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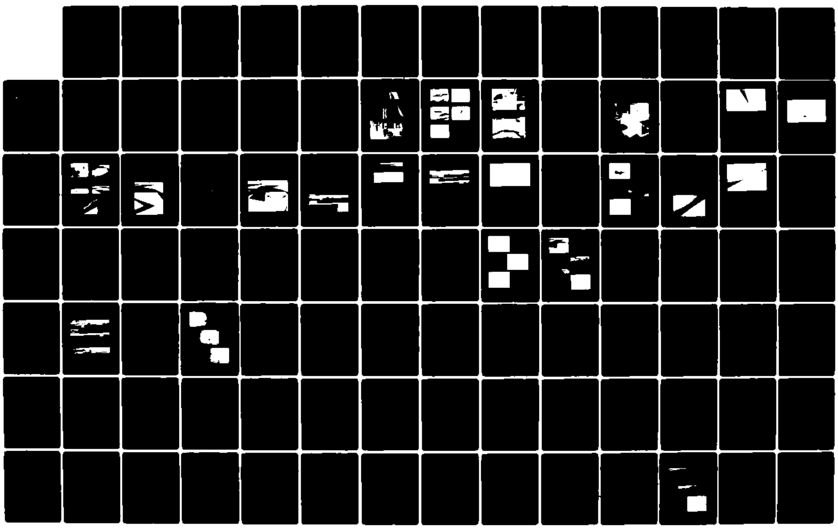

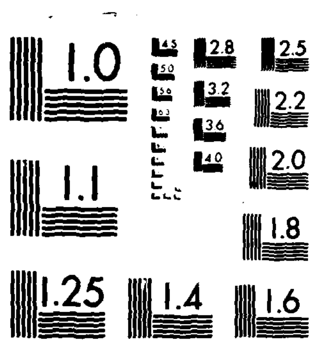

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ADVANCED TRAINING TECHNIQUES USING COMPUTER GENERATED IMAGERY

D. Coblitz, M. Verstegen, and D. Hauck
McDonnell Douglas Electronics Company
2600 North Third Street
St. Charles, MO 63301

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Final Technical Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objectives of this study were to generate new concepts in aircrew training methods that take advantage of the flexibility of computer generated imagery, to demonstrate examples, and to perform exploratory testing of these examples. The purposes of the testing were to determine pilot acceptance of the use of a simulator as a training device as opposed to just an aircraft replicator, and to provide a baseling of information from which detailed

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training experiments could be designed for future testing by others. These goals were met. In general, both student and instructor pilot reactions were quite favorable.

Experiments on ability to judge depression angles (e.g., for glideslope or dive angles) showed that this ability is quite poor among novice and experienced pilots alike. Methods of successfully improving these capabilities were demonstrated, but, found to be much more effective with limited experience pilot than with experienced pilots.

A new form of energy/maneuverability diagram was designed and implemented on a simulator visual system. A sample syllabus for use of this diagram in aircombat training is presented.

Studies of the minimal cues necessary for low level flight showed that, while the number of cues required by most pilots is quite large, the number required after appropriate training in visual cue understanding is suprisingly small.

SUMMARY

The objectives of this study were to generate new concepts in aircrew training methods that take advantage of the flexibility of computer generated imagery (CGI), to demonstrate examples, and to perform exploratory testing of these examples. The purpose of the exploratory testing was to provide a baseline of information from which detailed training experiments could be designed for future testing by others. All of these goals were met. In general, we found pilot reactions to the demonstrated examples to be quite favorable. The key to this, we believe, is the fact that the philosophy under which these concepts were generated was compatible with operational instructor pilots' and students' views. The philosophy was that it is worthwhile, when necessary or useful, to forgo pictorial realism in favor of operational realism. Additionally, the approach to simulator utilization was as a training tool, not as an aircraft replicator. It was recognized that, when viewed as an aircraft replicator, the simulator will always be found wanting; however, when viewed as a training tool, its potential has only just begun to be explored and is not limited simply to one-to-one transfer to the aircraft.

Examples of the types of techniques examined are:

a. Making visible in the simulator something the pilot normally cannot see in the aircraft but must visualize. (Fragmentation envelope during bomb delivery, weapon effectiveness envelopes, etc.)

b. Immediate scoring feedback provided to the student on the visual system.

c. Cursors under instructor or student control appearing in the out-the-window visual as a communication aid.

d. Performance envelope superimposed upon the outside scene.

e. Providing visible flight path history in the out-the-window scene and using it in conjunction with a multiple view point capability to allow the instructor and student to immediately review the flight path after a particular maneuver.

In more basic experiments, it was shown that novices and pilots alike are poor at visually judging dive angle or glide slope. In addition, the data show that it is easier to cure this problem with inexperienced pilots than with experienced pilots! A short period of training with artificial aids influenced many pilots with less than 190 hours experience both during and after its presentation. But, for most pilots having over 600 hours of experience, the artificial aids only affected their simulated flight paths during presentation.

In an experiment to determine the minimal cues that are necessary and sufficient for low level flight (straight and level or in level turns), we were surprized to find that, after gaining practice with minimal cues and after study of object motion cues, a single light point on the ground visible at any one time under reduced visibility conditions was sufficient!

The overall conclusion is that this approach to flight training can be both successful and well accepted by the pilot/instructor community. Further research of a transfer of training nature would be very helpful in quantifying the benefits. However, the benefits are in some cases so large and the cost to implement so small that one wonders whether waiting for transfer of training studies is prudent. Since implementation of these effects has already been done on the A-7D simulator at Davis Monthan AFB, it is recommended that detailed transfer studies be arranged and performed either there, or at a similarly equiped site that could utilize the same software. (The Undergraduate Pilot Trainer, UPT, at Williams AFB, AZ may be such a candidate.)

In the case of the angular judgement studies, the recommendation is that further research be performed to establish how pilots react to various illusions such as varying runway size or shape, "black hole" effects, sloping runways, and so on. More importantly, experiments should be performed to determine how pilots can be trained to overcome these illusions. The experiments with horizon depression cursors and velocity vectors are a first step in that direction. The results of this type of research would be safer flight for all pilots, civilian as well as military. Thus, this work is expected to also be of interest to the Federal Aviation Administration.

A video tape presentation demonstrating some of the effects described in this report has been made and is submitted along with this report. Unfortunately, the quality possible on standard monochromic 525 line video tape is not representative of the quality of the presentations as displayed on a color beam penetration visual system, but one can, through the video tape, get an idea of the dynamics involved.

PREFACE

We would like to express our gratitude to many people who contributed to the success of this effort over a period of four years. For encouraging us to work on such a stimulating and useful project, and for providing the necessary financial support, we thank Major Jack Thorpe and Dr. Genevieve Haddad of the U.S. Air Force Office of Scientific Research. For their assistance under subcontract in defining the redesign and suggested use of the energy-maneuverability diagram, as well as for providing experienced pilot opinion, we thank Drs. Jacob Richter and Shimon Ullman of Cambridge Intelligent Systems. For his invaluable help in the development of our implementation of variations of his original energy-maneuverability diagram, we are gratefull to Ralph Pruitt of McDonnell Aircraft Co. (MCAIR). The implementation itself we owe to Keith Brown of McDonnell Douglas Electronis Co. (MDEC). Larry Ross and David Rolston of MCAIR assisted in the early stages of concept generation. Douglas Dillard and Bob Elliot of MDEC implemented many of the concepts initially on an MDEC VITAL IV system. William Phelps of MDEC completed the implementation of many of the training concepts and made them play on the A7D flight simulator at Davis Monthan Air National Guard Base. To the Air National Guard we are thankful for their cooperation in allowing us to modify their simulator to demonstrate some new training approaches and for their very useful evaluations and suggestions. We thank William Schallert and Raymond Seggelke of MDEC for their efforts toward interfacing the flight simulator and joystick devices that were used during the in-house "flight" testing. Last, we must thank Dr. Stanley Roscoe and his students for performing the seminal experiments over a period of years that provided inspiration and confidence.

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INTRODUCTION

Aircraft simulators have been designed and used primarily as substitutes for actual aircraft. Computer generated imagery (CGI) provides the flexibility to enhance training in ways that cannot be done in an aircraft. This is the final report covering work performed from 1 April 1979 to 28 February 1983. The thrust of this research was to conceive and demonstrate new training approaches to take advantage of the flexiblity of CGI. Two broad categories of techniques are available to us:

(1) simulation of tasks untrainable in aircraft during peacetime but required during combat, and

(2) application of teaching/learning methods unavailable in aircraft.

Examples of the first category are surface-to-air missile (SAM) and air-to-air missile avoidance. This category was not emphasized, since many of these special effects are available in present simulation visual systems. The second category is exemplified by techniques such as allowing the student to view an engagement from various viewpoints (his own, ground threats', air threats', overview, etc.) or making visible something that the pilot must visualize but cannot see in the real world, such as the radar antenna pattern of an opposing aircraft during air-to-air combat or a diagram of the relative energy states of the aircraft and their flight envelopes. (See Figures 1 and 2).

The work has been performed over a series of three one year contracts. During the first period, literature was searched and experts consulted in the process of generating concepts for air crew training. The resulting list of generic and specific concepts is contained in the first annual report (Reference 1). A more brief version was presented at the Second Annual Interservice/Industry Training Equipment Conference at Salt Lake City, Utah in November 1980. The paper was published in the proceedings of that conference (Reference 2). During the second period, real time examples of several of the training concepts were implemented on a VITAL IV computer generated image system at McDonnell Douglas Electronics Co. (MDEC). A limited number of the examples were also installed on the A-7D aircraft simulator at the Air National Guard facility at Davis Monthan Air Base in Tucson,

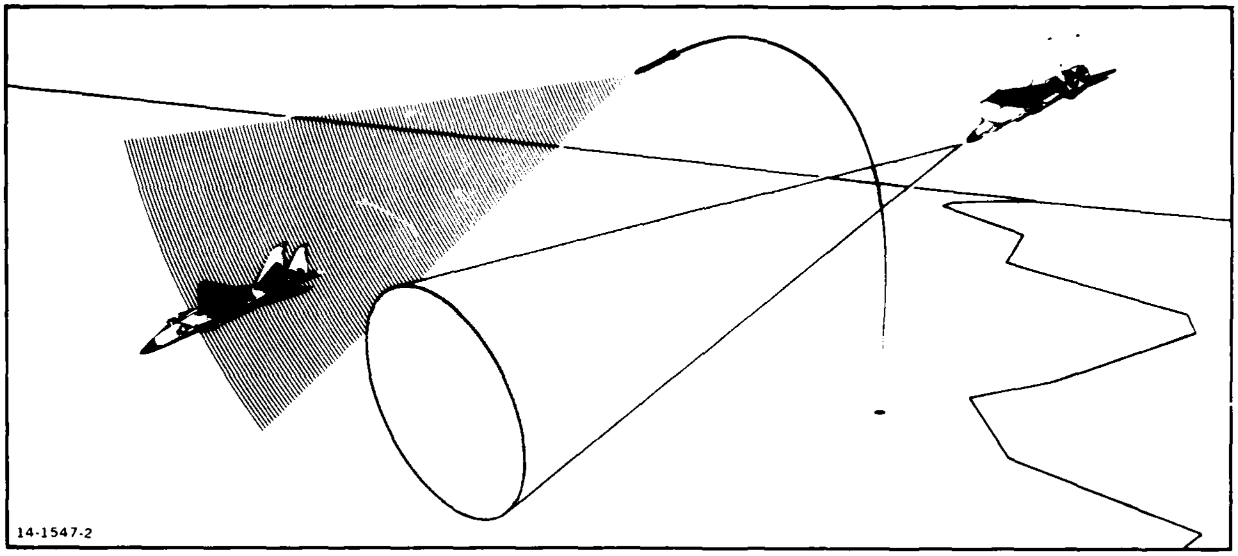

FIGURE 1. VISIBLE THREAT CONE

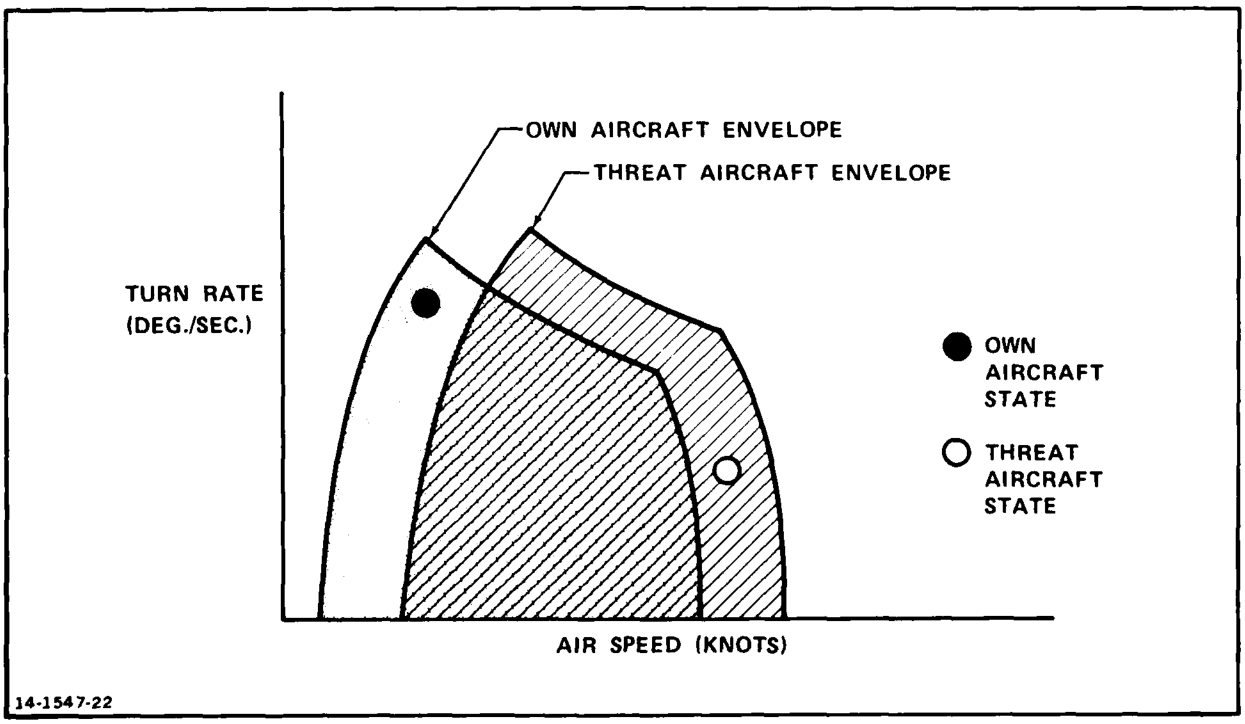

FIGURE 2. RELATIVE FLIGHT ENVELOPE PERFORMANCE DIAGRAM

Arizona. This work was reported in the second annual report (Reference 3). Feedback from the Air National Guard personnel was used during the final period of of this work. During this last period, additional examples were implemented, improvements were made to the previously created examples, and exploratory testing was performed both at MDEC and at the Air National Guard facility. In this final report the earlier work will be briefly reviewed and the work performed during the final period will be described in detail. Overall results, conclusions, and recommendations are presented.

CONCEPT GENERATION

The initial stages of this contract called for the generation of new concepts in aircrew training using computer generated images combined with a flight simulator. The emphasis was in complex combat skill training as opposed to simple tasks such as take-off and landing. The process originally envisioned is diagrammed in Figure 3.

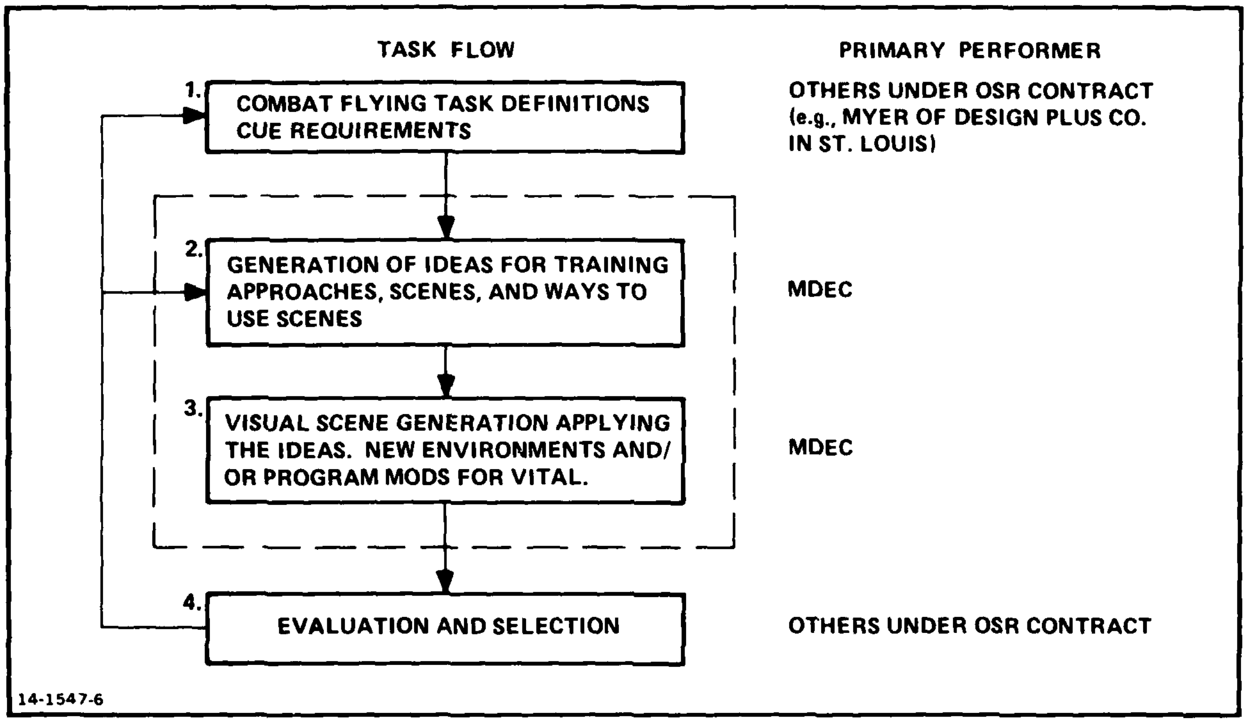

FIGURE 3. CONCEPT GENERATION PROCESS AND RESPONSIBILITIES

A team of individuals whose backgrounds span the fields of engineering, human factors, training psychology, visual perception, combat flight, simulation visual system design, aircraft design, and flight instruction was brought together for the idea generation process. In addition, a limited literature search was conducted. Useful information was also made available to the group from others under contract to AFOSR studying related topics. For example, tapes of structured interviews with Nellis AFB Fighter Weapons School students and instructors were made available by R. Meyer and J. Laveson of Design Plus Inc. The first part of the project consisted largley of "brainstorming" sessions with later individual follow-up assignments. Each resulting idea was synopsized on an index card regardless of its relevance. Forty-five such idea cards were created. To provide a framework for the idea generation process a list of key issues to be trained was drawn up (Table 1). Simultaneous with the generation of specific training techniques, a list of generic techniques was created as an aid to prevent our getting into a rut of essentially similar approaches. (See Appendix A and Table 1). Those concepts considered relevant were presented in the 1980 Annual Report (Reference 1). Also many of them were presented in a paper given at the Second Annual Interservice/Training Equipment Conference at Salt Lake City, Utah in November 1980 and are in the published Proceedings. The idea generation process continued throughout the succeeding stages of the contract with the benefit of feedback from the sample creation and exploratory testing. A number of significant ideas came from the Air National Guard instructors, simulator technicians, and students during evaluation on the A-7D simulator. Since these were mainly improvements to the implemented samples, they will be discussed later in the sections on sample implementation and exploratory testing. A bibliography of related literature was published in the second annual report (Reference 3).

TABLE 1. KEY ISSUES TO BE TRAINED

I. Factors Affecting Probability of Kill (P_K)

A. Energy Management

1. own

2. threat energy state

B. Offensive Weapons Systems

1. switchology

2. knowledge of best system selection

C. Assessment of Threat (Current)

1. status assessment

2. knowledge of what to do about it.

TABLE 1. KEY ISSUES TO BE TRAINED (CONT)

II. Factors Affecting Probability of Survival (P_S)

A. Energy Management

1. own

2. threat (know energy state of threat)

B. Defensive Systems Management

1. display threats

2. respond to threats

C. Assessment of Threats

1. status/number

2. knowledge of what to do about it.

III. Maximizing $P_K \times P_S$

IV. Low Level Fight

APPARATUS

Some of the concepts resulting from this effort were demonstrated on VITAL IV computer generated image (CGI) systems at the McDonnell Douglas Electronics Co. in St. Charles, Missouri and on the A-7D aircraft simulator at Davis Monthan Air National Guard Base in Tucson, Arizona. However, ideas generated could be demonstrated on any computer generated image system. This is an essential point. To do this may require changes in the details of the particular imagery used, but the training techniques per se should be capable of remaining intact despite wide variations in the detailed structure of the image content.

The equipment used on this project was a McDonnell Douglas Electronics Company off-the-shelf computer generated image system, model VITAL IV. This system consists of a general purpose minicomputer, special purpose high speed computational hardware, and a calligraphic (stroke driven) color display with collimating optics as shown in Figure 4. This display would normally be mounted outside the window of an aircraft simulator cockpit to display a representation of the "real world" to the pilot. The simulator position and attitude information in response to the pilot's controls is fed into the visual system, which correspondingly updates the scene thiry times per second. Typical scenes are shown in Figure 5. This type of system is presently in use for flight training on many simulators world wide. The scenes have in the past been made specifically to simulate the real world flight environment, including special effects such as variable weather conditions, surface-to-air missiles, air-to-air missiles, anti-aircraft artillary, tracer bullets, and so forth. Two such systems were utilized for this project. Basic studies in flight cue perception were performed on a laboratory system at MDEC. The remainder of the studies were performed on a three window VITAL system on the A-7D operational aircraft simulator at an Air National Guard Base. There are 21 such systems on A-7D and F-4 simulators, but only the one at Davis Monthan Air National Guard Base was modified to have the special effects generated during this project. That base was chosen since it had the best access to a large number of students and instructors with a broad range of experience. A picture of the simulator is shown in Figure 6. As is typical, the instructor console has a monitor which repeats the picture and head up display (HUD) seen by the pilot in the simulator cockpit. The instructor monitor is located on the upper left portion of the instructor console shown in Figure 7. On the lower right is the joystick used to

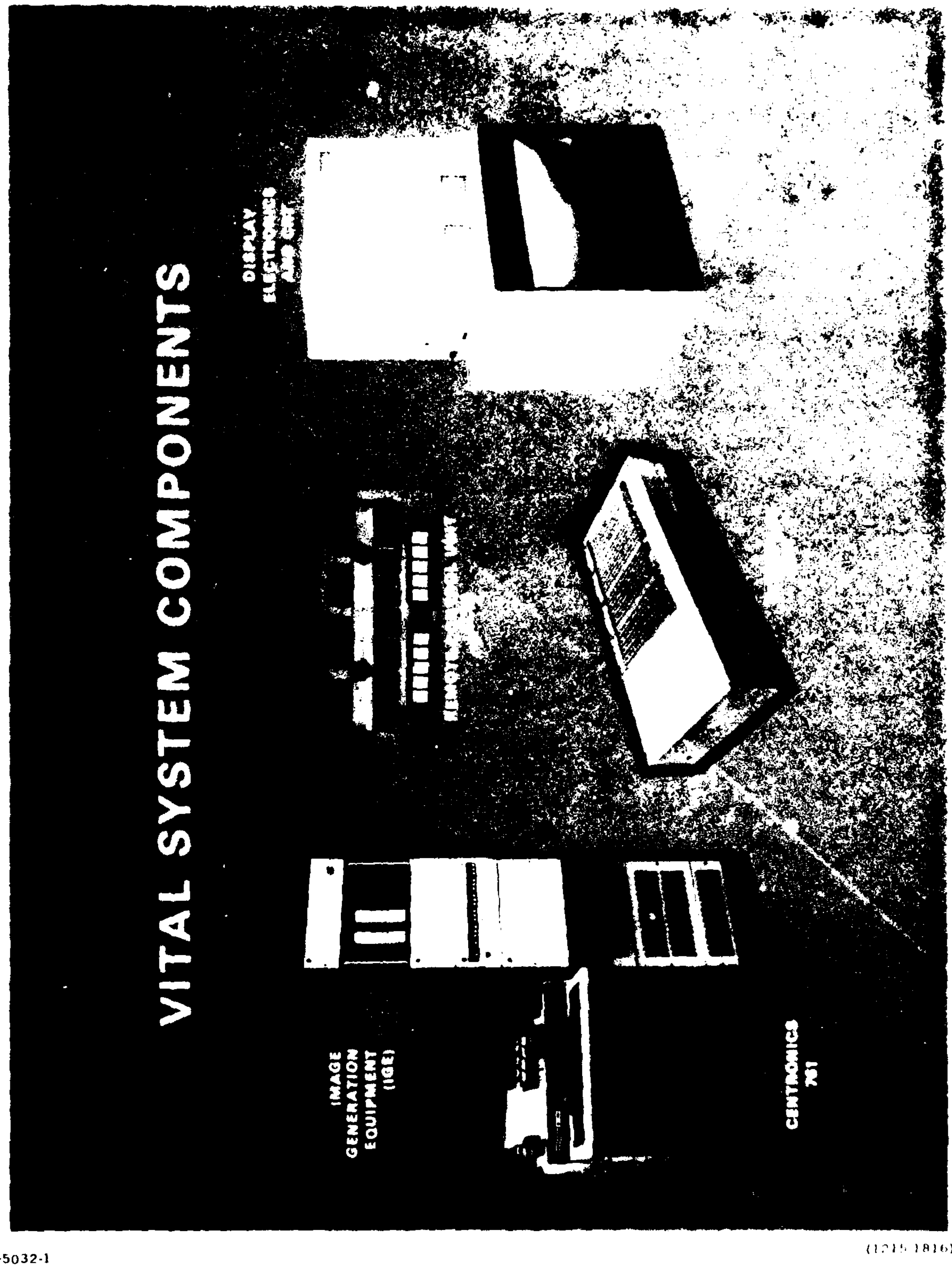

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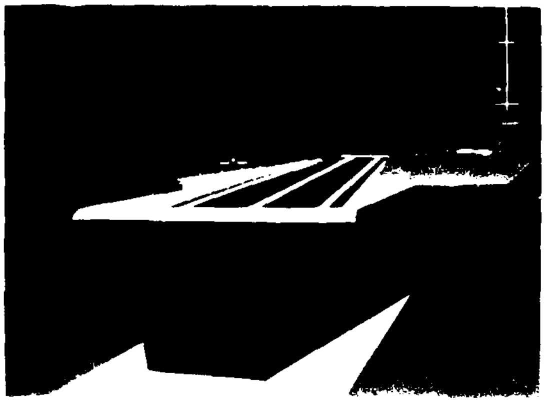
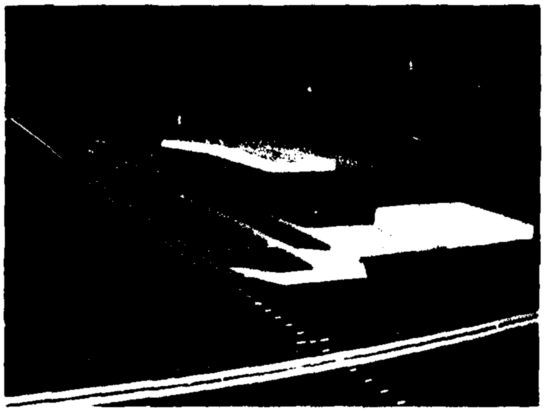
FIGURE 4. VITAL IV SYSTEM COMPONENTS

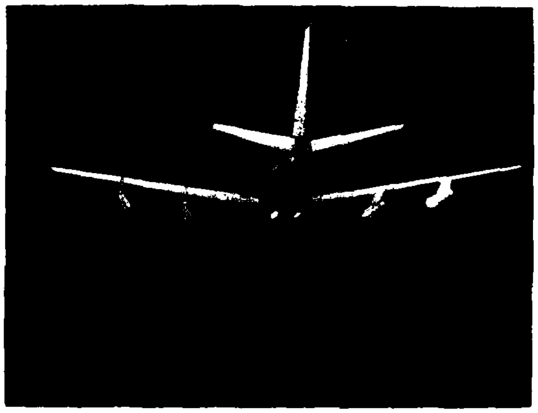


AIRCRAFT CARRIER WITH SEA SURFACE AND WAKE

NEW YORK – LAGUARDIA (TWILIGHT)



MINNEAPOLIS – ST. PAUL INTERNATIONAL (TWILIGHT)



KC-135 TANKER

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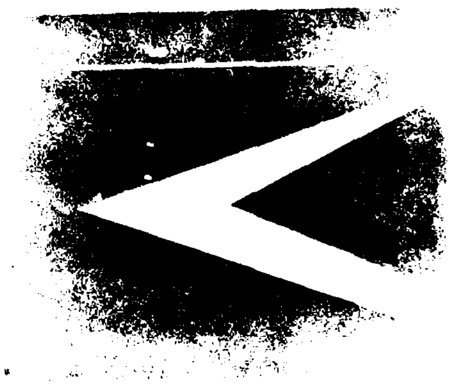

GROUND TARGETS

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FIGURE 5. TYPICAL STANDARD VITAL IV IMAGERY

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FIGURE 6. AIR NATIONAL GUARD A-7D SIMULATOR

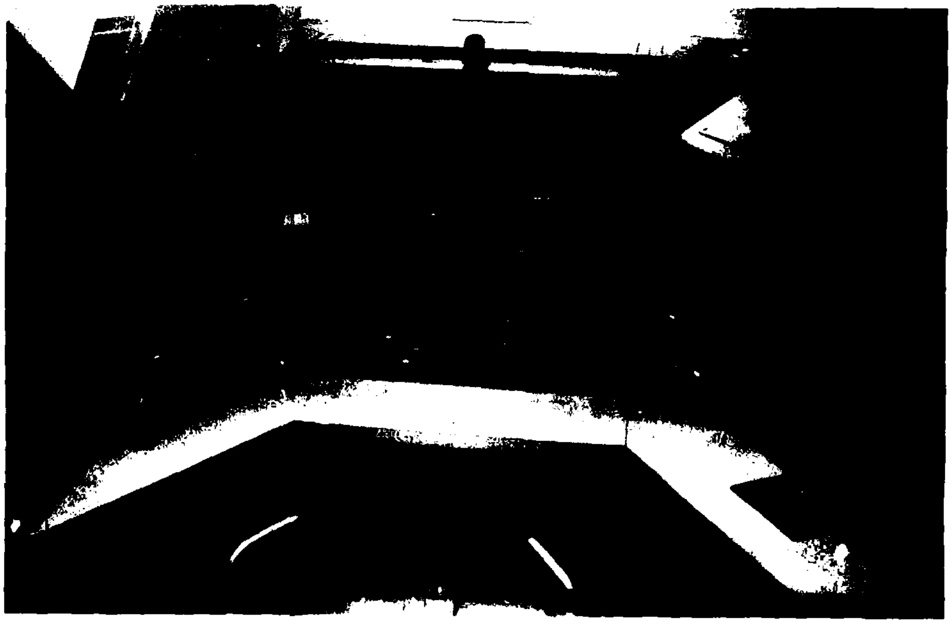

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FIGURE 7. AIR NATIONAL GUARD A-7D SIMULATOR

control an air target. Just beyond the right border of the picture is a radar overview display that allows the instructor to see the two aircrafts' positions. For the laboratory experiments at MDEC three modes of controlling the scene were utilized. A software program was used to reset the position of the "aircraft" wherever desired. A joystick was used to "fly" the system for some of the experiments. The third control device was a $5000 analog flight simulator that was interfaced to the VITAL IV for this project. It had flight characteristics and controls similar to a light aircraftas shown in Figure 8. The flight characteristics of the joystick were much simpler. It simply flew in whatever direction the aircraft nose was pointed. The joystick was used in experiments with novices for this reason.

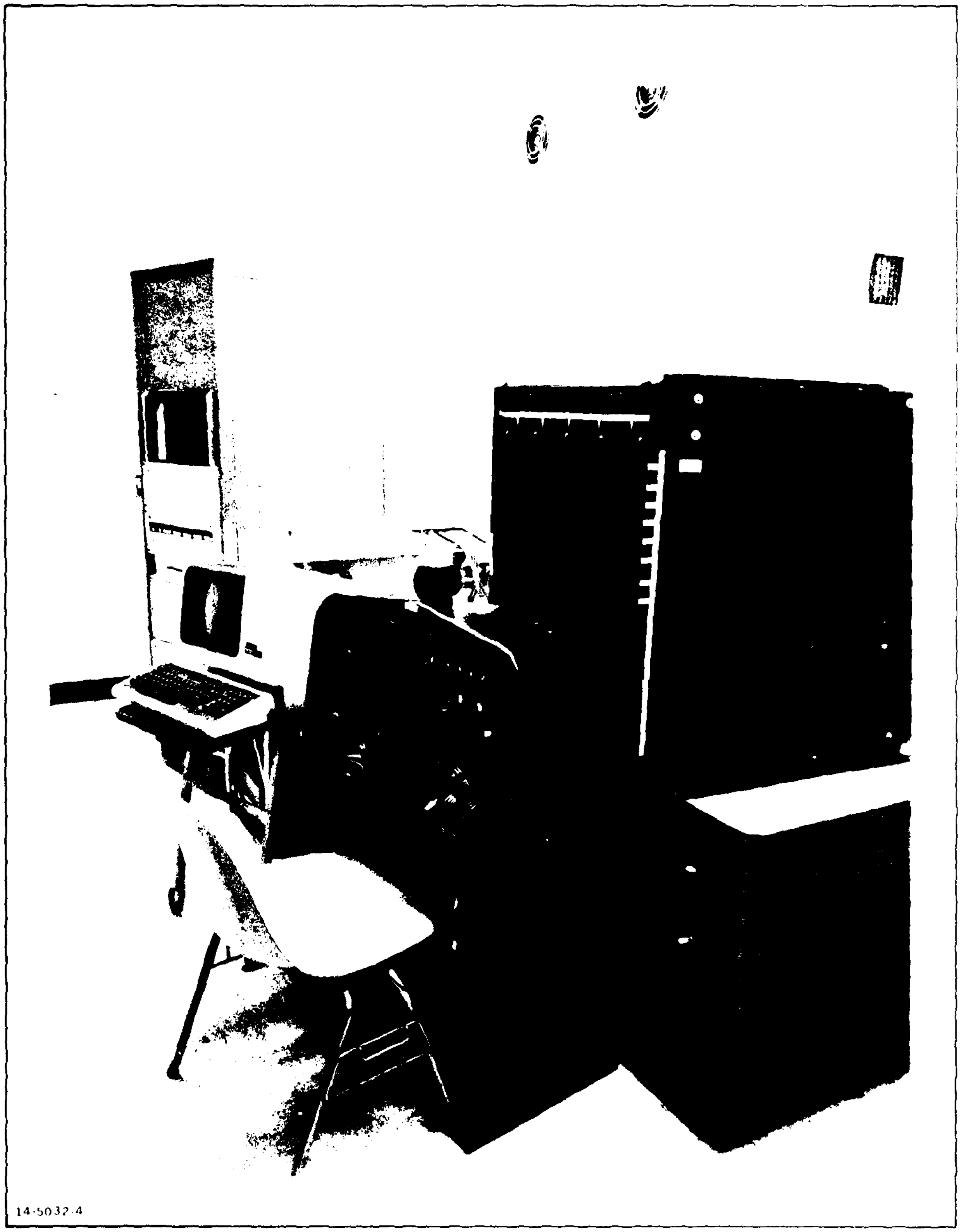

FIGURE 8. ANALOGUE FLIGHT SIMULATOR WITH VITAL IV

SAMPLE IMPLEMENTATION

In this section we will briefly decribe the sample concepts that were implemented followed by a discussion of typical modes of using the special effects. The sample concepts implemented were:

- o Visible sensor cone on an air threat,
- o Visible air track of own and/or threat aircraft,
- o Visible ground track of own aircraft,
- o Multiple viewpoint selection,
- o Immediate bomb scoring appearing on the students visual,
- o Emphasis of the tracer bullet closest to the target for air to air gunnery,
- o Instructor positionable cursor in visual display,
- o Cursor at selectable depression angle from the horizon (represents desired dive angle or glideslope),
- o Velocity vector cursor,
- o Visible air,
- o Light point reinforced air targets,
- o Energy/Maneuverability Diagram.

VISIBLE SENSOR CONE

One of the generic teaching aid methods (Appendix A) is to make visible something the pilot must visualize but cannot see in the real world. As an example of this technique, a scene was created of a MIG threat aircraft with a "lethal cone" attached to its nose. (See Figure 9). An arbitrary size and shape for the cone

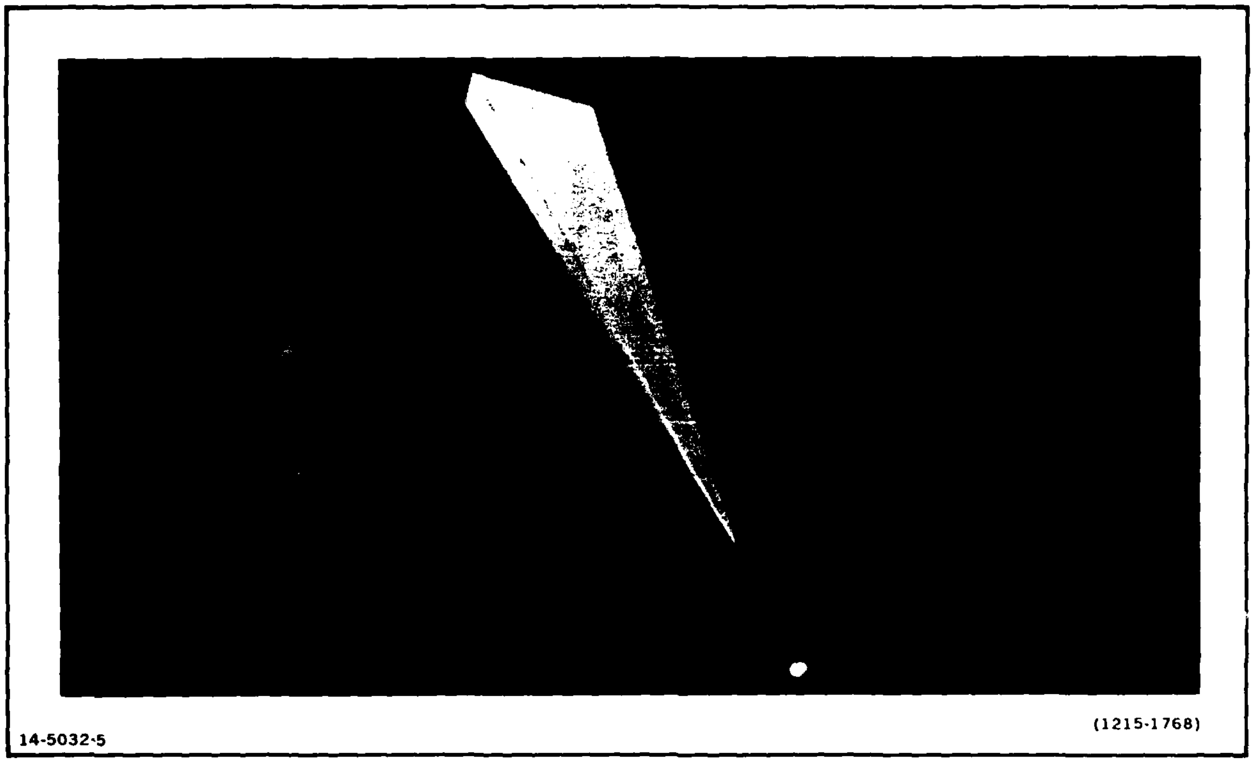

FIGURE 9. VISIBLE THREAT CONE

was chosen to represent a volume of space in front of the threat aircraft in which his radar could "lock on" to a target. The main objectives here were to teach the pilot how this normally invisible cone looks in three dimensions from the various positions attained during an engagement, and to allow him to develop techniques for avoiding it.

VISIBLE AIR TRACK OF OWN AND/OR THREAT AIRCRAFT

In a large number of situations it is useful for the pilot to know his or another aircraft's flight path either during or immediately after a maneuver. This can apply both to air-to-air and air-to-ground combat. In some cases this type of information is already being used in training. On the Air Combat Maneuvering Ranges (ACMR) several pilots can fly instrumented real aircraft in an engagement and later review on ground displays what happened as seen by an instructor operator from the ground during the engagement. This is very useful, but unfortunately requires delayed feedback of several hours. Some simulators present this information to the instructor/operator, but again it is unavailable to the pilot in the cockpit. We implemented a set of contrails formed by inserting light points into the environment in real time during a simulator flight. (See Figure 10). The lights were left behind each aircraft as they flew. A red light dropped from the left wing and a green one from the right wing at uniform time intervals along the flight path. An interval of one second was found to be acceptable. An alternate method also implemented was to leave a single contrail from the center of the aircraft.

FIGURE 10. VISIBLE AIR TRACK

VISIBLE GROUND TRACK OF OWN AIRCRAFT

When a ground track was selected, a string of yellow lights was left at ground level under the centerline of the aircraft. Either the air track or ground track or both could be selected by using spare Remote Control Unit switches on the instructor console.

MULTIPLE VIEWPOINT SELECTION

One of the key training needs frequently expressed by instructor pilots as being difficult to teach in the "real world" is referred to as "situation awareness". One combat experienced Israeli pilot defines a "crowded dog fight" as one in which there is information available to the pilot that of which he is unaware. Thus, performing basic fighter maneuvering may be sufficiently tasking for a beginner that no other aircraft need be present for him to be in a "crowded dogfight". Under this circumstance he may become disoriented and lose his awareness and understanding of his present situation. A larger number of aircraft may enter the fray before a more experienced pilot would lose his "situation awareness". To aid in training this crucial capability, we modified the A-7D simulator visual to allow the instructor to select any of several viewpoints for the student to view the situation from his cockpit. Most frequently, this was used in combination with a brief freeze of the action. (See Figure 11). Viewpoints that could be selected were:

- Overview,
- Profile view,
- View from a ground threat, such as a surface to air missile site,
- Target aircraft's view,
- Any other desired viewpoint could be selected by the instructor driving the viewpoint to the desired position with a joystick.

The Multiple Viewpoint and Visible Flight Paths were most often used together to provide both instructor and student with situation awareness when needed. The viewpoint was selected by use of thumbwheel switches on the instructor console.

IMMEDIATE BOMB SCORING

In the original purchase of the visual systems for the A-7D simulators, provisions were made to provide bomb scoring and release parameters to the instructor. The customer requested that the scoring appear only on the instructor's visual repeater monitor. Significant effort went into allowing the scores to appear only on the monitor without appearing on the students visual display. On our first trip to Davis Monthan under the AFOSR contract, the Air National Guard users of the system complained about this. It was a simple matter at that point to allow the scoring information to appear simultaneously on the student's and instructor's

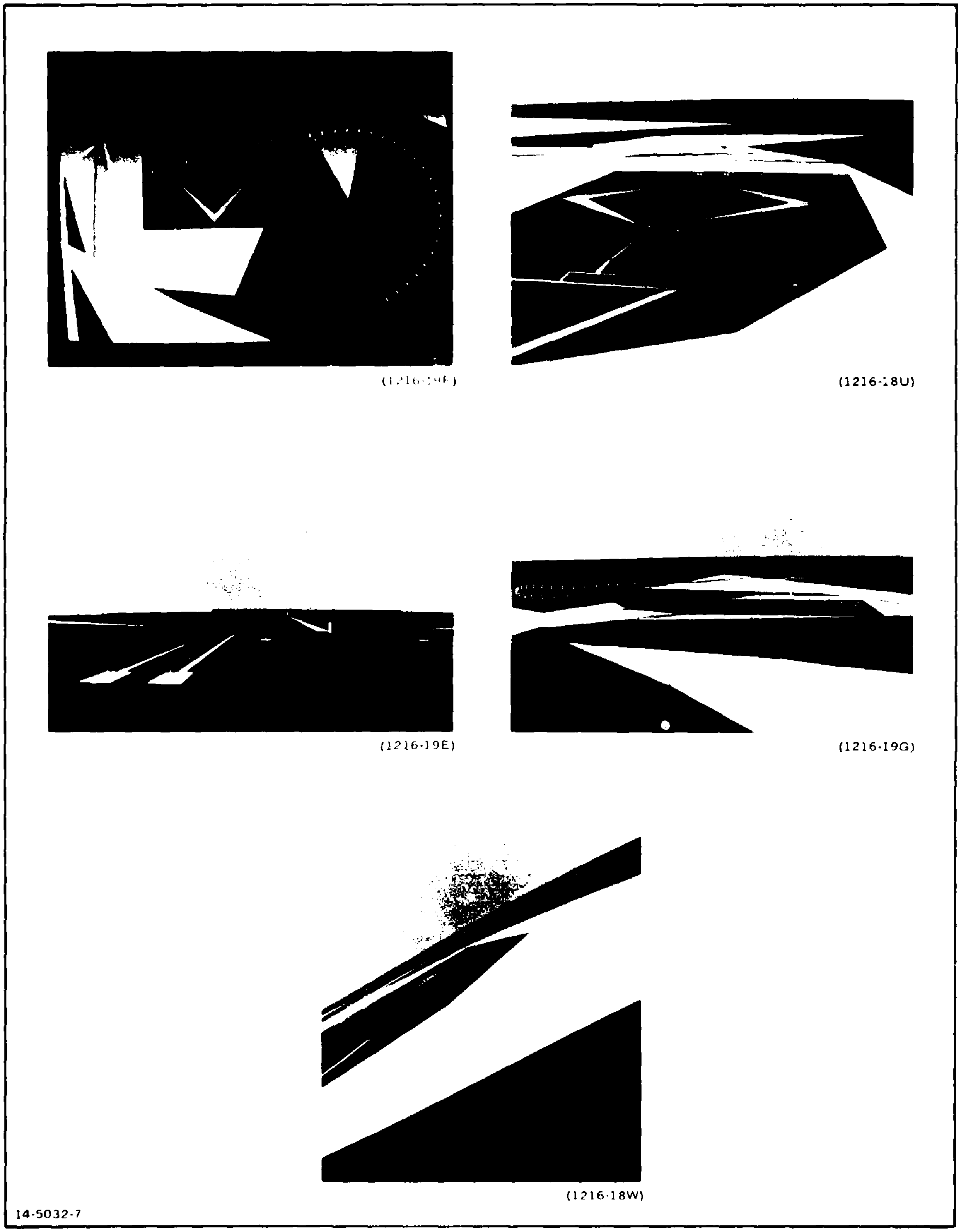

FIGURE 11. MULTIPLE VIEWPOINTS

displays immediately after each bomb drop. This was displayed at the top of the screen. (See Figure 12). The scoring information is a hit or miss indication followed, in order from left to right, by:

- clock angle (7 o'clock)
- miss distance (339 feet)
- angle of attack (0 degrees)
- "g" load (0.0)
- release altitude (2465 feet)
- minimum altitude (2465 feet)
- heading (264 degrees)
- pitch (-20 degrees)
- roll (-4 degrees).

