously, thus resulting in a complex man/machine operation. It was the measurement of the behavioral results of the interaction of these processes with each other and the system's environment that was the focus in addressing measurement issues.

This report is divided into five sections. The first analyzes the SHORAD/MANPAD engagement environment and identifies critical parameters that must be included in the experimentation system. The second describes various simulation approaches, facilities, devices, and materials and assesses the simulations' applicability to the RADES requirements. The third identifies the needed instrumentation for recording operator performance and presents a general blueprint for the fabrication of a RADES. The fourth discusses the development of a guidebook for generating scenarios and designing experiments to be followed and used in the experimentation system. The fifth details the experiments that are required to test the validity of the RADES facility.

IDENTIFICATION OF CRITICAL PARAMETERS

In order for a generalizable RADES to be created, a considerable amount of preliminary work was required. Following the suggestion of Lewis (1953), close attention was paid to the relationship between the physical organization of tasks and the complexities of behavior. This was especially true for tasks with significant stimulus cue elements such as target detection, recognition, identification, and engagement. The research problem that existed in establishing RADES was to identify and describe in detail those job environment characteristics that had to be simulated and those that could be ignored. This involved analyses of a range of job situations and conditions for each of the air defense weapon systems for which RADES might be used.

The analysis was based on information gathered from two sources--reference documents and subject matter experts (SMEs) for each weapon system. The reference documents included research reports, field manuals, technical manuals, crew drill procedures, simulation descriptions, soldier's and commander's manuals, Army training and evaluation programs, and Army training tests. The subject matter experts for the REDEYE, Chaparral, and Vulcan were field experienced. The STINGER, ROLAND, and SGT York SMEs had system experience only during the operational testing of the weapons.

In-depth interviews were conducted with the SMEs from the various systems concerning the engagement environment conditions, cues, and features that they encountered as systems operators. The interview was semistructured in that the SMEs were questioned about specific topical areas and, then, any potentially fruitful response was pursued in-depth. The topical areas that were covered were essentially the same for all systems. The outline that was followed for these mission, job, and task analysis interviews is presented below.

1. Position
   a. Types of environments
   b. Site characteristics and doctrine
   c. Restrictions on weapon use and movement

2. Detect target aircraft
   a. Who detects
   b. How--visual or analog representations
   c. Detection stimuli and their environment
   d. Limits on detection
   e. Interactions between stimuli and conditions

3. Target recognition
    a. Recognition characteristics and information
    b. Information for firing decisions
    c. Recognition skills
    d. Augmentation of operator senses
    e. Restrictions on identification
    f. Interactions between target recognition stimuli and conditions

4. Discrimination of engagement envelope
    a. Visual and electronic environment
    b. Tactical situations governing target engagement
    c. Physical and environmental conditions impacting engagement
    d. Engagement ranges and how it is determined that the target is within range
    e. Probable enemy air threat tactics
    f. Engagement decision rules

5. Engagement options
    a. Different modes of target detection, acquisition, identification, and tracking
    b. Rates of fire

6. Preparation for engagement
    a. Engagement options
    b. Preparation actions--arming, fusing, and energizing
    c. Special orientation or aiming procedures for infrared or radar acquisition

7. Aiming and firing the weapon
    a. Aiming cues and visual characteristics
    b. Aiming procedures
    c. Maintaining correct track
    d. Common aiming errors
    e. Aiming required after weapon is fired

The detailed analysis of the weapon systems' operational requirements proceeded in several stages. First, the systems as a whole were analyzed in terms of a general systems model as shown in Figure 1. Then each of the major elements--input and operational function variables--was analyzed in detail. The analysis of the input variables essentially identified the specific conditions, cues, and features of the engagement environment that have significant impact upon the operation of the weapon systems.

The analysis of the operational function variables took the form of a job and task analysis. The focus was on the job of the system operator, but inputs from other team and crew members were also identified. For example, as pointed out in the description of the weapon systems, the crew chief in the SGT York system plays an integral role in the engagement sequence along with the gunner. The results of the job analyses were used to develop a crew/crewman generic scenario for each of the six weapon systems.

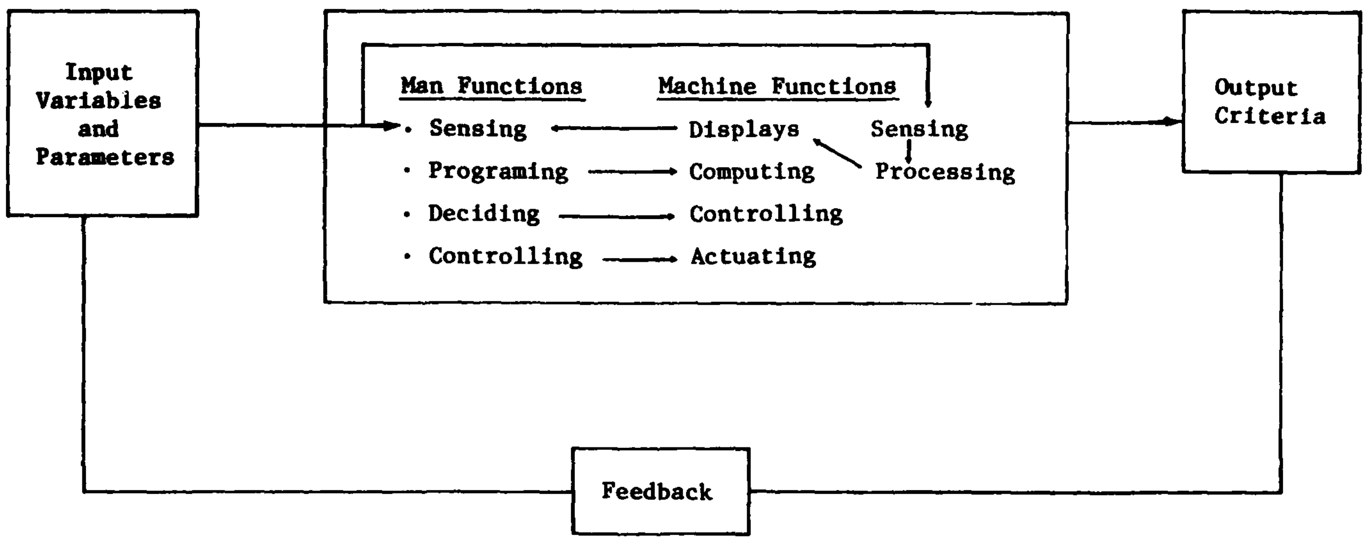

Figure 1. The general systems model used to guide task analyses.

Input Variables

Input variables were defined as independent and external to the man/machine operational subsystem. Significant input variables were identified as causing the system to take various actions in order to carry out its function. Some input factors establish fixed aspects of the system's status, while others continually vary and must be dynamically attended to by the system. Five major categories of input factors were identified for the RADES model:

1. System mission,
2. Command and control,
3. Logistical support,
4. Physical characteristics and atmospheric conditions of the environment, and
5. Target features and dynamics.

The analysis of engagement requirements revealed that the SHORAD/MANPAD weapon systems operate in an environment that is both static and dynamic. The weapon systems are usually emplaced in defense of a specific point critical to military operation or of an area over which control is to be maintained. The system is essentially static until an aerial target approaches or appears. During this period the crew, when on alert status, is involved in surveillance, searching the sky for targets. This activity is initiated by the alert status cue, which may be implied in the unit's mission, or specifically given from an outside source. The outside source can be a higher headquarters or an early warning alerting network, such as other Army units or the forward area alerting radar. Once an alerting cue is received, the system prepares for action as called for in its mission and by its command and control status.

The weapon also receives logistical support, which is necessary for sustained action over a period of time. At any one time the level of supplies, materials, missiles, and ammunition that a unit has is fixed. A fully supplied unit is prepared to carry out its mission. One not fully supplied must operate at some reduced level of mission capability. Either condition dictates a specified level of action that is possible. Mission and logistics factors can be assumed to be fixed as given parameters. Seldom, if ever, would these factors vary during a specific engagement sequence. The command and control variable could vary during an engagement sequence, but will be considered fixed for research purposes. Certain weapon system actions are allowed for given levels of these parameters and other actions are prohibited by the doctrine called forth by the parameters.

When emplaced, the physical environment presents a set of static conditions. The type of terrain, amount of foliage, and number of man-made structures fix the field of view of the crew members as they search for targets. Different emplacement locations may present vastly different fields of view. In some locations there may be significant masking of the horizon in some directions, terrain background in other directions, and unobstructed views to the horizon in other directions. In such a situation, the static aspect of these physical features becomes dynamic when an aircraft maneuvers in the area. It becomes dynamic in that as the aircraft maneuvers, its characteristics and features interact with the visual surround in several ways. It may be visible and then become masked by terrain features, foliage, or structures. Such interaction would interfere with or prevent detection, recognition, tracking, and ranging.

The atmospheric conditions tend to be quite variable and are mostly independent of the physical environment. They create a dynamic aspect to the system's environment in that the amount of illumination, the sun angle, and the cloud background are constantly changing. The composition of the atmosphere constantly changes depending on the wind, humidity, and temperature. A complex situation occurs when an aerial target appears. The interactions of two dynamic elements, the target and the atmosphere, create a difficult visual image problem at times. The specific dimensions of the environmental conditions that were identified as significantly interacting with other input factors were terrain and foliage features, illumination, sun angle, particle density, humidity, wind, and temperature.

The most dynamic aspect of the SHORAD/MANPAD environment is the aircraft target. There are two critical impacts that the target has upon the weapon system. The system's operator and the system equipment both function as sensors, and both sensor systems are absolutely essential to mission success. The operator receives visual and auditory signals that must be interpreted and acted upon. These signals come from two sources--from the target aircraft and from the system displays. The signals from the displays are transductions of signals that the equipment sensors have received from the target aircraft. In the case of the REDEYE, STINGER, and Chaparral, the systems pick up infrared signals from the heat of the exhaust system or from the engine of the target. These systems operate only if the IR signal is present from the target. The ROLAND, Vulcan, and SGT York receive and operate on a radar return signal. The Vulcan uses the radar signal for computing the aiming lead required for hitting the target when firing. The SGT York and the ROLAND use the radar signal for target tracking, and the ROLAND uses target position information for guidance commands to the missile. These systems rely, for total functional success, on both the operator's and the equipment's sensing of and acting on signals from the target. It is, therefore, essential that both kinds of signals be presented in the simulation facility.

