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I am submitting herewith a thesis written by Mark Maurice Jackson entitled "UH-60 Global Positioning System (GPS) Tactical Approach Investigation". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with major in Aviation Systems.

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UH-60 Global Positioning System (GPS)

Tactical Approach Investigation

A Thesis
Presented for the
Master of Science Degree

The University of Tennessee, Knoxville

Mark Maurice Jackson
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DEDICATION

This thesis is dedicated to my parents and sons

Mr. Maurice Bishop Jackson

Mrs. Ernestine Marie Jackson

and

Mr. Eric Mark Jackson

Mr. Lucas Daniel Jackson

who have given me invaluable educational opportunities and inspiration

Abstract

This thesis examines the feasibility of using steep Global Positioning System (GPS) approaches in Instrument Meteorological Conditions (IMC) for the military. The experiments were conducted in the UH-60A/L Flight Simulator at Fort Hood, Texas, with a crew of two pilots. The experiment investigated GPS instrument approach tasks with evaluation subtasks of: (1) a level flight conversion to approach airspeed configuration and glide slope intercept, (2) glide slope and localizer tracking, and (3) completion of the landing following breakout. Qualitative and quantitative data was collected on aircraft performance and handling qualities. Handling Quality Rating (HQR) were assigned to approach task and written comments on flight control inputs were collected.

The glide slope angles were varied, starting shallow and ending with a steep approach configuration. The glide slope angles were 10, 9, 8, 7, and 6 degrees. Each pilot flew each approach at various airspeeds, 120, 100, 90, 80, and 70 knots. Once the aircraft broke through the 100-feet Above Ground Level (AGL) weather ceiling, the pilots had to maneuver the aircraft to safely land the aircraft at the designated location in the marshalling area. The objective was to bring the aircraft to a 10-feet hover over the designated GPS landing point safely.

The results demonstrate the ability of the aircraft to safely fly GPS approaches into IMC conditions. The optimum approach combination was 7-degree glide slope at 70 knots. The worst configuration for all the approaches was 10-degree glide slope at 120 knots. Any approach above 10 degrees at 120 knots to 100 knots will result in major deficiencies with control being lost during some portion of the required operation during

breakout. An approach below 7 degrees glide slope angle does not provide safe aircraft clearance for obstacles. Evaluations revealed serious problems with pilot's loss of intended landing spot from the cockpit obstructing Field Of View (FOV) during aircraft deceleration for approaches above 8-degree glide slope and above 90 knots.

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List of Abbreviations

GPS	Global Positioning System
HQR	Handling Quality Rating
AGL	Above Ground Level
FOV	Field Of View
HSI	Horizontal Situation Indicator
VSI	Vertical Situation Indicator
PPS	Precision Positioning Service
IMC	Instrument Meteorological Conditions
CDU	Computer Display Unit
VA	Vertical Angle
IOS	Instructor/Operator Station
OS	Observer Station
ESSS	External Stores Support System
ERFS	Extended Range Fuel System
NVG	Night Vision Goggles
NOE	Nap-of-the-Earth
PLT/CPLT	Pilot/Copilot
DIG	Digital Image Generation
OTW	Out-The-Window
AFCS	Automatic Flight Control System
SAS	Stability Augmentation System
FPS	Flight Path Stabilization
KM	Kilometers
FAR	Flight Aviation Regulations
IFR	Instrument Flight Rules
MSL	Mean Sea Level
CG	Center of Gravity
ILS	Instrument Landing System
FAARP	Forward Area Arming and Refueling Point
FLOT	Forward Line Of Troops
VAR	Vibration Assessment Rating
FPM	Feet Per Minute

CHAPTER 1

INTRODUCTION

How accurately do we need to determine our position on the earth and in the airspace above? If we need something very accurate, how long will it take to determine our position? What if we are changing our position very rapidly? There are many applications for navigation and positioning for the static and near static situations. The emphasis in the 1990s has been in the use of the GPS. The system was used extensively during Operations Desert Shield and Desert Storm and played a decisive role in the success of the war. There are many applications and uses for the GPS system. The handheld GPS receiver is very popular with individual hunters, hikers, and people camping in remote areas of the world. Some of the handheld GPS systems provide accuracy up to 10 feet. Even the rental car agencies and automobile companies are equipping their cars with GPS systems with moving maps.

What if the situation is highly dynamic, as in airborne applications requiring attitude information and military applications (including Unmanned Aerial Vehicles) that rely on exact positioning and velocity information for targeting and weapons delivery? The overall GPS system provides accurate determination of position, velocity, and time. The system operates in all-weather conditions, which is very important for the success of military operations. The real-time positioning synchronizes the integration of ground and air operations. This system also operates continuously and is usable in a hostile environment. Using differential GPS and Precision Positioning Service (PPS) it becomes possible to use these systems for additional missions such as artillery targeting, close-air support, air drops, bombing, search and rescue, and target location (Clarke, 1994).

Additionally, knowing the exact position of friendly ground forces prevents fratricide from occurring. In non-combat operations, PPS accuracy will support navigation for supply distribution, equipment recovery, area reconnaissance, and many other military missions (Clarke, 1994). Most importantly, the GPS can provide easy location of wounded soldiers for medical evacuation operations. Additionally, GPS offers many other benefits and capabilities for military operations.

Integration and use of GPS for military helicopter operations has unlimited potential, not just for conducting steep approaches. GPS decreases the pilot navigation workload due to its many navigational features. GPS also provides the pilots with navigation information that is available on the instrument panel, which enables night missions to be flown. Most aviation missions are flown at night during low-level navigation operations. Low-level flying consists of flights approximately 50 feet above the highest obstacle to ensure survivability. This system allows the pilot to turn and follow the commands depicted on the flight instruments and give accurate distances to each waypoint or grid coordinate. Continued integration of GPS applications into military helicopters will only enhance helicopter effectiveness and increase the capabilities of U.S. Army Aviation.

Military helicopters must operate in adverse weather that restricts the visibility of the aviator. GPS offers precise grid coordinates and elevations data to guide the aircraft to an exact spot on the ground. This experiment will evaluate the potential of using GPS for helicopter approaches into confined areas supporting military insertion and extraction operations consistent with U.S. Army Aviation tactics. The GPS simulator investigation will demonstrate how steep instrument approaches could be accomplished with proper training and planning. Precision approaches into confined areas or hostile landing zones for military operations using GPS has unlimited potential. This thesis examines the use of GPS on helicopters for steep instrument approaches into confined areas. The breakout ceiling at the end of the approach was set at 100 feet AGL. Qualitative and quantitative data were collected during the approaches. Handling qualities were evaluated to highlight pilot workload.

CHAPTER 2

EXPERIMENTAL GPS AND APPARATUS

2.1 NAVSTAR GPS ACCURACY AND HOW SYSTEM WORKS

The NAVSTAR GPS is a space-based positioning system that provides highly accurate positioning, velocity, and time data. This system is designed to provide service to users worldwide on the ground, at sea, in the air, and in near space. The United States Department of Defense developed the GPS as a satellite-based radio navigation system to meet the needs of both the military and civilian communities (Clarke, 1994). This system provides vital information for navigation. The accuracy of the GPS is very important to the U.S. Army when dealing with military missions that rely on precision timing and coordination. Therefore, two questions that need to be answered are how accurate is the GPS and how does the GPS work.

The system is a form of celestial navigation because of a 24-satellite constellation, with 3 orbiting spares, placed in a high orbit circling the earth every 12 hours (Hotchkiss, 1994). The satellites repeat the ground tracks of 23 hours and 56 minutes. Normally, 5 satellites are in view at all times. Figure 2-1 shows the orbit of the satellites (All figures are located in the Appendices, page 35) . The satellites give GPS receivers anywhere in the world the current date, time, and locations of all the other satellites. The system also provides precise timing code that allows the satellites to calculate distances from other satellites.

The GPS receiver requires one satellite for each coordinate to calculate the position coordinates x, y, and z as shown in Figure 2-2. The three satellites calculate navigational-horizontal location on the earth surface, which is called 2-dimensional reporting (Hotchkiss, 1994). The fourth satellite reports time. The addition of the fourth satellite is called 3-dimensional reporting that provides altitude and horizontal location.

The GPS constellation broadcasts the signals to a receiver/processor operated by the user on the ground. Each range calculation includes a small error in each component. The accuracy of the system depends on two important factors (Clarke, 1994):

1. Error in the measurement of pseudo-ranges from each satellite being tracked.
2. Satellite-to-user geometry.

Statistical measurement of the navigation system errors yields a 95 percent confidence level for fixed positions (Clarke, 1994). Relating this confidence level to ground navigation, the GPS will only give accuracy between 25 to 100 meters.

This system is even more precise because of the United States canceling Selective Availability (SA) program. (Hotchkiss, 1994). In the past, the SA program could be overridden with a differential GPS application. The differential operation was a special facility positioned in an area of interest at a fixed point. The facility receives the GPS signals in real time and compares expected signals to be observed at a fixed point. The differences between the observed signal and predicted signals are given to the users as differential corrections (Clarke, 1994). This increased the precision to the users' GPS receiver.

2.2 DESCRIPTION OF NAVSTAR GPS

The C-11702/UR or Computer Display Unit (CDU)is mounted in the cockpit's lower consoles and provides position coordinates, altitude, speed, and time data for the pilots. The CDU in Figure 2-3 gives the pilot a vast amount of useful information. The data switch controls which information that is displayed in the data display window on the CDU. The functions of each indicator on the data switch are shown below (GPS, USAAVNC, 1992):

Control or Indicator	Function
1. POS (Position)	Allows display of present position or coordinate waypoint.
2. MSN (Mission)	Allows area navigation selection parameters.
3. OPT (Option)	Allows selection of display options.
4. STAT (Status)	Allows display of satellite status and performance data.
5. VAR-DTM	Variation and map datum.
6. ERR (Error)	Display cross track, track angle error, and vertical error.
7. WIND	Display of wind speed and direction.
8. DIS-TG	Display circle distance, time to go, bearing, and slant range.
9. TRK-GS	Display ground track, ground speed, time and Julian date.
10. DTK-VA	Display of desired track and vertical angle to destination.

This vital information keeps the pilots oriented on course and keeps the mission execution synchronized.

The MARK key is another very useful asset the GPS has to offer the pilots in a combat situation. This key enters the present position into the memory or freezes the position on the display. In a combat environment, the Mark key locates an enemy position during an aerial reconnaissance by instantaneously obtaining an eight-digit grid coordinate.

Programming the system for navigation is done with waypoints. Waypoints or grid coordinates are entered into the CDU with the waypoint key. The GPS is capable of storing 209 waypoints. The first waypoint is normally at a friendly staging area with the last at the landing zone to insert or extract friendly forces, and the points in between are checkpoints.

Pilots create the glide slope path angle with the Vertical Angle (VA) function on the CDU by inputting the desired glide slope angle. The pilots then input the desired waypoint coordinate and the GPS system programs the desired glide slope angle to connect with the waypoint on the ground. These selected numerical values are depicted correctly on the aircraft instruments. For example, if a vertical angle of -5.0 degrees is chosen for a glide slope, the aircraft's instruments will keep the aircraft on a -5.0 degree slope to the waypoint on the ground, within 10 feet.

2.3 NAVSTAR GPS CONFIGURATION ON BLACKHAWK

Navigation for Army Aviation is extremely important for the success of the mission. The U.S. Army has experimented with uses of GPS for the UH-60A Blackhawk helicopter. The system is made up of several components shown in Figure 2-4 (NAVCISP, 1993).

Figure 2-4 shows the function of each component and how the GPS signal is transferred through the system. The navigation information from waypoint to waypoint is depicted on the pilot's horizontal situation indicator (HSI) and vertical situation indicator

(VSI) instruments mounted on the pilot and copilot's instrument panels (Technical Manual -10, 1996). The HSI and VSI are shown in Figure 2-5 and Figure 2-6 respectively. The pilot selects a waypoint on the CDU, and the HSI and VSI provide navigational information to the pilot. The HSI has the number 1 bearing pointer that gives the heading to fly to the waypoint, course deviation bar that keeps the aircraft on course, and the course set displays that indicate the distance to waypoint in kilometers (Technical Manual -10, 1996). The VSI gives course tracking with the course deviation pointer and the roll command bar (Technical Manual -10, 1996). During a GPS programmed approach, the Glide slope Deviation Pointer, Collective Position Indicator, Roll Command Bar on VSI, and Course Deviation bar on HSI are used to keep the pilot on localizer course and on glide slope. The Course Set Display on the HSI shows the pilot the distance to the designated waypoint on the ground.

2.4 DESCRIPTION OF BLACKHAWK SIMULATOR

1. OPERATIONAL SYSTEM

The UH-60 Black Hawk Flight Simulator, designed and manufactured by CAE-Link Corporation, Binghamton, New York, has been specifically developed for flight simulation for UH-60 A/L aircraft. The flight simulator is a fixed-base device designed for training aviators in the use of UH-60A/L helicopters. Figure 2-7 shows the layout of the simulator room (Instructor Utilization Handbook, UH-60A/L Flight Simulator, 1998).

The flight simulator consists of a simulator compartment containing a cockpit (Pilot/Copilot station), Instructor/Operator Station (IOS), Observer Station (OS), and a six-degree-of-freedom motion system (See Figure 2-8). The simulator is equipped with a visual system that simulates natural helicopter environment surroundings. The central computer system controls the operation of the simulator complex. The simulator provides training in aircraft control, cockpit preflight before start, start, run-up, shutdown, and normal and emergency procedures, instrument flight operations, visual flight operations, sling load operations, External Stores Support System (ESSS), Extended Range Fuel System (ERFS), Night Vision Goggles (NVG), Doppler and GPS operation, Nap-of-the-Earth (NOE) flight, low-level flight, and contour flight. The assembly line airframe configurations, which serve as a basis for simulation and configuration, are the UH-60 A/L Black Hawk helicopter equipped with two T700 and T701 engines, respectively.

2. SIMULATOR COMPARTMENT

The simulator compartment houses the cockpit station and IOS as well as an observer station. The cockpit Pilot/Copilot (PLT/CPLT) station is located in the forward portion of the compartment. All the controls, indicators, and panels operation have the same appearance as those in the aircraft described in TM 1-1520-237-10, Operator's Manual for the UH-60A helicopter. Six loudspeakers in the simulator compartment are provided to simulate the aural cues. The PLT/CPLT seats are vibrated individually to simulate both continuous and periodic oscillations and vibrations experienced by the crew during normal and emergency flight conditions and maneuvers, including vibrations representing progressive malfunctions. Seat vibrations are isolated from the remainder of the observer and instructor/operator stations. The PLT/CPLT seats each have a red handle on the back of the seat, which, when pulled to the left, allows the seat to slide forward or rearward for ease of entry into the cockpit area.

3. INSTRUCTOR/OPERATOR STATION (IOS)

The IOS is located aft of the PLT/CPT station, Figure 2-8, in the simulator compartment (Instructor Utilization Handbook, UH-60A/L Flight Simulator, 1998). The IOS provides information and controls with which the instructor/operator can effectively monitor and evaluate student performance and control the training. The instructor/operator is also able to operate with limited capability from the CPLT seat position by using the Control Portable l Unit (CPU). Additional controls are provided on the auxiliary control panel between the PLT and CPLT seat positions.

4. MOTION SYSTEM

The simulator compartment is mounted on a 60-inch six-degree-of-freedom motion system consisting of a moving platform, assembly driven and supported from below by six identical hydraulic actuators (See Figure 2-9). The motion system is capable of providing pitch, roll, yaw, lateral, longitudinal, and vertical movement, as well as combinations thereof. Simulation includes the motion due to changes in aircraft attitude as a result of flight control and rotor operation, rough air and wind, changes in aircraft weight, and center of gravity, as well as emergency conditions and malfunctions (Instructor Utilization Handbook, UH-60A/L Flight Simulator, 1998). The simulation program causes the motion system to respond to aerodynamic forces and moments within the mechanical limits of the system. All motions except pitch are washed out to the neutral position after the computed accelerations have reached zero. Pitch attitude is maintained as necessary to simulate sustained longitudinal acceleration cues.

5. VISUAL SYSTEM

The simulator uses a Digital Image Generation (DIG) system to provide the necessary visual displays. A computer-generated database provides a tactical gaming area and airfield area of approximately 80 kilometers by 100 kilometers (Instructor Utilization Handbook, UH-60A/L Flight Simulator, 1998). The gaming area represents a generic terrain designed specifically to meet diverse training requirements related to utility helicopter operations.

The PLT/CPLT stations are provided with forward, left and right side window displays. The visual generation system provides imagery to every sensor display, including the Out-The-Window (OTW) scene. The display images are supplied by the DIG, which simulates day, dusk/dawn, and night operations. OTW scenes are illuminated from various sun angles during the day, feature sunset effects at dusk, and may contain cultural lighting such as beacons, strobes, and other man-made lights at dusk and at night. Searchlight and landing light action can be simulated only during dusk and night OTW scenes.

6. FLIGHT CONTROL SYSTEM

The flight control system in the simulator is an exact representation as in the aircraft (Technical Manual -10, 1996). Conventional irreversible helicopter controls are provided for the side-by-side pilot stations (See Figure 2-10). Control inputs are transferred from the cockpit to the rotor blades by mechanical linkages and hydraulic servos. The pilot a copilot controls is routed separately to combining linkage for each control axis. Outputs from the cockpit control are carried by mechanical linkage through the pilot assist servos to the mixing unit. The mixing unit combines, sums, and couples the cyclic, collective, and pedal inputs. It provides mechanical control mixing functions that are designed to eliminate inherent control coupling. The Automatic Flight Control System (AFCS) is designed to enhance the stability and handling qualities of the helicopter. The AFCS is comprised of four sub-systems: Stability Augmentation System (SAS); Trim, Flight Path Stabilization (FPS); and Stabilator. SAS is designed to provide short-term rate damping in the pitch, roll, and yaw axis. The FPS is designed to provide airspeed/pitch, roll, and heading hold. Above 60 knots, the FPS is also designed to provide turn coordination. The trim system provides a force feel reference for the cyclic and pedals. The stabilator is designed to improve flying qualities by changing its angle of incidence through electro-mechanical actuators in response to collective, airspeed, lateral acceleration, and pitch rate. The test flight control system in the simulator is representative of the aircraft.

2.5 NAVSTAR GPS CONFIGURATION IN BLACKHAWK SIMULATOR

The NAVSTAR GPS in the simulator has the exact CDU and inputs the same information into the HSI and VSI instrumentation displays as designed on the aircraft. The GPS functions and tracks the proper satellites as installed on the aircraft. The main difference is that the operator at the IOS station can modify certain GPS parameters for training and has more capabilities. These parameters and capabilities are discussed below.

The operator can view and edit the characteristics of a total of 209 waypoints similar to the use of the GPS CDU. The data comprising each waypoint is obtained from disk drives where the waypoints are stored. Three sets or catalogs can be selected. Selecting waypoint set members 1, 2, or 3 identifies disk record located on disk file. The GPS system therefore can store up to 3 times as many different waypoints as the CDU. The IOS can edit the waypoints and download waypoints into the GPS system for the pilots.

The IOS has a GPS Control Page that allows the operator to monitor and adjust all GPS functions during the flight (See Figure 2-11). This page displays a subset of information that is available through the GPS CDU. The operator can control simulation by providing edit capability to control parameters of the GPS simulation. A portion of the information on this page is display only. The GPS parameters, which may be edited through this page, include up to 18 satellites in view, jamming state, number of satellites to track, desired Figure-of-Merit, almanac data available, day of year, year, mission duration, and key entry display response message.

CHAPTER 3

TEST PROCEDURES

3.1 GENERAL

The experiments were conducted in the UH-60A/L Flight Simulator at Fort Hood Texas. Major Mark Jackson and CW5 Ronald Deshotel, UH-60 pilots with 1100 and 5300 hours of total flight times respectively, were the test pilots for the experiment. The simulator operator was a former military aviator with 3000 hours of total flight time and three years experience operating the UH-60 flight simulator.

Evaluation atmospheric conditions were set in the simulator at 100 feet AGL overcast, Instrument Flight Rules (IFR) condition from 100 feet AGL to 4000 feet Mean Sea Level (MSL). The breakout ceiling was set at 100 feet AGL to challenge the pilots in a possible real world tactical environment at the minimum safe breakout altitude possible. The senior simulator operator conducted several trial runs along with other qualified pilots to confirm the 100 feet AGL breakout ceiling would provide realistic results. The winds and turbulence were calm with no gusts, cross winds, or shear wind forces near the ground. The test was conducted in daylight conditions with a crew of two, full internal fuel, and no external stores. The engine start gross weight was 18,580 lb, with a Center of Gravity (CG) of 360.0 inches aft. The test was conducted with SAS1, SAS2, FPS, TRIM, and BOOST "ON", and the stabilator in the automatic mode.

The selected GPS approach glide slope and airspeed combinations corresponded to the flight director command laws on the aircraft instruments. The pilots were briefed that while flying GPS approaches, the response times were approximately two times more sensitive then a normal 3.5 degree Instrument Landing System (ILS) approach because of the GPS system design (GPS, 1992). Tactical scenarios were created to challenge and stress the pilots. The crew flew from a FAARP (Forward Area Arming and Refueling Point) through two waypoints and into a marshalling area just short of the Forward Line Of Troops (FLOT). Pathfinders in the marshalling area provided optimum approach heading and touch down grid coordinate for the UH-60 flight crew. Evaluation runs began with aircraft mode in level flight at 120 knots, 2000 feet MSL above the ground, once passing through waypoint 2, Figure 3-1, the crew decelerated the aircraft to test conditions. The aircraft was offset left from the localizer by 1000 feet in relation to waypoint 3 and the final approach fix, waypoint 2 (See Figure 3-1). Figure 3-2, shows the overhead view of the 150-foot square marshalling area. The different glide slope intercept locations, breakout location, and profile view of marshalling area are shown in Figure 3-3. Pilots were required to decelerate to a 10-foot hover above the GPS landing point within the 150-foot square marshalling area surrounded by 25-foot trees. The marshalling area altitude was 500 feet MSL. Pilots completed the vertical landing using visual cues.

The glide slope angles were varied, starting from a shallow approach and ending with a steep approach configuration. The glide slope angles were 10, 9, 8, 7, and 6 degrees. The UH-60 is a Category B aircraft, with approaches that are routinely flown at 120 Knots per FAR (Flight Aviation Regulations) Part 91. Therefore, the approaches began at 120 knots.

In order to determine the lowest acceptable airspeed, several limiting factors were weighed at lower airspeeds. For example, at airspeeds below 40 knots the pilot static airspeed indicator became unreliable. Airspeeds below 60 knots were not used because of FPS being inoperable. An allowance of 10 knots above the lowest unrestricted airspeed of 60 knots was used. This was done to make airspeed adjustments to assure desired airspeed and approach angle and rate of descent; therefore the slowest evaluated airspeed was 70 knots. The selected airspeeds that each pilot flew were 120, 100, 90, 80 and 70 knots. Once the aircraft descended through the 100-feet AGL weather ceiling, the pilots were required to maneuver the aircraft with flight control inputs to safely bring the aircraft to a 10-foot AGL hover over the intended landing point in the marshalling area.

3.2 DATA COLLECTION

The Cooper-Harper rating scale, found in Figure 4-4, was used to rate the handling qualities required to perform the tasks (Cooper, 1969). The scale assigns a HQR based on pilot aircraft controllability, aircraft performance, and pilot workload. Vibrations were rated using the Vibration Assessment Rating (VAR) scale presented in Figure 3-5 (Cooper, 1969).

The IOS operator configured the flight simulator to plot the evaluated GPS approach plots on an 12 KM and 2 KM scale. This corresponded to an overhead and profile view, respectively. Waypoint grid coordinates were input in the GPS CDU. Waypoint data was provided in the upper part of the map display. Plotting of the helicopter track began when the helicopter range to destination waypoint was within 12 KM and or 5 minutes from the touch down point. Each approach was plotted showing azimuth (meters) versus distance (KM) and elevation (meters) versus distance (KM) starting at 12 KM and zooming in showing the approach on a 2 KM scale. The approach model is show on Figure 3-6 (Instructor Utilization Handbook, UH-60A/L Flight

Simulator, 1998). Figure 3-7, shows each approach plotted with airspeed (knots) and altitude (feet) with respect to time (minutes).

3.3 EVALUATION TASK

The experiment investigated GPS instrument approach tasks with evaluation subtasks of: (1) a level flight conversion to approach airspeed configuration and glide slope intercept, (2) glide slope and localizer tracking, and (3) completion of the landing following breakout. The test and test conditions table is located in Figure 3-8. Handling Quality Rating (HQR) were assigned to approach task and written comments on flight control inputs were collected.

1. LEVEL FLIGHT CONVERSION TO APPROACH AIRSPEED CONFIGURATION AND GLIDE SLOPE INTERCEPT

Qualitative and quantitative data was collected on airspeed capture and glide slope intercept. Airspeed capture was conducted when the aircraft slowed from 120 knots to 100, 90, 80, and 70 knots. The aircraft was evaluated for ability to capture and maintain desired airspeed of +/- 5 knots, heading of +/- 5 degrees, and altitude of +/- 50 feet. Adequate ratings were achieved when aircraft maintained airspeed of +/- 10 knots, heading of +/- 10 degrees, and altitude of +/- 100 feet. Glide slope intercept was conducted for 10, 9, 8, 7, and 6-degree angles.

The aircraft was evaluated for ability to capture and intercept the glide slope with desired heading of +/- 5 degree and altitude of +/- 50 feet. Adequate results were achieved when aircraft maintained heading of +/- 10 degree and altitude of +/- 100 feet.

2. GLIDE SLOPE AND LOCALIZER TRACKING

Qualitative and quantitative data was collected on maintaining glide slope and localizer track for 10, 9, 8, 7, and 6-degree glide slope angles. The aircraft was evaluated for ability to maintain desired glide slope of +/- 1 degree and localizer track of +/- 1 degree. Adequate ratings were achieved when aircraft maintained glide slope of +/- 2.5 degree and localizer track of +/- 2.5 degree. These tolerances maintained the navigation systems' glide slope deviation pointer and course deviation pointer from reaching full needle defection.