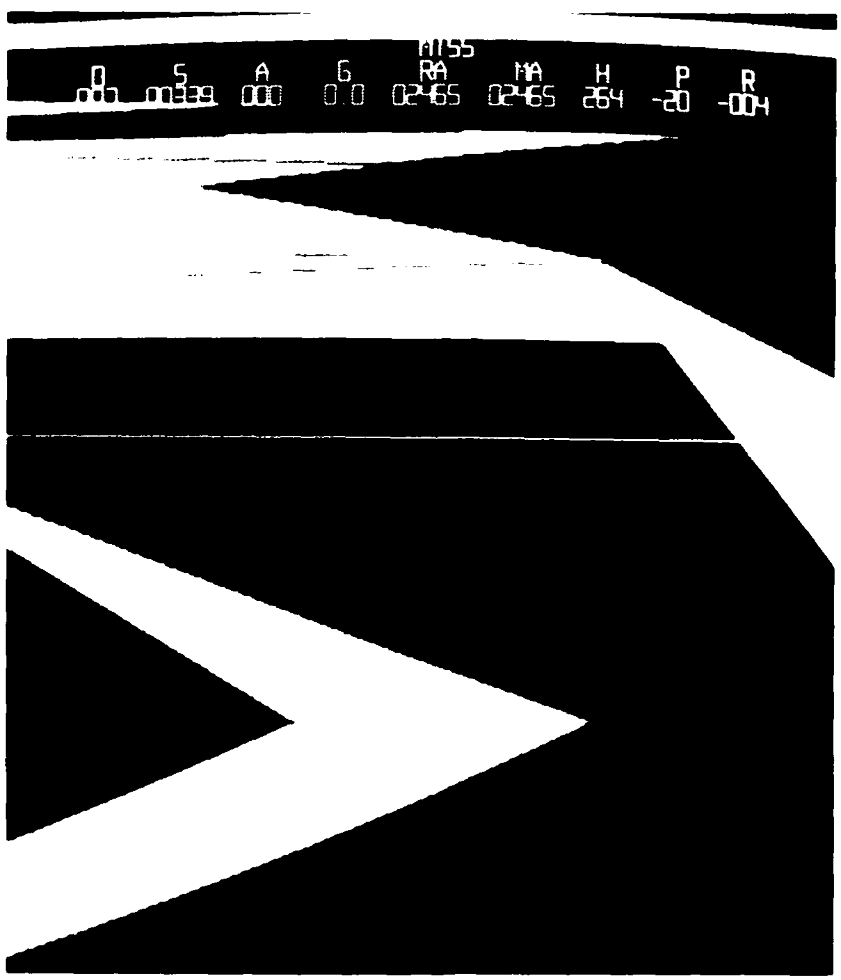

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FIGURE 12. IMMEDIATE BOMB SCORING

TRACER RANGE EMPHASIS

In air-to-air gunnery using tracer bullets, it is difficult to judge where the bullets pass closest to the target, and hence miss distance. A simple way proposed to aid this judgement was to indicate to the pilot where this point is. This could be accomplished in a number of ways. One is to change the brightness of the tracers once they have passed the target. (See Figure 13). Rather than have to change the brightness of a large number of tracers, we decided to brighten and defocus just the tracer bullet closest to the target. We thought that this would provide the simplest implementation. Another approach would have been to brighten each tracer briefly when its range equalled that of the target. However, we could forsee implementation problems with this approach since the positions of the bullets are not updated continuously but at 1/30 second intervals. Thus a tracer might never have a range exactly equal to the target. We thought the closest bullet approach would be essentially equivalent. As will be discussed in the results section, it turned out not to be. Perhaps a better approach might have been to brighten each tracer that was within a certain tolerance band of the range to the target.

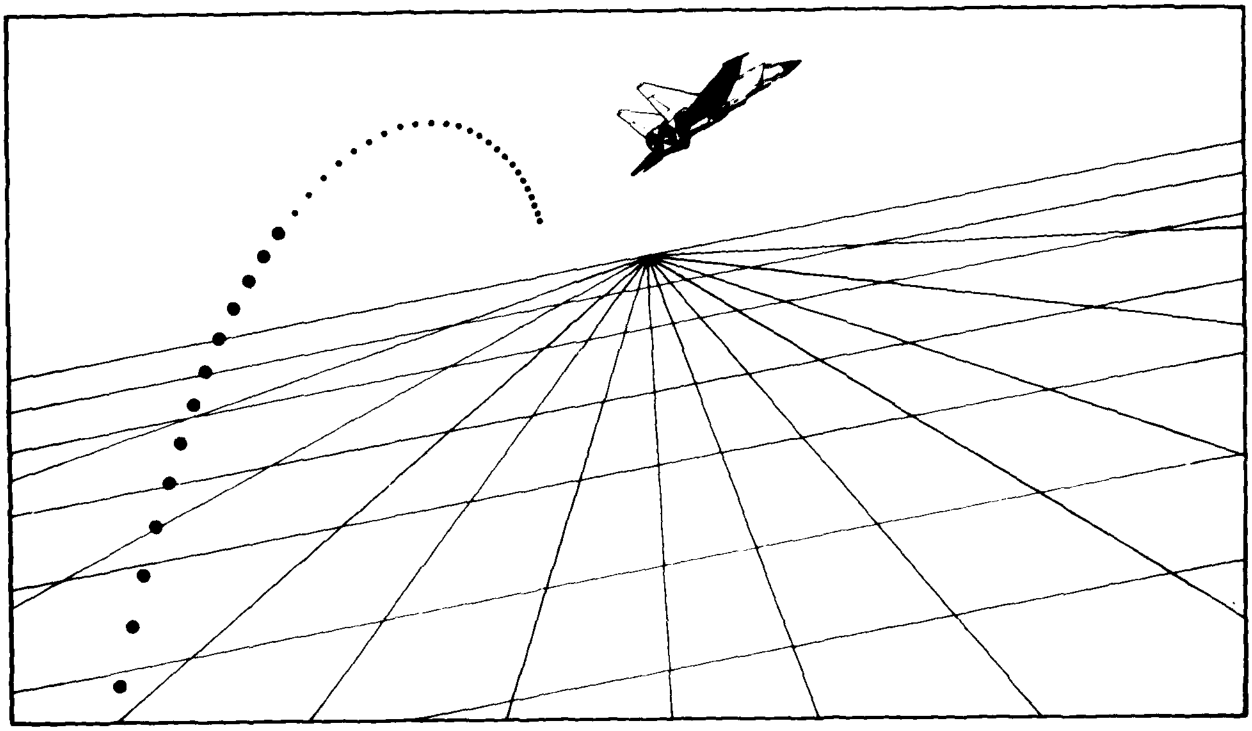

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FIGURE 13. TRACER RANGE JUDGEMENT SUPPLEMENT

INSTRUCTOR POSITIONABLE CURSOR

A cursor has long been used as a valuable tool in computer-aided design applications. It would be equally valuable as part of the computer generated scene in aircraft simulation visual systems. Thus, a cursor was installed that the instructor could position with a joystick at the console. (See Figure 14). The cursor appeared in the instructor monitor as well as in all three windows of the students cockpit displays. The instructor had a switch he could use to allow his monitor to repeat any of the three student windows. We would have liked to allow student control of the cursor as well, but there were no spare control mechanisms in the simulator cockpit.

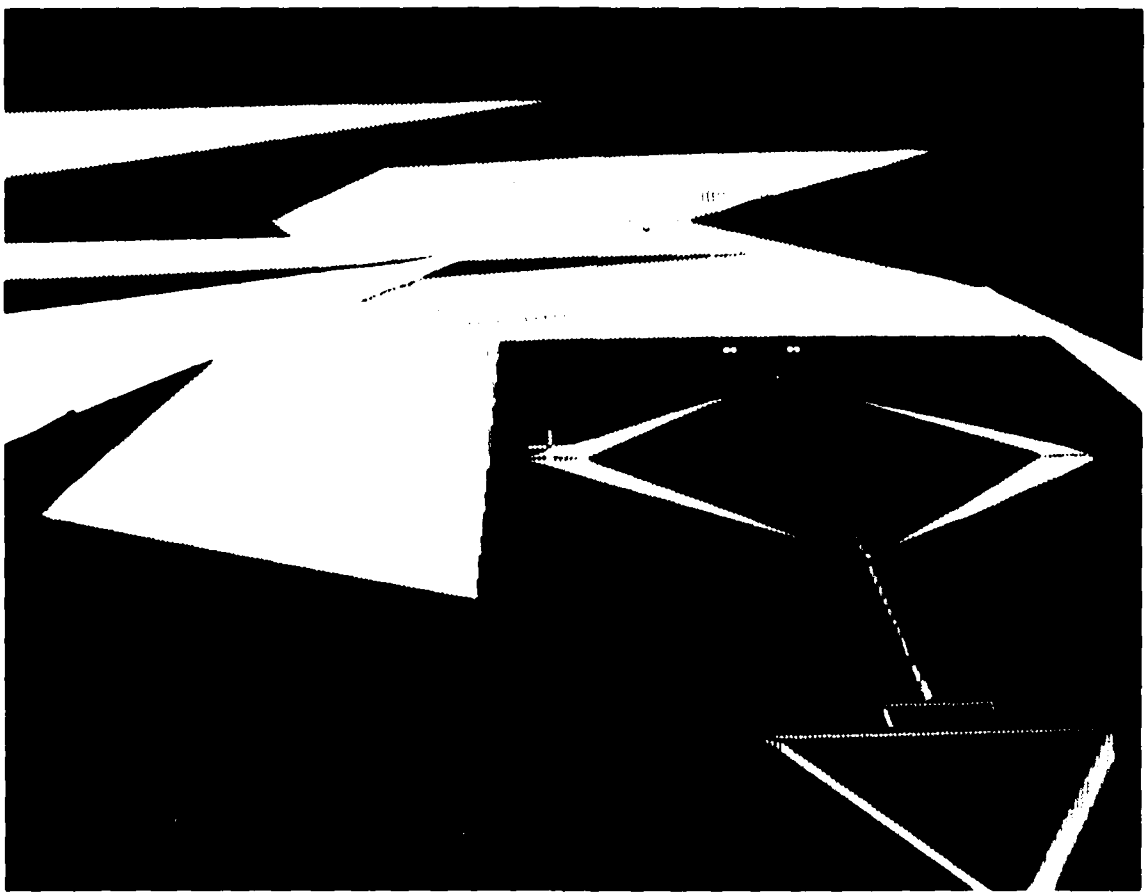

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FIGURE 14. INSTRUCTOR POSITIONABLE CURSOR

CURSOR AT SELECTABLE DEPRESSION ANGLE FROM THE HORIZON

A cursor type unique to flight training was installed. This is one which remains a fixed, selectable number of degrees below (or above) the horizon This could be set, for instance, to 3 degrees and it would represent a desired glideslope angle for landing. Any object appearing centered in the cursor is known to be located along a 3 degree slope from the aircraft and vice versa. (See Figure 15). If the cursor were set at a larger angle such as 10,15,20,30, or 45 degrees, it could be used to represent a desired dive angle for air-to-ground attack. Use of this type of cursor can help a student learn the correct sight picture for dive bombing or straffing. (See Figure 16). It can also be a great aid in learning to visually judge and correct glideslope for landing.

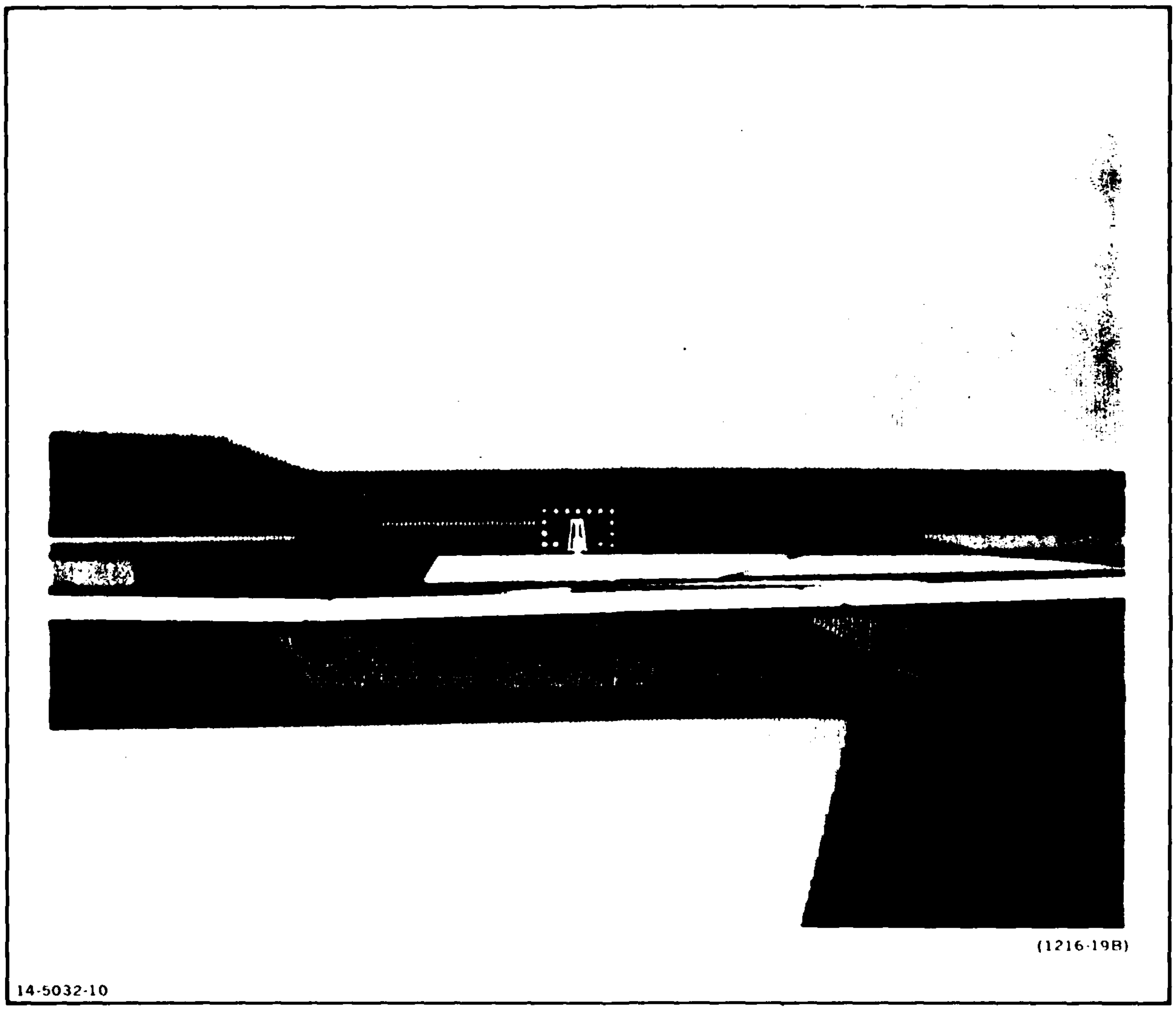

FIGURE 15. HORIZON DEPRESSION ANGLE CURSOR

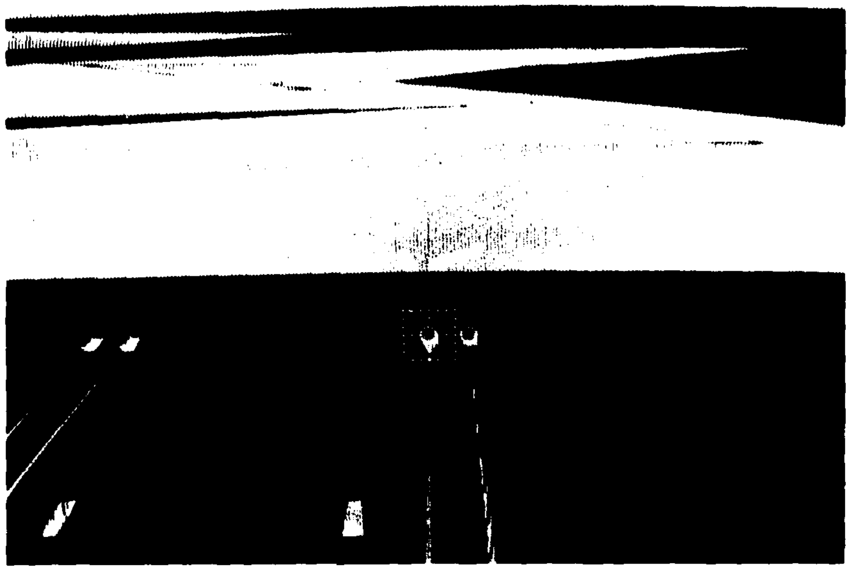

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FIGURE 16. HORIZON DEPRESSION CURSOR

VELOCITY VECTOR CURSOR

Another type of cursor we implemented was one showing where the aircraft was headed at any given time. This is referred to as the velocity vector. Since the velocity vector already appeared on the Head Up Display (HUD) on the A-7D, we did not use it on the simulator with the Air Guard pilots. We did, however, use it for the in-plant experiments. As with the other cursor types, the intensity of the cursor was adjustable so that the instructor could make it bright at the beginning while the student is learning its meaning and use. Yet the instructor could make it dimmer later so that it would not hide the intrinsic cues in the scene and would not become a crutch. (See Figure 17). One of the critical parameters in early flight training as well as in combat maneuvering is "angle of attack". This is roughly the angle between the velocity vector and the aircraft nose. Early in flight training students may confuse angle of attack and pitch. The velocity vector in conjunction with the "visible air" scene to be described later were very helpful in teaching the difference between angle of attack and pitch. They were also quite helpful in teaching how to judge your aim point (where the aircraft would hit if it continued on a staight course) from the motion of objects in the scene.

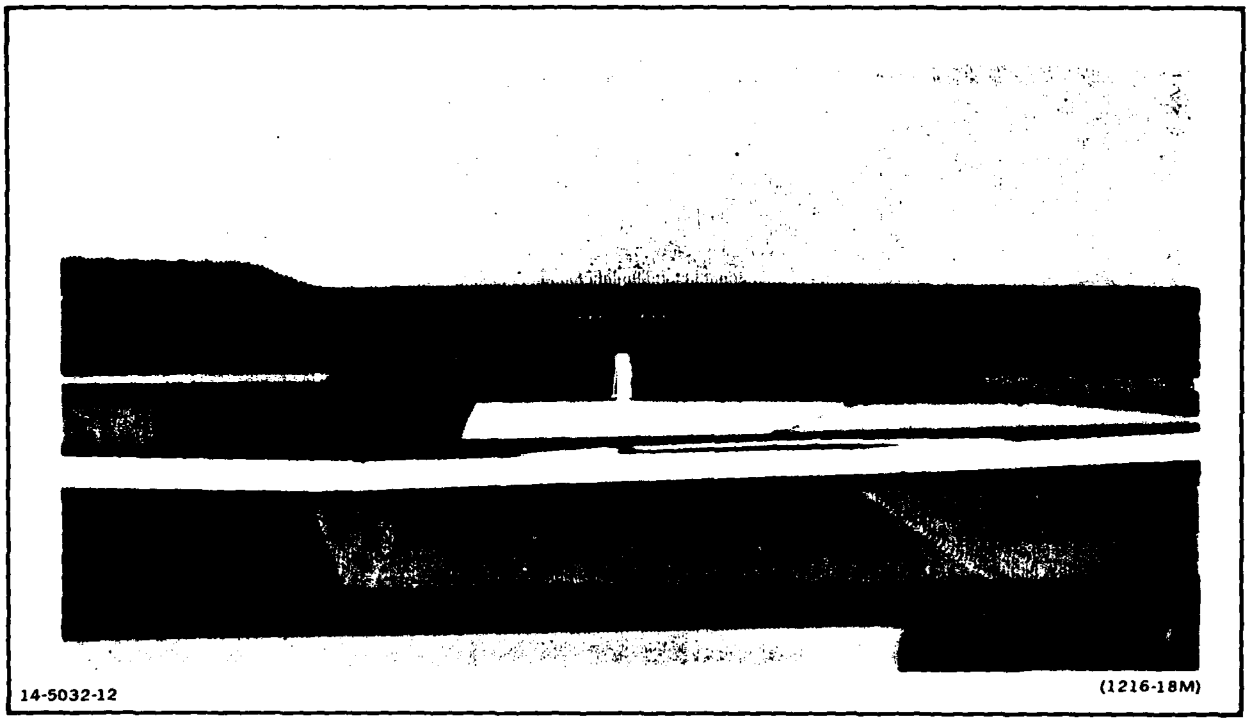


FIGURE 17. VELOCITY VECTOR CURSOR

VISIBLE AIR

A scene composed of 16,000 light points uniformly spaced to form a cube was made and is referred to as "visible air", (see Figure 18). It creates enthusiasm in the student since it has a "Star Wars" quality to it. It also is excellent for use in demonstrating a number of important visual aspects of flight. For instance, by flying through this scene a student can quickly learn the basics of how the motion of objects around the aircraft can convey his position and motion to him. This was easier with this type of scene since the student was not distracted by the objects themselves and hence could more readily pay attention to their pure motion. Another advantage to this scene is that it has no horizon and no pitch references. Thus the student can be introduced readily to the properties of his velocity vector and how to judge his aim point with less confusion than in the real world, where in addition to the relevant cues there are many irrelevant cues to confuse the novice. It is interesting, in this regard, to note that the Director of flight training at Parks College uses a similar technique in teaching students landing. If they are having trouble, he takes them up at night, when fewer irrelevant cues are available.

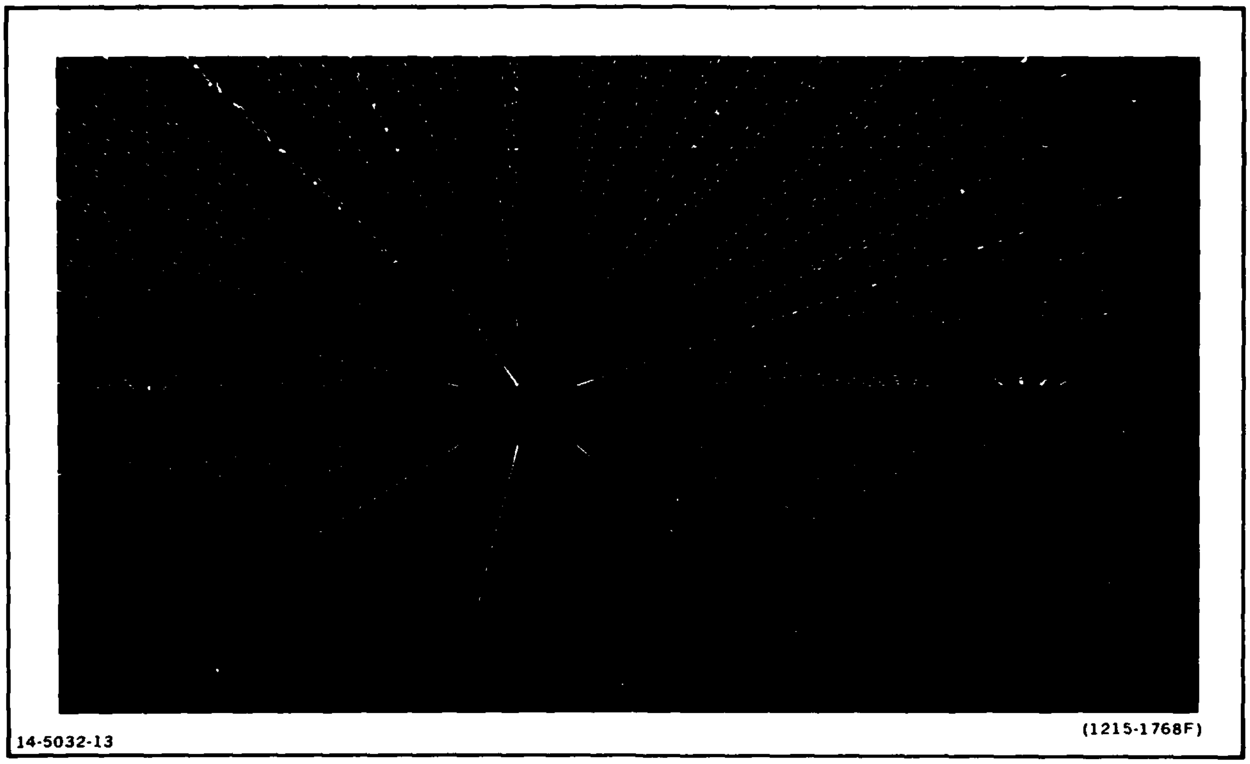


FIGURE 18. VISIBLE AIR FROM ANGLE OF ATTACK, PERSPECTIVE JUDGEMENT TRAINING, OR SENSE EXERCIZE

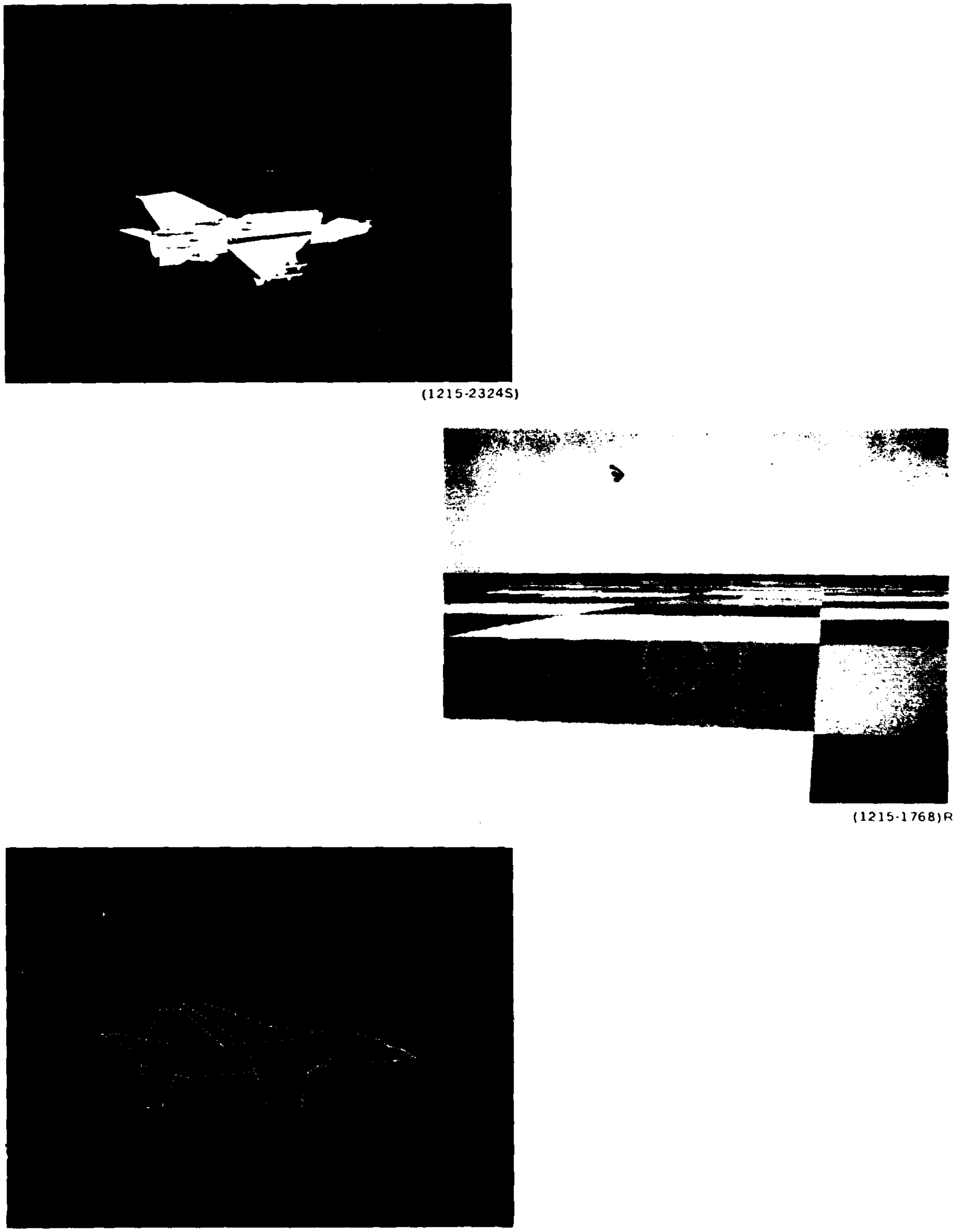
LIGHT POINT REINFORCED AIR TARGETS

The representation of air targets in computer generated visual systems has long been a source of debate. The major complaints from pilots have been that the detection and aspect recognition are frequently not possible at realistic ranges, and the the representations do not look realistic enough. They are not usually asked which of these problems is the more severe. Present real time computer generated image systems usually represent objects using either light points or shapes. The shapes are most often represented at 1000 lines per screen height raster density. Moreover, the position of these raster lines on most systems is fixed on the screen. "Calligraphic" image systems are ones that move the drawing beam directly from one position on the screen to another, as opposed to "raster scan" types which scan the screen in a fixed raster. One frequently unused advantage of the calligraphic type system is its ability to position the beam with great precision. Usually, the beam may be positioned for light points to at least one part in 4096 of the screen height! On the particular system we were using the start point for drawing a shape could also be positioned to one part in 4096.

Another factor that can be taken advantage of is the fact that it is common for the spot size of the electron beam of a cathode ray tube, (CRT), to grow with higher beam current, (brightness). Combining these two advantages one can make targets out of a combination of shapes and light points so that at close distances the target is represented by shapes to achieve a realistic looking solid appearance; however, as the range to the target increases the shapes, which quickly become difficult to see, can be faded out and a light point representation can be faded in. In addition, as the target reaches still greater ranges, the lights can be gradually reduced in intensity to correspondingly reduce the spot size. This technique, which we call "light point reinforced targets", was used to allow aspect recognition at near real world ranges. (See Figure 19).

ENERGY/MANEUVERABILITY DIAGRAM

In air combat it is critically important for a pilot to know not only his own aircraft's maximum limitations (performance envelope) but also those of his potential adversaries. A useful tool in this process is the energy/maneuverability diagram (References 4 and 5). This is normally a diagram of turn rate versus air speed. (See Figure 20). Use of such diagrams in training is not new. They are available to instructors, or to students in post flight briefings, on the instrumented air combat practice ranges. However, the problem of feedback delay of several hours occurs in this situation. In addition, most pilots have access to such a sophisicated system for at most two weeks a year. This is due in large part to the tremendous cost of purchasing and operating these systems. We decided, therefore, that it would be of tremendous advantage for a student of air combat to have access to this type of information on a daily or weekly basis in the simulator that he normally uses with his operational squadron. Recent helmet coupled display technology will make this feasible. In addition, such a helmet display would allow the pilot to see the performance envelope despite large head motions typical of air combat. Thus, we designed a new type of energy/maneuverability diagram containing altitude in addition to the standard information. (See Figures 21 and 22). The diagram consists of three parts: Axes systems, aircraft flight envelopes, and aircraft energy state indicators. The axes consist of an altitude axis and two velocity axes, one for each aircraft. Each of these is formed of a display coordinate lightstring. Each velocity axis is positioned at the aircraft's current altitude along the altitude axis. The altitude axis is fixed.



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(1215-1768)R

(1215-2324P)

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FIGURE 19. AIR TARGETS

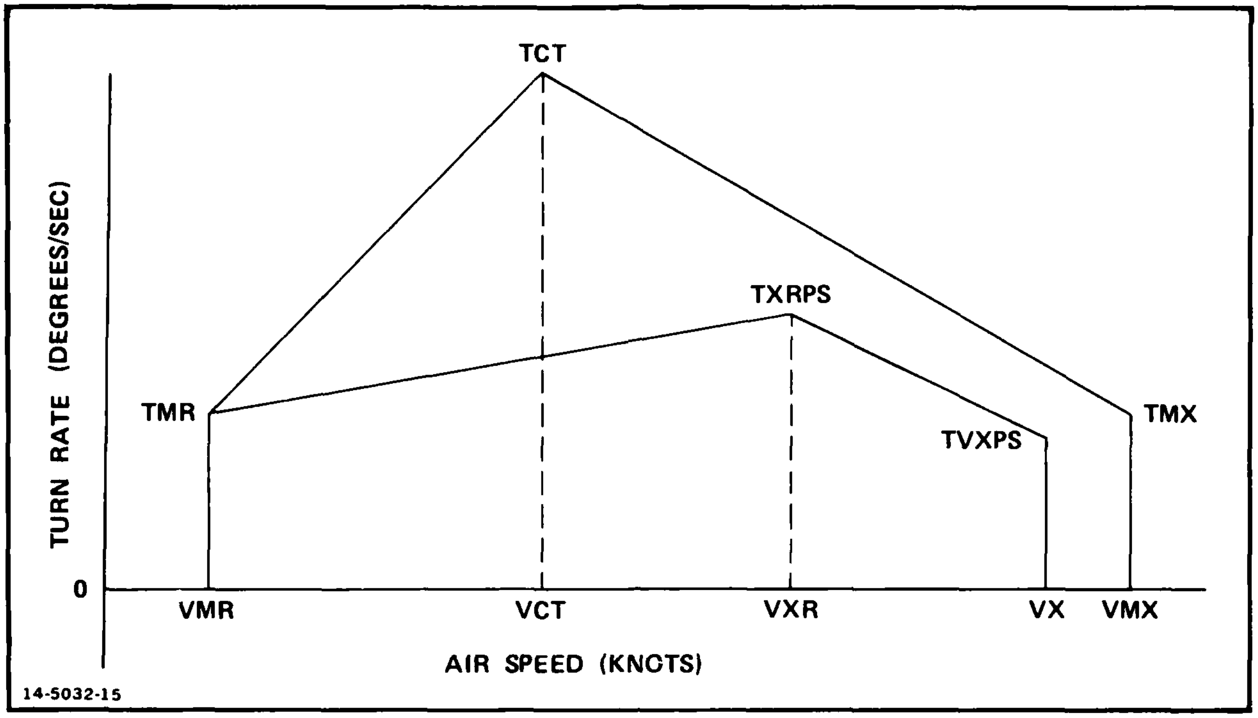


FIGURE 20. STANDARD ENERGY DIAGRAM

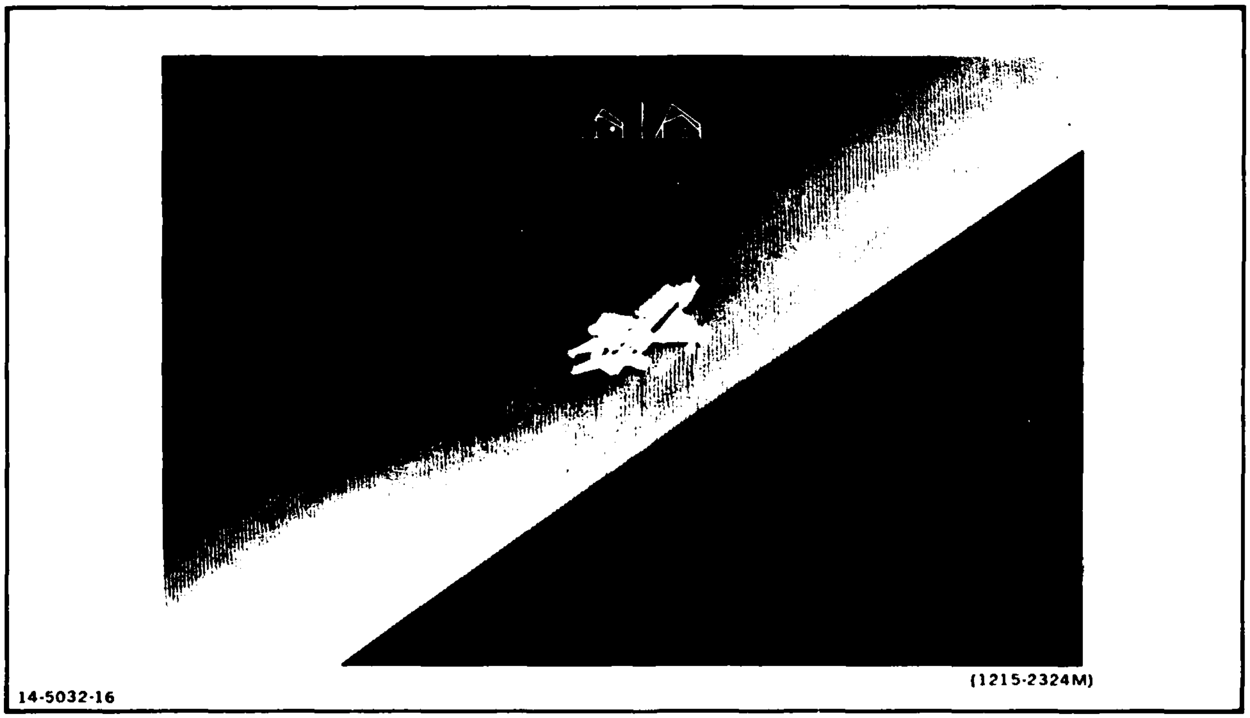


FIGURE 21. ENERGY MANEUVERABILITY DIAGRAM WITH ALTITUDE AXIS

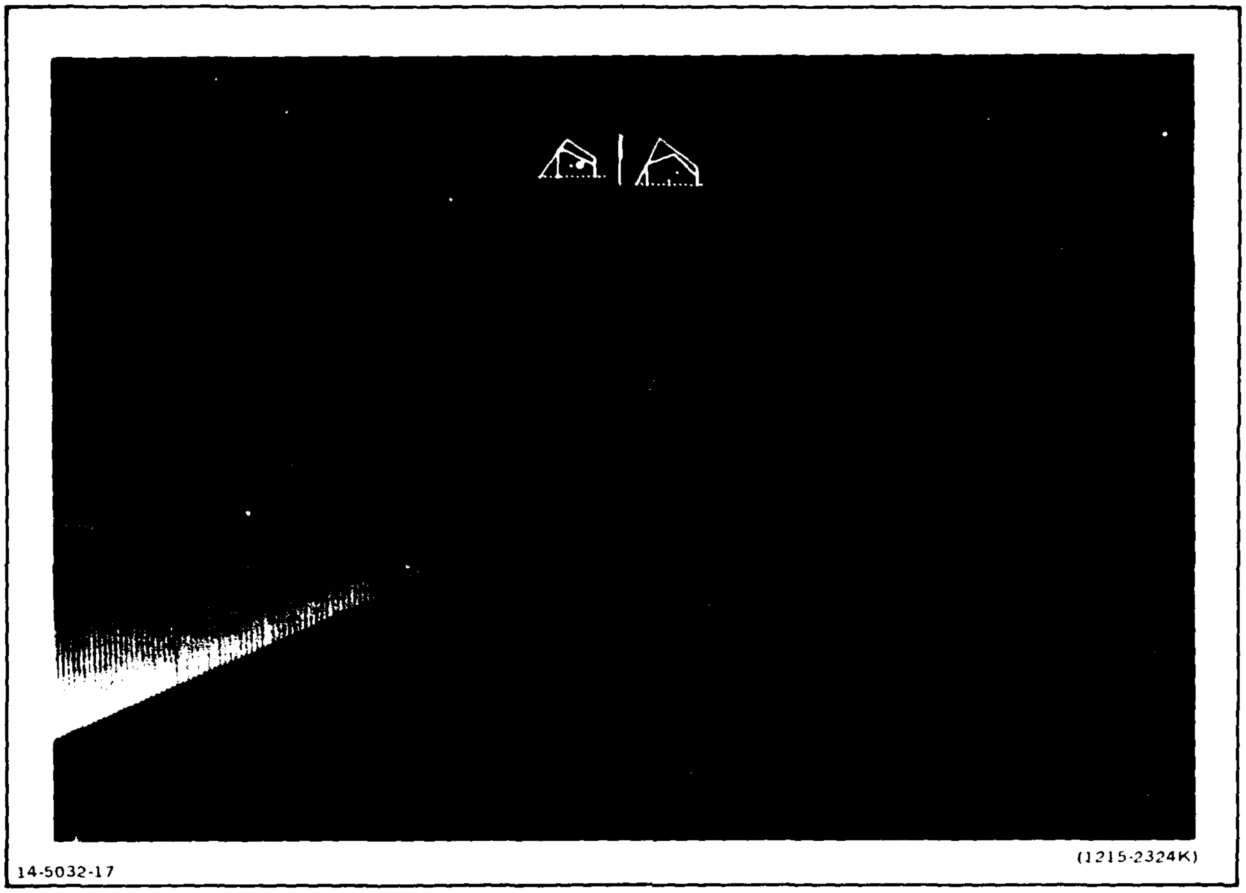
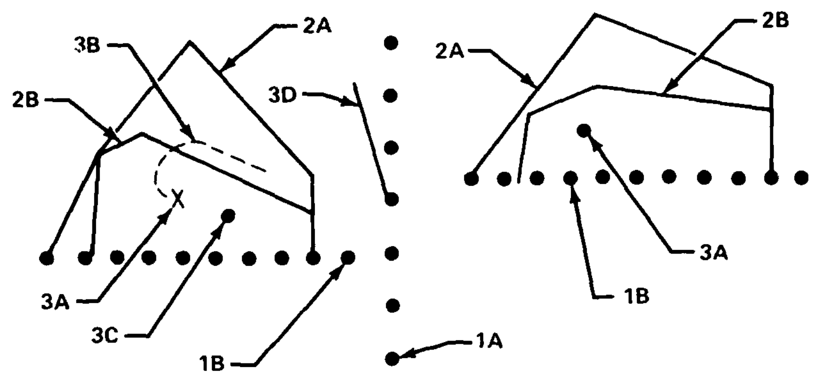


FIGURE 22. ENERGY DIAGRAM SHOWING OWN AIRCRAFT AT 5000 FEET AND THREAT AIRCRAFT NEAR ZERO ALTITUDE

The flight envelopes show the maximum turn rate and the maximum sustainable turn rate at full throttle as a function of airspeed and altitude for each aircraft. At low speeds - those below the speed at which the highest turn rate can be achieved - the maximum turn rate is limited by the lift line, that is to say, turning faster will result in the aircraft having too little lift to stay airborne. At speeds above the speed of maximum possible turn rate, the maximum turn rate is limited by the structural limits of the aircraft or the pilot. The sustainable turn rate divides the envelope into two parts: an energy loss region above it, and an energy gain region below. An aircraft in its energy gain region and at full throttle will increase speed or altitude; an aircraft in its loss region will descend or slow down. The flight envelope is formed from nine velocity-turn rate points whose exact values depend on the aircraft type and the current altitude. (See Figures 23 and 24).



1. THE AXES SYSTEMS WHICH CONSIST OF (A) THE ALTITUDE AXIS AND (B) THE VELOCITY AXIS FOR EACH AIRCRAFT;
2. THE FLIGHT ENVELOPES OF THE HOST SIMULATOR AND AN ENEMY AIRCRAFT SHOWING (A) THE MAXIMUM TURN RATE AT EACH VELOCITY AND (B) THE SUSTAINABLE TURN RATE AT FULL THROTTLE FOR EACH VELOCITY; AND
3. THE AIRCRAFT ENERGY STATE INDICATORS WHICH INCLUDE (A) THE AIRCRAFT'S CURRENT STATE, (B) THE HOST MARKER TRAIL, (C) THE ENEMY AIRCRAFT'S EQUIVALENT SPEED MARKER, AND (D) THE RELATIVE ENERGY GAIN INDICATOR.

14-5032-18

FIGURE 23. ENERGY MANEUVERABILITY DIAGRAM COMPONENTS

1) SPEED = 0 TURN RATE = 0

2) SPEED = MINIMUM AT FULL THROTTLE AND AFTERBURNER
TURN RATE = 0

3) SPEED = MINIMUM AT FULL THROTTLE AND AFTERBURNER
TURN RATE = MAXIMUM SUSTAINABLE AT THIS SPEED

4) SPEED = MINIMUM AT FULL THROTTLE AND AFTERBURNER
TURN RATE = MAXIMUM AT THIS SPEED

5) SPEED = SPEED OF MAXIMUM SUSTAINABLE TURN RATE
TURN RATE = MAXIMUM SUSTAINABLE

6) SPEED = SPEED OF MAXIMUM TURN RATE
TURN RATE = MAXIMUM

7) SPEED = MAXIMUM TURN RATE = MAXIMUM AT THIS SPEED

8) SPEED = MAXIMUM TURN RATE = MAXIMUM SUSTAINABLE AT THIS SPEED

9) SPEED = MAXIMUM TURN RATE = 0

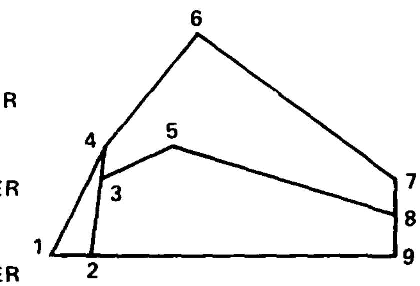


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FIGURE 24. ENERGY MANEUVERABILITY DIAGRAM DEFINED

Ficticious values were made up for our demonstrations and do not represent any real aircraft. Each aircraft's current speed and turn rate is indicated on its diagram by its current state marker. The threat aircraft's state is represented by a dot; your aircraft's state is represented by an "X". A trail of dots is attached to your aircraft's state marker to show its recent history. An "equivalent speed" marker for the threat aircraft is presented on your diagram showing the threat's current turn rate and the speed it would have your own altitude if it kept its total energy (kinetic plus potential) constant. Finally, there is a relative energy gain indicator which points toward the side of the aircraft that is gaining energy relative to the other aircraft. The tangent of the deflection of this indicator from vertical is proportional to the relative rate of energy gain. Alternatively, it could have represented relative energy instead of relative energy rate. The "own" and threat diagrams are separatly turned on by spare switches. Turning on the threat aircraft's diagram activates the relative energy gain indicator. The threat equivalent speed marker is on only when both diagrams are active. Though real lift and load limits are curved, they are approximated by straight lines.

EXPLORATORY TESTING

After implementing the above described special effects and teaching aids, we began exploratory testing to determine whether the concepts, when put into practice, indeed showed signs of having the utility we expected. Since such a broad range of aids and techniques for using those aids needed to be examined, we opted to examine each in a relatively shallow fashion rather than attempt to examine a few in great depth. It was our hope to proceed far enough on each one to accomplish two goals:

(1) to establish which of the concepts showed enough promise to warrant further extensive testing,

(2) to provide exploratory test data that would be helpful to anyone wanting to design and perform more detailed experiments on one or a few of the concepts.

With this in mind, we will now describe the exploratory testing. This section will be divided into two major parts: in-plant tests, and tests on an operational flight simulator.

AIRCRAFT CONTROL USING MINIMUM VISUAL ELEMENTS

A defineable point on the horizon and within plus or minus 45 degrees of the desired aircraft heading can be used as a referance to control aircraft roll, pitch, and yaw. The visual points on the horizon; however, do not provide any visual cue for judging aircraft altitude or air speed. A definable point on the horizon greater than plus or minus 45 degrees from the desired aircraft heading can be used as a reference for controling roll and yaw. A visual point of reference below the horizon can be used as a reference to supplement aircraft control. If altitude is known, the angular movement of ground referance points can be used to make speed judgements as well as controling the aircraft attitude. If airspeed is known, then the angular movement of the ground reference point can be used to make altitude judgements as well as controling aircraft attitude. The ability to use minimum visual cues allows the pilot to maintain control of the aircraft by interpreting the visual elements that are presently in his field of view. The minimum cue techniques can be demonstrated best with a grid of light points on the ground plane. As the pilot learns to interpret data from the light points' angular change, the number of points can be reduced until he is able to control the aircraft by interpreting the minimum visual cues in his field of view.

To learn to ascertain attitude and altitude changes from points closer than the horizon in limited visibility:

(1) Learn cues from symmetrical ground pattern relative movement,

(2) Gradually lower horizon by reducing visibility,

(3) Switch to a random ground pattern,

(4) Eventually, only one light point and the knowledge that it is on the ground should be sufficient to be able to fly straight and level.

Following this procedure, one of the authors (Don Hauck) was able to do left and right turns and pitch changes based on only one light point visible at a time. Don has 1700 flight hours experience and over 700 hours as a flight instructor, but was unable to do this until practicing as described above. In addition, he was able to teach one of our field service personnel, a pilot with 200 hours' experience, also to fly straight and level and in level "S" turns using the same techniques. He attempted to do this with shapes or points and found that, although it was possible with shapes, it required much more concentration than with points. This is most likely due to the lower contrast, resolution, and positional precision of shapes when compared to points.

The goal of this effort was not to be able to teach people to fly from one light point per se. Rather we were beginning to address a very common problem of flight. That is, the tendency to focus one's attention narrowly out the front of the aircraft when under stress, such as in low level flight. Our hypothesis was that if a pilot could learn to obtain sufficient information for flight from a small number of cues from any of a wide variety of directions, then he could spend a larger proportion of his attention and effort towards other important tasks. For instance, he could keep his eye on a target for a larger proportion of the time if he were able to obtain his flight cues also by looking at the target.