The information cues that the operator must act upon are additionally complex in that the dynamic interaction of the target with its physical and atmospheric environment constantly alters the visual information that is presented. The information must continually be sensed, interpreted, and acted upon. The detection, recognition, ranging, and tracking tasks are variously affected by how well the operator can and does handle the visual, cognitive, and psychomotor requirements.

Many target features and dynamics were identified as having potential impact on the visual perception responses of operators. The general physical parameters of a visual nature that were identified were the detailed target features including markings, size, color, shape, inherent contrast, luminance, reflectance, and exhaust smoke. Other target characteristics were identified as interacting with the tracking performance of the operators. These included target location in space (range, azimuth, and elevation) and motion (velocity, heading, and climb/dive angle). Atmospheric conditions and target characteristics interact so as to create sets of perceptual cues that are significant to target detection, recognition/identification, and tracking. These include the target/background contrast ratio, surface texture, degraded resolution, target cue discrimination, and size and shape constancy. The degree of similarity between high probability targets was considered another important issue for target identification. The relationship of the operator to the sun and target is also important. A last visual characteristic is an operator variable that may compound or enhance the detection of visual cues--visual acuity.

Importance of Interaction of Visual System Variables

The goal of RADES was stated as generating data about how well an operator can perform job tasks. Therefore, the conditions under which the performances are measured must include the necessary and sufficient experiences and cues that will validly represent the proficiency levels expected to be exhibited in the real world. Operator job performance requirements have been described as sets of procedural activities. Miller (1974) defined a procedure as a kind of behavior in which discrete, principally all-or-none, responses are made to cues or to specific values of cues in a continuous series of stimuli presentations. He further pointed out that the procedures are verbally mediated early in training. A conclusion reached from Miller's definition was that procedures could be expected to break down if all necessary cues were not present in a performance measurement situation.

The primary focus of the visual orientation of the SHORAD/MANPAD systems operators was determined to be the aircraft target, identified as the source of cues that trigger the starting and stopping of the engagement events. Environmental variables, especially atmospheric conditions, were found to interact with target characteristics to degrade or enhance the visual perception of cue information. It was concluded that these were interactions upon which the validity and generalizations of operator performance measures would depend in the RADES. Further, it was concluded that many of these interactions were probably nonlinear and would be difficult to simulate effectively.

Terrain features also interact with target cues but at a much grosser level, and the interactions were assumed to approach linearity and would present few problems for simulation, with one exception--when the target appears between the operator and terrain features, usually mountains. In this situation, the target/background contrast ratio may shift rapidly back and forth from negative to neutral to positive. A linear relationship may exist if the target were on a course headed directly toward the weapon system but would probably be nonlinear for crossing courses.

Visual System Variables

It was determined that there were three keys to representing the real world in a simulation facility: cueing, controlling, and task loading. In the RADES situation, task loading is primarily a function of cueing. The cueing problem as inferred above was the visual presentation problem. Where different operator responses would be required for different cues in the real world, the operator must be able to discriminate between the various cues in order to make the correct response. The sensitivity of the simulation, then, as suggested by Cream and Lambertson (1975), would have to be sufficient to ensure that the operator can discriminate among the cues that must be represented. The task of the engagement environment analysis team was to establish the minimum level of fidelity of cues that would ensure cue discrimination. In representing the visual system inputs, the basic problem to be dealt with was how to present the smallest object (cue source) that must be represented. Object size and maximum discrimination range under ideal conditions were identified as limiting factors. Given sufficient illuminance, enough time, and no interfering atmospheric conditions, object size and visual acuity of the observer interact to define maximum detection and discrimination problem, usually referred to as a resolution problem--the difficulty an observer of a specified level of visual acuity has in resolving the visual cue.

In viewing a target in the atmosphere, any serious limitation of visual range is due to what Middleton (1952) called the atmospheric aerosol (the aerial colloids). This condition is caused primarily by liquid droplets, the most important class of particles in the atmospheric aerosol. Large variations in the photometric properties of the atmosphere may occur as the content and density of the aerosol change. A second significant particle in the air is dust, with a third, smoke, increasing in significance with time, especially near large urban areas. The liquid droplets may vary in size from 10^{-6} to 10^{-1} centimeters (cm) in radius. The larger and more varied the atmospheric particles, the more that light is scattered. Any operator performance assessment where visual perception is critical cannot ignore the atmospheric variables if valid predictions across conditions are to be made.

In a particleless atmosphere, light is scattered by the molecules of the permanent gases in proportion to the inverse fourth power of the wavelength of the light (Middleton, 1952). In an atmosphere of a pure dry mixture of natural gases, visual range would be more than 350 kilometers (km). As nonpermanent particles are added to the atmosphere, the visual range, as well as the amount of illumination, is reduced. Four critical factors influence the visual system in terms of how far and what we can see:

1. The optical properties of the atmosphere.
2. The amount and distribution of natural and artificial light.
3. The characteristics of the target objects.
4. The properties of the eye.

The interactions of the factors are both linear and nonlinear. Shimmer, a disturbance of the atmosphere near the earth that occurs as the surface temperature increases above the atmospheric temperature, further complicates the visual system and must be represented in any visually oriented simulation. It was concluded that it would be prohibitively expensive to simulate these atmospheric conditions and their distortion.

The degradation of atmospheric conditions is defined in terms of the meteorological range--the range at which objects at known distances can be seen. As meteorological range is reduced the significant perceptual phenomenon of apparent target-to-background contrast ratio is also changed. Meteorological range is not necessarily omni-directional, thus the possibility exists of varying levels of contrast ratio in a wide search area such as found in the SHORAD/MANPAD environment. Apparent contrast ratio is also a function of the inherent target/background contrast, which usually changes as the target moves across the visual field because of (1) the varying background and (2) the sky/ground luminance ratio. Contrast is a subtle variable of considerable importance in target detection. It is also important in target recognition to the degree that critical target features may be nondiscriminable.

The visual threshold for a given target in terms of distance is a function of target size, the amount of light (luminance), and the amount of time the target remains projected on the retina. In other words, it takes time to see (detect) a given sized target at specific light levels. Under a given set of atmospheric conditions, the limiting factor for detecting a specific target with specific perceptual and physical characteristics in the real world is the visual acuity of the observer. As visual acuity varies from near perfect vision, the degrading atmospheric and target factors interact to produce increasingly poor target detection and identification performance. Duntley (1948) offered an equation that gave the probability of detecting a target at or near threshold as a function of all the abovementioned factors (except shimmer) plus several others, such as target range and altitude and several constants. The point in this discussion is that the visual target detection environment is very complex, and as mentioned earlier, very difficult to represent with a high degree of fidelity in any type of simulation.

Operational Function Variables

In initial listings of the operator tasks and in the analysis of the input variables, it became obvious that all system events were keyed to perceptual information, and the dominant perceptual system was vision. The auditory system does, however, become involved at two points. First, early warning information may be provided over the communication net or if a helicopter target is in the area, it may be heard before it can be seen. Second, the REDEYE, STINGER, and Chaparral systems use an auditory signal to indicate IR source lock-on by the IR sensor. These are important signals for initiating operator events but not as significant as the visual information that must be sensed without sensory aids.

The results of the analyses of the SHORAD/MANPAD systems engagement problem led to the adoption of a visually keyed event-oriented world view of the forward air defense environment. The rationale for adopting this view was that the entire engagement sequence followed in these systems' operations predominantly depended on a continual input and processing of visual information. Once the target has been visually detected, visual contact must be maintained at least until the weapon has been fired. Reliability of system functioning was seen as being tied to detecting and discriminating cues that consist of visual detail. Any condition that interacts significantly with the visual cues so as to degrade cue detection or discrimination would have to be present in the simulation environment in order for performance measurements to generalize to the real world. The more precise the descriptive model, the more sensitive it would have to be to the changing of parameter values. The sensitivity of the model would be accurate to the degree that interacting elements had been identified and included in the descriptive model.

The next step in the engagement environment analysis was to determine which of the input and operational variables interact significantly. This was done by using a matrix checklist. System operation variables were represented across the top of the matrix and input variables along the left-hand margin. A matrix was completed for each weapon system and then a composite matrix was prepared. The rationale for a composite matrix was that the RADES was conceived to serve all six SHORAD/MANPAD systems; therefore it must have the capability of presenting all relevant environmental conditions and signals for each system. The composite matrix is presented in Table 1. An "X" in a cell indicates that the input variable does influence a specific system operation for one or all of the systems.

SIMULATION EVALUATION

Real-world representation has been commonly referred to as the process of simulation. Simulation, however, has been both narrowly and broadly defined. Ruby, Jocoy, and Pelton (1963) defined simulation rather loosely as a representation of the characteristics of a system for the purpose of evaluating the performance of that system under various conditions. Westbrook (1961), in stressing system control, restricted his definition to the use of simulators. He said that simulators are facilities that allow an analog representation of a particular control element, a combination of control elements, or a complete system of environment, control, machine, man, and the functional operation of the system. Fraser (1966) broadened the definition but still emphasized analog transformation. He defined simulation as the art and science of representing the essential elements of a system out of their normal setting in such a manner that the representation would be a valid analog of the system under study. Redgrave (1962) provided a

Table 1

System Input/Operation Variable Interactions

SYSTEM OPERATION VARIABLES

	SEARCH & DETECT			IDENTIFY			ACQUIRE			TRACK			FIRE
	Audio Signature	Visual Image	Radar Image	Audio Signature	Visual Image	Electronic Code	Infrared Signature	Visual Image	Radar Image	Infrared Signature	Visual Image	Radar Image	
Physical Environment													
Terrain Contour	X	X	X	X	X	X	X	X	X	X	X	X	
Foliage Density	X	X	X	X	X	X	X	X	X	X	X	X	
Illuminance		X			X			X			X		
Atmosphere Conditions													
Particle Density	X	X	X	X	X		X	X	X	X	X	X	
Humidity Level	X	X	X	X	X		X	X	X	X	X	X	
Wind	X			X									
Temperature	X	X			X			X			X		
Shimmer		X			X			X			X		
Command and Control (Methods)													
Audio	X	X	X	X	X	X							
Visual	X	X	X	X	X	X							
TAC SOP		X	X		X	X							X
Identification Friend or Foe						X							

Table 1 (Cont'd)

