LEVEL II ②

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CONTROL-DISPLAY INVESTIGATION OF COMPLEX TRAJECTORY FLIGHT USING THE MICROWAVE LANDING SYSTEM

AD A096593

BENDIX CORPORATION
FLIGHT SYSTEMS DIVISION
TETERBORO, NEW JERSEY 07608

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

Report presents an analysis of overall control-display task for complex trajectory flight using MLS equipment. It explores the interrelationships of complex trajectory definition and geometry, approach plate design data entry, monitoring, displays, and controls. It recommends several electro-mechanical and electronic control-display configurations. It also recommends four candidate MLS equipment configurations with various levels of capability which are applicable to the USAF inventory.

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20. ABSTRACT (Continued)

MLS integration studies are presented for the C-130A/D,
F-111A/E, A-7D, F-15A, and KC-10A.

FOREWORD

This document is the final report for the
analysis phase of the Control-Display Invest-
igation of Complex Trajectory Flight using
the Microwave Landing System (MLS). The study
was conducted by the Systems Engineering Depart-
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iii

TABLE OF CONTENTS

v

TABLE OF CONTENTS (cont)

vi

TABLE OF CONTENTS (cont)

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (cont)

LIST OF ILLUSTRATIONS (cont)

LIST OF ILLUSTRATIONS (cont)

LIST OF ILLUSTRATIONS (cont)

LIST OF ILLUSTRATIONS (cont)

LIST OF ILLUSTRATIONS (cont)

LIST OF ILLUSTRATIONS (APPENDIX)

LIST OF ILLUSTRATION (APPENDIX) (cont)

LIST OF ILLUSTRATIONS (APPENDIX) (cont)

LIST OF TABLES

LIST OF ABBREVIATIONS

ADEU -Automatic Data Entry Unit

ADI - Attitude Director Indicator

ALS - Advanced Landing System

ALT - Altitude

APPR -Approach

ATC - Air Traffic Control

ATK - Along Track Distance to GPIP

AUX - Auxiliary

AZ - Azimuth

CADC -Central Air Data Computer

CAT - Category

CDI - Course Deviation Indicator

CDU - Control Display Unit

CRS - Course

CRT - Cathode Ray Tube

CTOL -Conventional Takeoff and Landing

CWS - Control Wheel Steering

cm - Centimeter

DABS -Discrete Address Beacon System

DAIS -Digital Avionics Instrumentation System

DIST -Distance

DME - Distance Measuring Equipment

DOT - Department of Transportation

DP - Descent Point

DPA - Desired Path Angle

DTK - Desired Track Angle

EADI -Electronic Attitude Director Indicator

EHSI -Electronic Horizontal Situation Indicator

ELEV -Elevation

ENG - Engage

FAP - Final Approach Point

FDSU -Flight Data Storage Unit

FIP - Final Intercept Point

FPA - Flight Path Angle

FPI - Flight Profile Investigation

FTP - Final Transition Point

GOR - General Operation Requirement

GPIP -Glide Path Intercept Point

GS - Glide Slope

GSI - Glide Slope Indicator

GSP - Ground Speed

HDG - Heading

HSI - Horizontal Situation Indicator

IAS - Indicated Airspeed

ICAO -International Civil Aviation Organization

IFR - Instrument Flight Rules

ILS - Instrument Landing System

ITP - Initial Transition Point

ITK - Inbound Track

km - Kilometer

L - Left

LCD - Liquid Crystal Display

LED - Light Emitting Diode

LOC - Localizer

MLS - Microwave Landing System

MLS-1-Direct ILS Replacement Configuration

MLS-2-Selectable Elevation & Azimuth Configuration

MLS-3-Selectable Intercept of Final Configuration

MLS-4-Complex Trajectory Configuration

MMLS -Military MLS

MTBF -Mean Time Between Failure

MTTR -Mean Time to Repair

m - Meter

NAFEC-National Aviation Facilities Experimental Center

NAV - Navigation

NPA - Path Angle to Next Waypoint

nm - Nautical Mile

OTK - Outbound Track

PAR - Precision Approach Radar

R - Right

RAD - Radius

RCVR -Receiver

RF - Radio Frequency

RNAV -Radio Navigation

RTP - RNAV Transition Point

RVR - Runway Visual Range

RWP - Range-to-Waypoint

RWY - Runway

SGMT- Segment

STOL -Short Takeoff & Landing

TAC - TACAN (Navaid)

TACAN-Tactical Air Navigation

TCV - Terminal Configured Vehicle

TERM -Terminal

TRK - Track

TRSB -Time Reference Scanning Beam

VFR - Visual Flight Rules

VHF - Very High Frequency

VNAV -Vertical Navigation

VOR - VHF Onmidirectional Range

VP - Vertical Flight Path

VTK - Vertical Path Error

WPT - Waypoint

XMTR- Transmitter

LIST OF ABBREVIATIONS - CONTINUED

XTK - Cross Track Error   3-D - 3-Dimensional

2-D - 2-Dimensional

1.0 INTRODUCTION AND SUMMARY

1.1   Purpose

The purpose of the Control-and-Display Investigation of Complex
Trajectory Flight using the Microwave Landing System (MLS) was to
develop design criteria to enable all USAF aircraft to be
fitted with the capability to fly MLS complex trajectories.
The investigation was to include analysis, design definition
and design validation phases. This is the final report for
the analysis phase.

1.2   Background

The MLS technique adopted by the United States and by ICAO is
the "Time Reference Scanning Beam (TRSB)". Phase III MLS
ground and airborne equipment has been developed by several
manufacturers. It provides three levels (see table below)
of expanded volumetric coverage of precision guidance data
which allows a suitably equipped aircraft fly a wide variety
of curved path multi-segmented approach paths in the terminal
area environment. The ability to fly these complex trajectories
enables approaches to be designed that avoid hostile areas,
obstructions and population centers.

MLS GROUND EQUIPMENT

LEVEL	AZIMUTH	ELEVATION	RANGE	DME ACCURACY
Small Community	$\pm10^{\circ}$	1° to 15°	15nm	none
Basic Narrow	$\pm40^{\circ}$	1° to 15°	20nm	100'
Basic Wide	$\pm60^{\circ}$	1° to 15°	20nm	100'

Since 1971, a national program for the development of a
universal civil/military MLS has been in progress. The program
has been managed by the FAA and supported by the DOD and NASA.
FAA efforts to date have been primarily directed toward
resolving signal format and ground installation problems.
The USAF and NASA have conducted programs to determine and
resolve issues associated with aircraft dynamics, airborne
systems and pilot acceptance of complex trajectory flight.
NASA flight test work has been done on their Boeing 737
Terminal Configured Vehicle (TCV). USAF flight test work has

1

been done on two T-39 aircraft specifically configured for MLS.

1.3 Scope

This report presents an analysis of the overall control-and-display task for complex trajectory flight using MLS equipment. It reviews the problems and test results of the USAF T-39 program and NASA 737 TCV program as they relate to this subject. It explores the interrelationships of complex trajectory definition and geometry, approach plate design monitoring, displays and controls. It recommends several electro-mechanical and electronic control-and-display configurations for further investigation via simulation and/or flight test. It also recommends several overall MLS equipment candidate configurations with different levels of complexity which are applicable to the USAF inventory. These configurations have been determined to be appropriate based on studies, contained herein, of 5 representative USAF aircraft:C-130A/D; F-111A/E; A-7D; F-15A; and, KC-10A.

1.4 Summary of Results

To conform to various levels of existing control-and-display capability, four general MLS configurations have been established which encompass the anticipated retrofit requirements for all USAF aircraft. These configurations range in complexity from a direct ILS replacement system, with no capability beyond a straight-in approach, to a full complex trajectory system. The equipment requirements and pilot workload levels associated with these configurations increase proportionally to the MLS capability obtained. Because pilot workload for MLS flight tends to be a determining factor in the level of MLS employed, a significant effort has gone into defining candidate control-and-display configurations which keep workload levels at a minimum. Of particular interest is the MLS-3, Selectable Intercept of Final Configuration. Although it provides only limited complex trajectory capability consisting of a maximum of two lateral and two vertical approach segments, its consequent simplicity for data entry and approach monitoring make it feasible for single-seat aircraft with flight director control. Such feasibility does not exist with a total complex trajectory system for this type aircraft unless automatic data entry and automatic approach coupling are also added. This, of course, greatly increases the retrofit costs. The following

2

is a brief description of the four MLS configurations:

- MLS-1, Direct ILS Replacement Configuration
  - Angle receiver, C-band antenna, and simple tuner required
  - DME and auxiliary data functions optional
  - No selectable azimuth and elevation angles
  - Raw deviation outputs, identical in format to ILS, are always referenced to the extended runway centerline and nominal glide slope of field
  - Useful for all classes of aircraft

- MLS-2, Selectable Azimuth and Elevation Configuration
  - Required and optional equipment same as for MLS-1
  - MLS tuner required, selection mechanisms for selecting desired azimuth and elevation angles as in Phase III MLS design
  - No low altitude IFR use seen for selectable azimuth function
  - Selectable elevation function useful for STOL and rotary wing aircraft

- MLS-3, Selectable Intercept of Final Configuration
  - Angle receiver, DME interrogator, C-band and L-band antennas and switching unit required
  - Also requires MLS navigation coupler, simple control panel, and AZ/DME display
  - Auxiliary data function optional
  - Provides precise low altitude IFR control along a selectable heading intercept and to a selectable final approach segment length
  - Provides 2-segment glide path capability
  - Allows close-in (less than 2 nm) final approach captures not possible with typical present day ILS approaches (7-10 nm final)
  - Useful for all classes of aircraft

- MLS-4, Complex Trajectory Configuration
  - Requires angle receiver, DME interrogator, and switching unit as in MLS-3
  - Requires fore and aft antennas installations, and antenna switching unit, if desired trajectories warrant
  - Requires more complex MLS navigation computer and AZ/DME display
  - CDU replaces control panel and contains auxiliary

3

data functions
- A generalized block diagram of the MLS-4 interface
  with a typical analog flight guidance system is
  shown in Figure 1.
- Provides precise low altitude IFR control along
  complex trajectory
- Probably not useful for single-seat aircraft nor
  two-seat aircraft without automatic approach
  coupling

The MLS retrofit configuration recommended for each of
the specific aircraft considered in this study was greatly
influenced by a review of the aircraft's existing control-
and-display capability. This review consisted of investiga-
tions into each aircraft's: autopilot, flight director, ILS
redundancy levels, and primary instrumentation. Pertinent
information on the five aircraft is included in the following
paragraphs. Table 1 summarizes this information and denotes
the recommended MLS configurations for the aircraft.

The autopilots on the F-111A/E, A-7D, and F-15A are "pilot
relief" type systems which do not include ILS modes of opera-
tion. The autopilots on the C-130A/D and KC-10A do have
ILS modes. It should be noted, however, that the C-130A/D
flight manual cautions the pilot that continuous monitoring
of the system is required below 1000 feet of altitude.

All five aircraft have flight director ILS modes. Raw data
from the ILS receiver is displayed on the ADI, HSI, and HUD
(for the F-111A/E and A-7D). Flight director commands are
displayed on the ADI and HUD. The C-130A/D does not have a
pitch steering bar. Instead a 2.5° nose down bias is dis-
played as a glide slope command on the ADI.

The C-130A/D, F-111A/E, A-7D, and F-15A are essentially
Category I aircraft containing a single set of ILS receivers
and flight director computers. The KC-10A has dual receivers
and computation allowing Category III operation.

The primary instrumentation utilized for navigation and
landing on all of these aircraft consists of electro-mechani-
cal indicators. Head-up displays are provided on the F-111A/E,
A-7D, and F-15A for final approach guidance. Since the HSI
on the five aircraft would be the primary display for situation
information during MLS complex trajectory flight, the

4

Figure 1 MLS Complex Trajectory Signal Flow

5
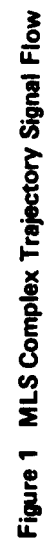
TABLE 1

EXISTING CAPABILITY / AIRCRAFT	# OF SEATS	ILS MODE AP	ILS MODE FD	EQPMT REDUNDANCY LEVEL	NAV & LAND INSTRUMENTATION	# OF BRG PTRS	HSI CAPABILITY AUTOSLEW CRS PTR	HDG BUG	DME READOUT	RECOMMENDED MLS CONFIGURATION
C-130A/D	2	X	X	Single	Electro-mechanical	0				MLS – 1
F-111A/E	1		X	Single	Electro-mechanical, HUD	1	X	X	X	MLS – 1
A-7D	1		X	Single	Electro-mechanical, HUD	2			X	MLS – 3
F-15A	1		X	Single	Electro-mechanical, HUD	1	X	X	X	MLS – 3
KC-10A	2	X	X	Dual	Electro-mechanical	1	X	X	X	MLS – 4

Existing Aircraft Capabilities and MLS Configuration Recommendations

NOTES:

1. Flight engineer stations exist on the C-130A/D and KC-10A.

2. The F-111A/E is a two-seat aircraft; however, only one seat has access to the MLS-related controls and displays.

6

functional capabilities of the specific HSIs were considered
to be important. Investigations into this instrument for each
aircraft revealed the following:

- C-130A/D - No bearing pointer (two RMIs on pilot's
  instrument panel, however), no autoslew capability
  of course pointer, no DME readout (separate indicator
  for TACAN DME)

- F-111A/E - Single bearing pointer, autoslew capability
  of course pointer and heading bug, DME readout

- A-7D - Two bearing pointers, no autoslew capability
  of course pointer, DME readout

- F-15A - Single bearing pointer, autoslew capability
  of course pointer and heading bug, DME readout,
  digital interface via central computer

- KC-10A - Single bearing pointer, autoslew capability
  of course pointer and heading bug, DME readout

The recommendation of the complex trajectory configuration for
the KC-10A is based on the assumption that the proposed electro-
mechanical display presentation and semi-automatic data entry
scheme is adequate for safe approach progress monitoring at
acceptable pilot workload levels for a pilot/copilot cockpit
arrangement. The KC-10A capability of automatic control to
touchdown also contributes to the validity of this assumption.

The recommendation of the selectable intercept of final
configuration for the F-15A and A-7D is based on the fact
that these are single-seat aircraft with only flight director
control capability. The simplified data entry scheme of the
MLS-3 configuration appears to reduce pilot workload to a
reasonable level whereby the close-in approach benefits of this
system are achievable in a practical manner. The proposed
electro-mechanical display presentation for this configuration
is identical to that for the complex trajectory system.
Since this configuration basically provides a controlled
ILS-type intercept, capture, and tracking maneuver, no problem
is anticipated in verifying the adequacy of the display
presentation.

The recommendation of the straight-in configuration for the
C-130A/D and F-111A/E was primarily due to anticipated
retrofit costs. The C-130A/D is an old aircraft with a

control-and-display scheme which does not lend itself to
the integration required for complex trajectory flight.
The autopilot operation needs improvement,and a vertical
axis flight director approach mode does not exist. Further
MLS retrofit work done for the C-130A/D should involve
consideration of an autopilot/flight director system update.
The F-111A/E has a different problem. Although the instrumen-
tation and control capabilities appear to support an MLS-3
configuration, cockpit space is very limited even for the
addition of an MLS AZ/DME display. Moreover, even though the
F-111A/E is a two-seat aircraft, only the left side contains
approach instrumentation.

The assumptions and recommendations herein discussed, are a
direct result of the more general complex trajectory analysis
efforts included in this report on: trajectory definition and
geometry requirements; monitoring and redundancy require-
ments; display information requirements; and, man-machine
interface requirements. From these requirements candidate
control-and-display configurations were developed for both
present-day and future aircraft. This has resulted in both
electro-mechanical and electronic display schemes applicable
to complex trajectory flight. Validation of the analysis
which generated these candidate configurations can only be
achieved via simulation and/or flight test efforts. The
following paragraphs summarize this general analysis work.

Complex trajectory definition and geometry requirements
are directly related to data entry, approach plate design,
and approach monitoring. It is generally accepted that
complex trajectories should be defined by straight line
segments connected by circular arcs of fixed radii. This
is generally accomplished for present-day RNAV systems by
defining points in space (i.e.,waypoints) in a latitude/
longitude/altitude or bearing/DME/altitude format. This
method was utilized on both the MLS-configured USAF T-39 and
NASA 737 TCV aircraft. Significant advantages result, however,
if the trajectory is defined as a path extending from the
runway touchdown point out to the limits of MLS coverage.
By building the trajectory with the magnetic course, length,
and flight path angle of each approach segment,the number of
data entries are reduced by 30% for an approach consisting of
3 lateral and 2 vertical segments. Moreover, the data required
to be entered by the pilot is in a form that is more relatable

8

to his way of thinking and should, therefore, reduce the
probability of entry error.

The design criteria for future approach plates for MLS
complex trajectory flight must consider data entry and
approach monitoring requirements. The approach plate
presentation must contain all the data required to completely
define the trajectory to the MLS computer. If this data is
based on a trajectory definition which results in minimum
data entries and is formatted in a concise manner (e.g., a
table), workload will be reduced. Several different 3-D
approach plate designs were investigated as part of the
analysis effort. These have definite advantages for complex
trajectory flight since they combine both the lateral and
vertical profiles in one overall view of the approach. This
will probably aid the pilot in approach monitoring. One
disadvantage occurs in that it is impossible to retain a
north-up relationship for approaches which run close to
north or south. Rotating the situation to provide a better
vantage point for the perspective view may or may not be
acceptable to the users. Further evaluation of this subject
must be conducted with pilots, traffic controllers, and
TERPS personnel.

Complex approach monitoring involves the pilot's use of
display information and/or equipment redundancy to detect
the presence of both gross and subtle failures. Possible
sources which can introduce these failures include the pilot,
CDU, MLS computer, and displays. Like Category III ILS
equipment, the MLS transmitter/receiver is assumed to be
self-monitored. Unlike ILS, however, the MLS receiver outputs
are not always easily interpretable with respect to the path
being flown. Depending on the approach, all three parameters
may be constantly changing during the complex portion. The
MLS data corresponds to the ILS information only during the
final approach segment.

Data entry errors involving the pilot, CDU, or computer are
detectable via a semi-automatic check procedure which must
be performed by the pilot. After entering the required
trajectory data, the pilot enters an along-track-distance
corresponding to a check point shown on the approach plate.
Based on this distance and the newly computed trajectory,
the computer calculates the check point's azimuth, DME,
and elevation. The pilot then verifies this data, shown

9

on the CDU, against the corresponding data shown on the approach plate. Any difference indicates an entry error or failure.

Gross failures which occur during the complex portion of the approach are detectable with the primary instruments (e.g., ADI, HSI, rate of climb). Subtle failures during the complex trajectory will probably go undetected until the final approach segment unless some form of automatic monitoring is employed. Monitoring on an MLS final approach is virtually identical to ILS except for the addition of DME. If the complex portion of an IFR approach is considered flight critical due to obstacle avoidance or for any other reason, equipment redundancy is probably required. Procedures for missed approaches, due to partial or complete loss of MLS data, must be carefully established for complex trajectories in obstacle areas. Simulation and/or flight test studies are required to determine the adequacy of these procedures during operations in both high and low traffic environments.

The display information presented to the pilot for complex trajectory flight must be sufficient for:

- Controlling the aircraft about the desired path

- Monitoring system operation and performance

- Maintaining orientation with respect to the path and the runway

Also the information must be presented in an integrated format to result in acceptable pilot workload levels. The recommended complex trajectory display parameters, computational source, and indicator type are shown below:

	SOURCE	MLS	ADI	HSI	CRT
AZIMUTH ANGLE	RCVR	X			X
RANGE-TO-GPIP	RCVR	X			X
LAT DEVIATION	RCVR/CMPTR			X	X
VERT DEVIATION	RCVR/CMPTR		X		X
DESIRED TRACK ANGLE	CMPTR			X	X
RANGE-ALONG-TRACK-TO-GPIP	CMPTR			X	X
BEARING-TO-STATION	CMPTR			X	X

	SOURCE	MLS	ADI	HSI	CRT
PATH ANTICIPATOR	CMPTR			X	X
FLIGHT PATH ANGLE	CMPTR		X		X
MAP DISPLAY	CMPTR				X
PREDICTOR	CMPTR				X

For an aircraft with electro-mechanical instrumentation, an MLS AZ/DME indicator is required as a computer-independent display of aircraft position. This display will be useful for monitoring approach progress and MLS operation. A typical example of the complex trajectory display format using electro-mechanical instrumentation is shown in Figure 2. For future aircraft with primary electronic displays, all information can be integrated within one CRT-type indicator. Figures 3 and 4 depict two color CRT display formats which have been devised for MLS complex trajectory flight. Although the static presentations appear to be quite "busy", it is felt that operation in a true and/or simulated dynamic environment will result in pilot acceptance.