3. LANDING

Qualitative and quantitative data was collected during breakout and landing on the intended spot in the marshalling area. These evaluations began once the aircraft descended through 100 feet AGL ceiling for each of the airspeed and glide slope combinations. During breakout, the aircraft was qualitatively evaluated for ability to control heading, field of view, and ground track over the ground. The aircraft was also evaluated on bringing the aircraft to a 10-foot AGL hover over the intended spot in the marshalling area. The desired tolerances were +/- 10 feet longitudinal and lateral and 10 foot AGL above ground. Adequate tolerances were +/- 20 feet longitudinal and lateral and 20 feet AGL above ground.

CHAPTER 4

EXPERIMENT RESULTS

4.1 GENERAL

The experimental tasks are described below for each of the evaluation subtasks of the instrument approaches.

4.2 LEVEL FLIGHT CONVERSION TO APPROACH AIRSPEED CONFIGURATION AND GLIDE SLOPE INTERCEPT

1. AIRSPEED CAPTURE

Figures 4-5 and 4-6, show the aircraft gaining approximately 200 feet of altitude once slowing from 120 knots to 70 knots. Airspeed capture was evaluated qualitatively during decelerating flight transitioning from tactical flight of 120 to 70 knots to maintain desired airspeed of +/- 5 knots, heading of +/- 5 degrees, and altitude of +/- 50 feet and adequate ratings for airspeed of +/- 10 knots, heading of +/- 10 degrees, and altitude of +/- 100 feet. With the aircraft trimmed at 120 Knots, 1000 feet pressure altitude, and deceleration of 6 knots per second was established by 3/4 inch aft cyclic accompanied by a 1 1/2 inch decrease in collective that decreased the dual engine torque by 20%. The aircraft exhibited uncommanded pitch oscillations of up to +/- 4 degree approximately every 2 seconds, requiring continuous readjustment of the cyclic to maintain constant deceleration. Cyclic control forces were light and provided minimal cue of off airspeed conditions. Frequent glances at the airspeed indicator were required approximately every 2 seconds to monitor the deceleration of the aircraft. Controls inputs were required between 5 and 10 knots prior to the desired airspeed in order to avoid an airspeed overshoot. Capturing the deceleration airspeed, from 6kt/sec deceleration, within +/- 10 knots was difficult, requiring an initial 1 1/2-inch forward cyclic input to increase the deceleration rate, followed by multiple 1/4-inch fore and aft cyclic inputs every second. Decelerating the aircraft during the approach from 120 to 70 knots was difficult to accomplish and prevented the pilot from performing secondary cockpit tasks, HQR 9.

2. GLIDE SLOPE INTERCEPT

Glide slope intercept was evaluated qualitatively during the 10 degree glide slope approach angle at 120 knots to maintain desired heading of +/- 5 degree and altitude of +/- 50 feet and adequate results when aircraft maintained heading of +/- 10 degree and altitude of +/- 100 feet. With the aircraft trimmed at 120 Knots, level flight, the collective was rapidly decreased 3 to 4 inches in an attempt to intercept the glide slope. With the collective almost completely down, the dual engine torque indicated only 10% of torque. Figure 4-7, shows that aircraft flew through the 10-degree glide slope by approximately 100 feet. This flight control movement places the aircraft into an almost auto-rotational descent using minimum power. This resulted in rates of descents above 1000 FPM. With the aircraft approaching an auto-rotational descent glide slope tracking, localizer tracking, and handling qualities during breakout were all adversely affected, HQR 9. These issues will be discussed below in sections 4.3 and 4.4.

3. REMAINING EVALUATIONS FOR LEVEL FLIGHT CONVERSION TO APPROACH AIRSPEED CONFIGURATION AND GLIDE SLOPE INTERCEPT

Figure 4-1, shows HQRs for the remaining approaches with respect to glide slope angle and airspeed combinations for level flight conversion to approach airspeed configuration and glide slope intercept. Figure 4-2, shows the handling qualities ratings using glide slope angle, and Figure 4-3 shows the handling qualities ratings using airspeed. Figure 4-4, depicts the HQR ratings with respect to each airspeed and glide slope angle combination for level flight conversion to approach airspeed configuration and glide slope intercept. The HQR ratings were grouped by numerical value with the understanding that tolerance scales were as follows: desired HQR 4 and below, adequate HQR 5-7, and inadequate or do not perform HQR 8-10.

During the level flight conversion to approach configuration and airspeed, the aircraft decelerated to the final approach airspeed. Desired and adequate airspeed captures were achieved on 90, 100 and 120 knots airspeeds. Ratings for the 80 and 70 knots airspeed were considered inadequate because of the additional pilot workload transiting from 120 to 80 or 70 knots.

Figure 4-2, shows that the steeper the glide slope angle the more difficult it was to intercept the glide slope. In glide slope angles above 9 degrees, the pilot had to significantly reduce the collective to ensure the aircraft intercepted the glide slope.

4.3 GLIDE SLOPE AND LOCALIZER TRACKING

Glide slope and localizer tracking was qualitatively evaluated during the 10-degree at 120-knot approach to maintain desired glide slope of +/- 1 degree and localizer track of +/- 1 degree and adequate ratings to maintain glide slope of +/- 2.5 degree and localizer track of +/- 2.5 degree. The pilot had difficulty tracking the localizer and maintaining glide slope track for 10-degree, 120-knot approach as shown in Figures 4-14, 4-15, and 4-16. As discussed in the glide slope intercept section above, the pilot had to significantly reduce the collective to intercept the glide slope, which proved unsuccessful. At high rates of descent, 2 to 3 inch collective inputs up and down were required every 2 seconds to maintain the aircraft on glide slope. With the large and frequent power changes, localizer tracking was adversely affected, handling qualities decreased rapidly, and pilot workload increased. Increased airspeed only exacerbated pilot workload because the large collective inputs required occurred faster and more frequently, HQR 10.

Glide slope and localizer tracking was qualitatively evaluated during the 8-degree at 70-knot approach. Slower airspeeds and shallower glide slope angle resulted in improved performance and handling qualities. This was illustrated for 8 degree 70 knot approach shown in Figures 4-17, 4-18, and 4-19. Less than 1/2 inch of collective and cyclic inputs every 5 seconds were required to maintain the aircraft on glide slope and localizer track, HQR 3.

1. REMAINING EVALUATIONS FOR GLIDE SLOPE AND LOCALIZER TRACKING

Figure 4-10, shows HQRs for the remaining approaches with respect to glide slope and localizer tracking. Figure 4-11, shows the handling qualities ratings using glide slope angle, and Figure 4-12 shows the handling qualities ratings using airspeeds. Figure 4-13, depicts the HQR ratings with respect to each airspeed and glide slope angle combination for glide slope and localizer tracking. The HQR ratings were grouped by numerical value with the understanding that tolerance scales were as follows: desired HQR 4 and below, adequate HQR 5-7, and inadequate or do not perform HQR 8-10.

The handling qualities ratings show that the steeper the glide slope and faster the airspeed, the more difficult it was to track the glide slope and localizer. Desired and adequate glide slope tracking ratings were achieved on the 6, 7, and 8-degree approaches. Ratings for the 9 and 10-degree glide slope degrade to inadequate (very high workload) ratings. Airspeeds above 100 knots degrade to inadequate and were desired and adequate at airspeeds below 100 knots. Localizer tracking was directly proportional to glide slope tracking in terms of handling qualities and workload for all run configurations.

4.4 COMPLETION OF LANDING FOLLOWING BREAKOUT

1. BREAKOUT HANDLING CONTROL

One of the main issues upon breakout was the FOV of the pilots during steep approaches at high airspeeds. At approaches above 8-degree glide slope and above 90 knots, the pilot's field of view was qualitatively evaluated. The deceleration attitude of the aircraft was approximately 10-12 degrees nose up once the aircraft cleared through the 100 feet AGL ceiling. Because of the aircraft nose high attitude, approximately 200 feet of the landing field was obstructed, HQR 8. During an approach into a hot landing zone the pilot will completely lose sight of the intended landing area. The severely blocked forward FOV during deceleration high airspeeds and steep approach angle limited the approach angle in this aircraft. The minimal aircraft small deck angles, shown in Figure 4-20, did not affect the FOV issues for the different glide slope and airspeed combinations.

2. VIBRATION

Vibration levels were qualitatively evaluated during all approaches. While conducting the approaches, a moderate for per revolution (4 per) was noticeable to both pilots while fully occupied by the task (VAR 6). The vibration was prevalent at 50 to 60 percent torque, at approximately 25 knots. This occurred at a critical portion of the approach (last 1/3 just prior to touchdown), and also while the pilot's FOV was minimized. The pilot should have noticed the vibration, thus increasing the amount of distractions during the approach. The moderate 4 per vibration at low torque and low airspeeds was a minimal problem.

3. AIRCRAFT CONTROL

Aircraft control was evaluated for airspeeds above 90 knots. Airspeeds above 90 knots caused the pilot to move the cyclic abruptly 2 inches forward and aft every second to attempt to decelerate and control the aircraft upon breakout. Figure 4-20, shows that distances traveled and time to stop the aircraft into the marshalling area was adequate but degraded to inadequate for airspeeds above 100 knots.. Maintaining control of the aircraft was difficult to impossible at these airspeeds. At airspeeds above 90 knots, the aircraft traveled longer distances and limited the amount of confined areas the aircraft could land. FOV issues came into play at airspeeds above 90 knots because of the large and frequent aft cyclic inputs required to decelerate the aircraft. During a confined area approach at airspeeds above 90 knots, the aircraft required considerable pilot compensation for control, HQR 8.

4. HEADING CONTROL

Heading control was qualitatively evaluated during airspeeds below 90 knots upon break out. The aircraft maintained heading above 60 knots due to FPS. Below 60 knots, the pilot had to input less than 1/4 inch of pedal every 5 seconds to maintain heading upon break out. Figure 4-20, shows that distance traveled and time to stop and control the aircraft was optimum and minimal at these airspeeds. Minimum pilot input was required to hold heading and to maintain FOV due to the minimal aft cyclic input to decelerate the aircraft, HQR 4. Within the scope of this test, heading control at airspeeds below 90 knots was adequate for GPS approaches.

5. LANDING ON SPOT

The aircraft was evaluated on bringing the aircraft to a 10-feet AGL hover over the intended spot in the marshalling area for 10-degree glide slope at 120 knots. The desired tolerances were +/- 10 feet longitudinal and lateral and 10 foot AGL above ground. Adequate tolerances were +/- 20 feet longitudinal and lateral and 20 feet AGL above ground. Once aircraft breakout occurred, the pilot attempted to slow the aircraft's high rate of descent, but failed, and the aircraft crashed into the ground bouncing up approximately 100 feet, shown in Figures 4-7, 4-8, and 4-9. IOS used the simulator crash override system to allow the pilot to complete the evaluation run, HQR 10.

6. REMAINING EVALUATIONS FOR COMPLETION OF LANDING FOLLOWING BREAKOUT

Figure 4-20, shows remaining aircraft sink rates, aircraft deck angles, distance traveled upon breakout, time to bring the aircraft to a 10 feet AGL hover, and HQRs for the approaches with respect to glide slope angle and airspeed combinations upon breakout for landing. Figure 4-21, shows the handling qualities ratings using glide slope angle, and Figure 4-22 shows the handling qualities ratings using airspeeds following breakout. Figure 4-23, depicts the HQR ratings with respect to each airspeed and glide slope angle combination for completion of landing following breakout. The HQR ratings were grouped by numerical values with the understanding that tolerance scales were as follows: desired HQR 4 and below, adequate HQR 5-7, and inadequate or do not perform

HQR 8-10. Figures 3-2 and 3-3, show dimensions for projected ILS touchdown point in the marshalling area.

Desired and adequate handling qualities rating were achieved at airspeeds and glide slope angle combinations below 100 knots and below 7 degree respectively. Ratings for the 6 and 7 degree glide slope degrade from desired to adequate at high airspeeds above 100 knots. The 9 and 10 degree glide slope ratings reflect both the complete loss of visual contact with the landing spot and the increased workload required to control aircraft at high (100 to 120 knots, as shown in Figure 4-22) approach airspeeds. Approaches at airspeeds above 100 knots and glide slope angles above 8 degree were degraded somewhat by the loss of intended landing spot from the cockpit field of view through the breakout in visibility conditions. While particular cockpit windshield FOV varies among aircraft models, this points to important criteria for developing an approach procedure and selecting a glide slope angle. Therefore, the pilot must ensure a clear landing spot on final approach whenever atmospheric visibility conditions permit, and certainly prior to moving over the landing spot.

The maximum acceptable sink rate was approximately 1000 Feet Per Minute (FPM). Any sink rate above 1000 FPM wind gusts, max gross weigh of aircraft, hot days, and tail winds significantly affected the handling qualities and controllability of the aircraft. From the results, the optimum descent rate was approximately 800 FPM. This allowed the pilot to maintain enough power during the approach, with a minor power increase upon breakout, to decrease the aircraft rate of descent. At 800 FPM the aircraft aft cyclic input was minimal, thus increasing the pilots FOV into the marshalling area. At glide slope angles above 9 degree, the aircraft was using minimum power (almost in auto-rotational descent) normally at rates of descents above 1000 FPM. During breakout, the pilot had to significantly increase power to decrease the aircraft rate of descent resulting in a high workload.

The steeper the glide slope and faster the airspeed the more difficult it was to control the aircraft and achieve the 10-foot AGL hover over a specific spot on the ground. FOV had a major effect on landing on a spot because of decreased aircraft control and locating the intended spot in marshalling area. Figures 4-21 and 4-22 show the desired, adequate, and inadequate glide slope and airspeeds for landing on an intended landing spot.

4.5 COMBINED OVERALL RESULTS

Combined results from HQRs contours for all of the evaluated task and subtasks listed in Figures 4-4, 4-13, and 4-23, are presented in Figure 4-24. The highlighted area represents the three evaluated tasks overlapped area based on the desired airspeeds and glide slope angles combination.

In setting boundaries for airspeed and glide slope angle, several factors were affected. These boundaries are depicted in Figure 4-24. Flying airspeeds above 90 knots the following occurred: FOV was degraded, increased workload, and handling qualities decreased. Flying glide slope angles above 8 degree glide slope angles the following occurred: glide slope intercept was more difficult, FOV upon break out was degraded, sink rates above 800 FPM, and handling qualities decreased. Qualitative comments from the pilots noted that any approach below 7-degree glide slope angle does not provide safe aircraft clearance for obstacles and prevented the pilot from locating the intended spot upon breakout. These three boundaries set the areas between desired and adequate to degrading adequate and inadequate.

After analyzing the quantitative combined overall HQR data in Figure 4-24 and reviewing the qualitative data, the 7-degree at 70 knots combination shown on Figures 4-25, 4-26, and 4-27 were determined as the overall desired or optimum airspeed glide slope angle combination. The aircraft effectively captured airspeed and intercepted the glide slope, tracked the glide slope and localizer, maintained FOV and control upon breakout, and landed on the intended landing spot in the marshalling area, overall HQR 2.

The worst configuration for all the approaches was 10-degree glide slope at 120 knots shown on Figures 4-7, 4-8, and 4-9. The pilot had to decrease the collective significantly and rapidly causing a high rate of descent just to intercept the glide slope. Large flight controls input were required to maintain the aircraft on localizer course and glide slope. Once aircraft breakout occurred, the pilot attempted to slow the aircraft's high rate of descent, but failed, and the aircraft crashed into the ground. Any approach above 10 degrees at 120 knots to 100 knots resulted in major deficiencies with control being lost during some portion of the required operation during breakout, thus losing the intended spot or crashing, HQR 10.

Installing a digital moving map in the cockpit would assist the pilots in situation awareness. The main area of assistance using digital moving map was during glide slope intercept. If the pilots could anticipate the descent for steep glide slope angles at high airspeeds, flying through the glide slope and rapid/significant decreases in the collective could be avoided. Moving digital map could also assist in locating and anticipating Final Approach Fix, thus increasing approach capture times and control of the aircraft.

Installing a flight director in the aircraft to assist the pilot in maintaining the glide slope and localizer track and to slow the aircraft airspeed during the approach would decrease pilot workload and increase handling qualities of the aircraft tremendously. This would allow the pilots to began approaches above 100 knots and have the flight director slow the aircraft to 80 knots or 70 knots before breakout and reach the desired airspeed glide slope angle combination region, shown in Figure 4-24. This would also decrease pilot workload and enable the pilot to fly glide slopes angles above 9 degree safely and effectively.

Installing an Advance flight director (auto pilot function) would automatically control the aircraft, locate the intended landing spot, and bring the aircraft to a 10-foot AGL hover upon breakout. This would significantly improve the HQRs and increase the aircraft airspeed to glide slope angle combinations for desired and adequate tolerances.

CHAPTER 5

CONCLUSION

This thesis examines the feasibility of using steep GPS approaches in IMC for the military. The experiments were conducted in the UH-60A/L Flight Simulator at Fort Hood, Texas, with a crew of two pilots. The experiment was conducted with all aircraft systems functioning normally, full engine power available (no one engine inoperative evaluations), and all approaches were carried through breakout to a vertical landing (no missed approaches). Qualitative and quantitative data was collected on aircraft performance and handling qualities. The glide slope angles were varied, starting steep and ending with a shallow approach configuration. The glide slope angles were 10, 9, 8, 7, and 6 degrees. Each pilot flew each approach at various airspeeds, 120, 100, 90, 80, and 70 knots. Based on the 50 simulated approaches flown by two pilots, the following conclusions are presented:

1. The Blackhawk simulator worked well to perform these experiments. Qualitative and quantitative data was able to be collected effectively. Setting useful evaluation parameters required many flights using trial and error methods. In the simulator, the operator could move the aircraft around the tactical battlefield in seconds compared to minutes or hours in the actual aircraft. This made adjusting parameters easy. The main advantage in using the simulator was that the pilots could push the evaluation parameter of the test and not worry about losing their lives by crashing the aircraft. Possible drawback was the simulator may not have provided a realistic environment, thus

effecting the HQR ratings. Aircraft flight hours in the simulator were less costly and easier to obtain.

2. Not having to instrument the actual aircraft to collect the specific quantitative data saved money and time. Collecting qualitative and quantitative data proved effective. The quantitative data supported the qualitative data and assisted in compiling the results. Collecting both types of data supported the analysis and conclusions.

3. When the aircraft was flown at constant airspeed and glide slope angle, the desired combination was 6 to 7 degree glide slopes at 70 to 80 knots. Airspeeds and glide slope angles above 100 knots and 9 degree were inadequate respectively, which resulted in degraded performance and handling qualities and increased pilot workload. Pilots commented on the loss of the landing spot from the cockpit FOV during 100 knots and above airspeeds.

4. Keeping the glide slope angle constant was a limitation of the GPS system installed in the aircraft and pathfinders on the ground. There was no way to program a variable contour. Keeping the glide slope angle constant and varying the airspeed during the approach was possible. Because the GPS ILS approach response times were two to three times more sensitive compared to a normal ILS approach, pilot workload exponentially increased during evaluation task where the pilots attempted to slow the aircraft while simultaneously tracking the glide slope and localizer course.

5. The maximum acceptable sink rate was approximately 1000 FPM. Any sink rate above 1000 FPM wind gusts, max gross weigh of aircraft, hot days, and tail winds significantly affected the handling qualities and controllability of the aircraft. From the results, the optimum descent rate was approximately 800 FPM.

CHAPTER 6

RECOMMENDATIONS

1. It is recommended to maintain the airspeed and glide slope angle constant, and fly approaches at 7-degree at 70 knots. If the aircraft is equipped with flight director to control airspeed deceleration, the airspeed can begin between 120 to 70 knots. The flight director will ensure the airspeed is at 70 knots upon breakout. This will ultimately ensure the aircraft will effectively capture airspeed and intercept the glide slope, track the glide slope and localizer, maintain FOV and control upon breakout, and land on the intend landing spot in the marshalling area.

2. It is recommended not to fly these approaches above a 10-degree glide slope at 120 knots.

3. Install a digital-moving map in the cockpit to assist the pilots in glide slope intercept and situation awareness.

4. Install a flight director using airspeed decelerator.

5. Install a fully coupled autopilot to control the aircraft during all phase of the approach to landing.

REFERENCES

1. Clark, Bill, Aviator's Guide to GPS, TAB Books: 1994

2. Hardesty, Mark, Evolution Leads to Revolution - Helicopter Flight Testing Using RTK DGPS Technology, The Boeing Company, Mesa Arizona, Published October 1999.

3. Hotchkiss, Noel J., A Comprehensive Guide to Land Navigation with GPS, Alexis Publishing: 1994.

4. Student Handout, Global Positioning System (GPS), United States Army Aviation Center Fort Rucker (USAAVNC), Alabama, 1992.

5. Student Handout, UH-60 Navigation and Command Instrument System Processor (NAVCISP), United States Army Aviation Center Fort Rucker (USAAVNC), Alabama, 1993.

6. Technical/Operator's Manual, UH-60 A/L and EH-60 A, United States Army Technical Manual 1-1520-237-10, Published Headquarters, Department of Army 31 October 1996.

7. Instructor Utilization Handbook, UH-60A/L Flight Simulator, Distribution to U.S. Government Agencies and their contractors, requests for this document refer to U.S. Army, STRICOM, Orlando, Florida, Change 1, 31 October 1998.

8. Federal Air Regulation (FAR) Part 91, General Operating and Flight Rules, Federal Aviation Administration (FAA), 1989.

9. Cooper, G.E. and Harper, R.P., The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities and Vibration scale, NASA TND-5153, 1969

10. Decker William A., Evaluation of Two Cockpit Display Concepts For Civil Tiltrotor Instrument Operations On Steep Approaches, NASA Ames Research Center, Moffett Field, California, June 1992.

11. Decker, William A., Piloted Simulator Investigations of a Civil Tilt-Rotor Aircraft on Steep Instrument Approaches, AHS 48th Annual Forum, Washington, D.C., June 1992.

12. Hindson, William S. and Chen, Robert T.N., Operational Tests of Noise Abatement Approaches for Rotorcraft Using Differential GPS for Guidance, NASA Ames Research Center, Moffett Field, California, June 1998.

13. Kimberlin, Ralph D., et.al., Program Plan for the Development of a Helicopter Terminal Area Instrument Procedures, FAA Final Report, Grant Number 93-G-007, October 1993.

APPENDICES

APPENDIX A

Figures for Experimental GPS and Apparatus (Chapter 2)