This can be very important for air to ground attack, since taking one's eye off the target can lead to loss of sight of the target, reacquisition being time consuming or impossible. Another use for this capability is for tactical formation flight. It has been demonstrated that the success of low level bombing is strongly related to the ability to maintain good tactical flight formation. This requires that a significant proportion of the pilot's time be spent looking to the side. To the extent that we could teach a pilot to fly with reduced need for looking to the front and with a lower level of anxiety about ground impact, one would expect an improvement in low level tactical formation flight, and hence a corresponding improvement in bombing mission success. Learning to fly while looking to the side is difficult, but can be done with practice. Obviously, one cannot hope to spend all of the time looking to the side, since obstacle avoidance requires looking in the direction of flight. However, most pilots, particularly under stress, spend far more of their attention toward the front of the aircraft than is necessary simply for obstacle clearance. This effect can be thought of as tunnel perception. The information may enter the viewer's eye, but not necessarily make an impact on his brain. One way to test for this phenomenon would be to use switch controlled scene elements. The instructor could make objects appear in the scene outside the forward view and check to see how long it takes the student to notice them. The "tunnel" tends to narrow and center forward under stress. One goal might be to expand the tunnel and move it off center after training while maintaining the same flight performance. Once one has had experience learning the expected motion of scene elements in various positions with respect to the aircraft in straight and level flight, then if an object moves left or right with respect to the expected trajectory, one has a yaw rate established and must adjust roll iteratively to null the undesired yaw.

It is actually easier to maintain the correct attitude in relation to the natural horizon during a climb than during cruise. In training aircraft, a one degree pitch change means about a five knot change in climb airspeed. It can become easy for most pilots to hold the correct climb attitude, because the total distance between the horizon and the end of the cowling or top of the instrument panel is small, so a pitch change is easily perceived as relative motion between the horizon and this reference part of the aircraft.

During cruise, the total distance between the top of the panel and the horizon is generally larger, depending on the aircraft seat height, and the pilot's sitting height. Therefore, pitch changes become more diffucult to judge. This is particularly true if the natural horizon is ragged or uneven, as in mountainous terrain, or in areas where it is obscured due to poor visibility. A pitch change of one degree in a typical training aircraft during cruise will produce about 100 feet per minute change in vertical speed. Over a period of many seconds, this will result in a substantial error in altitude.

For these reasons, a student can be taught to maintain a pitch attitude during cruise by holding the nose steady in relation to a terrain feature very close to the top of the panel or end of the cowling. The terrain feature can be anything, such as a road, water body, powerline, tree, field or building. Even if the aircraft is only 1000 feet above ground level, the subject will appear to remain stationary, or very nearly so, for a time long enough for even a very small pitch change to be immediately obvious.

For this technique to be completely effective, it is essential that the aircraft be trimmed perfectly. Pilots are taught that the trim controls' primary function is to relieve control pressures; however, their primary purpose is akin to that of an autopilot, that is, to help the aircraft fly by itself, thus letting the pilot divide his attention among the numerous tasks that make up flight management. The pilot should ascertain whether or not the aircraft is trimmed, not by lack of control pressures, but by whether or not the pitch attitude changes from the correct attitude "hands off". This should be done by attaining the correct pitch "picture", and then releasing the controls. After seeing which direction the nose moves, the pilot should immediately attain the correct pitch picture again, using the control stick or yoke, not the trim control. When the aircraft has stabilized again, the pilot should re-trim. This procedure should be repeated until the aircraft flies "hands off".

What is the correct attitude, and how is it determined? For every combination of gross weight, center of gravity, power setting, flap setting, angle of bank, pressure altitude, ambient temperature, humidity, and vertical speed, there is one, and only one, correct pitch attitude for what one wants the aircraft to do. It is the pilot's responsibility to identify this correct pitch attitude and trim the aircraft so it will fly by itself.

In this approach to flying, the instruments are there only to confirm that the pilot has visually established the correct attitude, and to help him fine tune it. A pilot who learns to control the aircraft by what his eyes see will find transitioning to other aircraft much easier than will the pilot who learns to control an aircraft by what his hands feel. Every aircraft "feels" different, but they all have a top of the panel or end of the cowling with a horizon in front of it.

To control heading as well as airspeed and altitude, one can use a similar procedure. That is, one gets the correct picture for a particular heading by holding some portion of the aircraft steady in reference to something on the ground. In this case, the reference line has to be vertical rather than horizontal. The pilot should first determine which point on the aircraft is directly ahead of him as he sits in the seat. Some students have a difficult time determining the visual flight path from their eyes that exactly parallels the aircraft's longitudinal axis. This path is a foot or so from the longitudinal axis, and intersects the horizon or ground about a foot or so from the same place that the longitudinal axis does. Thus, for all intents and purposes, the aircraft appears to the pilot to roll about the axis of this visual path, rather than the longitudinal axis of the aircraft.

With some students, it helps to put a piece of colored tape in front of them on the cowling parallel to the longitudinal axis. A way to do this accurately is to sight along the longitudinal axis while the aircraft is on the ground, and see what point on the horizon is lined up with it. Then a piece of tape can be placed appropriately. Once this mark on the aircraft has been established, it is a simple matter to get on the desired heading, see what spot on the horizon or ground the aircraft is lined up with, and maintain that "picture". The pilot must remember that if there are crosswinds and the point on the ground is close by, he cannot use it for the entire leg, but he must periodically select another point to maintain the desired heading. Otherwise, he would fly a curved path to the original point.

When the student can identify the correct "picture" in front of the aircraft, then he must look inside and use the instruments. First, he should set a general goal of looking at each item on the panel at least once every 30 to 60 seconds. This includes all flight and engine instruments, avionics, electrical and vacuum instruments and the outside air temperature gage.

If one accepts the idea that there is only one attitude for every combination of factors, then there are certain indication on the instruments for which one must look. So what is the correct way to use the instruments? One may think of them as being there to confirm that one has the right "picture" and to help fine tune it. It is helpful to think of controlling an aircraft as a series of small corrections which result in a series of close approximations of what one is attempting to get the aircraft to do. When the student has learned to think about controlling the aircraft in terms of "pictures", he will have little difficulty flying solely by reference to instruments.

DIVE ANGLE AND AIM POINT JUDGEMENT

Overview

By performing these experiments we intended to determine the validity of some of the concepts put forth in this report. The first experiment was designed to establish how well subjects could judge depression angles at a close distance. The second experiment was designed to determine how well subjects could judge glideslope angles on a collimated VITAL IV visual system, and to determine how visual training would influence these judgements. The third and last experiment was designed to measure the amount of influence non-real world visual training cues have on simulated flight performance. Finally, the experiments performed allowed comparisons between glideslope angle judgements made close to the runway versus judgements made far from the runway. For a discussion of the experimental procedures refer to Appendix B.

Term Definitions

Non-Real World Visual Cues

Any items in the visual presentation to the student which would not be found in actual flight or would not look the same in actual flight. For example, a cursor with which the instructor can position over objects in the scene. Figure 25-D.

Depression Angle

Angle measured perpendicular to the horizon from the horizon to some point below the horizon. This angle corresponds to a defined glideslope or dive angle.

Depression Angle From Horizon Technique

A method to determine whether the instantaneous position of an aircraft is on a predefined glidepath or dive angle (Reference 6). The method comprises visually comparing the desired depression angle with the angle separating a specific point on the ground from the horizon line. (Note: This is not to be confused with pitch angle). A natural horizon may not always be available. For instance, hilltop lights beyond the airport may elevate the apparent horizon to a confusing height. By practicing the projection of the runway edge lights, a pilot can learn to create an imaginary horizon. This is particularly useful in low visibility. An advantage of the depression angle technique is that it is invarient with the size, shape, or slope of the runway.

Velocity Vector Cursor

A visual indication to the pilot of the extended flight path of the aircraft. Figure 25-A.

Visible Air Space

A scene containing a cubic array of 16,000 uniformly spaced lightpoints used to demonstrate the motion of objects in various positions during flight. Figure 25-C.

Horizon Depression Cursor

A cursor in the visual scene that remains fixed at a given depression angle. Figure 25-B.

Depression Angle Judgement - Experiment 1

The intent of conducting the depression angle judgement experiment was to ascertain how accurately subjects could judge depression angles at a distance of 6 feet. The results clearly show that the subjects were quite inaccurate at judging depression angles. (See Figure 26). The average judgement was in error by 37% with 75% of the recorded observations being underestimated. Dividing the subjects into experienced and inexperienced groups reveals that flight experienced subjects were somewhat more accurate identifying depression angles. The experienced group averaged a 31% error and inexperienced averaged 39% error. Considering the crucial angles of 1.5 degs. and 3 degs., the results are even more significant. The experienced averaged 38% and 40% error respecitively, and the inexperienced averaged 52% and 38% error respectively.

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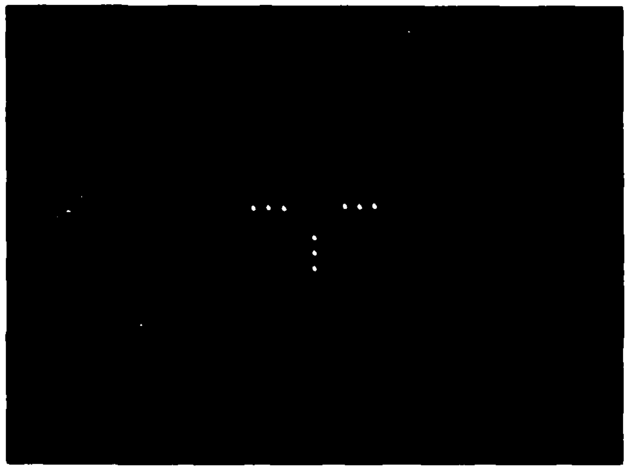

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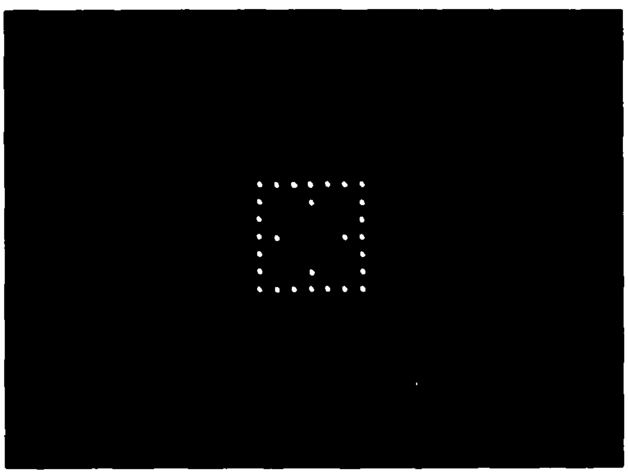

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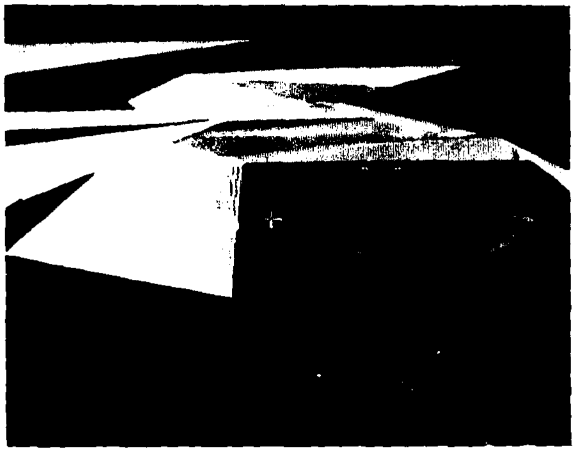
FIGURE 25. NON-REAL WORLD VISUAL TRAINING AIDS (SHEET 1 OF 2)



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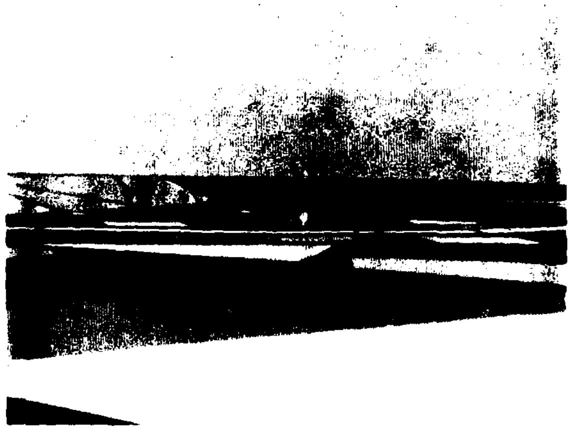

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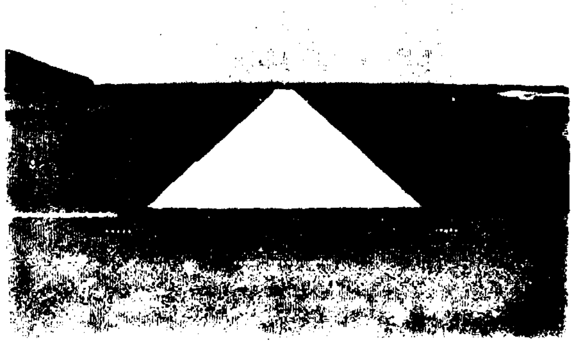

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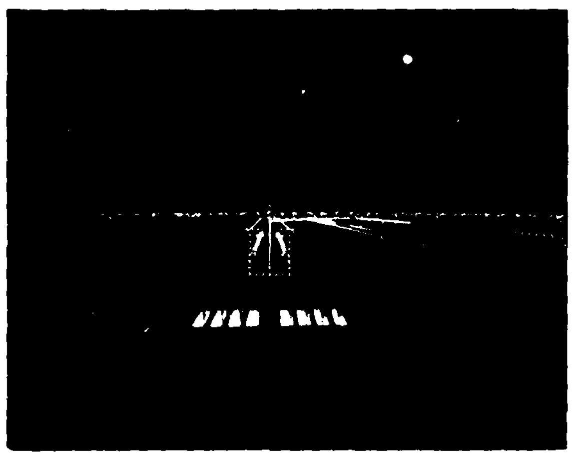

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FIGURE 25. NON-REAL WORLD VISUAL TRAINING AIDS (SHEET 2 OF 2)

Average Judged Angle
(percent error of average judged angle)

Correct Response -	1.5	3.0	6.0	15.0	30.0
Entire Group Response	.79	1.84	4.04	10.12	19.80
	(47.5%)	(38.9%)	(32.7%)	(32.8%)	(34.0%)
Experienced Group Response	.94	1.81	4.38	11.55	21.48
	(37.8%)	(39.8%)	(27.0%)	(23.0%)	(28.4%)
Inexperienced Group Response	.73	1.85	3.92	9.48	19.28
	(51.6%)	(38.4%)	(34.7%)	(36.8%)	(35.7%)

FIGURE 26. DEPRESSION ANGLE JUDGEMENT RESULTS

Such significant errors clearly demonstrate that all pilots, experienced and inexperienced alike, would likely benefit from some type of formal training in angular identification. This training could be accomplished with the use of depression cursors or similar techniques employable with CGI systems.

VITAL Angular Judgement - Experiment 2

Several reasons for investigating the VITAL angular judgement experiment were:

1. To ascertain how well subjects could judge glidepath angles using the VITAL IV visual display.

2. To determine the amount of influence visual training would have on these judgements.

3. To compare judgements of an angle at two different distances.

The results indicate that subjects shown no examples or provided no training were quite inaccurate at judging glidepath angles. (See Figure 27.) Several reasons exist that possibly explain their inaccuracy. From the Depression Angle

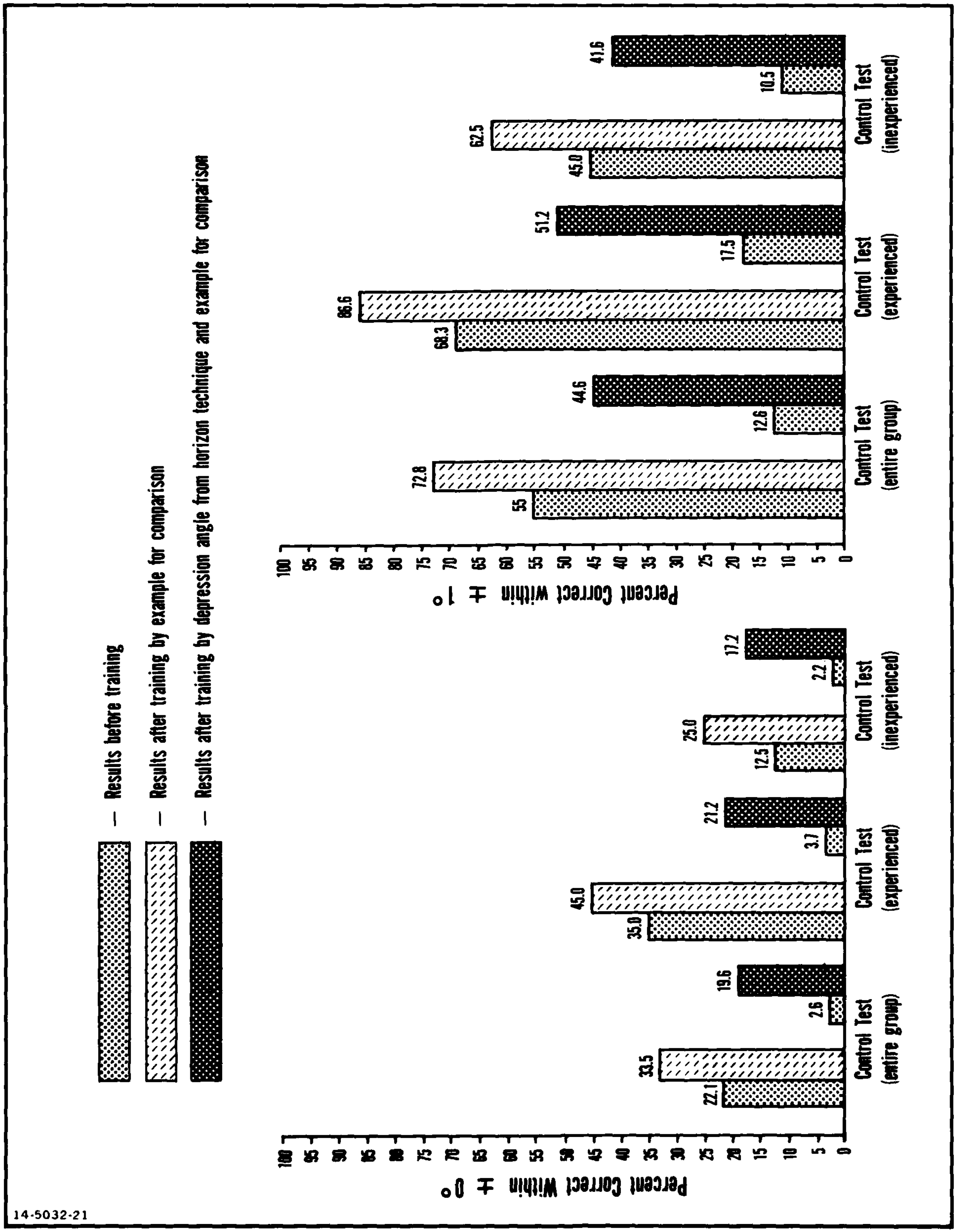


FIGURE 27. VITAL ANGULAR JUDGEMENT RESULTS

Judgement Experiment it was established that the subjects were quite inaccurate at judging depression angles. The unfamiliarity judging glideslope angles using only visual cues without the help of instruments or VASI's or using incorrect visual cues may have also accounted for the poor judgements.

The results clearly indicate that subjects' angular judgements were significantly influenced through visual training. (See Figure 27). By showing the control subjects an example of a 3 degree glideslope angle, their judgement were improved by an average of 18%. By instructing the test subjects as to the depression angle from horizon technique for judging glideslope angles, in addition to providing an example of a 3 degree glideslope angle, their judgements were improved an average of 32%. In summary, the glideslope angle estimating ability of control subjects and test subjects improved by simply providing an example of a glideslope angle for comparison.

NOTE

> As subjects were gathered for the experiments they were placed in test or control groups depending upon flight experience levels. This was done to perserve a balance in group experience levels. The result was a control group that performed astonishingly better than the test group. We suggest that for future experiments of this nature, results of baseline tests be used for placement of subjects in control or test groups.

More importantly, by exposing the test subjects to the use of the depression angle from horizon technique the test subjects used static, unambiguous visual cues in their judgements. It should be noted that the improvements in angular judgements were accomplished with an investment of only 5 minutes training time per subject.

When comparing judgements of a 5 degree glideslope angle at two different downrange distances, one mile and three miles, several interesting points are raised. Of the thirteen test subjects, twelve were more accurate in pretraining judgements at 1 mile than 3 miles averaging 21.1 degrees and 25.3 degrees respectively. (See Figure 28). Although not formally studied, several possible explanations exist for the overall poor performance and the discrepancy due to distance.

Subject	3 Miles: Pretaining Response	3 Miles: Post-Training Response	1 Mile: Pretraining Response	1 Mile: Post-Training Response
18	10 deg.	6 deg.	8 deg.	4 deg.
14	35 "	20 "	30 "	12.5 "
13	17.5 "	9 "	10 "	6.5 "
9	11 "	6.5 "	10 "	8 "
7	17.5 "	11 "	13.5 "	8.5 "
6	27.5 "	13.5 "	25 "	8.5 "
2	6. "	5.5 "	5.5 "	5 "
17	16 "	7 "	17.5 "	4.5 "
3	19 "	4.5 "	18.5 "	5 "
10	37.5 "	20 "	42.5 "	15 "
5	27.5 "	3.5 "	25 "	3.5 "
20	6.5 "	6.5 "	42.5 "	12.5 "
1	40 "	6 "	26.5 "	4.5 "
Average Response -	25.38 "	9.15"	21.11"	7.80 "

FIGURE 28. 5 DEGREE GLIDEPATH JUDGEMENT RESULTS

As for overall performance, when subjects were given the task of judging a glideslope angle many were concerned with altitude-downrange distance. This is not to say that glideslope angles cannot be derived from altitude-downrange distances, but its determination from these variables is a considerably difficult task. Complicating the task of judging glideslope angles from altitude-downrange distances is that the cues used to judge these variables are often difficult to comprehend providing ambiguous information.

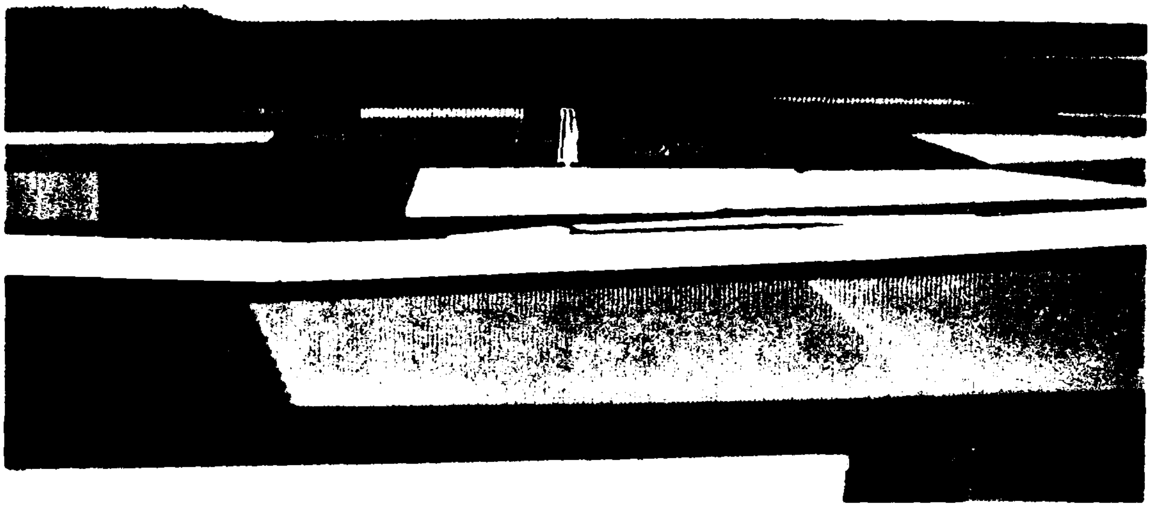
For example, considering that subjects were required to only use visual cues while making their decisions, it can be assumed that the runway's shape was significant. There exists a difficulty in using the runway image as a visual cue.

That is, the information obtainable from its shape may be ambiguous and difficult to use when judging angles. A runway viewed from three miles downrange from a glideslope angle of five degrees is distant enough to cause the distance separating the runway ends (front and back course threshold) to be insignificant perceptually. This causes the runway's sides to appear to run near parallel, giving the runway a rectangular shape. On the other hand, a runway viewed one mile downrange from a five degree glideslope angle is close enough to cause the distance separating the runway's ends to be significant perceptually. This causes the runway's sides to appear to run convergent, giving the runway a trapezoidal shape. (See Figure 29). This perceptual change in runway shape provides straightforward information on aircraft altitude, but requires pilots to be proficient in converting altitude-down range distance to glideslope angles. On the otherhand, the information on glideslope angle directly obtainable from runway shape is certainly not straightforward. For example, when subjects were asked how they determined glidepath angle from runway shape they were uncertain of their method but were confident that their judgements were accurate even when they were grossly inaccurate.

Additional complications arise from the use of runway shape. These include variations in runway length, width, length-to-width ratio, surrounding terrain, runway slope, and visibility. Not to mention the fact that runway shape methods cannot be applied to forced landings where no runway exists.

There is a possible hazard in using the runway shape to determine glideslope angle. If a pilot looks for a runway to have a trapezoidal shape from a distance at which is not possible, given an acceptable glideslope angle, he could be forced to lower his altitude to a hazardous level. This danger may not concern experienced pilots flying under normal conditions. To inexperienced pilots flying under adverse weather conditions or flying to unfamiliar runway configurations, the danger of low level approaches should not be complicated by the use of unstable visual cues.

The post-training angular judgement results of 9.1 deg. and 7.8 deg. for 3 miles and 1 mile respectively reinforce the finding that visual impressions can be significantly improved through training. (See Figure 28). With 11 out of 13 test subjects being more accurate at judging angles at 1 mile than 3 miles and overall



(1216-18D)

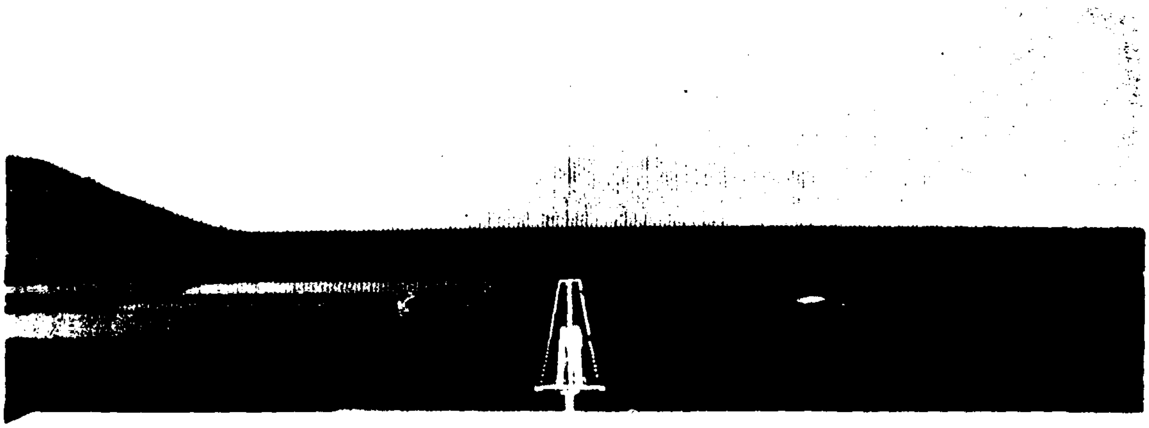


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FIGURE 29. RUNWAY SHAPE AS A VISUAL CUE

average judgements at 1 mile being more accurate than at 3 miles raises a question of the effect of distance on angular judgements. Since all these subjects were instructed in the use of the depression angle from horizon technique for judging glideslope angles, it can be established that the visual cues used were static and unambiguous. Still several elements of the scene may have accounted for the distance discrepancy, i.e., scene content density, runway shape, and picture resolution. Although not formally examined it was found that if subjects were positioned at several different distances downrange each having the same altitude many subjects felt as if their altitude would change as their position changed. (See Figure 30.) This perceived illusion of altitude changes with changes in downrange distance is a possible explanation for the effects of distance on glideslope angle judgements. When examining why subjects felt as if their altitude changed with changes in downrange distance it was found that if the subjects were instructed on how to determine aircraft aimpoint and movement by watching the movement of points within the scene and re-examined, the subjects no longer felt as if their altitude changed with changes in downrange distance.

Dividing the subject pool into experienced and inexperienced groups, reveals that experienced subjects suffer the same angular judgement deficiencies as inexperienced subjects. The findings also reveal that experienced subjects are capable of gaining as much as inexperienced subjects from training. Since significant improvements were observed through minimal training we suggest that all pilots, experienced and inexperienced alike, receive initial and continued visual training in definable glideslope angle judgements. Training may be achieved using techniques such as the depression angle from horizon, or developing training aids such as the horizon depression cursor employable on CGI systems.

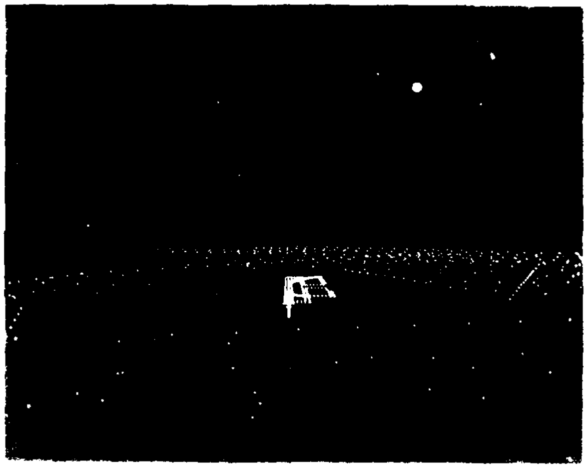
Non-Real World Visual Training Cue - Experiment 3

The intent of this experiment was to ascertain the degree of influence non-real world visual training cues, velocity vector cursor, horizon depression cursor and visual air space have on simulated flight performance. For a discussion of the experimental procedures refer to Appendix B-Experiment Three.

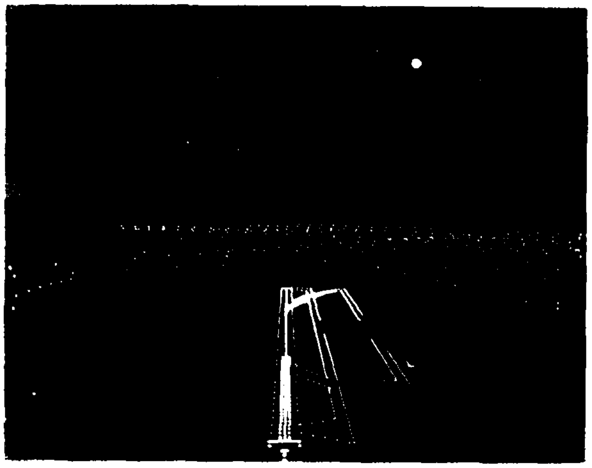
Control Group

When evaluating the control subjects' flight paths it is easily observed that their performances were little influenced by the practice flight sessions. See

(1216 18R)



(1216-18P)



(1216-19)

14 5032 23

FIGURE 30. DISTANCE EFFECTS ON GLIDESLOPE ANGLES

subjects 1,4,8,11,12,15,16, and 19 of Appendix D. Their final approaches, from pretraining and control sessions, typically mimicked each other showing o stinence to learning from the additional flight time. These results indicate that the control subjects, both experienced (subjects 12, 15, 19) and inexperienced (subjects 1,4,8,11,16) were unable or unwilling to either recognize, diagnose or modify their flight deficiencies. Their graphs clearly demonstrate the need for training since they deviated greatly from the desired approach and landing.

In order to evaluate subject flight performances, data on aircraft position (crossrange, downrange, and altitude) was recorded at several points along the aircrafts approach paths. This data was recorded on an average every 5100 ft. This provides each approach with 14 aircraft position points, which were later converted into crossrange versus downrange and altitude versus downrange graphs. (Appendix D).

Evaluation of the graphs was performed through inspection from which we sought evidence concerning subject learning, visual cue influence and overall performance. More specifically, evidence was sought concerning one versus two axis aircraft control, axis priorities, aimpoint detection, influence in glideslope angle, influences in angle relative to runway, error detection and correction, and overall performance.

Test Group

Inexperienced Subjects

The discussion of the test group results is divided by experience level into two major sections. Within each section, references to particular subjects simulated flight performances are made. These subjects performances best typify the points being discussed. The results of all subject flight performances are located in Appendix D by experience level.

Pretraining

Evaluation of the inexperienced pilots pretraining flight performances clearly demonstrates a need for training. As a group, the inexperienced subjects most common error was in glidepath judgement. Either subjects flew directly to the runway or they attempted to achieve an appropriate glideslope angle, but were unable to judge that angle correctly. (Subjects 3,6, 7,12). As individuals, the inexperienced pilots suffered an array of flight performance problems. For example, subjects 20,5 and 2 experienced difficulty controlling angle relative to the runway. Subjects 5 and 3 flew at dangerously low altitudes from 4 miles out. The error detectioning and correcting abilities of all participants was often late and inaccurate. Subjects 3,5,17 and 20 showed a tendency to only control the aircraft in a single axis at a time, either crossrange or altitude.

Devoting attention to a single axis would cause the performance along the unattended altitude axis to deteriorate. To correct this, the pilot would have to switch his attention from one axis to the other leading to a poor performance along the unattended axis. The inability to attend to both axis simultaneously ultimately lead to the erratic pretraining flight performances.

Training

Evaluation of the training flight performance results clearly reveals that the inexperienced pilots were very successful using and understanding the visual cursors. The evidence for this finding becomes obvious when comparing pretraining and training flight paths. The most pronounced improvements were in glideslope angle estimations and error detections and corrections. All pilots improved their glidepath angle estimations with the visual cursors active. As examples, subjects 6 and 17 performed astonishing well at judging and maintaining a three degree glidepath angle. Error detections and corrections were executed earlier with increased accuracy by most pilots when aided by the visual cursors. Marked improvements are found when re-evaluating individual performance problems discussed earlier. Subjects 2,5 and 20 improved their control of angle relative to the runway. The danger of low level approaches was eliminated by both pilots 5 and 3. Most importantly, subjects 3,5,17, and 20 were able to partially attend to both crossrange and altitude axes simultaneously. The group's overall improvement supports the finding that the inexperienced subjects were capable of using and understanding the visual cursors.

Post-Training

Evaluation of the inexperienced subjects' post-training flight paths is divided into two sections: A novice pilot section containing subjects

20,5,10,3 and 17 who all have less than 80 hours flight experience; and a limited experience pilot section contain subjects 2, 6 and 7 who have experience levels between 120 and 190 flight hours.

Novice Pilots

As mentioned in the pretraining discussion, all the novice subjects except number 10 were only capable of controlling the aircraft alone a single axis at a time. Then these subjects showed a small increase in their ability to attend to both axes during the training session. Evaluation of their post-training flight paths reveals that these pilots were unable to retain any of their multi-attention capabilities shown during the training session. Their post-training approaches reveal the same erratic aircraft control found in pretraining approaches. Subjects 20, 5,3 and 7 performed even more erratically in post-training approaches than pretraining approaches. In order to explain this peculiar finding, we examined the quickness with which errors were detected and corrected. During the training session, error detections and corrections were performed earlier with greater magnitude by all subjects. This ability is what causes the novice pilots' post-training apporaches to be more erratic than his pretraining approaches. The novice pilot performed his aircraft heading corrections, in whichever axis he was attending to, earlier with greater magnitude than his pretraining approaches. This required him to then make larger corrections to the unattended axis once he switched his attention to it. His newly acquired ability to correct for his aircraft's heading sooner and faster ultimately lead to the erratic post-training approaches.

We suggest that for future experimentation or actual training in which novice pilots are participants, that their inability to multi-task be recognized. As we have found, requiring novice pilots to multi-task may produce unanticipated results. Through the training session we provided the novice pilots the ability to fly more effectively along a single axis when they actually required training on how to effectively monitor two axes. Thus, it may have been quite effective to have let the computer maintain one axis (azimuth or glideslope) while the student learned to cope with the other.

Limited Experience Pilots

Evaluation of the limited experience pilots' post-training flight paths reveals some promising results. Re-evaluating their pretraining results indicates that these susbjects showed a need for training. Specifically, they required training in how to better judge their intended glideslope angle correctly. Evaluation of their training approaches shows a significant understanding of how to use the cursors. With the cursors, all the limited experience pilots flew with glideslope angles very near the desired 3 degrees and were able to control the aircraft's angle relative to the runway with considerable accuracy. The evaluation of the post-training approaches clearly demonstrates that the limited experience pilots were considerably influenced by the short 15 minute training session. All the post-training approaches show increased control over the aircraft's crossrange relative to the runway. The most significant evidence for the finding that the training session influenced these pilots' post-training performance is found in glideslope angle judgement, error detection, and correction. All pilots increased their ability to detect and correct for the aircraft's heading sooner with increased proficiency during the post-training approaches. The approaches of subjects 2, 7, and the night approach of subject 6 reveal that they were capable of closely estimating and maintaining the desired 3 degree glidepath angle. This is a clear improvement over their pretraining glidepath angle estimations. Thus, from the short training session, these pilots were influenced to better detect and correct aircraft crossrange error, control angle relative to the runway, and estimate a desirable glidepath angle.

Experienced Pilots

Evaluation of pretraining flight performances of experienced subjects clearly demonstrates a need for training. As a group, the the experienced pilots suffered one major performance problem. The inability to correctly identify a 3 degree glideslope angle with the exception of subject 14. Although they attempted to achieve a desirable glideslope angle, they were unable to judge that angle correctly. Thus, pretraining approaches tended to be shallow of the instructed 3 degrees glideslope angle.

Evaluation of experienced pilots training session flight paths indicates that they were quite capable of understanding and using the visual training cursors. As a group, error detections and corrections were performed earlier with increased accuracy. They were also able to gauge either glidepath angle or angle relative to runway or both more accurately during this session. In general, the groups performance improved during the training session in which the visual cursors were active.

Evaluation of the experienced pilots post-training approaches reveals an unfortunate result. The experienced subjects failed to learn or retain any influence from the visual training session. This is evident in that the post-training approaches closely mimick the pretraining approaches, demonstrating the same flight deficiencies as before training. Several possible explanations exist that could explain this finding. The most reasonable being that the visual training session of 15 minutes was insufficient. These pilot averaged 2800 flight hours, and 15 minutes training time was insufficient to retrain what their experience had taught them. Another explanation for this finding may be that the subjects were unwilling to change established flight habits. It must be noted that they did not have an opportunity to review plots of their pre-training and training performances.

It is interesting also to note that one subject, number 18, had commented that he really knew what 3 degrees looked like since he had just flown many approaches recently. Yet, his recorded performance was low in pretraining, quite good during training, and low afterward. A flaw in our brief training procedure was that he left prior to our having made the plots of his approaches. Certainly he would have been surprised by the size of his errors. Perhaps after being shown that, he would have been more receptive to changing his habits. We suggest that different training techniques be developed for the re-training of experienced pilots. They are likely to require more exposure time and proof of their errors.

These results strongly support the need for early visual training. We do not have sufficient data to conclude how experienced pilots can best be trained to r... ...n the improvements shown during training. It is interesting that our results conflict with the theory that the novice is prone to use artificial cues as crutches and grow dependent on them, while experienced pilots would be less susceptable to dependency effects. We found exactly the opposite to be true!

ENERGY/MANEUVERABILITY DIAGRAM DESIGN

In addition to the tests related to basic flight cues, work was performed in-plant to develop and demonstrate an energy/maneuverability diagram in use on a flight simulator visual. Cambridge Intelligent Systems aided in the redesign of the energy diagram to include altitude information (Appendix F). They also provided a sample syllabus for use of the diagram (Appendix G). A description of the new diagram is given in Figures 23 and 24.

Photographs of the new diagram in various situations are shown in Figures 21 & 22.

It was found that the best size for the diagram on the VITAL IV system was five degrees. This was small enough to obtain information from the diagram with a single glance while large enough to allow the necessary information to be resolved. Other advantages of the small size were that it provided a minimum distraction from the rest of the scene and covered up a minimum of the scene. The original concept for inclusion of altitude information was to use a three dimensional diagram. After some effort, this approach was abandoned. No satisfactory cure was found for the problem of learning to interpret the needed information rapidly from a three dimensional graph. Various combinations of shapes, colors, and points, as well as different orientations for the axes were tried. All of the approaches were implemented in order to determine whether they were less confusing when displayed on the system and moving in real time. Unfortunately, none of the three dimensional versions proved satisfactory. The two dimensional dynamic graph was found to be much easier and quicker to interpret, as well as being easier to implement.

TESTS AT DAVIS MONTHAN AIR NATIONAL GUARD BASE

Since the bulk of the new concepts in air crew training dealt with tactical training, we installed a number of them on the A-7D aircraft simulator at Davis

Monthan Air National Guard Base in Tucson, Arizona. This site was selected for its broad range of pilot experience, from beginners to 7480 hours including combat experience. We demonstrated the new training tools to students and instructors, then solicited their opinions with a questionaire. By the way, we found it absolutely imperative to be present during the filling out of each questionaire to achieve results. Four pilots who participated in the evaluations were short on time and agreed to fill out the questionaires later. It never happened. We could have had all the student volunteers we wanted if we had realized earlier that we should post for volunteers in addition to asking the operations officer to schedule volunteers. The scheduler was reluctant (without at first revealing this to us) to ask people to volunteer, because they were already working long hours. After visiting the operations area, however, we realized that many students were interested to participate but hadn't been aware of the opportunity.

Since the special effects were to be installed on a non-interference with training basis, most of the installation and debugging work was done during the night shift with the help of the night simulator technicians. Thus, they quickly became the most fami iar of the Air Guard personnel with how to operate the various special effects. We did not have time, after installation and testing, to teach the instructor pilots how to use the special effects. We believed that the simulator technicians would show the instructor the proper use of these techniques however this prove unsatisfactory. Thus, when we called back a month or so after our trip to Davis Monthan to see whether any of the effects were being used, we were told they were not using them because they were too busy training. At first this seemed discouraging, but after some thought it seemed a fairly natural result. The reason being that, when under time pressure, the instructors reverted to their normal way of doing things to avoid having to experiment with something new. Thus, we believe that their lack of use of the effects is not in contradiction with the enthusiasm they expressed when we were demonstrating them. The results of the evaluations are given in Appendix E. They are presented in a series of tables which parallel the questionaires we had the pilots fill out after each flight. The results were averaged in various groupings: whole group, students only, instructor pilots without combat experience, and instructor pilots with combat experience. The number of subjects responding to each question varied. The experience level of each subject who filled out the questionaire is listed in table 2.

TABLE 2. EXPERIENCE LEVEL OF AIR NATIONAL GUARD EVALUATORS

SUBJECT TYPE	FLIGHT EXPERIENCE	COMBAT EXPERIENCE
instructor	7480 hrs.	500 hrs.
instructor	4100 hrs.	
instructor	3500+hrs.	360 hrs.
student	2895 hrs.	
instructor	1950 hrs.	
student	280 hrs.	
student	260 hrs.	
student	230 hrs.	
student	225 hrs.	
student	176 hrs.	

In the general comments & suggestions section of our evaluation form, the most experienced pilot commented, "Enhanced visual aids for the A7 simulator are good tools for the instructor to use for increasing student pilot training proficiency. These visual aids make communication between the instructor on the console and the student in the cockpit much clearer and effective." This was representative of the feelings of most of the evaluators, despite the fact that each liked some effects better than others or suggested improvements, and despite the fact that a few students and instructors were unenthusiastic. A comment from one of these was, "...I'm not enthusiastic about the value of the new video presentation. You are attempting to stretch the capabilities of a system not capable of expansion. A new video program does not a sac-sim make. (Ed.-I believe this is a reference to a simulator for air combat). Without a full view display and greater physical sensation, the new program has gee-whiz value only. Keep in mind that I only played with the presentation for a short time." One must recall that the A7 simulator only has three windows. Some of the pilots were enthusiastic about the special effects partially because the field of view of the simulator is restrictive. They found, for instance, that the contrail and multiple viewpoint capabilities helped them to maintain situation awareness in the simulator despite the limited field of view, thus allowing them to practice tasks in this simulator that they were previously unable to, such as air intercept. Another example was the use of the overview capability to allow a student to pick out landmarks that could guide his turn onto final approach to a target for air to ground attack. Admittedly, this is a poor solution to the problem compared to provision of a full field of view; however, prior to installation of the special effects all approaches for air to ground attacks in the simulator were straight in, partially because of this problem.

The pilot comments included a number of suggested improvements to the effects we demonstrated or new similar types of effects. These will now be discussed. Perhaps the most frequent comment was that, although the threat cone as demonstrated can be of use, it would be much more usefull to show a volume behind the threat aircraft representing the offensive missile and cannon delivery limits (distances and angles) and how they vary with load factors, angle-off, closure rates, etc. There were several other comments related to the visible sensor cone. A student commented that the sensor cone, "helps determine aggressors heading in basic fighter maneuevering (BFM)." One combat experienced pilot's suggestion was to have a tail cone and a nose cone of different colors. Finally, one student commented, "The sensor cone is useless as is. The idea of the MIG's radar cone is good, but a lock-on would be much more effective. This would help to show how hard to manuever to break lock and service. Something hooked up to the RHAW (radar warning device) would be an aid." Finally, the cone inspired one of the instructors to suggest that a similar visible volume be placed on the ground during bombing practice to represent the fragmentation envelope of your aircraft's bomb. This is a volume the pilot must learn to avoid. A similar concept is to show ground threat lethality envelopes.

With regard to the contrails showing the aircraft's flight paths and the multiple viewpoint capabilities, which were almost exclusively used together, the comments were as follows. The most experienced instructor said, "Air to ground attack with no special effects visible during flight, but with demonstration and student paths visible during replay using multiple viewpoints is good for analyzing errors and promoting corrective actions." One instructor and one student commented that, when trying to follow a visible demonstration path there was a tendency to concentrate on the contrail rather than on ground references and aircraft parameters. Another student suggested, "If a student is able to see a plan (ground track) and profile view of his 'desired' trajectories prior to ever attempting them, he has a much more thorough concept of his required maneuvering.

Follow this up with a 'follow the dots' program for one or two run-ins and he should be well on his way! I found the instructor cursor, bomb placement marker, and immediate scoring all very helpful in this phase. Good program!" An instructor agreed that air to ground attack with no special effects visible during flight, but demonstration and student paths visible during replay using multiple viewpoints is, "the way to go". Regarding air to air combat, most of the pilots found the contrails helpful. In fact, after we came back from our first attempt at installing the special effects, they complained that the contrails did not work right when they flew far enough to transition to another environment. We fixed that on our second trip, but the point is that they used this effect in our absense or they would never have complained. The contrails were used in air to air in several ways. They helped to see aspect and angles. They also helped located the target when it was out of visual range or outside the simulator field of view. This allowed the students to practice air intercepts in the simulator despite the limited field of view. One student commented that the contrails could be improved by making the offender's contrails a different color from your own. There was some discussion of whether there should be two contrails, one from each wing as we had it, or one contrail from the centerline of the aircraft. Although no strong conclusions were drawn favoring either approach, there was a tendency to favor a single, longer contrail for air to ground work, but the dual shorter contrails for air to air. Most of the pilots did not see any utility in a ground track per se, particularly since the air track in a plan view is equivalent. However, we found that from oblique viewpoints the ground track was useful, not on its own, but because it more clearly established the ground level for better understanding the vertical aspect of the air track.

Ron Hughes of the Air Force Human Resources Laboratory suggested an additional viewpoint be made available. This would be the view from a surface to air missile (SAM) in flight toward your aircraft to show the effectiveness, or lack of it, of your evasive tactics. He also suggested that the SAM leave contrails to learn its timing since it is not seen after the initial launch burn until the last few seconds of it's flight.

The immediate bomb scoring was appreciated by all. The only additional improvements suggested were that the scoring appear just above the horizon (we had it at the top of the screen), and that it stay up longer. Originally, the score stayed on for 5 seconds and could be redisplayed by pressing a console button. The pilots preferred that the score stay up 10-15 seconds to allow complete discussion of the performance while the score is up. The bomb marker was programmed to stay in the scene until another bomb was dropped. This was quite acceptable. The scoring parameters of most interest were release altitude and minimum altitude. One student mentioned that he would prefer the scoring information in meters.