The man-machine interface problems with MLS flight are basically associated with the workload requirements of complex trajectory data entry. Because automatic data entry is an expensive alternative in terms of both initial purchase cost and recurring logistics costs, manual data entry will probably be used on a widespread basis until an inexpensive ground-to-air transponder system is perfected which can accomplish this task. Even then a back-up manual entry scheme will be required. Manual data entry for MLS, like for RNAV, is accomplished with a CDU. For retrofit aircraft it is anticipated that a new MLS CDU will be incorporated. For future aircraft the MLS functions can be easily incorporated into an integrated multifunction keyboard and controller. Basic CDU requirements include the need to design logic which: leads the pilot to the data which has to be entered; minimizes operations; and, is simple to use. The unit should also utilize terminology which is familiar to the pilot. A typical MLS CDU is shown in Figure 5. It integrates all the control functions (except the ILS/MLS selection switch) associated with MLS complex trajectory flight into one unit. These functions include:

11

- Data Entry
- Channel Select
- Audio Volume Select
- Antenna Mode Select
- Complex Trajectory Mode Select
- Auxiliary Data Select

For the proposed configurations which do not fully utilize the total MLS complex trajectory capability, there is a significant decrease in control function complexity. The data entry task is considerably reduced for the MLS-2 and MLS-3 configurations, and is completely eliminated for MLS-1. This, by itself, reduces pilot workload for approach set-up procedures to a level which closely approximates that for ILS. Figure 6 depicts typical panels for the direct ILS replacement, selectable elevation and azimuth, and selectable intercept of final MLS configurations.

1.5   Report Organization

The remainder of this report presents information in the following order:

- Section 2.0 contains a discussion of the problems associated with MLS complex trajectory flight and its relationship with USAF requirements.

- Section 3.0 presents overall design criteria for complex trajectory flight. This includes detailed discussions on trajectory definition and geometry requirements, monitoring and redundancy, display information parameters, and man-machine interfaces.

- Section 4.0 presents candidate control-and-display configurations for four levels of MLS capability. This information has been generalized to make it applicable to present and future aircraft within the USAF inventory. As a result information is presented for both electro-mechanical and electronic display schemes.

- Section 5.0 presents the results of studies conducted on five specific USAF aircraft. For the C-130A/D, F-111A/E, A-7D, and F-15A, technical orders for the systems related to an MLS retrofit were reviewed.

12

TRANSITION
ALERT LIGHT

RANGE-TO-GPIP
= 5.6 NM

AIRCRAFT AZIMUTH
ANGLE = 30° TO LEFT

DME   AZ
  5 . 6   ◯   L 3 0   ◯   ◯

GLIDE PATH
DEVIATION
= ¼ DOT
BELOW

FLIGHT
PATH =
5° DOWN

RANGE-TO-TRANSITION
= 3.1nm

3 1   0 4 5

DESIRED
TRACK
ANGLE
= 45°

BEARING TO
STATION
= 40°

045

060

LATERAL
DEVIATION
= ½ DOT
LEFT

270   180

225

NEXT COURSE =
RUNWAY HEADING
= 000°
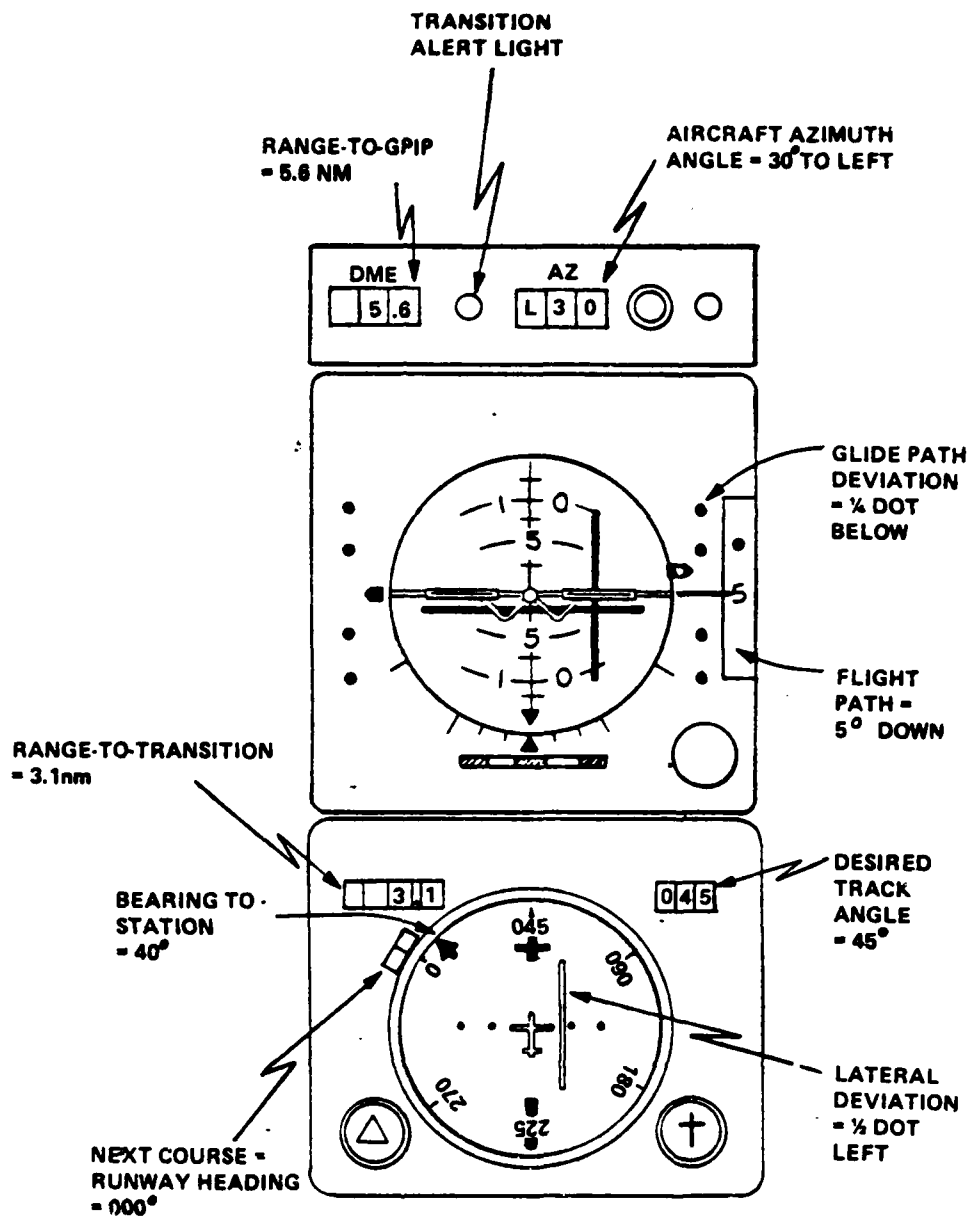
Figure 2   Typical Complex Trajectory Electro-Mechanical Instrumentation

13
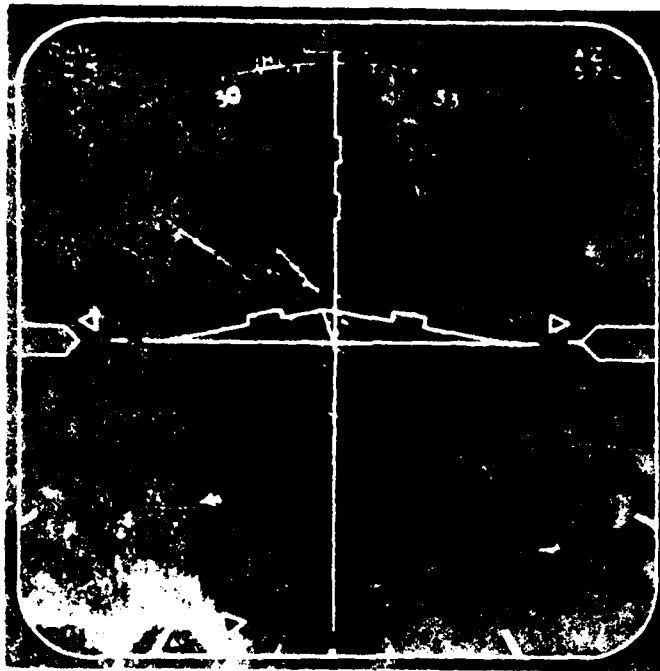
Figure 3. 3D Color Display
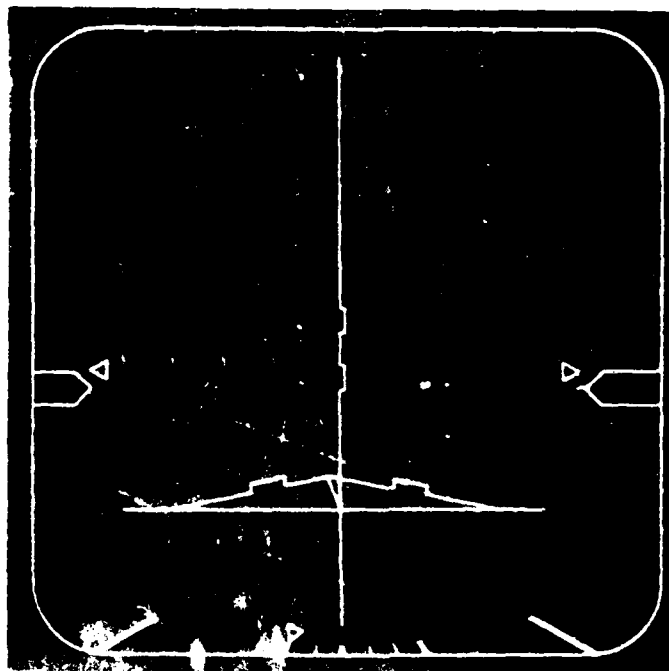
Figure 4. 2D Color Display
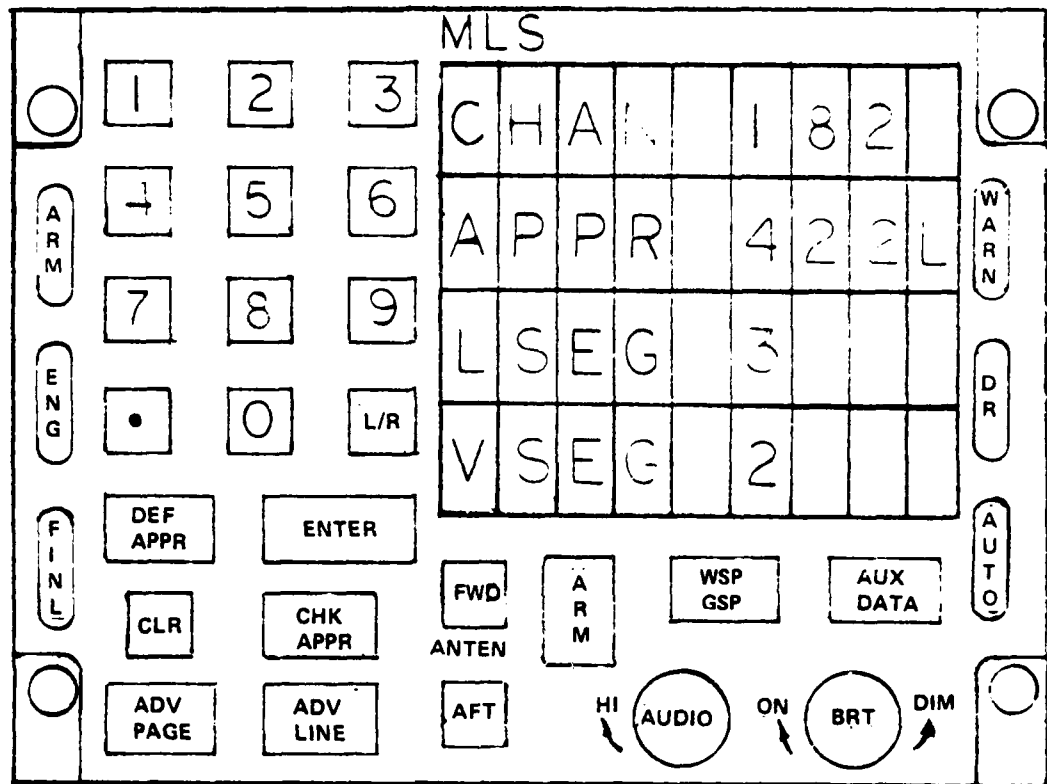
Figure 5   Typical Complex Trajectory CDU
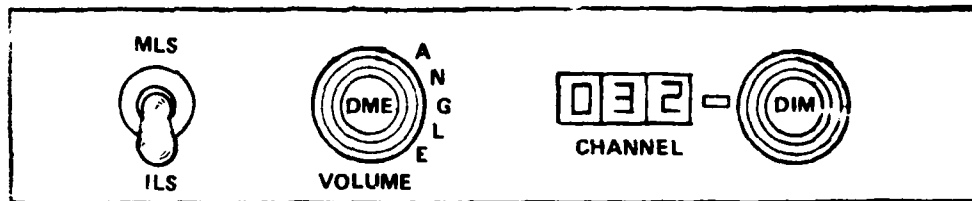
MLS—1, Direct ILS Replacement Tuner
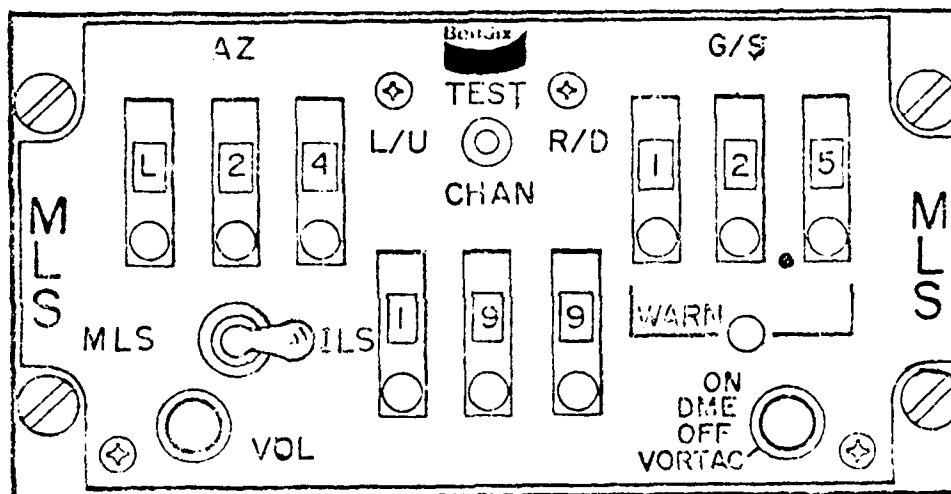
MLS—2, Selectable Azimuth And Elevation Tuner/Selector
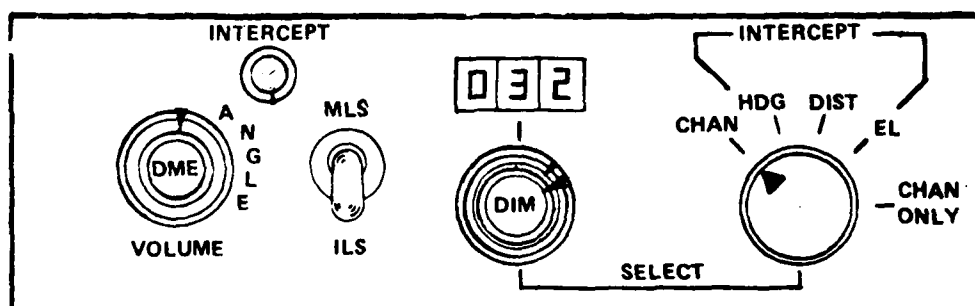
MLS—3, Selectable Intercept Of Final Controller

Figure 6   Typical Panels For General MLS Configurations

For the KC-10A, information was obtained from McDonnell-Douglas directly since T.O.s do not exist. This information was compiled and is included to provide a description of the existing aircraft. Based on this, MLS configuration recommendations are included for each aircraft.

● Section 6.0 presents proposed issues associated with a design definition phase activity. These issues require further concept refinement and evaluation in a closed-loop cockpit simulator environment.

● Appendix A contains a list of references obtained during a background survey for this investigation.

● Appendix B provides an analytical insight into the role of a predictor in an electronic horizontal situation display.

● Appendix C presents on overview of the USAF T-39 MLS and NASA TCV programs as they relate to the subjects of this study. Also included are synopses of several other studies which are applicable to the subject matter contained herein.

● Appendix D presents an overview of various 3-D image representations of MLS complex trajectories. It also presents general design criteria for a 3-D display format.

● Appendix E contains a detailed task description of the pilot procedures involved with flying and monitoring an MLS complex trajectory approach on the USAF T-39. The procedures are based on the T-39 with electro-mechanical instrumentation rather than the one with the electronic display.

17

2.0 DISCUSSION OF THE PROBLEM

2.1   Description of MLS

MLS is an all-weather landing system consisting of ground and
airborne transmitter/receiver equipment. It provides precise
high-integrity guidance signals over a wide coverage sector.
These signals are relatively unaffected by topography, airport
structures, overflying and taxiing aircraft, ground vehicular
traffic,and weather. MLS ground equipment can be deployed in
remote, generally hostile physical environments and will
provide basic high reliability performance (MTBF $\cong$ 1000 hrs)
with minimal attention(MTTR $\cong$ .36 hrs.)

A total MLS, in its most expanded present form (FAA Phase III
MLS), consists of:

- Ground Transmitters (typically laid out as shown in Figure 7)
  - Front and back azimuth phased array antennas
  - Approach and flare phased array antennas
  - Precision L-band DME antenna

- Airborne equipment (excluding complex trajectory compu-
  tational and control/display requirements)
  - C-band angle receiver, nose and tail omnidirectional
    antennas, and antennas switching unit.

  - L-band DME interrogator and antenna

  - Control panel, as shown in Figure 8, for selection
    of MLS channel, azimuth and elevation angle

  - Auxiliary data panel, as shown in Figure 9 for dis-
    play of ground transmitted parameters such as
    runway heading and condition (wet or dry),
    transmitter operational status (CAT I, CAT II,
    CAT III), and minimum glide path for the runway.

  - DME indicator

MLS provides many advantages over the present day ILS. These
advantages include:

- Greatly increased volumetric data coverage
  - 1° to 20° of elevation data vs. a $3^{\circ} \pm 0.7^{\circ}$ glide
    slope.