SYSTEM OPERATION VARIABLES

	SEARCH & DETECT			IDENTIFY			ACQUIRE			TRACK			FIRE
	Audio Signature	Visual Image	Radar Image	Audio Signature	Visual Image	Electronic Code	Infrared Signature	Visual Image	Radar Image	Infrared Signature	Visual Image	Radar Image	
Target Parameters													
Physical:													
Features, Markings		X	X		X								
Size		X	X		X			X	X		X	X	
Reflected Luminance		X			X			X			X		
Color		X			X			X			X		
Shape		X			X								
Inherent Contrast		X			X						X		
Radar Reflectance			X						X			X	
Heat							X				X		
Sound	X			X									
Smoke		X			X			X			X		
Motion:													
Velocity	X	X	X	X	X		X	X	X	X	X	X	
Heading	X	X	X	X	X		X	X	X	X	X	X	
Climb/Dive Angle	X	X	X	X	X		X	X	X	X	X	X	
Location in Space:													
Range	X	X	X	X	X		X	X	X	X	X	X	X
Azimuth	X	X	X	X	X		X	X	X	X	X	X	X
Elevation		X			X			X			X		

Table 1 (Cont'd)

SYSTEM OPERATION VARIABLES

	SEARCH & DETECT			IDENTIFY			ACQUIRE			TRACK			FIRE
	Audio Signature	Visual Image	Radar Image	Audio Signature	Visual Image	Electronic Code	Infrared Signature	Visual Image	Radar Image	Infrared Signature	Visual Image	Radar Image	
Target Parameters (Cont'd)													
Ancillary Features		X	X		X			X	X		X	X	
Behaviors:													
Absolute Hostile Actions					X								
Possible Hostile Actions					X								
Perceptual Constructs													
Texture					X			X			X		
Target Cue Discrimination					X								
Contrast Ratio (Target/ Background)		X			X			X			X		
Size & Shape Constancies					X								
Resolution Degradation		X			X			X			X		
Other Factors													
Visual Acuity		X			X			X			X		
Degree of Target Similarity					X								
Sun/Target/Crewman Aspect		X			X			X			X		

more useful definition by emphasizing transformation for the convenience of meeting special purposes. Simulation, he said, was a representation or technique that transforms, either iconically or by abstraction, selected aspects of the real world out of their resident framework into a form more convenient for the analyst's purpose. The broader definition of a simulation explicit in Redgrave's definition was used in this project.

The approach taken in evaluating simulation approaches was inductive in nature. Theoretical simulation models were identified and assessed with reference to the SHORAD/MANPAD essential variables, requirements, and their simulation design criteria. This led to the selection of the designation of a theoretical model most appropriate for representing the engagement environment. Specific examples of the selected simulation that currently exist were next identified. When possible, observations of their devices and facilities in operation were made. In other cases several demonstrations were requested. Finally, it was determined if and to what degree each device and facility could meet the equipment and operator input requirements.

Types of Simulation

The types of simulation used to represent the real world were described by Shannon (1975) as falling on a continuum representing the degree of fidelity existing in the simulation. This relationship, along with some specific examples of simulation methods, can be shown as follows:

Type of Simulation:	Iconic	Analog	Symbolic
Simulation Method:	Physical Reality Scales Aspects of Reality	Graphs Charts Management Games	Computer Model Math Model
Degree of Fidelity:	Real World	Artificial World	Abstract World

Iconic simulation is a representation of the real world in some physical form. Examples would be a simulator of a weapon system, a reduced-scale aircraft model, nonfunctioning mock-ups of equipment and its environment, and film (still or motion) presentations of the real world.

Analog simulation involves the substitution of one or more properties of the real world by a different property. For example, distance can be represented by time and speed. Or the influence of illumination on detection range can be represented in a two-dimensional chart. Verbal descriptions, as used in management games, are analog simulations of physical and mental activities.

Symbolic simulation models often use mathematical abstractions of the significant elements of the real world and of their relationships. Differential equations are common examples of symbolic simulations. Because only those elements and interactions that are specifically written into the equation are dealt with in subsequent simulation studies, special care must be taken to ensure that the symbolic model is a valid representation of the problem (Shannon, 1975).

Model Design Questions

In the development of simulation facilities, Shannon (1975) stresses that several modeling questions must first be addressed. They are

1. Must the simulation be dynamic or static?
2. Is a stochastic or deterministic model required?
3. Should the model provide for continuous or discrete changes in system state?

A static model provides for only a cross sectional view of the system, which assumes that changes do not occur in the relationships between system elements. The dynamic model provides for changes in element relationships over time, if they occur in the real world. Since the focus of the RADES project is on whole task performance, the measurement objectives cannot be met by reducing the engagement sequence to static cross sectional segments. The SHORAD/MANPAD operators employ real-time control skills where error correction is essential in order to cope with deviations and unexpected, rapid changes in a target's behavior. Therefore, dynamic changing variables in the environment are critical to the accurate measurement of performance across conditions. To use other than a dynamic simulation would be an unjustified simplification leading to erroneous extrapolations of performance. A second dynamic requirement is that previous air defense operator performance studies have not used objective measures of whole task performance, and whole task performance cannot be estimated or inferred from part task measures without risk. The simulation model must be dynamic.

A deterministic model assumes that all possible actions and interactions that would occur in the real world can be specified. A stochastic model makes no such assumption, but bases the selection of system responses on an analysis of the conditions and information available when action cues arise. The specific impact on performance of many variables is not known, and many of the interactions between input variables and performance may not be linear. Therefore, a deterministic model should not be assumed. The purpose for the human in most systems is his versatility and capability of handling previously unencountered events. Man does this through his perceptual and cognitive system, gathering information and reaching decisions for action not possible where control devices have not been programed to handle specific unexpected events. The cognitive decision-making processes are difficult to model, so for most situations, it has not been tried very often. The human operator will interact with the presentation of information from his unique combination of individual differences. He may well react in unexpected and not deterministic ways. For the results of decision making to be validly assessed, the dimensions of the information sources must be representable and controllable. Motion and the changing aspect of the target are two of the most important sources of information, which dictate a dynamic, stochastic model.

A continuous model provides for continuous changes in the state of the system during simulation, whereas a discrete model represents changing states in a stepwise manner. Since the angular acceleration rates of an aerial target cannot be predicted in the real world, the selection of the size of the steps in a discrete model may reduce a very difficult or impossible tracking problem to a relatively easy but unrealistic one. The separate engagement events are not independent, discrete events. In many engagement situations, the behavioral requirements for one event in the sequence may have been met during a previous event. For example, information obtained during identification may influence the decision to fire the weapon. Most behaviors required for carrying out the weapon system mission are directly correlated to the changing position, aspect, size, angle, speed, and maneuvers of the target. The model must therefore provide for the continuous status changes in the target/system relationship.

The analysis of the RADES purpose led to additional requirements that the simulation model must meet, thus constraining the simplification analysis to some degree. First, the operator whose performance is to be assessed must be allowed to complete the entire engagement sequence without interruption by the measurement process. It was required that performance be measured at least at the task level and preferably have a capability of measuring job skills. Performance is to be measured over a broad range of exogenous parameters and variable levels. It would be desirable that performance be measured under conditions where the interactions between variables change during the engagement. And, finally, it was required to be able to use the same facility with all current and future SHORAD/MANPAD weapon systems. The data bases to be generated by use of the facility would produce statements descriptive of the performance relationships of individual tasks with each other, and also between individual tasks and the outcome of the entire engagement sequence.

The elements of the first criterion set eliminated the use of all nondynamic types of simulation for representation of aerial targets. Continuous rather than discrete movement of the target would also be required.

At this point, the kinds of simulation options that remained included any means of target presentation where dynamic, continuous movement would occur. The only other requirement was that the system operator have the capability to react in any way that would be expected in the real world, which would include the reaction to unusual and unexpected events. So, in terms of the three general types of simulation, most analog simulations would be eliminated. Both iconic and symbolic simulations could meet the dynamic and continuous requirement. Iconic would be most appropriate for the stochastic requirement, but the computer-generated symbolic simulation could approximate this requirement.

Specific Simulation Decisions

Establishing the second criterion set focused on identifying those variables that define the physical and psychological aspects of the real environment that absolutely must be maintained in the simulation, those that would be desirable but not absolutely essential, and those that would not be of significant interest for the RADES purpose.

The 39 environmental and target characteristics listed in Table 1 were reviewed by Army Research Institute (ARI) and Applied Science Associates (ASA) representatives, and 18 characteristics were identified for the next analysis step. The list was reduced in number because of the difficulty in handling such a large number of items in a comparative rating scheme. The reduction was possible because several individual variables had the same kind of impact on the system operation variables. For example, two physical environment variables, terrain contour and foliage density, are important for consideration because they can mask the view of a target aircraft. Rather than list both, they were combined into a variable called target masking.

Each of the six categories of input variables--physical environment, atmospheric conditions, command and control, target parameters, perceptual constructs, and other factors--was reviewed. It was found that several variables from different categories could be combined because of their similar impact on operator performance. The remaining variables were listed separately in the final list. For example, the remaining physical environment variable, illuminance, was listed separately as ambient illuminance.

Each of the categories will be discussed in terms of how the variables were combined. Target parameters were listed in Table 1 in five subcategories: physical, motion, location, ancillary features, and behaviors. Each of these categories was reviewed and variables subsequently listed separately or combined as follows. The physical features listing combined target markings, size, color, shape, reflectance, heat, sound, and smoke. The motion variables were listed as three-dimensional target motion. The location in space variables were subsumed under viewing area of which two levels were included--360° in azimuth and 90° in elevation and 180° in azimuth and 90° in elevation. Target behaviors are important as cues to target identification and were combined with the command and control variable, identification friend or foe, and listed as IFF information. The inherent contrast variable was combined with sun/target/crewman aspect and contrast ratio. The remaining target parameters--reflected luminance and ancillary features--were listed separately because of their importance to the visual cueing requirements in the engagement sequence.

The atmospheric condition of shimmer was combined with the perceptual construct of resolution degradation to form target resolution in the final list. Other atmospheric conditions were listed separately except wind, which was important only to the audio signature of the target.

The perceptual constructs of target cue discrimination and size/shape constancies were combined with degree of target similarity to form target similarity. Texture was listed as target texture. The one remaining variable, acuity, was eliminated because it is an operator variable. It was listed as an input variable because, in the real world, visual acuity is the limiting factor in target detection and recognition by individual observers.

The final list of 18 engagement environment features that were rated as to their importance for experimental purposes of being represented in a simulation facility included target physical features; three-dimensional target motion; viewing area--360° azimuth, 90° elevation, and 180° azimuth, 90° elevation; target/background contrast ratio; target resolution; terrain masking; command and control; ambient illuminance; reflected luminance; target similarity; target ordnance; target texture; target ancillary equipment; IFF information; aerial particles; ambient temperature; and humidity.