The tracer emphasis was not particularly successful. Although the concept was thought to have potential, the implementation showing the nearest bullet brighter than the rest was not acceptable. For long bursts of bullets it worked, but for short bursts the closest bullet would brighten just after leaving the muzzle and stay bright till reaching the target. Then the last bullet in the burst would be bright and stay bright until it hit the ground. Thus, for short bursts the brightening really added no useful information about the range to the target and was confusing. One comment was, "Tracer range emphasis could be improved by having the emphasis only passing abeam the target." Another pilot suggested that a digital range readout would help calibrate the pilot's eye. This is very similar to another of their suggestions, which was to have a ranging cursor for air to ground attack which would read out the range to whatever point on the ground it was placed on.

The instructors and students both liked the availability of the instructor cursor for describing visually what the instructor is saying about a point on the ground. Even those who did not have an opportunity to use it said they thought it was a good idea.

A suggested improvement to the horizon depression cursor was to make it a line extending across all windows instead of a small box. Although at first we thought the horizon depression cursor might duplicate information from the pitch ladder on the Head Up Display (HUD), we found that it was still usefull because it was limited only to the field of view of the visual instead of the narrow HUD field of view. The response to the horizon cursor for tactical use was less than enthusiastic. For landing training it proved of good utility.

The velocity vector was not used on the A7 simulator, since it would have duplicated the one on the HUD.

The light point reinforced air target (T2B) turned out to be quite worthwhile. When we compared the range at which this target was visible with the corresponding range for the MIG target made of shapes only, we were astonished to find that the T2B was only visible 1.25 times as far. Then we discovered the reason. The model of the MIG had been expanded to four times life size to allow them to be able to see it far enough away to be able to use it! Of course, this would be terrible for learning to judge target range for gunnery or air to air missile launch.

We did not take the Energy/Maneuverability Diagram with us to the A7 site, because that aircraft's mission is primarily air to ground. Some of the instructors expressed interest in it anyway, so we made a quick attempt to install it, but did not have time to do so successfully.

Discussions with Fighter Weapons School Instructors Regarding Low Level Flight

While at the base, we were encouraged to visit the fighter weapons school to discuss our project and low level flight training. Following is some discussion of a "streaming or shear plane effect" quite evident during low level high speed flight but absent or much less apparent in the Advanced Simulator for Pilot Training at William AFB, Az. Messrs. Miller and Dampsher of the Air National Guard Fighter Weapons School, and Drs. Richter and Ullman of the Israel Air Force all described the effect similarly, but they apparently don't all use it similarly. The Israelis said they teach the use of the "shear plane" for altitude judgement at low altitudes.

To provide better understanding of the comments to follow, we will now briefly describe this effect. When one looks at the terrain, particularly to the side of the aircraft, during high speed low level flight, one sees the terrain streaming past the aircraft. If one trackes an object with his eye, then nearer objects still appear to move towards the rear of the aircraft. However, objects farther than the one being followed appear to move in the same direction as the aircraft. The object one's eye is tracking appears stationary. This effect is the one the Fighter Weapons School instructors find either lacking or much to subtle in the ASPT simulator. Their theory as to why this is missing is that the simulator does not have the information to show this effect because it is not tracking the eye. This is an unlikely explanation. However, the fact that they don't see the effect in the simulator must be accepted, expained, and remedied. One of the authors (D.C.) has looked for and seen this effect on commercial airline flights.

The Israelis go one step further in describing their "streaming effect". They agree that the point of shearing (between objects whose apparent motion is with the aircraft's and those whose motion is against it) is centered whereever the eye is tracking. However, they claim that, when one gazes at the horizon without fixation on an object, there is another "shear line", and the location of this shear line is a cue to one's altitude.

The following is our own explanation of why these effects occur in the real world and why they are absent, or reduced, on some simulator visual systems. To understand why the effects do not occur in the simulator, one must first understand why they do occur in the real world. We believe the explanation is to be found in the study of movement detection thresholds. Most of the data required probably already exists in the literature of movement detection and of apparent movement. Let's presume, for the sake of discussion, that the data exists. If there turn out to be quantitative gaps one can always do experiments to fill them. To reduce the problem to its simplest form, let's discuss what happens when one looks at two points, P1 and P2, at some angle apart, A, and moving with respect to the observer at angular rates R1 and R2 respectively. This will be a little "gedanken" experiment. If R1 equals R2, then the points will not appear to move with respect to each other. If R1 and R2 differ only slightly, then again they will not appear to move with respect to each other. As the relative rate of motion between P1 and P2 continues to increase, a threshhold, Rt, will be reached at which the relative motion is detectable. It is quite natural to presume that the farther appart the two points, (i.e. the larger the angle, A), the higher will be the threshhold rate of relative motion required for the motion to be detected. In addition, the relative motion detection threshhold can be expected to be a function of other variables, such as the absolute rates, R1 and R2, the position on the retina, the type and rate of eye and head motion, etc. One other fact needs to be noted. It is that the actual angular rate of motion of a farther object will always be less than a nearer one. Now we are ready to begin explaining the various streaming and shear line phenomena. When flying at high altitude or low speed, objects that are close to each other do not move at rates that differ sufficiently for the relative motion to be detected. In this case, the objects therefore will appear to move in the same direction if at all. If one is low enough and fast enough, then objects near each other and at some distance from the aircraft will have relative rates of motion different enough to be detectable.

If the eye smoothly tracks the nearer point, then it's apparent rate of motion may be zero. In this case, since the farther object will be moving slower, its apparent rate will be less than zero, that is it will appear to move backwards from normal. Thus, if the aircraft is moving forward, normally objects on the ground would appear to move backward relative to the aircraft. But, for an object that is further than the one being tracked with the eye, any detectable relative motion will appear to make the farther point move in the same direction as the aircraft!

The difference between the aircraft and ASPT simulator perceptions of the *shearing effect* may be due to several relevant differences between the two that exist despite the fact that computed parallax effects may be perfect. Three differences that exist and could be expected to contribute significantly are:

(1) course resolution
(2) low contrast
(3) low density of scene elements.

Let's examine how each of these could contribute to reduced perception of the shearing effect. The course resolution applies not only to optical resolution (the smallest resolvable separation between two points), but also applies to positional resolution (the fineness with which a single point may be positioned). When the positional resolution is poor, the *ability to detect relative* motion between objects or parts of objects in the scene is limited by the system rather than by the observor's eye. This could be expected to lead to a poorer detection of "shearing" than in the real world. Low contrast would also be expected to reduce one's threshhold for motion detection, although this may be arguable. Low scene density means that objects will be farther apart in general than in the real world which also would raise the threshhold for "shearing" detection. Another difference between most simulator visual systems and the real world is that there are more vertical objects in the real world. At altitude, this is not too apparent, but at low level an interesting thing happens. We discussed the fact that the "shearing" effect occurs when a large enough difference in the motion of adjacent objects exists. This condition is much easier to establish when a near object with vertical aspect occults or hides a farther object. That is because, from a low viewpoint, the top of the vertical object may be adjacent in visual angle to an object on the ground at a much larger range. Thus, the relative rates of motion would be great and very strong streaming and paralax effects occur. The state of the art in visual simulation now allows for more abundance of such scene elements compared to the late 1960's, when the ASPT was designed. In addition, present day calligraphic visuals offer very high contrast and precision of object motion. We looked for these effects in the "visible air" scene on the VITAL IV and found them to be present. (See Figure 18).

OVERALL RESULTS

The objectives of this study were to generate new concepts in aircrew training methods that take advantage of the flexibility of computer generated imagery (CGI), to demonstrate examples, and to perform exploratory testing of these examples. The purpose of the exploratory testing was to provide a baseline of information from which detailed training experiments could be designed for future testing by others. All of these goals were met. In general, we found pilot reactions to the demonstrated examples to be quite favorable. The key to this, we believe, is the fact that the philosophy under which these concepts were generated was compatible with operational instructor pilots' and students' views. The philosophy was that it is worthwhile, when necessary or useful, to forgo pictorial realism in favor of operational realism. Additionally, the approach to simulator utilization was as a training tool, not as an aircraft replicator. It was recognized that, when viewed as an aircraft replicator, the simulator will always be found wanting; however, when viewed as a training tool, its potential has only just begun to be explored and is not limited simply to one-to-one transfer to the aircraft. Examples of the types of techniques examined are:

a. Making visible in the simulator something the pilot normally cannot see in the aircraft but must visualize. (Fragmentation envelope during bomb delivery, weapon effectiveness envelopes, etc.)

b. Immediate scoring feedback provided to the student on the visual system.

c. Cursors under instructor or student control appearing in the out-the-window visual as a communication aid.

d. Performance envelope superimposed upon the outside scene.

e. Providing visible flight path history in the out-the-window scene and using it in conjunction with a multiple viewpoint capability to allow the instructor and student to immediately review the flight path after a particular maneuver.

In more basic experiments, it was shown that novices and pilots alike are poor at visually judging dive angle or glide slope. In addition, the data show that it is easier to cure this problem with inexperienced pilots than with experienced pilots! A short period of training with artificial aids influenced many pilots with less than 190 hours experience both during and after its presentation. But, for most pilots having over 600 hours of experience, the artificial aids only affected their simulated flight paths during presentation. We would expect better results with the experienced pilots had we immediately shown them graphs of their performance and the improvement with the artificial aids and techniques. Then, perhaps, they would have been more interested in changing their habits.

In an experiment to determine the minimal cues that are necessary and sufficient for low level flight (straight and level or in level turns), we were surprized to find that, after gaining practice with minimal cues, and after study of object motion cues, a single light point on the ground visible at any one time under reduced visibility conditions was sufficient!

OVERALL CONCLUSIONS AND RECOMMENDATIONS

The overall conclusion is that this approach to flight training can be bot successful and well accepted by the pilot/instructor community. It is an aid to both the instructor and the student. To the student these visual aids reinforce abstract concepts and appear to permit a faster assimulation of data. To the instructor these aids enable him to be more effective and efficient. Further research of a transfer of training nature and instructional methodology would be very helpful in quantifying the benefits. However, the benefits are in some cases so large and the cost to implement so small that one wonders whether waiting for expensive transfer of training studies is prudent. Since implementation of these effects has already been done on the A-7D simulator at Davis Monthan AFB, it is recommended that detailed transfer studies be arranged and performed either there, or at a similarly equiped site that could utilize the same software. (The Undergraduate Pilot Trainer, UPT, at Williams AFB, AZ may be such a candidate.)

In the case of the angular judgement studies, the recommendation is that further research be performed to establish how pilots react to various illusions such as varying runway size or shape, "black hole" effects, sloping runways, and so on. More importantly, experiments should be performed to determine how pilots can be trained to overcome these illusions. The experiments with horizon depression cursors and velocity vectors are a first step in that direction. Additional work to examine how to train experienced pilots as opposed to inexperienced pilots would be most useful.

The results of this type of research would be safer flight for all pilots, civilian as well as military. Thus, this work is expected to also be of interest to the Federal Aviation Administration.

A video tape presentation, demonstrating some of the effects described in this report, has been made and is submitted along with this report. Unfortunately, the quality possible on standard monochomic 525 line video tape is not representative of the quality of the presentations as displayed on a color beam penetration visual system, but one can, through the video tape, get an idea of the dynamics involved.

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APPENDIX A

GENERIC TEACHING AID DESCRIPTIONS

APPENDIX A

1. Make "Visible" Something the Pilot Normally Cannot See, But Tries to Model in His Mind. For example, let's say a pilot knows that another aircraft will have to get him within 10-degree cone and within a six-mile range to lock on some particular kind of missile. This "cone of danger" emanating from the nose of the other aircraft needs to be visualized by the pilot, so that he may avoid it. This visualization in three dimensions under a wide variety of circumstances could be taught by simply showing the cone emanating from the other aircraft in a computer generated image visual system. As the pilot flies against this target, he can learn to internalize the image of the lethal cone for use in the "real world", where the cone is invisible. Obviously, there are many other examples of situations where this technique of making a cue available in the simulator that is hidden in the real world would be expected to be useful for training.

2. Scoring/Error Feedback. This is not a new technique, but it certainly could be used in new ways. Computer generated image out of the cockpit displays provide the opportunity for quicker feedback, which is known to produce quicker learning. An example of this technique would be to superimpose scoring data on the pilot's outside scene during a training flight in the simulator. For instance, the pilot's probability of survival could be displayed in a corner of the scene as a bar graph ranging from zero to one and if the probability gets too low, the computer could display a brief explanation of what he has done wrong immediately while he is still in the cockpit, instead of waiting until later. Or for bombing practice, miss distances and aircraft parameters at time of release could be shown after each bombing pass.

3. Feed Forward/Predictors. An example here would be during air-to-air combat. When a pilot is one the offensive, he could be shown where his present course and closure rate would cause him to intercept the target's flight plane.

4. Discrete Indicators. A simple discrete indicator can be used to teach the student to recognize and respond to a particular situation. In teaching low level flight, if it is desired to stay below 250 feet, a simple tone or indicator could be given when that limit is reached or exceeded.

5. Pointers for Instructor and/or Student. It has long been known that a simple pointer is useful in communication about visual displays, yet no aircraft simulator has such a pointer available for use in the out-of-the-window scene.

6. Adaptive Aids. This is an extremely broad category which must be carefully used to avoid student dependence on the aid, but can be extremely effective in quickly making the student capable of performing correctly. The visible adaptive glide slope of Gavan Lintern[1] of the University Illinois is an example.

7. Awareness Stimulators. There is a dangerous tendency for a pilot while performing a difficult task, such as air-to-ground or aid-to-air attack, to focus on that task to the exclusion of perception of other events around him. To maintain the pilot's awareness, other objects or event could be presented in the scene, such as other aircraft, and the pilot's ability to monitor them during his task could be included in his score for the task.

8. Demonstration/Exaggeration. If a subtle cue must be detected by the pilot, it can be helpful to exaggerate the cure first, so that the pilot has an altitude below which he is so involved in avoiding ground impact that he can not perform other tasks. That altitude is his "comfort level".

   If it is desired to demonstrate to the pilot that his comfort level depends on his speed, a simulated course may be flown at Mach 3 and then at 30 knots before allowing him to learn his comfort level for more normal speeds.

9. Cue Supplements or Cue Augmentation. Again, subtle cues may initially be supplemented with more obvious ones, to lead quickly to correct performance and then weaned away as the student's proficiency increases. This would be particularly adapted to the case where the pilot is learning two different tasks simultaneoulsy, while one is dependent upon the other. For example, in

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1. Lintern, Gavan, Transfer of Landing Skills after Training with supplementary Cues, Proceedings of Human Factor Society, October 1979, p. 301-304.

landing, the two tasks are: One cannot control the airplane without perceiving the flight path. One cannot control the airplane without perceiving the flight path and one cannot test one's flight path perception before getting the aircraft under control. This contradiction can be avoided by supplementing the normally subtle flight path perceptual cue until control is learned and then teaching the perceptual task of detecting glideslope deviations from subtle cues.

10. Cue Indicators. There are many subtle cues in flying. They may be indicated to the student in a vairety of ways such as, use of "pointer, exaggeration, elimination of other extraneous cues, and so forth".

11. Time Compression/Expansion. Sometimes events occur too quickly for the novice to appreciate them individually and to think through the ramifications. Conersely, the more experienced student may need to "overlearn" one task, as to be able to perform other tasks simulataneously, One could slow the system down for the former and speed it up for the latter. This technique might also be used to simualte the situation when one's internal clock is running faster than normal.

12. Quantization of Time. A task can be broken into discrete steps such as in the task taxonomy of Robert Meyer.[2]. These may be learned singly in whatever order is best suited to learning. Examples would be the backward chaining technique of Hughes[3], or a slide presentation.

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2. Meyer, R. Laveson, J., Pape, G.; Development and Application of a Task Taxonomy for Tactical Flying, AFHRL-TR-78-42, Air Force Systems Command, Brooks AFB, Texas, Sept. 1978.

3. Hughes, R. G., Advanced Training Features: Bridging the Gap Between In-Flight and Simulator Based Models for Training, AFHRL-TR-78-96, Air Force Human Resources Laboratory, Flying Training Division, Williams AFB, AZ, March 1979.

13. Sense Exercise. A computer generated visual system can readily be used to give a student practice in certain types of fine perceptual tasks with feedback such as immediate knowledge of results. There are many useful examples of this technique; one could practice closure rate judgements, target aspect from motion judgements, landing flow pattern discrimination, low contrast target detection, scan patterns, and so on.

14. Dynamic Observer Control of Scene and Cues. For example, if it is desired to teach a student to judge target aspect, he could be given control of the target as if it were a remotely piloted vehicle. If the aspect was uncertain, he could test it by seeing how it responds to his control inputs.

15. Analogies. It is often useful to show similarities between a task to be learned and a more familiar task. It may be even be useful to teach a simple task for later use in analogy to a more complex task.

16. Perspective Changes. Advanced pilots generally do not view their actions from their own viewpoint, but abstract the situation to an overview or "God's eye view". Some simulator instructor stations show this viewpoint to the instructor or to the student after an engagement. More immediate feedback to facilitate this perspective abstraction could be given by allowing the student to change the viewpoint being displayed while still in the cockpit. Other viewpoints could also be helpful, such as how he looks to a ground threat or to his opponent.

APPENDIX B

APPENDIX B - EXPERIMENTAL PROCEDURES

APPENDIX B - EXPERIMENTAL PROCEDURES

OVERVIEW

In order to facilitate reading this report, the following discussion of the experimental procedures was made an appendix instead of being distributed throughout the body of the text.

The intent of these experiments was to determine the validity of some of the concepts put forth in this report.

The first experiment was designed to determine how well subjects could judge depression angles. The second experiment was designed to determine how well subjects could judge glideslope angles from static images on a collimated VITAL IV visual display and to determine how training would influence their judgement. The third and last experiment was designed to measure the amount of influence non-real world visual training cues have on simulated flight performances. Finally, the experiments allow comparisons between glideslope angle judgements made close to the runway versus judgements made far from the runway.

SUBJECTS

A total of twenty subjects divided into two groups, test and control, made up the subject pool. The test group contained thirteen subjects and the control group contained seven subjects. Each of these groups was subdivided into experienced and inexperienced groups. All inexperienced subjects had less than 190 hours flight experience, while all the experienced subjects had greater than 600 flight hours. Subjects ranged in flight hour experience from 0 to 7500 flight hours, with the average number of flight hours for each group being:

Control Total Group	913 flight hours/subject
Test Total Group	909 flight hours/subject
Control Experienced Group	2041 flight hours/subject
Test Experienced Group	2800 flight hours/subject
Control Inexperienced Group	61 flight hours/subject
Test Inexperienced Group	74 flight hours/subject

The test subjects were selected from several locations to provide a subject pool with a broad range of experience: Nine Parks College flight students, one Parks College flight instructor, seven MDEC employees and three private pilot/-instructors. (See Tables B-1 & B-2).

TABLE B-1. CONTROL SUBJECTS FLIGHT EXPERIENCE

Subject No.	Flight Hours	
1	0	Flight Naive - MDEC
4	20	Private Pilot - MDEC
8	115	Private Pilot - Parks College
11	10	Flight Student - Parks College
12	1775	Private Pilot/Instructor
15	4000	Private Pilot - MDEC
16	100	Private Pilot - MDEC
19	350	Private Pilot - MDEC

TABLE B-2. TEST SUBJECTS FLIGHT EXPERIENCE

Subject No.	Flight Hours	
2	120	Private Pilot - MDEC
3	60	Private Pilot - Parks College
5	20	Flight Student - Parks College
6	150	Private Pilot - Parks College
7	190	Private Pilot - Parks College
9	600	Private Pilot - MDEC
10	30	Flight Student - Parks College
13	900	Instructor - Parks College
14	2200	Private Pilot/Instructor
17	80	Private Pilot - Parks College
18	7500	Private Pilot/Instructor
20	20	Flight Student - Parks College

EXPERIMENTS

All twenty subjects participated in the three experiments. As a prerequisite to participation, all subjects were required to read and sign a "Human Factors Research Consent Form". Participation was strictly voluntary. A sample of the consent form is given in Appendix C.

DEPRESSION ANGLE JUDGEMENT - EXPERIMENT ONE

The purpose of this experiment was to determine the degree of accuracy of which subjects could judge simple depression angles from a distance of 6 feet. Due to the simple nature of the experiment no control group was used. Subjects were positioned at a fixed distance, unknown to them, away from an eight foot chart. A line was on the chart at the subject's eye level. This line corresponded to zero degree depression. The subjects were instructed that a proctor would move a pointer down from the horizon line to a point, selected by the subject, that corresponded to a prescribed angle the subject was to estimate. This was done for depression angles of 3 deg., 15 deg., 1.5 deg., 6 deg., and 30 deg., in that order. All estimates were recorded and can be seen in Tables B-3 and B-4.

TABLE B-3. DEPRESSION ANGLE JUDGEMENT RESULTS

Average Judged Angle
(Percent Error of Average Judged Angle)

Correct Response =	1.5 deg.	3.0 deg.	6.0 deg.	15.0 deg.	30.0 deg.
Entire Group Response	0.79 deg.	1.84 deg.	4.04 deg.	10.12 deg.	19.80 deg.
	(47.5%)	(38.9%)	(32.7%)	(32.8%)	(34.0%)
Experienced Group Response	0.94 deg.	1.81 deg.	4.38 deg.	11.55 deg.	21.48 deg.
	(37.8%)	(39.8%)	(27.0%)	(23.0%)	(28.4%)
Inexperienced Group Response	0.73 deg.	1.85 deg.	3.92 deg.	9.48 deg.	19.28 deg.
	(51.6%)	(38.4%)	(34.7%)	(36.8%)	(35.7%)

TABLE B-4. DEPRESSION ANGLE JUDGEMENT RESULTS

Correct Responses =	1.5 deg.	3.0 deg.	6.0 deg.	15.0 deg.	30.0 deg.
Subject No.	Actual Responses				
1	0.511	2.04	2.35	6.21	8.43
2	2.24	3.88	8.02	19.83	33.16
3	1.53	3.50	8.23	17.54	26.40
4	0.92	2.54	5.81	12.38	24.65
5	1.22	2.30	4.39	8.73	19.44
6	0.56	2.24	5.71	9.72	18.83
7	0.40	1.63	3.27	5.50	9.92
8	0.40	0.81	1.73	3.37	5.71
9	1.12	2.24	4.69	14.61	30.12
10	0.511	2.14	3.98	7.92	15.75
11	1.53	3.16	6.36	11.45	23.97
12	0.76	2.54	4.79	10.57	17.72
13	0.613	1.73	3.52	7.57	7.82
14	2.35	5.65	8.33	12.68	19.19
15	1.84	4.13	7.22	13.16	25.19
16	4.4	8.33	11.70	17.77	30.66
17	1.22	3.67	5.30	9.32	13.74
18	0.81	1.81	4.49	10.22	22.67
19	1.22	2.14	3.98	11.60	23.58
20	1.43	3.16	7.22	15.89	28.19

VITAL ANGULAR JUDGEMENT - EXPERIMENT TWO

The reasons for performing the VITAL angular judgement experiments were three-fold. One, to determine how well subjects could judge glideslope with respect to predefined angles on VITAL. Two, to determine the amount of influence training could have on these judgements. Three, to compare judgements made at varying distances.

The experiment was divided into three parts. Part One was performed by both control and test subjects, Part Two by control subjects only, and Part Three by test subjects only.

In Part One subjects were shown four alternating night and day scenes. Within each scene the subjects task was to judge his apparent glideslope angle at 5 different positions on final approach to landing (Figure B-1). Subjects were informed that judgements within 1/2 a degree were permitted. They were not given any suggestions as to how to go about their task, and were permitted to take as long as necessary to respond.

In Part Two the control subjects were shown a night and a day scene each from three miles downrange. Altitude was such that their glideslope angle was three degrees. They were instructed that this glideslope angle was three degrees and allowed to study the scene until they felt confident that they could recognize that angle as three degrees. Then each subject was retested in the same manner at Part One.

In Part Three subjects were given instruction as to how to use the depression angle from horizon technique for judging glideslope angles. This was done using a diagram (Figure B-2) in order not to give the test subjects extra experience with VITAL. (See Term Definitions.) They were then shown a three degree glideslope angle as in Part Two and retested as in Part One. The results of this experiment can be seen in Tables B-5 and B-6.

Performed by visually comparing the depression angle, D, separating a specific point on the ground (touchdown blocks) from the horizon line, with the desired depression angle. Once the desired angle, D, is reached, then the glidepath angle, G, is known by the principle of similar triangles, (G=D).

(5 positions from which subjects judged their apparent glideslope angle.)

	Distance (Mi) From Runway	Night	Day	Night	Day
Position 1	0.5	7 deg.	1 deg.	1 deg.	7 deg.
Position 2	1.0	6 deg.	5 deg.	5 deg.	6 deg.
Position 3	3.0	5 deg.	2 deg.	2 deg.	5 deg.
Position 4	6.0	4 deg.	4 deg.	4 deg.	4 deg.
Position 5	12.0	3 deg.	3 deg.	3 deg.	3 deg.

FIGURE B-1. GLIDE PATH ANGLES TO LANDING

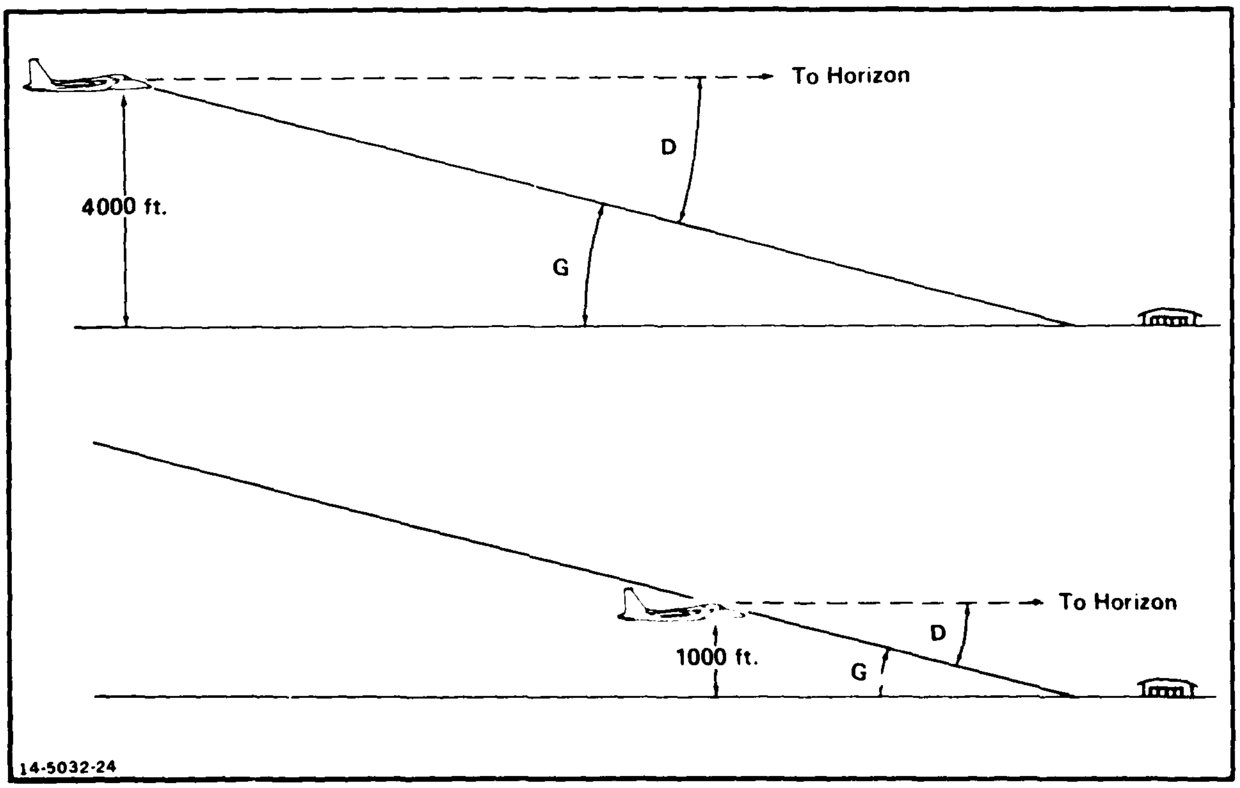


FIGURE B-2. DEPRESSION ANGLE FROM HORIZON TECHNIQUE FOR JUDGING GLIDESLOPE ANGLES

TABLE B-5. VITAL ANGULAR JUDGEMENT RESULTS

Percent Correct

Group	Before Training: Responses Within 0 deg	Before Training: Responses Within +/- 1 deg	After Training by Depression Angle From Horizon Technique: Responses Within 0 deg	After Training by Depression Angle From Horizon Technique: Responses Within +/- 1 deg
Entire Test Group	2.6	12.6	19.6	44.6
Experienced Test Group	3.7	17.5	21.2	51.2
Inexperienced Test Group	2.2	10.5	17.2	41.6

Group	Before Training: Responses Within 0 deg	Before Training: Responses Within +/- 1 deg	After Training by Example: Responses Within 0 deg	After Training by Example: Responses Within +/- 1 deg
Entire Control Group	22.1	55.0	33.5	72.8
Experienced Control Group	35.0	68.3	45.0	86.6
Inexperienced Control Group	12.5	45.0	25.0	62.5

TABLE B-6. VITAL ANGULAR JUDGEMENT RESULTS

Number Correct Out of Twenty

Subject No.	Before Training: Responses Within 0 deg	Before Training: Responses Within +/- 1 deg	After Training by Depression Angle from Horizon Technique: Responses Within 0 deg	After Training by Depression Angle from Horizon Technique: Responses Within +/- 1 deg
1	0	1	4	12
2	4	15	6	15
3	0	1	6	11
5	0	0	8	12
6	0	0	2	4
7	0	0	0	3
9	0	0	4	13
10	0	0	0	2
13	2	4	2	4
14	0	4	7	10
17	0	2	4	10
18	1	6	7	14
20	0	0	1	6
4	3	6	4	11
8	0	2	5	11
11	4	11	4	12
12	2	10	4	12
15	11	15	14	20
16	3	17	7	16
19	8	16	9	20

NON-REAL WORLD VISUAL CUE TRAINING - EXPERIMENT THREE

The purpose of this experiment was to establish the amount of influence the non-real world visual cues, horizon depression cursor, velocity vector cursor and visual air space would have on simulated flight performance. (See Term Definitions.)

Overview

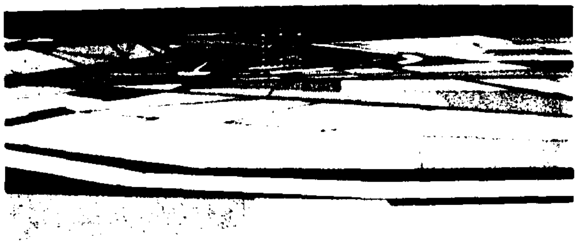
The forward velocity of all approaches was fixed at 220 mph for the entire approach. The movement of real world visual cues is vitally important in visual approaches. Thus the high velocity emphasized their movements. It was also desirable to make the task of an approach unfamiliar. The unfamiliarity would tax the subjects mental capacity, holding his attention. Due to the unfamiliarity of the task and the nature of the exercise a joystick was chosen as the student response instrument for the visual system. The joystick flew with a constant zero angle of attack (i.e., it went where the nose of the aircraft was pointed).

The experiment was divided into three parts. Part One was performed by both control and test subjects, Part Two by control subjects only, and Part Three by test subjects only.

In Part One, control and test subjects were first instructed on how to use the joystick driver for aircraft control. They were told of the simulated aircrafts high velocity and the reasons for it. They were instructed to fly the simulated aircraft on a course that would use three degrees as a glideslope angle. The subjects were informed that their downrange starting distance would be 13.5 miles and that each approach would have a varying altitude and crossrange starting distance. Subjects were given help only in situations where the aircraft's altitude became zero or the subject had become totally disoriented with respect to the runway. If this occurred the aircraft was repositioned and the subject allowed to restart his approach. A practice period of 15 minutes was used, which included scenes for day and night approaches. Upon finishing the practice session, subjects flew two final pretraining approaches, one day and one night. They were instructed to use three degrees as a glideslope angle. The day approach starting position was above the three degree glideslope and to the right of the runway, while the night approach starting position was below the three degree glideslope and to the left of the runway (Figure B-3). During these simulated visual approaches the aircraft crossrange, downrange and altitude were recorded at several points along the flight path. This data was later converted to crossrange versus downrange and altitude versus downrange graphic representations of the aircraft's flight path. (Appendix D).

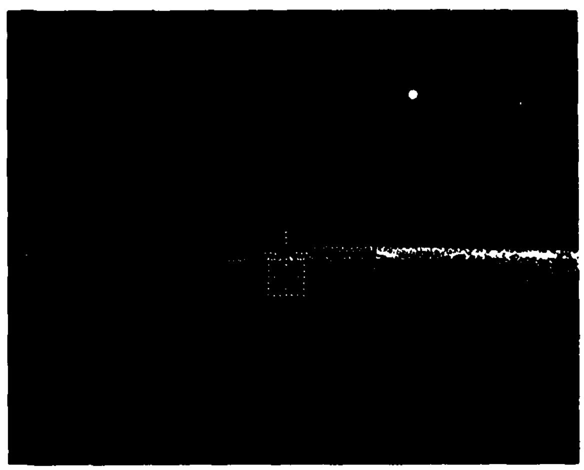
In Part Two of the experiment, control subjects were allowed an additional familiarity period of 15 minutes. They were given no feedback or instruction concerning their flight performance. At the end of the practice period they made two final approaches from the same starting points as the final starting points in Part One. Their instructions and the data collection were the same as in Part One.

In Part Three of the experiment test subjects were shown the visible air scene and informed concerning its contents and usage. They were introduced to the horizon depression cursor and velocity vector cursor and given instruction concerning their usages. The brightness of the cursors at this time was high for instructional purposes (Figure B-3). The test subjects were then allowed a 15 minute training period with feedback and visual cues active. After which the subjects flew two final training approaches as in Part One with horizon depression cursor and velocity vector active. Their instructions and the manner of data collection was the same as in Part One. Two post training approaches without supplementary visual cues were flown as a final test for the test subjects. Again their instruction and the manner of data collection was the same as in Part One.



(1216-18)

(1216-18B)



(1216-19A)

14-5032-25

FIGURE B-3. SIMULATED AIRCRAFT STARTING POSITIONS (SHEET 1 OF 2)

APPENDIX C

SAMPLE HUMAN FACTORS RESEARCH CONSENT FORM

INFORMED CONSENT FOR PARTICIPATION IN A HUMAN FACTORS RESEARCH PROJECT

APPENDIX C

SAMPLE HUMAN FACTORS RESEARCH CONSENT FORMS

INFORMED CONSENT FOR PARTICIPATION IN A HUMAN FACTORS RESEARCH PROJECT

I, ____________________________, state that I am over eighteen (18) years of age, and that I am willing to participate in a program of research being conducted by McDonnell Douglas Electronics Company. I acknowledge that I have been informed of the nature and purpose of the research and that it is not intended to benefit my personal health. I acknowledge that ________________________ has explained fully any attendant discomforts or risks to be expected, and that I have been informed that these do not exceed the ordinary risks of daily life. I acknowledge that ___________________ has offered to answer any inquiries which I may make concerning the procedures to be followed, and that I have been informed that I may withdraw from participation at any time without prejudice. I freely and voluntarily consent to participate in this research project entitled "ADVANCED TRAINING TECHNIQUES USING COMPUTER GENERATED IMAGERY". I acknowledge that I do not now have and have never had any epilepsy or epileptic seizures and acknowledge that such absence of epilepsy is important to this research inasmuch as the displays I will view during this research could potentially induce epileptic seizures in persons with a history of such seizures. I agree that the next time I operate an aircraft, after having participated in any one experimental/research session comtemplated by this research project, I will operate such aircraft only on the condition that an FAA certified instructor be present in the aircraft cockpit during such operation.

____ ______________________

(Signature of Volunteer) (Date)

____

(Signature of Staff Member Who has Witnessed this Explanation)

AD-A129 215 ADVANCED TRAINING TECHNIQUES USING COMPUTER GENERATED IMAGERY(U) MCDONNELL DOUGLAS ELECTRONICS CO ST CHARLES MO D COBLITZ ET AL. 28 FEB 83 MDC-M3027 2/2

UNCLASSIFIED AFOSR-TR-83-0460 F49620-79-C-0067 F/G 5/9 NL

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DATE
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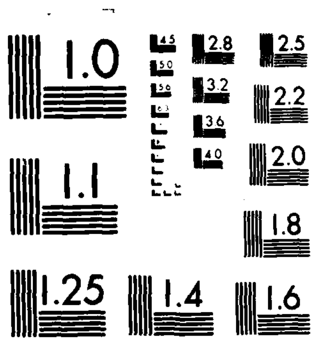

1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

The McDonnell Douglas Electronics Company is being sponsored by the U.S. Air Force Office of Scientific Research to perform studies hopefully leading to better training of Air Force pilots by using computer generated imagery. As a participant in this study you will be shown various experimental flight training displays and asked to perform simulated flight tasks and make visual judgements based upon these displays. These experiments are not related to the Parks College flight curriculum and in no way will your performance here prejudice your grades in your course work at Parks. Since this is an experimental study we cannot predict whether your participation will affect your normal flight training either positively, negatively, or not at all. We will appreciate feedback from you and your instructors in this regard. Your participation is entirely voluntary and you may withdraw at any time without prejudice.

APPENDIX D

NON-REAL WORLD VISUAL CUE TRAINING DATA

APPENDIX D

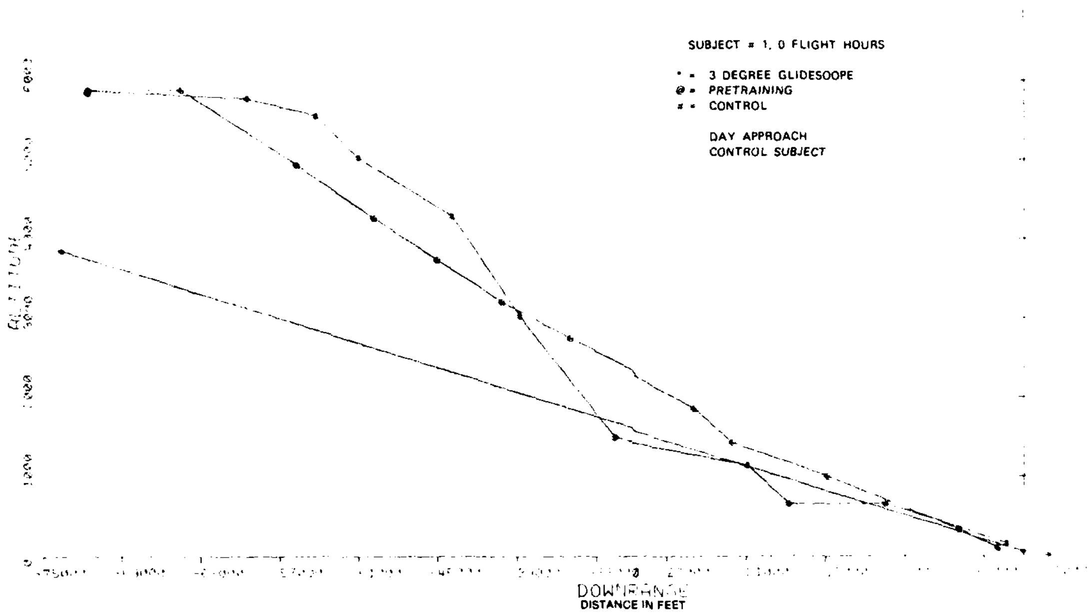
NON-REAL WORLD VISUAL CUE TRAINING DATA

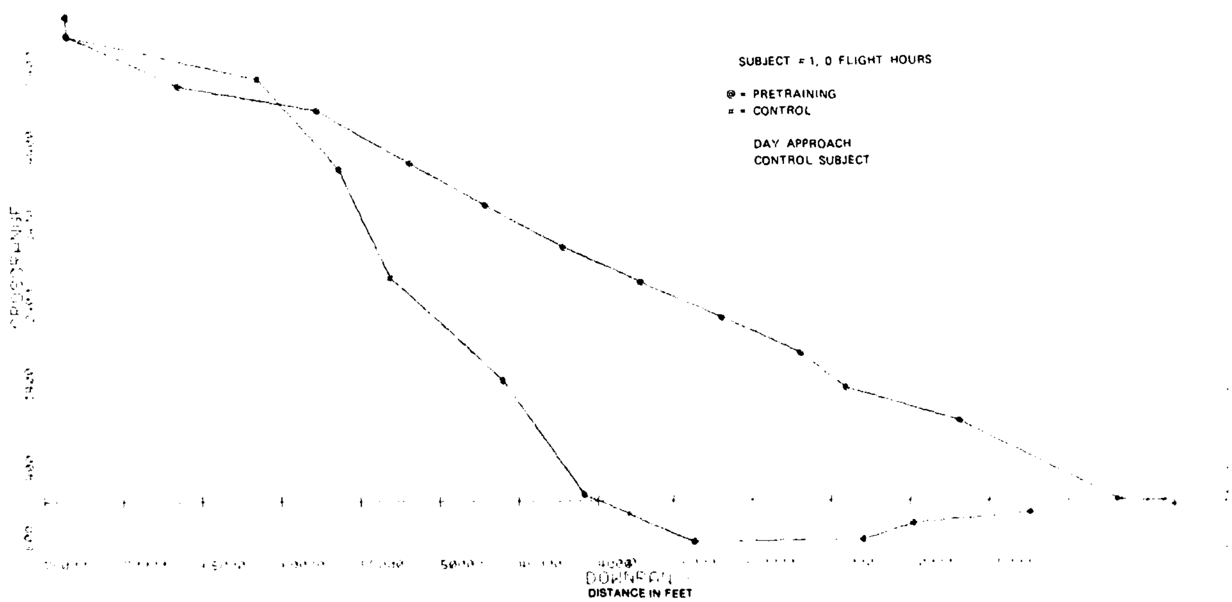
TABLE D-1. CONTROL SUBJECTS FLIGHT EXPERIENCE

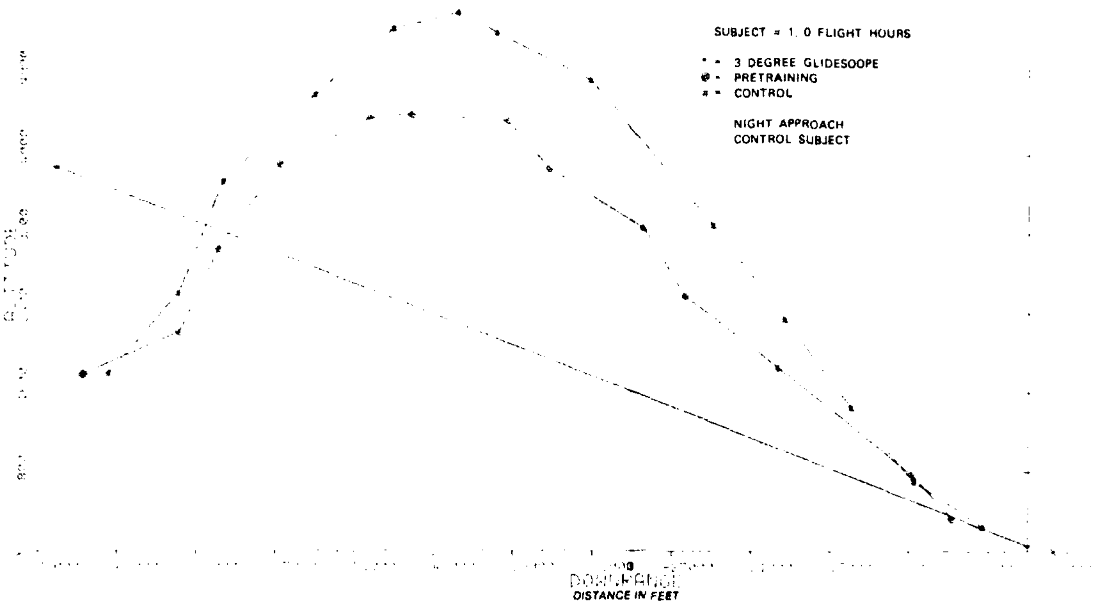
Subject Number	Number of Flight Hours
1	0
11	10
4	20
16	100
8	115
19	350
12	1725
15	4000

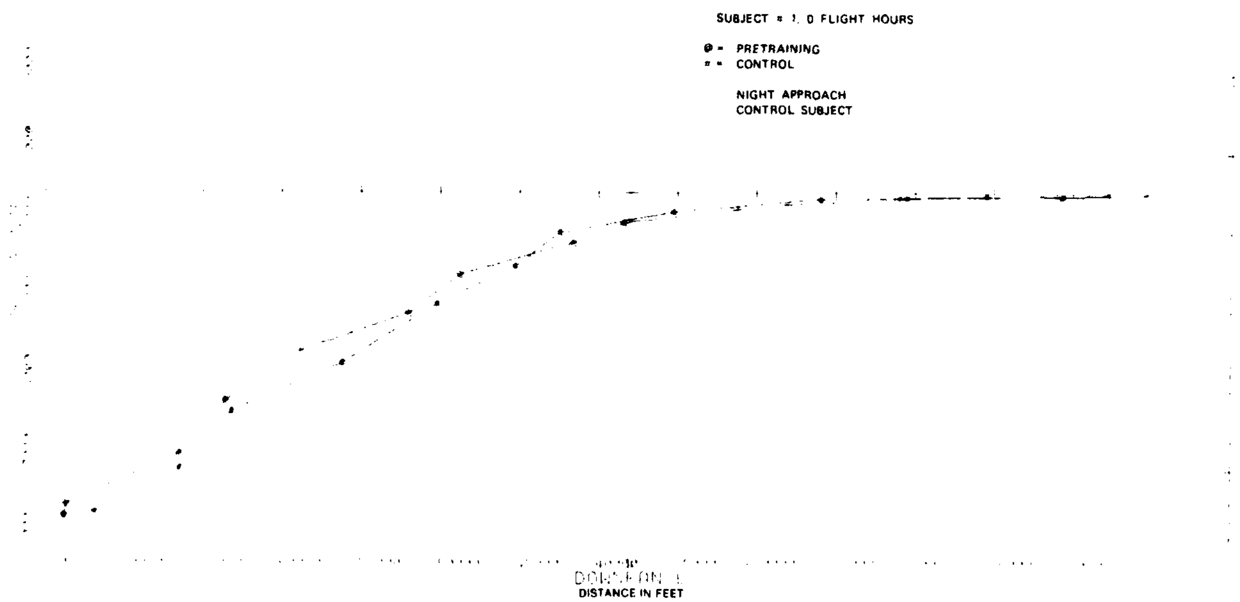
It is important to notice that due to machine limitations graph scaling may vary.

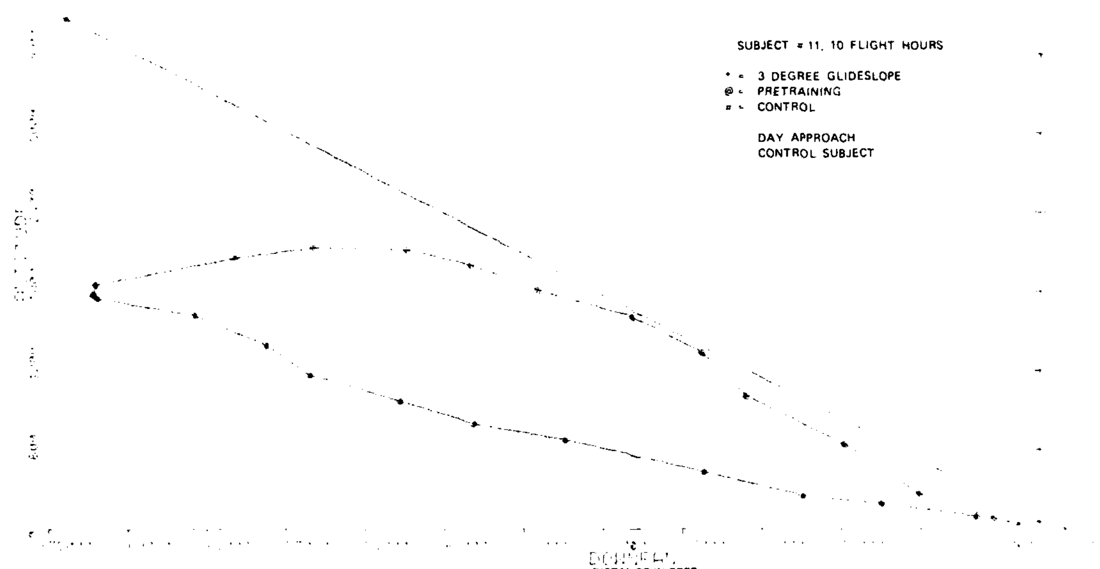
The two closest tic marks on the crossrange axis represent the edges of a 200 foot wide runway.