18
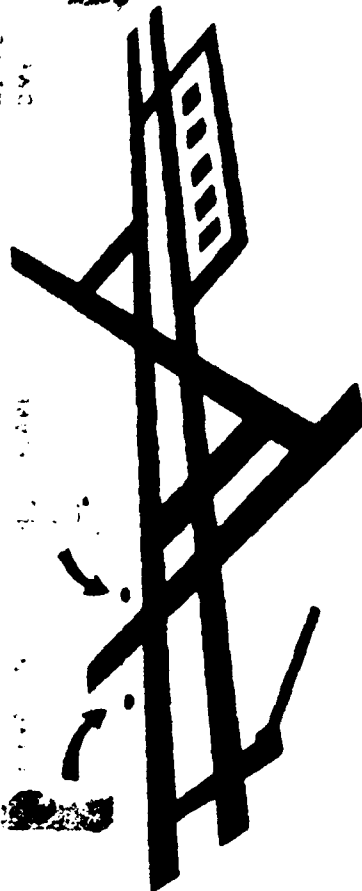
Figure 7 MLS Ground Equipment
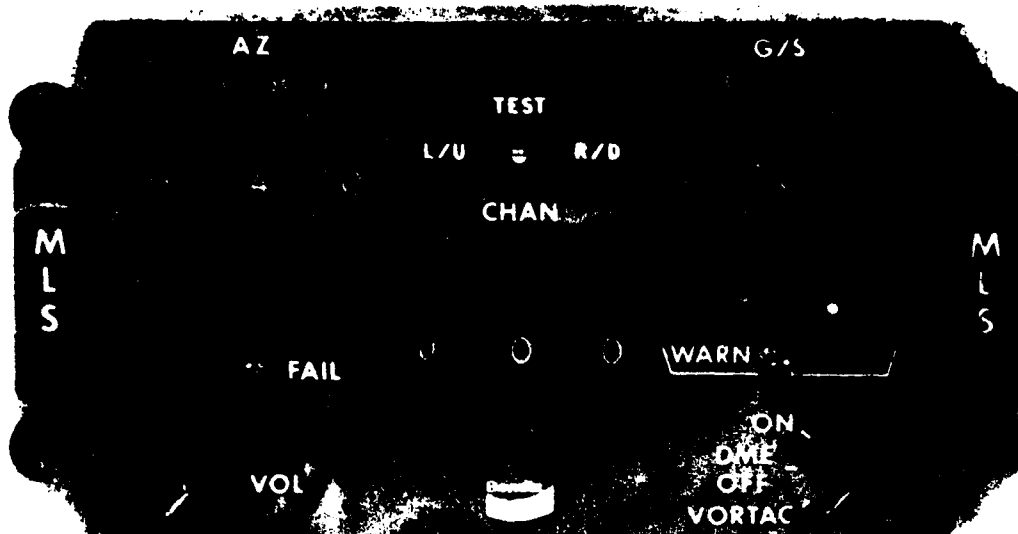
Figure 8 Phase III MLS Control Panel
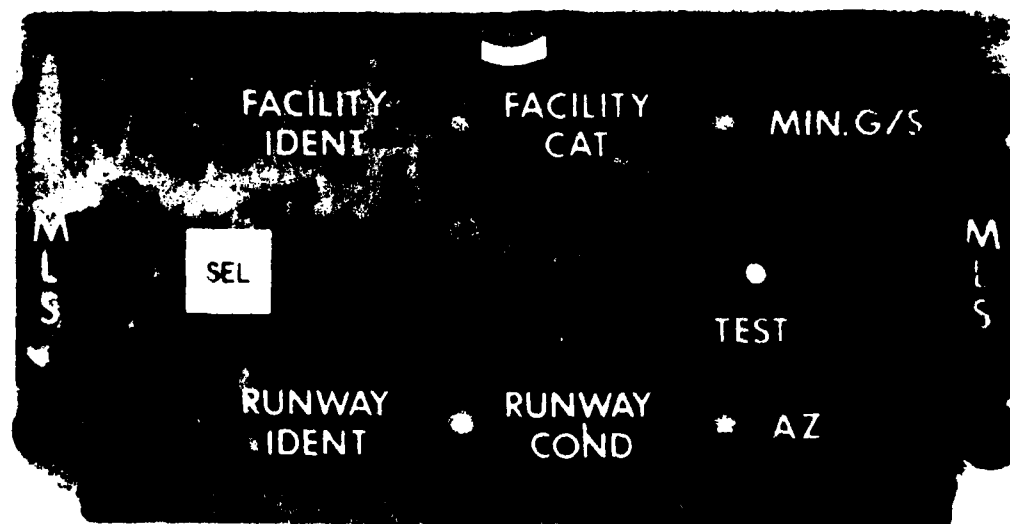
Figure 9 Phase III MLS Auxiliary Data Panel

- $\pm$ 60° of azimuth data vs. a $\pm$ 2° localizer

- Angle guidance and precision DME to a range of
  20 nm

- Back azimuth guidance of $\pm$ 40° to a range of 5 nm

● A receiver data format that provides a digital output for
  aircraft position as an absolute azimuth and elevation
  angle, as well as analog outputs (like ILS) for angular
  deviation about the selected azimuth and elevation angle.

● Increased data accuracy and improved signal quality
  - Eliminates low frequency beam bends inherent with
    the ILS

● Missed approach and take off guidance

● Derivation of a terrain -independent altitude above the
  ground which can be used to improve the flare control law.

● 200 frequency channel capability as opposed to 80 for ILS
  - MLS operates from 5031.00 to 5090.10 to MHz with
    300 KHz spacing

From the MLS absolute angular position and DME data, an on-
board digital "MLS navigation computer" (this may be an
existing RNAV or flight control computer; or it may be a
new computer dedicated to MLS guidance) can precisely compute
present aircraft position in rectangular coordinates, compare
it to a predefined path with respect to the ground, develop
guidance commands and/or error signals, and thereby result
in aircraft control about a complex trajectory.

2.2   Complex Trajectory Flight

Two examples of complex trajectories flown by the USAF T-39
at the National Aviation Facilities Experimental Center (NAFEC)
in Atlantic City, N.J. are shown in Figures 10 and 11
Each approach is made up of a series of waypoints connected
by straight-line segments beginning outside MLS coverage
under VORTAC or RNAV guidance and ending at the missed approach
point. Transitions between straight-line segments are made
about circular arcs of fixed radii.

21
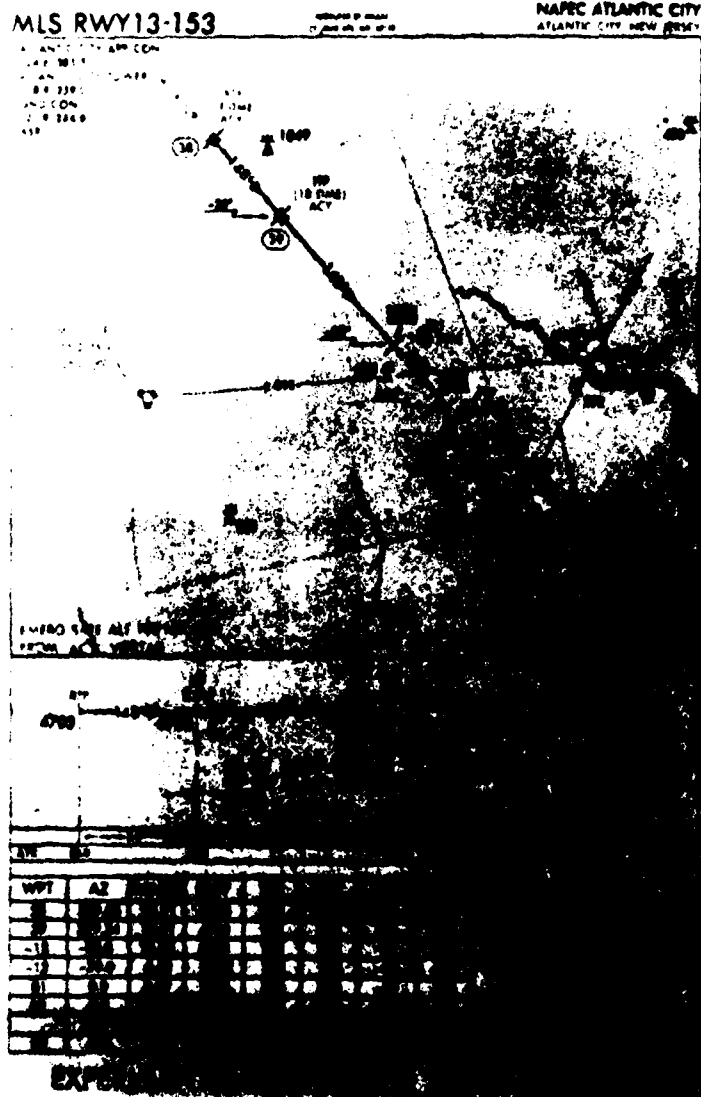
Figure 10   MLS Complex Trajectory -- MLS RWY13-153

22
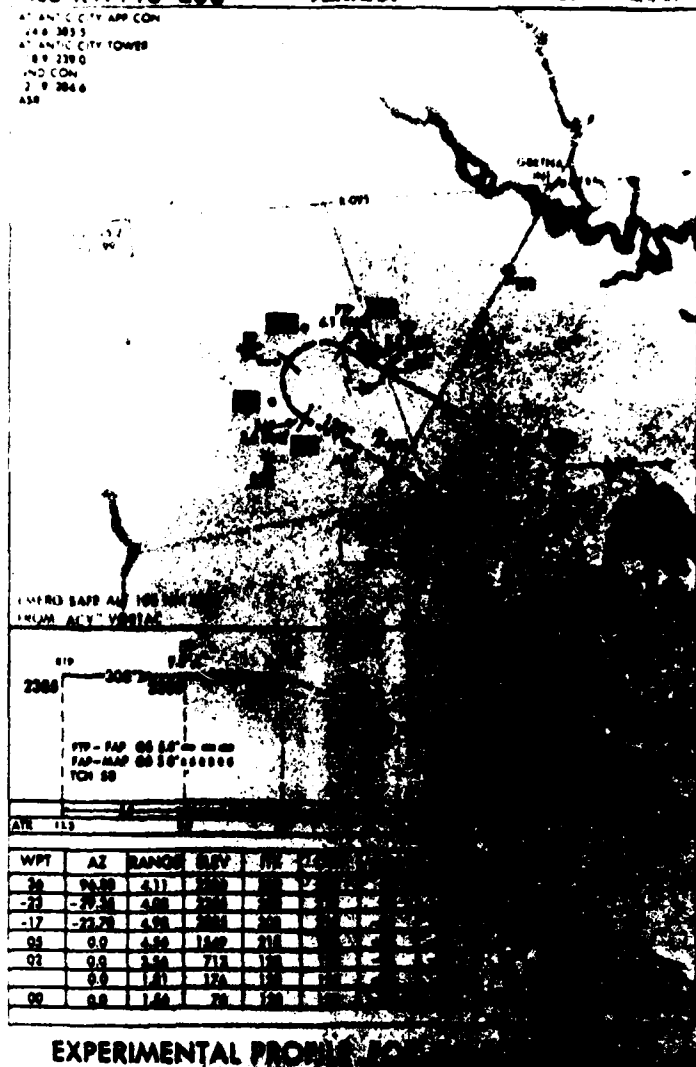
Figure 11 MLS Complex Trajectory -- MLS RWY13-253

In general. an infinite number of complex approach profiles can be described within the wide MLS data coverage. Multi-segmented paths can be defined in both the lateral and vertical axes. Control of the aircraft about these paths can result in:

- Increased terminal air traffic density
  - A reduction in aircraft landing times via 90° intercepts to short final approach lengths (six miles or less)
  - More efficient sequencing of aircraft by having high and low speed aircraft fly different approach paths to the airport so that the faster aircraft can effectively "pass" the slower aircraft

- Effective noise abatement procedures by defining profiles which avoid population centers and by utilizing two or even three segment descents.

- Obstruction avoidance whereby aircraft can fly into airports not serviceable by ILS due to the position of mountains.

- Ground fire avoidance whereby the military can avoid flying over known enemy territories and can minimize risk by flying dissimilar approaches.

2.3   Control-and-Display Issues

The difficult problems encountered with complex trajectory flight in the terminal area primarily relate to pilot workload and air traffic control considerations. They are not associated with implementing autopilot and flight director control law equations to accurately fly the desired path. MLS control laws developed for the T-39 utilizing crosstrack deviation, and track angle error and ground speed to derive crosstrack deviation rate, in the lateral axis; and utilizing vertical track deviation and rate, derived in a complementary filter scheme using vertical speed and normal acceleration, in the vertical axis - provided a smooth transition into MLS coverage, an immediate capture of the first MLS segment and accurate tracking throughout the approach. The problems in attaining Category II and III performance levels for landing appear to be easier to solve for MLS than for ILS due to the quality of the signal.

Problems, which require further study and which will be
discussed in various levels of detail within this report,
relate to:

- Pilot workload- the pilot's ability to perform the
  necessary tasks to: define the desired trajectory to
  the computer; actuate and maintain control of the
  aircraft via the flight director or autopilot MLS mode;
  continuously monitor his situation using the available
  displays; and, detect failures quickly.

- Display information requirements and integrated display
  presentation formats to result in acceptable levels
  of pilot workload throughout the maneuver.

- Trajectory definition to the computer and its relation-
  ship with the approach plate format and pilot monitoring
  techniques.

- Entry procedures into MLS coverage including transitions
  from RNAV, TACAN, VNAV and altitude hold.

- Equipment redundancy requirements during the complex
  portion (i.e., other than the straight-in final segment)
  of an IFR approach which may involve obstacle or ground
  fire avoidance.

Other problems which require further study but are not
discussed in significant detail within this report involve:

- Air traffic control procedures to take maximum advantage
  of MLS without any sacrifice in safety.

- Accuracy requirements during the straight line segments
  and circular arc transitions of the complex portion
  of the approach.

- Missed approach procedures during the complex portion of
  the approach.

- Improvements in autoland control laws through the use
  of terrain independent altitude, ground speed and wind
  speed information derived from MLS.

2.4 MLS Integration in USAF Inventory

2.4.1 Review of GOR

A "General Operation Requirement (GOR) for an Advanced Landing System (ALS)" has been defined by the Department of the Air Force per AFCS 702-78. It addresses the operational deficiencies of the present generation of precision approach and landing systems (PAR and ILS) used by USAF aircraft; and, it establishes requirements which, when implemented, will correct these deficiencies. The GOR has not been validated by HQ USAF and some format and content changes can be expected in the eventually approved requirements document. The following is a review of the GOR as it pertains to this study.

Neither Precision Approach Radar (PAR) nor ILS can provide a true zero visibility landing capability without great expense. nor can they provide any significant degree of approach path flexibility. Since ILS ground systems are physically large and are extremely sensitive to their physical environment, ILS is not suitable for general use in tactical situations. Although PAR is not as severely limited by siting constraints, it is a highly complex system with high acquisition, installation, operation and maintenance costs. PARs are limited in range (9 nm for present-day systems and only up to 20 nm for the TPN-19), are unable to perform to Category III criteria, and have extreme difficulty in performing to Category II. The ALS is required to overcome these deficiencies and support various levels of operational missions with various levels of performance requirements.

At the lowest level, the ALS should provide ICAO Category I service and a quick set-up capability to satisfy short term contingency requirements or other limited operations. These include operations at:

- An Assault Landing Zone consisting of a sufficiently level field or clearing of a size to permit landings by tactical aircraft, forward air control and rotary wing aircraft. The area may by camouflaged and only primitive area markers would be present.

- An Extraction Zone consisting of an open field or clearing to permit cargo aircraft flyovers at approximately ten feet above ground level (AGL).

- A Drop Zone, possibly in the vicinity of rough
  terrain, whereby cargo aircraft approaches and
  airdrops may be conducted as low as 50 feet AGL.

- Locations where frequent helicopter activities are
  required for combat rescue, medical evacuation,
  and selective airlift.

Limited operations ground equipment should provide:
$\pm 20^\circ$ of azimuth coverage and 1 to 15° of elevation coverage to
a range of 10 nm. Back course coverage is not required.

At the second level, the ALS should provide ICAO Category II
service (expandable to Category III) for tactical operations.
Tactical operations will typically be conducted in a bare
base environment at site which has evolved from the build
up of a limited operations site. Aircraft operations will
normally include tactical fighters, medium transports, and
helicopters. RPVs may also be present. Although only a
single runway (typically 2,000 to 12,000 feet in length)
may be available, operations must support high recovery
rates. Curved approach paths may be used to avoid hostile
fire areas and for traffic separation.

Tactical operations ground equipment should provide $\pm 40^\circ$
of azimuth coverage and 1 to 20° of elevation coverage to
a range of 20 nm. Back course coverage of $\pm 40^\circ$ should be
provided to a range of 5 nm.

At the highest level, the ALS should provide ICAO Category
III service for full scale operations. These operations
would be typified by a main base with parallel runways of
up to 15,000 feet and serviceing all aircraft types. High
aircraft recovery rates (one per minute per runway) could
be expected on the parallel runways separated by not less
than 2500 feet. Curved approach paths may be used to aid
in traffic control and for avoiding selected areas of the
approach and departure sectors which would result in a flight
path over densely populated residential areas.

Signal coverage of the ground equipment installed for full
scale operations is identical to that described above for
tactical operations.

Three levels of ALS avionics equipment were considered in the

GOR and were related to the various aircraft types as follows:

1) __Austere Avionics__: Cost would be a primary consider-
   ation in this avionics configuration; however,
   the equipment must be capable of providing the
   equivalent of ICAO Category I service. Cost
   considerations may dictate that range information
   be provided by the TACAN/DME system. The mission
   of aircraft in this category would primarily be
   conducted in VFR conditions. Some types of
   attack (A-10), trainers (T-37), and utility
   aircraft would use this category of equipment.
   May be combined with Standard Avionics so that
   only two categories of Avionics exist.

2) __Standard Avionics__: Capable of ICAO Category II
   approaches in IFR conditions. Classes of air-
   craft requiring avionics in this category would
   include some of the cargo aircraft (C-130), the
   heavy bombers (B-52), tankers (KC-135), most
   fighters, and advance trainers (T-38).

3) __Advanced Avionics__: Capable of Category IIIA, B,
   and C approaches and landing. Aircraft requiring
   avionics in this category would include some of
   the cargo aircraft (C-5, C-141), air defense
   interceptors, and RPVs.

In general, it was stressed that aircraft with any level of
ALS avionics should be capable of landing at any field with
ALS ground equipment to at least, the performance criteria
associated with the lowest level of ground or airborne equip-
ment capability.

2.4.2   General MLS Retrofit Assumptions and Considerations

The integration of MLS into an existing aircraft, in the most
cost-effective manner, is a difficult problem. Tradeoffs,
relating to a cost-effective design, must address the possi-
bilities of: adding new computers, displays, and panels;
modifying existing computers, displays, and panels; replacing
old units with new units which contain both the old and new
functions; or, some optimum combination of all of these. This
study has not attempted to provide a detailed analysis of
these combinations.

For this study it has been theorized that a cost-effective
MLS retrofit of USAF aircraft will not result in significant
philosophy and/or configuration changes for the particular
aircraft. That is, MLS modes of operation will not be added
to autopilots which do not presently have ILS modes; dual
redundant MLS receivers will not be added to configurations
which presently incorporate single ILS receivers; and, present
electro-mechanical instruments will not be replaced with
electronic CRT type equipment. New information requirements
for MLS complex trajectory flight will be both integrated
into existing displays via switching and presented on a new
display if cockpit space permits. These compromises are
felt to be required to remain within the probable retrofit
budget constraints.

For these reasons, the level of complex trajectory capability
possible with the various aircraft will depend primarily on
the aircraft's existing level of automation and display.
This was shown in the USAF/T-39 Program by comparing complex
approaches made with standard flight director steering commands
and those made using autopilot control. The workload asso-
ciated with controlling power settings, maintaining orientation
and monitoring instrumentation for failures while manually
flying command bars was determined to be excessive during
complex maneuvers using standard electromechanical displays.
With autopilot control, however, workload was greatly reduced
to the point whereby better display and control function
integration could result in pilot acceptability. Since, of
the aircraft being studied, only the KC-10A and C-130 have
autopilot approach modes; it might be assumed that only these
aircraft would be able to fly MLS complex trajectories.
This is not necessarily true, however, since a reduction
in the level of complex trajectory flight may obviate the
need for an autopilot.

For example, an approach consisting of a 90° intercept to a
short final leg with a constant 3° glide slope descent, may
result in acceptable pilot workloads with only flight director
control. A short final type of an approach, while not fully
utilizing MLS capabilities, may provide significant advantages
for getting fighter and attack aircraft on the ground in
minimum amounts of time and at recovery rates consistent
with the ALS GOR.

Table 2 shows the benefits obtained from the wide MLS

29

coverage in terms of the ability to perform 90° intercept captures of the final approach segment very close to the runway threshold. Shown, for comparison purposes, is turn rate data with respect to: a typical ±2° ILS localizer; a civil ±10° small community MLS; a limited operations military ± 20° MLS; and, a ±40° MLS. The data consists of the maximum aircraft speed at which the maneuver can be successfully accomplished, with minimal overshoot of the extended runway centerline, using maximum bank angles of 30° and 45° . Also shown as part of the data is the distance to the runway threshold after the aircraft has rolled out on to the final approach segment; and, the maximum altitude at which the maneuver can occur if the aircraft is to remain on, or below, a 3° glide slope beam. The maneuver could also be performed as a descending turn using a glide path angle greater than 3° for the initial descent on to final.

From the data it can be seen that the localizer geometry does not allow this type of maneuver, even when travelling at 120 knots, unless the aircraft is 10 or more miles from the runway threshold. Contrary to this, a 2 nm capture is possible at 140 knots with the narrow ±10° MLS beam. With the ±20° MLS beam, 90° intercepts can be performed by even high approach speed aircraft 2 nm from the runway threshold.

In Section 4.1 a general MLS control-and-display configuration is described which takes advantage of the wide MLS coverage to the extent specified here. It provides precise guidance over any selectable intercept angle to a selectable final approach distance. It also allows selection of a two-segment descent profile.