The 18 items were next subjected to a scaling procedure to determine the importance of including each item as a controlled variable in the simulation facility. The scaling approach used was based on a well-developed methodology known as riskless multiattribute utility measurement (MAUM) (Edwards, 1976). MAUM establishes a functional relationship among individual factors (i.e., target/environment variables with performance behaviors) that defines an explicit value structure that can serve as a basis for decisions concerning simulation system characteristics.

The MAUM-based procedure involved soliciting the opinions of experts concerning the importance of the various target and environmental characteristics to the assessment of SHORAD/MANPAD operator performance capabilities. The four experts involved in the scaling exercise have been involved in similar research to that which will be focused on in the ARI facility, and/or they have been associated with air defense weapon systems research and evaluation. Using the utility-theory-based scaling procedures, the importance of specific characteristics was combined across scalers to produce a weight for each characteristic. The scalers worked independently of each other, but their results produced a high level of general agreement. The total scale weights of the items and the weights for each scaler are shown in Table 2. The degree of rater agreement with the final ordering of the specific input variable according to the average of the scale values was assessed by running a Pearson-product moment correlation between the individual raters scale values and the mean scale values. The coefficients of correlation were as follows: rater #1 = .87; #2 = .48; #3 = .85; and #4 = .82. All four coefficients were statistically significant at the .05

Table 2

Scale Values for Environment
and Target Input Variables

Input Variables	Raters 1	2	3	4	Mean Value
1. Three-Dimensional Target Motion	18.9	16.3	16.7	9.8	15.4
2. Target Physical Features	23.6	13.0	7.3	10.8	13.7
3. Target/Background Contrast Ratio	11.8	3.6	6.3	15.7	9.4
4. Target Resolution	9.4	2.3	5.8	17.2	8.7
5. Ambient Illuminance	4.7	5.9	3.2	14.7	7.2
6. Viewing Area--360° Azimuth, 90° Elevation	14.1	0.8	4.6	4.9	6.1
7. Command and Control	5.9	14.6	2.3	1.2	6.0
8. Reflected Illuminance	3.5	2.6	2.7	12.3	5.3
9. Viewing Area--180° Azimuth, 90° Elevation	1.2	13.0	0.2	2.5	4.2
10. Target Masking	7.1	0.7	4.2	0.5	3.1
11. Target Similarity	4.7	1.6	5.2	0.7	3.1
12. IFF Information	1.2	8.1	2.1	0.9	3.1
13. Target Texture	1.9	2.6	2.5	1.7	2.2
14. Target Ordnance	2.4	3.3	0.4	0.2	2.0
15. Target Ancillary Equipment	1.4	3.3	0.6	2.2	1.9
16. Aerial Particles	0.7	2.9	1.3	1.1	1.5
17. Ambient Temperature	0.5	2.6	1.9	1.0	1.5
18. Humidity	0.2	2.9	1.5	0.7	1.4

level. The root mean square interrater reliability was .68, significant beyond the .01 level. These results could be interpreted in terms of the relative position of each variable in the criterion list. By dividing the scale of one variable by the value of another, a statement of comparative worth representing one variable relative to a second can be made. For example, the three-dimensional target motion variable has a relative worth of 7 as compared to the target texture value (15.4 ÷ 2.2). Another way to state this comparison would be to say that it is seven times as important to include three-dimensional target motion in the simulation facility than it is to include target texture.

All 18 of the input variable criteria were used to evaluate the technical capability of each type of simulation that met the general operator and equipment requirements. Specific simulation devices and facilities were identified throughout the research project and were subsequently assessed against the 18 scaled criteria. The various simulation devices and facilities will next be discussed prior to presenting the results of criteria evaluation.

Simulation Devices and Facilities

The specific simulation materials, devices, and facilities identified as having at least some of the required characteristics for the RADES fell into two categories: (1) aerial target simulators and (2) environmental simulators.

Specific examples of aerial target and environmental simulators were identified, described, and evaluated. These simulators were evaluated in terms of the equipment and operator input requirements. The required inputs for equipment are radar signals and infrared signatures. The operator inputs are primarily visual cues and the command and control conditions. Each of these classes of simulators are discussed in turn below. Some means of target presentation are an integral part of environmental simulators, but the target systems were evaluated separately.

Aerial Target Simulators

Simulation of aerial targets was found to be the most important aspect of the total engagement environment to be simulated because it provides the critical input to both equipment and operator performances. The United States Army Air Defense School has used aerial targets to represent actual target aircraft for decades. These targets have taken three general forms, with varying degrees of visual and functional fidelity: three-dimensional (3-D) dynamic targets; two-dimensional representations; and symbolic designations.

The dynamic 3-D targets that have been used by the U.S. Army were designed to meet specific purposes, most of which did not correspond to the needs in this project. This target group includes the following:

1. Actual aircraft flown as drone targets.
2. Reduced-scale flying models of actual aircraft.
3. Small-scale targets not representing actual aircraft--Firebee, radio-controlled aerial target (RCAT), and radio-controlled miniature aerial target (RCMAT).
4. Ballistic targets that have the flight characteristics of an artillery round--ballistic aerial target system (BATS).
5. Towed banners and sleeves that are not much more than two-dimensional moving targets not representing any real target.

Drone Aircraft. Drone targets have the appearance of an actual aircraft. In some cases, tactical aircraft taken out of the inventory have been used in this role, such as the F-84. These targets are powered by full-sized jet engines.

Reduced-Scale Flying Models. Visually guided and radio-controlled reduced-scale model aircraft vary in the validity of their representation of actual tactical aircraft. However, some manufacturers produce models that are near replicas of the real aircraft. Flight dynamics appear to be quite valid when the model is piloted by a skilled controller. Scale size varies from 1/4 down to 1/72. Most of the available models are constructed of fiberglass fuselages and styrofoam wings. Some balsa wood construction is used. Reduced-scale models have been demonstrated at Fort Bliss. Dynamic Simulation of Cucamonga, CA, has demonstrated its radio-controlled scaled aerial targets (RCSAT), some successfully, others unsuccessfully. It has models that represent a variety of aerial targets. Visual fidelity of RCSAT models observed was realistic. A flight demonstration of a 1/4 scale model did not present valid flight characteristics because the engine that was used was not large enough to generate sufficient power at the Fort Bliss altitude. The second scale models demonstrated at Fort Bliss are manufactured by Hobby Products of Oak Lawn, IL. These are of fiberglass construction and have excellent visual profiles.

Small-Scale Representative Targets. This category contains the majority of targets that the USAADS has been using for over 25 years. Included are the Firebee, radio-controlled aerial target, and the radio-controlled miniature aerial target. These targets look like a nonidentifiable aircraft. They have been used as targets for live fire training exercises.

The RCMAT built by RS Systems, Inc. of Beltsville, MD, initially used as a firing target, is essentially a flying wing of styrofoam construction. It is hand launched, has a weight of 5 lb., and flies at a speed of 25-80 knots. A kit has been put together by RS Systems to modify the RCMAT by adding a fuselage and vertical stabilizer so that it is configured like a MIG-27, a MIG-21, an F-16, or an A-7. A Soviet SU line (i.e., SU-7, SU-11, SU-15, SU-17, and SU-19) can also be readily fabricated. The F-4, F-55, F-14, F-15, F-111, and A-4 are suitable for augmentation. In addition, four international types could be developed--Jaguar, Mirage 2000 and 50, and Panovia Tornado. The RCMAT can carry a payload of up to 3 lb., so ordnance, ancillary equipment, or an additional IR source can be added.

During the project, six demonstrations of the RCMAT were attended by ASA and ARI personnel. The first demonstration of an unmodified RCMAT was to determine the stability of the target under windy conditions and to assess the realism of the flight characteristics. These characteristics were also observed in subsequent demonstrations. Next, modified versions representing the MIG-27 and A-7 were demonstrated to determine the validity of the augmented target profile and its flight characteristics. The consensus among those attending the demonstrations was that the modified RCMAT presented fairly high validity profiles of real aircraft from a side view. With experienced controllers the flight characteristics were quite realistic.

Since the Warsaw Pact tactical operations involve multiple aircraft, a demonstration was requested by ARI in which a pair of RCMATs were flown following a flight maneuver scenario representative of those used by Warsaw Pact pilots. With but little practice, the experienced controllers were able to successfully demonstrate these types of tactical maneuvers.

In another demonstration, an untrained individual tried his hand at the controls of an RCMAT already airborne and within a few minutes was flying the model with little difficulty. Interviews with different flying model "pilots" indicated that learning the controlling procedures was not difficult for most people they had observed or taught, but acquiring the skill of precision control was a function of whether the person could orient himself as if he were at the controls within the aircraft. This requires a fairly high spatial relations ability.

Two autopilot mechanisms, used to stabilize both roll and pitch, were also demonstrated on the RCMAT. One demonstration was of an electrostatic autopilot, and the other was of a pressurestatic one. Both worked quite well, but there were some disadvantages to each. Both are susceptible to changes in some atmospheric conditions.

Ballistic Aerial Target System. The BATS is a missile-like target used for live firing practice. It is launched like an artillery round and has the same kind of trajectory. Its flight time is very short with no maneuvering possible. It presents a low-fidelity three-dimensional target.

Towed Banners and Sleeves. These aerial targets are towed by a live aircraft or by the Firebee-type target. They have very low fidelity and essentially represent a flat rectangular surface at which to fire gun systems.

Aerial targets are also simulated using two-dimensional representations. These vary all the way from the static bullseye target used in assessing the proficiency of systems that engage ground targets to the computer-generated images (CGI) used primarily in the simulation of ground targets in aircraft cockpit simulators. In between would fall various forms of photographic target simulation. Still photographs of targets are seldom used. Motion pictures of actual aircraft in flight or of static or moving aircraft models have been used often for producing aircraft recognition training and testing materials. Video and laser-generated targets have also been used, primarily for presentation in an aircraft cockpit simulator.

Some specific application of two-dimensional targets were identified during the project. Five environmental simulators used various forms of dynamic and continuous target generation and presentation systems. The USAADS' Moving Target Simulator (MTS) (FM 44-18-1) is used for REDEYE and STINGER training. The MTS uses a 16mm motion picture presentation of an aircraft image that is grayish white in color. This constant negative-contrast ratio target has some detail that is detectable at close ranges. The negative contrast of the target is required to mask the projection of an infrared spot onto the aircraft image which is required for REDEYE and STINGER tracking and lock-on. The horizontal and vertical movement of the target image on the MTS background surface gives some appearance of three-dimensional motion. However, the resolution of the target is lower than that found in the real world, primarily because of the pegboard-like background surface.