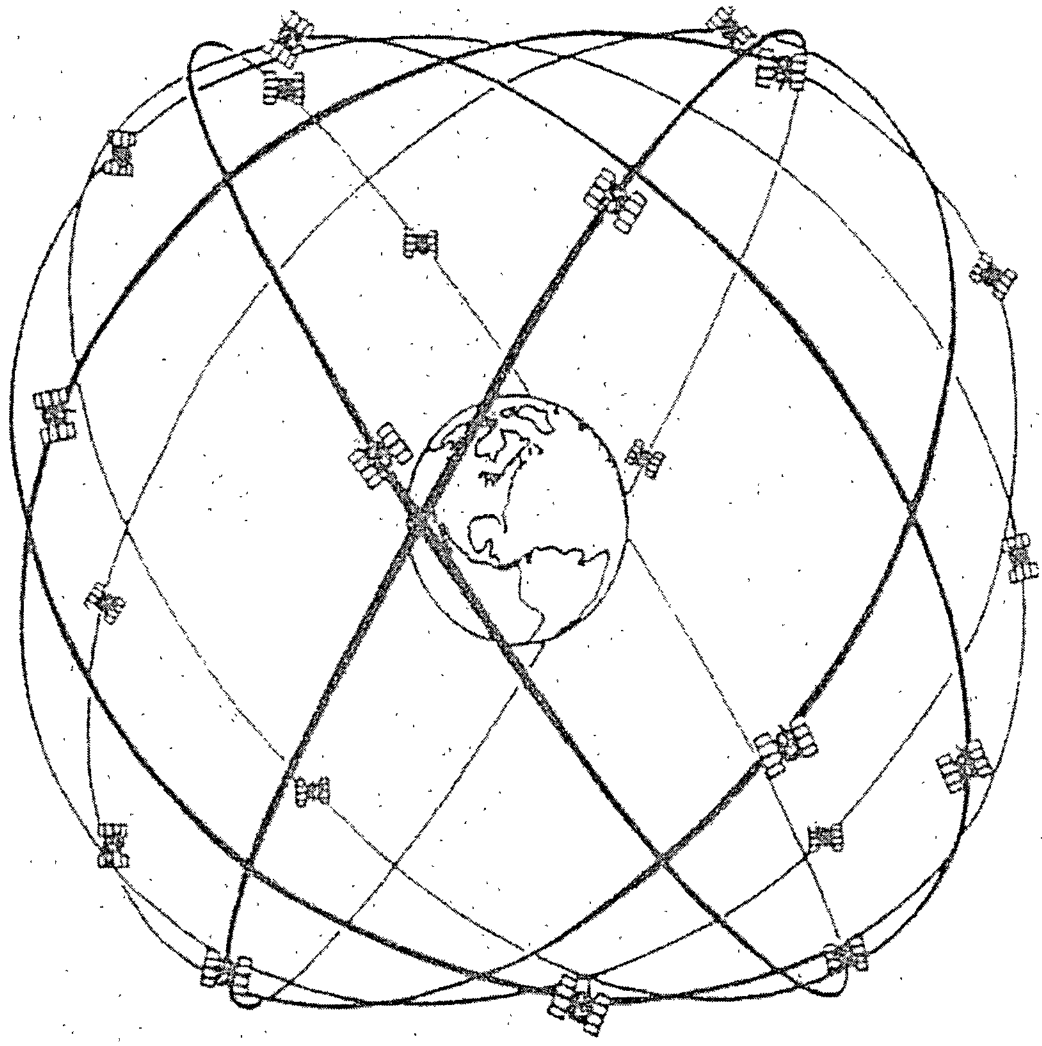


Figure 2-1. Orbit of Satellites

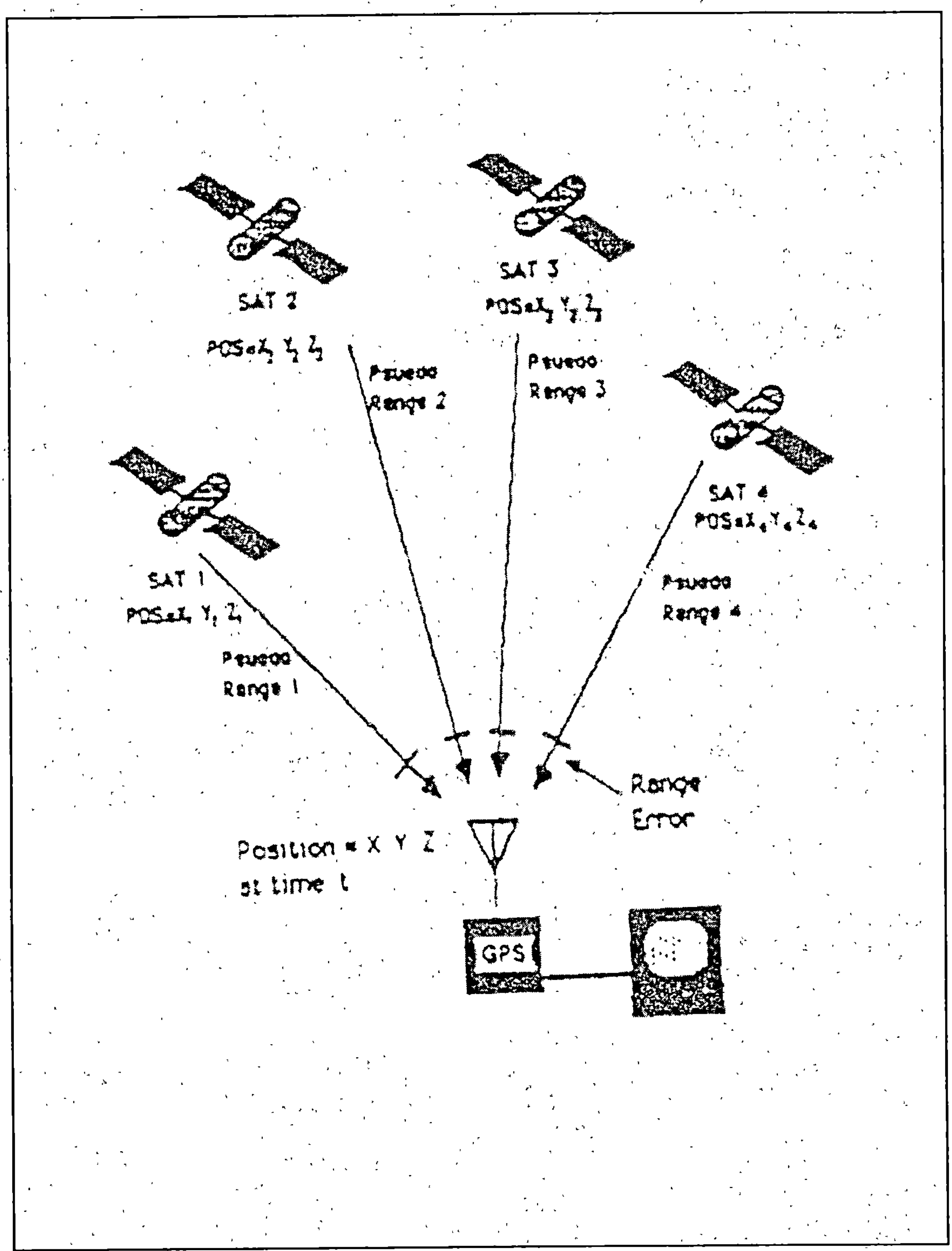


Figure 2-2. GPS Satellites

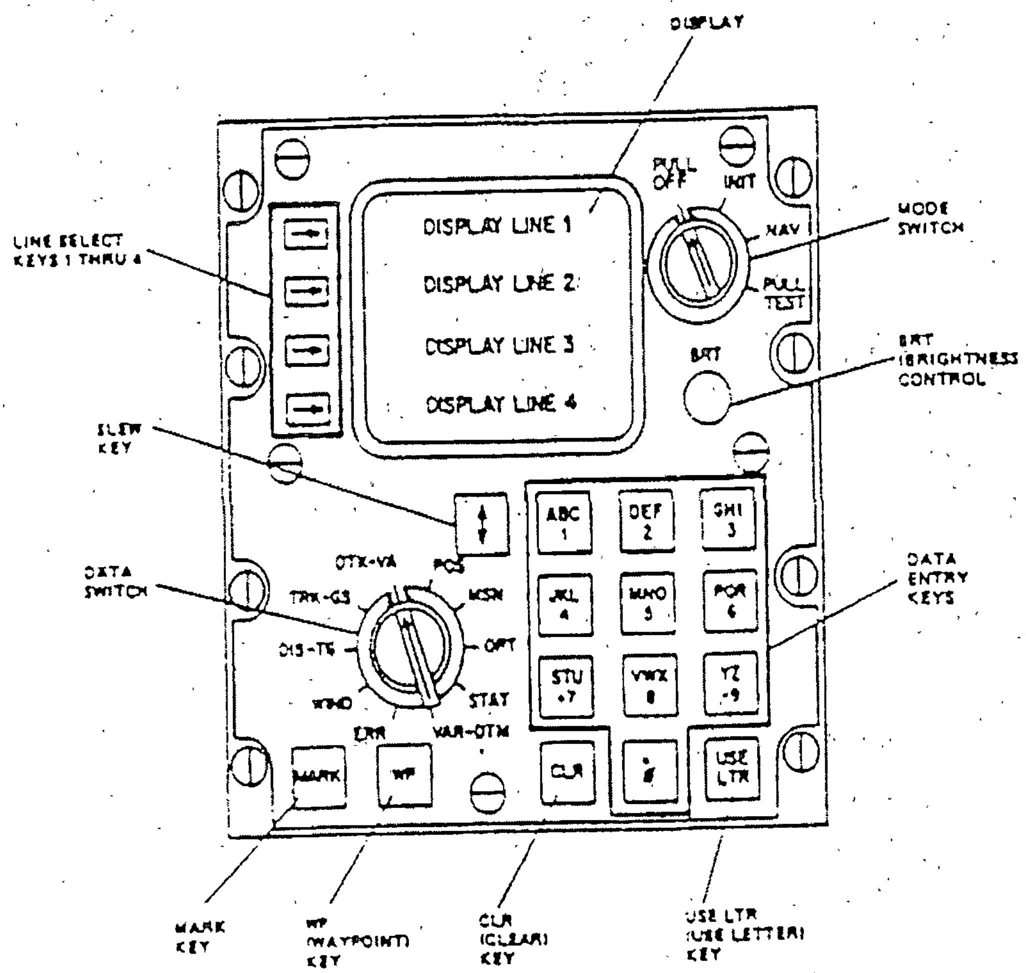


Figure 2-3. Compute Display Unit

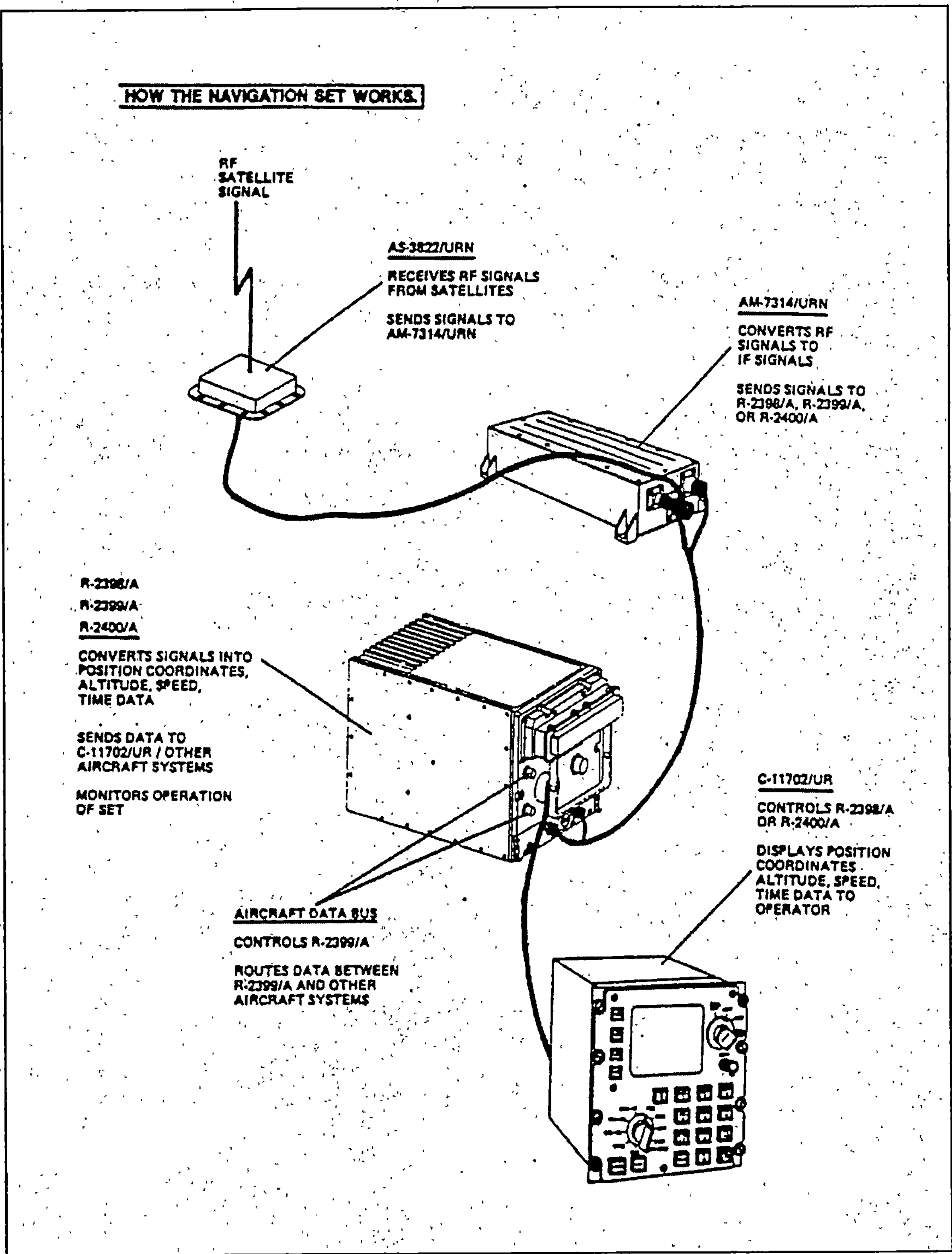


Figure 2-4. NAVSTAR GPS Component Functions and Setup

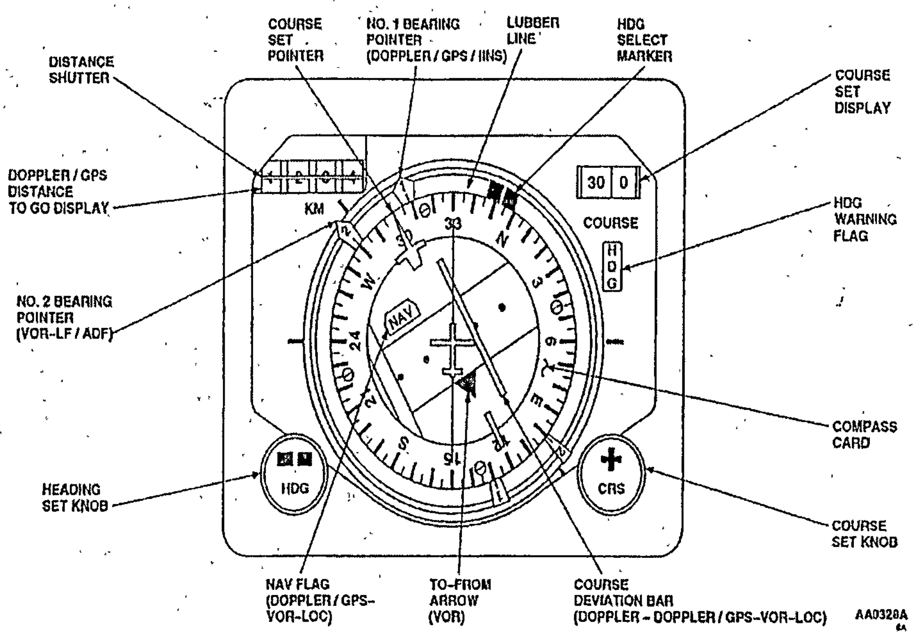


Figure 2-5. Horizontal Situation Indicator

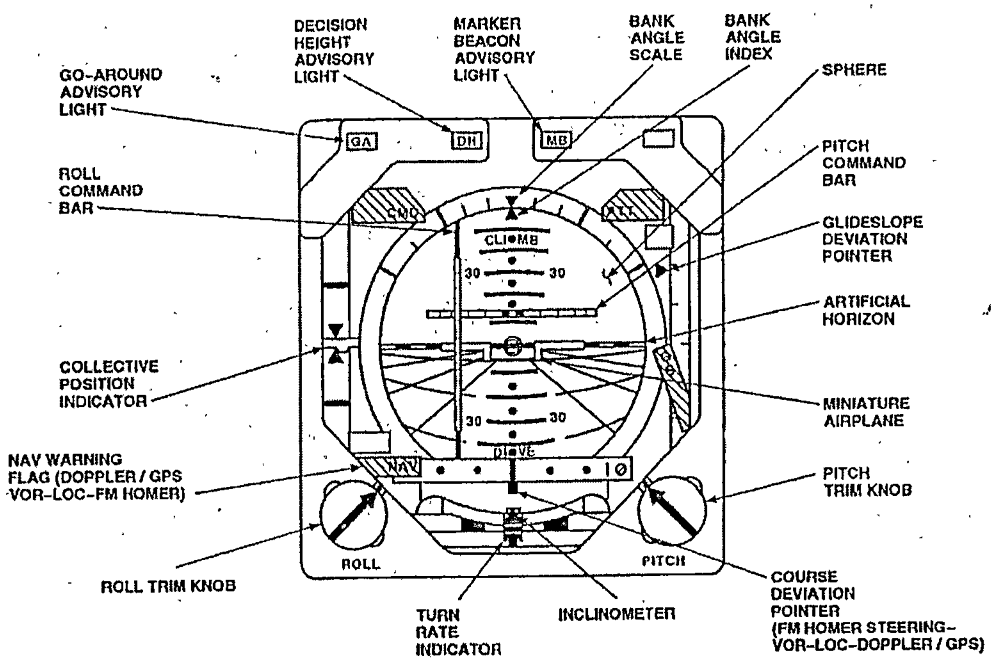


Figure 2-6. Vertical Situation Indicator

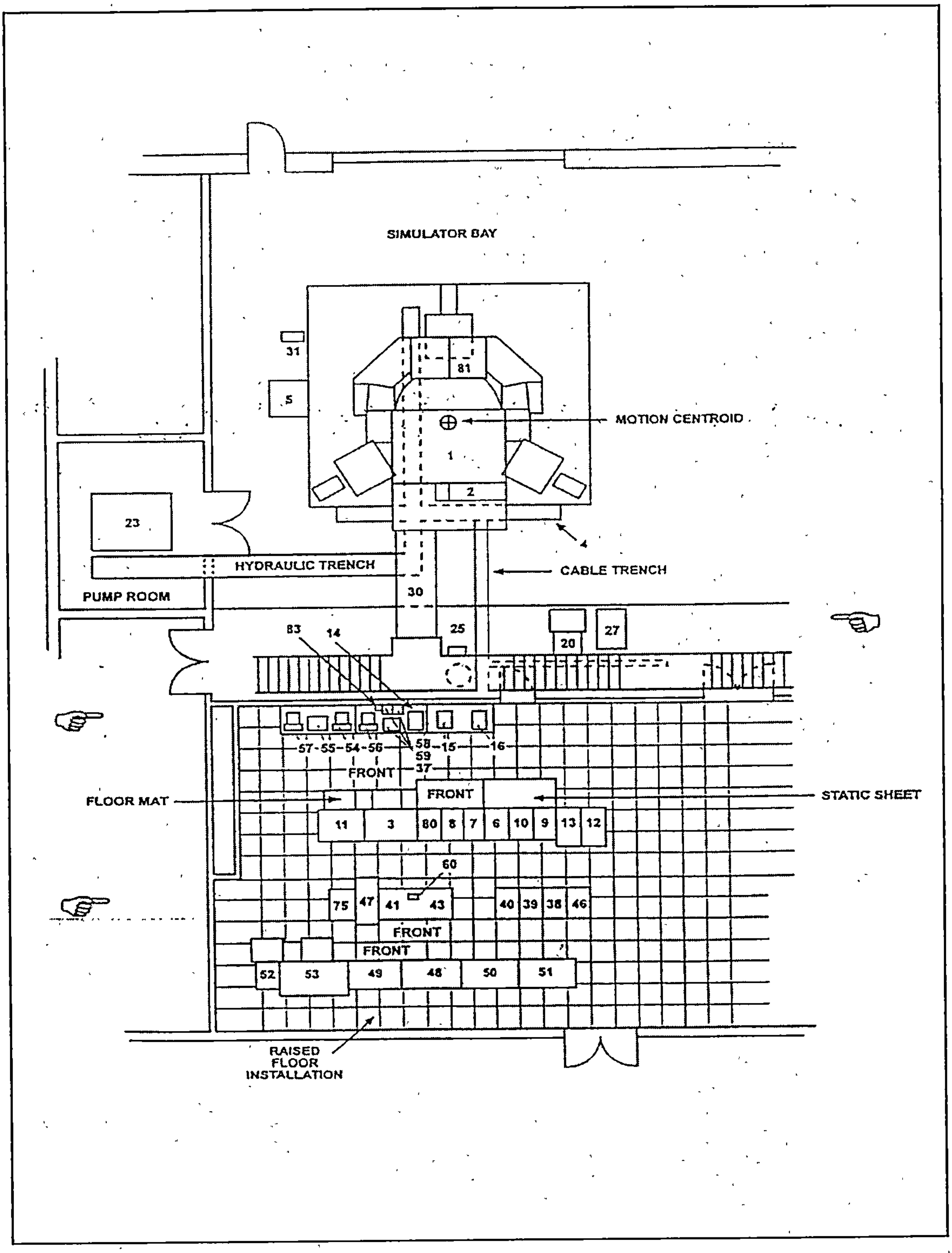


Figure 2-7. UH-60Flight Simulator Typical Layout

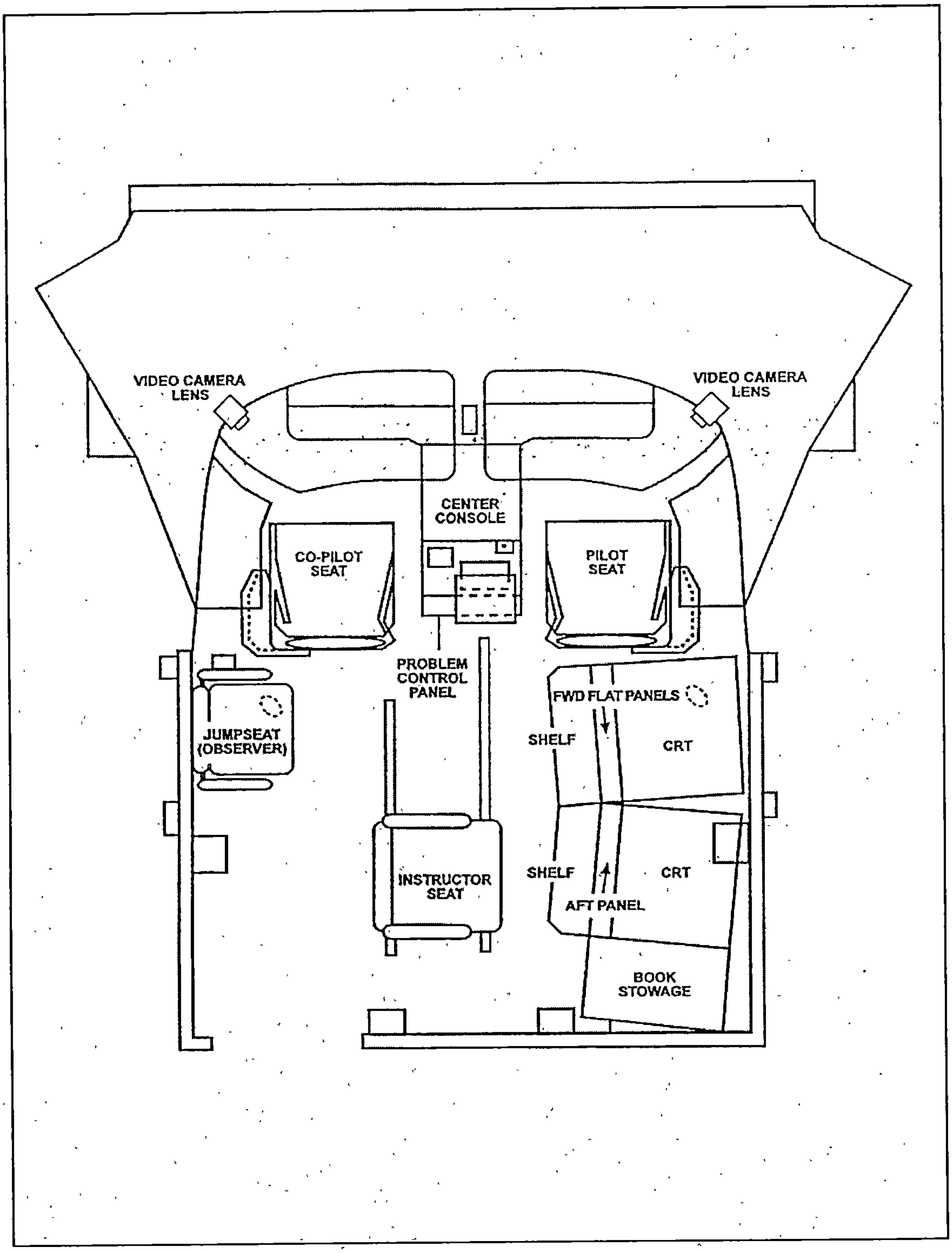


Figure 2-8. Instructor/Operator Station

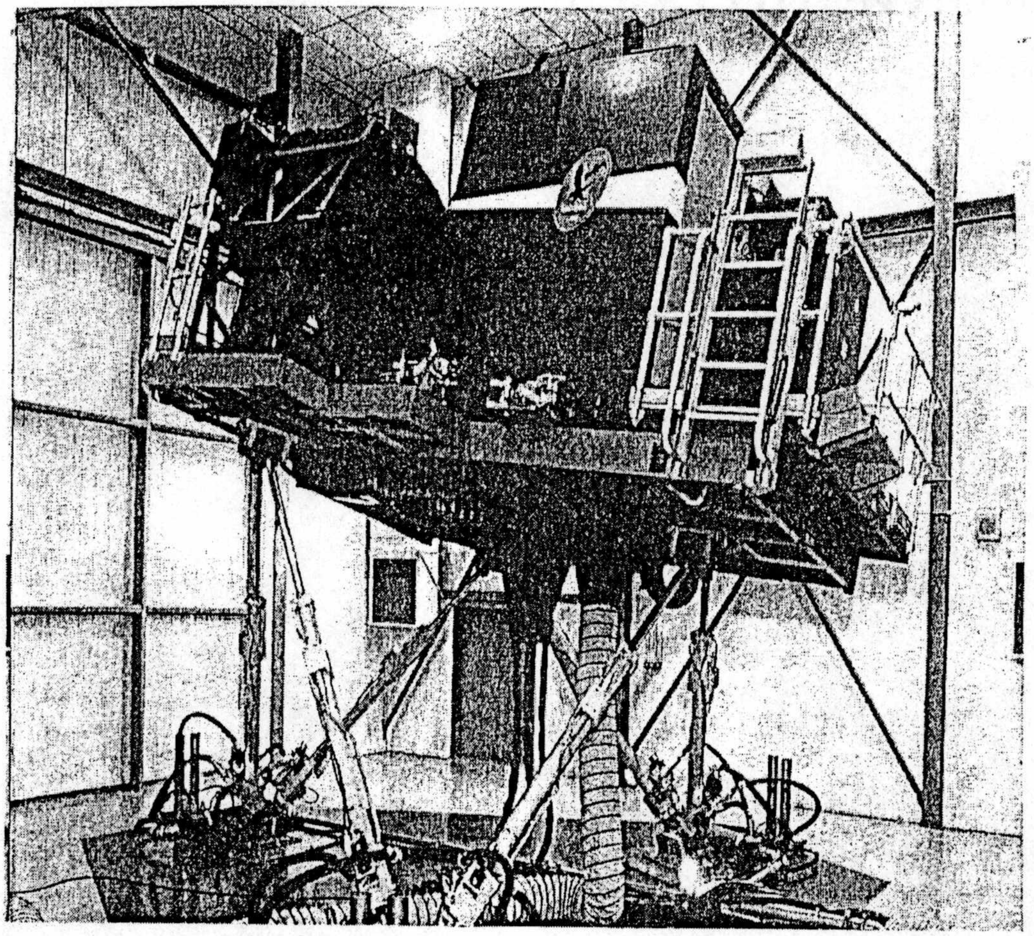
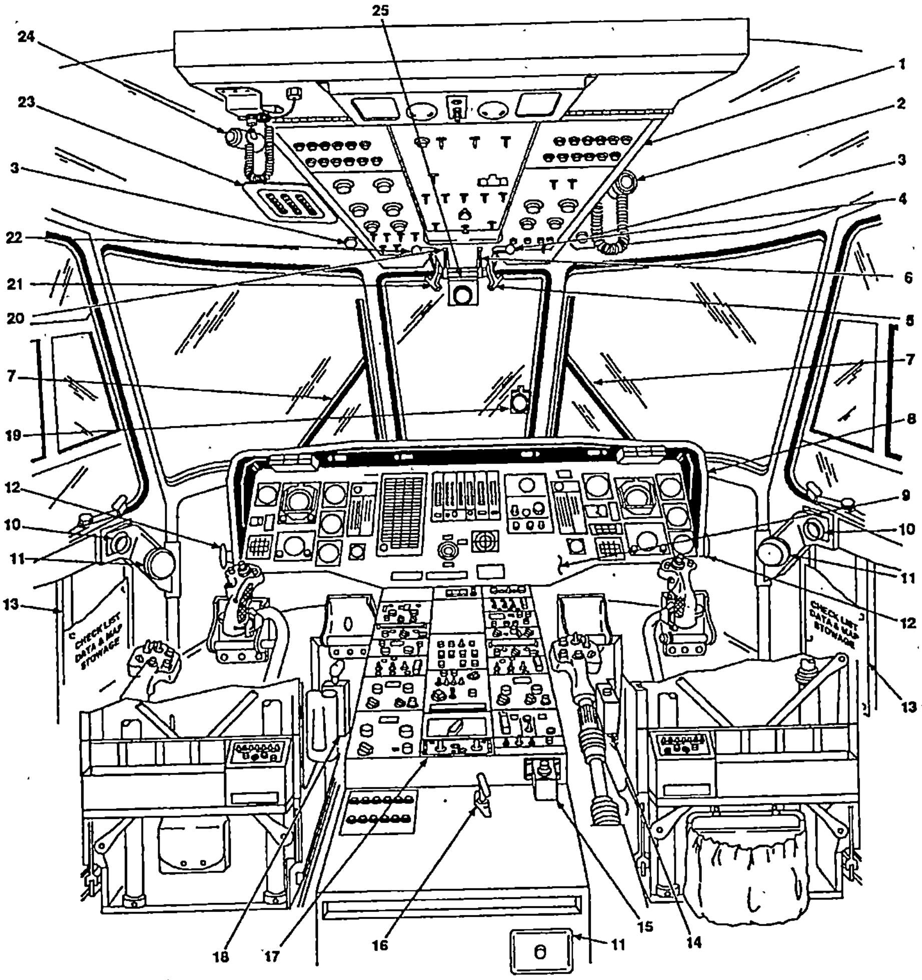