3.0 COMPLEX TRAJECTORY FLIGHT CONTROL-AND-DISPLAY

DESIGN CRITERIA

3.1   Complex Trajectory Geometry Definitions
       and Requirements

3.1.1   Possible Trajectories

Ideally the MLS allows for the use of any complex trajectory
which can be mathematically defined. However, at present,
there appears to be no mission requirements which can not
be satisfied by trajectories composed entirely of straight
line segments and circular arcs in the vertical and horizontal
planes.

This simplification in requirements is significant from
several aspects. First, and perhaps foremost, is that
it allows the approach plate designer relatively simple
calculations to define and illustrate the horizontal track.
This also allows simple calculations for vertical path
transitions which must be specified first in terms of along
track distance (although they may be shown on the approach
plate in many other ways). Along track distance (ATK)
is defined as the distance along the trajectory measured
in the horizontal plane. The reference point for this
measurement is the GPIP (Glide Path Intercept Point),
which is the point on the runway where the glide slope
extension intercepts the runway.

Secondly, this simplification is carried over into the
MLS computer which now has only restricted types of traject-
ories to compute from the input data, i.e., there are
only straight line segments connected by circular arcs.

The greatest drawback to confining the trajectory geometry
in this manner is that it is physically impossible for
an aircraft to fly these trajectories exactly. For instance,
the transition from a straight horizontal track segment to
a horizontal circular arc requires an infinite roll rate
if no error is to occur. Similarly, in the vertical plane,
an infinite rate of normal acceleration is required.

31

TABLE 2

* SPD/BANK ANGLE/FINAL APPR LENGTH/MAX. ALTITUDE AFTER ROLLOUT TO BE ON OR ON OR BELOW 3°GS

RANGE TO THRESH (NM) ALONG FINAL HDG AT 90° INTERCEPT	±2° BEAM WIDTH RWY LENGTH		±10° BEAM WIDTH RWY LENGTH		±20 BEAM WIDTH RWY LENGTH		±40 BEAM WIDTH RWY LENGTH	
	10,000'	7,000'	10,000'	7,000'	10,000'	7,000'	10,000'	7,000'
1	NOT ATTAINABLE (NA)	NA	NA	NA	140KT/30°/0.51NM/162'* 180/45/0.53/168		→	
2	NA		140/30/1.51/480 180/45/1.53/487	130/30/1.57/501 170/45/1.58/503	200/30/0.99/315 200/45/1.42/451	190/30/1.09/347 200/45/1.42/451	200/30/0.99/315 200/45/1.42/451	
3	NA		150/30/2.43/775 190/45/2.47/788		200/30/1.99/634 200/45/2.42/700		→	
4	NA		170/30/3.27/1042 200/45/3.41/1086		200/30/2.99/953 200/45/3.41/1086		→	
5	NA		190/30/4.09/1302 200/45/4.42/1407		200/30/3.99/1271 200/45/4.42/1407		→	
6	NA		200/30/4.49/1590 200/45/5.42/1726		→		→	
10	120/45/9.79/3119		200/30/8.99/2864 200/45/9.42/3000		→		→	
15	120/30/14.6/4663 160/45/14.8/4660		200/30/14.0/4458 200/45/14.4/4594		→		→	
20	150/30/19.2/6130 180/45/19.5/6222		200/30/19.0/6051 200/45/19.4/6187		→		→	

Speed/Bank Relationship for 90° Intercepts of Final

These limitations are overcome by precognitive cues
which cause the changes to start earlier, and although
errors are not zero, they are sufficiently small to satisfy
the accuracy requirements. It must also be remembered that
during the final leg of an approach, at least twenty to forty
seconds of straight flight are required to allow the pilot
to orient himself and to assess the validity and accuracy
with which final touchdown will occur.

3.1.2   Radius of the Circular Arc

Two basic questions arise relative to the circular arc
paths. First, should the arc radius be defined on the
approach plate or should it be left to the pilot's discretion
to select? It is most desirable to show both the vertical
and the horizontal transition points on both the vertical
and horizontal projections of the approach plate. If the
turn radius is changed, the ATK to every point preceding the
turn is changed. As a result, the vertical transitions
are shown erroneously on the horizontal projection and the
horizontal transitions are shown erroneously on the vertical
projection. This consideration alone is a sufficient reason
to require that a specific approach plate shall show a
prescribed radius for every turn.

This problem is illustrated in Figures 12a and 12b.
Figure 12a shows the horizontal and vertical profiles
for a typical approach with a three degree glide slope
angle, and a 123 degree turn of one mile radius. Note that
the descent is initiated while in the turn.

Figure 12b illustrates the same approach but utilizes
a two mile turn radius. Note that every transition point has
moved with respect to the GPIP and that the descent is now
initiated before the turn. Basic MLS azimuth, elevation,
and range data which might be given for checks along
the trajectory (data not shown in the figure) are vastly
different for the two trajectories. In addition, the ATK
for the horizontal transitions have changed in a manner too
complicated for the pilot to compute in a reasonable amount
of time.

In summary, if the pilot is given an approach plate correspond-
ing to a prescribed radius of turn and he changes that
radius when defining the trajectory to the MLS computer,
the resulting trajectory will, in general be very different
in many aspects. These differences will make the information
on the approach plate virtually useless for the purpose
of monitoring the progress and the accuracy of the approach.

33
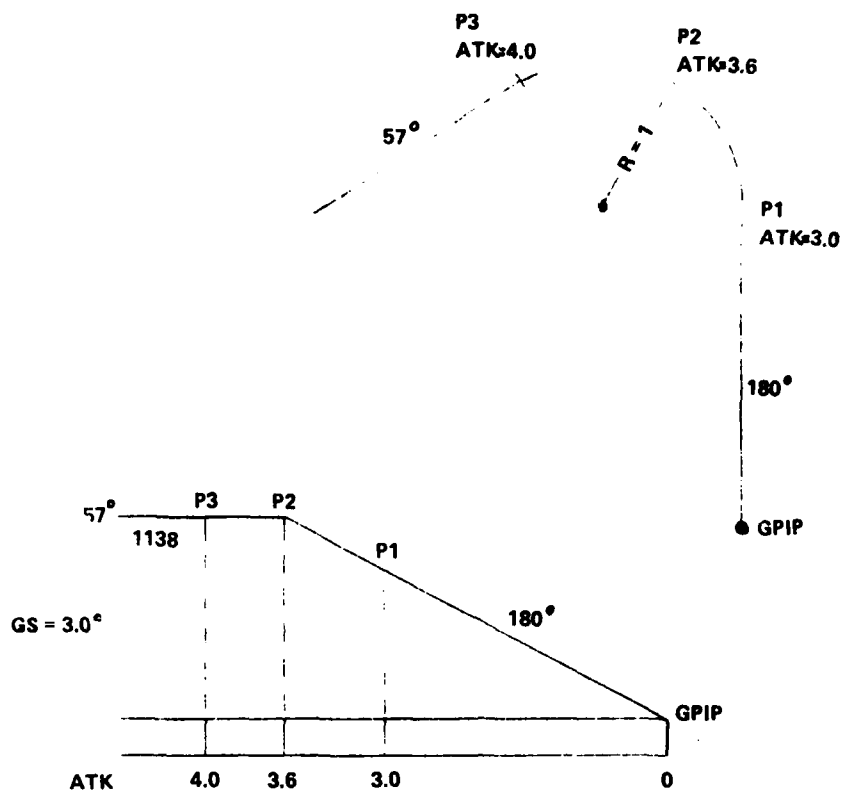
Figure 12a Radius Of Turn One Mile
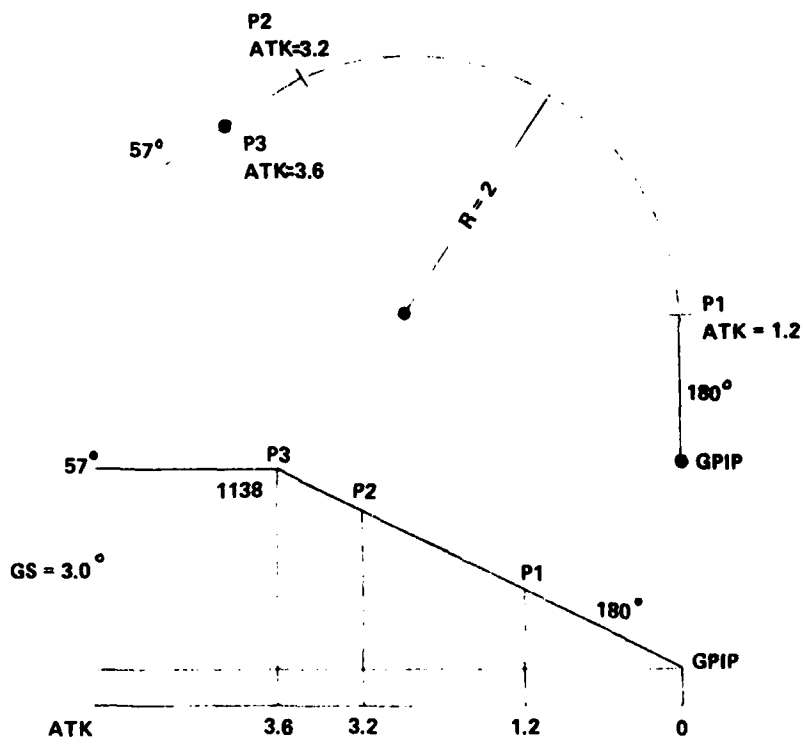
Figure 12b Radius Of Turn Two Miles

Figure 12 Effect Of Change In Turn Radius

The next logical question is what should be the prescribed
radius of turn. The turn should correspond to the smallest
bank angle (largest turn radius) consistent with traffic
which result in significant coupling of horizontal and
verical motion are discouraged. Since the bank angle re-
quired to fly a particular circular arc varies with the
square of the approach speed, designers must consider the
type of aircraft to be flying the approach when defining
the trajectory's radius of turn. This characteristic is
shown in Figure 13 for two different radii.

Bank angles of less than 30 degrees are required to track
a 1 nm radius of turn at approach speeds of 180 knots or
less. For speeds up to 240 knots, a 2 nm radius is required
to hold bank angles below 25 degrees. Due to these per-
formance limitations, several trajectories with different
radii will be required for landing zones which are used by
both high and low speed aircraft. The alternative is to
define all the trajectories for the high speed aircraft thereby
penializing the low speed aircraft in terms of approach man-
euverability.

The same basic criteria hold true for transitions in the
vertical plane. In the absence of other overriding
criteria, a trajectory should be defined which corresponds
to about .05 g's at normal approach speeds.

The same type of variation due to speed occurs in the
vertical plane insofar as normal acceleration is concerned,
as depicted in Figure 14. From these figures it becomes
apparent that low speed aircraft (e.g., STOL) are, in particular
being severely limited by restricting their flight to the
same maneuvers as CTOL aircraft. For this reason, and
because STOL aircraft will be subject to different traffic
control considerations, it would be advisable to provide
additional approach plates for the exclusive use of STOL
aircraft. These approach plates would provide sharper
turns, more rapid changes in flight path angle, and of course
the steeper descent angles for which these aircraft have been
designed.

In any event, it is important that, for all aircraft
types, all transitions have been completed and that stabilized
straight-in-flight has been established before the decision
height is reached.
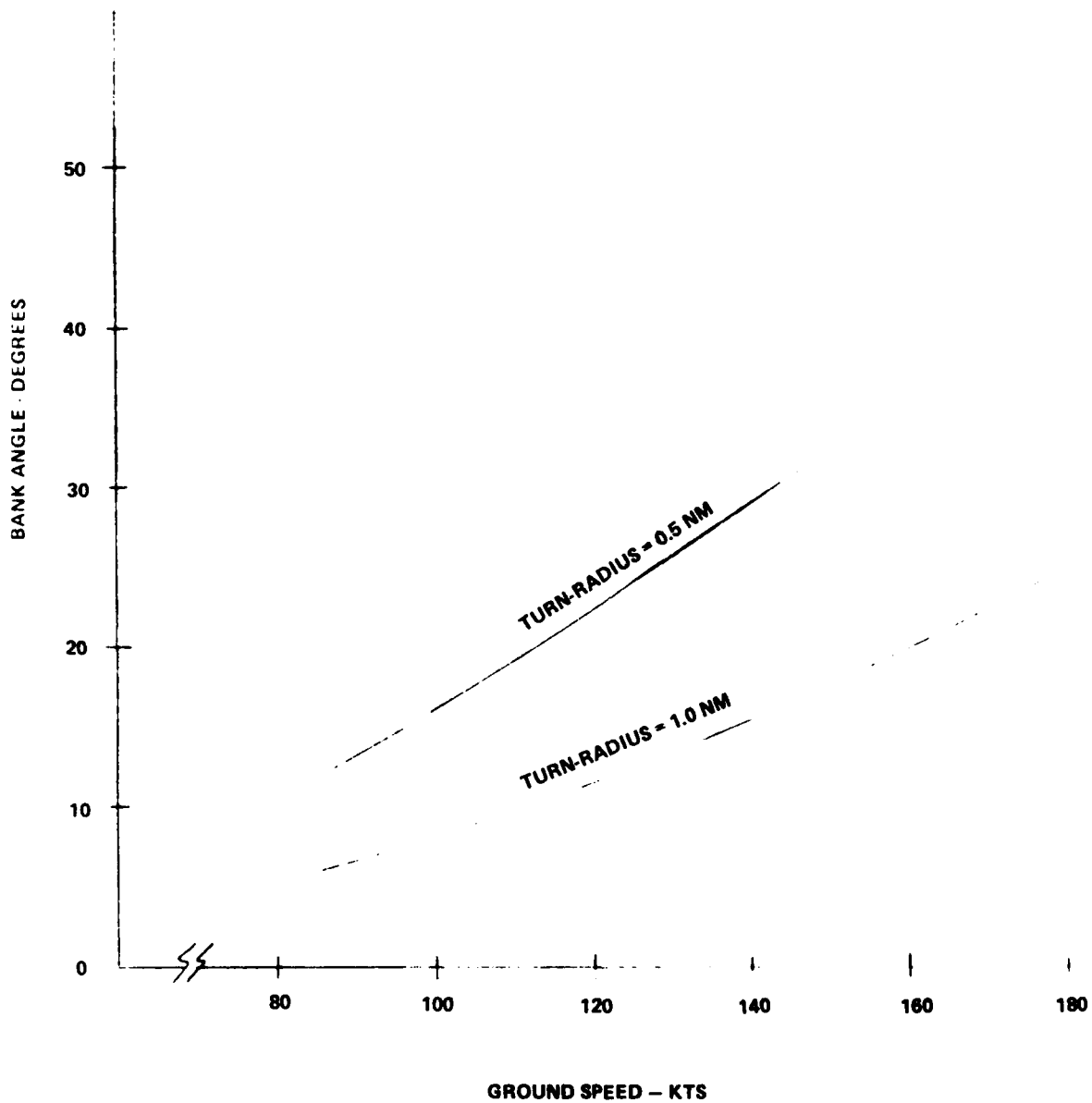
Figure 13 Variation of Required Bank Angle With Speed

36
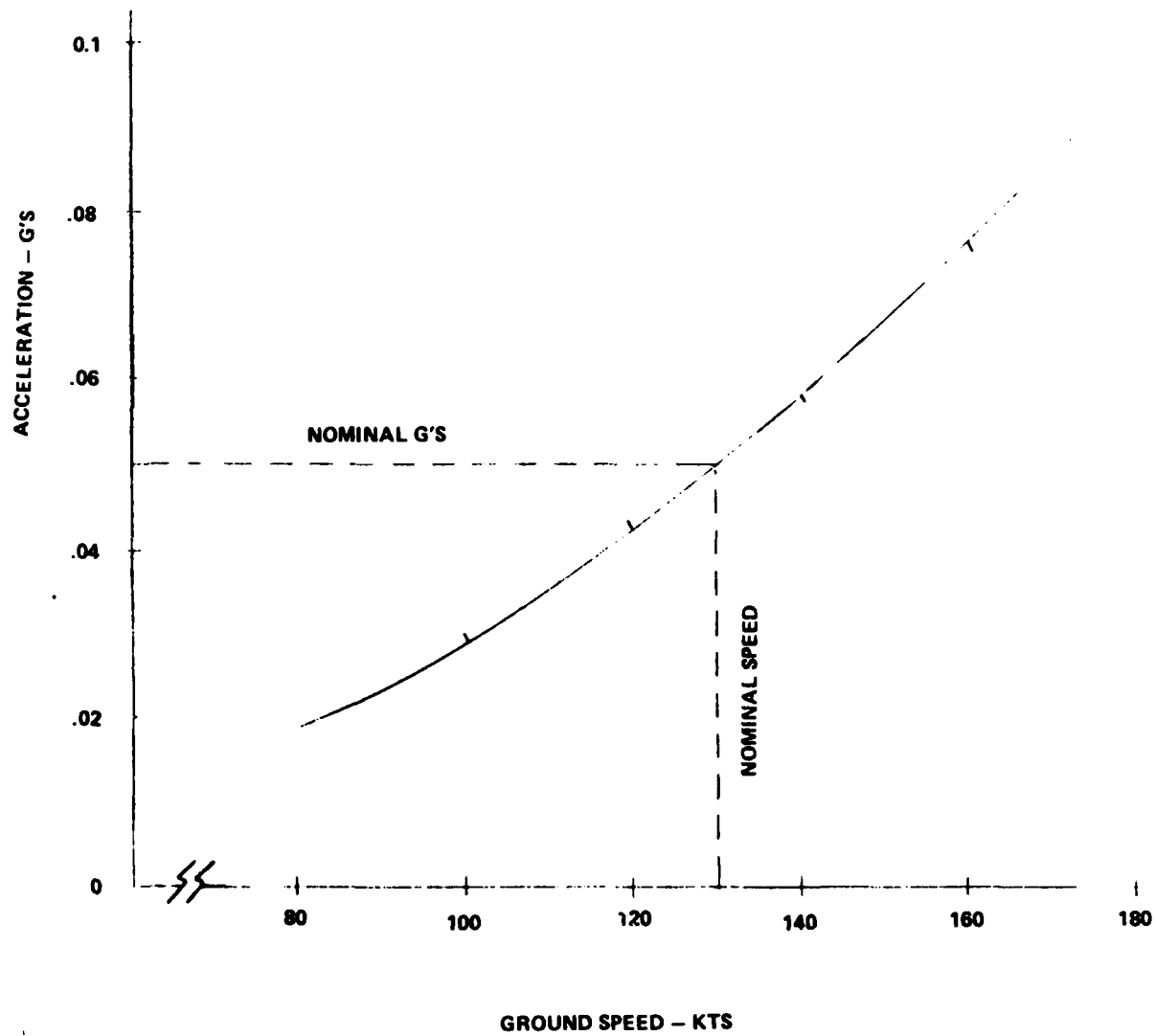
Figure 14 Variation of Normal Acceleration With Speed

37

3.1.3 Designation of MLS Waypoints

The MLS waypoints define the complex trajectory to the MLS
computer. Two basic alternate methods of defining these
waypoints were considered.

The first method, used in present-day RNAV systems, was
also used in the USAF FPI Program. The waypoints were
designated at the intersection of the straight line segments
of the trajectory. Since the aircraft always flew along
a circular arc connecting these segments it never actually
flew through the waypoints.

These waypoints were used by the crew as progress check-
points, and the data associated with them was the only
data available to be used by the crew as a reasonableness
check that the aircraft was accurately flying the desired
track. However, since the aircraft never actually passed
through the waypoints, the waypoint coordinates had very
limited value from a monitoring viewpoint.

An alternate method of defining waypoint/progress check
points, which circumvents this problem, is to define
waypoints which are actually on the trajectory. These
points may be at the transitions between the straight and
circular track segments, or anywhere along these segments.

This alternate method appears to be most promising from
a monitoring viewpoint and will be evaluated in the next
phase of study. The detailed means by which trajectories
are defined to the MLS computer, in this manner, is treated
elsewhere in this report. It is of interest here, however,
to demonstrate how the choice of designating waypoints
affects the amount of data (and thus workload) which the
pilot must enter into the CDU to define the trajectory
to the MLS computer.

Let us examine a general trajectory such as depicted in
Figure 15a. This trajectory is made up of the GPIP two
horizontal waypoints (1&3), and two vertical waypoints
(2&4, assumed to be not coincident with the horizontal
waypoints).