A motion picture system is also used in a second dome simulation, the Controlled Environment Moving Target Weapons Trainer (the Dome Trainer), to present the aerial target. It is used for anti-aircraft gun training. The target is projected onto the inner dome surface with a 35mm projector. The targets are films of actual aircraft, so they present a realistic, but two-dimensional, image.

Another two-dimensional aerial target presentation system was found in McDonnell Douglas' Manned Air Combat (MAC) simulator used for training pilots. The target is a video display of scale model airplanes. The model planes are mounted in front of a camera which moves in response to the controls of the trainer as they are manipulated by the student pilot. The target image luminance, resolution, and size are optimized to simulate aircraft ranges from 200 ft. to several miles.

A laser image generation system was found in Link's Synthetic Flight Training System, which uses an enclosed cockpit environment with a visual display created at the windshield of the cockpit. The images that are presented are those seen in an air-to-ground view of the world. The laser essentially flies over a model terrain board in response to the controls as they are manipulated by the trainee. The resolution of this system is quite high and provides an improved signal-to-noise ratio; enhanced simulation of night, dusk, and daylight conditions; improved depth of field; and a wider field of view than a regular video system.

The U.S. Air Force (USAF) uses a computer image generation system in its Advanced Simulator for Undergraduate Pilot Training at Williams Air Base. A visual presentation is provided at the windshield of the enclosed cockpit environment. The windshield is actually divided into six separate screens, each of which is flat and about 3 ft. by 3 ft. Manipulation of the cockpit controls also provides input to the image generation system. However, the image resolution is only 6 arc minutes, whereas the human eye has the capability of resolving an object of less than 1 arc minute.

One other target simulation method that was reviewed was one being developed by the U.S. Army Air Defense School for aircraft recognition training. When this program is completed it will be known as Visual Aircraft Recognition (VACR) training. A presentation of sequentially shot still photographs of scale model aircraft was prepared for use with the technical extension training (TEC) program's besler que see projection device. The process of producing the film that was demonstrated was reported to be very tedious. First, the scale models were built to exact detailed descriptions. The photography was even more tedious. The model was suspended by monofilament fibers and sequentially photographed, with each succeeding shot requiring the target to be placed in a new position--a position change that would be seen if actual aircraft were photographed in flight with a very high-speed camera. The film was made for projection onto the small screen surface (about 8 in. by 10 in.) of the besler que see.

Two-dimensional iconic simulations using motion pictures can present a fairly high-fidelity representation of the real world, capturing much of the atmospheric conditions and target characteristics that must be represented. However, instead of the visual acuity of the observer being the limiting factor in the visual problem as it is in the real world, the resolution and information content of the projected images become the determining factors for detection and identification tasks. The available resolution in film varies with the quality and speed of the film. Some film has resolution capabilities better than the eye, but is relatively expensive. The less expensive film has a resolution level below that of the eye. But regardless of the film quality, the primary problem with photographic images is that the amount of information available about the target in a single frame of the film would be fixed. Additional information cannot be obtained by using magnification (either by projection lens or by binoculars). With reference to the visual acuity of observers, operators with higher levels of visual acuity than that represented by the camera lens, the quality of the film, the projection system, and the projection surface could not perform as well in a film simulation as they could in the real world. The result is an assumption that the maximum acuity of all observers would be fixed at a level defined by the resolution of the camera, film quality, projection lens, and projection surface. This problem would reduce the generalization of detection and recognition results from studies where film was used as target images.

All target simulation systems were evaluated and compared with one another on two levels. First, it was determined to what degree each of the specific aircraft target simulations could meet the simulation facility requirements. The assessment of these capabilities assumed no modifications to a device. The estimate of this capability was made in terms of the estimated percent to which the requirements could be met. Both operator and equipment input requirements were assessed. The weapon systems must have infrared and/or radar input in order for the system to function. The IFF information does not need to come directly from the target, so it is not an absolute requirement. The capability estimates are presented in Table 3.

The results of this assessment indicate that all two-dimensional targets, plus the banners and sleeves cannot be considered for the ARI simulation facility. These do not meet the equipment input requirements. The two-dimensional targets also do not meet the three-dimensional target motion requirement for operator input. This motion requirement was the highest rated operator input variable.

The second level of evaluation of target simulation capabilities used the input variables, scale values of these variables, and the percent capability estimates. The remaining three-dimensional targets were assessed by multiplying these figures to produce a simulation capability index (SCI). The SCI was first computed for each operator input variable for each target. The index for each variable was then summed across all operator input variables to obtain the aggregate operator SCI for each target. The aggregate operator SCI was then combined with the equipment capability estimate to obtain the total SCI. Table 4 presents the results of this assessment process. The SCIs for the RCSAT, Hobby Craft models, RCMAT, and the Drone simulations were identical. This is not surprising since all except the Drone are similar scale model aerial targets. In Shannon's (1975) terminology, these would be called three-dimensional, scaled iconic simulation devices.

Environmental Simulators

Several specific simulations of the real-world environment were studied in addition to the scaled iconic targets. These included the USAADS' Moving Target Simulator, McDonnell Douglas' Manned Air Combat Simulator, Link's Synthetic Flight Training System, RFD Systems' Controlled Environment Moving Target Weapons Trainer, and the USAF's Advanced Simulator for Undergraduate Pilot Training. All of these facilities were designed primarily as trainers. For the most part, the training programs are part task programs. All of these simulation systems use indoor controlled environments. The MTS, the Dome trainer, and the MAC all use a 40- to 60-foot dome enclosure with fixed training stations. Aircraft targets are projected from movie film onto the inner surface of the domes. The composition of the inner surface varies from a pegboard surface in the MTS to an aluminum painted surface in the MAC. Along with the surface variation

Table 3

Estimates of Simulation Capabilities of Aircraft Target Simulators

	Two-Dimensional Targets						Three-Dimensional Targets						
Input Variables	CGI	VACR	Link Laser	MAC Video	Dome 35mm Film	MTS 16mm Film	Banner and Sleeve	BATS	Firebee RCAT	RCSAT	Hobby Craft	RCMAT	Drones
Operator Inputs													
3-D Target Motion	0	0	0	0	0	0	10	0	100	100	100	100	100
Target Physical Features	60	100	0	80	100	60	0	0	25	100	100	100	100
Target/Background Contrast	50	75	100	50	75	20	10	10	90	100	100	100	100
Target Resolution	50	75	100	90	60	40	75	75	75	100	100	100	100
Reflected **Luminance**	0	80	60	50	75	20	10	10	90	100	100	100	100
Target Similarity	30	100	0	80	90	75	0	0	20	100	100	100	100
IFF . **Information--** Target Behavior	20	0	0	75	100	100	0	0	25	100	100	100	100
Target Texture	50	80	90	80	75	20	0	10	90	100	100	100	100
Target Ordnance	60	100	0	90	100	100	0	0	0	100	100	100	100
Target Ancillary Equipment	60	100	0	90	100	100	0	0	0	100	100	100	100
Equipment Inputs													
IFF Information--, Electronic	0	0	0	0	0	0	0	0	0	0	0	0	0
Infrared Source	0	0	0	0	0	100	0	100	100	100	100	100	100
Radar Reflectance	0	0	0	0	0	0	0	100	100	100	100	100	100

Note: Estimates are percent of desired level of fidelity.

Table 4

Simulation Capabilities Index for Aircraft Target Simulators

Input	Three-Dimensional Targets					
	BATS	Firebee RCAT	RCSAT	Hobby Craft	RCMAT	Drones
Operator Inputs						
3-D Target Motion	0	15.4	15.4	15.4	15.4	15.4
Target Physical Features	0	3.4	13.7	13.7	13.7	13.7
Target/Background Contrast	0.9	8.5	9.4	9.4	9.4	9.4
Target Resolution	6.5	6.5	8.7	8.7	8.7	8.7
Reflected Luminance	0.5	4.8	5.3	5.3	5.3	5.3
Target Similarity	0	0.6	3.1	3.1	3.1	3.1
IFF Information--Target Behavior	0	0.8	3.1	3.1	3.1	3.1
Target Texture	0.2	2.0	2.2	2.2	2.2	2.2
Target Ordnance	0	0	2.0	2.0	2.0	2.0
Target Ancillary Equipment	0	0	1.9	1.9	1.9	1.9
Aggregate Operation	8.1	42.0	64.8	64.8	64.8	64.8
Equipment Inputs						
IFF Information--Electronic						
Infrared Source	100	100	100	100	100	100
Radar Reflectance	100	100	100	100	100	100
Total SCI	8.1	42.0	64.8	64.8	64.8	64.8

Note: Cell numbers are the products of the input variable.

there is also a corresponding target resolution variation. Target resolution varies from poor in the MTS to good in the MAC. All have background scenes that provide some realism to the field of view. The scenes are variable film projections in the Dome Trainer and the MAC. The background of the MTS is painted on the dome surface. A background projection system for the MTS has been proposed by Brunswick Corporation (Brunswick, 1980) on which realistic terrain scenes would be projected through a 160° lens with brilliant color illumination. This would allow a change of the environmental background, and could produce a variation in the target/background contrast ratio which does not occur now.

All dome simulators have a quadraspheric viewing area. The MAC provides a wraparound projection of an environmental scene that is greater than 180°. The others, because of weapon and equipment positioning within the dome, have a 160° or less viewing area. All have a 90° range of elevation. The MAC, designed for use in pilot training, projects air-to-air and air-to-ground views, whereas the Dome Trainer and MTS use a ground-to-air view. All three systems have a controlled environment where environmental conditions are fixed. One of the major problems with existing environmental simulators is that the aircraft-to-sun operator relationships are fixed. As a result, a constant target-to-background contrast ratio is maintained which is not realistic. The target/background contrast ratio is fixed in the MTS, but could be varied somewhat with the Brunswick background projection system. The MAC has the greatest flexibility for creating varying levels of interactive variables because of its real-time target projections system. Another major prohibitive limitation of all simulators is that, as currently configured, a weapon system requiring a radar return from the target could not be studied in these simulations.

The same method used to evaluate target simulation devices was applied to the environmental simulators. Since the three-dimensional aircraft were the target devices found to meet the RADES requirements, it was decided that the environment in which these models would be used should be included in the assessment of environmental simulators. The environment in which the scale model targets would be used would be a section of land in a real-world setting. Actually, targets with different scale values could be used in the same physical space. The size of the land parcel required for performance measurement tests and experiments should conform to the scale of the largest aircraft to be used. The only physical aspect of the actual SHORAD/MANPAD engagement environment that must be physically and psychologically simulated would be the target aircraft and its dynamic characteristics. The physical dimension that is not scaled is angular velocity, which provides a primary basis for the psychological reality of a reduced-scale simulation of the real world. This is the basis for the degree of realism that exists in any simulation involving a moving target.