SUBJECT # 1, 0 FLIGHT HOURS
* = 3 DEGREE GLIDESOOPE
@ = PRETRAINING
# = CONTROL
DAY APPROACH
CONTROL SUBJECT
ALTITUDE
DOWNRANGE
DISTANCE IN FEET

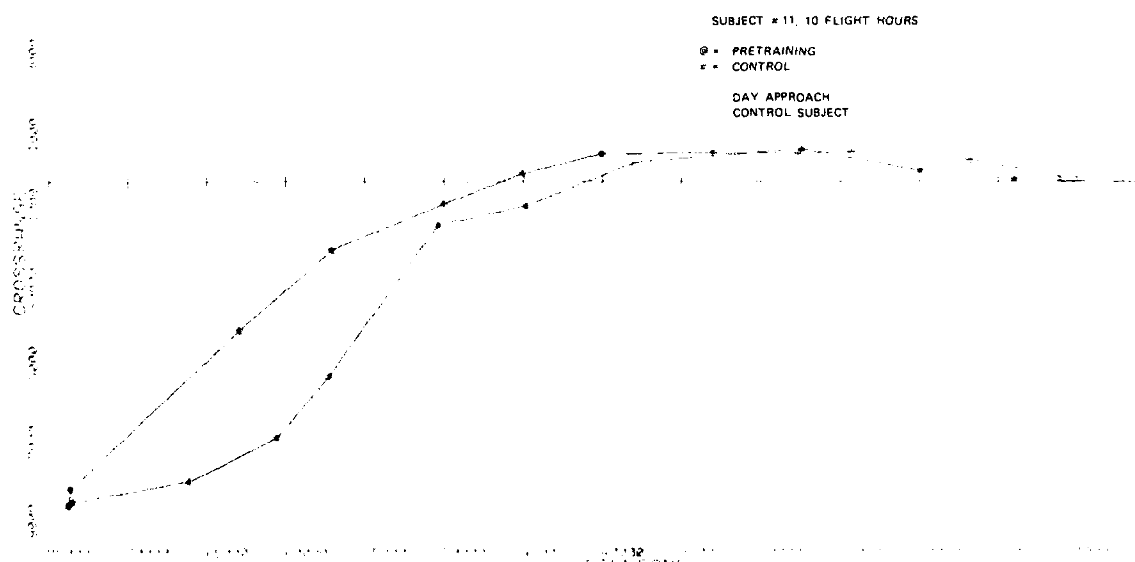

SUBJECT # 1, 0 FLIGHT HOURS
@ = PRETRAINING
# = CONTROL
DAY APPROACH
CONTROL SUBJECT
DISTANCE IN FEET


SUBJECT = 1. 0 FLIGHT HOURS
* = 3 DEGREE GLIDESOOPE
@ = PRETRAINING
# = CONTROL
NIGHT APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

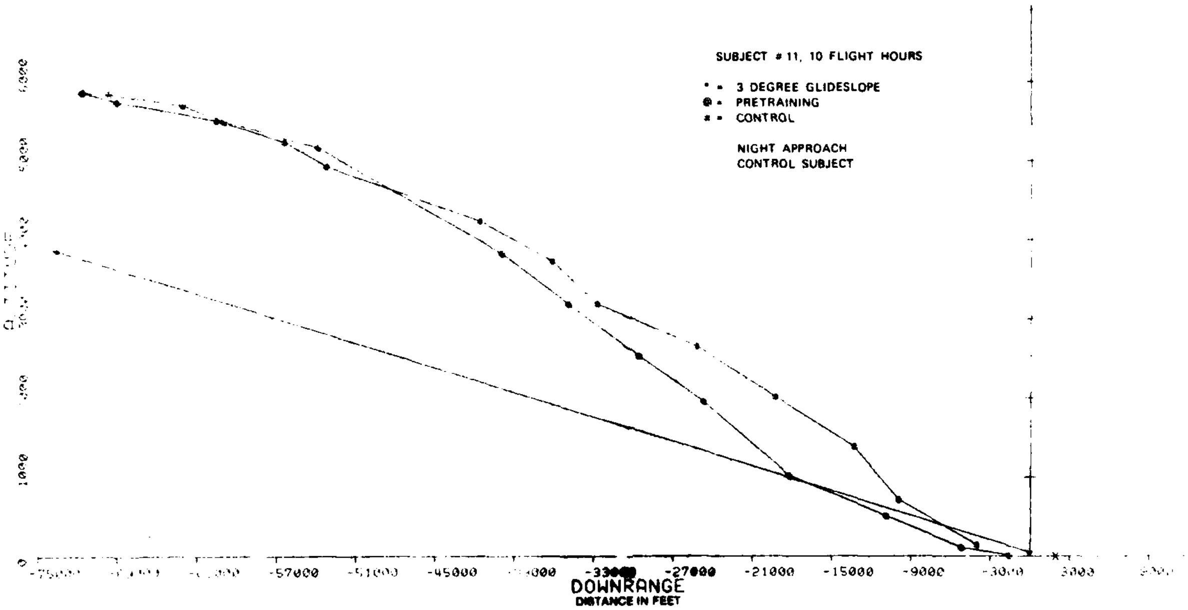

SUBJECT = 1. 0 FLIGHT HOURS
@ = PRETRAINING
# = CONTROL
NIGHT APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

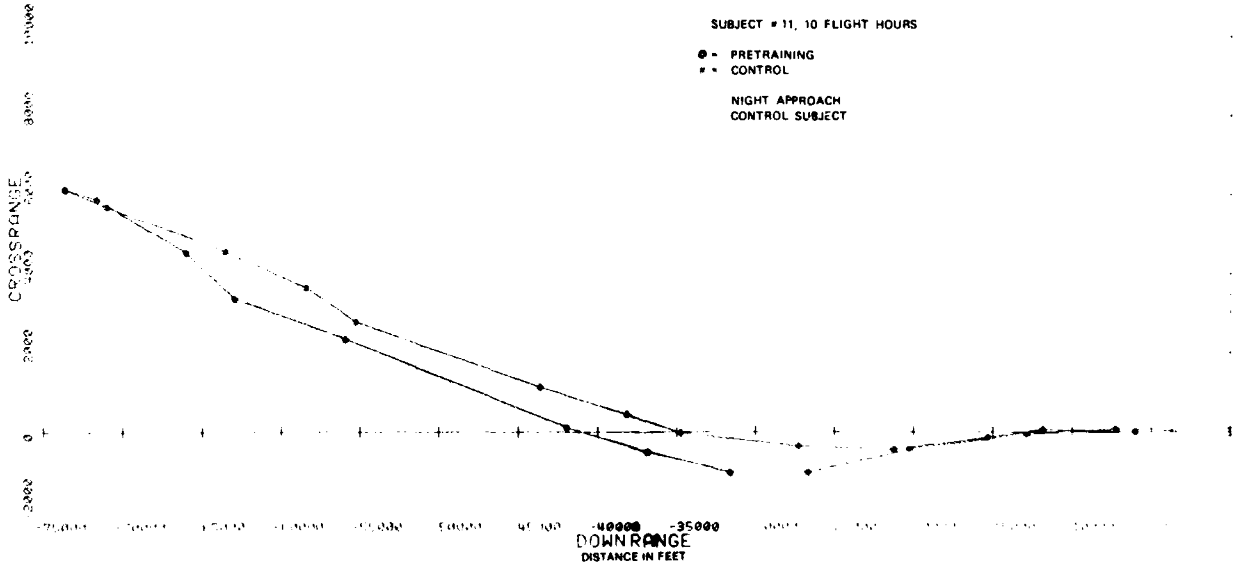


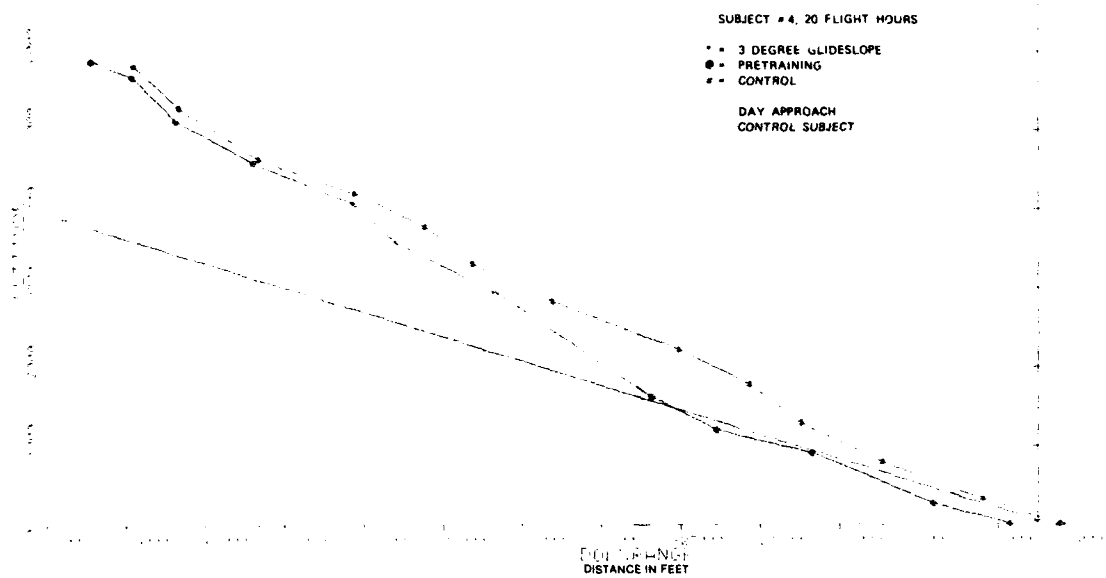
DISTANCE IN FEET



DISTANCE IN FEET


SUBJECT # 11, 10 FLIGHT HOURS
3 DEGREE GLIDESLOPE
PRETRAINING
CONTROL
NIGHT APPROACH
CONTROL SUBJECT
-57000
-51000
-45000
-33000
-27000
-21000
-15000
-9000
3000
1000
DOWNRANGE
DISTANCE IN FEET


SUBJECT # 11, 10 FLIGHT HOURS
PRETRAINING
CONTROL
NIGHT APPROACH
CONTROL SUBJECT
CROSSRANGE
2000
-40000
-35000
DOWN RANGE
DISTANCE IN FEET


SUBJECT # 4, 20 FLIGHT HOURS
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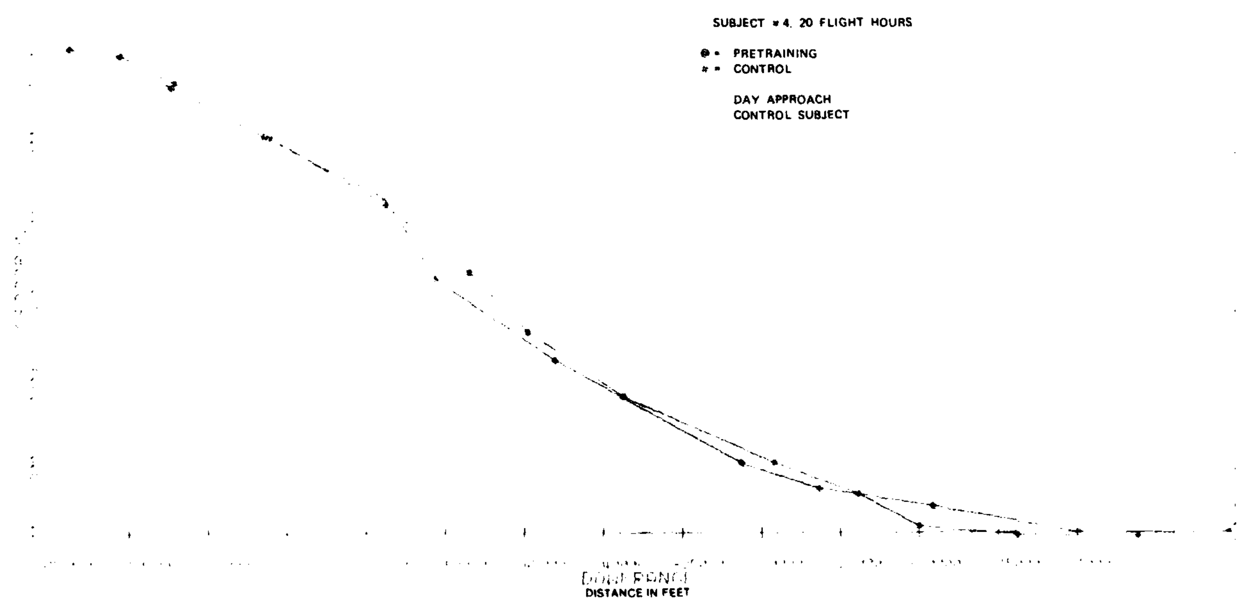
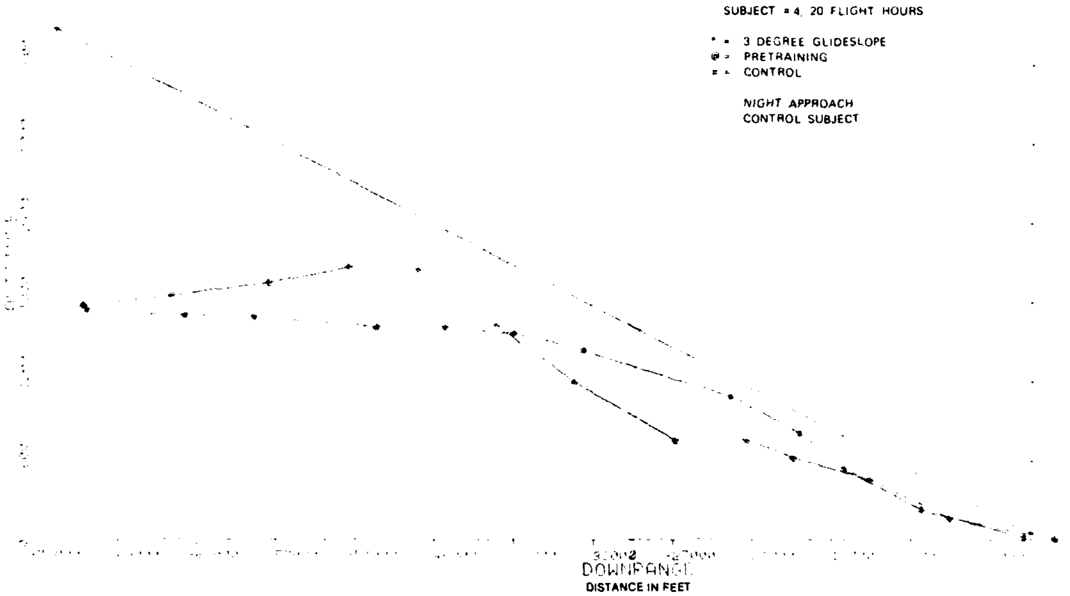
● = PRETRAINING
= CONTROL
DAY APPROACH
CONTROL SUBJECT
DISTANCE IN FEET


SUBJECT # 4, 20 FLIGHT HOURS
● = PRETRAINING
= CONTROL
DAY APPROACH
CONTROL SUBJECT
DISTANCE IN FEET


SUBJECT # 4, 20 FLIGHT HOURS
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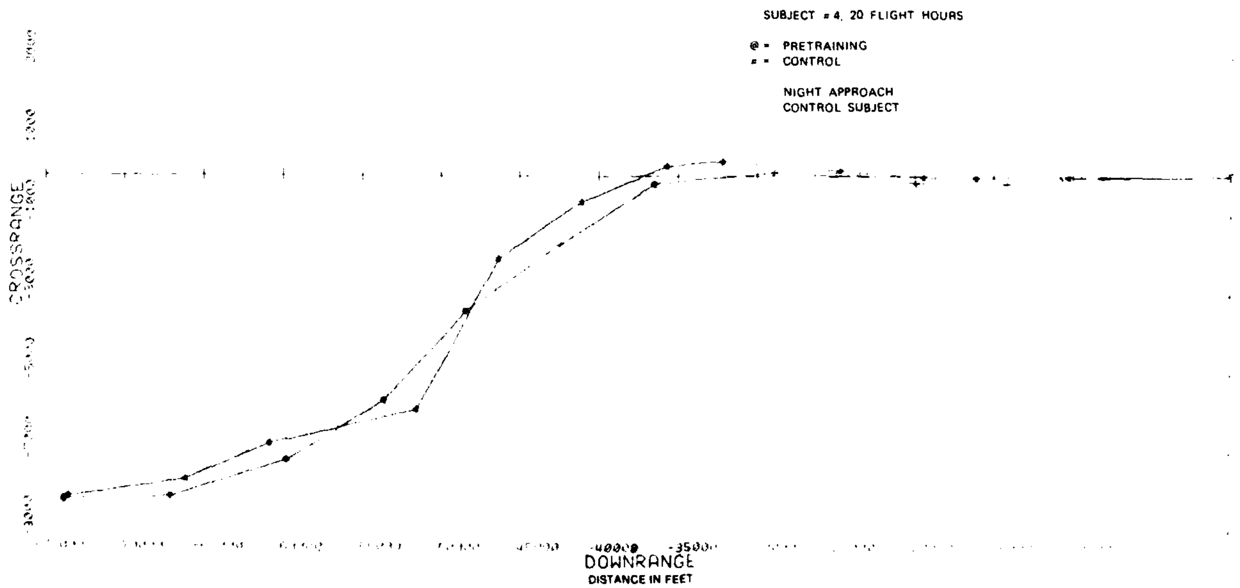
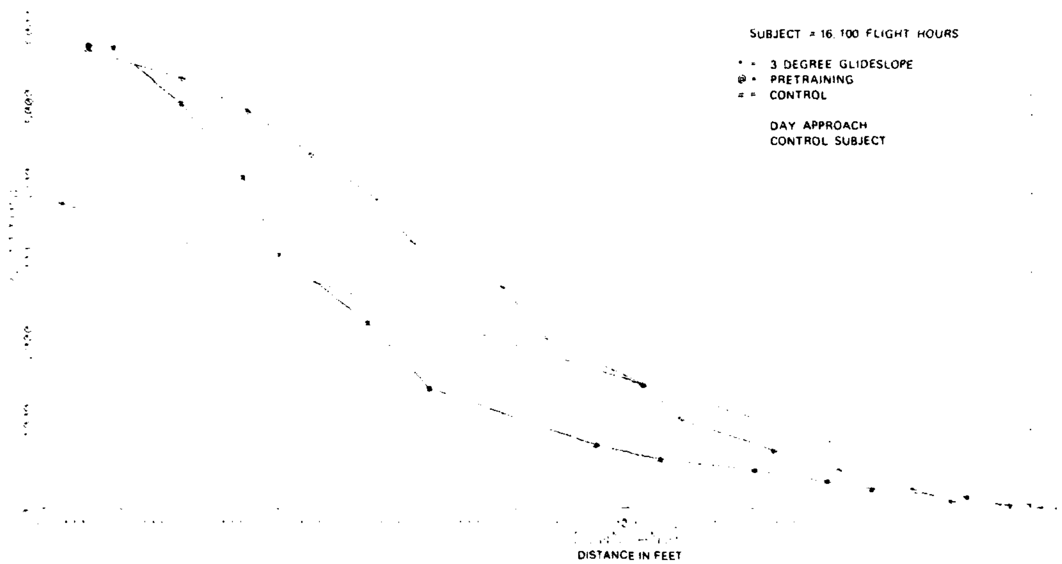
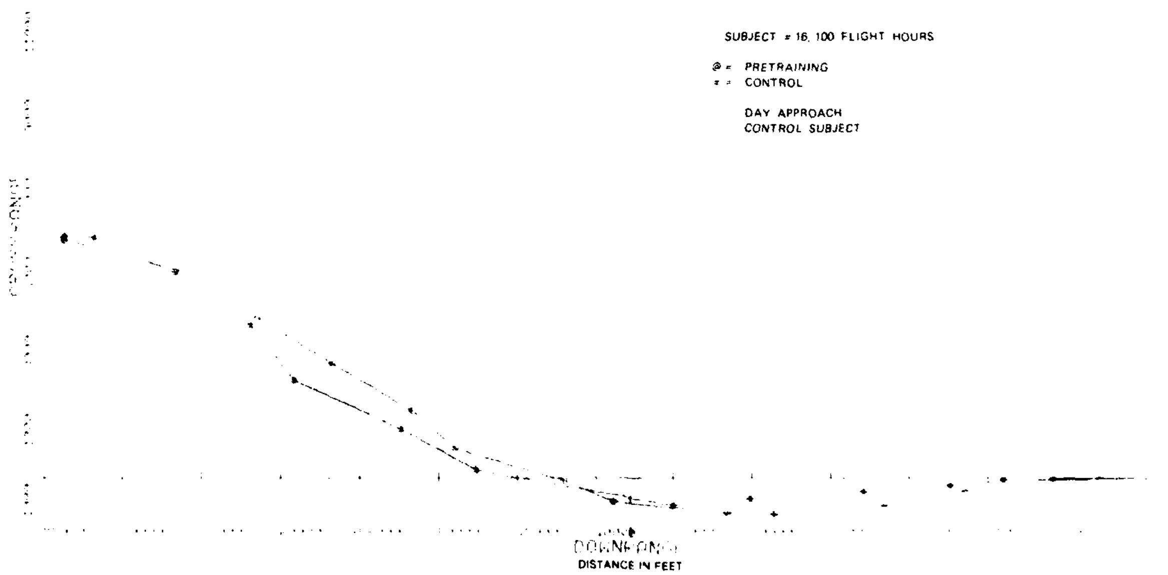
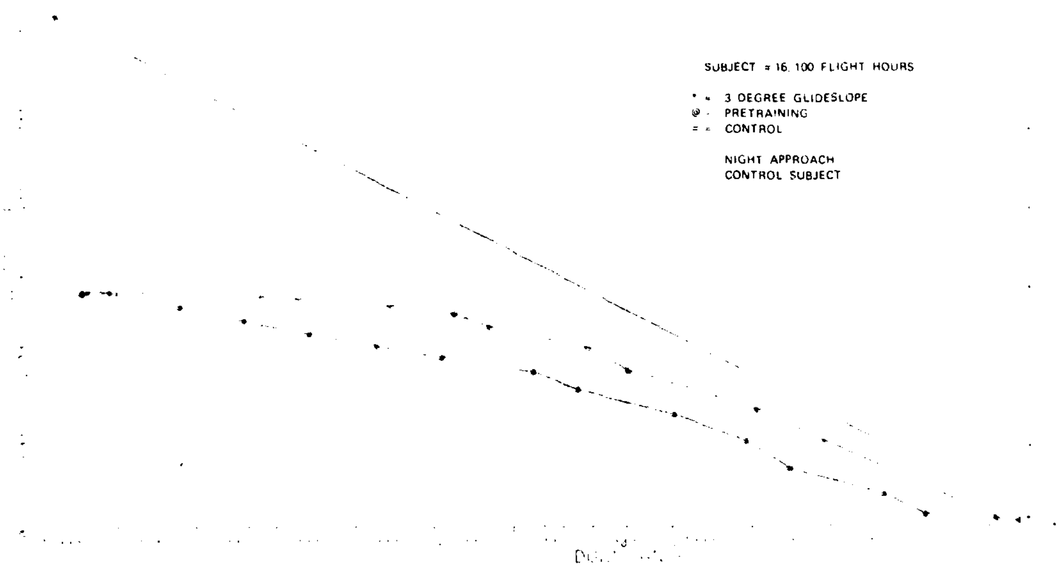
@ = PRETRAINING
# = CONTROL
NIGHT APPROACH
CONTROL SUBJECT
DOWNRANGE
DISTANCE IN FEET

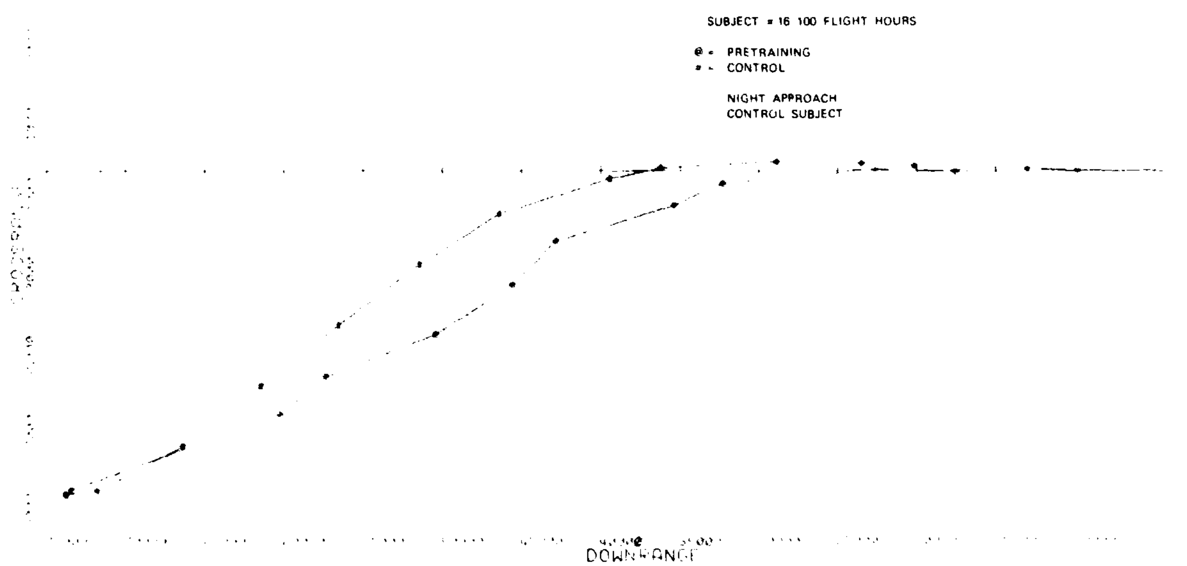

SUBJECT # 4, 20 FLIGHT HOURS
@ = PRETRAINING
# = CONTROL
NIGHT APPROACH
CONTROL SUBJECT
CROSSRANGE
-40000
-35000
DOWNRANGE
DISTANCE IN FEET


SUBJECT = 16,100 FLIGHT HOURS
* = 3 DEGREE GLIDESLOPE
@ = PRETRAINING
# = CONTROL
DAY APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

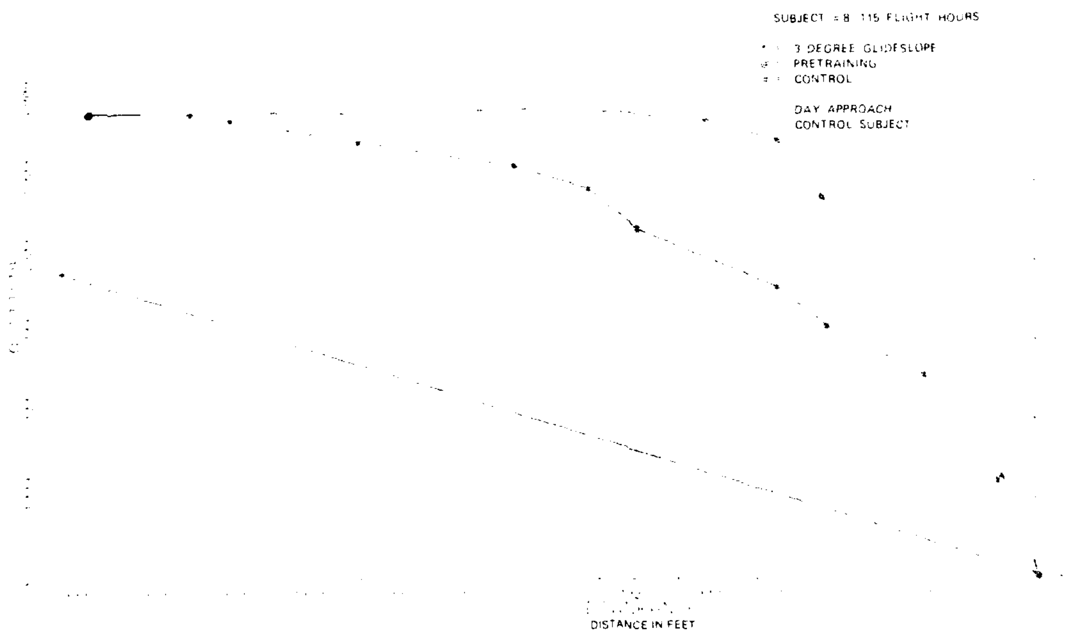

SUBJECT = 16,100 FLIGHT HOURS
@ = PRETRAINING
# = CONTROL
DAY APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

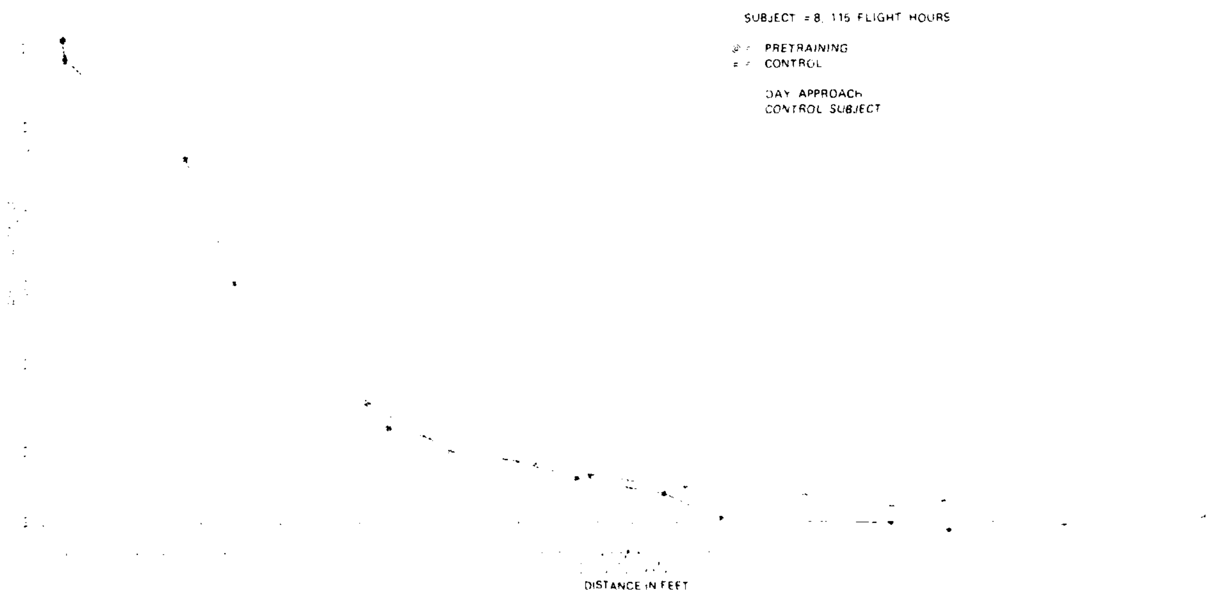


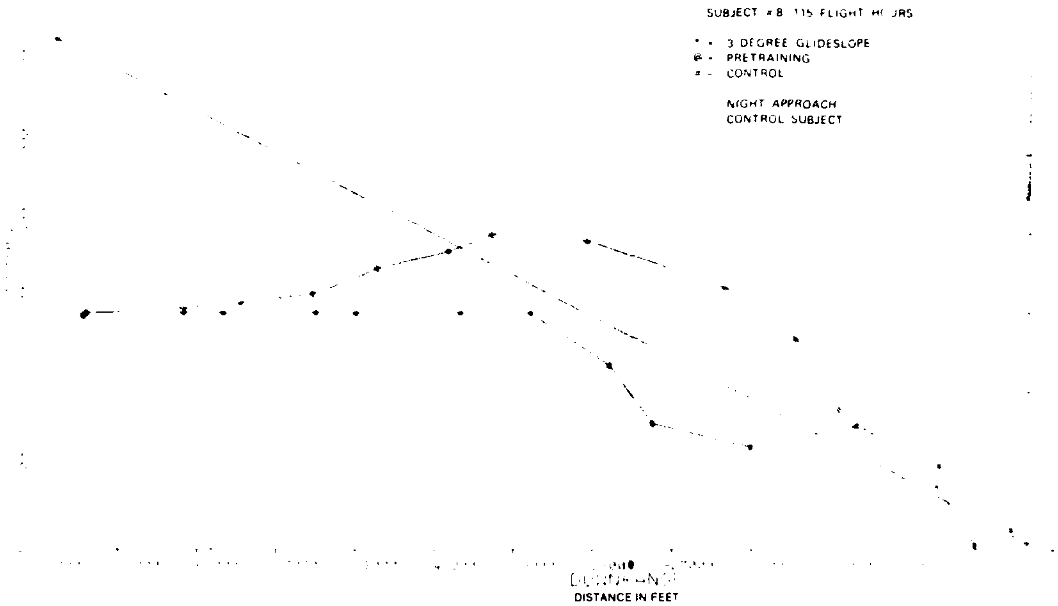
DISTANCE IN FEET

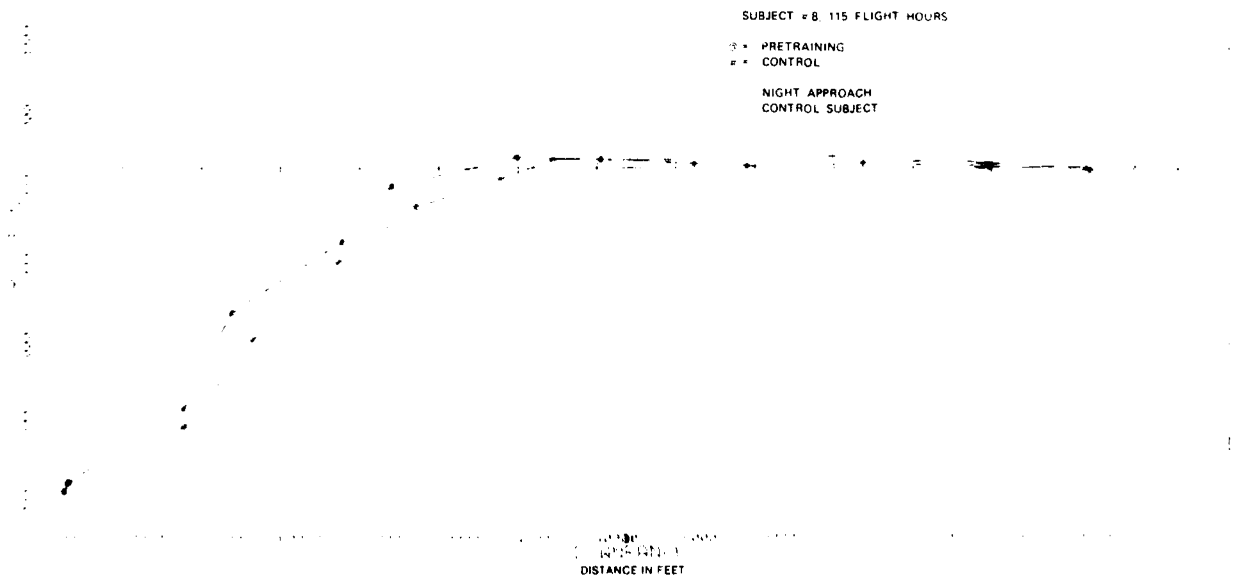


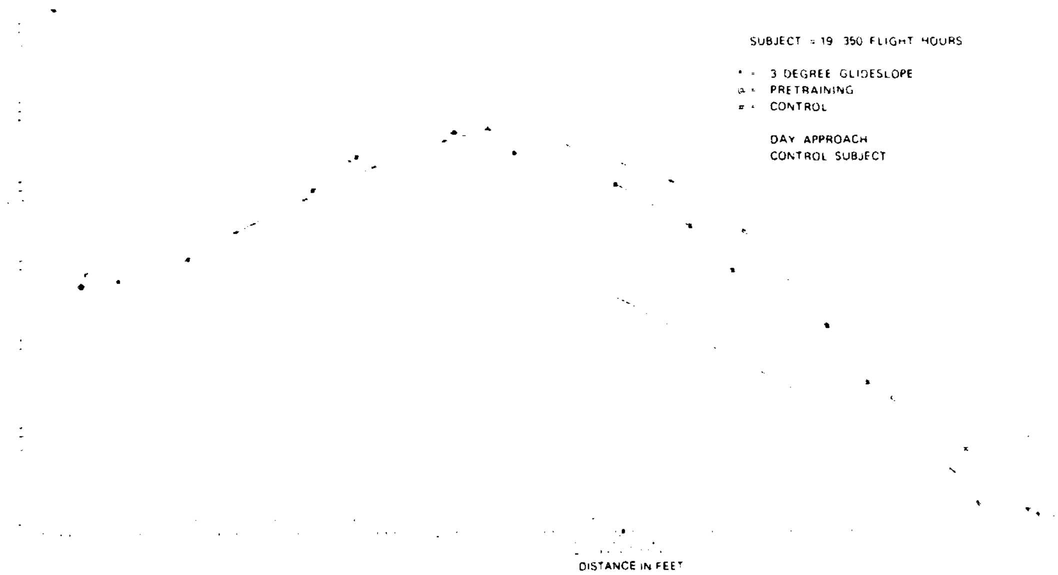
DISTANCE IN FEET

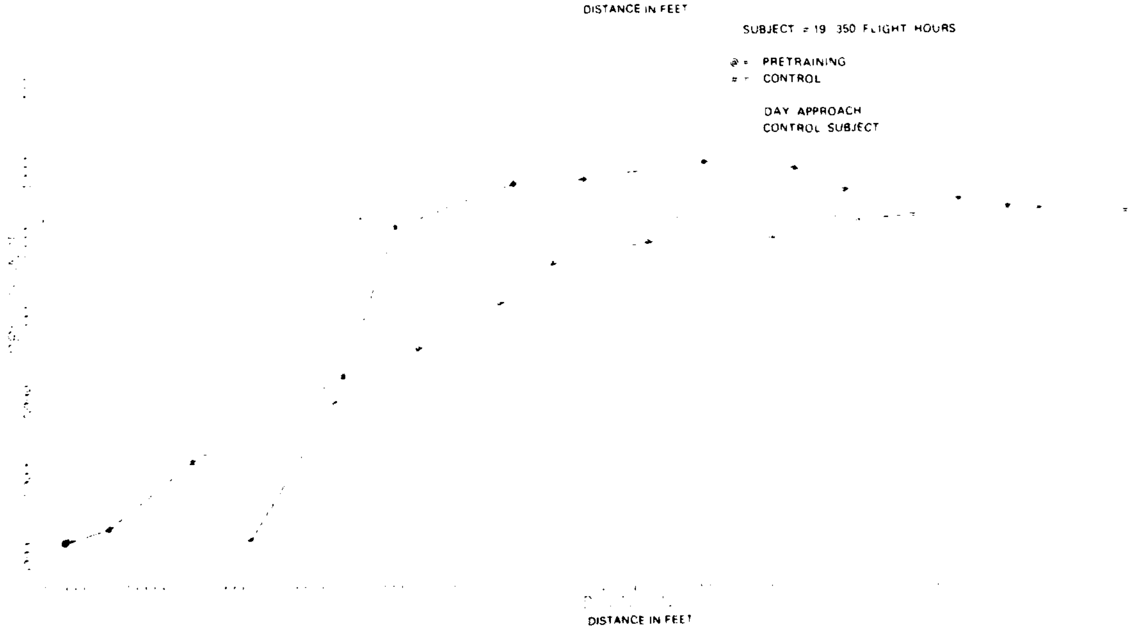

SUBJECT #8, 115 FLIGHT HOURS
3 DEGREE GLIDESLOPE
PRETRAINING
CONTROL
DAY APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

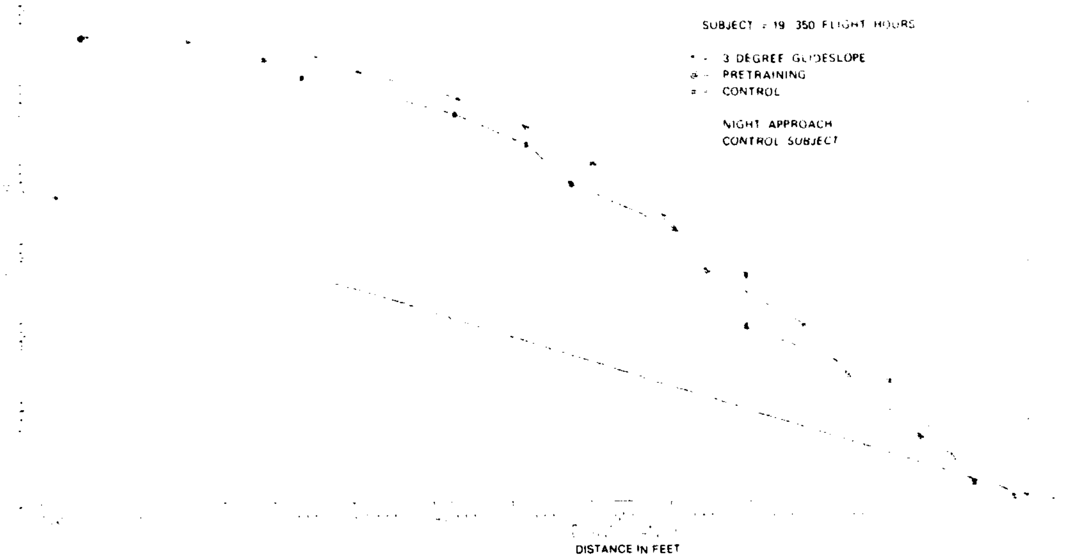

SUBJECT #8, 115 FLIGHT HOURS
PRETRAINING
CONTROL
DAY APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

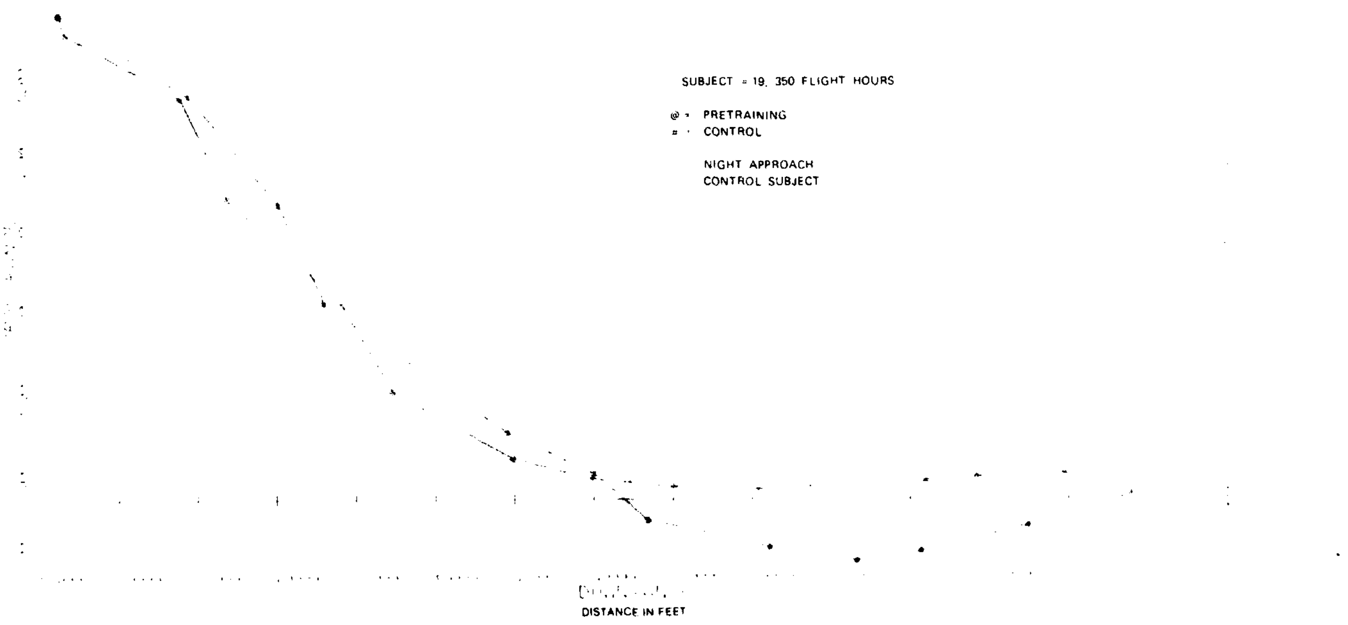

SUBJECT #8, 115 FLIGHT HOURS
* - 3 DEGREE GLIDESLOPE
@ - PRETRAINING
# - CONTROL
NIGHT APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

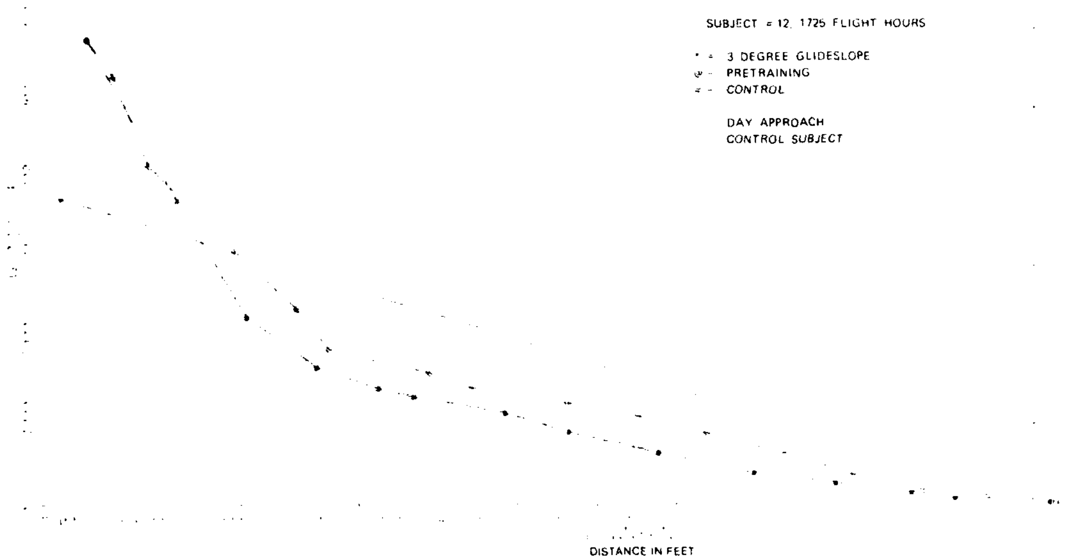

SUBJECT #8, 115 FLIGHT HOURS
@ - PRETRAINING
# - CONTROL
NIGHT APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

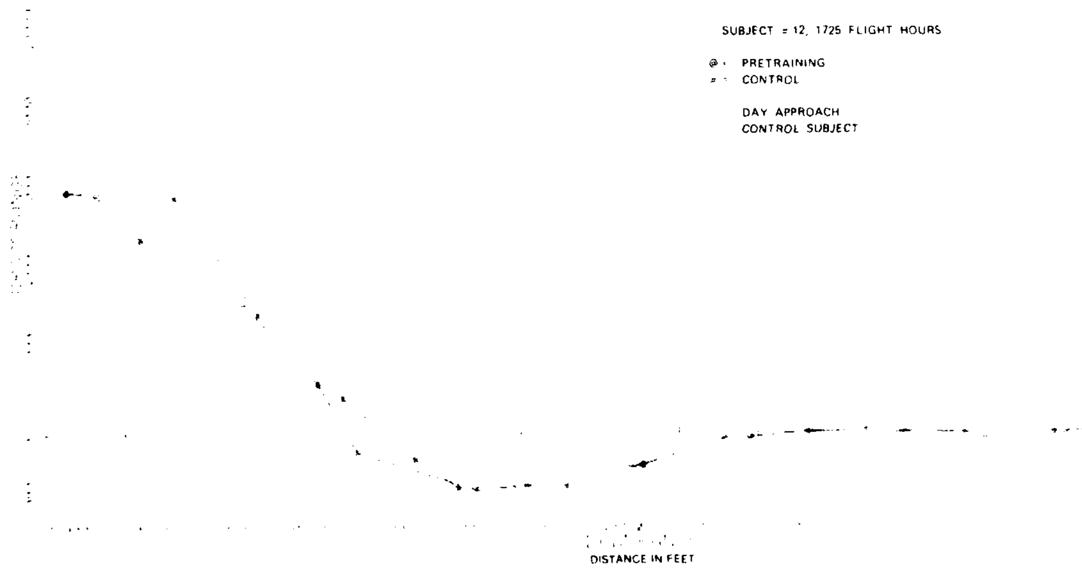

SUBJECT = 19 350 FLIGHT HOURS
* = 3 DEGREE GLIDESLOPE
@ = PRETRAINING
# = CONTROL
DAY APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