With the present T-39/MLS navigation program the crew
member inserts, via the CDU; the inbound course to the
first waypoint, the MLS azimuth, MLS horizontal range,
and barometric altitude of each of the waypoints (including
the touchdown point), and the runway course. In addition,
he must insert the turn radius about WP1 and WP3 if they
are different from a standard turn. Note that the present
program is limited so that a vertical waypoint can not be
located on a curved horizontal path.

The alternate means of specifying the same trajectory
is depicted in Figure 15b.   The horizontal trajectory
is specified first by inserting the runway course and the
range to the first circular arc transition (note that the
trajectory is being specified starting at the GPIP).
Next the arc radius and turn direction are inserted.
This is followed by the course and range from the end of
the first transition to the beginning of the second transi-
tion, the next radius and the turn direction, and finally
the initial inbound course. Next the vertical trajectory
is defined by the glide slope angle of the final leg, the
along track distance (ATK) from the GPIP at which the
glide slope transition is initiated, the previous glide-
slope angle and the ATK at which it is initiated. Note
that vertical transition points, whose location is now
inserted via ATK, can now be situated on a curved path
segment.

Let us now examine the difference in the number of data
inputs required to define the track.

   1) Present Method
    5 MLS Azimuths
    5 MLS Ranges
    5 Baro Altitudes
    2 Radii
    2 Courses
   19 Total
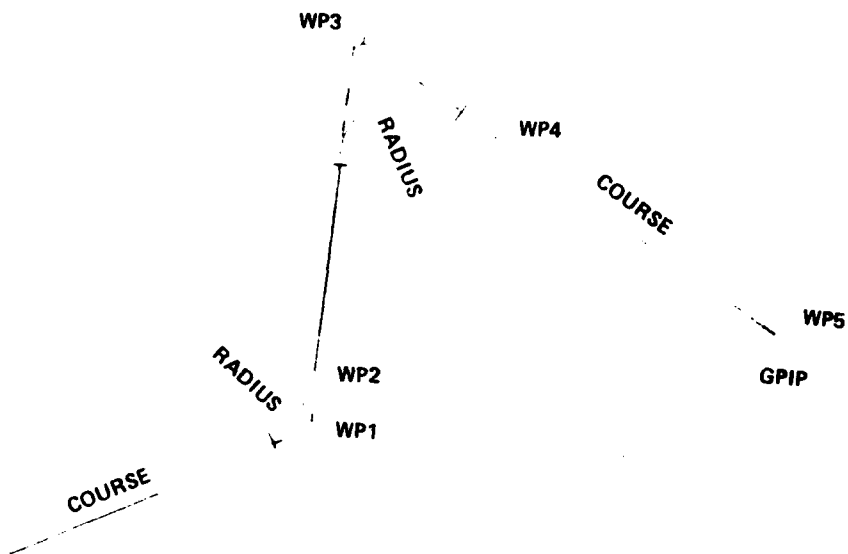
Figure 15a
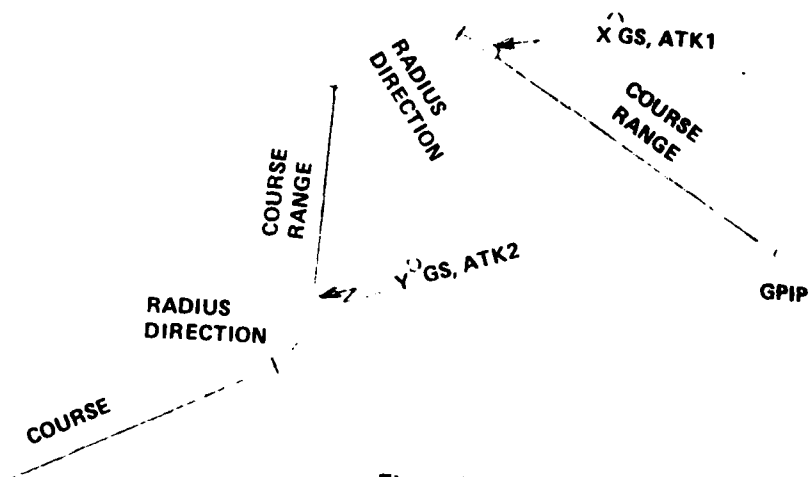
Figure 15b

Figure 15 Two Alternate Means Defining Trajectories

```
             2)   Alternate Method
                  3 Courses
                  2 Turn Directions
                  2 Ranges
                  2 Radii
                  2 G.S. Angles
                  2 ATK's
                 13 Total
```

This is a significant decrease in data entry requirements
and represents in itself a significant relief in pilot
workload.   In addition, the alternate method is specifying
the trajectory in the same terms which the pilot normally
thinks of his flight, e.g., left turn to 128 degrees, initiate
let-down 6 miles from touchdown, etc.

3.1.4   Approach Plate Design

From a human factors viewpoint there is an obvious advantage
to designing the MLS approach plate to appear in the
same format as the familiar conventional charts published as
Low Altitude Instrument Approach Procedures.   To accommodate
and facilitate MLS approaches, the following additions to
these charts are recommended.

1) The waypoints/progress check points should be
   sequentially numbered and should be on the
   designated horizontal and vertical trajectories.
2) The data illustrated for these points should show
   the basic MLS azimuth, range, and elevation angle
   with respect to the MLS transmitters.   (Barometric
   altitude may be used in place of MLS elevation
   angle).
3) Prescribed turn radii should be illustrated.
4) A table should be added, containing data in
   the format and sequence necessary to define the
   trajectory to the MLS computer.

The first requirement stems from the fact that the way-
points/progress checkpoints are used by the crew as a
reasonableness check that the aircraft is flying the desired
trajectory (for instance, the point of intersection of two
linear segments which have been connected by a circular
arc) has only limited value from this viewpoint.

The second requirement stems also from a monitoring consideration. In order to have a high degree of confidence in the validity of the trajectory being flown, it is desirable to check against the lowest level (least processing) of aircraft position data.

The third requirement results from the fact that the MLS computer, in a turn, will output its error information based upon the deviation of the aircraft from a prescribed circular track segment. The pilot must therefore fly this preselected circular track (as opposed to an arbitrary one of his choice), connecting the straight line segments, if he wishes his error display to remain nulled. In addition, it is obvious that since the trajectory may contain descending turns, any deviation from the prescribed horizontal turn trajectory would also require changes from the prescribed glide path angle in order to exit the turn at the required altitude.

The fourth requirement comes about from considerations of the pilot interface with the CDU for manual insertions of trajectory data. In general, the MLS trajectories are too complex to expect the pilot to simply extract the data and the sequence of data entry from the horizontal and vertical projections on the approach plate. Even for relatively simple trajectories, significant workload simplification result by tabulating the data to be loaded on a dedicated portion of the approach plate.

Note that the tabulated data need not have a direct correspondence to the data shown on other parts of the profile, and that the crew may not, necessarily, have a requirement to know the meaning of this data other than that it defines the trajectory to the MLS computer. Thus, many types of alpha-numeric coding techniques are possible with the final aim being to allow simple entry interface with the CDU and also to allow the MLS computer to check the validity of the data introduced.

On the other hand, it may be best to present this data in a format which makes apparent the meaning of each entry. The argument for this arrangement is that if the pilot knows the meaning of each data entry, he is less apt to enter it erroneously, e.g., if the pilot is to enter a course angle of 324 degrees he is less likely to enter

824 or 432 since he knows inherently that no such courses exist. Similarly, if he is to enter a vertical path angle of 3.2 degrees, he is less apt to enter 32 degrees. Thus, it may well be that the pilot workload of entering, checking, and correcting erroneously entered data (averaged over many flights) may be less if the format of the data entry is such as to allow a correlation between the data to be entered and the physical world. Even if more initial data entries are required, the average workload may decrease because less correction of errors is required.

Figure 16 illustrates an approach plate used in the USAF FPI Program. The MLS profile is displayed as a horizontal map and a vertical (unrolled) profile. Numbered waypoints are displayed on the horizontal map along with corresponding courses, MLS azimuths, and DME readings. The vertical profile displays the barometric altitudes, glide slope angles, distances between checkpoints and transition points, along track distances (referenced to the glide path intercept point) and the MLS elevation angles. Note that it is difficult, to obtain a spatial correspondence between the horizontal and vertical projections.

The table in the lower left corner contains, in tabulated form, the data necessary to define the profile to the MLS computer and other data which expresses the profile in different terms. The actual data, which was entered into the MLS computer via the CDU in order to define the trajectory, was the MLS azimuth angle, the range from the DME transmitter and the elevation (barometric attitude) of each of the waypoints. In addition, the inbound track angle to the first MLS waypoint and the runway course were also entered via the CDU. If waypoint 32 is considered as an MLS waypoint (it is just within MLS coverage), the total number of waypoints needed to describe this trajectory was six. Since three coordinates were entered for each waypoint in addition to the first inbound and runway courses, the total number of entries to the CDU was twenty.

Figure 17 illustrates the same trajectory designated in a different manner. Waypoints are designated at vertical and horizontal transition points and numbered sequentially so that waypoint "zero" corresponds to the GPIP. These waypoint numbers appear on both the horizontal and vertical projections thereby facilitating the process of correlation

MLS RWY13-257 · PRODUCED BY DMAAC · NAFEC ATLANTIC CITY
ATLANTIC CITY, NEW JERSEY

ATLANTIC CITY APP CON
124.6 385.5
ATLANTIC CITY TOWER
118.9 239.0
GND CON
121.9 284.6
ASR

GRETNA INT · 275°
095°
R-095
MIV 115.2 Chan 99
J19
FTP 6.0 DME
-07° · 2-20° · 308° · 272° · 33
RP
32 · 263°
06 · 041
FTP (2.6 DME) ACY
RTP (6.0 DME) ACY
R-033
FAP 3.6 DME
128% · Δ317
Δ328
MAP

ATLANTIC CITY
108.6 ACY
Chan 23

EMERG SAFE ALT 100 NM 4200 FROM "ACY" VORTAC
MIN SAFE ALT 25 NM 2100 FROM "ACY" VORTAC

MISSED APPROACH
Climbing left turn to
2000 via ACY R-039 to
Gretna Int and hold

RTP · 263° · 12.4% · 308° · FTP 5.2%
3022 · 3022 · 3022
FTP-FAP GS 5.0° ------
FAP-MAP GS 3.0° ••••••
TCH 58
RP 3.4%
2186
FAP 3.0%
1351 ••••128% MAP
176

ATK 15.1 | 6.0 | 3.0 | 7.1 | 1.57 | 5.6 | 1.57 | 4.0 | 3.75 | 0.25

ELEV 76 · Δ120

WPT	AZ	RANGE	ELEV	ITK	OTK	DPA	NPA
33	56.34	5.97	3022	263	263	00	00
32	00.01	2.70	3022	263	303	00	00
-24	-19.50	5.91	3022	308	218	00	-05
-19	-16.95	6.86	3022	308	218	00	-05
06	0.0	6.56	2186	218	128	-05	-05
04	0.0	5.56	1351	128	128	-05	-03
	0.0	1.81	176	128	128	-03	-03
00	0.0	1.56	76	128	128	-03	00

EXPERIMENTAL PROFILE FOR IFC RD USE ONLY

Figure 16 FPI Approach Plate

44

MLS RWY 13-257

LEG	CRS	RNGE	Y/P
X - 3	263	NAV	0
3 - 2	308	3.0	0
2 - 1	LFT	C1.0	5.0
1 - 0	123	4.0	3.0

-20°
6.0 DME
②
FTP

308°

-35°
2.6 DME
③
263°
ITP

FAP
①
5.6 DME

128°

MAP
⊚

ITP
12.4°
③

FTP
5.2°
②

263°
308°

FAP
3.0°
①

3022

CHK   ②-① GS 5.0°

128°

MAP
⊚

ELEV
76

①-⊚ GS 3.0°

ATK 20   10.1   3.0   7.1   3.1   4.0   3.75   .25   .25
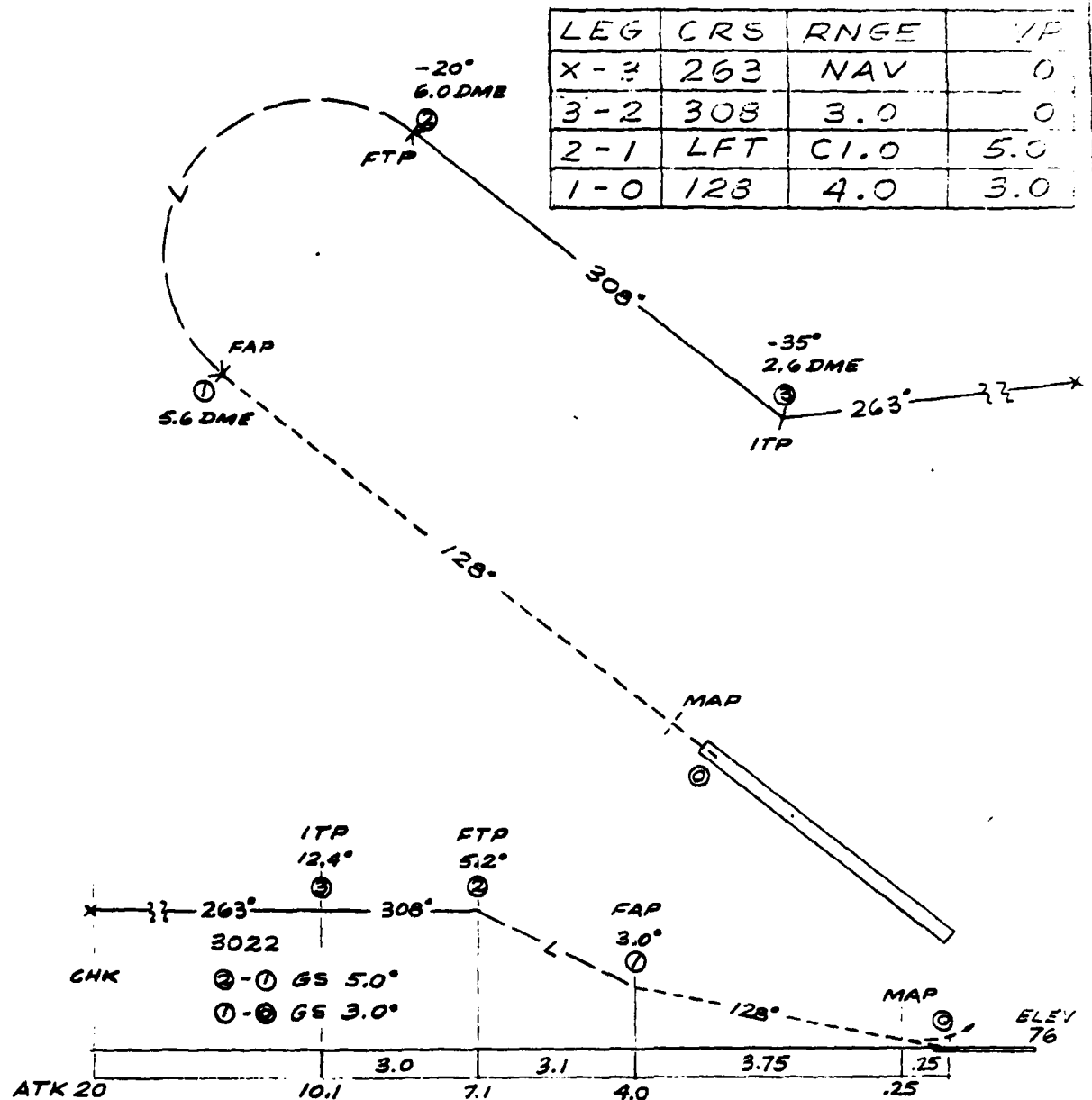
Figure 17 MLS RWY 13-257

45

between the projections. As shown in the tabulated data, the
trajectory is now defined to the computer in terms of its
segments (legs) rather than in terms of waypoints. Straight
line segments are designated by their course, their length,
and their vertical path angles. Circular arc segments
are designated by their direction of turn (left or right),
their radius (measured in the horizontal projection) and
their vertical path angles. Note that for the example
shown, the number of data entries via the CDU is now ten,
half of the previous requirement (only the inbound course
for the first leg is entered).

An alternative to the concept of separate horizontal and
vertical profiles, and the correlation problems they
present, is the integrated "3D" perspective approach plate
illustrated in Figure 18 . The characteristics of the
trajectory in three-dimensional space are now much simpler
to visualize.

All of the alpha-numeric data that was previously spread
over the two projections must now be incorporated into one,
and consequently there is some tendency for the illustration
to appear obscure or cluttered. For the trajectories
considered this did not prove to be a problem.

One additional problem that a "3D" perspective presents
comes about because the remainder of the approach plate
(e.g., topographical features) is not in 3D perspective.
As a result, the trajectory projection on the horizontal
plane appears distorted, in both shape and position,
relative to the remainder of the features. To overcome
this a "3D pseudo-perspective" approach plate was considered.

Figure 19 depicts such a pseudo-perspective plate.
Note that now the trajectory projection on the horizontal
plane is the same as in Figures 16 and 17. The
shape,size,and position of the horizontal projection can
now be consistent with the remainder of the horizontal map.

Figure 20 represents the finished product. A comparison
with Figure 16 illustrates the significant improvement
in visualizing and extracting pertinent data about the
complex trajectory from the approach plate.

LEG	CRS	RNGE	VP
X-3	263	NAV	0
3-2	308	3.0	0
2-1	LFT	C1.0	5.0
1-0	128	4.0	3.0

Figure 18 CDI   30° "3-D Perspective"; -1 NM/Inch   MLS RWY 13-257

LEG	CRS	RNGE	VP
X-3	263	NAV	O
3-2	308	3.0	O
2-1	LFT	C1.0	5.0
1-0	123	4.0	3.0
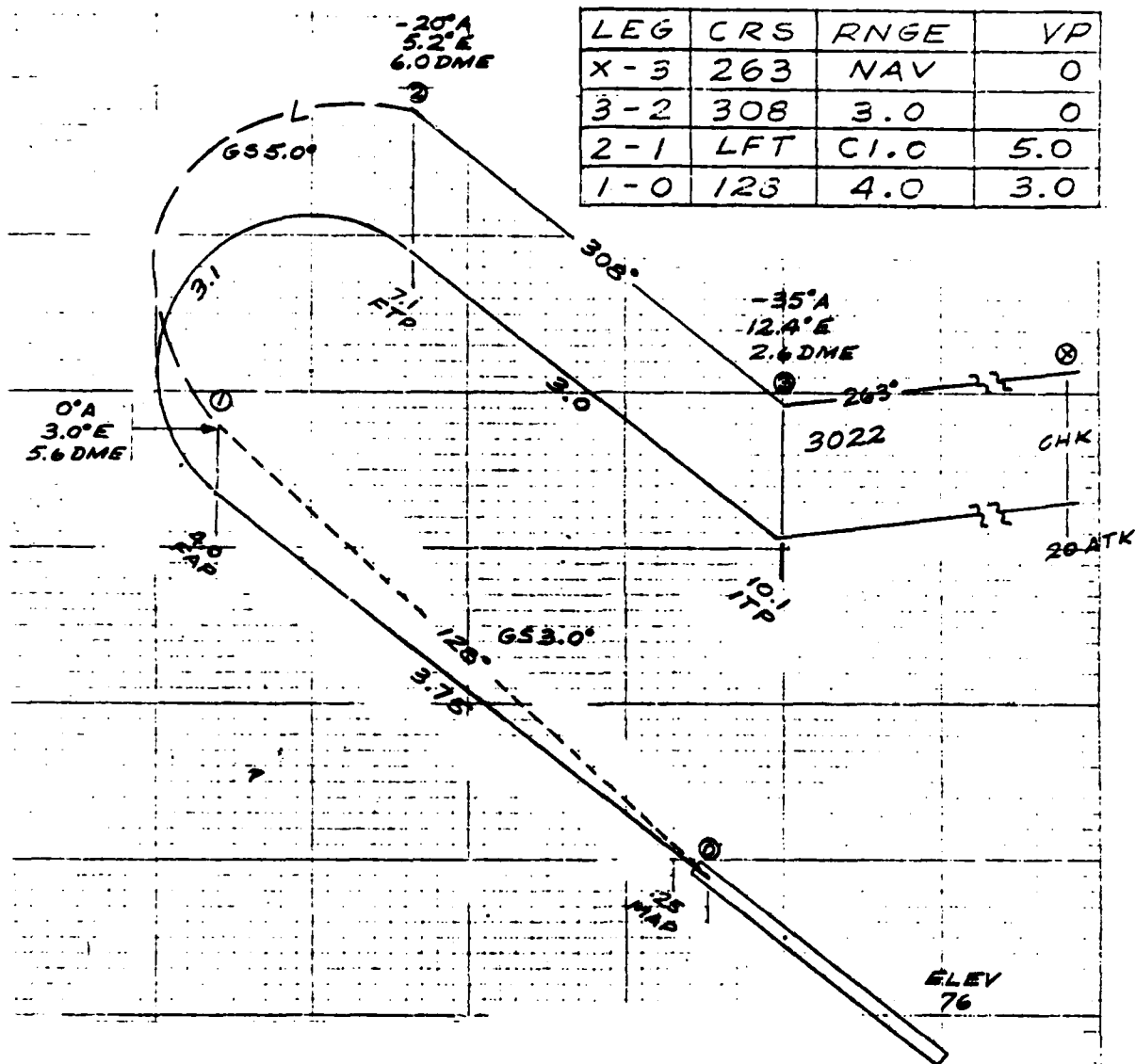
Figure 19 CDI "3-D Perspective"; -1 NM/Inch MLS RWY 13-257