Each of the six real-world simulations discussed were first assessed in terms of their capability in presenting and controlling the relevant operator and equipment input variables. Then these percent estimates were multiplied by the scale values of the environmental variables to produce the SCI for each variable for each simulation. An aggregate SCI was obtained for the operator variables for each simulator by summing across variables. The SCIs for the environmental simulators are presented in Table 5.

The reduced-scale iconic facility is the only representation of the engagement environments that was found to provide both of the essential equipment input variables--infrared signal and radar return. The MTS provides an infrared signal but not the radar return.

When the operator input variables were assessed and combined with the equipment capability estimates, all forms of engagement environment representation except the reduced-scale method dropped from further consideration. This occurred because the infrared and/or radar return are absolutely required for all SHORAD/MANPAD weapon system operation. An initial requirement for this study was that simulation devices and facilities were to be assessed as they were found to exist. Therefore, major modifications to any device or facility were not considered. The results of the assessment under those conditions were as follows:

	Operator SCI	Equipment Input Capability	Total SCI
1. Reduced scale iconic	58.6	100	58.6
2. Link	31.7	0	0
3. MAC	25.4	0	0
4. Dome trainer	22.1	0	0
5. USAF-CGI trainer	15.3	0	0
6. MTS	13.8	0	0

Table 5

Simulation Capabilities Index for Environmental Simulation

Input Variable	Scale Values	Environmental Simulators											
		MTS		MAC		Link		Dome		USAF		Scaled Iconic	
Operator Input		%	SCI	%	SCI	%	SCI	%	SCI	%	SCI	%	SCI
3-D Target Motion	15.4	0	0	0	0	0	0	0	0	0	0	100	15.4
Target/Background Contrast	9.4	20	1.9	50	4.7	100	9.4	75	7.1	50	4.7	100	9.4
Target Resolution	8.7	40	3.5	90	7.8	100	8.7	60	5.2	50	4.4	100	8.7
Ambient Illuminance	7.2	25	1.8	100	7.2	100	7.2	25	1.8	10	0.7	100	7.2
Viewing Area													
360° 90°	6.1	0	0	0	0	0	0	0	0	0	0	100	6.1
180° 90°	4.2	80	3.4	100	4.2	80	3.4	80	3.4	60	2.5	100	4.2
Target Masking	3.1	5	0.2	0	0	0	0	50	1.6	0	0	100	3.1
Aerial Particles	1.5	0	0	0	0	0	0	0	0	0	0	100	1.5
Temperature	1.5	100	1.5	100	1.5	100	1.5	100	1.5	100	1.5	100	1.5
Humidity	1.4	100	1.5	100	1.5	100	1.5	100	1.5	100	1.5	100	1.5
			13.8		25.4		31.7		22.1		15.3		58.6
Equipment Input													
Infrared		100	100	0	0	0	0	0	0	0	0	100	100
Radar Return		0	0	0	0	0	0	0	0	0	0	100	100

RADES FACILITY DESIGN

Instrumentation

At least three kinds of data would have to be collected in the RADES facility in order to evaluate operator performance. The primary set of data would be the operator performance measures reflecting the various dependent variables. Second, criterion data would be needed to assess the accuracy of performance, in this case the location in space of the target with reference to the system operator. Third, measures of both physical and atmospheric environmental variables would be required for generalizing the results or specifying levels of performance under given conditions.

Different instrumentation systems would need to be designed, assembled, and tested to gather the data and conduct research in the RADES. They are described below.

Performance Measures and Recording. Three types of information, relative to the performance measures of the weapon system crew, should be recorded as functions of time during each engagement scenario. One is the voice communication of each crew member; another is the discrete operation switches activated by each crew member as each one progresses through the engagement sequence; and the third type of information is, where applicable, the sight picture information available to the crew/crewman.

If a voice intercom system exists for the particular weapon system under test, a tape recorder could be connected into the intercom system and the resulting voice signals recorded as a function of time, from time equals zero--when the model aircraft should be theoretically observed--to the time of completion of the engagement scenario. If an intercom system does not exist, then a microphone and amplifier could be provided for each crew member. The voice communication could be recorded on magnetic tape during each engagement scenario.

To monitor discrete events performed by each crew member, electronic circuitry could be designed so that each switch closure would generate a signal which could be recorded on magnetic tape. A standard time base could be recorded simultaneously on another channel of the tape recorder.

Aircraft Information. In order for crew/crewman performance measures to provide meaningful information, the measures must be related to the aircraft location in space, its velocity vector, and its aspect in relation to the crew/crewman. Spatial data on the aircraft could be gathered by one of two systems. A telemetry system, such as that used by the U.S. Army Air Defense Board (Alderete, 1980), could be used. It operates in the ultra high frequency (UHF) and consists of A station interrogators and micro B unit transponders. A tracking radar, such as the IHAWK and

Nike-Hercules, could also be used. A computer mated to either the telemetry or radar system could be used to provide aspect and velocity vector information by differentiating the change in spatial coordinates. Aircraft information could be recorded on magnetic tape with a time reference added.

Atmospheric Environment Characterization. It was assumed that a central instrument site could be placed at the geometric center of the RADES facility and that atmospheric measurements taken at this site would be representative of the various atmospheric parameter values throughout the approximately 2 km^3 volume of the atmosphere used by the RADES.

An instrument van or building could be used at the site. It could provide protection for instrumentation and serve as a platform for the mounting of the atmospheric sensors. These sensors could be mounted on a tower attached to the roof of the instrument building so that the sensors would be approximately 20 ft. above the earth's surface. The following instruments could be mounted on the tower to make the measurements as required:

1. Wind--anemometer and wind vane.
2. Temperature--carbon rod thermistors.
3. Humidity--power aspirated dew point sensor or carbon resistor hygrometer.
4. Pressure--pressure sensor.
5. Solar radiation--hemispheric total radiation pyranometer.
6. Particle density--intake of the particle size and number density counter.
7. Optical atmospheric turbulence--sensor for the determination of turbulence.

The hemispheric total radiation pyranometer would be used to give an estimate of cloud cover over the RADES facility. The pyranometer measures the total incoming solar radiation from the sky. The pyranometer readings, coupled with a curve of maximum radiation received at a specific latitude, longitude, and elevation as a function of time of day, would serve to measure the degree of cloudiness during each engagement scenario.

The measurements obtained by the above-listed instruments would serve to determine the various atmospheric variables necessary to characterize the atmosphere during each engagement scenario; however, these measurements would need to be related to accurate determinations of the atmospheric visual range existing during the time each engagement scenario is run. Two additional instruments would be required: an integrating nephelometer for the determination of atmosphere scattering coefficient (which leads to the calculation of visual range); and a telephotometer, which gives a direct reading of visual range by recording the radiance values of a distant target and the background sky.

During each engagement scenario the output signals from all of the instruments except the radar could be recorded on magnetic tape, along with the signals from a standard time generator. The analysis of these data would serve to relate atmospheric wind, temperature, relative humidity, pressure, solar radiation and cloud cover, particle density, and turbulence to the visual range existing at the time of the engagement scenario.

In addition to these measurements, turbulence and temperature sensors could be mounted on the model aircraft. Data from these sensors would be transmitted to a ground-based receiver located at the central instrumentation site and there recorded on magnetic tape. These turbulence data would be compared to the turbulence data recorded at the ground-based instrument site to determine whether or not atmospheric turbulence measured at the central instrument site is representative of the atmospheric turbulence existing between the weapon system personnel and the model aircraft.

Timing and Intrafacility Interface. The performance measures should be obtained in relation to a dynamic scenario. This requires that multiple conditions and events be correlated temporally for analysis. A timing generator could be used to provide meter timing to the recording equipment.

The difference in selected atmospheric conditions provides information on the aircraft illumination level available to the crew/crewman and the possible level of image distortion. In order to obtain this differential information like instruments must be located near the air defense systems and on the aircraft. A UHF telemetry transmitter and receiver could be used for obtaining the required sensor reading from the aircraft.

Aircraft Control. Control of the scaled aircraft over the range of the facility requires that two areas of control be considered: the simulated attack maneuver close to the air defense system and the approach path from a distance beyond the visibility of the system crew. Conventional or modified radio control systems could be used for guidance of the scaled aircraft. The distant approach could be accomplished by hand-off of aircraft control from one controller midway along the approach path to a second controller colocated with the air defense system. An auto pilot system could be used to aid in aircraft control during the hand-off procedure.

Scaled Aircraft. An arsenal of both hostile and friendly aerial targets along with fuel and ground support packages would be needed. The aircraft should include the following:

Hostile

1. MIG-17, Fresco
2. MIG-21, Fishbed
3. MIG-23, Flogger
4. YAK-36, Forger
5. SU-19, Fencer
6. SU-7B, Fitter A
7. SU-17, Fitter B
8. AN-12, Cub
9. IL-76, Candid
10. MI-24, Hind D
11. MI-6, Hook
12. M-8, Hip

Friend

13. F-4, Phantom
14. F-16, Fighting Falcon
15. F-104, Starfighter
16. F-15, Eagle
17. F-5, Freedom Fighter/Tiger II
18. A-10, Thunderbolt
19. F-105, Thunderchief
20. F-111, TFX
21. CH-47, Chinook
22. AH-1, Cobra
23. UH-I, Iroquois
24. OH-58, Kiowa

Air Defense System Interface. The control systems for the six air defense systems would need to be analyzed with respect to operator performance scenarios, and then each air defense system's unique interface between the system and the relevant measuring equipment could be designed. In addition to these interfaces, a manually operated event recorded input device could be designed. The manual input device could be used by a test observer to record events in addition to those that can be input automatically by monitoring the system.

Data Reduction Package. A data reduction package should be designed for use in converting magnetically recorded data into a form appropriate for data analysis.

General RADES Layout

RADES would consist of a parcel of land at Fort Bliss, TX, or White Sands Missile Range, NM, of sufficient size to represent the area that would allow maximum detection ranges of tactical aircraft. Since reduced-scale dynamic flying models would be used as aerial targets, the size of the area would be determined by the scale factor of the model aircraft. Previous detection ranges that have been reported (Frederickson, Follettie, & Baldwin, 1967) were up to 15,000 m. If the radio-controlled miniature aerial target (scale = 1/8.7) currently used by the U.S. Army Air Defense School is to be used by ARI, the radius of the area would have to be about 2 km. The usable air space above the area, determined by the characteristics of the weapon systems, would be up to an altitude of 1,000 ft.