Figure 2-9.UH-60 Black Hawk Flight Simulator

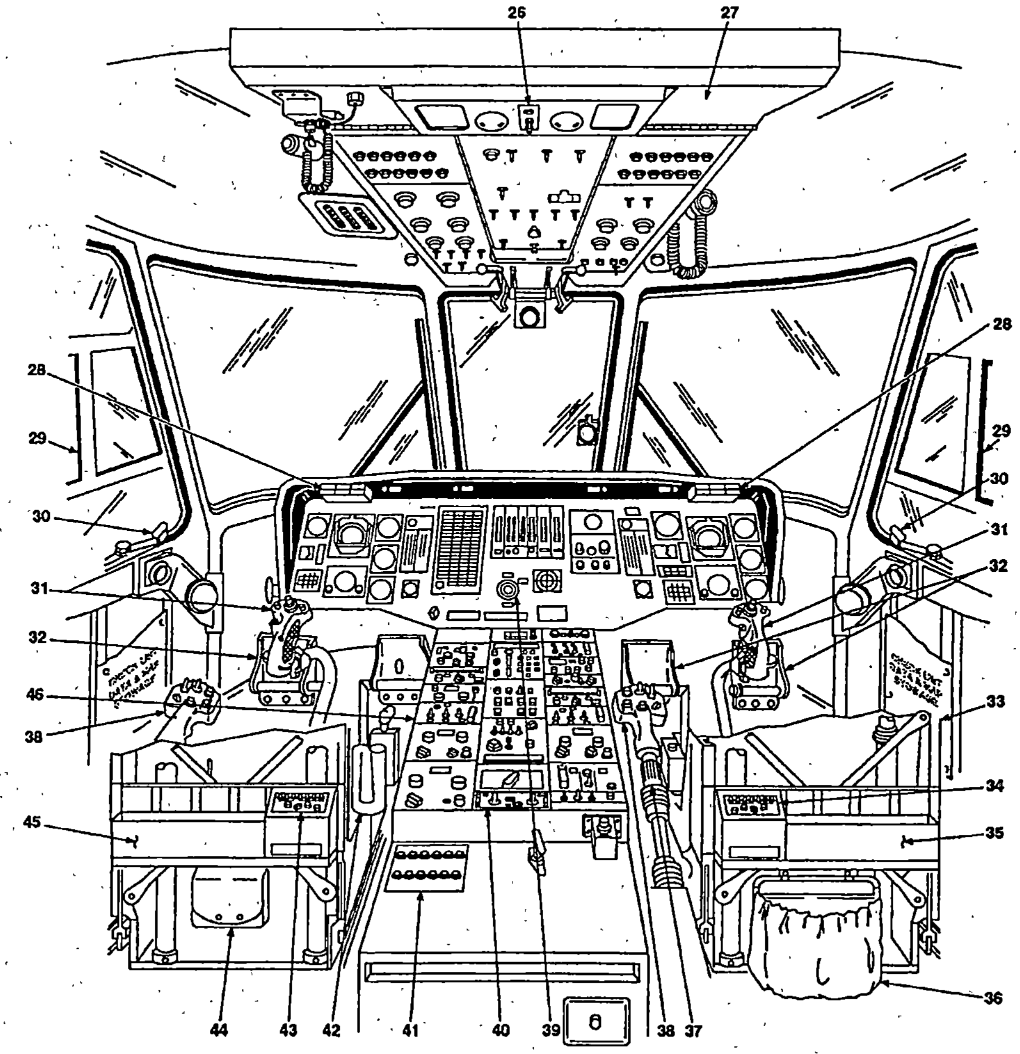


1. UPPER CONSOLE
2. PILOT'S COCKPIT UTILITY LIGHT
3. FREE-AIR TEMPERATURE GAGE (ON HELICOPTERS WITH HEATED CENTER WINDSHIELD)
4. NO. 2 ENGINE FUEL SELECTOR LEVER
5. NO. 2 ENGINE OFF / FIRE T-HANDLE
6. NO. 2 ENGINE POWER CONTROL LEVER
7. WINDSHIELD WIPER
8. INSTRUMENT PANEL GLARE SHIELD
9. INSTRUMENT PANEL
10. VENT / DEFOGGER
11. ASHTRAY
12. PEDAL ADJUST LEVER
13. MAP / DATA CASE
14. CABIN DOME LIGHTS DIMMER
15. CHAFF RELEASE SWITCH
16. PARKING BRAKE LEVER
17. FUEL BOOST PUMP PANEL
18. LOWER CONSOLE UTILITY LIGHT
19. STANDBY (MAGNETIC COMPASS)
20. NO. 1 ENGINE POWER CONTROL LEVER
21. NO. 1 ENGINE OFF / FIRE T-HANDLE
22. NO. 1 ENGINE FUEL SELECTOR LEVER
23. EH AC ESNTL BUS CIRCUIT BREAKER PANEL
24. EH COPILOT'S COCKPIT UTILITY LIGHT
25. FREE-AIR TEMPERATURE GAGE (ON HELICOPTERS WITHOUT HEATED CENTER WINDSHIELD)

AA0515_1A

Figure 2-10. UH-60 Cockpit Layout (Sheet 1)

TM 1-1520-237-10



26. COCKPIT FLOODLIGHT CONTROL
27. UPPER CONSOLE
28. MASTER WARNING PANEL
29. SLIDING WINDOW
30. COCKPIT DOOR EMERGENCY RELEASE
31. CYCLIC STICK
32. DIRECTIONAL CONTROL PEDALS
33. PILOT'S SEAT
34. CREW CHIEF / GUNNER ICS CONTROL PANEL
35. CREW CHIEF AMMUNITION / GRENADE STOWAGE COMPARTMENT
36. STOWAGE BAG
37. COLLECTIVE STICK FRICTION CONTROL
38. COLLECTIVE STICK GRIP
39. ENGINE IGNITION KEYLOCK
40. LOWER CONSOLE
41. BATTERY / BATTERY UTILITY BUS CIRCUIT BREAKER PANEL
42. FIRE EXTINGUISHER
43. GUNNER'S ICS CONTROL PANEL
44. FIRST AID KIT
45. GUNNER'S AMMUNITION / GRENADE
46. COPILOT'S SIDE LOWER CONSOLE

Figure 2-10. UH-60 Cockpit Layout (Sheet 2)

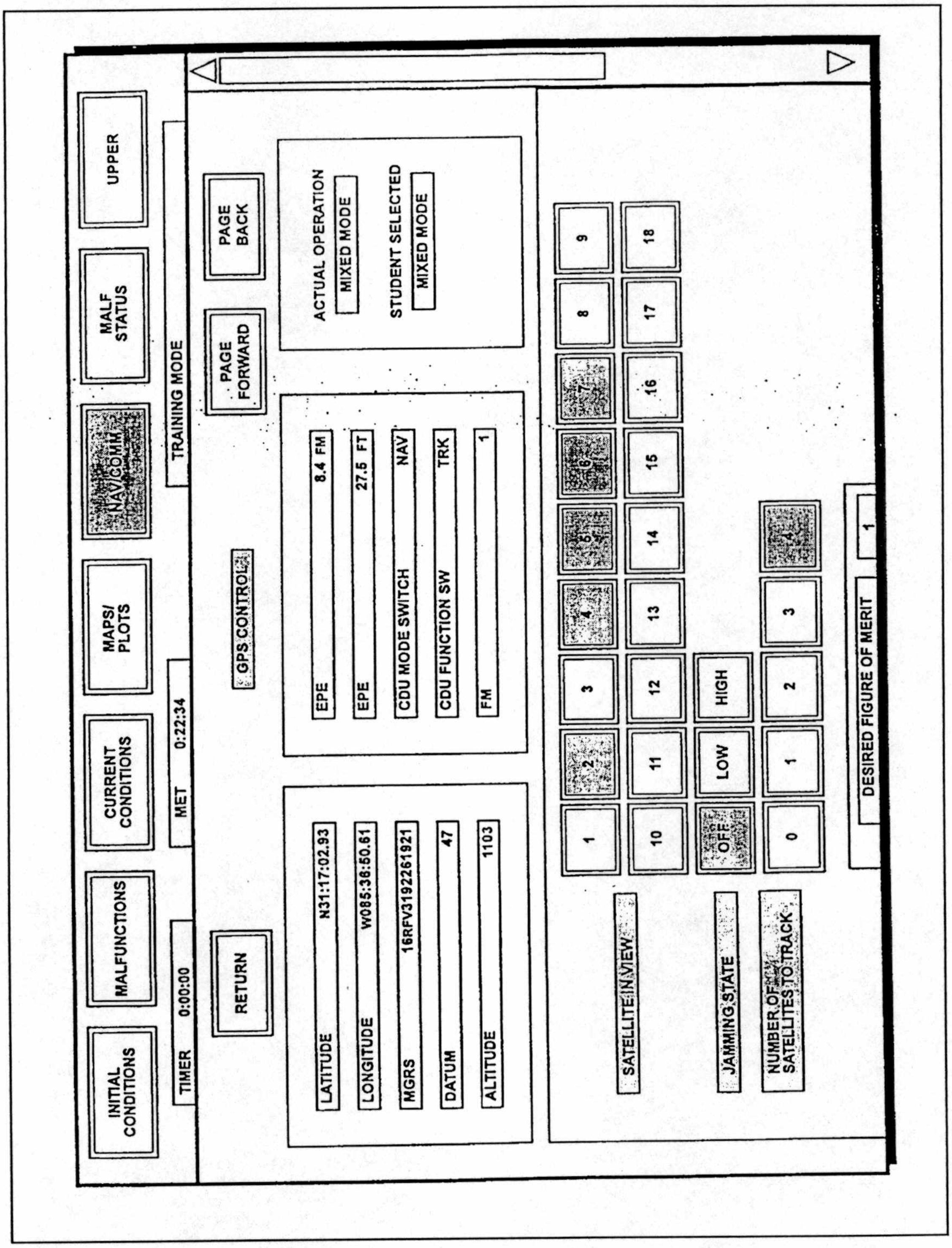


Figure 2-11. GPS Control Page

APPENDIX B
Figures for Test Procedures

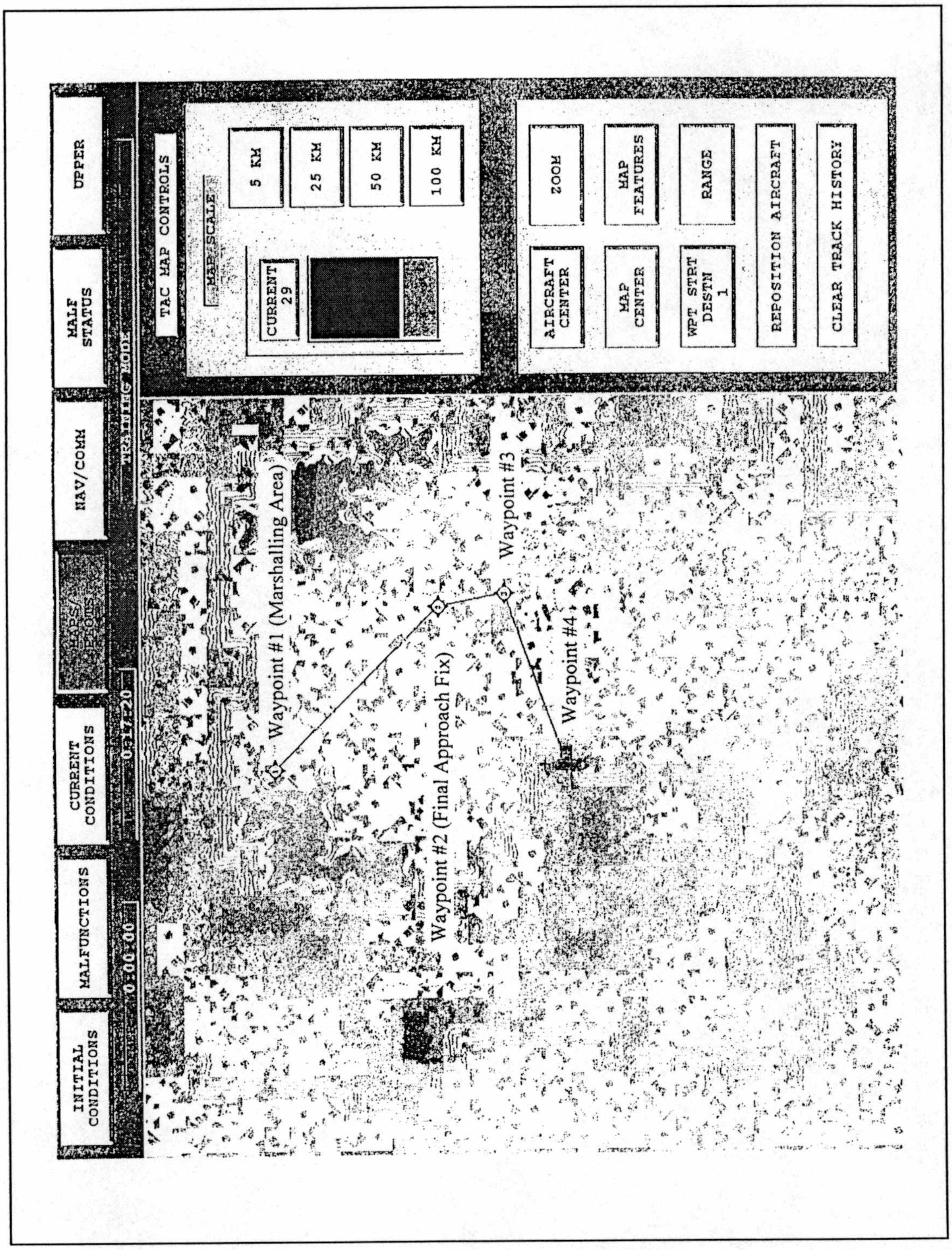


Figure 3-1. Tactical Mission Scenario

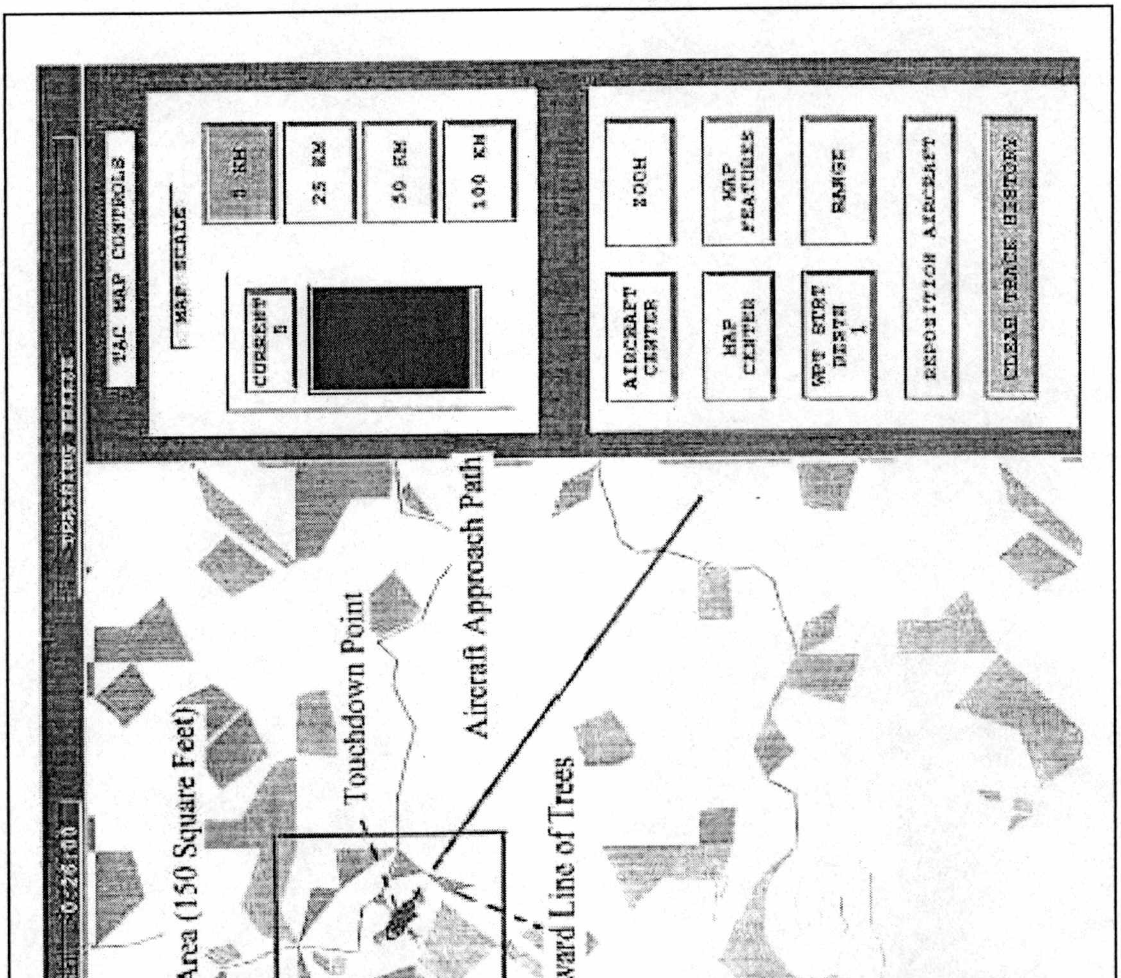


Figure 3-2. Top View of Marshalling Area

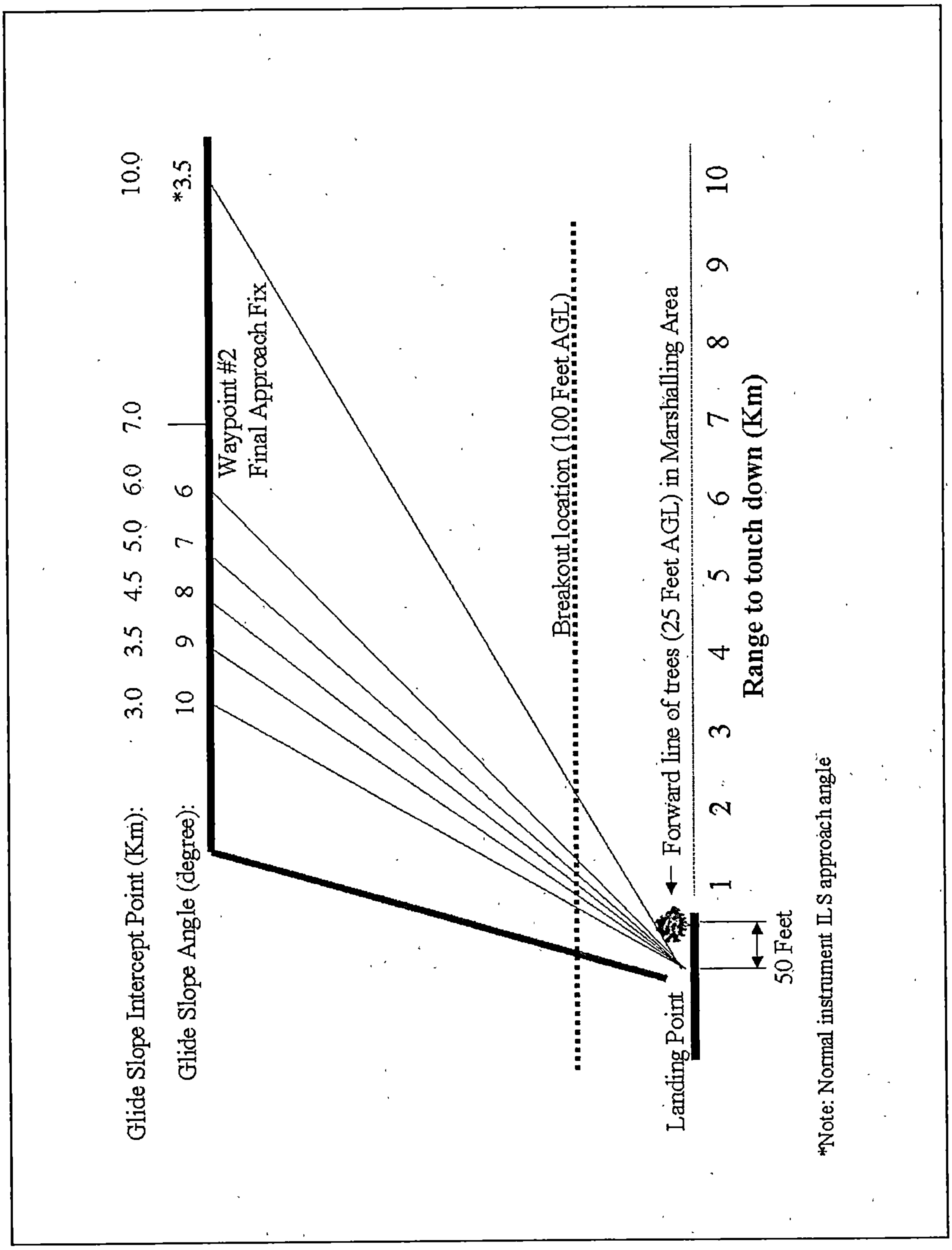


Figure 3-3. Glide Slope Intercept Locations

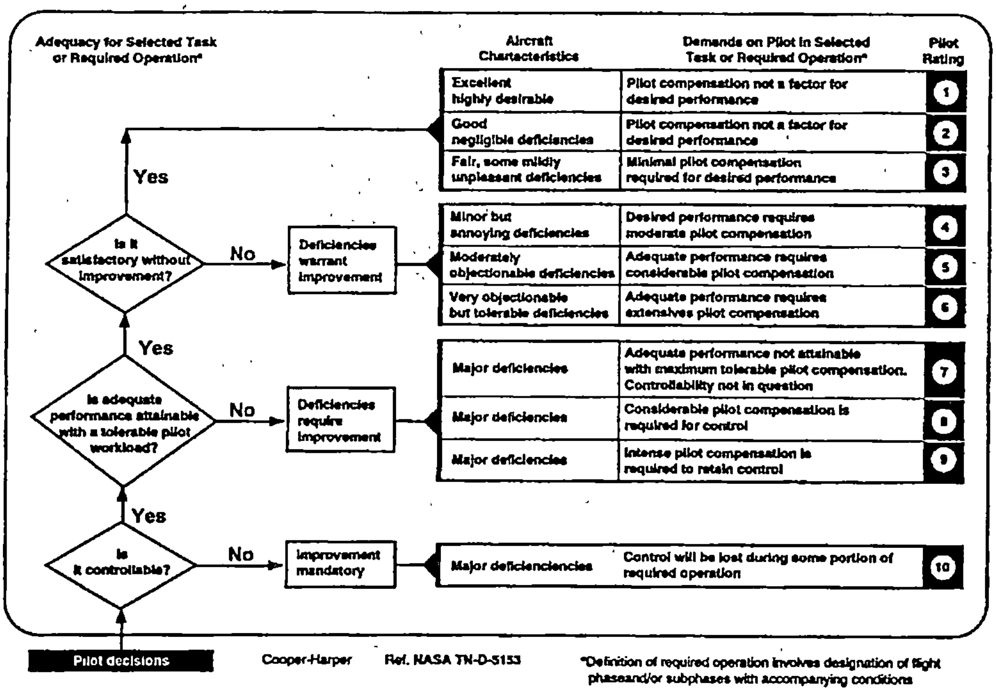


Figure 3-4. Cooper-Harper Rating Scale

RATING SCALE FOR QUALITATIVE ASSESSMENT OF VIBRATION

SCALE No.	LEVEL	SUBJECTIVE VIBRATION ASSESSMENT
		No perceptible vibration
1 2 3	Light	Not apparent to experienced aircrew occupied by their tasks, but noticeable if attention is directed to it or not otherwise occupied.
4 5 6	Moderate	Experienced aircrews, fully occupied by their tasks, are aware of vibration but it does not intrude so that work is affected, at least over a short period.
7 8 9	Severe	Vibration is immediately apparent to experienced aircrew when fully occupied. Performance of primary task may be affected, but control of the rotorcraft or aircrew duties are not seriously impaired if, when necessary, secondary tasks are neglected.
10	Intolerable	Physical discomfort or concern for the safety of the rotorcraft. Sole preoccupation to reduce vibration.