48
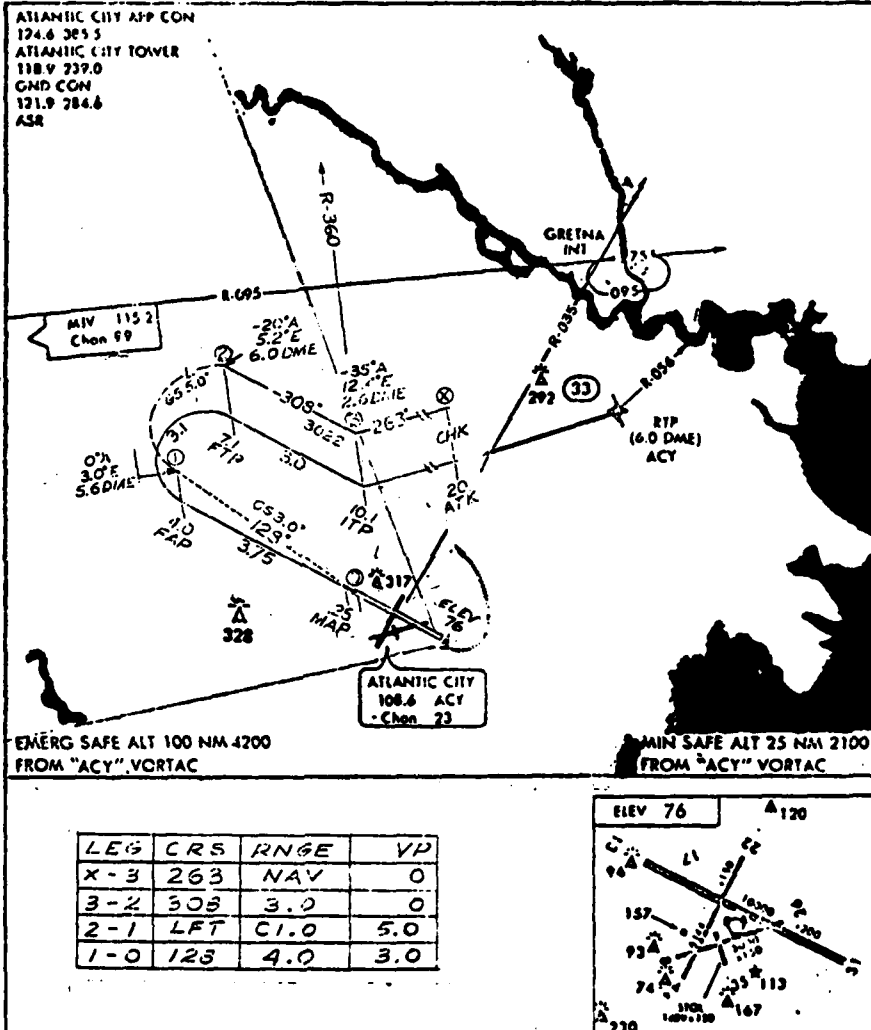
Figure 20 Typical 3-D Approach Plate

49

An additional factor relative to the 3D approach plate
requires consideration from a human factors viewpoint.
It will not always be possible to maintain a "North-Up"
orientation for the approach plate. If the straight line
segments of a trajectory run north-south, the trajectory
and its horizontal projection will be coincident. In fact,
the value of the 3D projection is degraded if the segments
run close to north-south.

It will therefore be necessary for the approach plate
designer to rotate the trajectory into a position which
results in maximum advantage of the 3D perspective.
Figures   21, 22 and 23   illustrate the effectiveness
of such a rotation in clarifying the 3D perspective.
Figures 24 and   25   show two different versions of the
same "teardrop" trajectory and demonstrate that the approach
plate designer must be free to select the projection which
most adequately depicts the trajectory. Clearly, the version
of Figure   25   is far superior to that of Figure 24
which requires looking through the vertical "walls" to see
the remainder of the trajectory.

3.1.5   Profile Commonality

It is expected that certain standard trajectories will
be common to many aircraft and airports. In these instances,
it will only be necessary to insert into the CDU the class
or identifying numbers of the trajectory and a minimum of
data which distinguishes this particular trajectory from
all others in its class. This represents an enormous
saving in workload contributed by the CDU interface.

Consider for example a trajectory which consists of a
U-turn (trombone) in the horizontal plane and a constant
glide slope in the vertical plane. Further assume that the
U-turn is always composed of: a downwind flight parallel
to, but offset, from the runway; a fixed radius 180 degree
turn to the left terminating on runway heading at a fixed
distance of 2 miles from touchdown; and, a constant 3
degree glide slope. Thus, the only variable in this class
of U-turns is the runway heading; moreover, by inserting
two numbers (the trajectory class and the runway heading)
the trajectory is defined. Note that the approach plate
would illustrate all details of this trajectory, but
the tabulated data would contain only the information
required to define it to the MLS computer.

LEG	CRS	RNGE	VP
X-5	210	NAV	0
5-4	210	1.5	6.0
4-3	RT	C0.7	0
3-2	250	2.2	0
2-1	LFT	C0.7	0
1-0	160	2.0	4.0
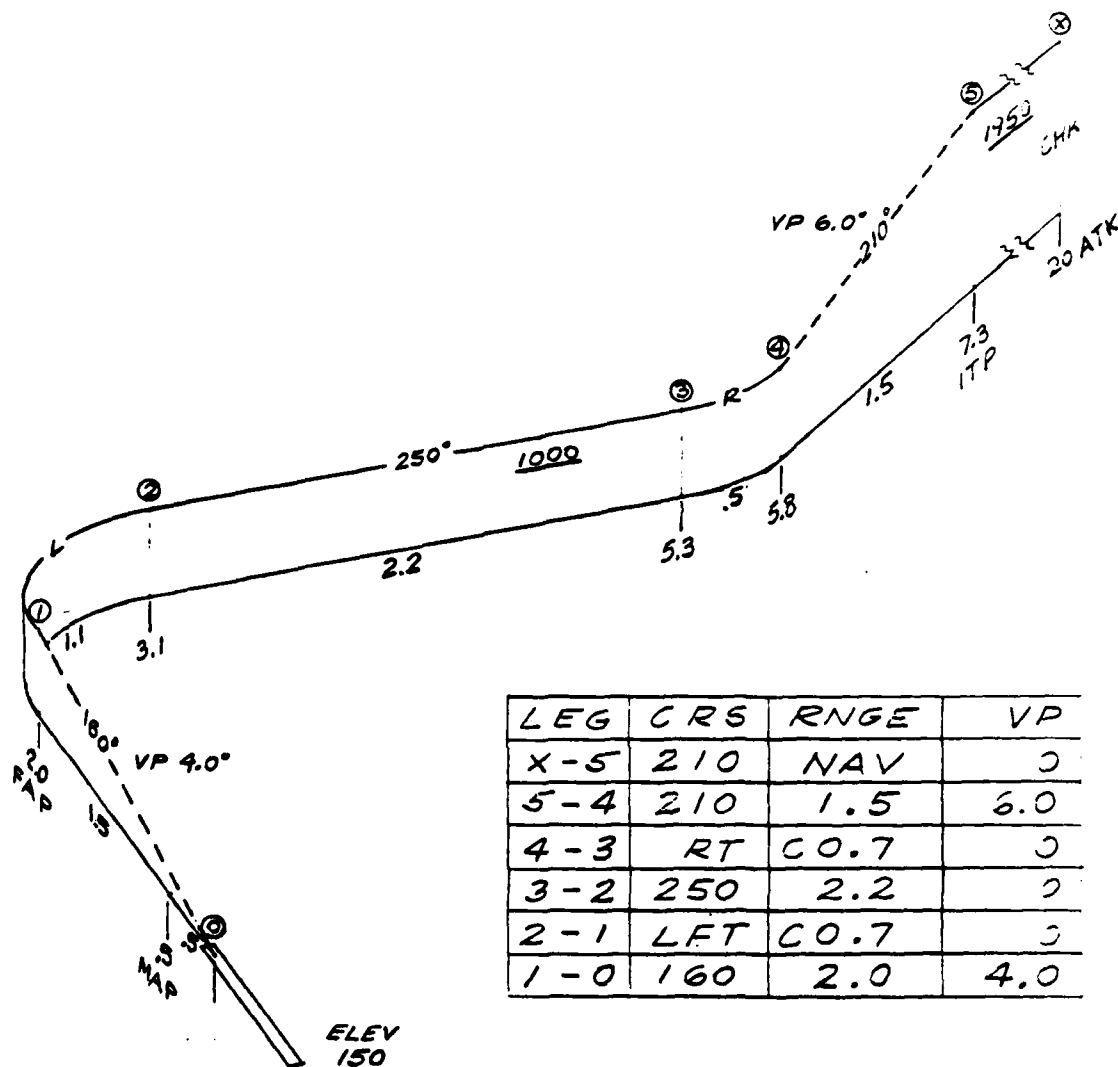
Figure 21 CDI 30° Perspective; 1.5"/NM MLS EWR 16L

51

LEG	CRS	RNGE	VP
X - 4	15	NAV	O
4 - 3	15	2.0	O
3 - 2	LFT	C1.7	O
2 - 1	LFT	C1.7	3.0
1 - 0	180	5.2	3.0

Figure 22 CDI   MLS STL 18L

52

LEG	CRS	RNGE	VP
X - 7	60	NAV	0
7 - 6	60	2.4	0
6 - 5	RT	C1.0	0
5 - 4	120	0.3	0
4 - 3	120	1.5	5.0
3 - 2	RT	C1.0	5.0
2 - 1	RT	C1.0	3.0
1 - 0	180	3.7	3.0

Figure 23 CDI MLS STL 18R

LEG	CRS	RNGE	VP
X - 6	36	NAV	0
6 - 5	36	3.0	5.0
5 - 4	LFT	C 1.0	5.0
4 - 3	0	2.0	5.0
3 - 2	LFT	C 1.0	5.0
2 - 1	LFT	C 1.0	3.0
1 - 0	180	5.0	3.0
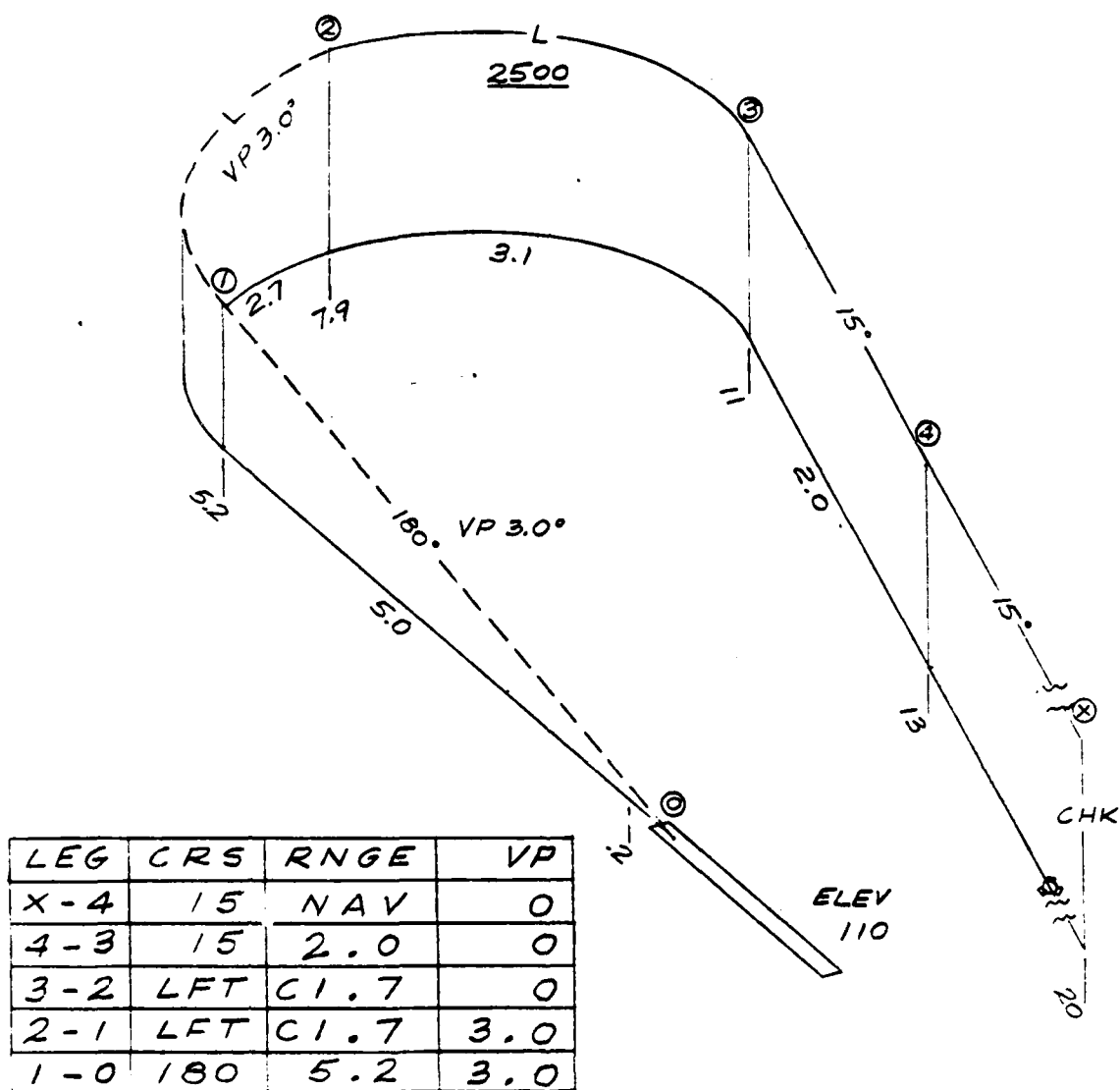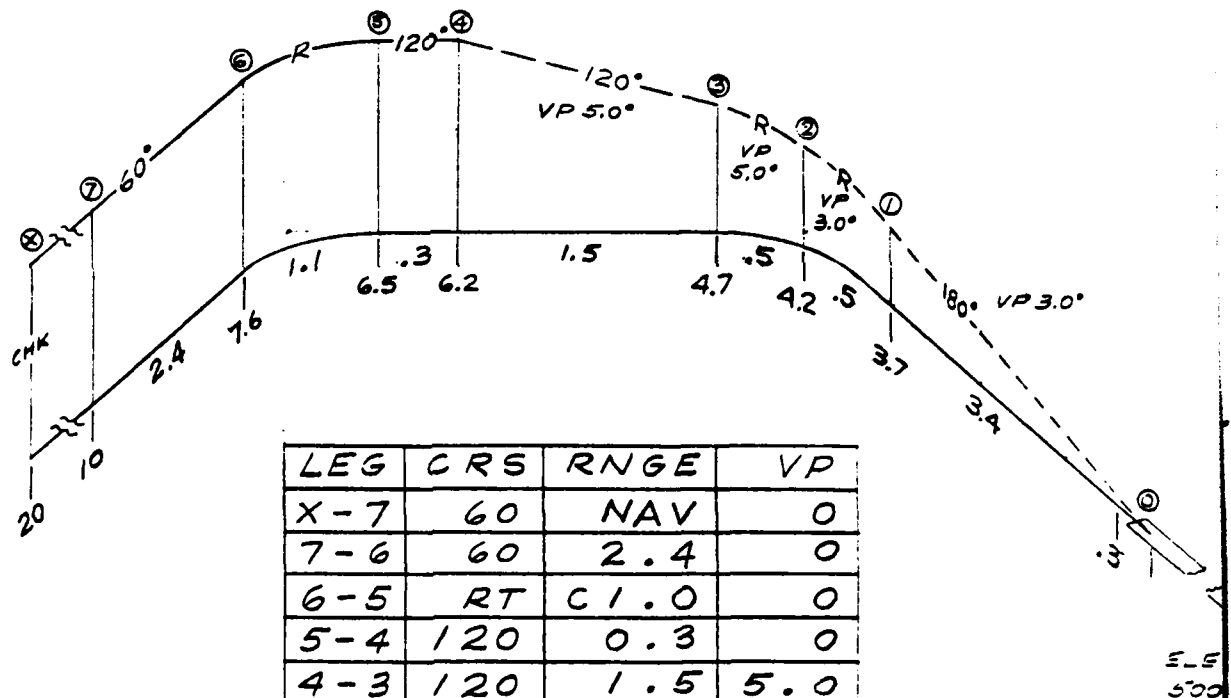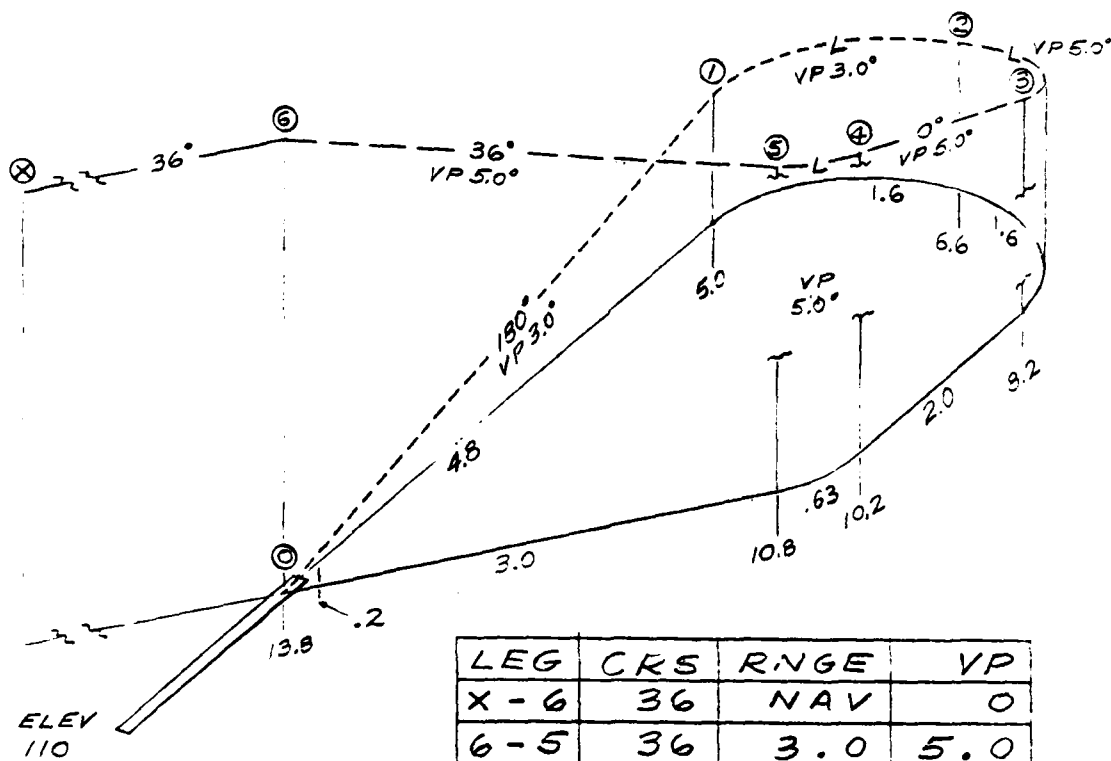
Figure 24 CDI MLS OAK 18L (Version 1)