A sample physical layout of the RADES is presented as Figure 2. The data collection site, where the weapon systems would be located, is placed in the center of the range (site center-SC) to provide for maximum

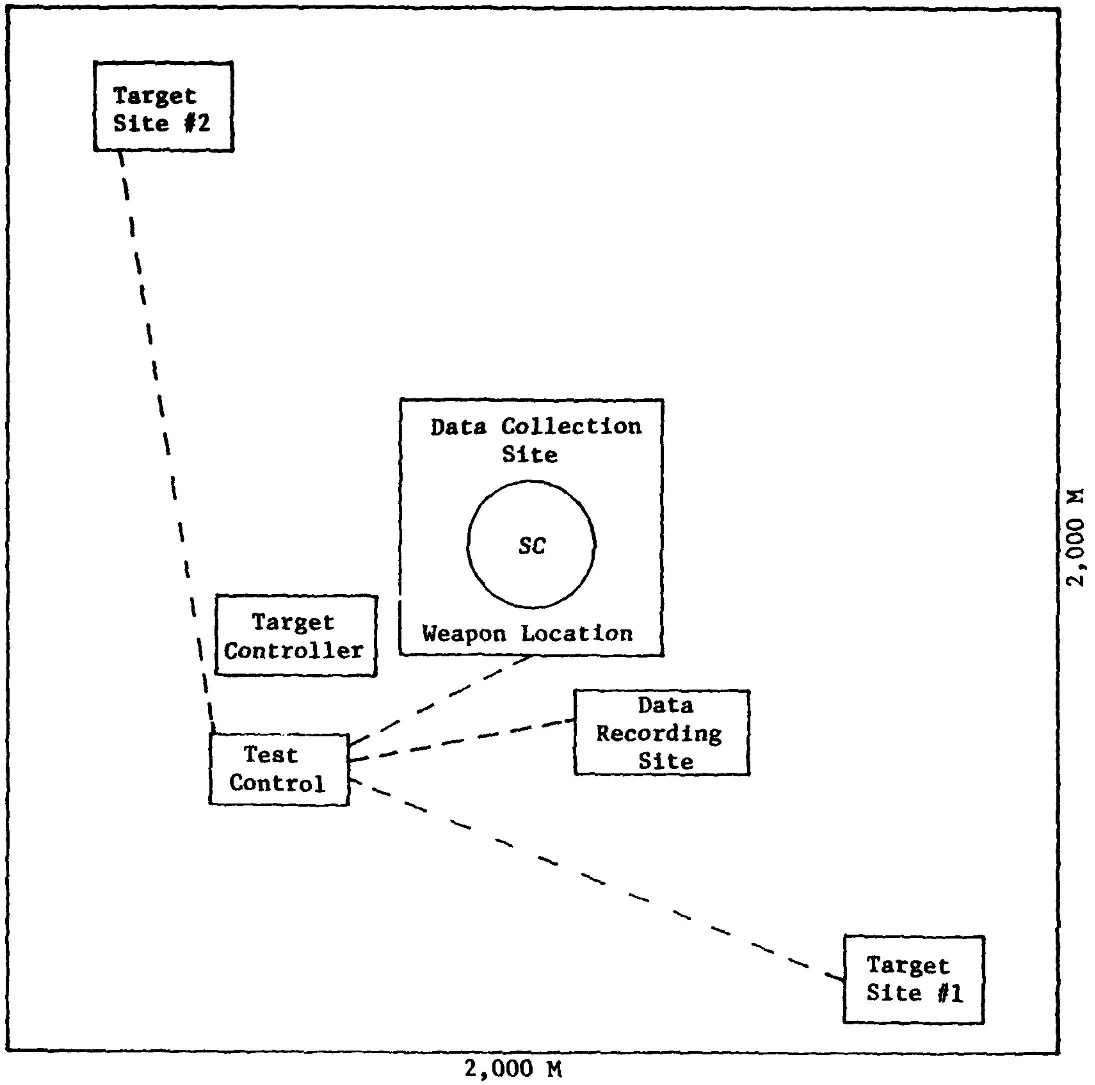

Figure 2. Sample RADES layout.

use of the dedicated area. Target controller/launch sites would be placed up-range and down-range so as to provide for constant visual contact between the controllers and their targets while flying from any direction. A secondary controller site could be colocated with the test controller for final maneuver of the target.

The test control location would be located approximately 75 m from SC, out of hearing range of the systems operators. The data recording site would be about 50 m from SC. The target sites would be located 1,000 to 1,200 m from SC, out of visual and auditory range of the operators. The idea is to be able to launch a target without the air defense systems operators being aware of it. It may be that the controllers might have to be located nearer SC so as to be able to maintain visual contact with the target, while it is both near the launch site and the SC. With this arrangement of target sites, aircraft could be launched so as to attack from any direction with total surprise.

The equipment to be located at each target site would be aerial targets. This would essentially be 15 targets at each location. One ground support unit and an aircraft control set, with appropriate antennae, would also be provided to each site. Two target controllers would be located at each site. Each site would be equipped with one field telephone connected by field wire to the test control station. This would require approximately 1,000 m of field wire for each location. The target site would need no special preparation, since the reduced-scale models are lightweight and hand launchable.

The data collection site would be located about 100 m from test control. No special preparation would be needed if the field phone wire were to be picked up each day when test runs are completed. The performance measurement instrumentation interfaces should be wired up each test day. The interface package should be designed for plug-in installation. The package could be connected to recording equipment located at the data recording site, located approximately 75 m away, near the test control center. One field phone could be located at the data collection site. One hundred meters of field wire would be required for the phone connection. Video and audio recording equipment would be located with the weapon systems for recording nondiscrete operator responses and voice responses.

The test control center is where all test coordination would occur. The test director would have field phone contact with both target sites, the data collection site, and the data recording site. The only equipment the test director would need would be a portable table, chair, and clipboards for test control documents.

All remaining instrumentation and equipment could be located at the data recording site. The atmospheric and meteorological measurements could be made from there, as could the target/background luminance measurements to determine the contrast ratio. The operator performance measures would be recorded there and the time base reference would be generated there. The equipment and instruments should be securely installed in a mobile van. The exact placement of the equipment would be dictated by access requirements.

When the equipment and instrumentation are separated into the various subsystems, they form the conceptual model depicted in Figure 3. The fabrication of the RADES facility in reality is the assembly and interfacing of the equipment and instrumentation and is not to be conceived as a permanent physical entity as is the MTS or one of the domed facilities. The RADES facility would be a modular subsystem that can be configured to meet various performance measurement requirements. Structure comes from the specific experimental tests that are to be run.

SCENARIO GENERATION GUIDE

The information from the analysis of the SHORAD/MANPAD engagement environment led to the conclusion that the characteristics of the target and conditions of the environment could be represented using the same simulation elements for all systems. Aerial targets follow the same flight patterns and use the same tactics in the forward edge of the battle area (FEBA) regardless of the air defense system. Once enemy pilots become aware of the presence of air defense weapons, they would initially use standard evasion procedures. Therefore, any scenario can be used in the study of any weapon system.

The tactics used by enemy aircraft to attack a ground target would also be similar regardless of which kind of SHORAD/MANPAD system was in the area. The analysis of the tactics used by Warsaw Pact aircraft revealed that several maneuvers are used for attacking a target. Speeds, altitude, climb/dive angle, and heading may all vary during any one attack run. The tactics also call for attacks on ground targets to be carried out by units of two, four, or eight aircraft. The most common configuration to be expected would be four aircraft flying in two elements of two aircraft each. One element provides a diversion on the first attack run while the other element delivers its ordnance. The aircraft switch element roles for a second run. Various delivery techniques are used such as the low-altitude bombing run, low-level penetration, and sneak and peek.

The kinds of ordnance carried by the target aircraft will vary, as will their mission. Flight behavior is one cue used in the identification of an aircraft as friend or foe. Flight behavior is a function of mission, ordnance, and proximity to the ground target.

All of the target and environmental characteristics must be taken into consideration when describing any specific situation that could occur in the FEBA where SHORAD/MANPAD systems are emplaced and prepared to engage hostile