Note: Assessment using the above scale should include an estimate of the predominant frequency which may be expressed in relation to rotor speed e.g. VAR= One per rotor revolution

Figure 3-5. Vibration Scale

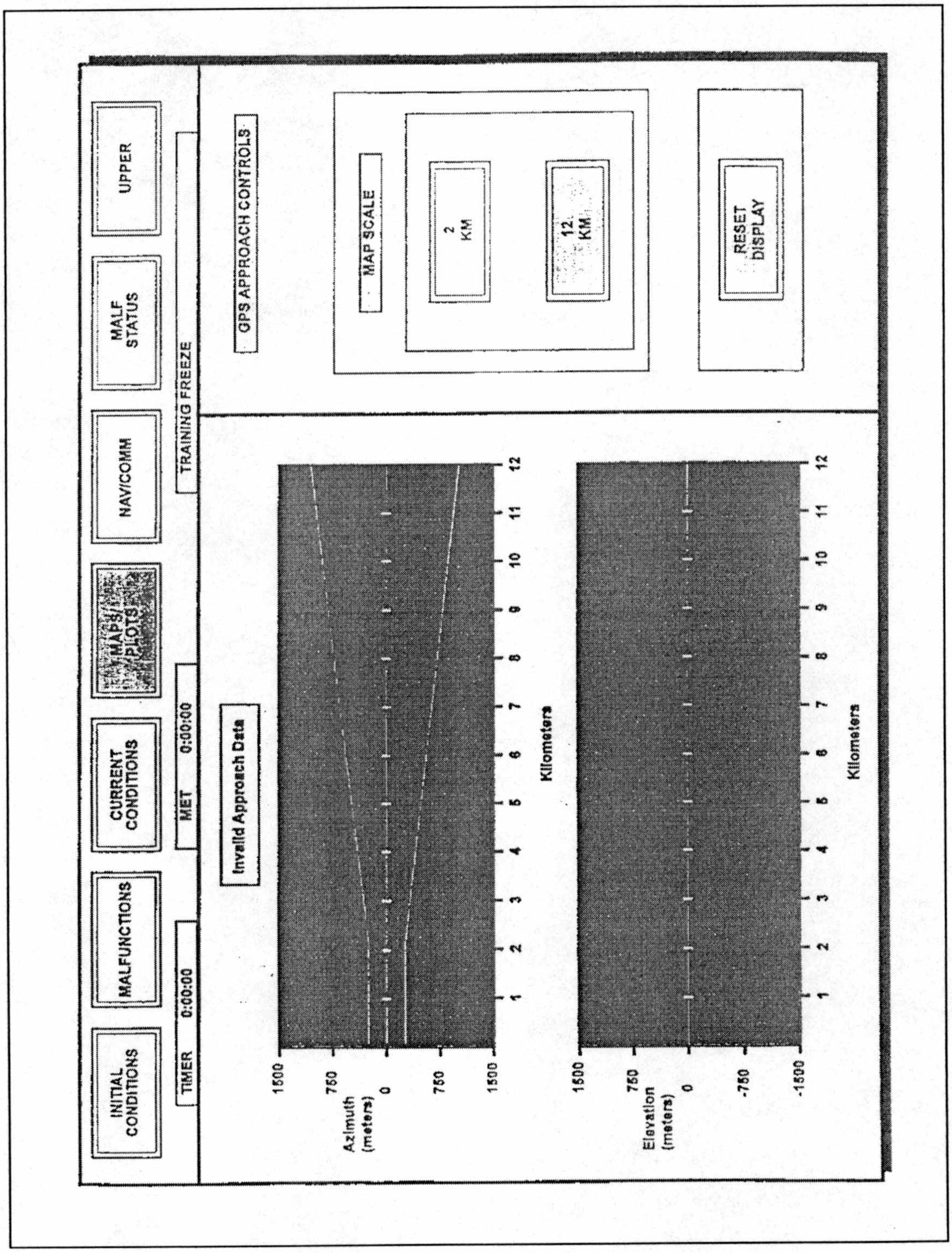


Figure 3-6. GPS Approach Plots Azimuth and Elevation vs Distance (12KM)

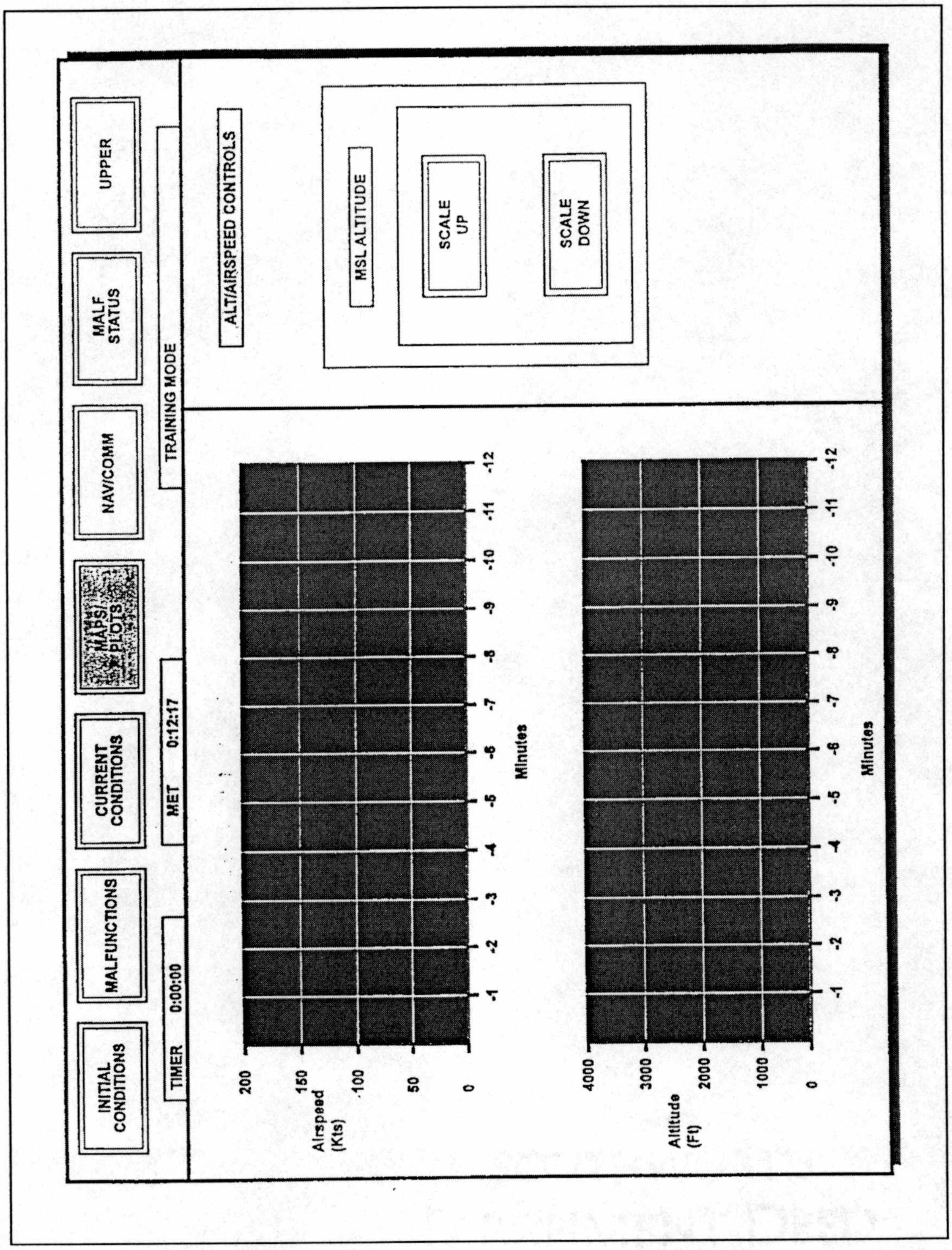


Figure 3-7. GPS Approach Plots Airspeed and Altitude vs Time

TEST AND TEST CONDITIONS

Task	Subtask	Altitude (feet)	Airspeed (Knots)	Glide slope Angle (Degree)	Remarks (1) (2) (5)
Level flight conversion to approach airspeed configuration and glide slope intercept	Airspeed Capture (3) (4)	2000 MSL	120, 100, 90, 80, 70	10, 9, 8, 7, 6	Winds were calm
	Glide slope Intercept				
Glide slope & Localizer Tracking	Maintain Glide slope & Localizer	2000 MSL – 100 AGL			
Landing	Breakout handling Control	100 AGL			
	Landing on intended Spot	10 AGL	120 - 0		

Notes:

(1) No external loads, all doors closed, BOOST, SAS1, SAS2, FPS, and TRIM – ON.
(2) Engine start gross weight was 18580 lb and CG of 360.0 inches aft, Sea Level.
(3) Evaluation runs began with aircraft in level flight at 120 knots, 2000 feet MSL
(4) Crew would configure the aircraft once passing through the last waypoint #2 approximately 7 KM out from the landing spot to the evaluation run airspeed.
(5) Both pilots flew the five airspeeds for each of the five glide slope angles.

Figure 3-8. Test and Test Conditions

Appendix C

Experimental Results (Chapter 4)

Airspeed (Knots)	Angle (Degree)	Pilot #1 (HQRs)	Pilot #2 (HQRs)
120	10	3	3
120	9	2	3
120	8	2	2
120	7	1	2
120	6	2	1
100	10	5	6
100	9	4	5
100	8	4	3
100	7	2	2
100	6	2	3
90	10	6	6
90	9	5	5
90	8	4	3
90	7	3	2
90	6	3	3
80	10	8	7
80	9	6	6
80	8	5	5
80	7	4	4
80	6	3	4
70	10	8	8
70	9	6	7
70	8	5	5
70	7	5	4
70	6	4	3

Figure 4-1. Level Flight Conversion to Approach Airspeed Configuration and Glide Slope Intercept HQR ratings

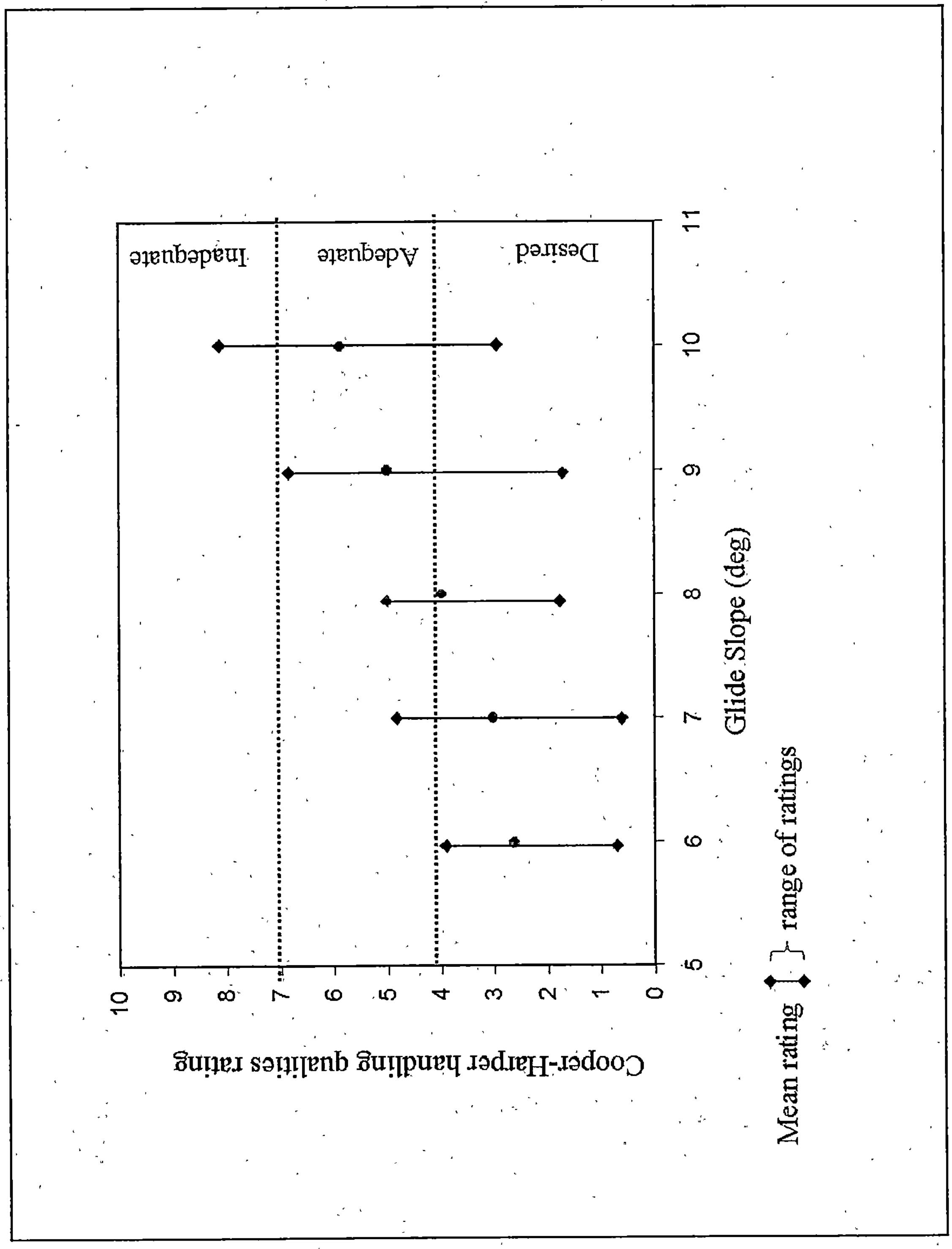


Figure 4-2. Handling Qualities Ratings Using Glide Slope

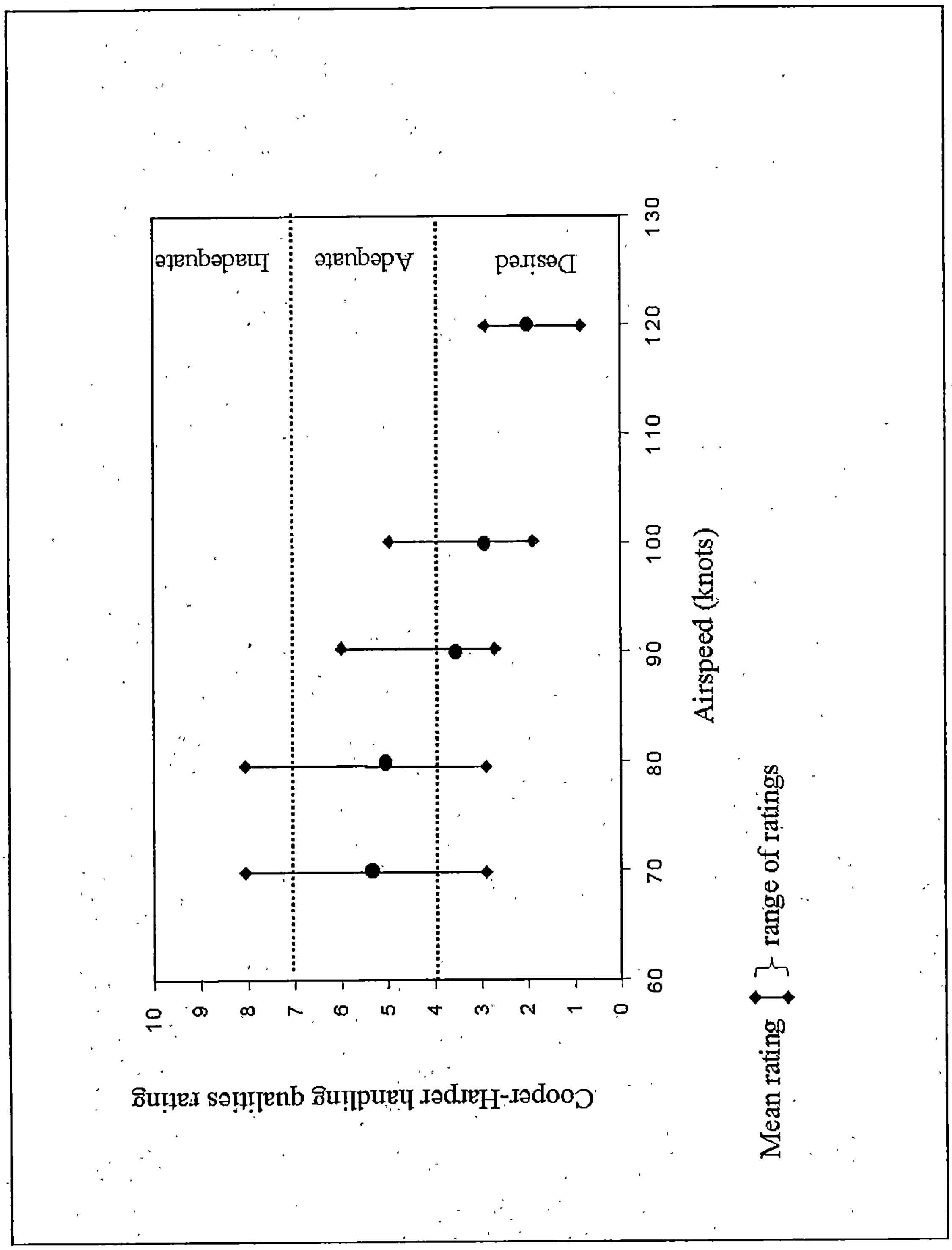


Figure 4-3. Handling Qualities Ratings Using Airspeed

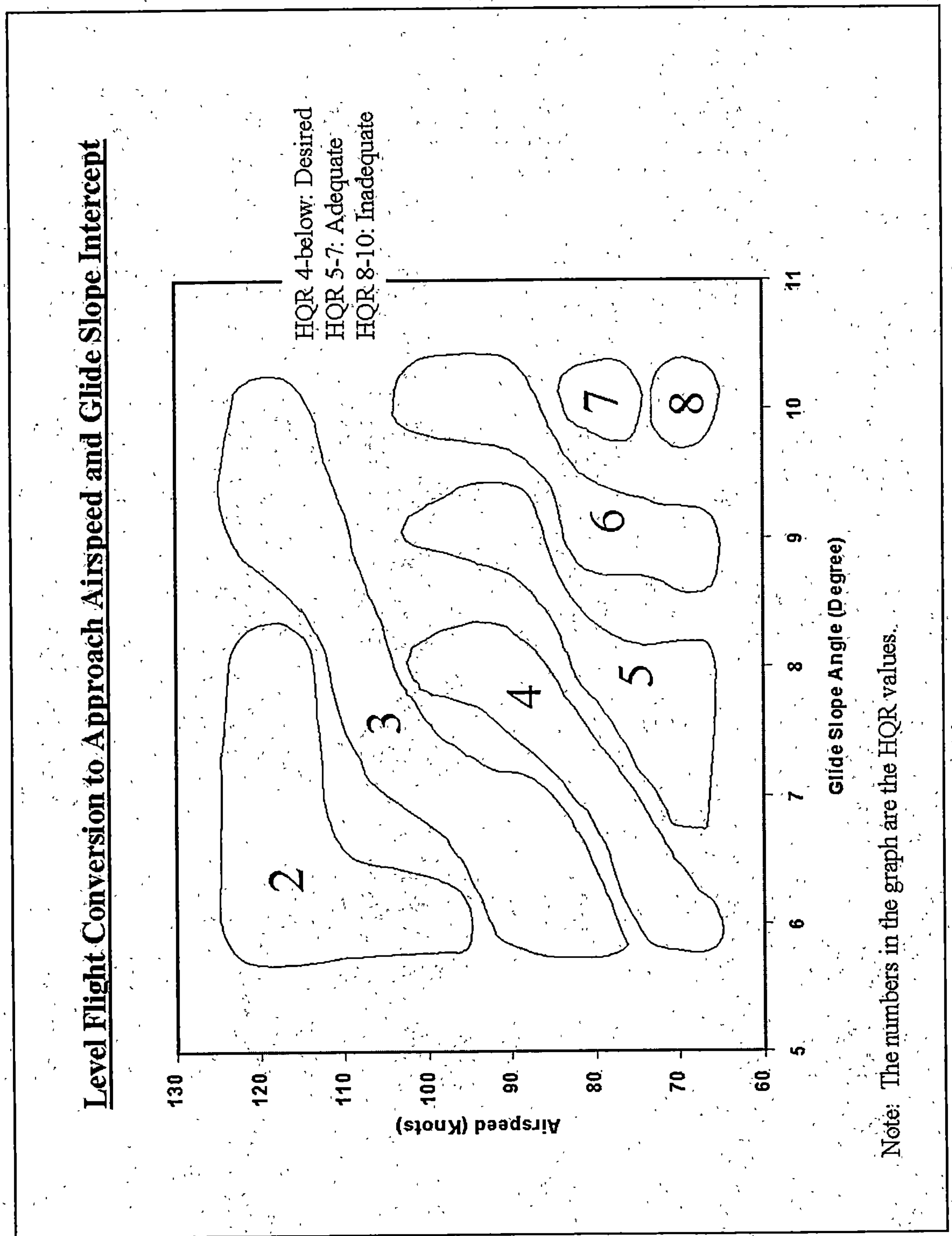


Figure 4-4. Handling Qualities Ratings Using Grouping

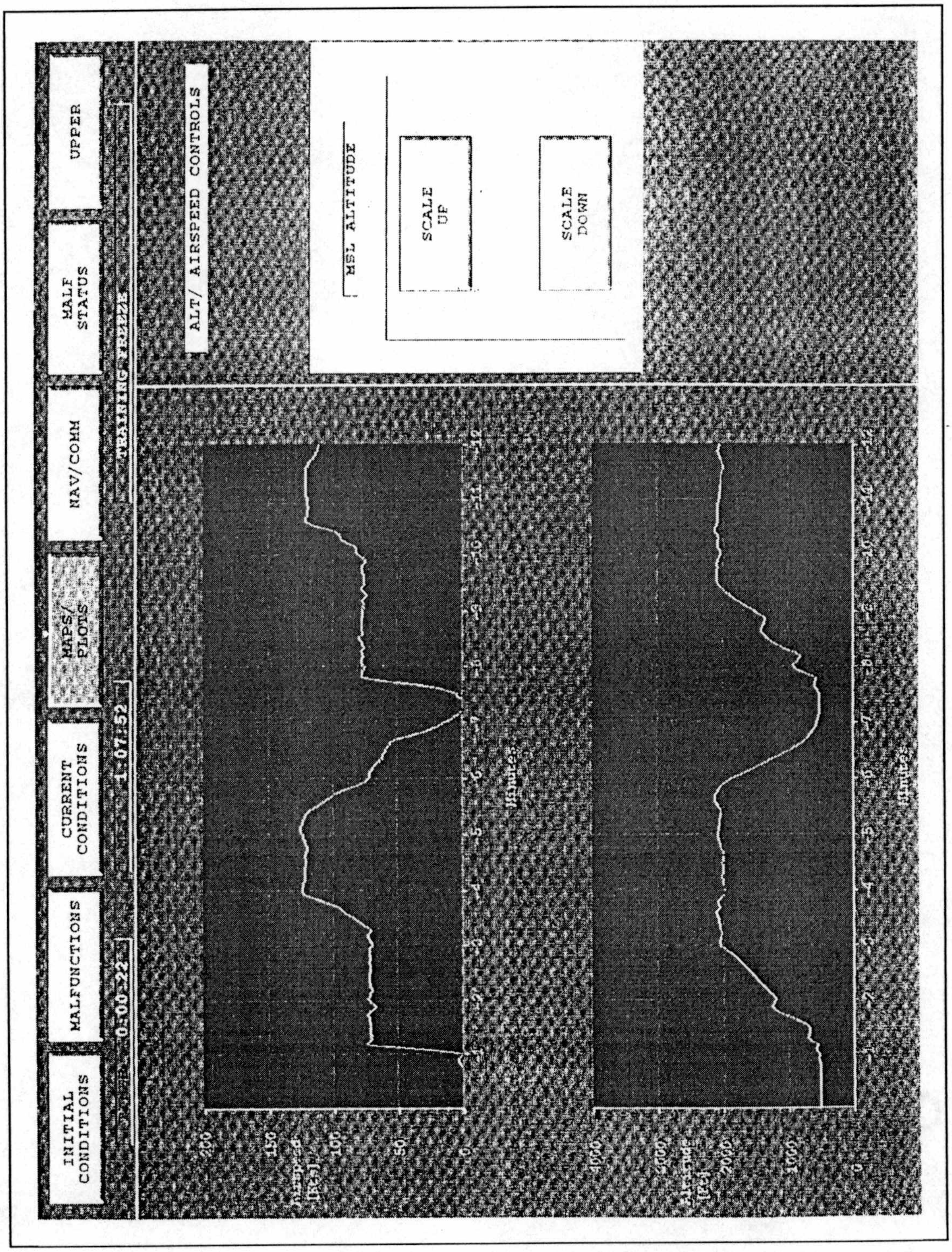


Figure 4-5. GPS Approach Plots Airspeed and Altitude vs Time
6 degree slowing from 120 knots to 80 knots