LEG	CRS	RNGE	VP
X-6	36	NAV	0
6-5	36	3.0	5.0
5-4	LFT	C1.0	5.0
4-3	0	2.0	5.0
3-2	LFT	C1.0	5.0
2-1	LFT	C1.0	3.0
1-0	180	5.0	3.0
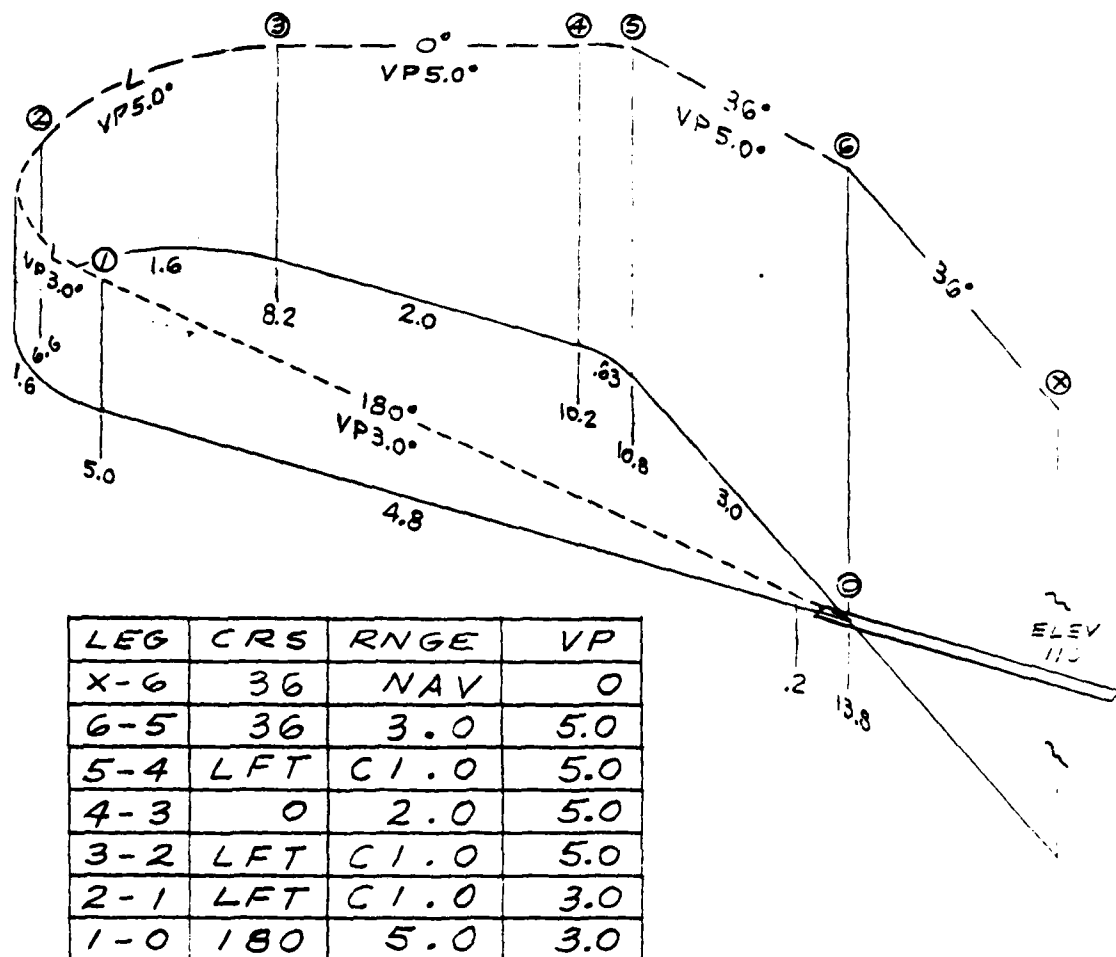
Figure 25 CDI MLS OAK 18L (Version 2)

55

It is anticipated that the great majority of MLS trajectories
will eventually be classified into these standard type
maneuvers. Fortunately, the MLS avionics development effort
is still at the stage where the capability to accomodate
these standard trajectories could be added to the specification.
It is necessary that the civil/military agencies define
these standards soon so that retrofit of the avionics can
be avoided.

If a significant percentage of MLS trajectories can be
classified into a small number of standard trajectories,
it will impact other facets of MLS requirements and tradeoffs
(i.e.,CDU design and interface considerations, means of
cross-checking data entry, automatic vs. manual profile
insertion and approach plate design).

3.2   Complex Trajectory Monitoring and Redundancy
         Requirements

3.2.1   General Considerations

With the advent of MLS, aircraft will be capable of making
precision approaches which are not confined to the conven-
tional ILS "straight-in" types. Virtually all combinations
of trajectories composed of circular arcs and straight
line segments will be possible both in the horizontal and
vertical planes. The value of these complex trajectories
lies primarily in their ability to contribute to a higher
recovery rate, obstacle avoidance, noise abatement, and
to avoid overflying enemy territory. If MLS trajectories
are defined and used to achieve this greater capability,
a corresponding danger will, in some instances, accompany
their use. For instance, if the trajectory is used for
obstacle avoidance, an undetected malfunction carries
with it connotations of extreme danger.

There is an analogy to this situation in flying ILS approaches
under IFR conditions. When Category I,II,and III approaches
were made possible by more accurate and sophisticated
equipment, the danger of the proximity of the ground had
to be addressed. This resulted in the FAA requirements
dealing with monitored, fail-passive and fail-operational
equipment. The final requirements took many years to
formulate since the capabilities of the human pilot to
monitor and react to failures could only be assessed over

a multitude of real landings. A similar situation now
exists with regard to flying complex trajectories which are
critical from the viewpoint of the proximity of obstacles,
enemy fire, on other aircraft.

It is the purpose of this section to make a start in the
direction of defining the monitoring and redundancy require-
ments for complex MLS trajectories. Wherever applicable,
information gleaned from the USAF FPI Program and from
ILS IFR approaches are used. The reader will note that
the conclusions are conservative. That is, more complexity
is proposed until it can be proven that simpler systems are
safe.

3.2.2   The Pilot As a Monitor During Complex Trajectory Flight

The typical MLS complex trajectory may consist of two or
three straight line segments, connected by two or three
different flight path angles in the vertical plane. The
flight path angle changes may occur during the turns.

The FPI program has demonstrated that if the aircraft
is under manual control, the workload associated with flying
these trajectories precludes monitoring to determine whether
the trajectory being flown is the trajectory desired. This
is not to say that gross errors can not be detected. For
instance, the pilot can detect that he is being asked to
turn in the wrong direction or that the bank angle
required to fly the turn is much too large, or that his
descent rate has been too high for too long, etc.

The detection of even these gross errors is not easily
accomplished because in order to determine the reasonable-
ness of a particular maneuver at a particular time, the pilot
must know where he is in progress along the trajectory.
The only means he has to determine his progress (with
present displays) is a digital readout of his upcoming
waypoint which he must correlate with his approach plate,
forcing his attention away from his control/display. He
may also rely upon his memory of what the approach plate
looked like, but he cannot be expected to memorize the
characteristics of a complex trajectory.

If the aircraft is under automatic control, the pilot

57

has considerably more time for monitoring. He may refer to
the approach plate more easily to determine the reasonable-
ness of the trajectory he is flying, and can more easily
detect gross errors and monitor his progress along the
trajectory. He can not, however, monitor accurately
his position with respect to the runway or with respect
to the approach plate trajectory. This is not meant to
imply that he can not monitor his position relative to the
trajectory to which he is being controlled. The difficulty
comes about when due to a fault, that trajectory is different
from the approach plate trajectory, or when the error from
the trajectory is being computed erroneously.

In order to detect these subtle types of faults he must
have an independent reference to monitor against. If
we assume that the transmitters and receivers are adequately
self-monitored, then the faults which are of concern are:
those of the MLS computer which performs the error computation
for display; and, the control/display itself.

These types of faults could be detected by comparing the
raw data output of the receiver to known coordinates of
the approach plate. This is equivalent to the type of
monitoring performed by the pilot during an ILS approach
when he utilizes raw localizer and glide slope deviation
signals from the receivers.

The raw data output from the MLS receivers are azimuth
angle, elevation angle,and slant range. That is, they are in
polar coordinates. When flying a complex trajectory, or
any path which is not a straight line pointing directly at
the azimuth and elevation transmitters; these coordinates
are constantly changing, and their significance is also
changing. For instance, when flying a path which is per-
pendicular to (or makes a large angle to) the runway course,
the aircraft's lateral deviation from the path is a function
primarily of range error and elevation angle. When flying
at a shallow angle to the runway course, lateral deviation
is a function primarily of azimuth angle error and range.

Thus, even if the pilot knew the MLS coordinates of every
point on the approach plate trajectory and the raw data
corresponding to his present position, it would be difficult
to assess quantitatively his errors from the desired path.
Furthermore, and equally important, he cannot distinguish

58

between being on the trajectory but not at the progress point he believes, and being off the trajectory. In addition because the raw data is constantly changing with time (unlike the straight-in ILS approach where the azimuth and elevation angles are fixed) the pilot must constantly "chase" the raw data to assure that a failure has not occurred since his last check.

3.2.3 Recommended Design Criteria To Enable Pilot Monitoring of Complex Trajectories

It is recommended that the following equipment be evaluated in further studies for the purpose of determining their value as aids to pilot monitoring of complex trajectory flight.

1) A means whereby the pilot may quickly and easily determine that the data he entered to define the complex trajectory was entered fault free.

2) An electronic display which pictorially illustrates the complete horizontal and vertical trajectories and the aircrafts progress along them.

3) A digital display driven by the MLS receivers (independent of the MLS computer) which allows the direct readout of basic azimuth angle, elevation angle and range. Means should be provided to "freeze" the displayed data either by pilot action or by the MLS computer. The data shall "unfreeze" automatically after TBD seconds.

4) Printed raw data coordinates at strategic points along the trajectories, illustrated on the approach plate.

It is expected that the above functions will give the pilot the capability of checking raw data at known progress points against those on the approach plate. It remains to be determined whether he has sufficient time to do so, in manual and automatic flight, and whether he can relate this data to path deviation data well enough to distinguish between expected deviations during normal flight and

59

deviations caused by faults.

3.2.4   The Pilot As a Monitor on the Final Approach Leg

On the final approach leg, the trajectory will be a fixed
course and descent angle. In addition to his manual
control/display and/or his automatic landing system, the
pilot will have available to him raw data indicating
angular deviations from both the selected azimuth and
elevation angles and distance to touchdown.

Aside from the addition of range information, this is
the same raw data format presented to him during present
day ILS approaches. It is therefore safe to assume that the
pilot's ability to monitor will have the same characteristics
as presently exhibited during ILS approaches.

3.2.5   Missed Approaches

A missed approach may have to be executed due to detected
malfunctions or other crew emergencies. On the final
approach leg, a missed ILS approach is executed by overflying
the missed approach zone where obstacles are nonexistant
(or controlled) and from where the pilot knows the predeter-
mined missed approach profile.

On the final approach leg, the MLS missed approach will
be flown in the same manner. However, an aborted landing
initiated during complex trajectory flight may present a
different type of problem. The potential severity of the
problem depends on why the aircraft is flying a complex
trajectory. If the path is being flown, for instance, to
avoid obstacles under IFR conditions, an aborted approach
obviously carries with it the danger of impacting these
obstacles. Flying up or leveling out is, of course, the
correct and natural thing to do, but since the aircraft
may be below the height of nearby obstacles its horizontal
path is equally important.

In the general case of general trajectories and arbitrary
obstacle locations, the pilot is expected to find it very
difficult to safely abort from his complex trajectory
flight. To do so, he must know his position and direction
of flight just prior to abort, refer to his approach plate
which shows the location and height of those obstacles;

60

decide upon a flight path which will avoid those obstacles; and then, with no ground based reference system to assist him, fly out of his dangerous situation.

It is suggested here that the safest procedure may be to continue flight onto the final leg to the runway (from where the abort procedure is safe and well defined) and execute his normal missed approach procedure. However it is doubtful that he can accomplish this safely without the MLS system or an equivalent ground based reference system.

We must therefore draw the conclusion that for some intended uses of MLS it is insufficient from a safety viewpoint merely to know that a failure exists. It would also be necessary to have a means of continuing accurate flight to at least the final leg (or to landing) in the presence of that failure, that is, the system must be fail-operative.

Note that this requirement is independent of whether the aircraft is equipped to perform Category I, II, or III landings. These categories are associated with visual range in the vicinity of the touchdown point on the runway. The fail-operative requirement stems from visibility considerations in the vicinity of higher altitude obstacles.

3.2.6 Recommended Monitoring and Redundancy Requirements For MLS Avionics Equipment

The specification of monitoring and redundancy requirements for MLS airborne equipment is premature from the viewpoint that these requirements must stem from an assessment of pilot capability to control and monitor complex trajectory flight. This assessment is not yet complete; however, for the purpose of initiating a dialogue on this subject and to demonstrate the hardware repercussions associated with various pilot capabilities, the following alternatives are proposed.

In all instances it is proposed that the MLS computer(s) will directly drive the controls/displays and furnish steering commands to the automatic flight control system(s) during the complex portions of the trajectory. After initiation of the final straight-in approach leg, control will revert to the automatic flight control system(s)

61

and the flight director computer(s) which will drive the
control/display(s). These systems will receive raw deviation
data directly from the MLS receiver(s).

Thus, the monitoring and redundancy requirements fall
into two distinct categories - requirements before the
final leg during complex trajectory flight, and requirements
during the final approach leg.

The latter requirements are expected to be similar to those
specified by FAA Advisory Circular 120-29, dated 9/25/70
(with attachments and revisions) for Category I and Category
II landings and Advisory Circular 120-28B, dated 12/1/77
for Category IIIa landings.

During complex trajectory flight, if we assume that the
pilot can both adequately manually fly and detect faults
(other than received faults) and that he can adequately
execute a missed approach anywhere along the trajectory
without MLS data, the avionics requirements would be:

>   a) A single self-monitored receiver
>
>   b) A single independent raw data display
>
>   c) A single MLS computer
>
>   d) A single control/display or
>   A single autopilot

If he can adequately fly but not simultaneously monitor,
the requirements would be:

>   a) A single self-monitored receiver
>
>   b) A monitored MLS computer
>
>   c) A monitored control/display or
>   A monitored autopilot

If, he can not adequately execute a missed approach, the
requirements would be:

>   a) Dual self-monitored receivers

b) Dual monitored MLS computers

c) Dual monitored control/displays or
Dual monitored autopilots or
A monitored autopilot and a monitored display.

3.3 Complex Trajectory Display Information Requirements

3.3.1 General Display Information Criteria

In order to safely fly complex trajectory paths in the
lateral and vertical axes using MLS, the pilot requires a
significant amount of information. This information must
be sufficient for:

- Controlling the aircraft about the desired path

- Monitoring aircraft systems' operation and performance

- Maintaining orientation with respect to the path
  and the runway

Moreover, the required display parameters must be formatted
in an integrated cockpit presentation to result in acceptable
pilot workload. Where workload increases beyond acceptable
levels, automation and/or better display integration is
required.

Although the display parameters to be utilized on a specific
aircraft can only be determined by an analysis of the
aircraft's existing systems' configurations and the desired
level of MLS complex trajectory capability, a generalized
set of MLS derived display parameters can be defined. Once
defined, the specific aircraft's display parameters can
be selected from the general list as compromises are made
in conducting a cost-effective retrofit program.

In general, the display presentation technique can be quite
different when standard electro-mechanical indicators and
electronic CRT-type displays are considered. Much more
capability is available when using a programmable display (e.g.,
the Bendix three-color CRT which is to be used in the simulator
phase of this program). This capability should result in
a more easily interpretable pictorial representation of the
display information. Since most present-day USAF aircraft

either do not have programmable CRT's at all, or only use them as part of a weapons delivery system, the display information discussions in this section are primarily tailored to those aircraft with a standard ADI and HSI. The general information requirements, however, are also applicable to the electronic CRT's.

3.3.2   Complex Trajectory Display Parameters

Table 3   contains a listing of present displays used for basic aircraft control and navigation in the non-MLS environment. For complex trajectory flight, the control and performance display parameters shown are used intact and maintain their importance. The command and navigation displays are also used, as in ILS or TACAN, but in this case are driven from MLS computations. When MLS is used as a direct replacement system for ILS and only straight-in approaches are required, the display information shown in the table is sufficient for safe flight. When MLS, however, is used in flying complex trajectories, the display information shown is insufficient.

Table   4   contains a listing of possible MLS derived display parameters. The parameters have been divided into MLS receiver and MLS computer outputs. A discussion on each parameter follows.

Table 3   Present Aircraft Displays

COMMAND	CONTROL	PERFORMANCE	NAVIGATION
PITCH STEERING BAR	ATTITUDE	AIRSPEED	BEARING
ROLL STEERING BAR	POWER	ALTITUDE	COURSE DEVIATION (CDI)
		HEADING	GLIDE SLOPE DEVIATION (GSI)
		VERTICAL VELOCITY	DME
		ANGLE OF ATTACK	TO-FROM

Table 4   MLS Derived Display Parameters

MLS RECEIVER	MLS COMPUTER
*AZIMUTH ANGLE	*DESIRED TRACK ANGLE
ELEVATION ANGLE	*LATERAL DEVIATION
RANGE-TO-STATION	*VERTICAL DEVIATION
*RANGE-TO-GPIP	RANGE-TO-WAYPOINT
RANGE RATE	*RANGE-ALONG-TRACK-TO-TOUCHDOWN
HEIGHT ABOVE RUNWAY	BEARING-TO-WAYPOINT
VERTICAL VELOCITY	*BEARING-TO-STATION
*LATERAL DEVIATION	FLIGHT PATH ANGLE
*VERTICAL DEVIATION	*PATH ANTICIPATOR
	AIRCRAFT POSITION PREDICTOR
	GROUND SPEED
	WIND SPEED AND DIRECTION
	EST. TIME TO GO TO:
	● WAYPOINT
	● TOUCHDOWN

*Recommended for display in existing USAF aircraft

MLS Receiver Outputs: As presently configured for the FAA
Phase III MLS, the angle receiver outputs the aircraft's
azimuth angle and elevation angle in the conical coordinate
system in a digital format. It also outputs lateral and
vertical deviation from the selected azimuth and glide slope
angle, respectively, in an analog format. The MLS DME
receiver outputs aircraft range information in the form
of slant range distance to the site or the GPIP, range
rate and height above the runway's altitude.

Azimuth Angle is defined as the angle between the runway
centerline and the line connecting the azimuth ground site
with the aircraft (see Figure 26a).   A full capability
MLS ground facility will provide azimuth coverage of ± 60
degrees about the runway centerline for a distance of at
least 20 nautical miles. The present Phase III MLS airborne
system provides a digital readout of azimuth angle in 1
degree increments,with the runway heading defined as 0
degree azimuth. With the aircraft 30 degrees to the left
of the centerline, the display reads 30L.

From human factor considerations it may be better to relate

AZ ANTENNA

1000 FT

RUNWAY
LENGTH = 10,000 FT

EL
SITE

1000 FT

GLIDE
SLOPE = 3°

TYPICAL MLS SITE GEOMETRY

Figure 26c

AZ ANTENNA

45°

N

30°

075°
RADIAL

AIRCRAFT

AZIMUTH ANGLE RELATIVE
TO MAGNETIC NORTH

Figure 26b

AZ ANTENNA

RUNWAY

AZIMUTH
ANGLE
= 39 L

AIRCRAFT

AZIMUTH ANGLE RELATIVE
TO RUNWAY

Figure 26a

Figure 26 Azimuth Angle Geometry

aircraft azimuth angle to radial information with respect
to magnetic north (see Figure 26b).   The pilot's inter-
pretation process of his situation will then be similar to
that which he experiences presently with VOR and TACAN
navaids.   It will also tend to make his transition from enroute
navigation to INS terminal navigation simpler. The radial
computation can be easily done within the MLS angle receiver
because runway heading is one of the auxiliary data parameters
which will be transmitted from the ground. By adding or
subtracting azimuth angle from the runway heading, the
aircraft's present radial to the ground site can be calculated
and displayed. Since an "L" (for left) or "R" (for right)
is required with a two-digit number to define the aircraft's
azimuth angle, displaying 0 to 360 degree radial information
does not result in a large increase in additional numeric
readout hardware. This concept requires further study in a
simulator or flight test program.