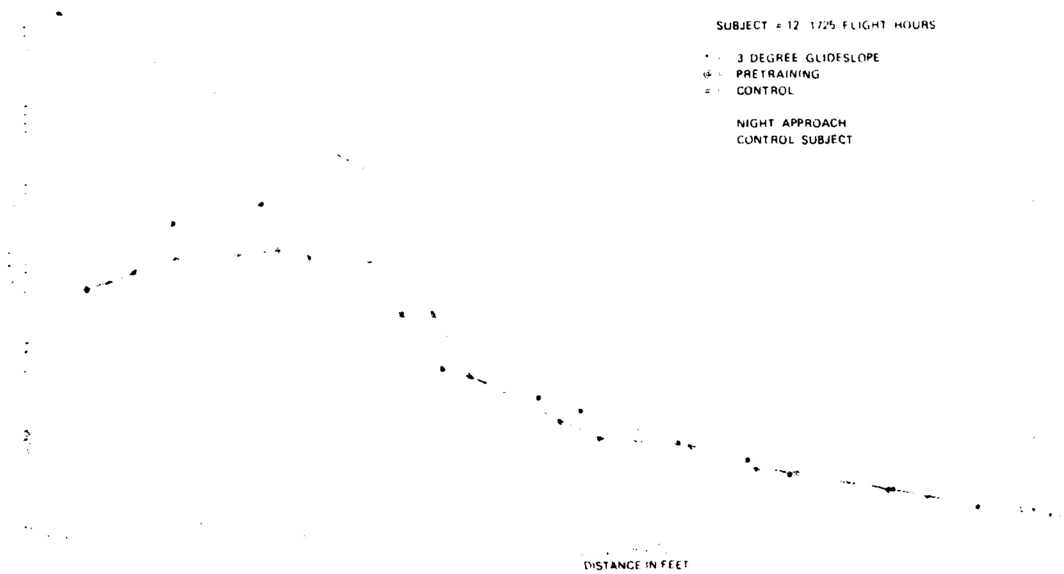

SUBJECT = 19 350 FLIGHT HOURS
@ = PRETRAINING
# = CONTROL
DAY APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

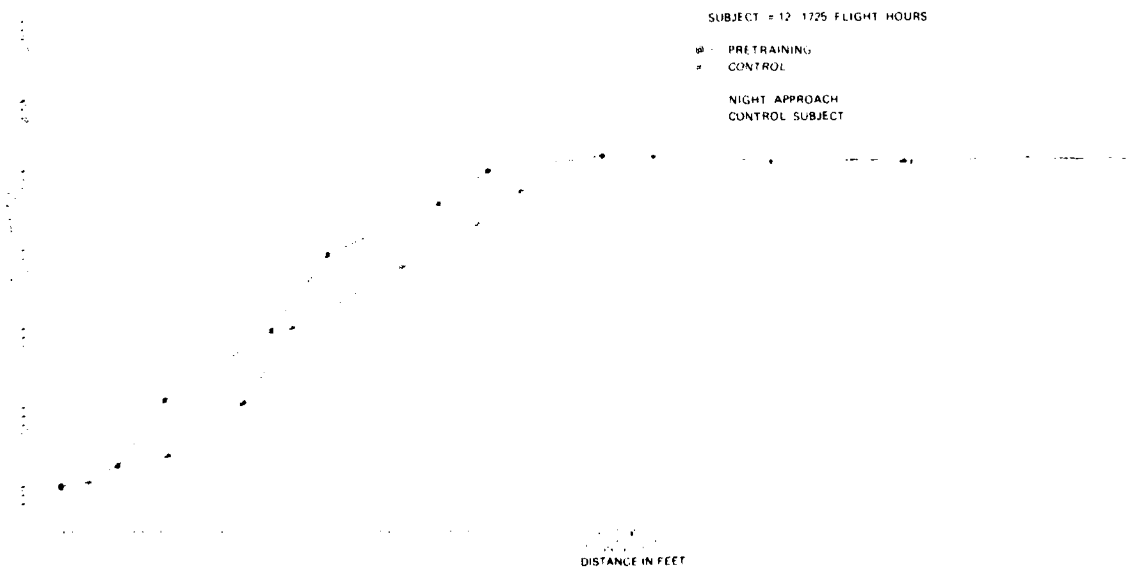

SUBJECT = 19, 350 FLIGHT HOURS
* - 3 DEGREE GLIDESLOPE
@ - PRETRAINING
# - CONTROL
NIGHT APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

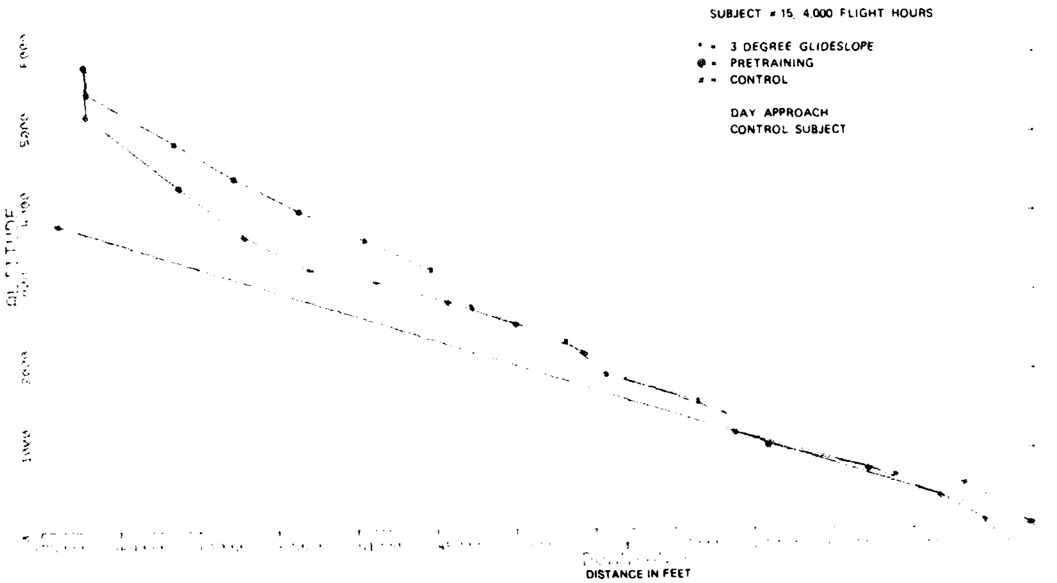

SUBJECT = 19, 350 FLIGHT HOURS
@ - PRETRAINING
# - CONTROL
NIGHT APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

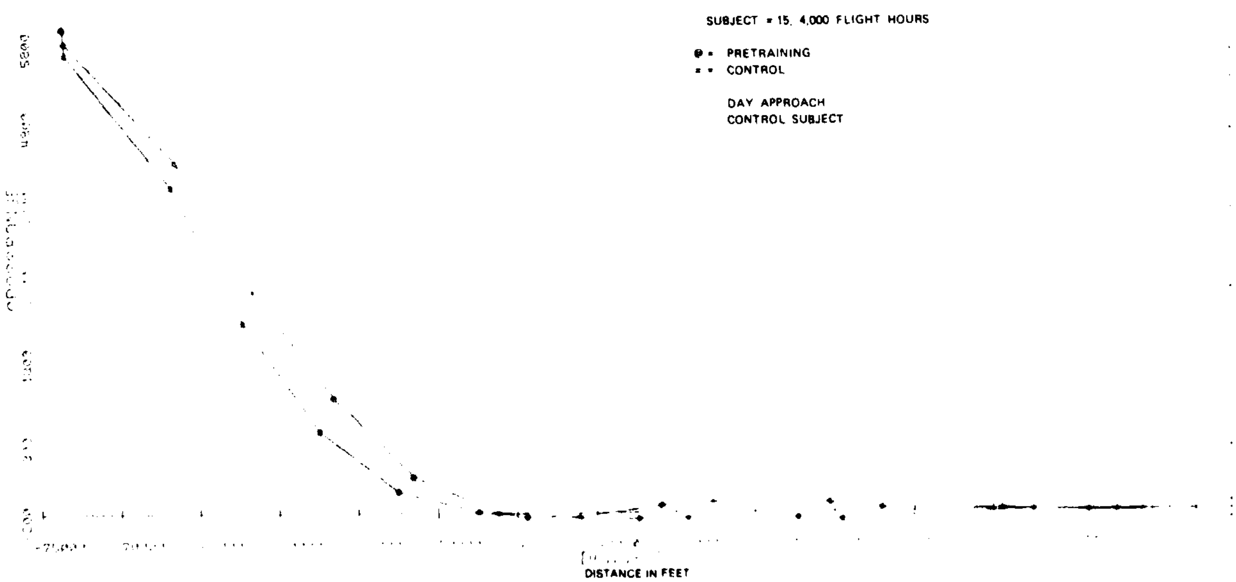

SUBJECT = 12, 1725 FLIGHT HOURS
* = 3 DEGREE GLIDESLOPE
@ - PRETRAINING
# - CONTROL
DAY APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

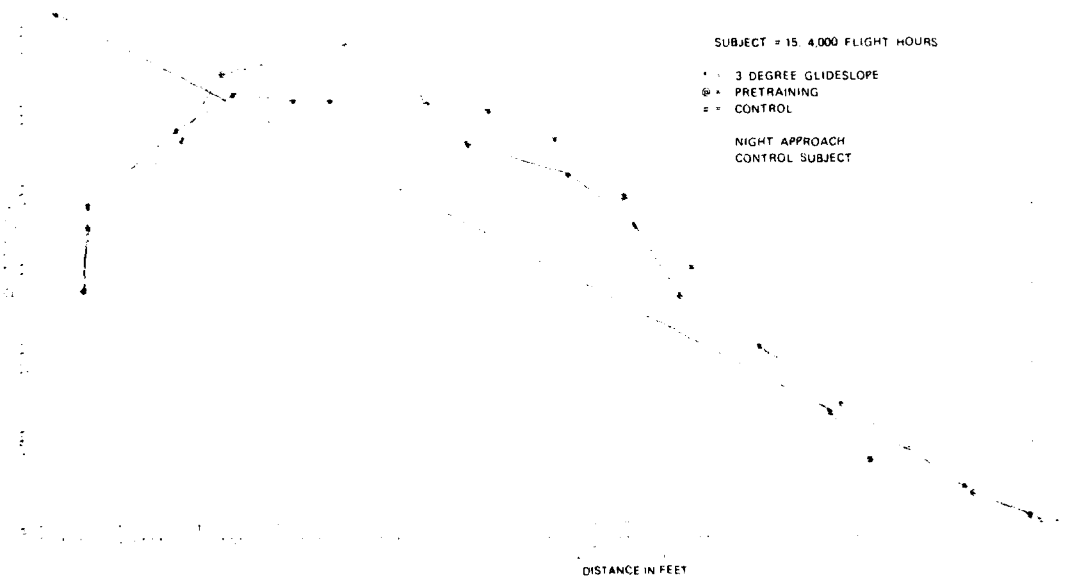

SUBJECT = 12, 1725 FLIGHT HOURS
@ - PRETRAINING
# - CONTROL
DAY APPROACH
CONTROL SUBJECT
DISTANCE IN FEET


SUBJECT = 12 1725 FLIGHT HOURS
3 DEGREE GLIDESLOPE
PRETRAINING
CONTROL
NIGHT APPROACH
CONTROL SUBJECT
DISTANCE IN FEET


SUBJECT = 12 1725 FLIGHT HOURS
PRETRAINING
CONTROL
NIGHT APPROACH
CONTROL SUBJECT
DISTANCE IN FEET


SUBJECT # 15, 4,000 FLIGHT HOURS
* = 3 DEGREE GLIDESLOPE
● = PRETRAINING
= CONTROL
DAY APPROACH
CONTROL SUBJECT
DISTANCE IN FEET


SUBJECT # 15, 4,000 FLIGHT HOURS
● = PRETRAINING
= CONTROL
DAY APPROACH
CONTROL SUBJECT
DISTANCE IN FEET


SUBJECT # 15, 4,000 FLIGHT HOURS
3 DEGREE GLIDESLOPE
PRETRAINING
CONTROL
NIGHT APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

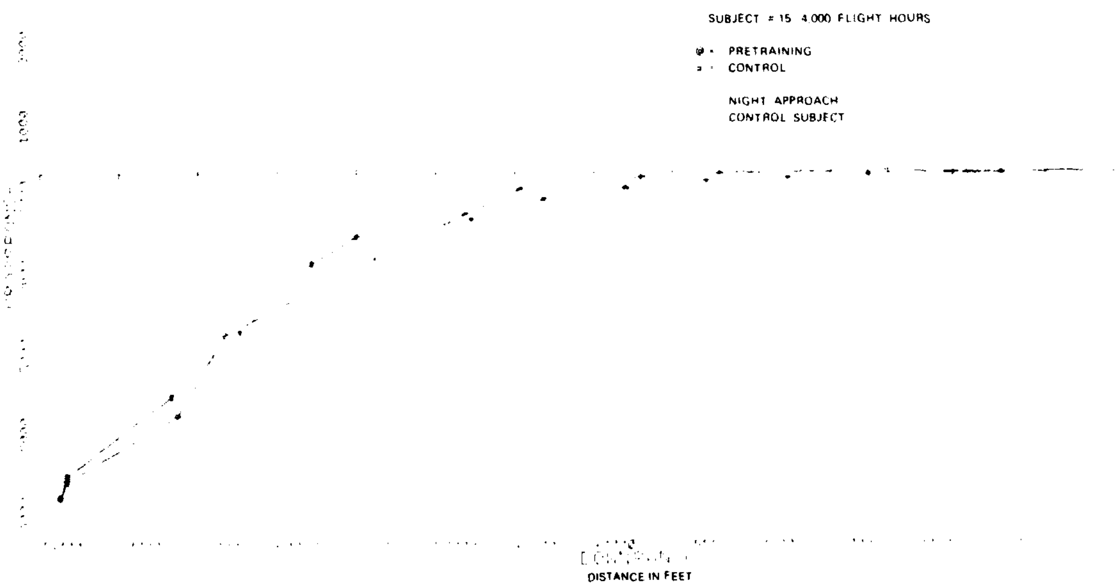
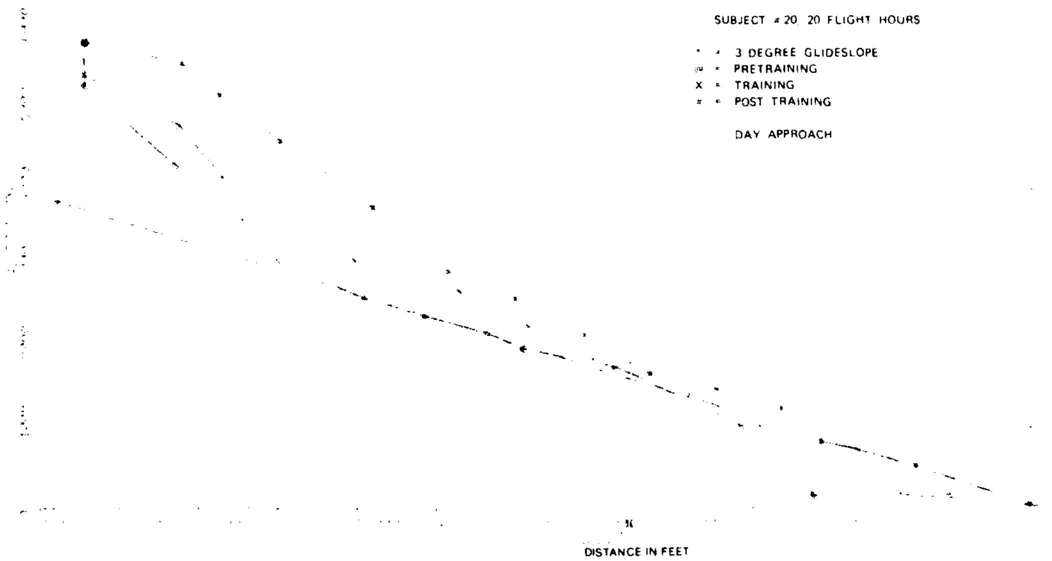

SUBJECT # 15 4,000 FLIGHT HOURS
PRETRAINING
CONTROL
NIGHT APPROACH
CONTROL SUBJECT
DISTANCE IN FEET

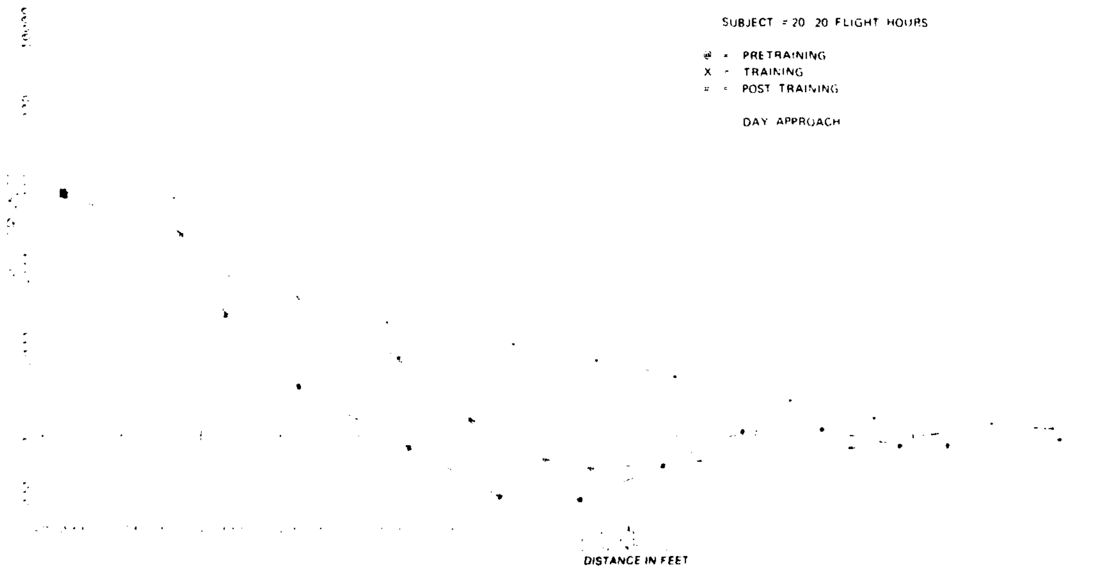
TABLE D-2. TEST SUBJECTS

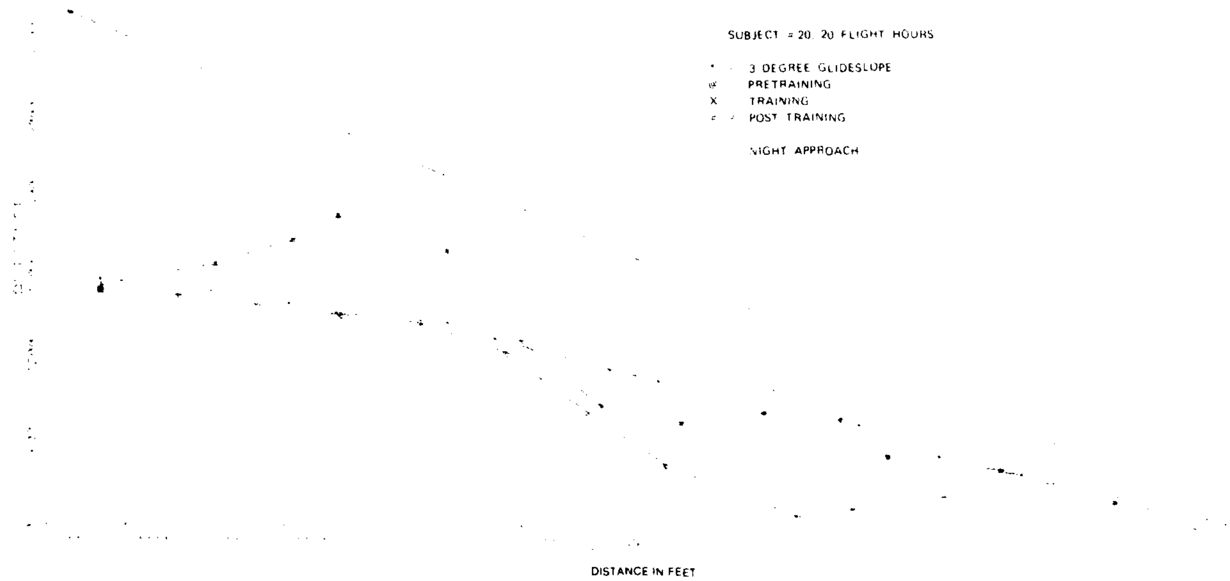
Subject Number	Number of Flight Hours
20	20
5	20
10	30
3	60
17	80
2	120
6	150
7	190
9	600
13	900
14	2200
18	7500

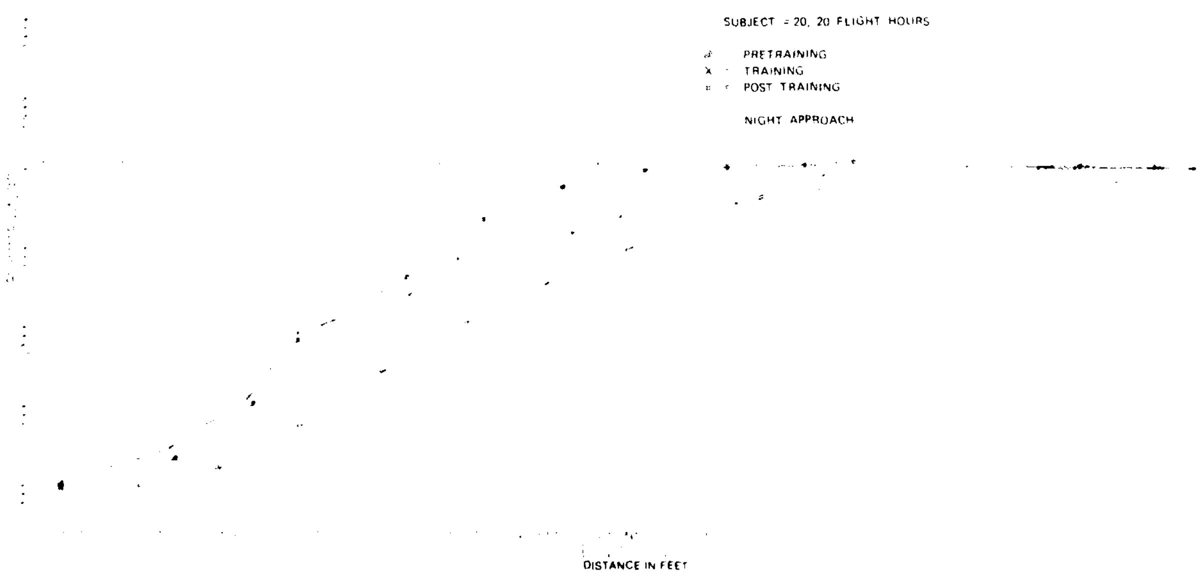
It is important to notice that due to machine limitations graph scaling may vary.

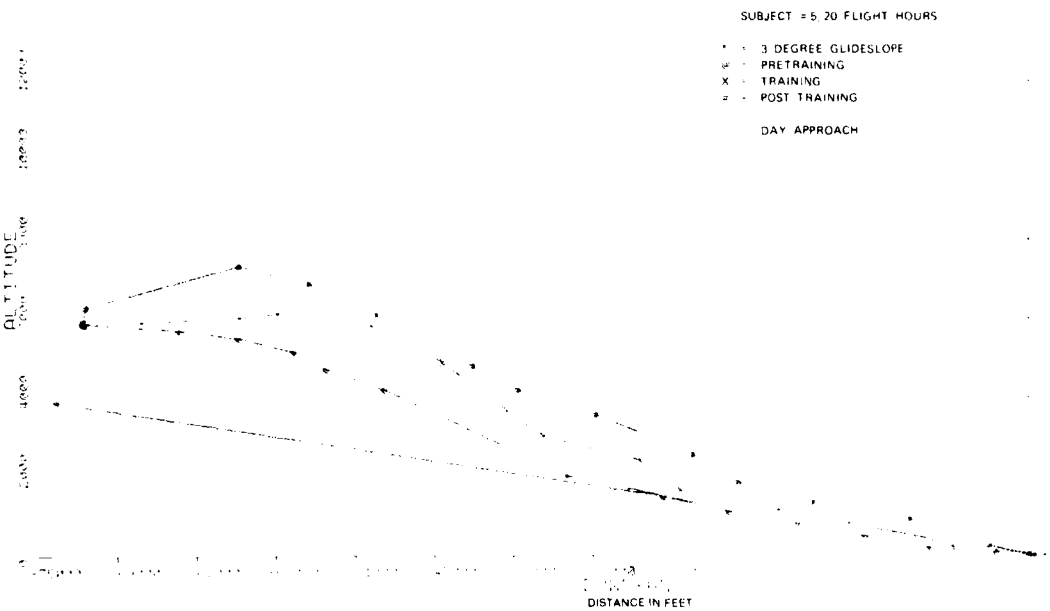
The two closest tic marks on the crossrange axis represent the edges of a 200 foot wide runway.

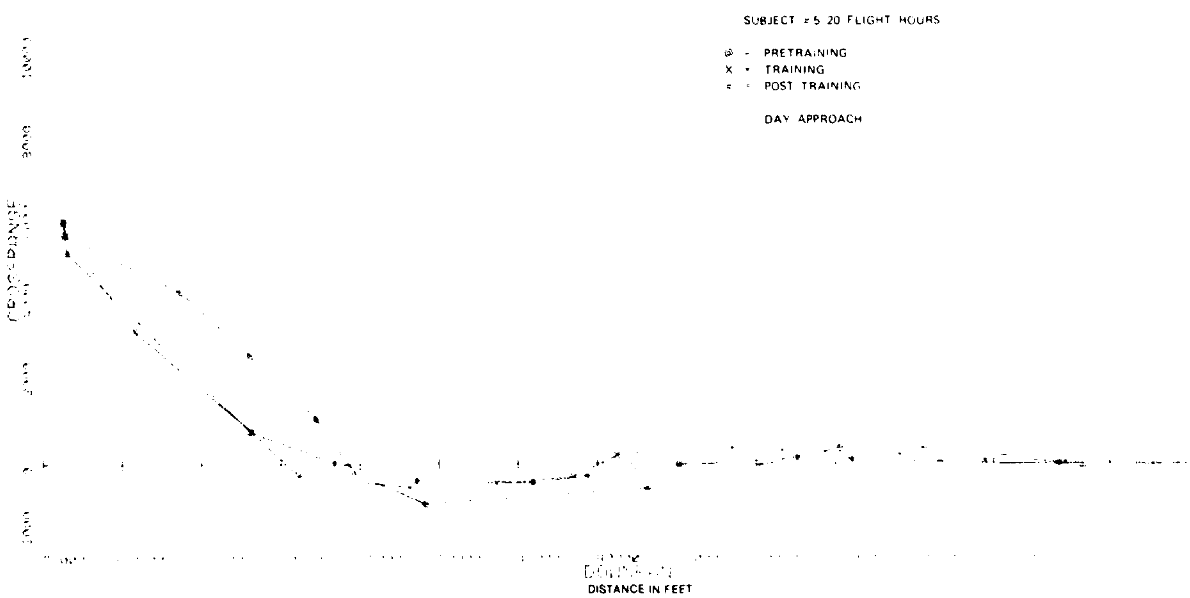

SUBJECT # 20 20 FLIGHT HOURS
• = 3 DEGREE GLIDESLOPE
@ = PRETRAINING
X = TRAINING
# = POST TRAINING
DAY APPROACH
DISTANCE IN FEET

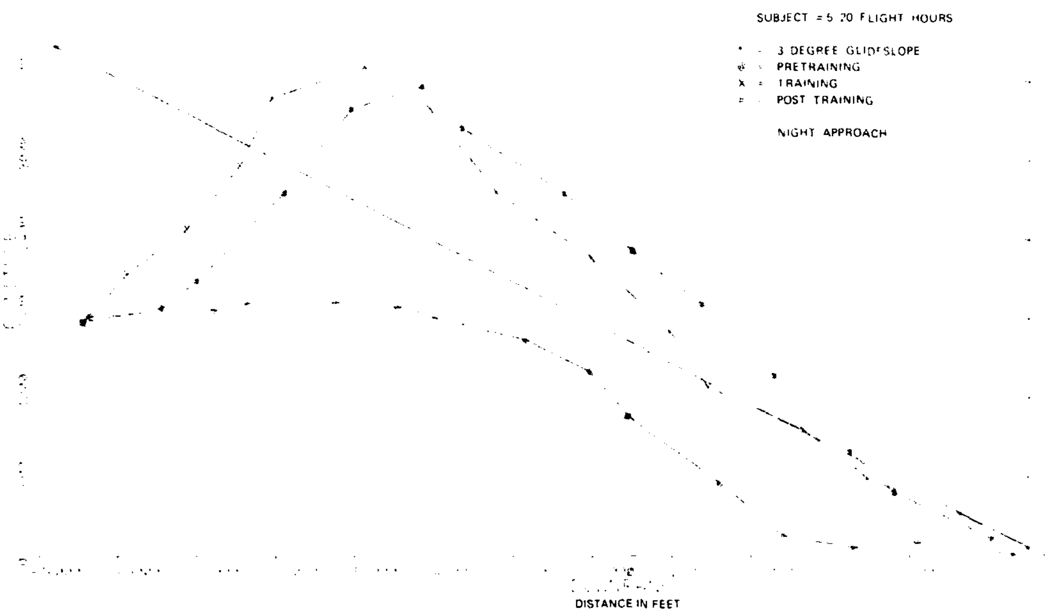

SUBJECT # 20 20 FLIGHT HOURS
@ = PRETRAINING
X = TRAINING
# = POST TRAINING
DAY APPROACH
DISTANCE IN FEET


SUBJECT = 20, 20 FLIGHT HOURS
3 DEGREE GLIDESLOPE
PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET


SUBJECT = 20, 20 FLIGHT HOURS
PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET


SUBJECT =5 20 FLIGHT HOURS
3 DEGREE GLIDESLOPE
PRETRAINING
X - TRAINING
POST TRAINING
DAY APPROACH
ALTITUDE
DISTANCE IN FEET


SUBJECT =5 20 FLIGHT HOURS
@ - PRETRAINING
X - TRAINING
POST TRAINING
DAY APPROACH
DISTANCE IN FEET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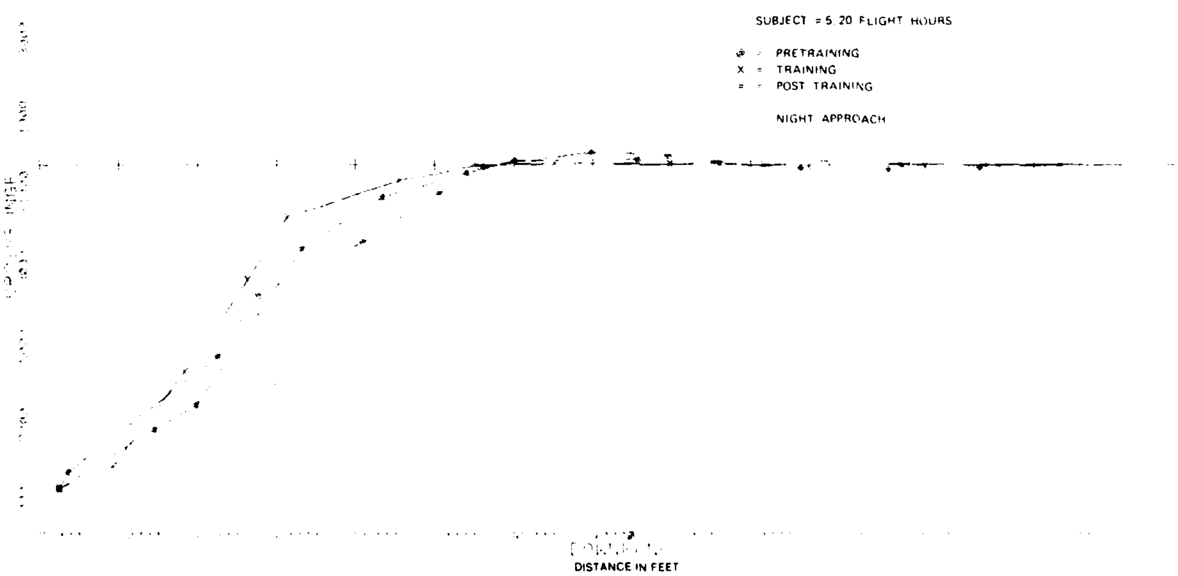
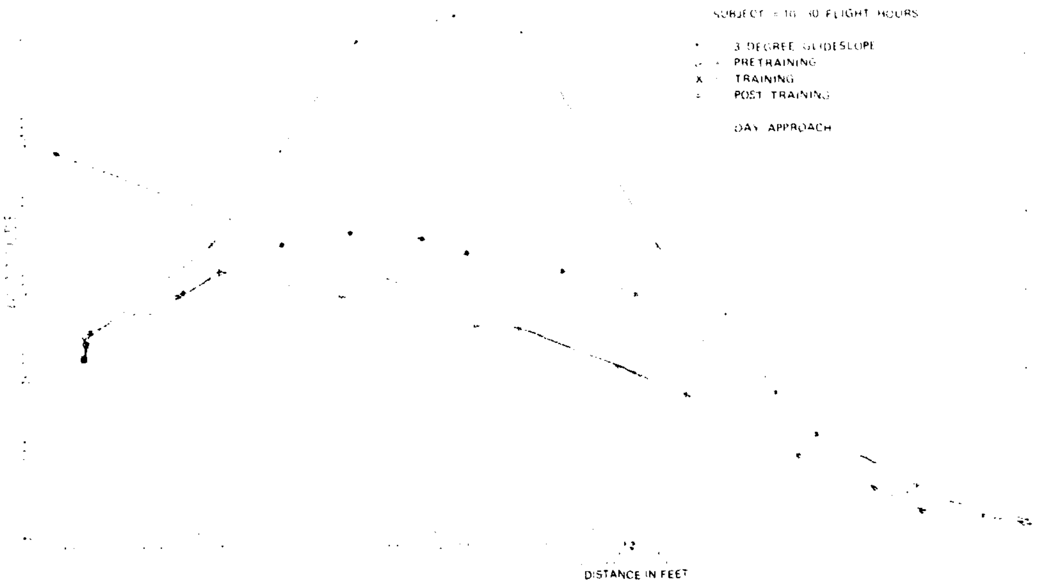
3 DEGREE GLIDESLOPE
PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET


SUBJECT = 5 20 FLIGHT HOURS
PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET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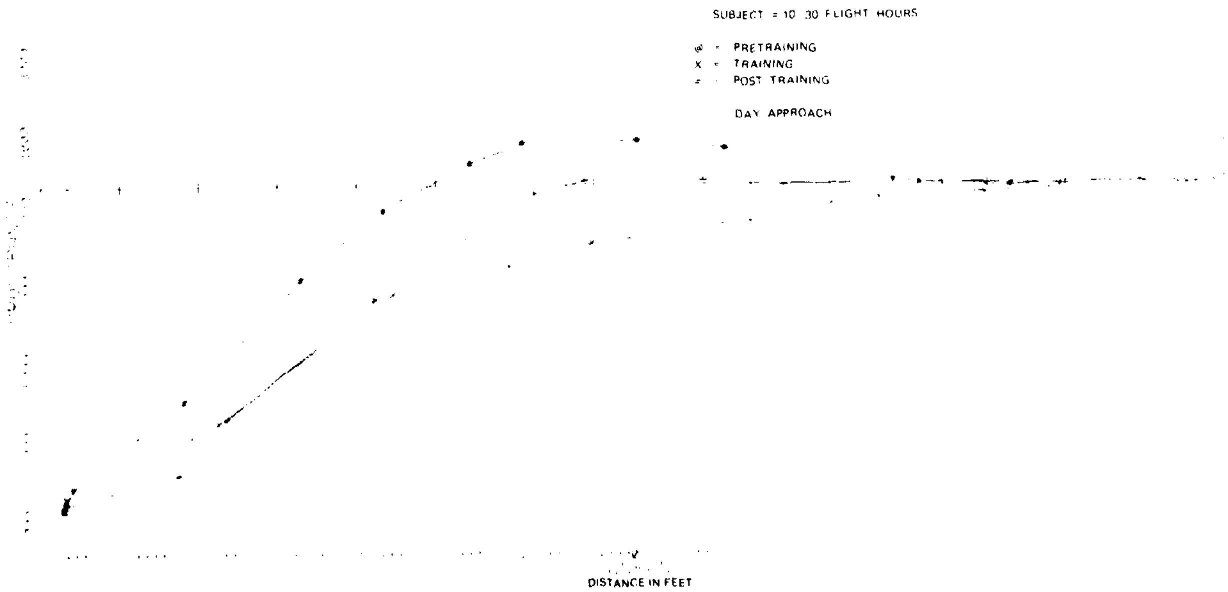
3 DEGREE GLIDESLOPE
PRETRAINING
X = TRAINING
POST TRAINING
DAY APPROACH
DISTANCE IN FEET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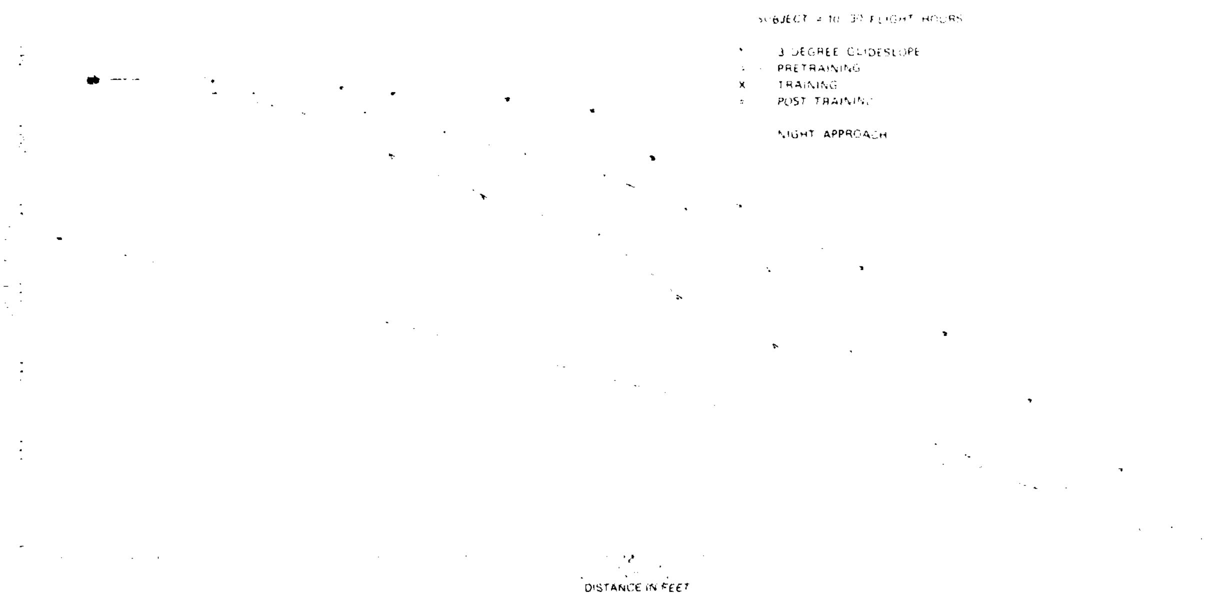
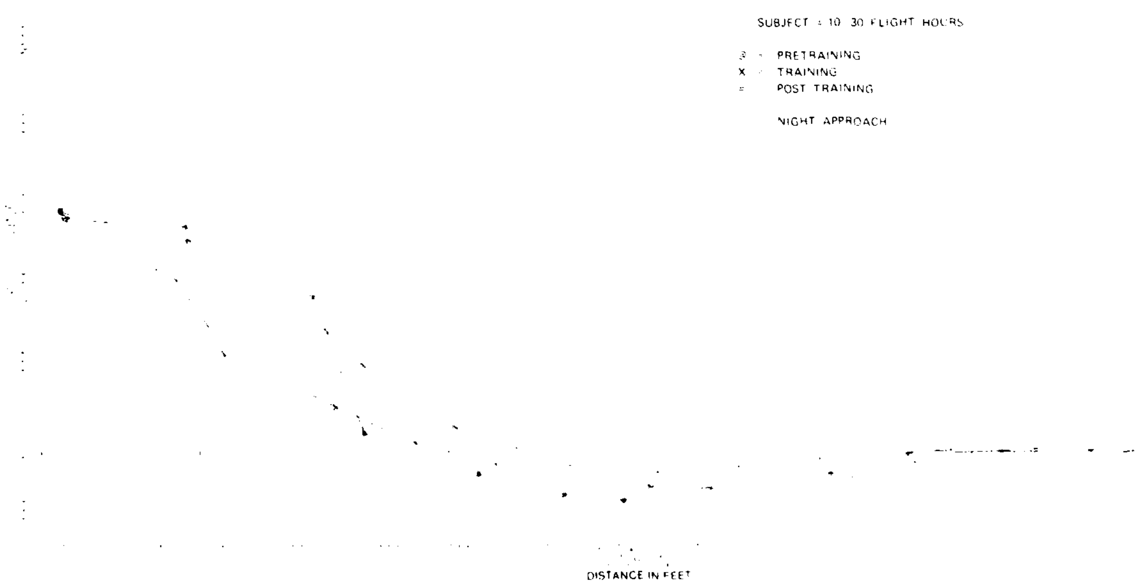
PRETRAINING
X = TRAINING
POST TRAINING
DAY APPROACH
DISTANCE IN FEET


3 DEGREE GLIDESLOPE
PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET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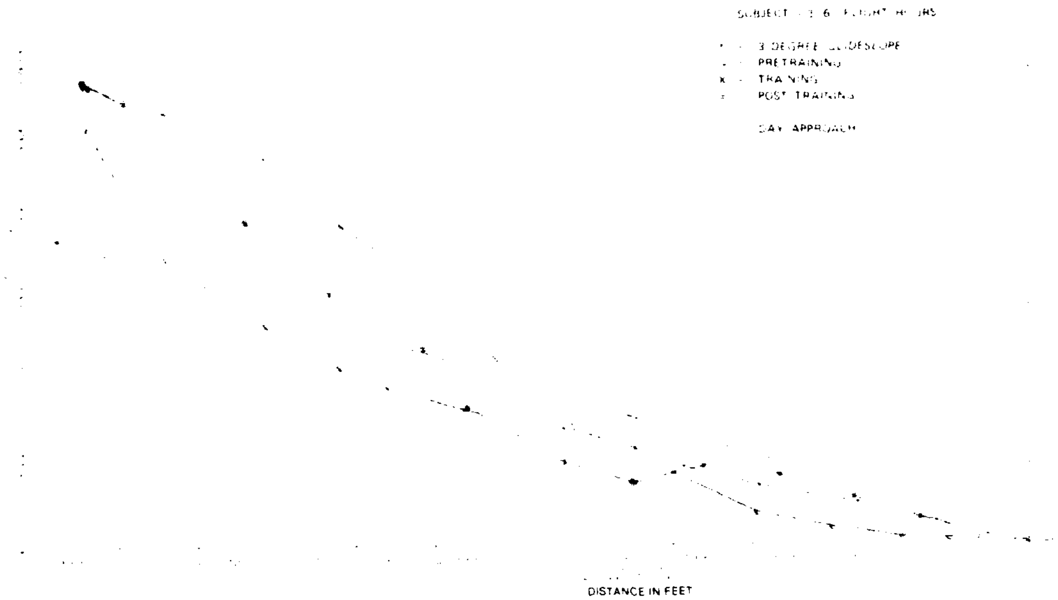
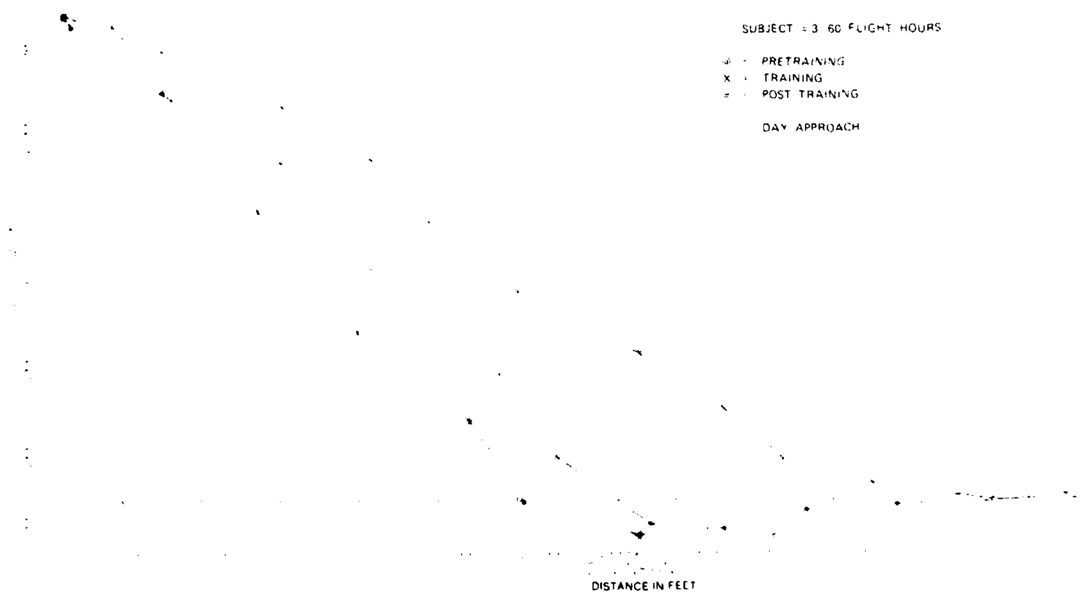
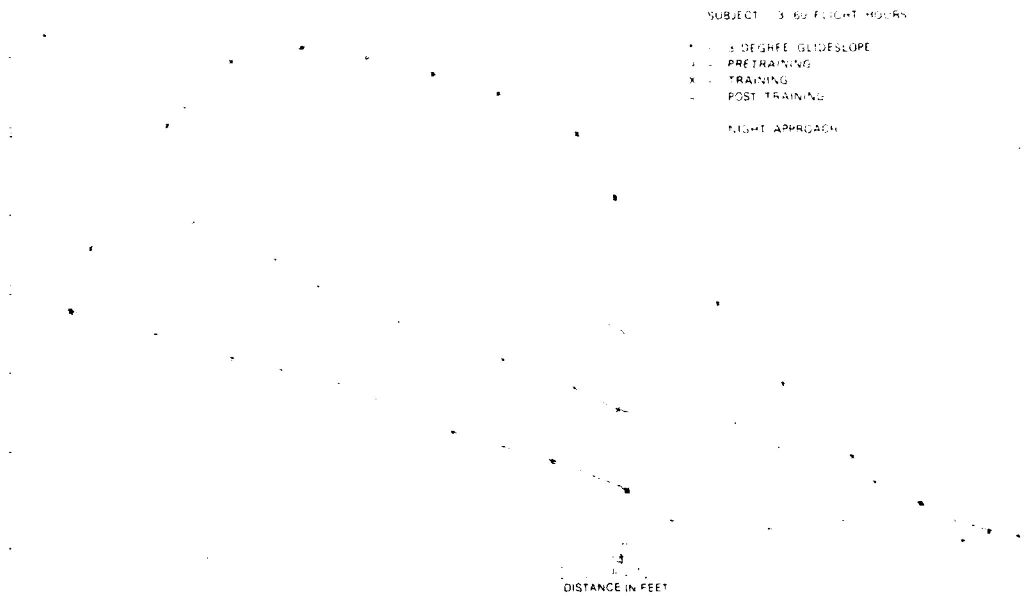
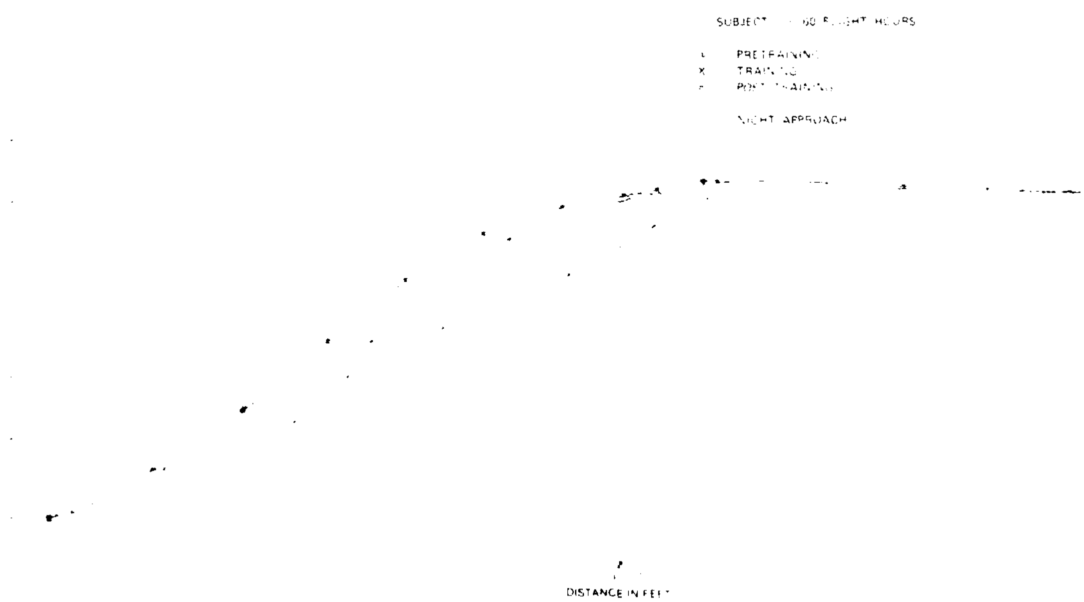
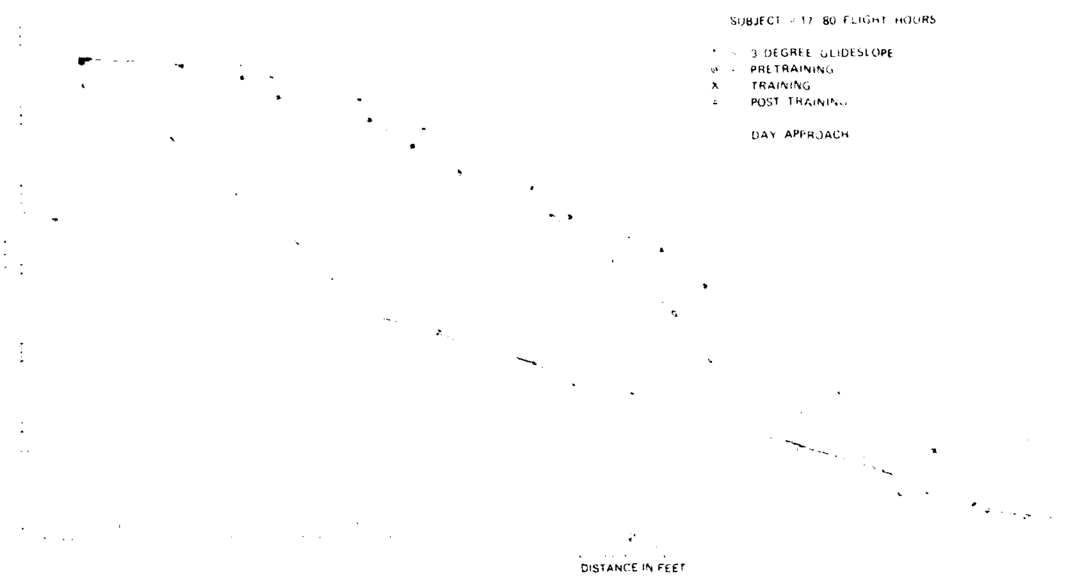
PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET

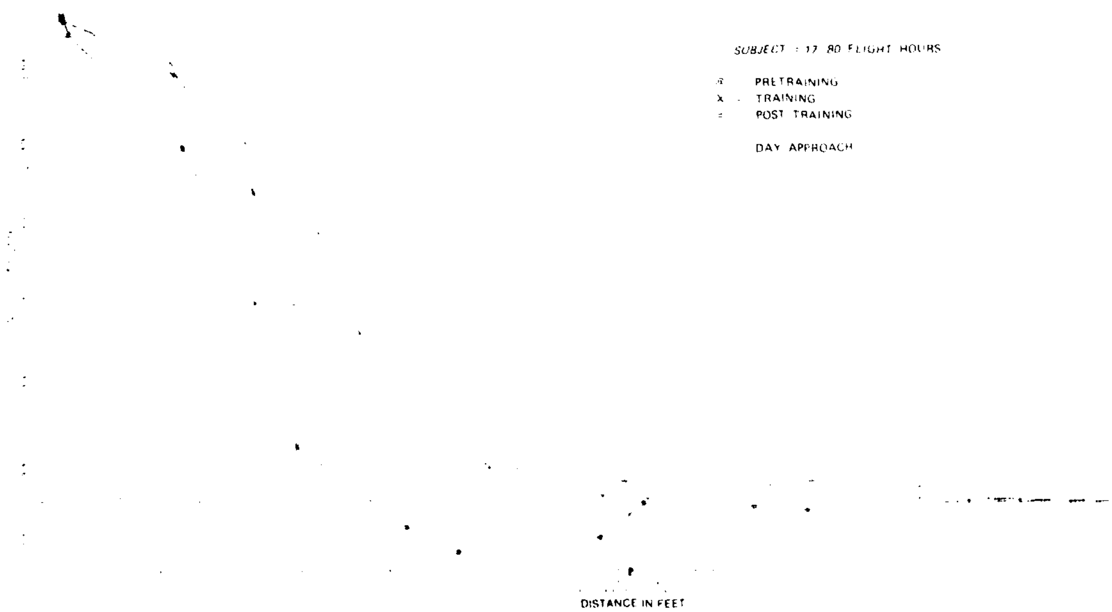

PRETRAINING
DISTANCE IN FEET


SUBJECT #3 60 FLIGHT HOURS
PRETRAINING
TRAINING
POST TRAINING
DAY APPROACH
DISTANCE IN FEET

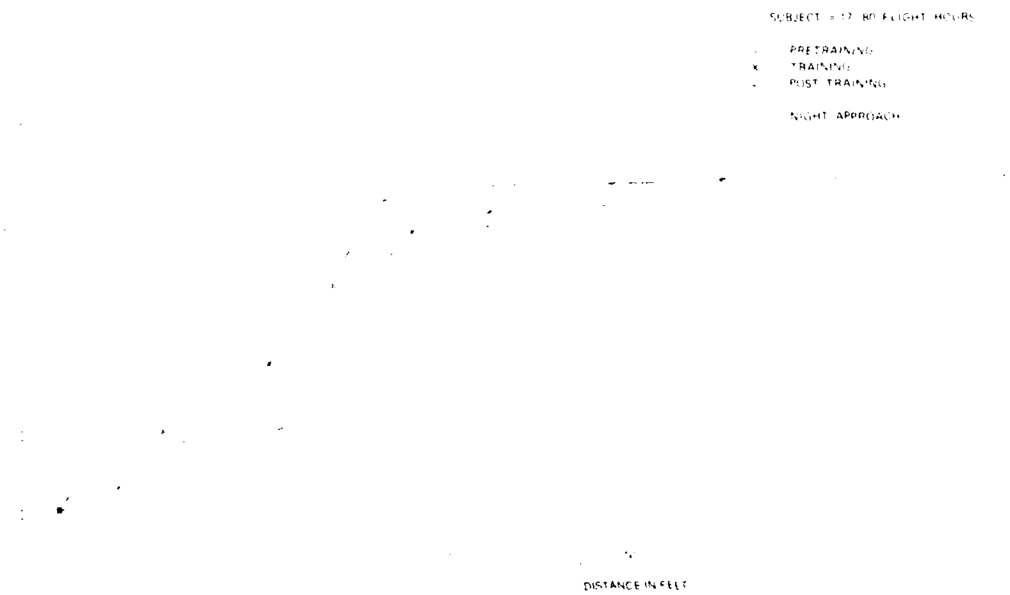

SUBJECT 3 60 FLIGHT HOURS
3 DEGREE GLIDESLOPE
PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET

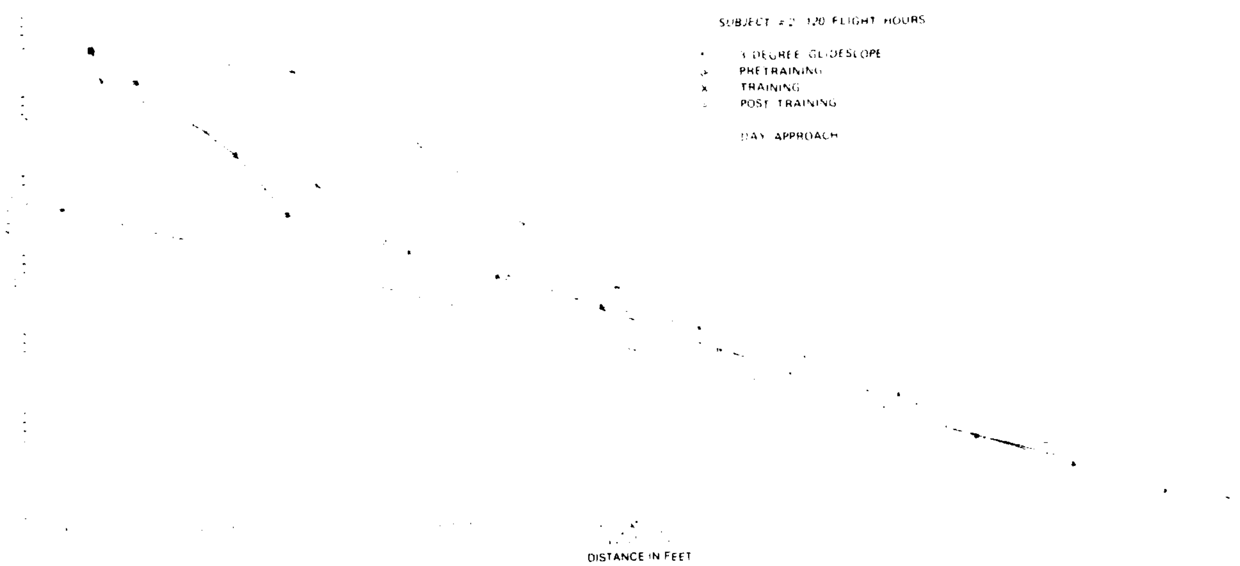

SUBJECT 60 FLIGHT HOURS
PRETRAINING
NIGHT APPROACH
DISTANCE IN FEET


SUBJECT = 17 80 FLIGHT HOURS
* - 3 DEGREE GLIDESLOPE
ø - PRETRAINING
X - TRAINING
= POST TRAINING
DAY APPROACH
DISTANCE IN FEET


SUBJECT = 17 80 FLIGHT HOURS
ø PRETRAINING
X - TRAINING
= POST TRAINING
DAY APPROACH
DISTANCE IN FEET


PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET


PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET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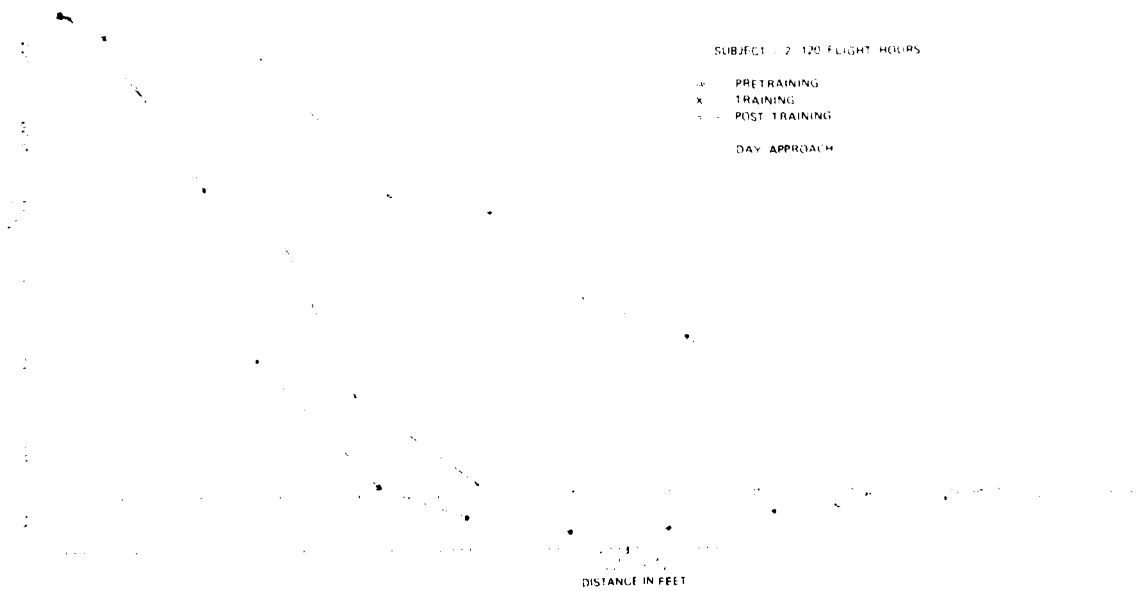
3 DEGREE GLIDESLOPE
PRETRAINING
TRAINING
POST TRAINING
DAY APPROACH
DISTANCE IN FEET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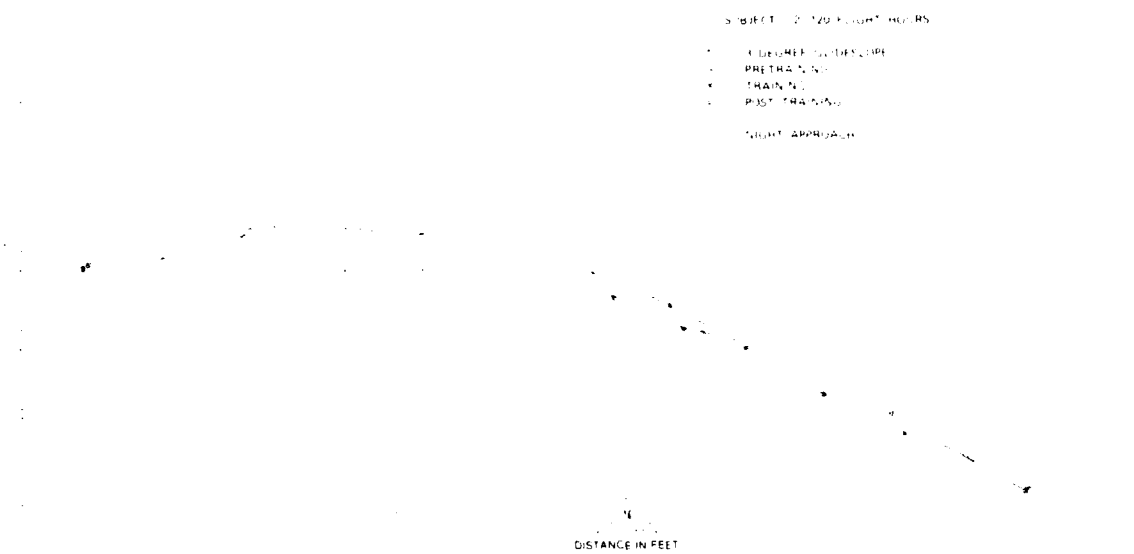
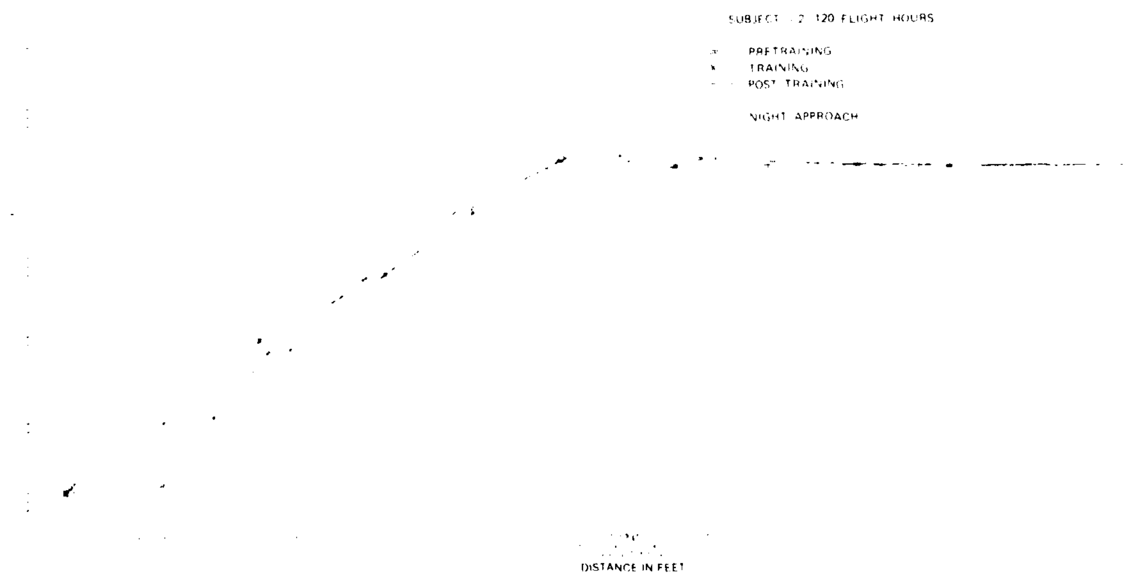
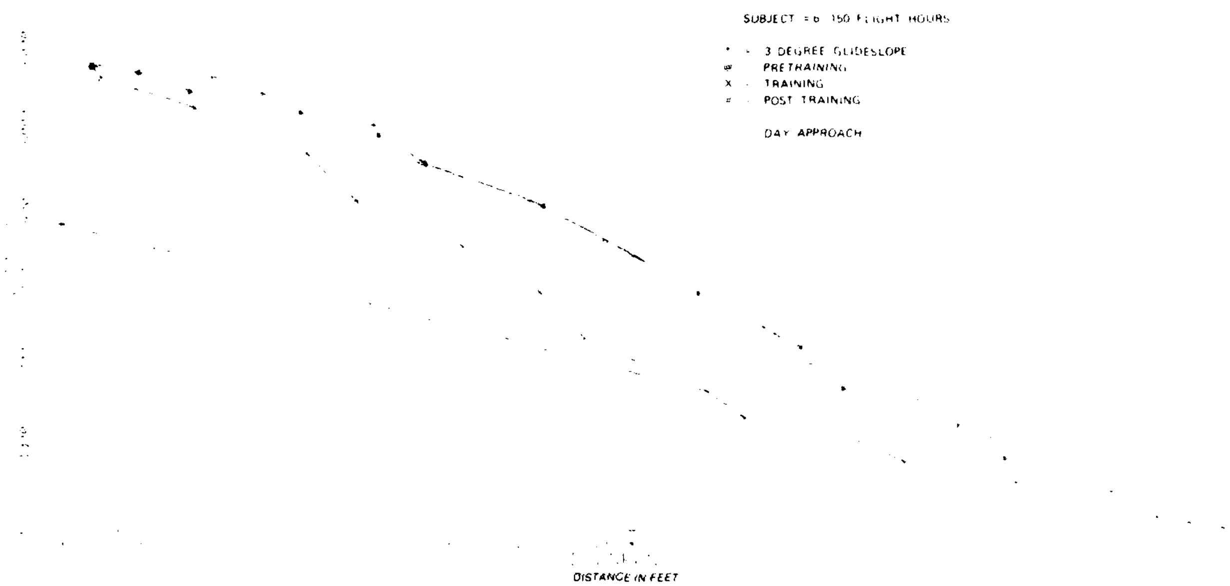
PRETRAINING
TRAINING
POST TRAINING
DAY APPROACH
DISTANCE IN FEET


DISTANCE IN FEET


SUBJECT 2 120 FLIGHT HOURS
PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET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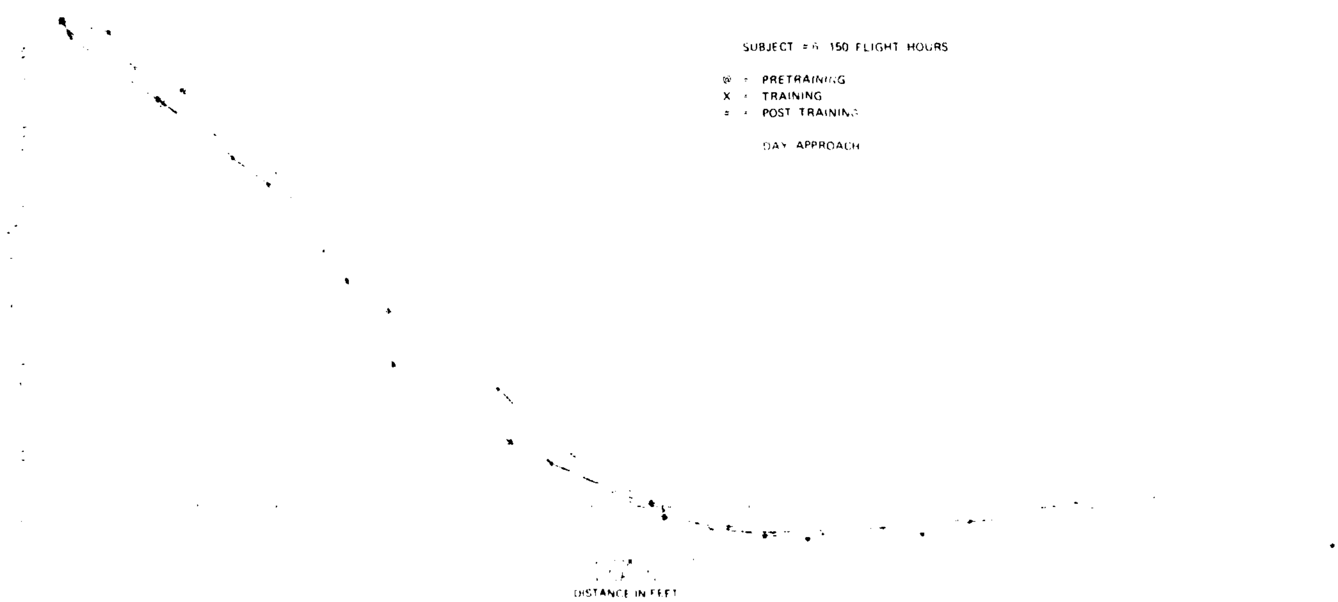
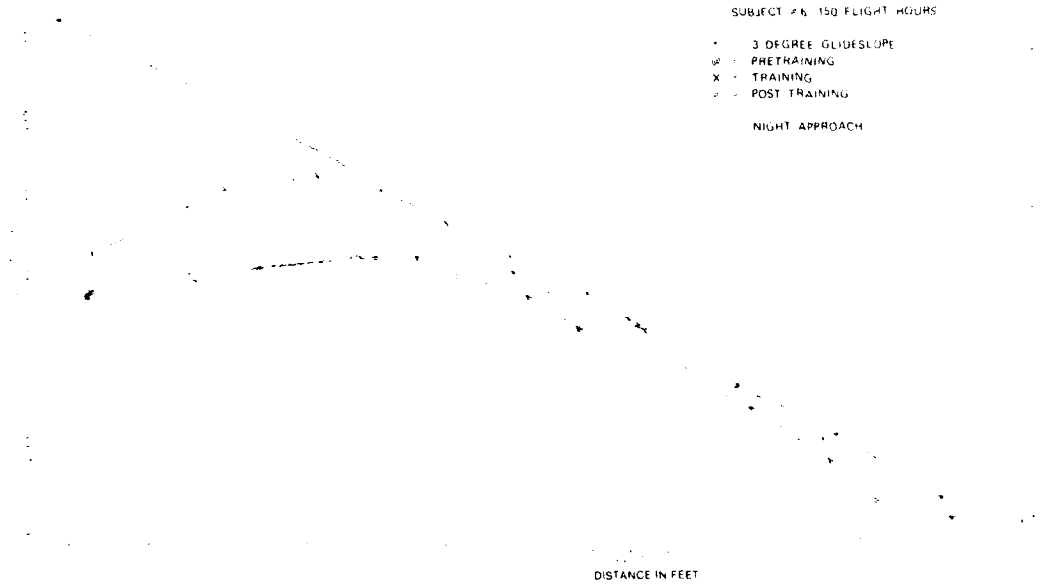
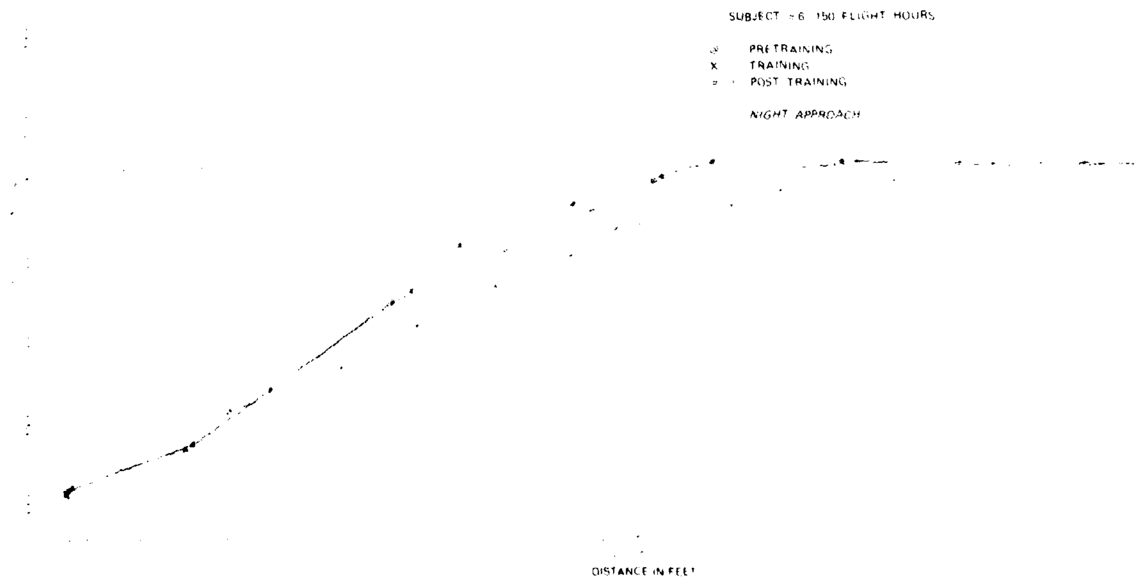
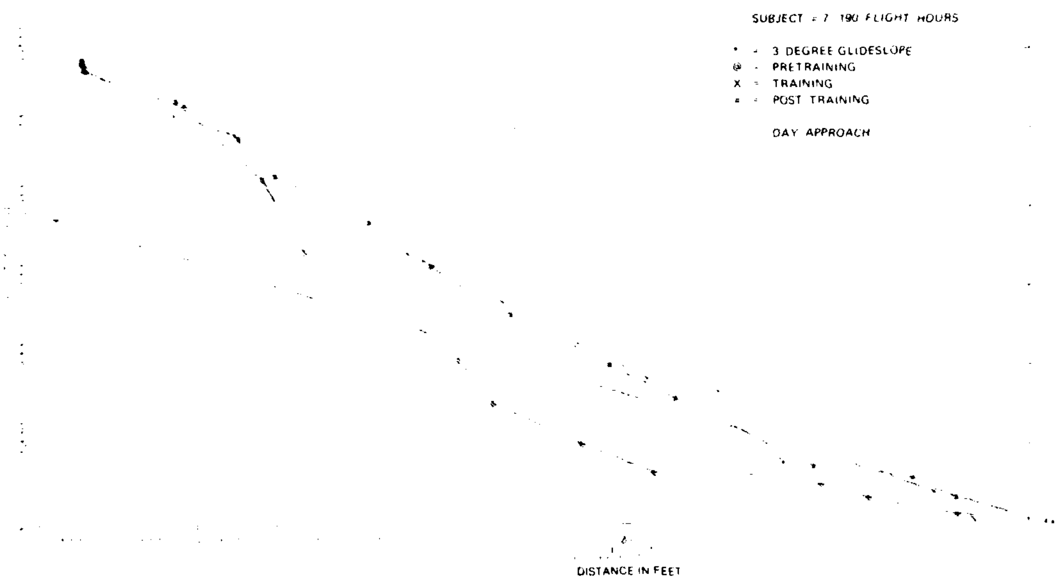
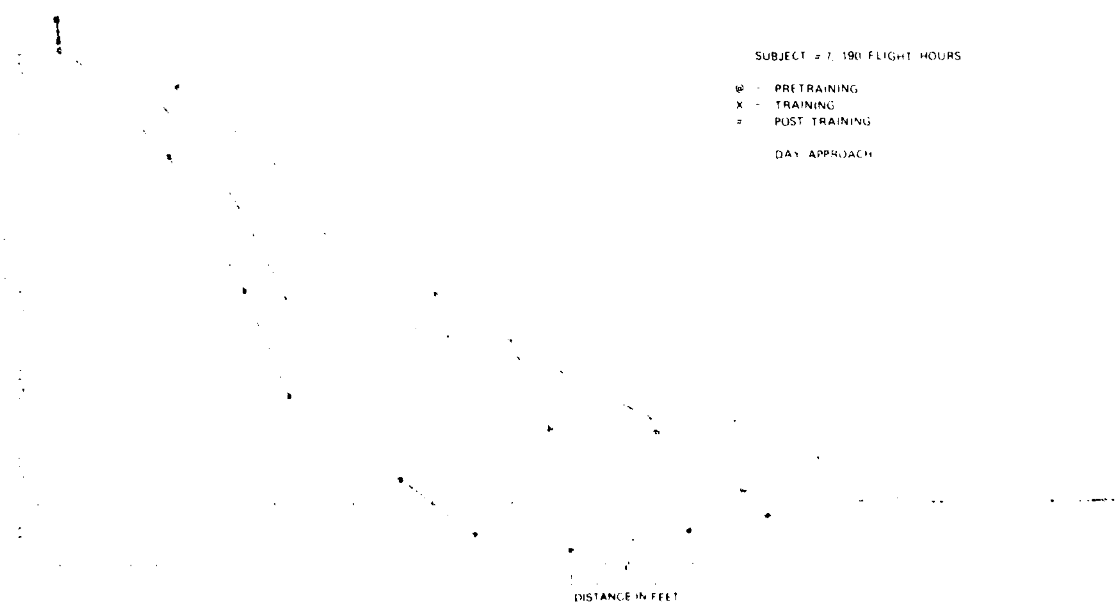
* = 3 DEGREE GLIDESLOPE
@ = PRETRAINING
X = TRAINING
# = POST TRAINING
DAY APPROACH
DISTANCE IN FEET

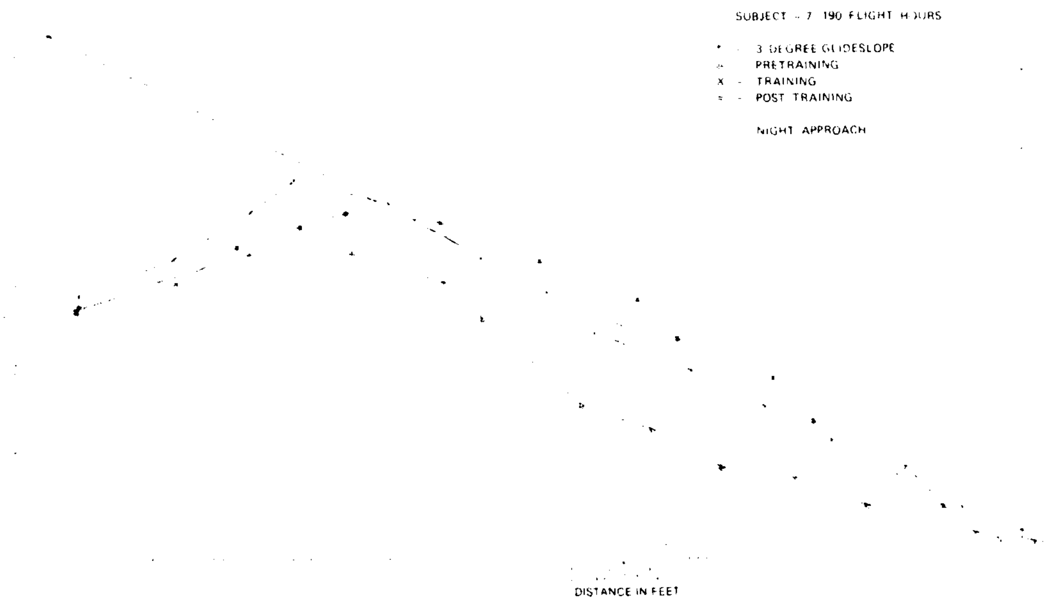

SUBJECT #6 150 FLIGHT HOURS
@ = PRETRAINING
X = TRAINING
# = POST TRAINING
DAY APPROACH
DISTANCE IN FEET

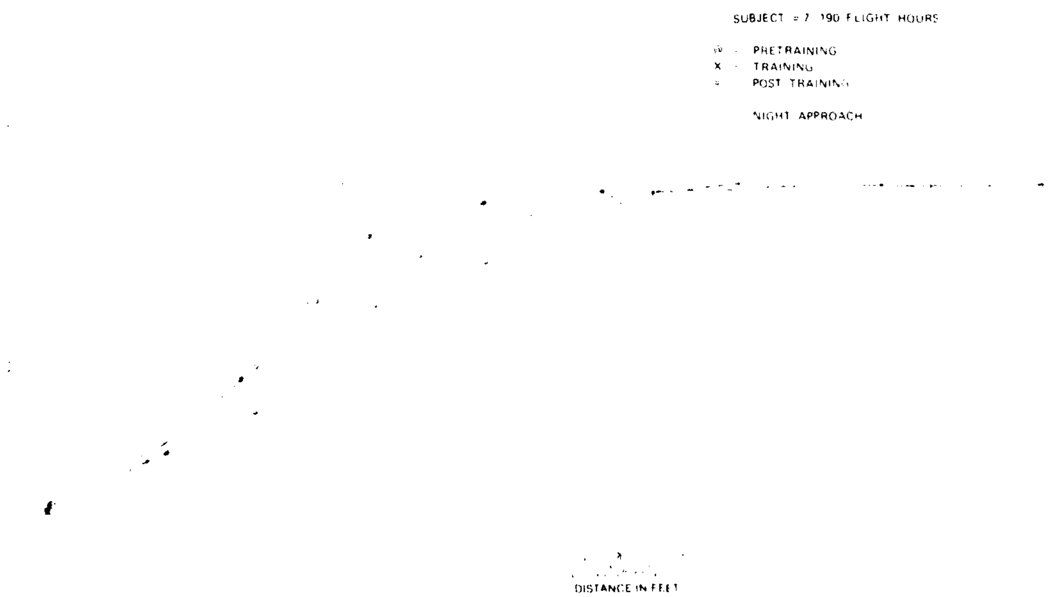

SUBJECT #6 150 FLIGHT HOURS
• 3 DEGREE GLIDESLOPE
PRETRAINING
X - TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET

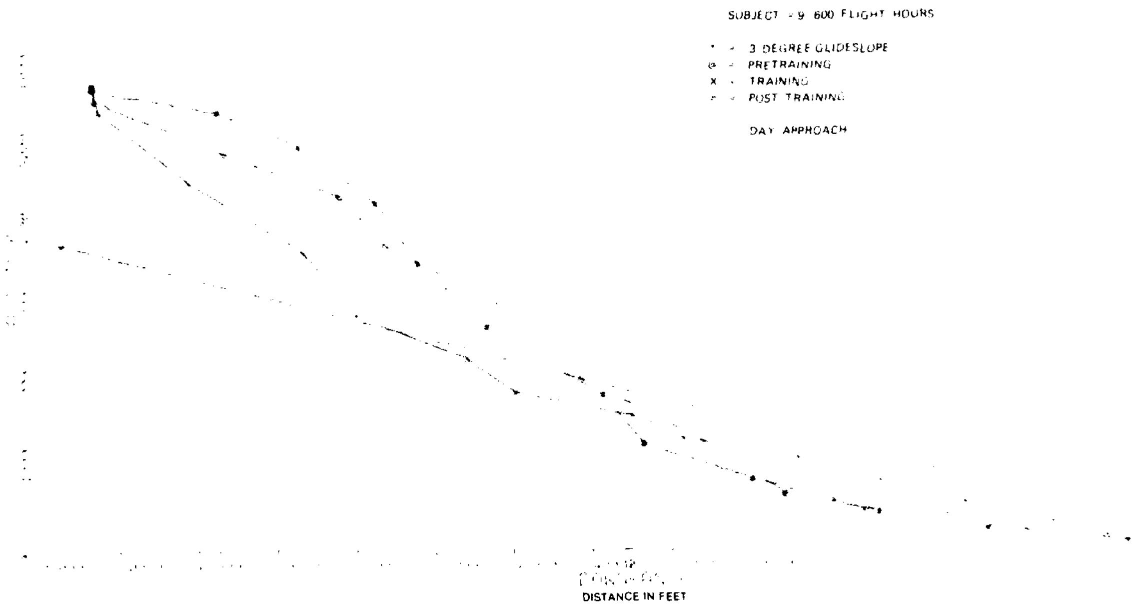

SUBJECT #6 150 FLIGHT HOURS
PRETRAINING
X TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET


SUBJECT = 7 190 FLIGHT HOURS
* - 3 DEGREE GLIDESLOPE
@ - PRETRAINING
X - TRAINING
- POST TRAINING
DAY APPROACH
DISTANCE IN FEET

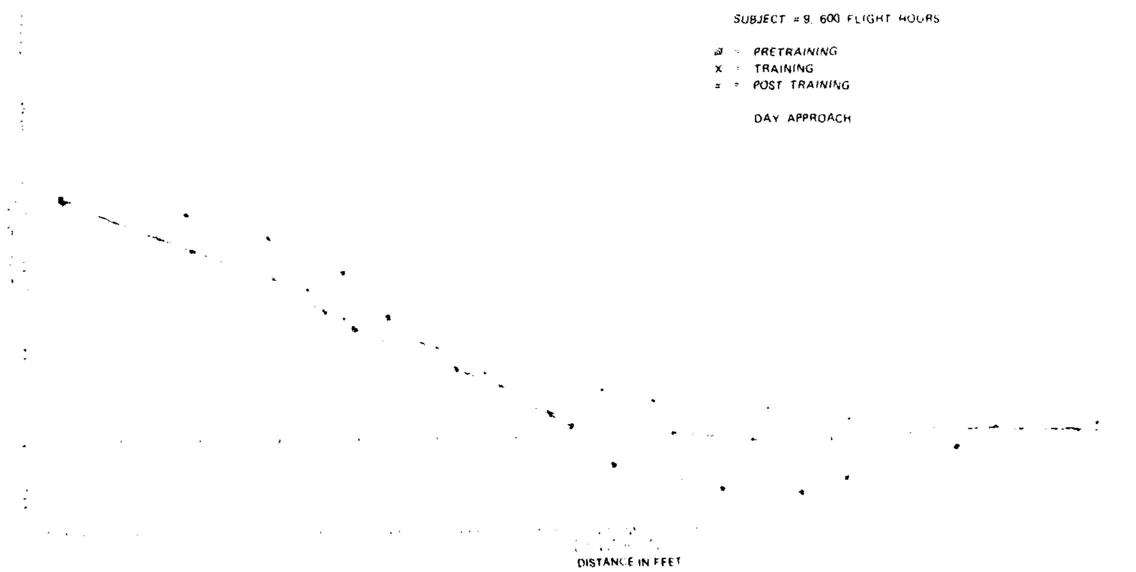

SUBJECT = 7 190 FLIGHT HOURS
@ - PRETRAINING
X - TRAINING
- POST TRAINING
DAY APPROACH
DISTANCE IN FEET


SUBJECT = 7 190 FLIGHT HOURS
* - 3 DEGREE GLIDESLOPE
- PRETRAINING
X - TRAINING
- POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET

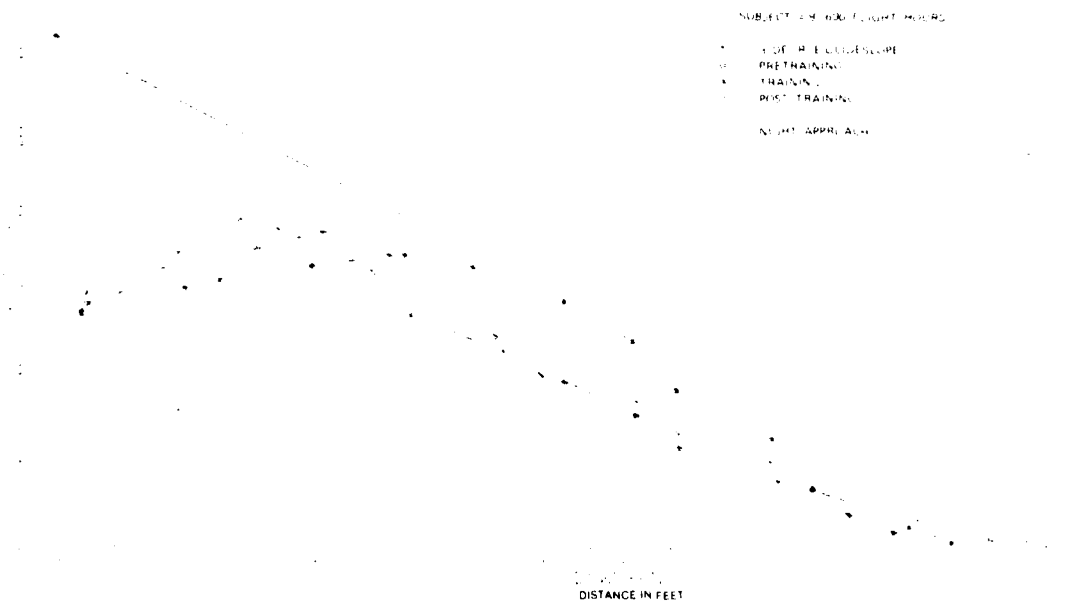

SUBJECT = 7 190 FLIGHT HOURS
- PRETRAINING
X - TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET

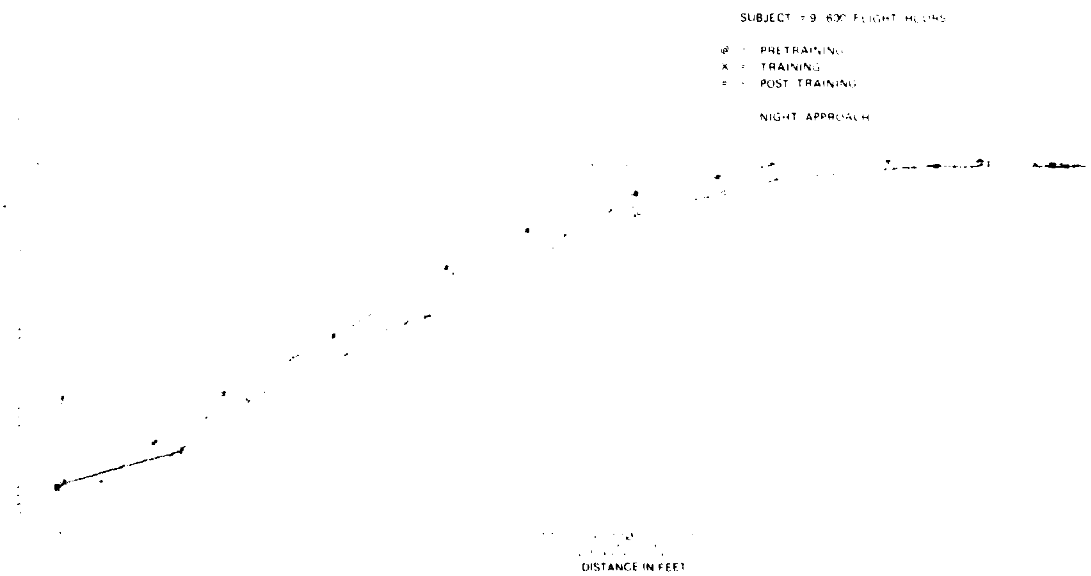


SUBJECT #9 600 FLIGHT HOURS
3 DEGREE GLIDESLOPE
PRETRAINING
TRAINING
POST TRAINING
DAY APPROACH
DISTANCE IN FEET



SUBJECT #9 600 FLIGHT HOURS
PRETRAINING
TRAINING
POST TRAINING
DAY APPROACH
DISTANCE IN FEET


PRETRAINING
POST TRAINING
DISTANCE IN FEET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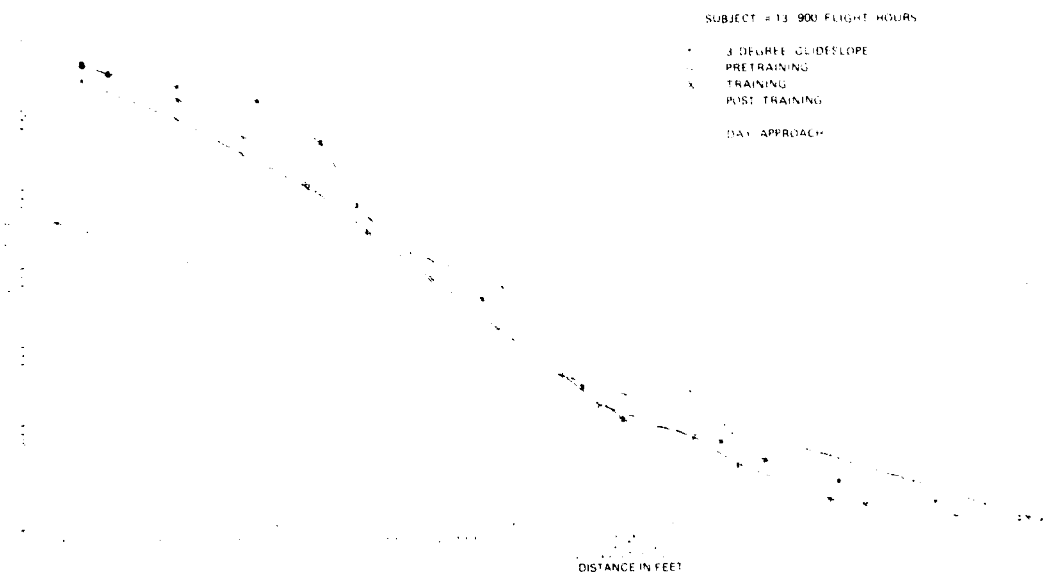
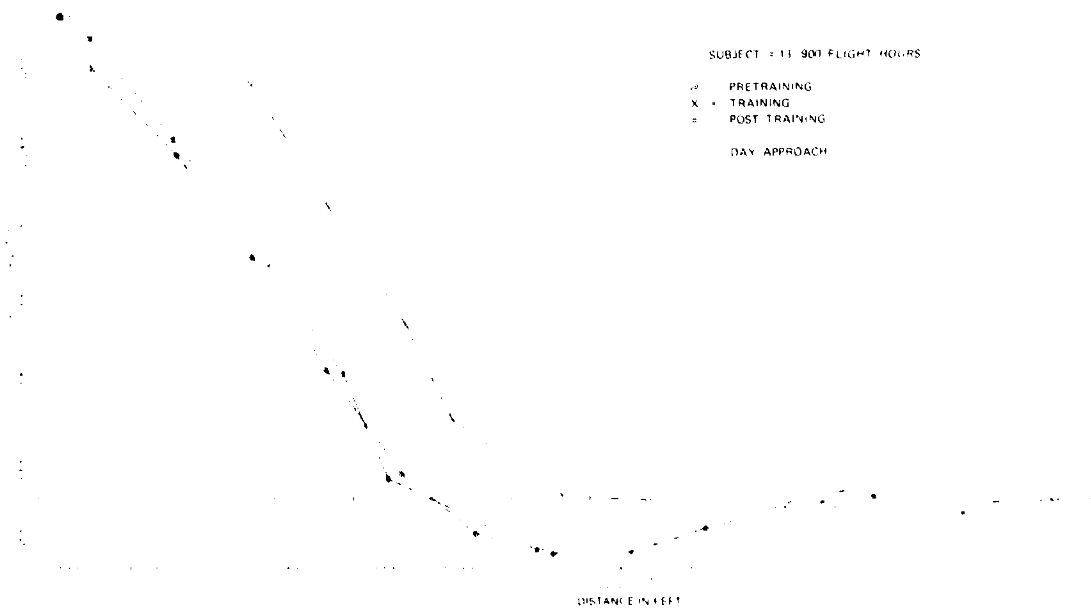
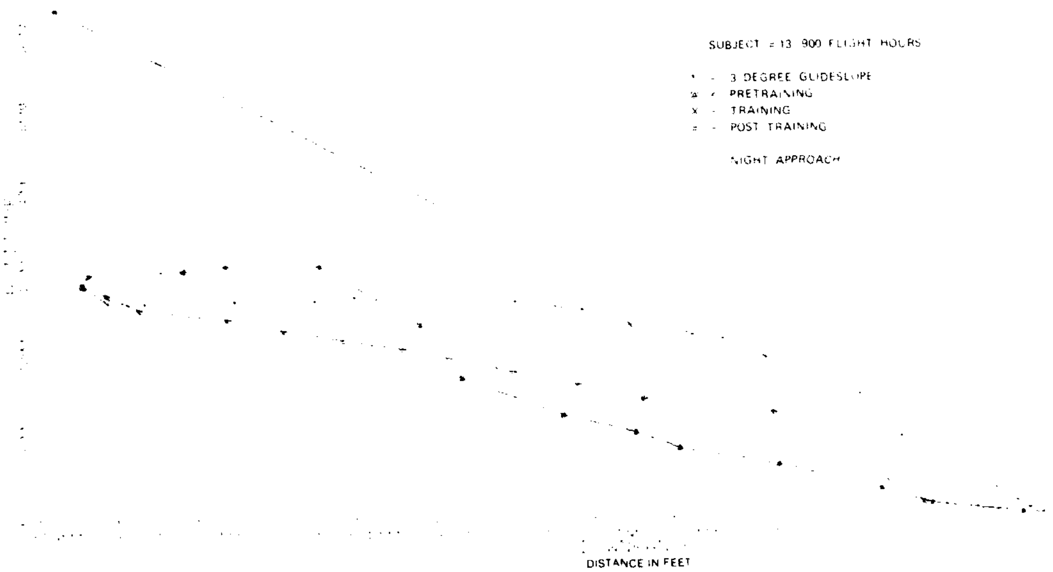
PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET


SUBJECT # 13 900 FLIGHT HOURS
3 DEGREE GLIDESLOPE
PRETRAINING
TRAINING
POST TRAINING
DAY APPROACH
DISTANCE IN FEET


SUBJECT # 13 900 FLIGHT HOURS
PRETRAINING
TRAINING
POST TRAINING
DAY APPROACH
DISTANCE IN FEET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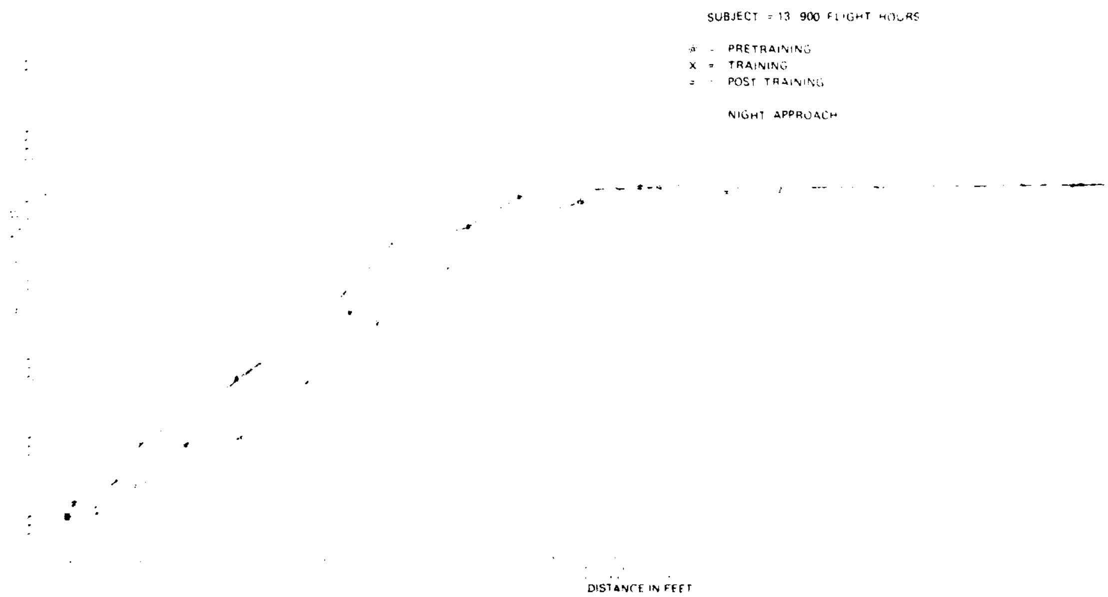
3 DEGREE GLIDESLOPE
PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET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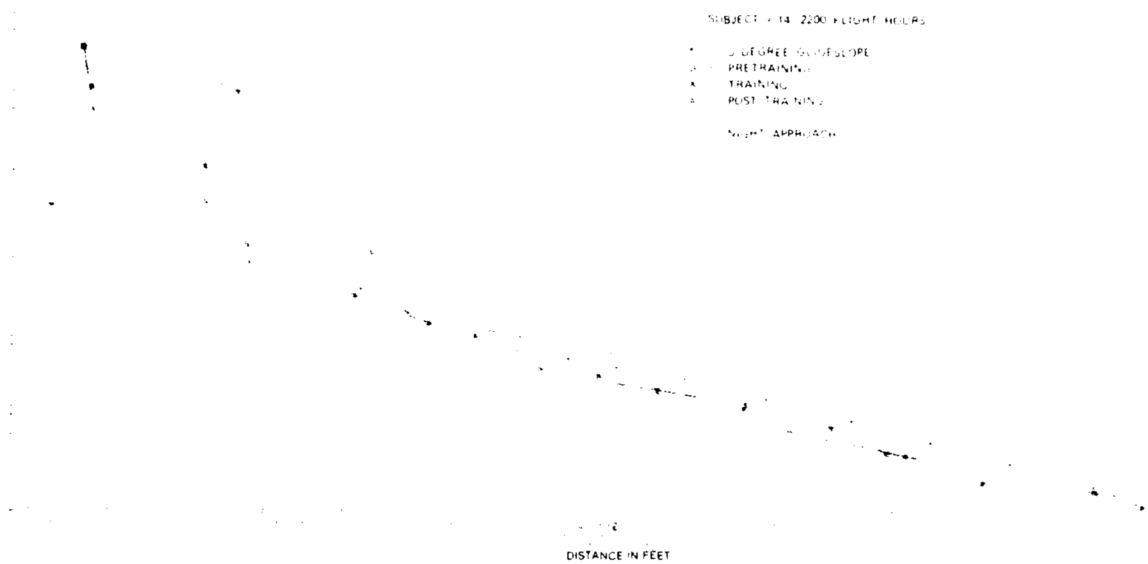
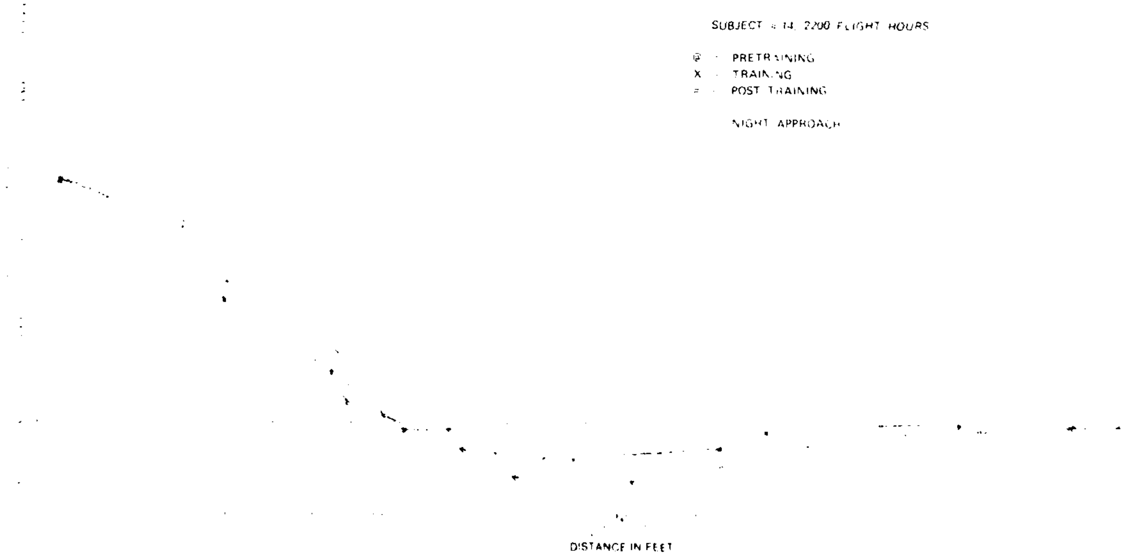
PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET


SUBJECT # 14, 2200 FLIGHT HOURS
* - 3 DEGREE GLIDESLOPE
@ - PRETRAINING
X - TRAINING
- POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET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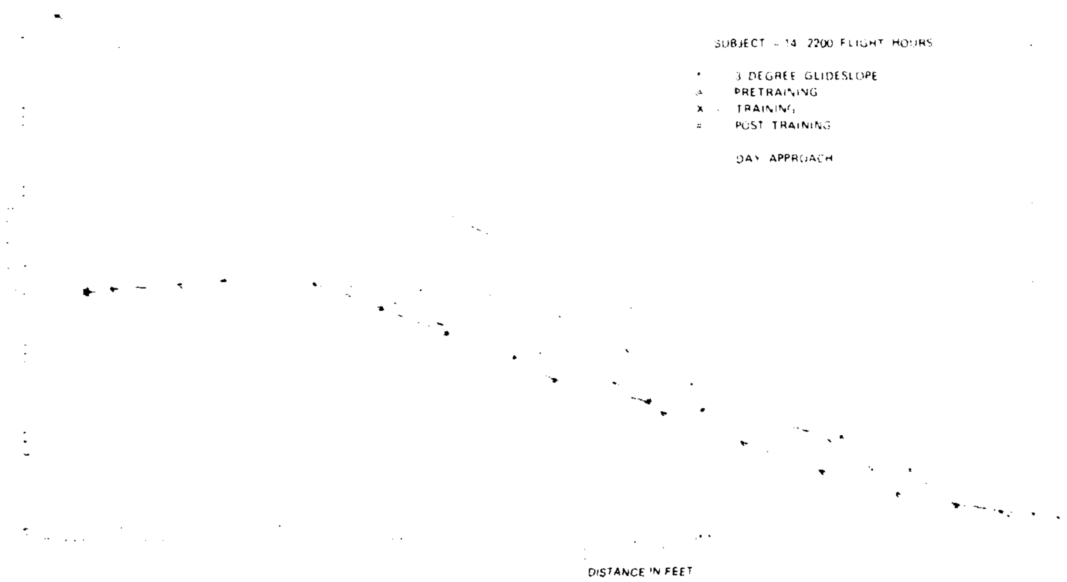
@ - PRETRAINING
X - TRAINING
- POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET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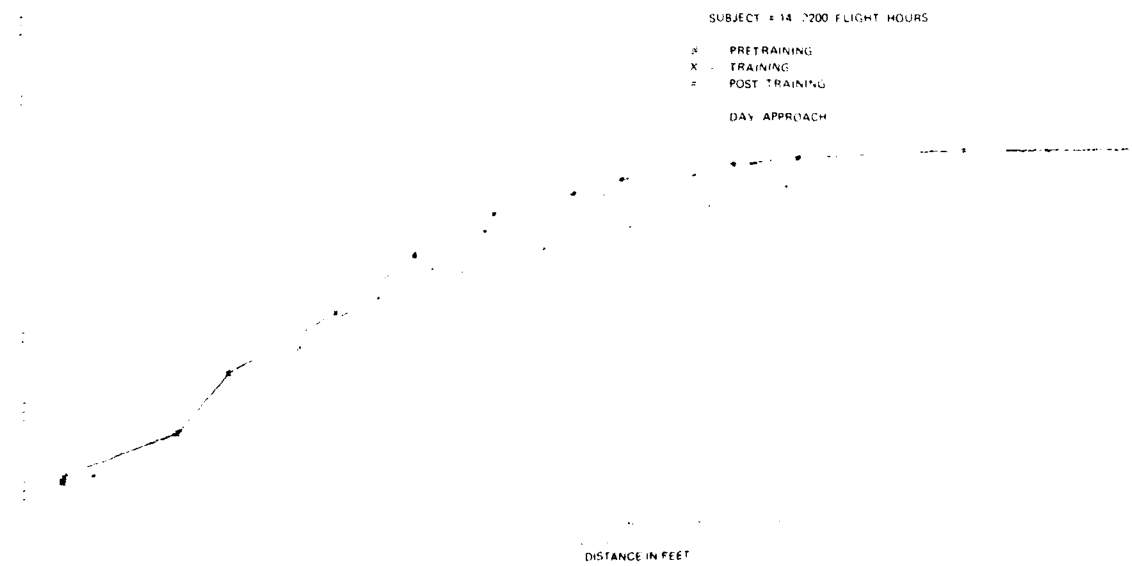
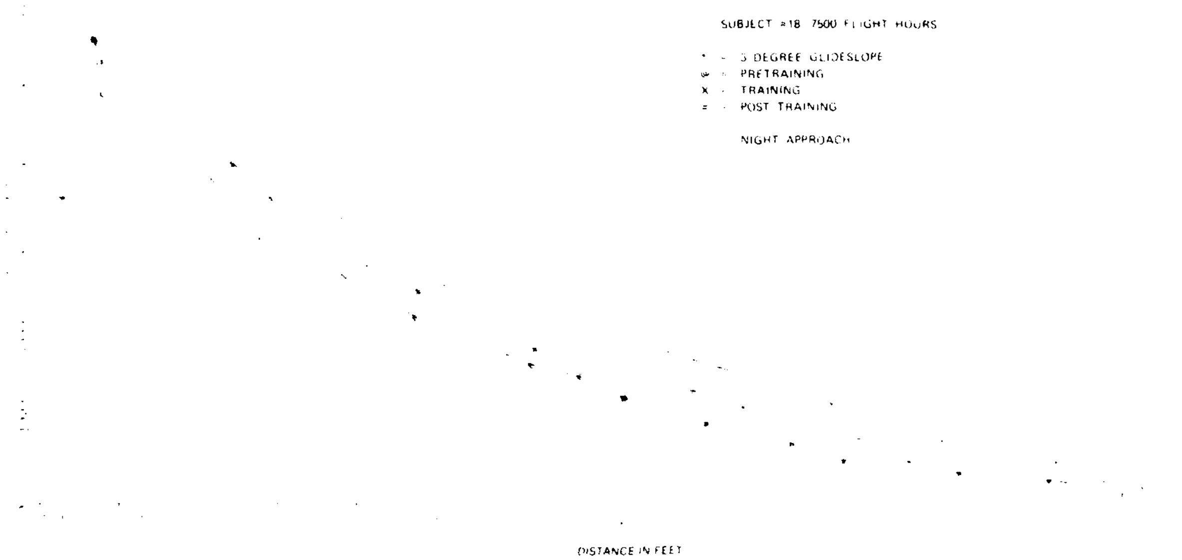
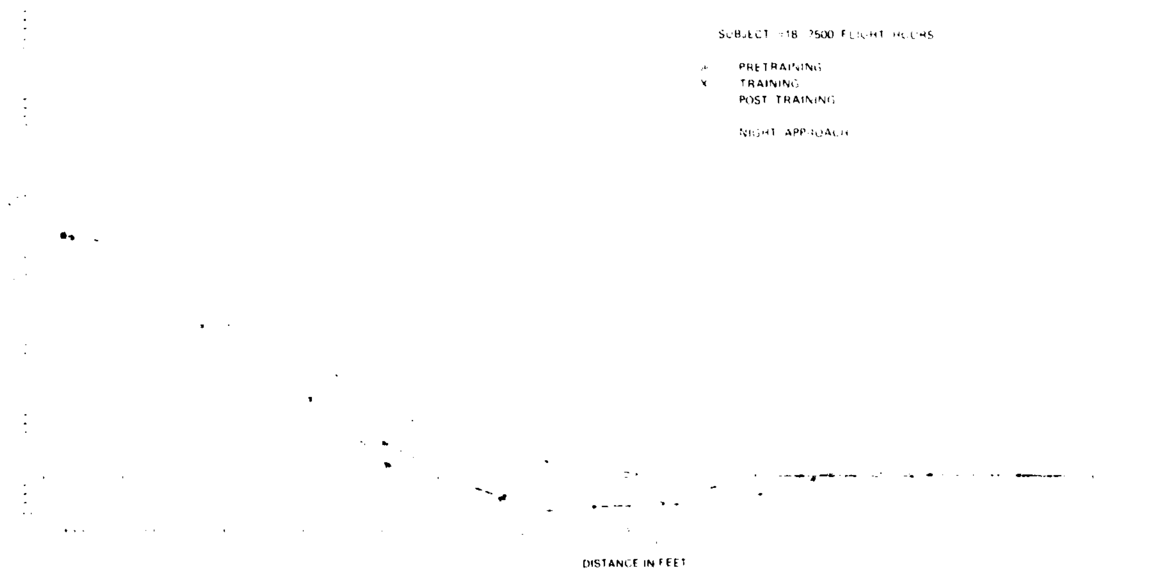
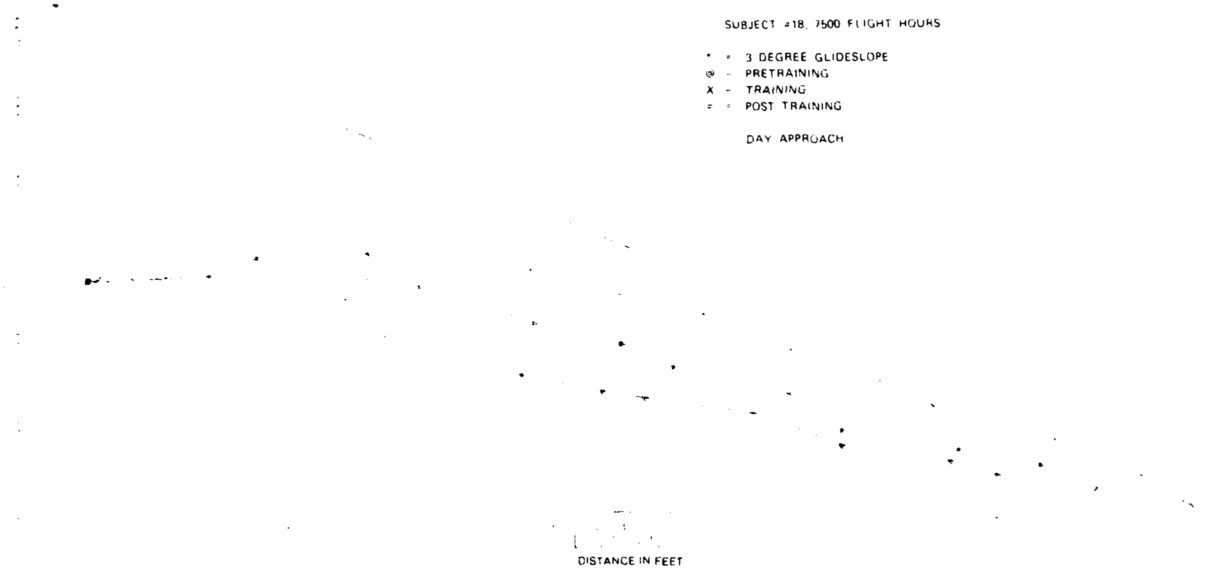
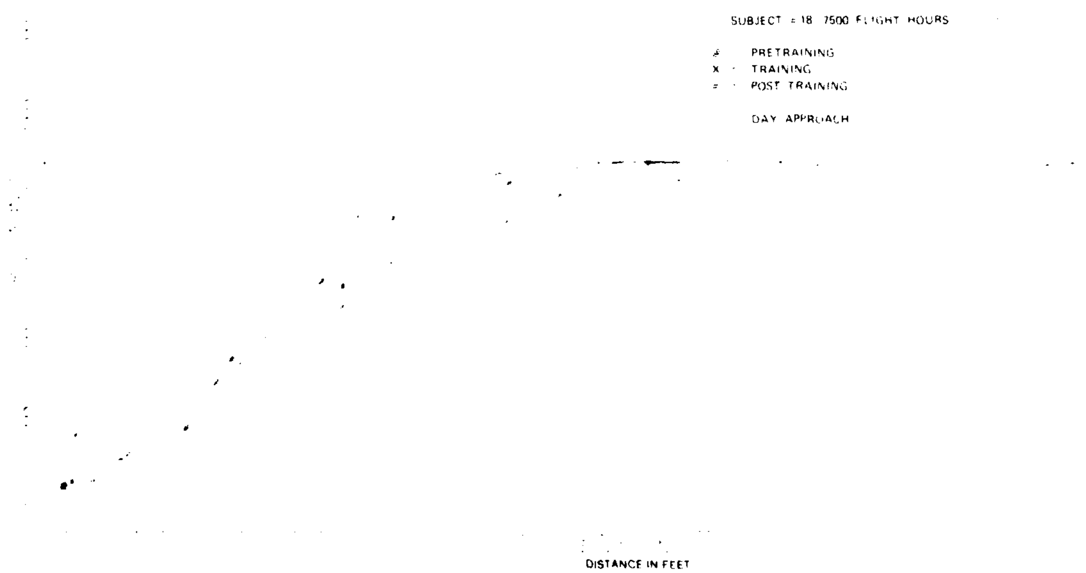
* 3 DEGREE GLIDESLOPE
* PRETRAINING
X - TRAINING
POST TRAINING
DAY APPROACH
DISTANCE IN FEET


SUBJECT # 14 2200 FLIGHT HOURS
* PRETRAINING
X - TRAINING
POST TRAINING
DAY APPROACH
DISTANCE IN FEET


SUBJECT #18 7500 FLIGHT HOURS
3 DEGREE GLIDESLOPE
PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET


SUBJECT #18 7500 FLIGHT HOURS
PRETRAINING
TRAINING
POST TRAINING
NIGHT APPROACH
DISTANCE IN FEET


SUBJECT #18, 7500 FLIGHT HOURS
* = 3 DEGREE GLIDESLOPE
@ = PRETRAINING
X = TRAINING
# = POST TRAINING
DAY APPROACH
DISTANCE IN FEET


SUBJECT #18 7500 FLIGHT HOURS
PRETRAINING
TRAINING
POST TRAINING
DAY APPROACH
DISTANCE IN FEET

APPENDIX E

AIR NATIONAL GUARD PILOT EVALUATION RESULTS

1. Did you have an opportunity to use this effect?

no (0)	a little (1)	some (2)	a lot (3)	no data (-)

MEAN ANSWER

EFFECT	TOTAL	STUDENTS	NO COMBAT INSTRUCTORS	COMBAT EXPERIENCED INSTRUCTORS
Visible Sensor Cone	1.90	2.00	2.00	1.50
Contrail path				
Ground track	1.70	1.83	2.00	1.00
Air track	1.90	1.83	2.50	1.50
Both together	1.00	1.00	1.50	0.00
Tracer Range Emphasis	1.89	2.17	1.00	2.00
Horizon Depression Cursor	1.44	1.67	0.50	2.00
Instructor Cursor	0.44	.50	.50	0.00
Immediate Scoring Feedback	1.78	2.00	1.50	1.00
Light point Enhanced Target	1.50	2.00	1.00	0.00
Multiple Viewpoints	1.22	1.33	0.5	2.00

2. Did you find this effect helpful?

no	a little	some	a lot	no data
(0)	(1)	(2)	(3)	(-)

MEAN ANSWER

EFFECT	TOTAL	STUDENTS	NO COMBAT INSTRUCTORS	COMBAT EXPERIENCED INSTRUCTORS
Visible Sensor Cone	1.36	1.43	0.00	2.50
Contrail path				
Ground track	1.55	2.00	0.00	2.00
Air track	1.63	1.71	1.50	1.5
Both together	1.00	1.20	0.50	-
Tracer Range				
Emphasis	1.11	1.29	0.00	1.00
Horizon Depression				
Cursor	1.44	1.42	0.00	3.00
Instructor Cursor				
Immediate Scoring				
Feedback	1.89	2.00	1.50	2.00
Light point				
Enhanced Target	2.40	2.25	3.00	-
Multiple Viewpoints	1.71	1.40	3.00	2.00

3. Could this effect be made more useful?

no (0)	a little (1)	some (2)	a lot (3)	no data (-)

MEAN ANSWER

EFFECT	TOTAL	STUDENTS	NO COMBAT INSTRUCTORS	COMBAT EXPERIENCED INSTRUCTORS
Visible Sensor Cone	1.83	1.33	2.0	3.0
Contrail path				
Ground track	1.00	0.75	1.50	-
Air track	1.00	0.75	1.50	-
Both together	1.20	1.00	1.50	-
Tracer Range Emphasis	1.00	0.67	0.00	3.00
Horizon Depression Cursor	0.00	0.00	0.00	-
Instructor Cursor	0.00	0.00	0.00	-
Immediate Scoring Feedback	1.11	0.75	2.00	3.00
Light point Enhanced Target	1.25	0.66	3.00	-
Multiple Viewpoints	0.00	0.00	0.00	-

4. What applications would be appropriate for this effect? Explain.

Effect	Answer
Visible Sensor Cone	________________
Contrail path	
Ground track	________________
Air track	________________
Both together	________________
	(Since these were essay type answers
Tracer Range	they could not be averaged, but the
	responses are discussed in the text.)
Emphasis	________________
Horizon Depression	
Cursor	________________
Instructor Cursor	________________
Immediate Scoring	
Feedback	________________
Light point	
Enhanced Target	________________
Multiple Viewpoints	________________

5. Would (or did) this effect affect your learning speed?

Much Slower (-2)	Slower (-1)	Neutral (0)	Faster (1)	Much Faster (2)	No Data (-)

MEAN ANSWER

EFFECT	TOTAL	STUDENTS	NO COMBAT INSTRUCTORS	COMBAT EXPERIENCED INSTRUCTORS
Visible Sensor Cone	0.86	0.86	0.00	2.00
Contrail path				
Ground track	1.00	1.20	0.0	-
Air track	1.17	1.00	2.0	-
Both together	0.83	1.00	0.00	1.00
Tracer Range Emphasis	-0.17	-0.25	-1.00	1.00
Horizon Depression Cursor	0.67	0.75	0.00	1.00
Instructor Cursor	1.50	1.00	2.00	2.00
Immediate Scoring Feedback	1.28	1.20	2.00	1.00
Light point Enhanced Target	1.20	1.00	2.00	-
Multiple Viewpoints	1.00	0.75	1.00	2.00

6. Would or did use of this effect affect your performance?

Worse (-1.5)	Not at all (0)	Better (1)	Much Better (2)	No Data (-)

MEAN ANSWER

EFFECT	TOTAL	STUDENTS	NO COMBAT INSTRUCTORS	COMBAT EXPERIENCED INSTRUCTORS
Visible Sensor Cone	0.43	0.60	0.00	-
Contrail path				
Ground track	0.57	0.80	0.00	-
Air track	0.85	1.00	0.50	-
Both together	0.67	1.00	0.00	-
Tracer Range Emphasis	-0.07	-0.08	0.00	-
Horizon Depression Cursor	0.21	0.50	-1.50	-
Instructor Cursor	0.75	0.67	1.00	-
Immediate Scoring Feedback	1.29	1.33	1.00	-
Light point Enhanced Target	0.80	0.75	1.00	-
Multiple Viewpoints	0.80	0.75	1.00	-

7. Did or would this effect help you communicate with your instructor/student?

Interfered (-1.5)	Neutral (0)	Helped Some (1)	Helped A Lot (2)	No Data (-)

MEAN ANSWER

EFFECT	TOTAL	STUDENTS	NO COMBAT INSTRUCTORS	COMBAT EXPERIENCED INSTRUCTORS
Visible Sensor Cone	0.30	0.75	-1.5	-
Contrail path				
Ground track	1.00	1.25	0.00	-
Air track	1.40	1.25	2.00	-
Both together	0.80	1.00	0.00	-
Tracer Range Emphasis	-0.10	0.25	-1.50	-
Horizon Depression Cursor	0.10	0.50	-1.50	-
Instructor Cursor	1.33	1.00	2.00	-
Immediate Scoring Feedback	1.20	1.25	1.00	-
Light point Enhanced Target	1.00	0.67	2.00	-
Multiple Viewpoints	1.25	1.00	2.00	-

8. How did you use this effect?

Effect	Answer
Visible Sensor Cone	______
Contrail path Ground track	______
Air track	______
Both together	______
Tracer Range Emphasis	(Since these were essay type answers they could not be averaged, but the responses are discussed in the text.) ______
Horizon Depression Cursor	______
Instructor Cursor	______
Immediate Scoring Feedback	______
Light point Enhanced Target	______
Multiple Viewpoints	______

9. For what tasks did you use this effect?

Effect	Answer
Visible Sensor Cone	______________
Contrail path Ground track	______________
Air track	______________
Both together	______________
Tracer Range	(Since these were essay type answers they could not be averaged, but the responses are discussed in the text.)
Emphasis	______________
Horizon Depression Cursor	______________
Instructor Cursor	______________
Immediate Scoring Feedback	______________
Light point Enhanced Target	______________
Multiple Viewpoints	______________

APPENDIX F

TACTICAL DECISION MAKING SYSTEM: A FINAL REPORT

APPENDIX F

TACTICAL DECISION MAKING SYSTEM: A FINAL REPORT

submitted by J. Richter and S. Ullman from C.I.S.
to D. Coblitz from M.D.E.C.

The proposed project

The Tactical Decision Making System, described in detail in the original proposal, was intended to evaluate the alidity of the approach of using flight simulators as a training tool for tactical decision making. It was founded on the premise that by presenting information that is on the one hand relevant to critical decisions during operational flight, but on the other hand never presented explicitly in the real flight environment, the trainee could be trained to understand and exploit the relations and interactions between this information and his own actions and decisions.

The goal of the first stage of this study, which was carried out throughout the passing year (1981-82), was to implement a useful display of Energy Maneuverability (EM) graphs on the VITAL-V1 system, and to prepare a basis of their evaluation. The role of Drs. Richter and Ullman of C.I.S. was to design to display, help in its implementation on the VITAL-IV, and develop a preliminary concept for its intended use that will also be used to asses the usefulness of the display.

The design of the EM display

The first step in the system's design consisted of a verification of the need for such a system, and the comparison of our basic ideas with those of potential users in the Air Force and Navy. We have met with professional air combat instructors in the ACMR unit at NAS Miramar, and in the ACMI at AFB Nellis, as well as with people in MAC-AIR who implemented the use of EM diagrams as a debriefing tool in thses units. It was made clear to us that although the professional instructors saw a great potential for using such a system as a debriefing tool, its actual present use was very limited, due mainly to a relative degree of ignorance on the part of most pilots regardings the subtleties of its meaning. To our minds, it is evident that a training system that will train the pilot to understand and manipulate the EM graph in a simulator environment, would also prepare the pilot for the efficient use of these tools as debreifing devices. At the same time, an EM display to be used in flight simulation must meet more stringent requirements than the displays used in debriefing systems because it is supposed to be analysed in real time during the flight. It was the goal of the second stage of this study to design such a display.

In this second step a display was designed that will permit the presentation of the EM graphs of two different aircrafts in such a way, that the information pertaining to each one, as well as the relative situation between them, can be extracted with minimal effort demands. The EM presentation problem is complicated by the fact that the graphs are essentially three-dimensional (see Figure F-1) and a representation that will be simple enough to be read in real time, and at the time present two separate two-dimensional diagrams, one for each aircraft's EM graph at the current altitude. The diagrams also travel along a common vertical altitude axis that will be used for comparison. A detailed description of this design was sent to MDEC for implementation.

The implementation

The basic display of the EM graphs was implemented at MDEC and then revised by Drs. Richter and Ullman in collaboration with MDEC staff in order to reach a final configuration of the display that will be most useful in terms of aking the appropirate inforation accessible, and at the same time the least distracting. The main characteristics of the final display (Figure F-2) are as follows:

1. Two graphs, one in green for me, and one in red for him are presented side by side.

2. The graphs are made of points dense enought to appear as solid lines, and each is dynamically interpulated using seven data points for the envelop and sustained turn, as indicated in the design sent by CIS to MDEC.

3. The two graphs slide along a common vertical altitude axis so as to facilitate the altitude comparison while maintaining the separation of the two graphs.

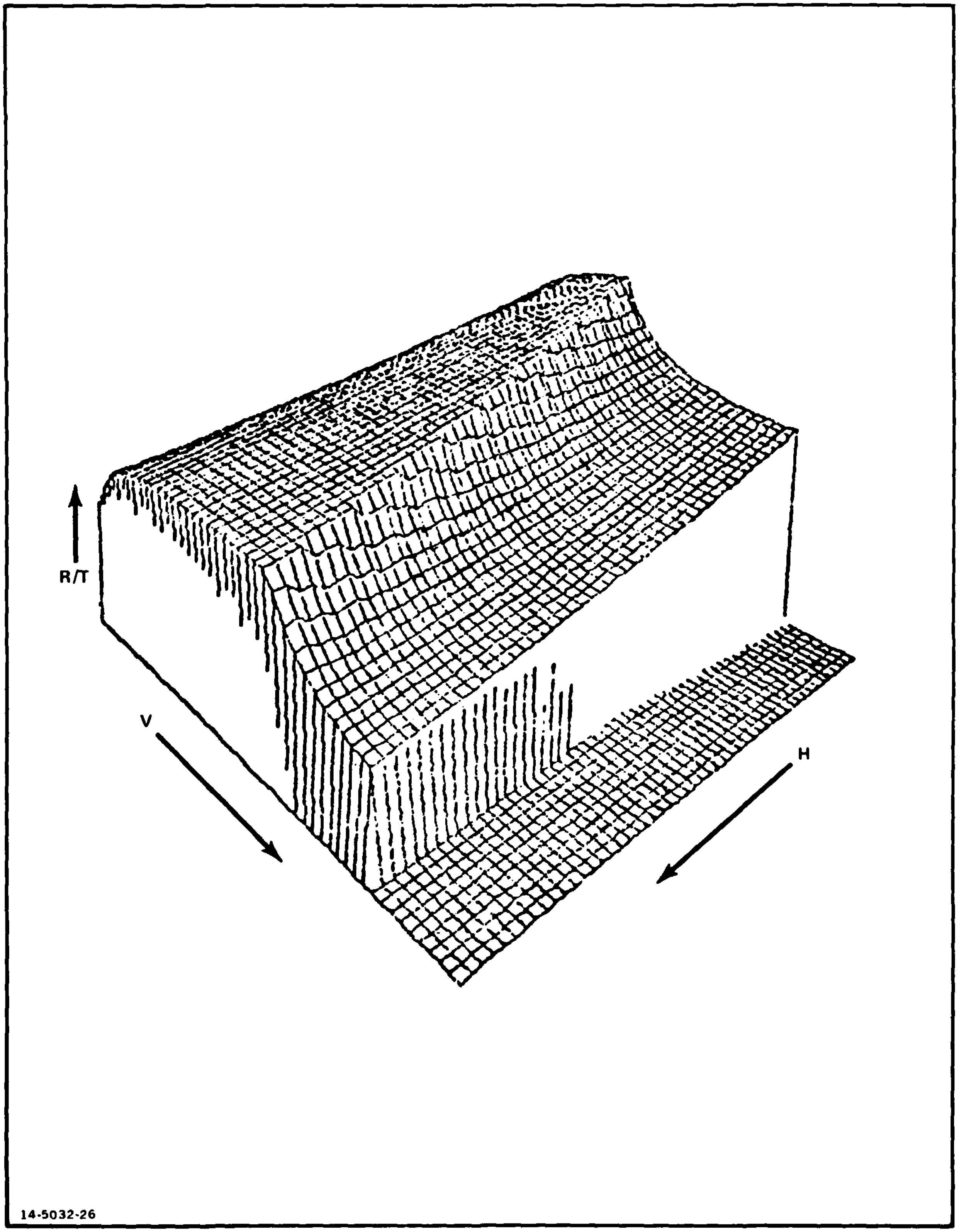


FIGURE F-1. ENERGY MANEUVERABILITY GRAPH

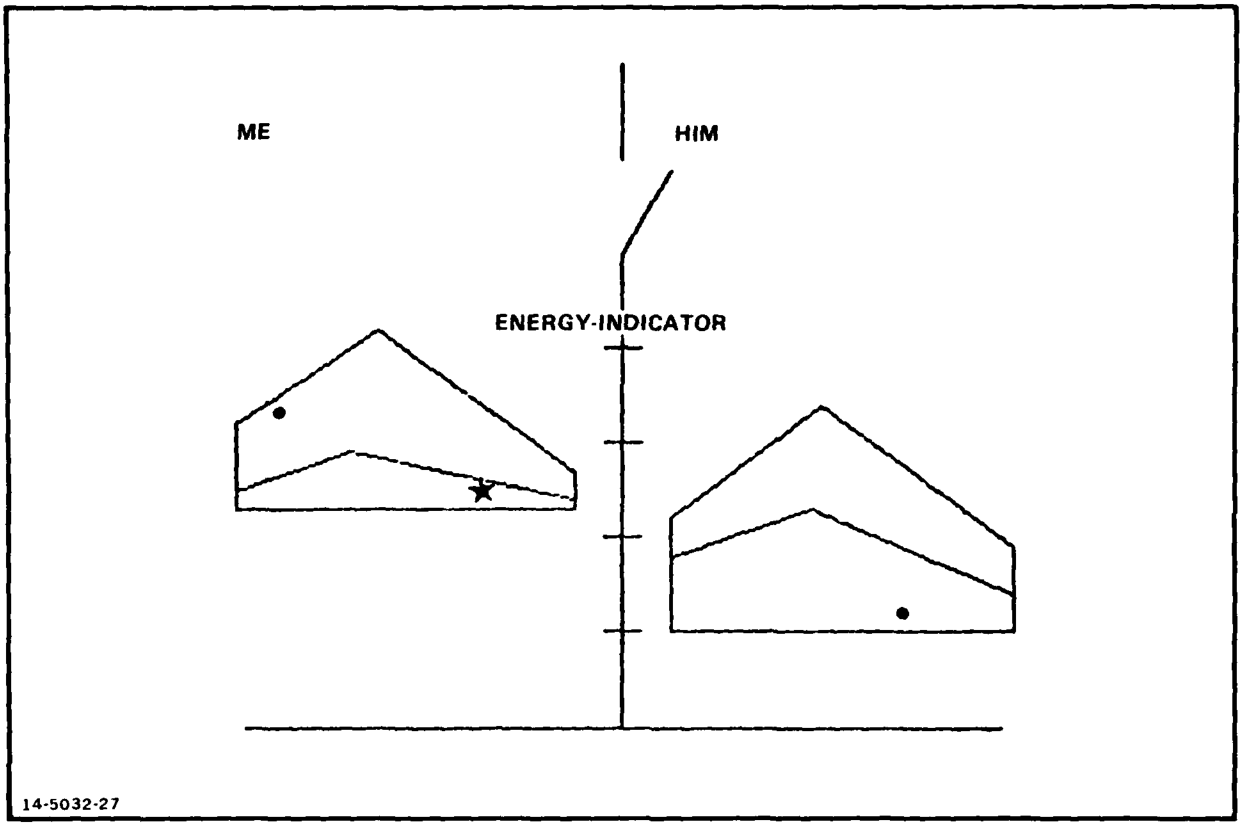


FIGURE F-2. ENERGY MANEUVERABILITY CONFIGURATION

The length of this axis and a common zero altitude line help also to estimate the absolute altitude of each of the represented aircrafts.

4. The conveninet size that is a trade-off between ease of reading and occulusion of scene features was found to be 5^{o} per graph (5^{o} x 10^{o} for the entire display).

5. The present state of each of the aircrafts will be indicated by a point on his own graph of the same color as the graph. The present state of him will be indicated also on me graph (in red color) to facilitate the comparison.

6. The relative energy will also be made explicit by a small bar, a part of the alitude axis, that will turn to either direction to indicate energy superiority of that aircraft. The angle of this bar will be relative to the aircrafts' energy difference.

7. To help predict the future energy state a "history trail" will be attached to the present state point indicators. These trails will have a programmable time length and will vary from long trails for simple, slow changing exercises, to no trail in complex, fast changing ones.

8. The graphs will be presented in a fixed position of the image frame superposed on the changing outside scene.

A concept for the use of the EM display

The training states for the use of the EM graphs by a student pilot as we envisioned them are as follows:

1. The basic stage is the study of the studenmt's own aircraft and its behavior in the EM domain. At this state the pilot must learn the effect of the nature of his control actions (smooth vs. rough, slow vs. fast etc.) on the energy, and understand the energy cost of all the alternative paths for getting from a given starting position to a final desired state. This state is crucial if the pilot is to develop a capacity to combine the spatial demands of his maneuvers with the energy demands of the given situation.

2. The next stage is the one-vs.-one training where the pilot learns to select the appropriate maneuver as determined by a combination of spatial and energy considerations. In this state the pilot can be trained to analyze the situation and derive from it the space and energy demands that will determine his manuevers. An important element at this stage is the training against different types of aircrafts. This is crucial for the creation of a basis that will help the pilot to choose the correct tactics against an unknown enemy whose EM graphs have been presented to him.

3. The last stage is a large scale integration of all the previous information to let the pilot optimize his desired combat domain (speed, altitude, tactics, etc.) according to the number and type of aircrafts, type of weapons, time and space parameters, in a many-vs.-many situation. It is important to understand that in this case the pilot does not optimize his actions with respect to any single EM. He responds to the overall situation and tries to use his own EM parameters so as to maximize the overall survivability and effectivity during a mission.

The goal of the project during the first year was to give a bisc concept for the first of these training stages, namely the basic training of a single aircraft. For this purpose a syllabus was constructed for a training session, that covers the major areas of interest in the interactions between the pilot's actions and the selected flight-paht and the energy cost of the maneuver. This syllabus is to be tested on a real simulator, and the starting parameters for the exercises are to be selected so as to maximize the differences between alternative lfight-paths. We have also prepared a detailed description of the first exercise in the syllabus to be performed in MDEC in conjunction with a hypothetical aircraft performance implemented on their system (enclosed with this report).

The proposed syllabus, after its adoption to a given aircraft, will supply, we believe, a good basis for evaluating the concepts on which this project was based. A future pursuit of the subsequent stages of the project has the potential of resulting in a unique environment that is unattainable in real flight training. It will also result in a better understanding by the student of some crucial parameters of the air combat, and will facilitate the use of the sophisticated debriefing systems already in existance.

Detailed condition for manuever demonstration
(To be implemented by MDEC)

1. The exercise we chose for this demonstration is the first one in the syllabus:

The 180° turn altitude gain.

2. The exercises will be performed with the characteristics of aircraft-1 in your letter.

The starting conditions for all three alternatives are 400 Kts., 10,000'.

Alternative paths

a. Pull vertically on the envelope limit until upside down on the horizon and then roll to level flight.

b. Pull horizontally on the sustained turn line untill 180^{o} (speed should stay at 400 Kts.) then pull up to 60^{o} above the horizon on the sustained turn line (speed should decrease because of the altitude gain) and push to level off at the same altitude you have reached in the first path.

c. Pull diagonally to the same altitude as in a. and b. and to 180^{o} turn. The angle above the horizon should be adjusted so that the desired altitude and direction are reached simultaneously (in the neighborhood of 20^{o} above the horizon), and the speed should decrease because of the continuous altitude gain.

Try all the above with different history trails. Monitor and compare speed and time at termination.

APPENDIX G

ENERGY/MANEUVERABILITY TRAINING

APPENDIX G

DRAFT SYLLABUS FOR SIMULATOR ENERGY/MANEUVERABILITY TRAINING

Jacob Richter, C.I.S.

The main purpose of this syllabus is to cover a range of exercises for a single aircraft that will let the pilot interact simultaneously with the HVT graph (altitude, velocity, turn rate) and relate the performance of his aircraft to the energy domain. The exercises are ment to result in a clear difference in the energy domain between two or more possible options for performing a given manuever. After experimenting with these exercises on a visual display with a HVT display only those exercises showing such clear differences will be kept and adopted to the right speed range in order to try them on a flight simulator.

The first set of exercises is an example that is going to cover the subjects: (1) speed-altitude trade off. (II) Acceleration. (III) Rate of acceleration.

Essentially every single exercise is to be repeated twice: once in a speed then the corner velocity, and once in a speed higher thant the corner velocity. This repetition, together with the design of the exercises that will cover the areas below and above the line of $P_s = 0$, (P_s = specific excess power) will cover the R.T./Velocity plane of the HVT graph.

(1) Speed-Altitude trade off

a. 180° turn and altitude gain: In this exercise starting velocity and the altitude gain are kept constant (a typical alt. gain is in the range of 3000 -5000 feet). The dependant variable is the velocity a t termination. The options to be performed are:

1. Imelman turn (vertical turn to 180°).

2. Oblique turn (changing altitude and direction simultaneously throughout the exercise).

3. Flat turn and a staricase pull up at the end of the turn.

Depending on the velocity at the beginning of the exercise the expected lesson is: Turn at corner velocity reduce speed if higher by first pulling up (Imelman), or gather speed by a flat turn if lower and then pull up.

b. 3υ0^{o} decending turn, low speed: In this exercise the starting point will be at low speed and a given altitude reserve. The dependant variable is the time for complition of a 360^{o} turn. The options for performance are:

1. Tight turn with simultaneously decent.

2. Acceleration to a desired speed and then tight turn to cover the 360^{o}.

This exercise will be performed from low speed only and is expected to result in an understanding of a very delicate balance between acceleration time and minimal time for complition of the turn. A possible performance at high speed will show the superiority of tightest turn there and will throw more light on the special problem when performing in low speed.

(II) Acceleration

a. 360^{o} flat turn: Here the time and starting speed are fixed, there is an unlimited altutide reserve. The dependant variable is the speed at the ened of the turn. Options for performance are:

1. Simultaneous turn and acceleration.

2. Acceleration using the reserve altitude and a subsequent climbing turn.

The trade off between time needed for acceleration to optimal speed and minimum time for a turn is expected to be emphasized from another point, the acceleration, or a P_s gain domain being covered.

b. A race to a far and high point (simulating a chase of a high and fast target). Here the distance and altitude of the target point, as well as the starting speed and altitude of the chaser are fixed. Time and speed at arrival to the point are the dependant variable. The options for performance are*

1. Simutaneous climb and acceleration.

2. Acceleration to optimal speed (decending) and a subsequent optimal climb.

Here we will check the adequacy of using the HVT graph for a situation that does not involve a turn, a situation it was not desinged for but for which it is hopefully adequate.

(III) Rate of acceleration

a. 180^{o} flat turn. All the stable parameters of the turn are fixed and the only independant variable is the rate of entering the radial acceleration rate. The dependant variable is the speed at completion of 180^{o}. The rate will be changed continuously to cover the range of the effect.

b. An altitude gain staircase with not direction change. Starting and final altitude, starting speed and time for completion are fixed. The independant variable is the rate of pulling up to the desired G value. The dependant variable is the speed at completion.

c. A split-S turn (vertical decenting 180^{o} turn). All stable parameters fixed and the rate of pulling up to the desired G value is changed. The dependant variable is the altitude loss.

In all three of these exercises we expect to cover and demonstrate by the HVT graph, the importance of rate of acceleration to the energy state. We will also show the difference in its importance at different domains of the HVT graph.

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