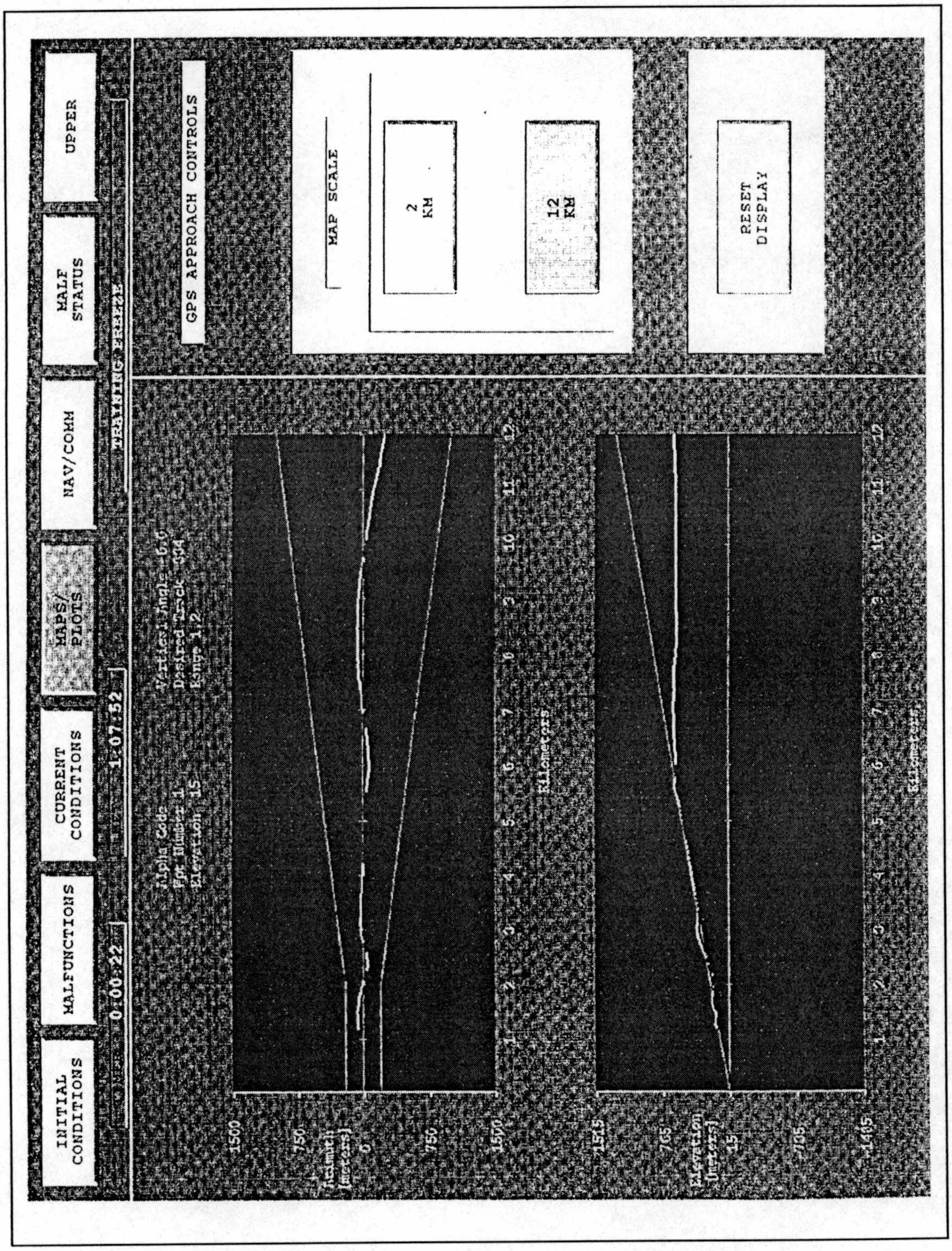


Figure 4-6. GPS Approach Plots Azimuth and Elevation vs Distance (12 KM)
6 degree slowing from 120 to 80 knots

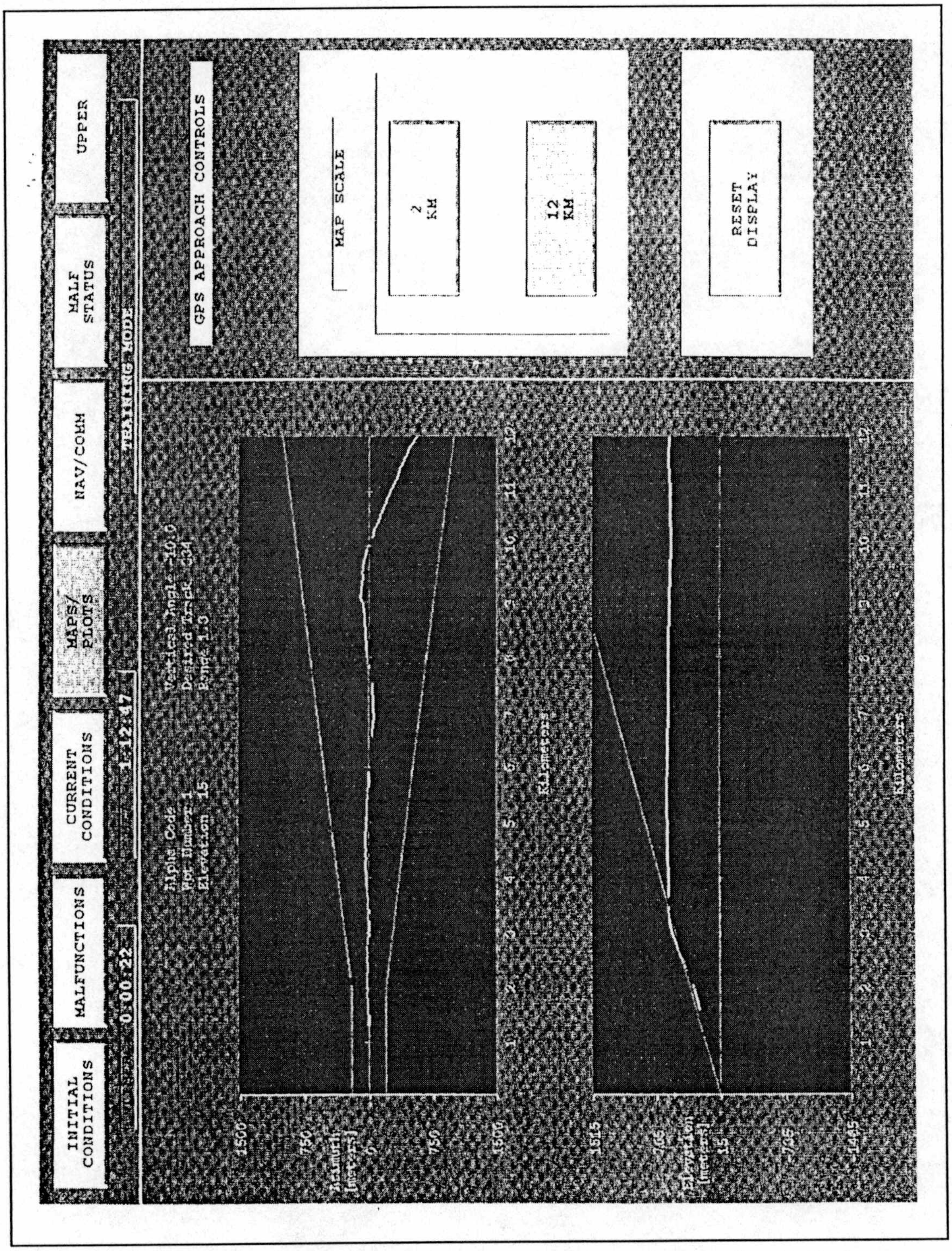


Figure 4-7. GPS Approach Plots Azimuth and Elevation vs Distance (12 KM)
10 degree at120 knots

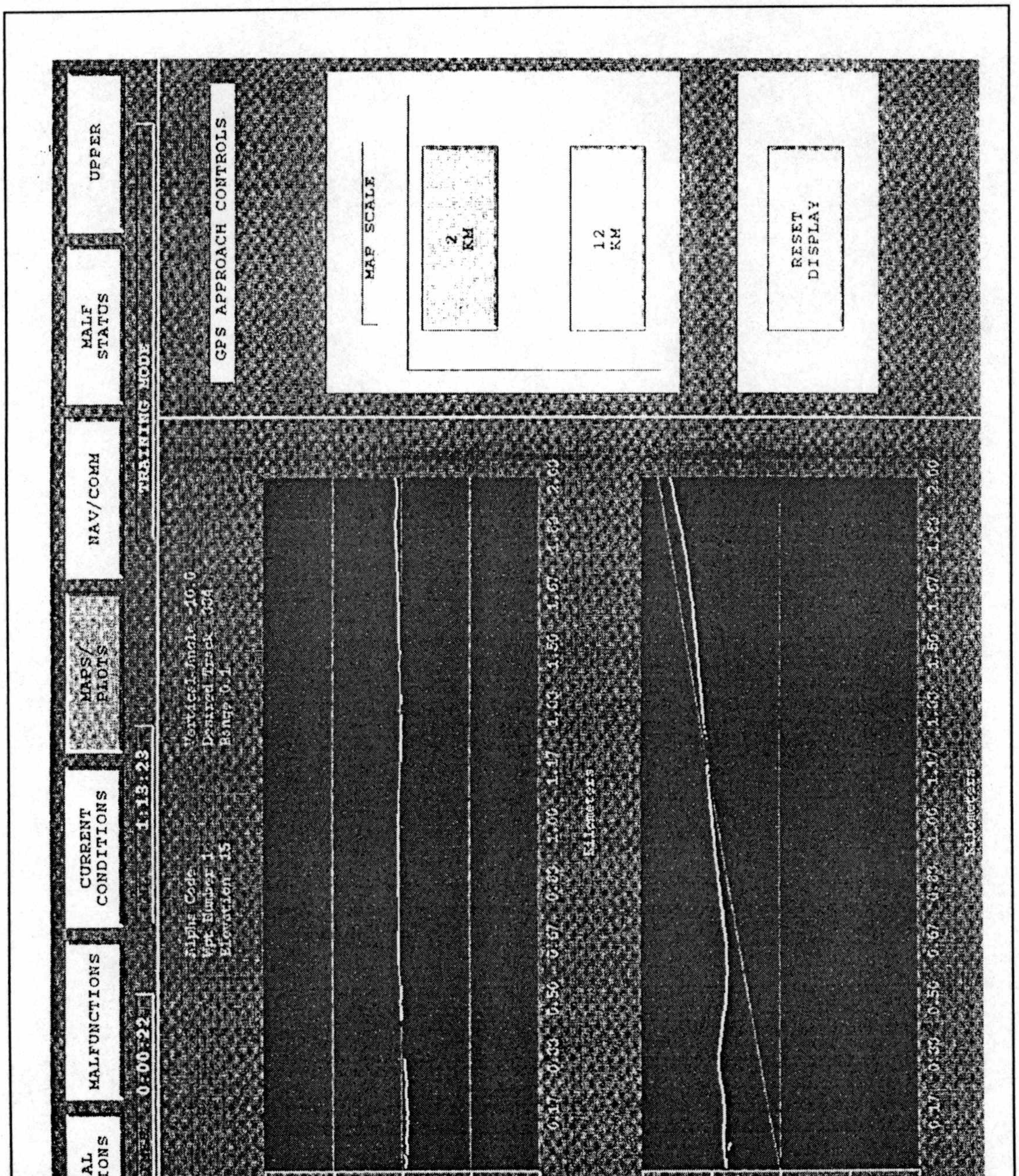


Figure 4-8. GPS Approach Plots Azimuth and Elevation vs Distance (2 KM)
10 degree at 120 knots

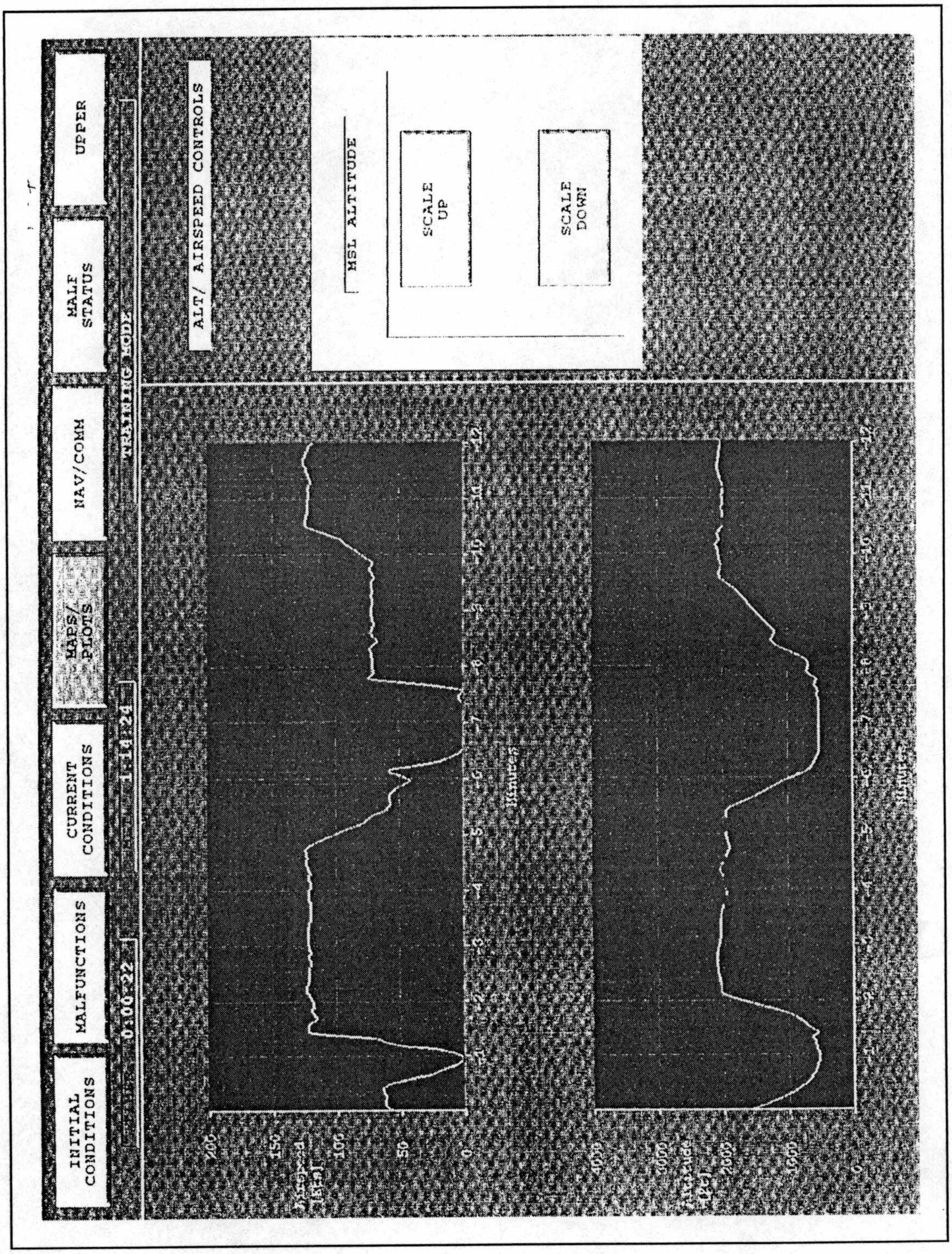


Figure 4-9. GPS Approach Plots Airspeed and Altitude vs Time
10 degree at 120 knots

Airspeed (Knots)	Angle (Degree)	Pilot #1 (HQRs)	Pilot #2 (HQRs)
120	10	9	9
120	9	8	9
120	8	7	7
120	7	6	6
120	6	5	5
100	10	8	7
100	9	8	8
100	8	7	8
100	7	6	7
100	6	4	5
90	10	7	7
90	9	7	8
90	8	6	7
90	7	5	5
90	6	4	5
80	10	6	7
80	9	7	6
80	8	6	6
80	7	4	5
80	6	3	3
70	10	6	7
70	9	5	5
70	8	3	4
70	7	2	3
70	6	2	1

Figure 4-10. Glide Slope and Localizer Tracking HQR Ratings

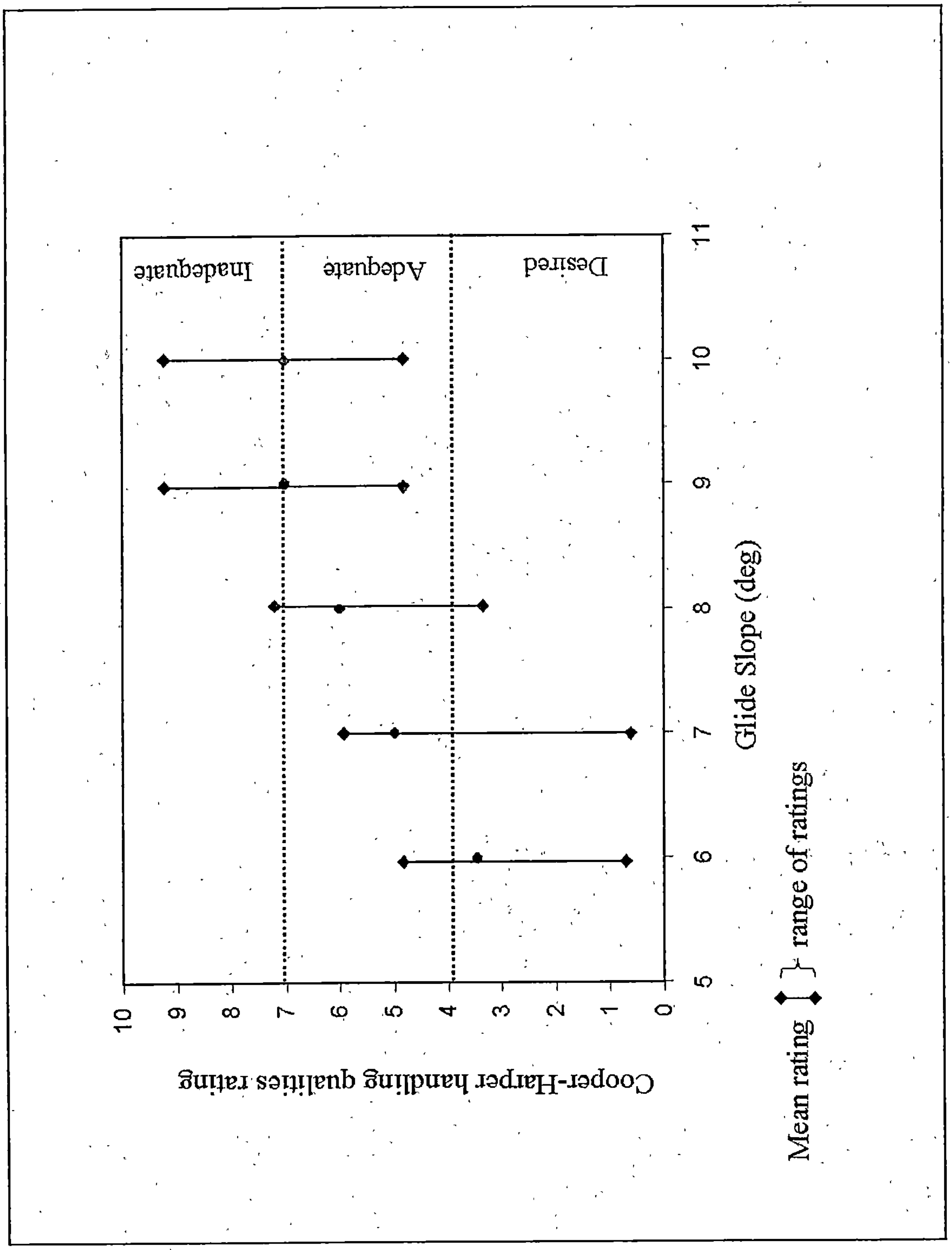


Figure 4-11. Handling Qualities Ratings Using Glide Slope

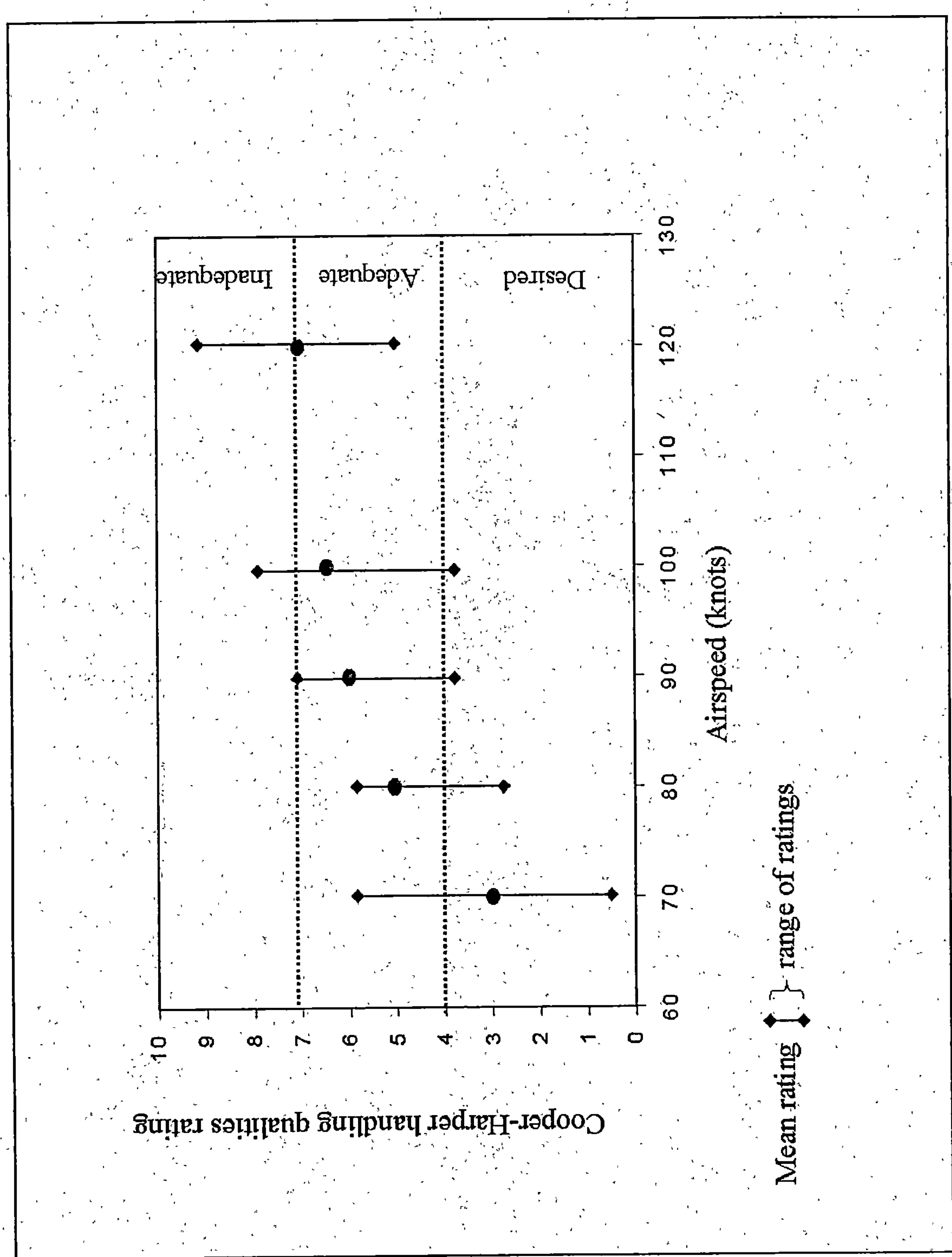


Figure 4-12. Handling Qualities Ratings Using Airspeed

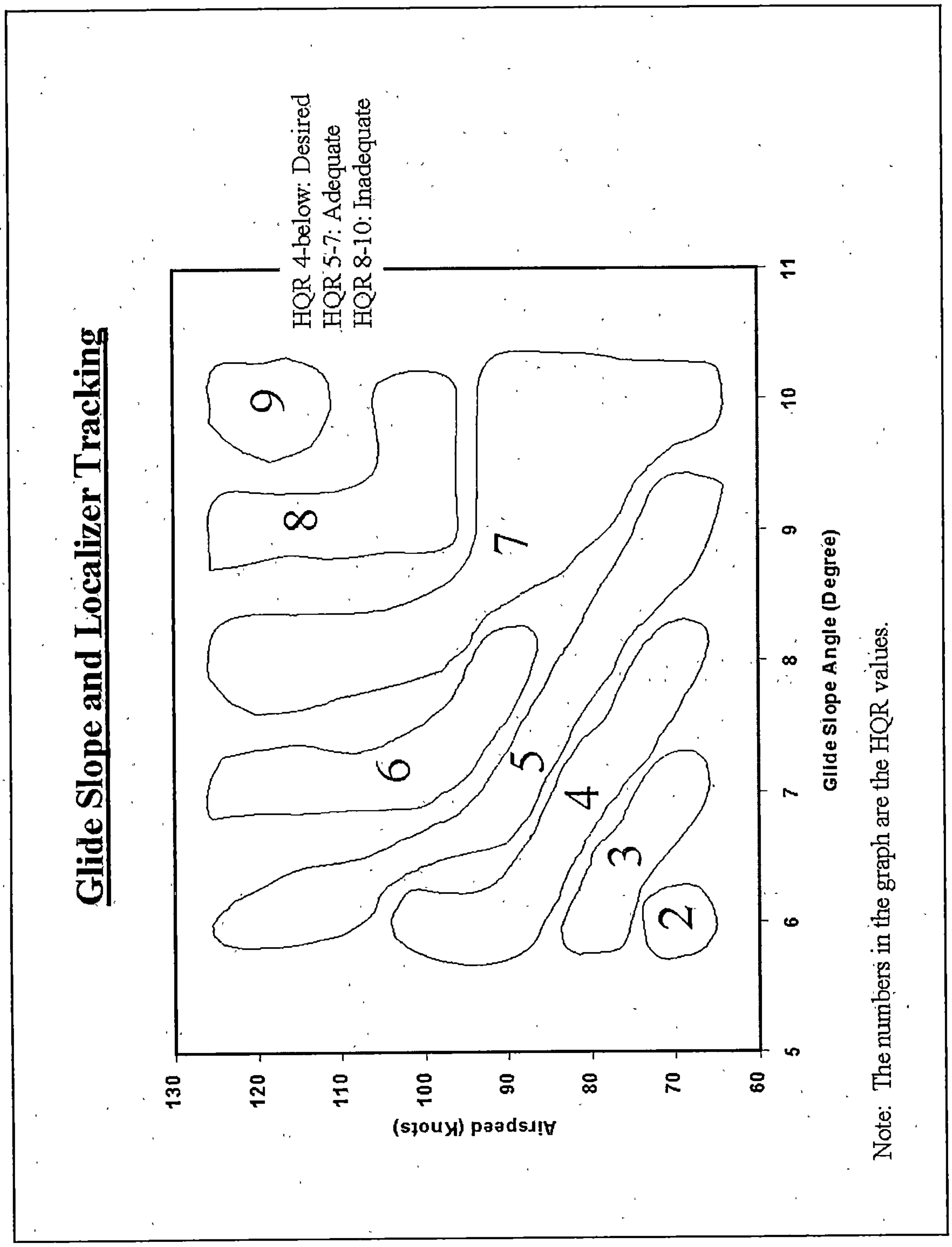


Figure 4-13. Handling Qualities Ratings Using Grouping

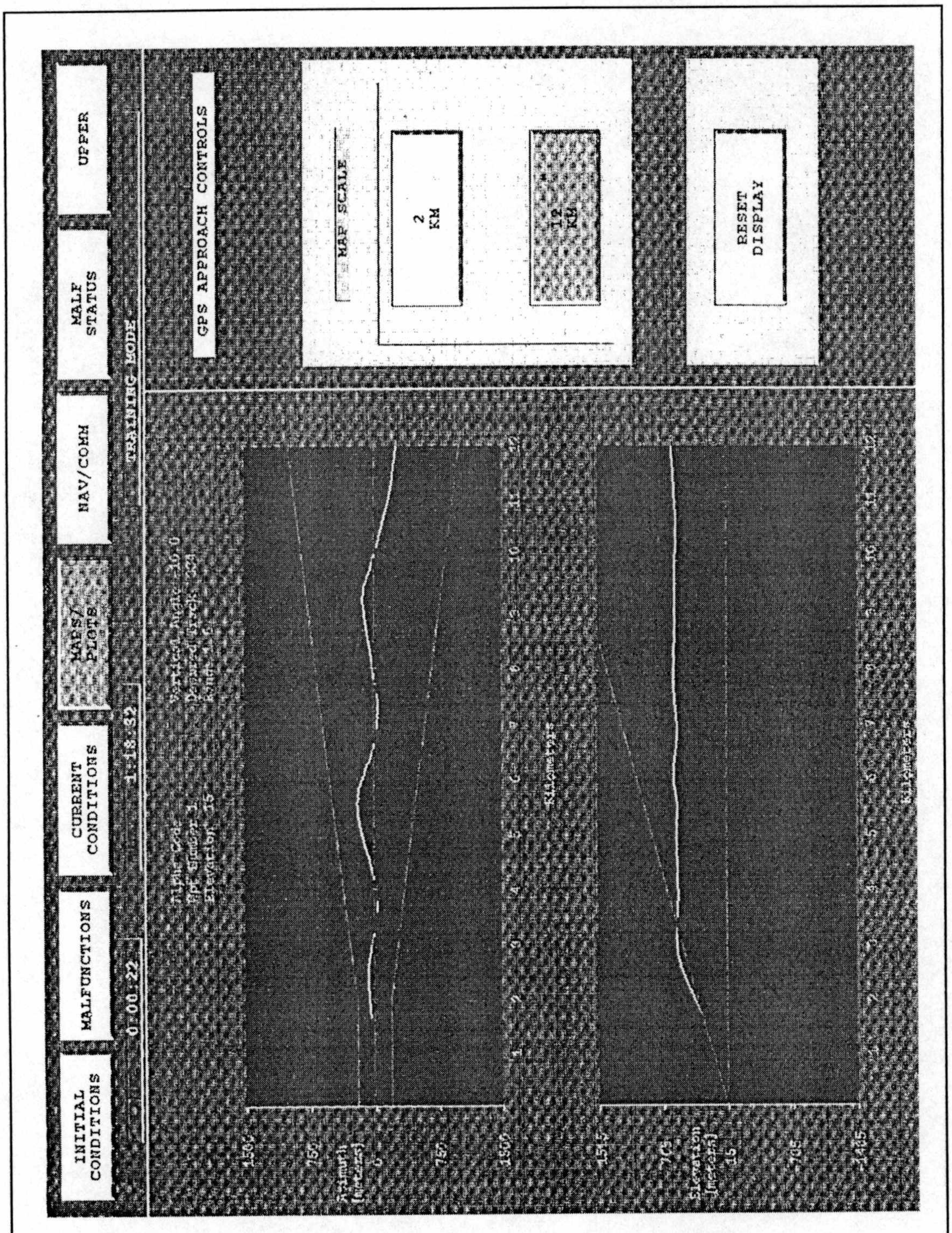


Figure 4-14. GPS Approach Plots Azimuth and Elevation vs Distance (12 KM)
10 degree at 120 knots