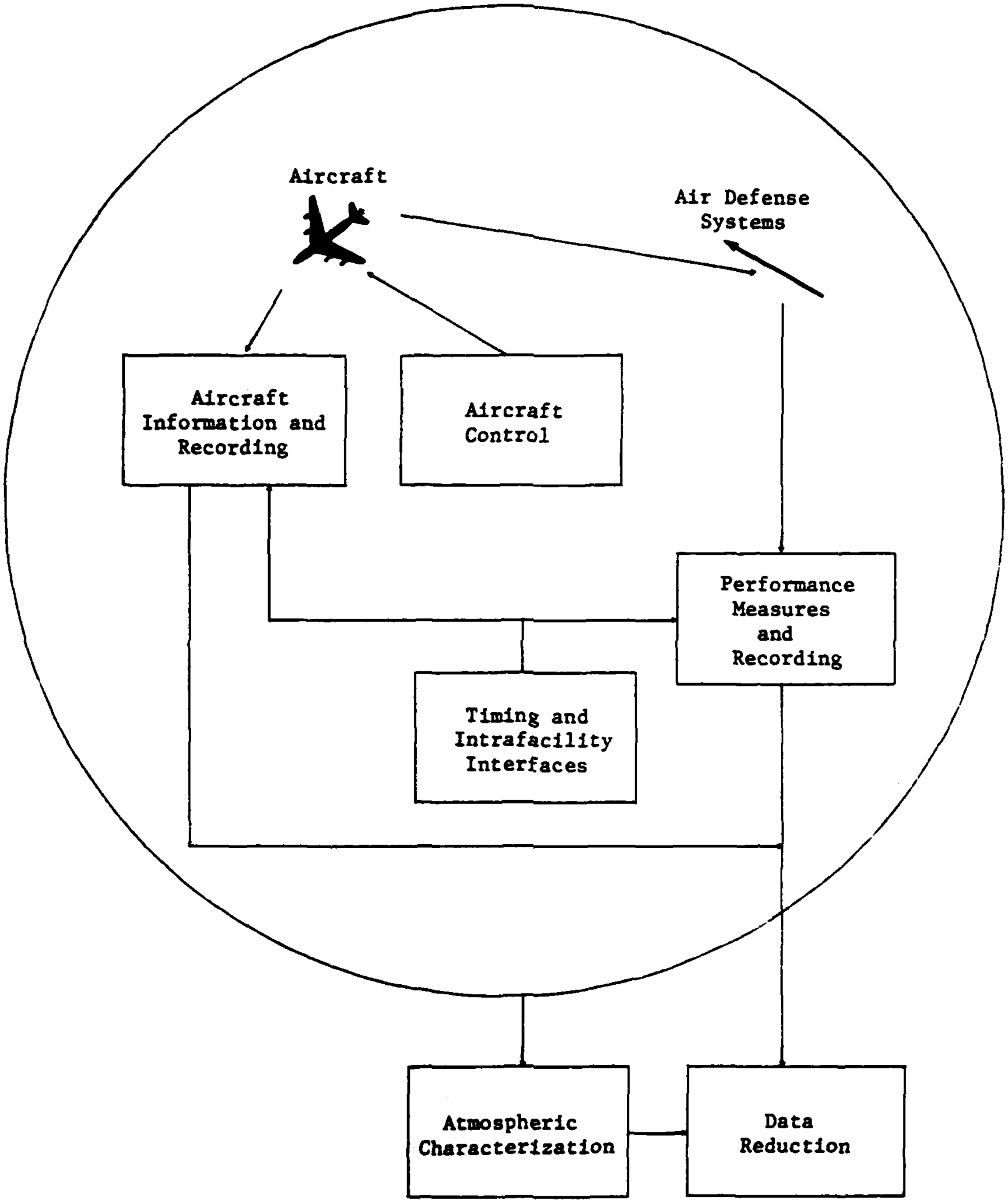

Figure 3. RADES facility instrumentation subsystems.

aircraft. There are innumerable possible combinations of target and environmental variables that could occur. In order to provide a representative sample of SHORAD/MANPAD environments, a guide (Dawdy & Carter, 1982) for developing specific target/environment scenarios was developed. By using the guide, a researcher can develop a specific scenario to meet the needs of a particular experiment. The guide was designed to assure that all of the critical SHORAD/MANPAD engagement variables would be considered in the preparation of a test. The guide consists of instructions on how to prepare the following items: (1) scenario description (SD), (2) scenario specification sheet (SSS), (3) scenario generator (SG), and (4) system crew response procedure (SCRP). Each item is briefly described below.

Scenario Description. The SD presents a narrative description of the flight pattern of the target aircraft and the actions of the weapon system. Researchers can obtain an overview of the weapon system performance requirements in relationship to the target. This overview aids in the conceptualization of the specific experimental design for a test.

Scenario Specification Sheet. The SSS is a form on which the specific characteristics of the scenario are designated. The critical input variables that were identified in the analysis of SHORAD/MANPAD engagement environment were used as the reference for constructing the SSS. The primary purpose of an SSS is to make sure that those variables that could influence operator performance are accounted for.

Scenario Generator. The SG provides the control information for specifying the initial status of the air defense weapon system and the subsequent change in system status that will occur during an engagement sequence. The initial status is determined by designating the command and control inputs, which include the defense readiness condition, state of air defense emergency, the level of air defense warning, the state of alert, the rules of engagement, and the method of control of unit operation. The SG also provides a set of procedures for preparing an aircraft attack scenario. The scenario is based on the designated aircraft threat, which is a function of enemy aircraft performance parameters and tactical delivery methods. Information needed to prepare the attack scenario includes the type of aircraft, aircraft performance characteristics, and tactical delivery methods for weapons and targets. The SG produces an exact description of the aircraft's behavior with reference to the target being attacked on a particular run. Aircraft speed, altitude, azimuth, climb or dive angle, and distance from the target are specified for the point in the dive run when maneuver changes occur.

System Crew Response Procedure. The SCRP is a description of the cues, actions, and sequence of actions performed by the operators in each air defense weapon system. The dynamic status of a system is described in terms of the events that occur in the target engagement sequence. Since all systems have varying operations requirements, a specific SCRP was prepared for each system. Two scenarios were provided for the Vulcan since the manual and radar operation modes were reported to be used about equally often.

RADES VALIDATION

Before the RADES facility can be used to evaluate SHORAD/MANPAD weapon systems operators, its validity must be established. For RADES the issue of facility validation essentially is one that relates primarily to determining the effect that aerial target relative size has on the performance of air defense weapon system operators during an engagement sequence. All aspects of the system environment are exactly as they would be in real-world, full-scale aerial target engagement studies except the size of the target. Using reduced-scale aerial targets results in a target simulation situation. In other words, the only elements of the SHORAD/MANPAD engagement environment that are simulated are the aerial target and its speed. Therefore, the only aspect of the facility that must be validated is the target representation subsystem.

Five approaches, three empirical and two rational, were identified as methods for validating the facility. The empirical methods include backcasting, forecasting, and master performance. The rational methods are a detection equation comparison and a master turing test. Each of the five methods is discussed below.

Backcasting. The backcasting validation process would be an attempt to produce data similar to that collected by various researchers in the earlier studies of operator performance mentioned in the introduction to this report. These earlier studies were primarily aircraft detection and identification studies, and were conducted with live aircraft primarily under desert environment conditions, many at Fort Bliss, TX. The purpose of these validation tests would be to determine whether the RADES environment can produce results similar to those produced using live aircraft. In studying the detection and identification activities for the facility validation, it would not be necessary to tie this initial research to a specific weapon. In fact, to maximize the correspondence between those validation tests and the earlier research results, ground observers independent of weapon systems should be used. The data collected in these experiments would be compared to the part task data collected in the previous studies.

It would not be expected that exact replication would, however, be possible because of anticipated operator sample differences. In several of the earlier studies (Frederickson, et al, 1967; Baldwin, 1973) professional research personnel were used as observers in the tests. Their motivation level was high. They were considerably above average in mental functioning, and they were interested in the research. Subjects drawn from the pool of those available for assignment to a research project usually do not have these characteristics. Also, atmospheric conditions have changed in the Fort Bliss/White Sands area which might degrade detection ranges as compared to the earlier studies. At the time of the earlier tests, visual range exceeded 90 mi. Today, the increased amount of haze in the atmosphere has reduced the visual range to around 60 mi.

Forecasting. The forecasting tests would involve an attempt to validate operator performance levels predicted from the results of studies conducted in the RADES. These tests would essentially be a validation of a prediction of operator performances based upon the results of the second set of tests. One or more of the feasibility experiments could be replicated in an environment like the National Training Center (NTC) at Fort Irwin, CA. A second possible site for conducting the criterion test for the forecasting validation experiment would be the Red Flag Operation at Nellis Air Force Base, NV.

Master Performance. This approach to validating RADES would use weapon system operators that are of the highest skill level. The master performance tests would use three different targets, two different scaled dynamic flying targets, and live tactical aircraft. Under this condition, the question of whether the same data could be obtained using scaled targets as would be obtained using live aircraft could be answered with less reservation than might occur if the physical surroundings differed, as would be the case at NTC and Nellis Air Force Base.

The rationale for using a master performance test is that if the reduced-scale aerial targets validly represent the full-scale live aircraft, the master operator should perform at a mastery level. His engagement behaviors should occur in the correct order and within the performance envelope of the weapon system. He should successfully engage the target. The target range when each event occurs should allow each subsequent event to occur in time for successful completion of the mission. If an operator who is highly proficient in the real-world setting can perform at or near his proficiency level, then it can be concluded that the simulation system is a valid representation of the real world. Empirical data would be the strongest evidence for this conclusion but should be used in conjunction with the results of the other validation tests.

Detection Equation Comparison. The theoretical detection range will be computed for each trial for all three targets used in the master performance test. These data could be compared with the actual detection ranges that were obtained. The rationale for this validation approach is that if the reduced-scale targets are valid representations of live aircraft, similar relationships should be found between their empirical data and the theoretical data, as is found for the live aircraft on trials run under similar flight paths. If the environmental conditions and aircraft characteristics were exactly the same, this comparison should produce the same results as comparison of the empirical data of the reduced-scale and live aircraft trials. However, both sets of variables vary. The inherent contrast of the targets alone could produce different detection ranges. The sun angle and background illumination will change from trial to trial, which will cause the target/background contrast ratio to change. So probably the best validation data, at least for detection, would be found in this validation approach.

Master Turing Test. The last validation method would involve obtaining the reactions of the master operator of each weapon system. A questionnaire could be developed to gather information from the operators. The situation created by the target, the dynamics of the flight pattern, and the operational relationship to the weapon system functioning would be topics to be addressed. The operators would also be asked their opinion about the accuracy of their performance on each trial. That is, did they perform each engagement in sequence and at a range that allowed successful completion of the mission?

This validation is the least important but could indicate reasons for the empirical data failing to meet validation criteria. This is essentially a test of face validity. If the operator feels that the reduced-scale target does not represent a real target, his performance might be affected.

SUMMARY

The purpose of this research project was to determine the feasibility of developing a realistic air defense experimentation system that could be used to generate a data base of forward area weapon systems operator performance parameters that would not be significantly different from performance data obtained under real-world conditions.

A thorough analysis of the SHORAD/MANPAD engagement environment and the systems performance requirements led to the conclusion that man-ascendant system operation is driven by perception, processing, and reacting to visual cues primarily, and auditory cues secondarily. Critical system decisions rely on the timeliness and accuracy of this performance throughout the engagement sequence. Therefore, a visually cued, event-oriented view of the SHORAD/MANPAD engagement environment was adopted for the descriptive and simulation modeling efforts.

The target aircraft and its immediate physical and perceptual surroundings were selected as the key to simulation evaluation and design. A total of 18 target/environment characteristics were selected, evaluated, and then established as simulation evaluation criteria. These characteristics were also used in the establishment of a methodology for designing specific SHORAD/MANPAD simulation scenarios. The guidelines, developed for specifying scenario characteristics, were a major product of this research project.

Three categories of simulation were evaluated initially to select the approach that would most effectively meet the purpose of the RADES project. These were the abstract, analog, and iconic types. The analysis and evaluation of various specified methods within simulation categories led to the conclusion that the reduced-scale iconic simulation approach would most validly represent the critical target and environmental characteristics required in the RADES.

Instrumentation that would be required to assess operator performance and conduct experimental research in the RADES was detailed. A sample layout of the facility was presented. The physical environment would be a 2 km by 2 km parcel of Fort Bliss range area.

It was concluded that validation experimentation would be needed before the facility could be used to evaluate SHORAD/MANPAD weapon systems operators. Five methods, three empirical and two rational, were discussed.

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