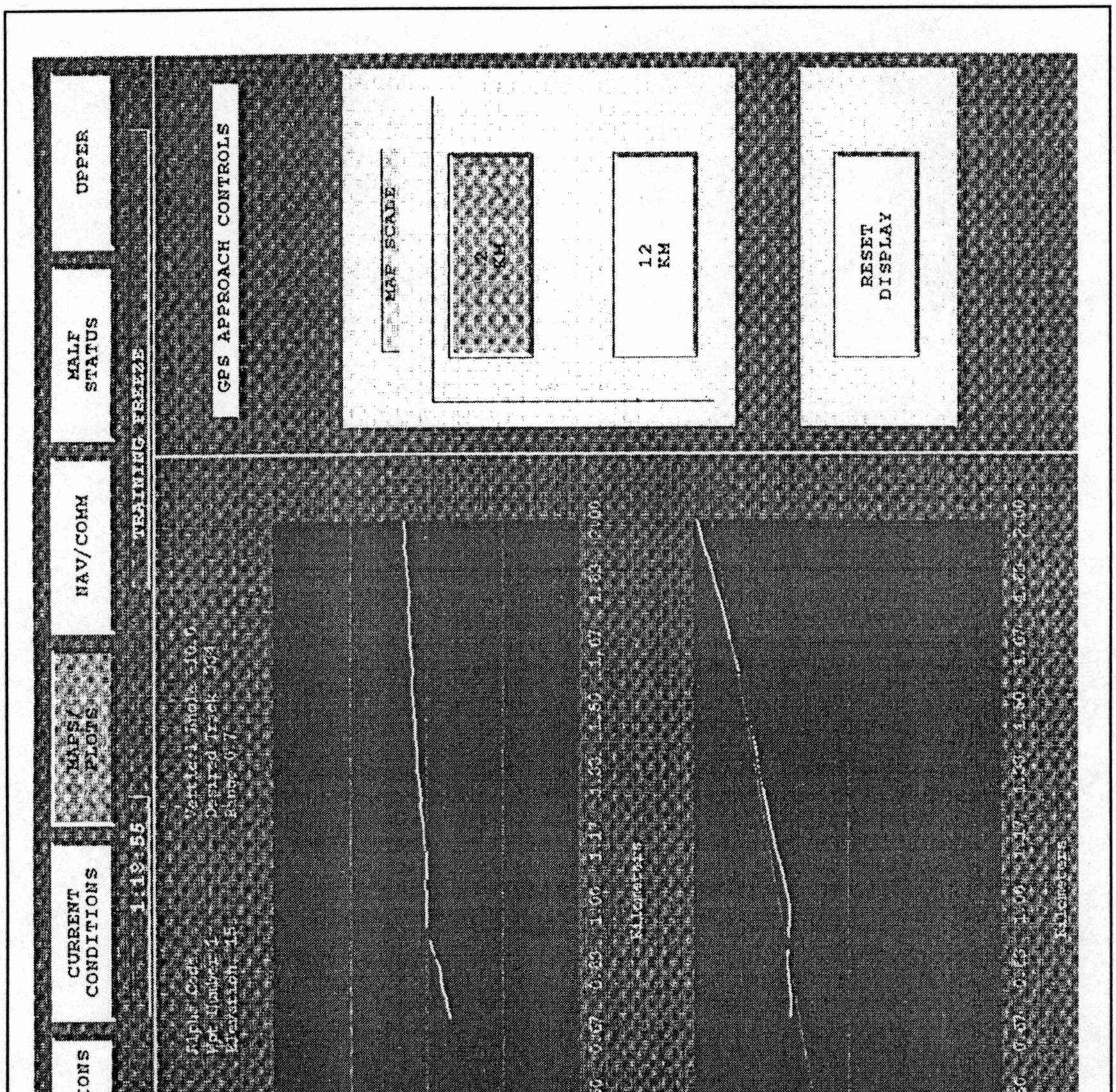


Figure 4-15. GPS Approach Plots Azimuth and Elevation vs Distance (2 KM)
10 degree at 120 knots

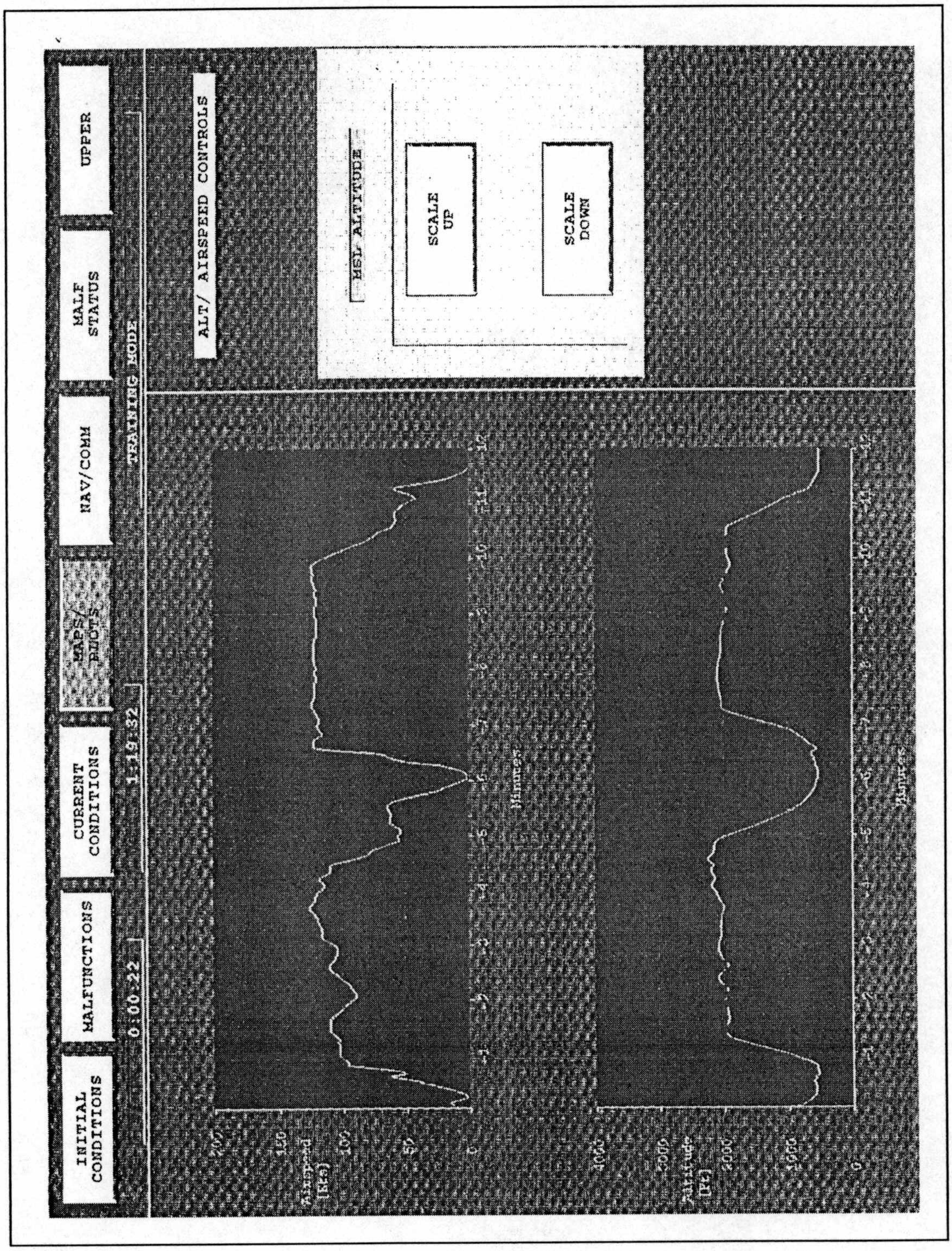


Figure 4-16. GPS Approach Plots Airspeed and Altitude vs Time
10 degree at 120 knots

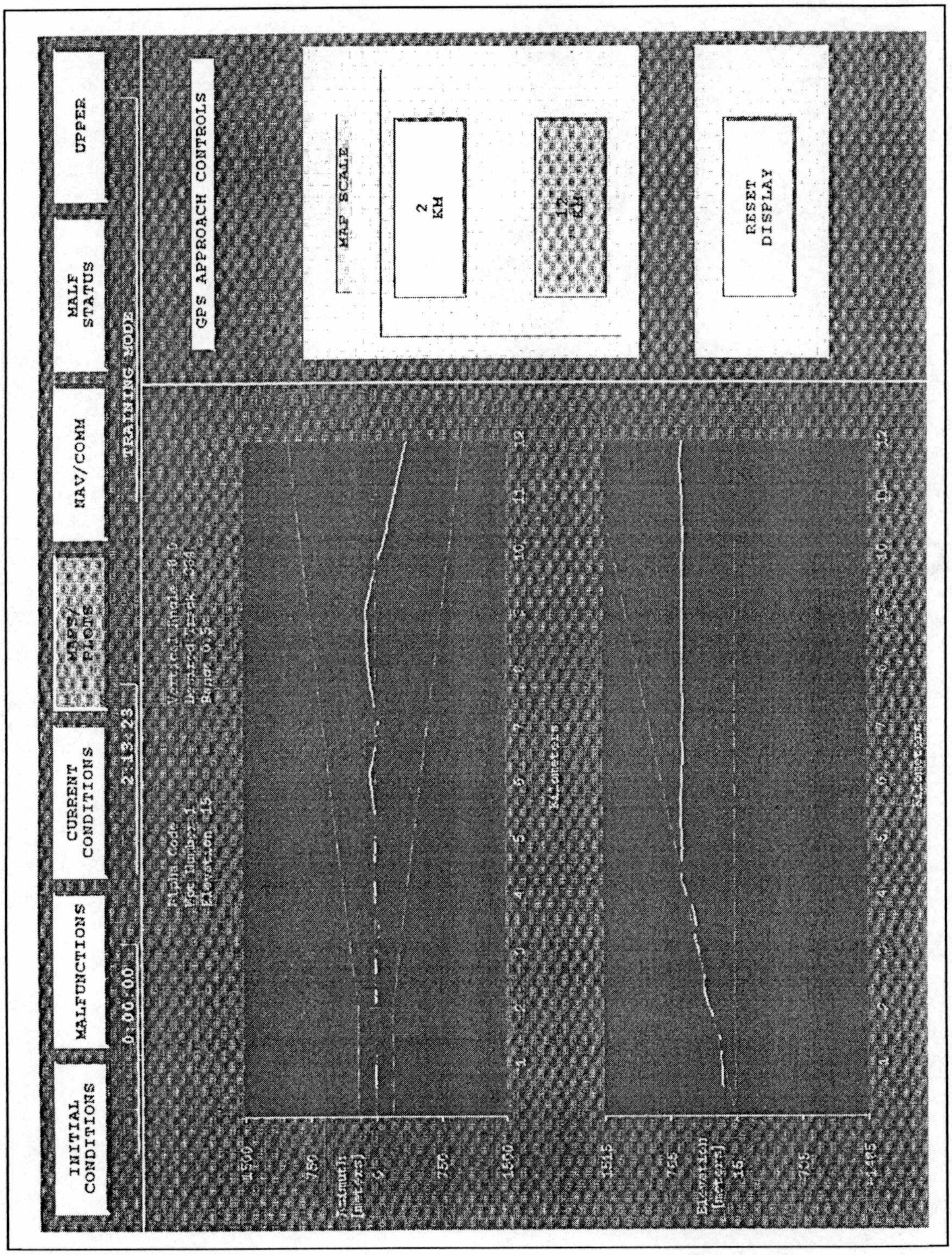


Figure 4-17. GPS Approach Plots Azimuth and Elevation vs Distance (12 KM)
8 degree at 70 knots

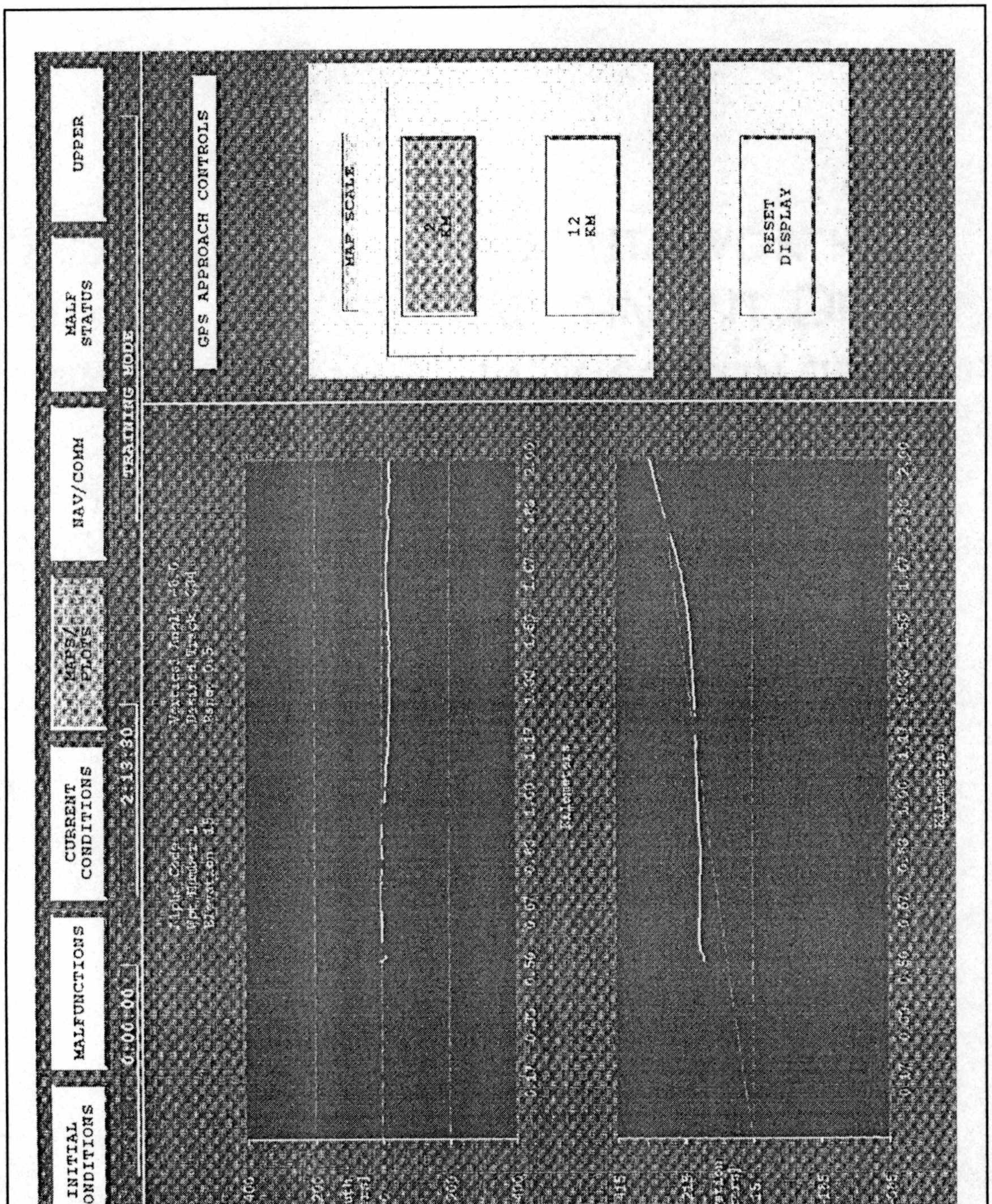


Figure 4-18. GPS Approach Plots Azimuth and Elevation vs Distance (2 KM)
8 degree at 70 knots

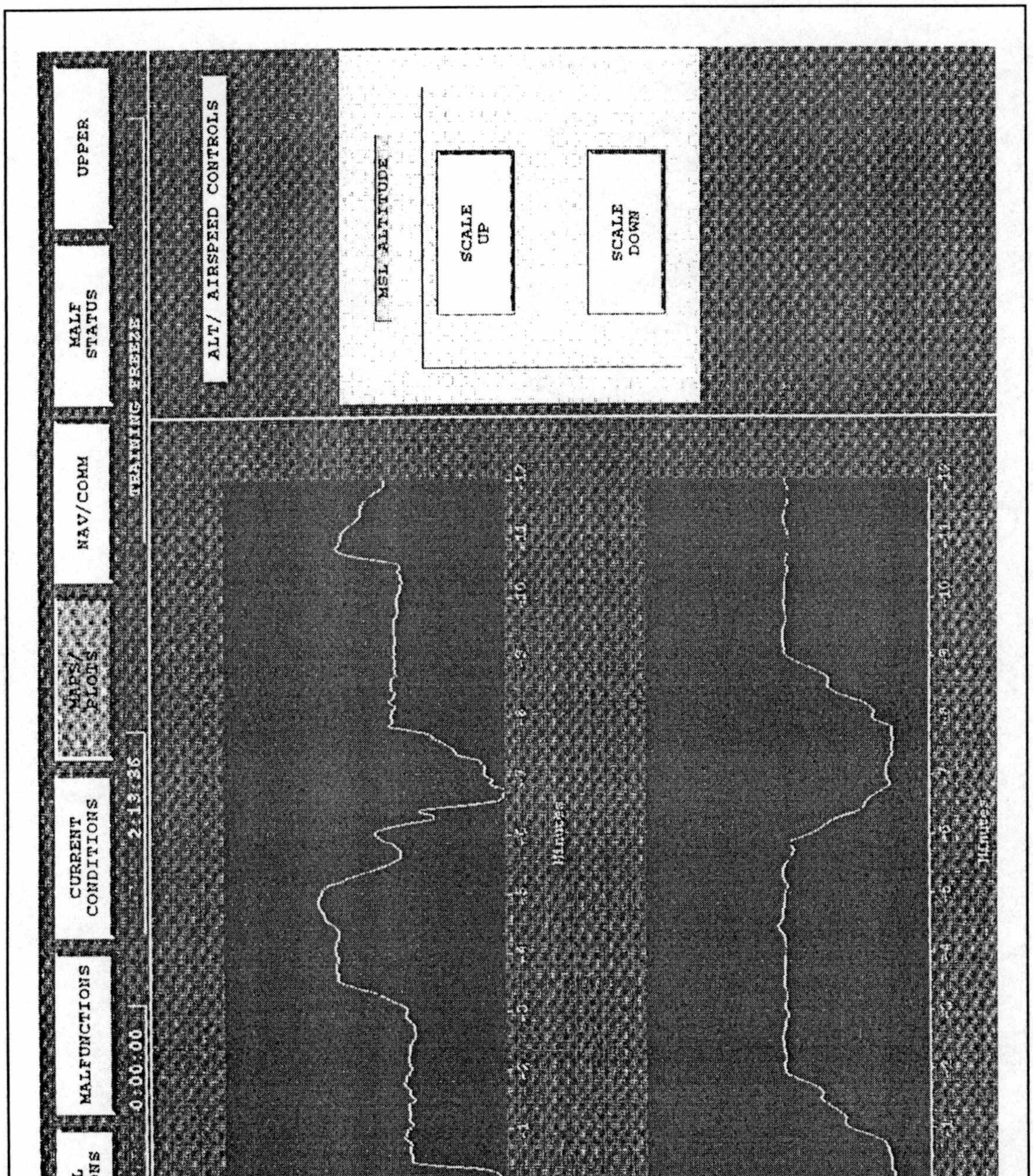


Figure 4-19. GPS Approach Plots Airspeed and Altitude vs Time
8 degree at 70 knots

Airspeed (Knots)	Angle Angle (Degree)	Aircraft sink rate FPM (Calculated) (FPM)	Aircraft sink rate FPM (Actual) (FPM)	Aircraft deck Angle (Degree)	Distance Traveled upon brake out (Feet)	Time to decelerate upon brake out (Seconds)	Pilot #2 HQR	Pilot #3 HQR
120	10	2109.154	2500	0	140*	20*	10	10
120	9	1900.072	2000	0	140	19	10	10
120	8	1690.412	1700	0	120	18	9	8
120	7	1480.237	1550	0	110	17	7	7
120	6	1269.613	1400	1	105	17	8	7
100	10	1757.628	1800	1	130	19	10	10
100	9	1583.393	1700	2	120	17	9	9
100	8	1408.677	1500	2	115	16	9	8
100	7	1233.531	1300	2	100	15	7	7
100	6	1058.010	1100	3	90	15	6	5
90	10	1581.866	1650	2	110	17	9	9
90	9	1425.054	1500	2	100	16	8	8
90	8	1267.809	1350	2	100	14	7	7
90	7	1110.178	1200	2	85	13	7	6
90	6	952.209	1000	2	80	12	5	5
80	10	1406.103	1500	0	100	16	8	8
80	9	1266.715	1350	2	100	14	8	7
80	8	1126.941	1200	2	85	14	6	6
80	7	986.825	1000	1	75	13	5	5
80	6	846.408	900	1	70	13	4	4
70	10	1230.340	1300	0	95	13	7	7
70	9	1108.375	1200	1	85	12	6	5
70	8	986.074	1000	1	85	11	5	4
70	7	863.472	850	1	70	11	2	2
70	6	740.607	800	1	70	11	3	4

* The aircraft crashed into the ground upon breakout. IOS operator had to use the crash over ride system for the pilots to continue the test run.

Figure 4-20. Landing HQR Ratings and Data

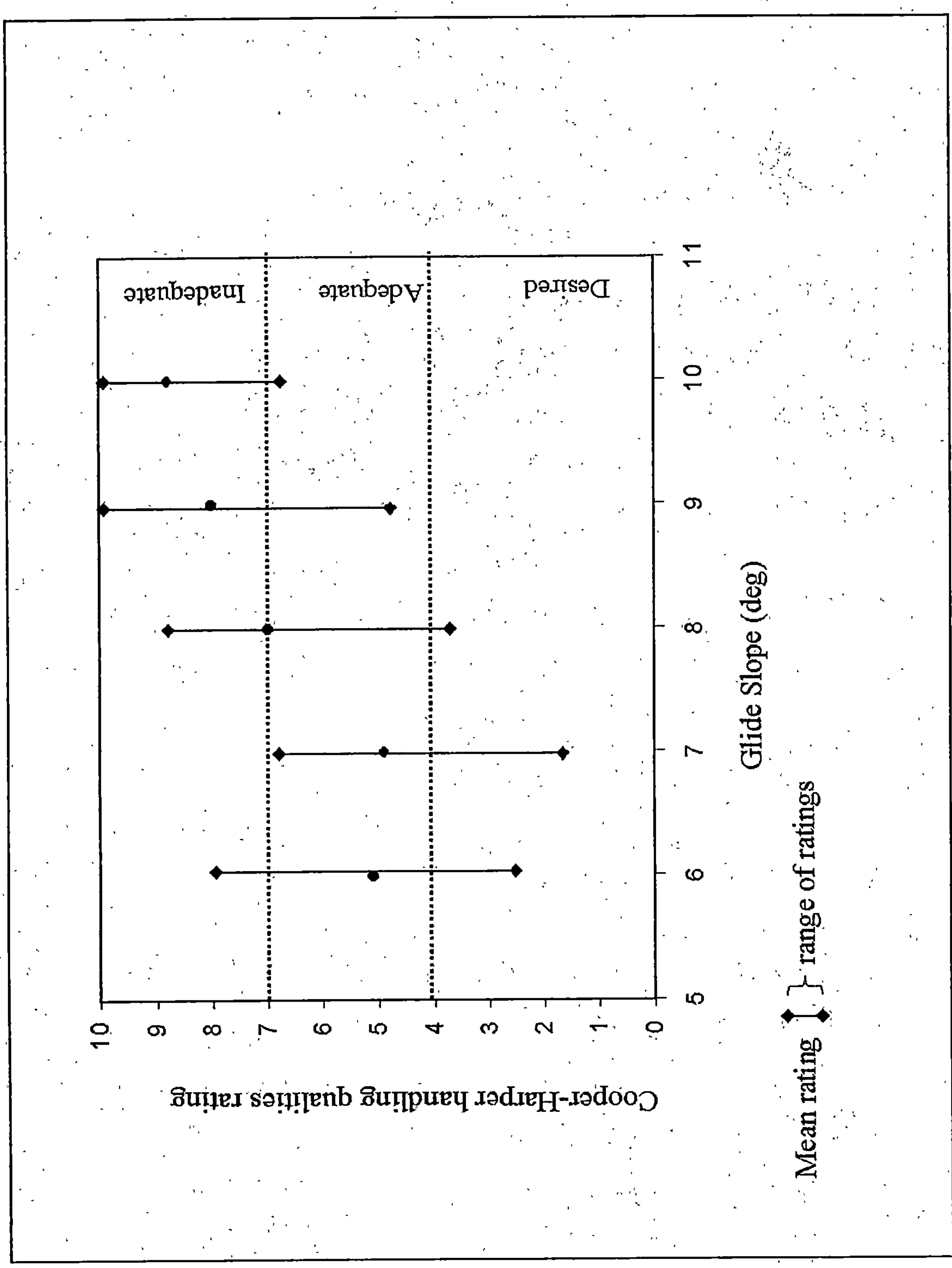


Figure 4-21. Handling Qualities Ratings Using Glide Slope

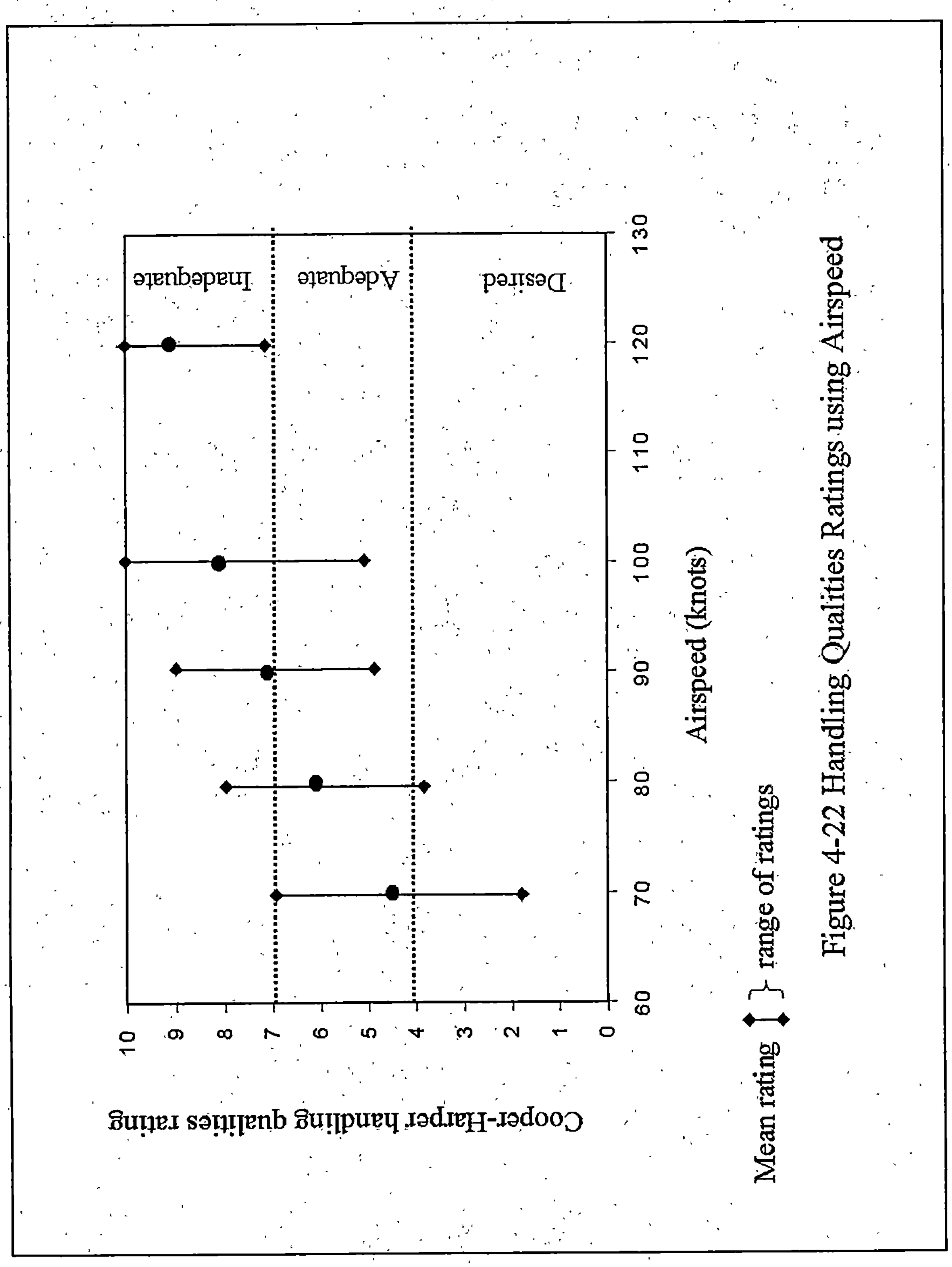


Figure 4-22. Handling Qualities Ratings Using Airspeed

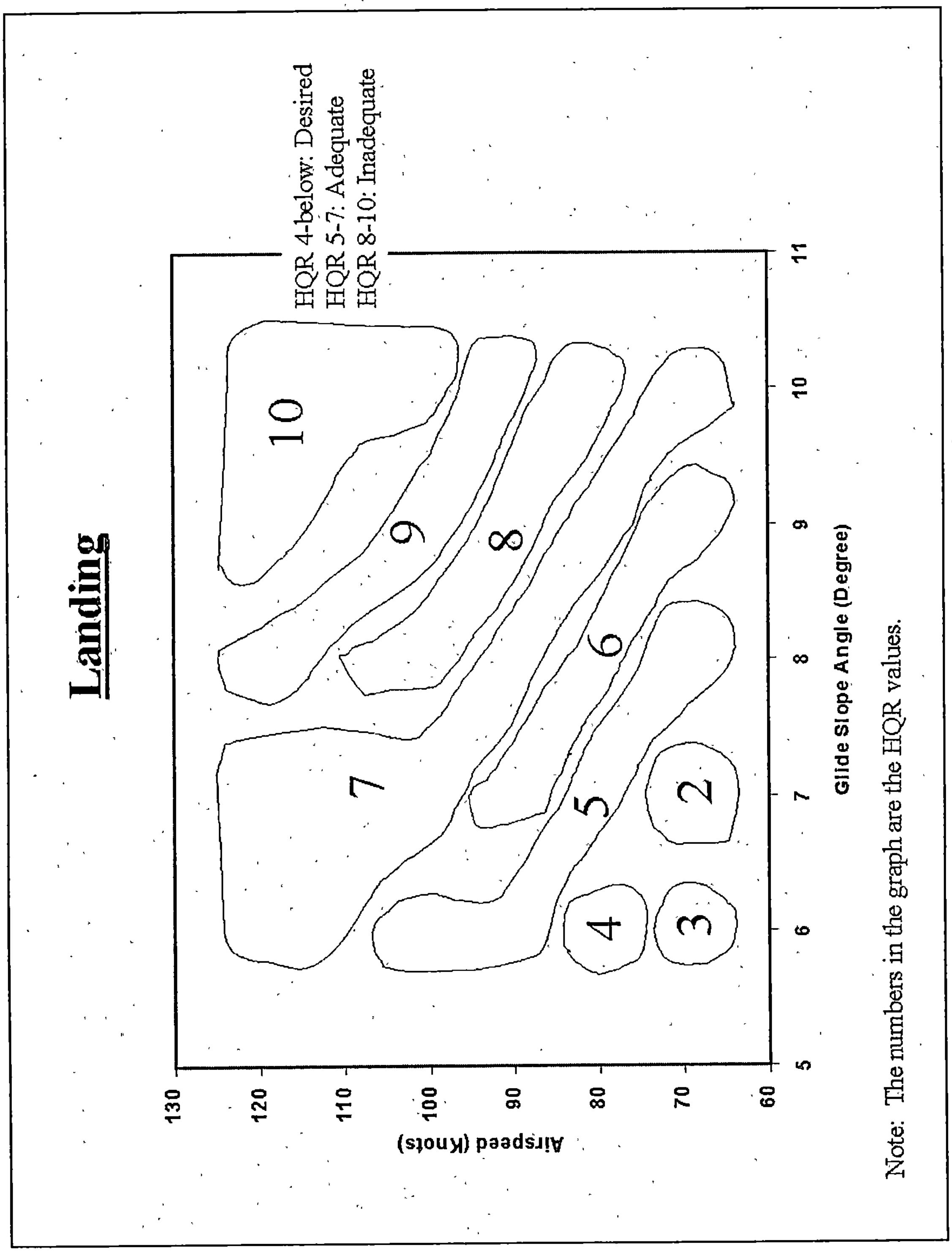


Figure 4-23. Handling Qualities Ratings Using Grouping

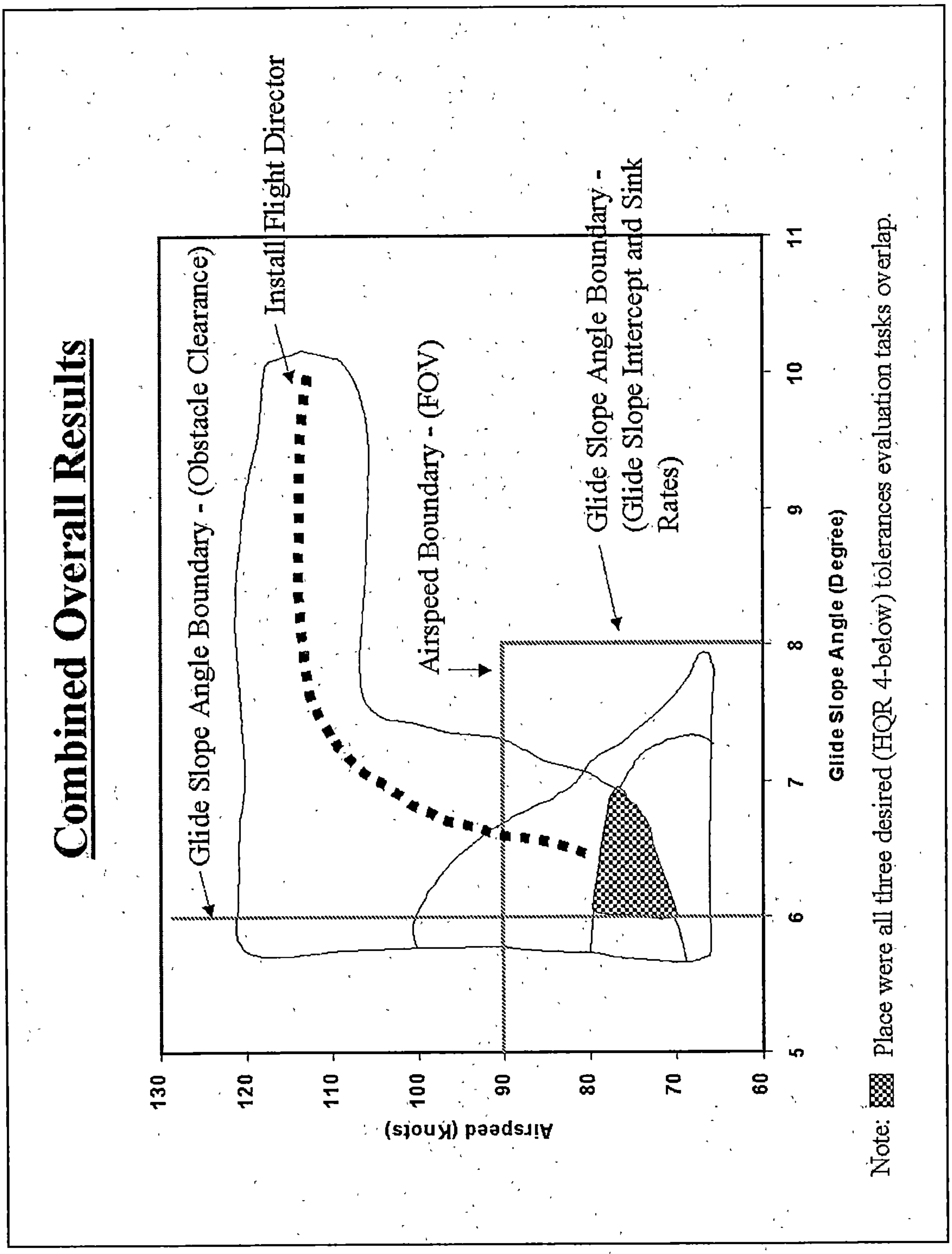


Figure 4-24: Combined Overall HQR Results

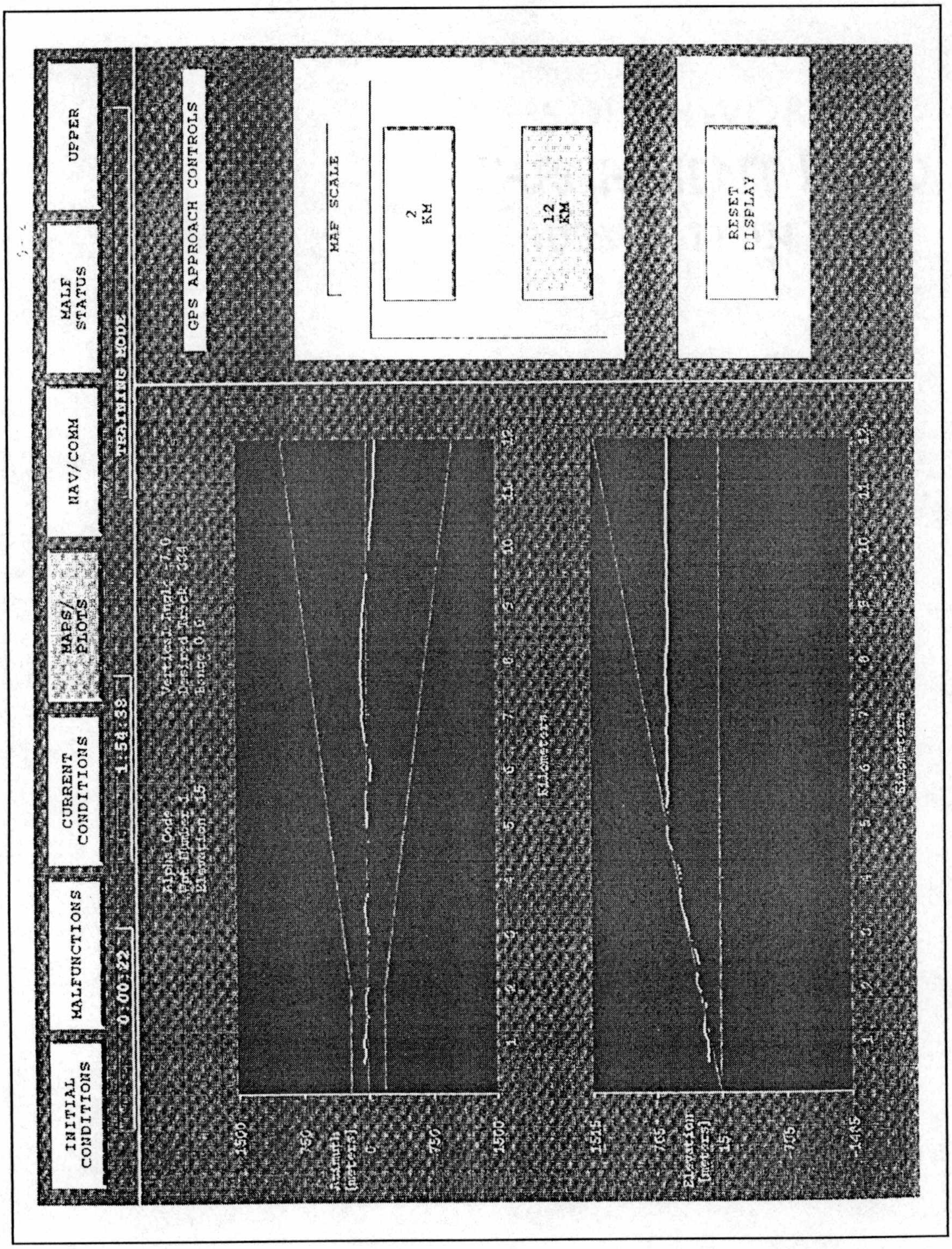


Figure 4-25. GPS Approach Plots Azimuth and Elevation vs Distance (12 KM)
7 degree at 70 knots

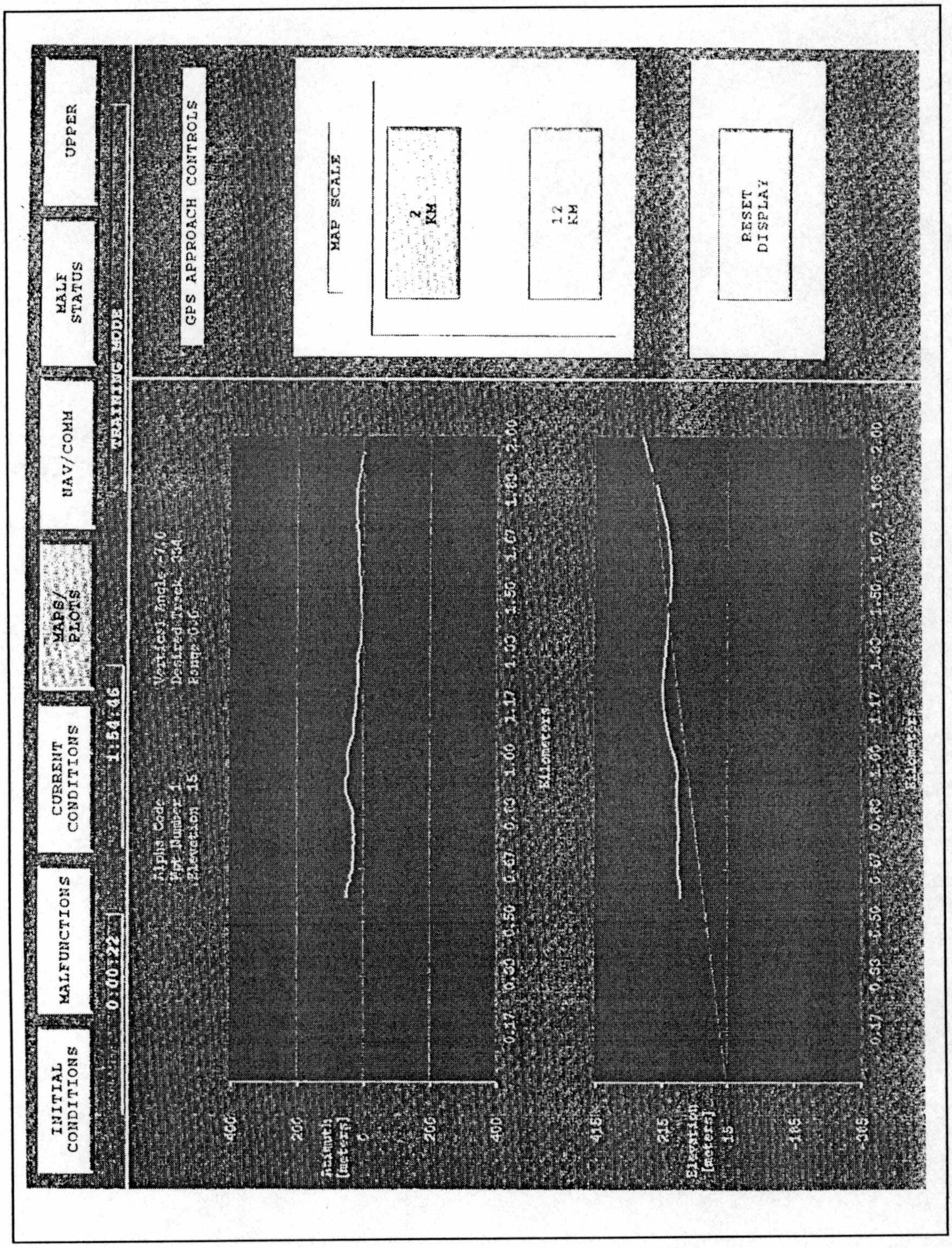


Figure 4-26. GPS Approach Plots Azimuth and Elevation vs Distance (2 KM)
7 degree at 70 knots

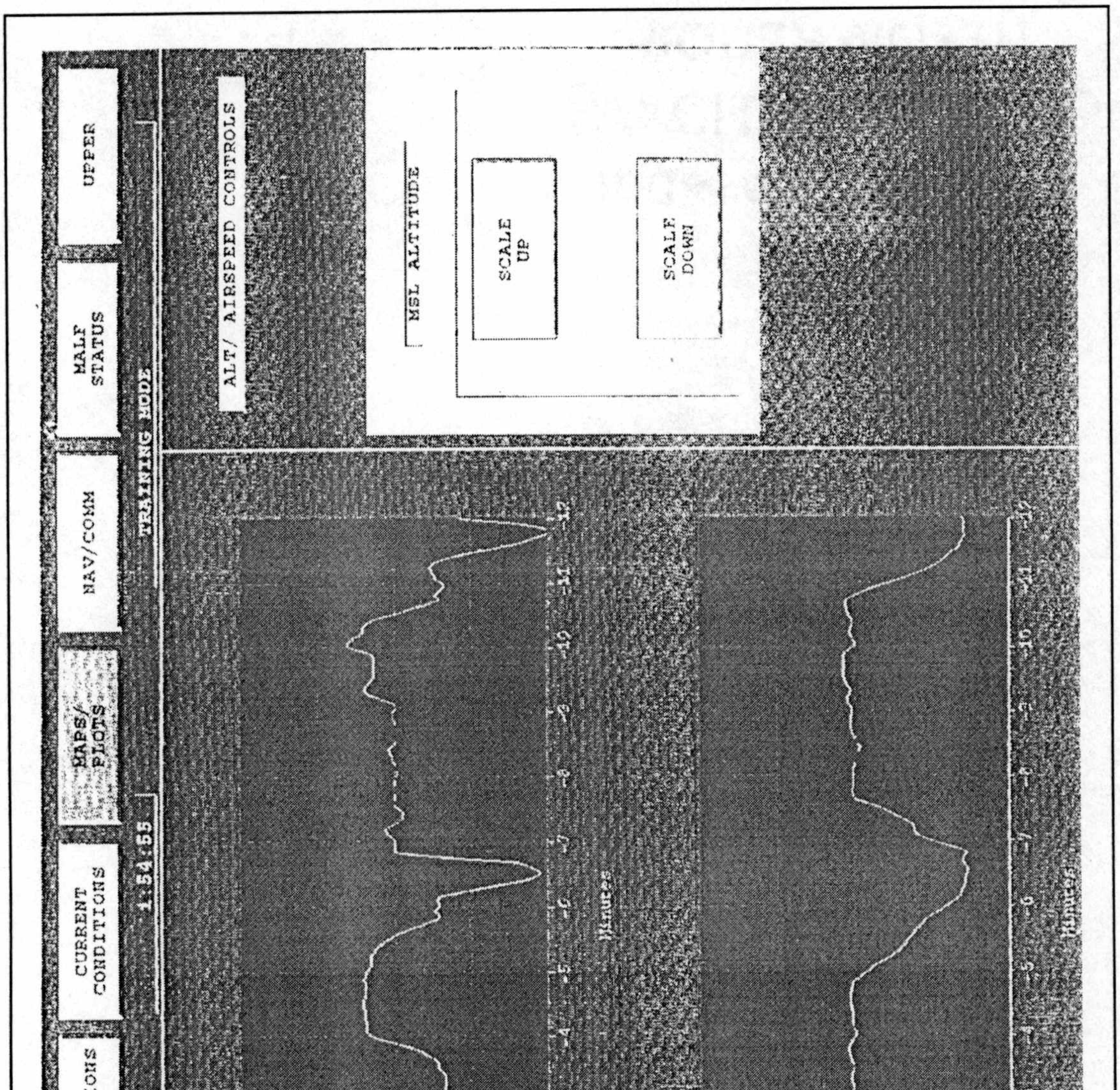


Figure 4-27. GPS Approach Plots Airspeed and Altitude vs Time
7 degree at 70 knots

VITA

Mark Maurice Jackson was born in Philadelphia Pennsylvania on October 27, 1963. He attended schools in the public system of Reston, Virginia, the Fairfax County Public School System, where he graduated from South Lakes High School in May 1982. He entered West Virginia University during August of 1982 where in May, 1986 he received the Bachelor of Science in Civil Engineering and was commissioned a Second Lieutenant in the United States Army. After graduation, he entered active duty and has served for the past thirteen years in the following military occupations: Combat Engineer, Army Aviator (qualified to fly both rotary wing and fixed wing aircraft), and as an Acquisition Officer. During his active duty service, he completed the Master's program in Mechanical Engineering at Boston University, May 1991 and the Master's program in Aerospace Engineering at University of Alabama, December 1999.

He is currently on active duty, at the rank of Major, working as the Assistant Project Manager (APM) for UH-60 Black Hawk Recapitalization Project in the Utility Helicopters Project Management Office, United States Army Aviation and Missile Command, Redstone Arsenal, Alabama.