It is recommended that a digital readout of azimuth angle
be displayed for MLS complex trajectory flight. Because the
parameter is raw data direct from the MLS receiver, it can
be used for crosscheck of computed commands and data for
the aircraft with sophisticated complex trajectory capability.
For the aircraft with less sophisticated computational
capability or no automatic approach capability, it can be
used as an aid in providing anticipation for close-in
captures of straight-in ILS-type approaches not presently
possible due to the coverage limitations of the ILS.

If a digital display of azimuth is provided, several areas
must be considered in determining the resolution of the
readout. If the display's primary function is to cross-
check aircraft position during the complex portion of the
approach, the resolution of 1 degree found on the present
instrument is more than adequate. If, however, the display
is also intended as an accurate final approach monitor of
position, a greater resolution of 0.2 degrees or 0.5 degrees
is required. The need for greater resolution during the
final approach becomes apparent when a 0.5 degree azimuth
angle (this is where the display would switch to 1L or 1R)
is analyzed in terms of deviation in feet from the runway
centerline. With the runway geometry shown in Figure 26c
a 0.5 degree error in azimuth angle results in a 105 ft.
deviation at 100 ft. of altitude. This is well outside
the Category II (75 ft.) and Category III (27 ft.) 2-sigma

deviation windows. A resolution of 0.2 degrees (0.1
degree error causes change in readout) corresponds to 21
ft. and 0.5 degrees (.25 degree error causes change in
readout) to 52 ft. In terms of human factors, if the
digital readout is to be used for final approach monitoring,
it would probably be better to have the pilot viewing deviation
from null (i.e.,about 0 degrees AZ) rather than with respect
to a radial. In other words it is easier to interpret
a display of 0.5 L as an error rather than displaying
275.5 and having the pilot mentally relate to the runway
heading in deriving his angular deviation.

At this point in time,without the aid of further studies
on the subject, it is recommended that azimuth angle be
displayed as presently done in the Phase III system (i.e.,
about a 0 degree runway centerline reference with a resolution
of 1 degree). The digital display should be used a gross
indication of position and should not be primary for monitoring
on the final approach segment.

Elevation Angle is defined as the angle between the extended
runway centerline ground level and the aircraft (see
Figure 27a.).

A full capability MLS ground facility will provide elevation
coverage from 1 degree to 15 degrees above the ground
level. The present Phase III MLS airborne system does
not provide a display of this parameter; however, a display
is provided in the MLS configured USAF T-39. Although the
parameter is easily used for crosscheck of aircraft position
in the vertical axis on the final approach leg where its
value should remain constant (equal to the desired glide
slope), elevation angle cannot be easily used during the
initial segment of a two-segment descent because it is
constantly changing (see Figure 27b).

With present ILS systems, the pilot monitors deviation
from the glide slope on his glide slope pointer during the
final approach. He will also have this information with
MLS thus making a display of elevation angle redundant for
this portion of the approach. Since elevation angle is
difficult to use during complex approach segments, reliance
on altitude appears to be the best solution. For these
reasons, no display of elevation angle is contemplated.

DESIRED 2-SEGMENT
DESCENT FROM FLIGHT
PATH ANLE OF 5° TO 3°

ELEVATION
ANGLE = 4°
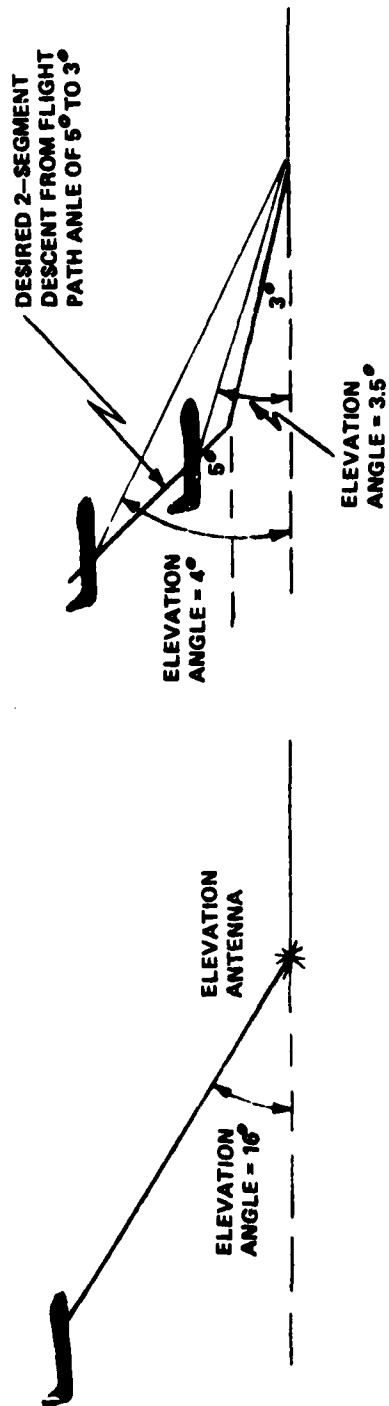
ELEVATION
ANGLE = 3.5°

ELEVATION / FLIGHT PATH ANGLE
RELATIONSHIP FOR 2 - SEGMENT DESCENT

Figure 27b

ELEVATION ANTENNA

ELEVATION
ANGLE = 16°

ELEVATION ANGLE

Figure 27a

Figure 27 Elevation Angle Geometry

69

Range-to-GPIP/Range-to-Station are defined as the slant
range distances from the aircraft to the respective reference
point on the ground (see Figure 28a).   The "glide path
intercept point (GPIP)" is defined as the intersection
point of the runway centerline and the plane, passing through
the phase center of the elevation antenna, at an angle to
the ground of the selected final approach glide slope
(see Figure 28b).   The MLS DME receiver has the capability
of supplying either signal to the aircraft control-and-
display systems.

From a pilot's informational viewpoint, the desired reference
for DME changes as a function of the phase of MLS flight.
At all times, except after touchdown, the best reference
point appears to be the GPIP since it relates the pilot
directly to the runway touchdown zone.   During ground rollout
the best reference would be the DME ground site or,preferably,
the end of the runway.   In the Phase III MLS system this
capability is provided in the form of an option whereby,
if exercised, the reference is switched at touchdown as
a function of landing gear compression.   This, however,
results in a discontinuity in displayed information and
possible pilot confusion.   If the option is not exercised
in the Phase III system, the DME information presently
displayed on the MLS DME indicator is flagged as the air-
craft passes the GPIP.   This is also undesirable since
significant information is lost during a critical portion
of the flight; moreover, the flagged indication might be
disconcerting.

As a means of eliminating unwanted confusion and maintaining
available information, it is suggested that distance to
the GPIP always be displayed.   That is, the signal should
be computed within the MLS DME receiver as:

> Range-to-GPIP= Absolute Value of (Range- to -
>   Station minus Distance from DME
>   Site to GPIP*)
> *obtained from auxiliary data information trans-
> mitted from ground

On final approach and landing, the signal will be steadily
decreasing toward zero.   At the GPIP and beyond, the signal
will go to zero and then steadily increase during touch-
down and ground rollout.   From this an indication of distance

70

ELEVATION ANTENNA
PHASE CENTER

RUNWAY

GPIP

H= HEIGHT
OF EL
ANTENNA

SELECTED
FINAL
GLIDE
SLOPE

GLIDE PATH INTERCEPT POINT

Figure 28b

DME SITE

AZ SITE

EL SITE

GPIP

RANGE-TO-STATION

RANGE-TO-GPIP

AIRCRAFT
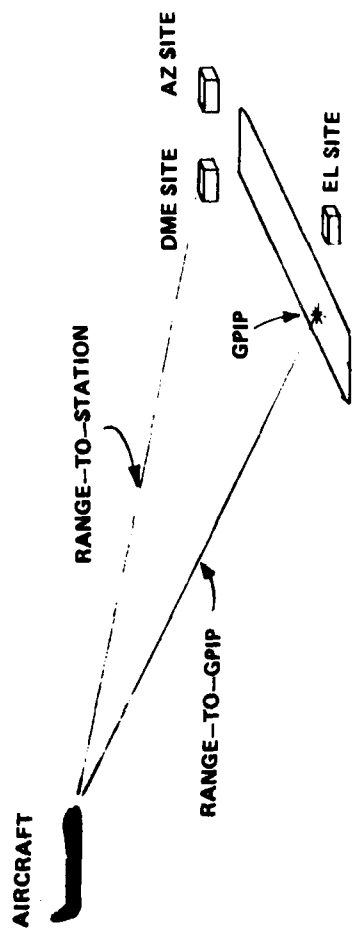
RANGE-TO-GPIP/STATION

Figure 28a

Figure 28 Range And Glide Path Intercept Point

71
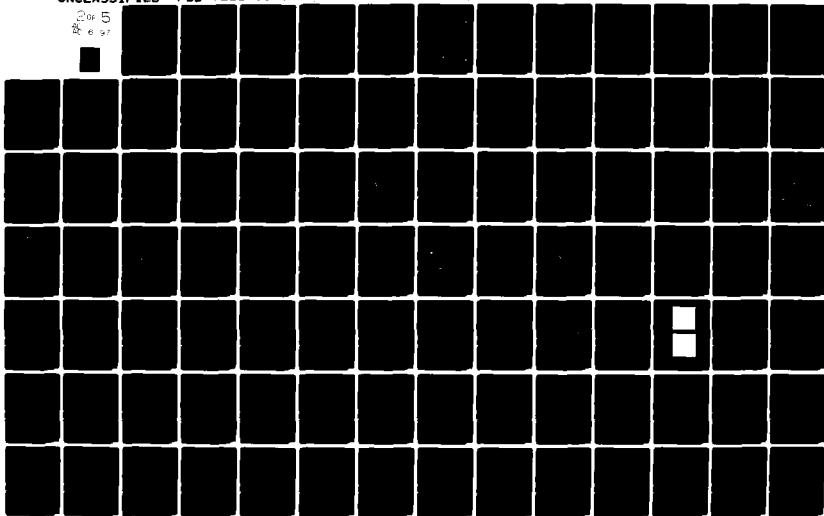
to the end of the runway can be mentally computed if
runway distance markers are not visible due to weather.
To further clarify the aircraft's situation the TO-FROM
indicator could be used during MLS flight and switched at
the GPIP. This,however, is not felt to be necessary.

It is recommended that a digital readout of range-to-GPIP
be displayed for MLS complex trajectory flight. Because
the parameter is raw MLS data, like azimuth angle, it can
be used for crosscheck of computed commands and computed
data. It also becomes a replacement for marker beacon
information during straight-in ILS-type approaches. Assuming
a 3 degree final glide path angle, the displayed DME distance
is directly relatable to desired altitude in that each
nautical mile of DME is equivalent to approximately 300
feet above the runway elevation. This simple relationship
would not exist if the DME was referenced to the DME site.

It is recommended that the resolution of the digital
display be 0.1 nautical miles in the air. This will enable
sufficient crosscheck capability to detect many errors with
respect to the desired path and also will provide sufficiently
resolved situation information with respect to the runway.

Range Rate is computed within the MLS DME receiver by
differentiating the range signal. Although this parameter
provides a reasonable indication of ground speed when the
aircraft is heading directly at the DME transmitter (e.g.,
during the final approach or when flying along an azimuth
radial) its use for CTOL and STOL aircraft is otherwise
limited.

Primary use of this function is made by VTOL aircraft during
hover and approach operations.

Height Above Runway elevation is computed within the Phase III MLS
DME receiver by multiplying the range-to-GPIP by the sine
of the approach elevation angle Because azimuth angle is not
taken into consideration in the computation of range-to-GPIP,
the signal is accurate only along the 0 degree azimuth angle.
If the accuracy is sufficient, this parameter can be very
useful during the initial portion of automatic flare
control due to its terrain-independent qualities. It
does not, however, eliminate the need for a radio altimeter

because the signal is lost when the aircraft passes the elevation site.

Since most USAF aircraft do not have automatic landing modes and since, for those that do, use of this signal would involve a significant modification to the flare control law: use and/or display of this parameter is not recommended.

If this height is calculated using the flare elevation angle (instead of the approach elevation angle) and the corresponding DME range, it does become a direct replacement for the radio altimeter with the advantage of being terrain independent. Since the signal would be available throughout the landing maneuver, it would provide significant improvements to automatic flare control without modification to existing control laws.

Vertical Velocity is not presently computed in the Phase III MLS hardware. If computed in future military hardware (as defined by the draft MMLS specification), it could be used in conjunction with ground speed to compute flight path angle. Since ground speed must be derived in a computer, MLS vertical velocity could be derived in the same computer. This would eliminate the need for a new dedicated receiver output.

Lateral Deviation from the selected azimuth radial is the MLS equivalent to the ILS localizer deviation signal. To make straight-in MLS approaches compatible with existing USAF approach couplers and flight director computers, the MLS lateral and vertical deviation signals must be identical in format to the ILS deviation signals.

MLS lateral deviation with respect to the extended runway centerline (or 0 degree azimuth radial) should be displayed on the course deviation indicator (CDI) during the final approach segment of complex trajectories. This parameter is the primary source of runway centerline guidance both in the air and on the ground.

Vertical Deviation from the selected glide slope angle is the MLS equivalent to the ILS glide slope deviation signal. This parameter is the primary source of vertical guidance during the final approach segment and should be displayed on the glide slope indicator.

MLS Computer Outputs: In order to precisely fly trajectories of more than one lateral and/or vertical segment, the pilot requires information not supplied by the MLS receivers.

A computer is required to calculate: deviations between the aircraft's present position and desired position; distances along the track from the aircraft to the next course or glide path change; and, angles which relate the desired trajectory and the aircraft's position to the runway. Along with these calculations, the computer must provide the proper interface format for the signals to be displayed.

The following parameters can be obtained from the MLS computer, which has as its inputs both the definition of the desired complex trajectory and the MLS related receiver data.

Desired Track Angle is the magnetic course of the particular lateral trajectory segment currently being flown.

For ILS, the desired track angle of the entire approach corresponds to the runway heading. Prior to initiating the approach, the pilot manually sets this angle on his HSI course pointer to properly orient his primary horizontal situation display.

For MLS complex trajectories, the desired track angle changes as the aircraft progresses along the approach (see Figure 29. Based on typical MLS approach profiles flown by the USAF T-39 and NASA 737; three, and sometimes four course changes, can occur during a seven or eight minute approach. Under these types of maneuvering conditions it is important for the pilot to remain constantly oriented with his desired (and computer-commanded) direction of flight. Due to pilot workloads and required path tracking accuracies during this portion of flight, it is recommended that the desired track angle be constantly displayed to the pilot. This can be accomplished, as with present-day RNAV systems, by automatically slewing the course pointer and readout on the HSI via computer commands. Under tracking conditions, this results in a course pointer that is always pointing up. This automatic method has been used quite successfully on the T-39 aircraft. Slewing accuracies of less than 1 degree of track angle have been achieved.

It should be noted that all HSI's do not contain an automatic course slew function. For those aircraft without this function, the MLS integration task must include a tradeoff of HSI replacement costs versus a reduction in MLS capability.

Lateral Deviation, generated within the MLS computer (as

74

MLS RWY 13L-351   JOHN F KENNEDY INTERNATIONAL

EXPERIMENTAL PROFILE FOR USAF IFC USE ONLY

1. DTK is constant 041° to waypoint 39
2. DTK smoothly transitions from 041° to 133° as the
   aircraft progresses along the circular arc from
   waypoint 39 to waypoint 37
3. DTK is constant 133° from waypoint 37 to touchdown

Figure 29 Desired Track Angle (DTK)

75

opposed to the output from the MLS receiver), represents
the aircraft's crosstrack error from the desired lateral
path (see Figure 30a).   This signal is the primary
reference for lateral axis control during the complex portion
of the approach and should be presented on the CDI.   The
signal should be scaled such that useful information is
obtained throughout the entire approach.   This results
in a conflict due to the need to provide deviation data
that is not saturated during the initial capture maneuver
yet provides sufficient sensitivity for accurate control
during the tracking phase.   A solution for this problem,
determined in the T-39 program, consisted of making the
CDI sensitivity inversely proportional to altitude according
to a gain schedule which approximated an ILS localizer signal.
Since this display parameter is the primary reference for
tracking performance, it is directly associated with obstacle
avoidance and air traffic control.   For this reason it is
recommended that a standard scaling be established for this
parameter for all aircraft.   Insufficient analysis of this
problem was done on the T-39 to warrant recommendation of
its solution for this standard.

For the final approach segment of the complex trajectory,
the lateral deviation signal on the CDI should automatically
switch from the computed crosstrack error to the raw MLS
receiver output.   This eliminates a source of error intro-
duction (i.e.,MLS computer) and enhances the pilot's
ability to monitor the approach to touchdown.

Vertical Deviation, generated within the MLS computer
(as opposed to the output from the MLS receiver), represents
the aircraft's vertical track error from the desired vertical
path (see Figure 30b).   This signal is the primary
reference for vertical axis control during the complex
portion of the approach and should be presented on the
glide slope indicator.   For the same reasons as those
described above for the lateral deviation signal, the
scaling of this signal should be standardized for all
aircraft and the raw MLS receiver vertical deviation output
should be automatically switched in for the final approach
segment.

Range-to-Waypoint represents the distance along the desired
lateral track from the aircraft to the next waypoint transition
(see Figure 30c).   This parameter provides the pilot with

VERTICAL DEVIATION (VTK)
Figure 30b

VTK

A/C

RANGE-ALONG-TRACK-TO-TOUCHDOWN (RAT)
Figure 30d

RWP = RAT - 7NM
= 2NM

7NM

RAT = 9NM

4NM

2NM

3NM

4NM

GPIP

A/C
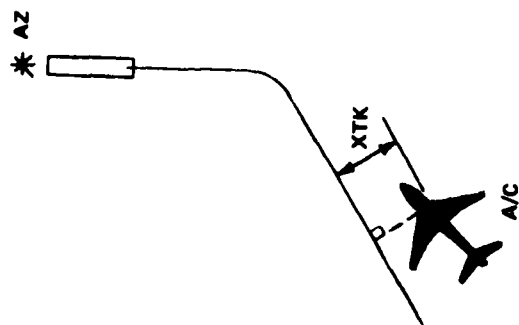
LATERAL DEVIATION (XTK)
Figure 30a

AZ

XTK

A/C
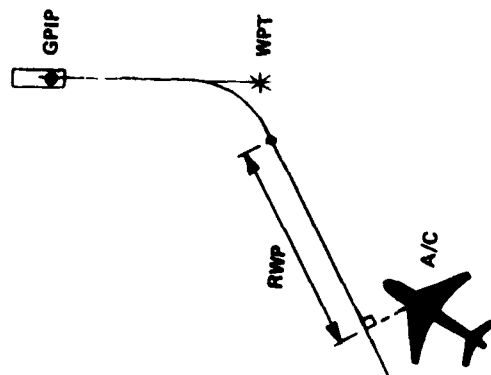
RANGE – TO – WAYPOINT
Figure 30c

GPIP

WPT

RWP

A/C

Figure 30 Computed Deviation And Range Parameters

a key piece of short term orientational information during
the complex portion of the approach.

Range-Along-Track-to-Touchdown represents the distance
along the desired lateral track from the aircraft to the
GPIP (see Figure 30d).   This parameter, like range-to-
waypoint, provides significant orientational information
for complex approaches. Unlike range-to-waypoint, however,
this information can be for both long and short term use
and is, therefore, recommended. It is long term since the
pilot is continuously informed of his true distance along
the desired path to touchdown. It is short term if the
approach plate is designed to indicate this parameter at
the segment transition points. By a mental subtraction the
pilot can quickly calculate his distance to the next
waypoint transition (see Figure 30d).   Both range-to-
waypoint and range-along-track-to-touchdown (only one of
these parameters is required) should be presented as
discrete numerical information, as is presently done for
TACAN DME, on the HSI or a dedicated DME indicator. Like
the raw DME information from the MLS DME receiver, the
display of this parameter should provide resolution to
0.1 nautical miles.

Bearing-to-Waypoint represents the relative bearing of the
aircraft to the next waypoint transition. Like range-to
waypoint, it is significant short term orientational information
throughout the complex approach.

Bearing-to-Station represents the relative bearing of the
aircraft to the MLS azimuth ground site. This signal is
derived from azimuth and aircraft heading information in
the MLS computer not in the MLS receiver. This parameter
also provides the pilot with significant long-term orientational
information of the runway position. Typically, information
of this nature is presented on an HSI, RMI, or BDHI bearing
pointer.

Flight Path Angle can be accurately derived within the
MLS computer by calculating $\gamma = \tan^{-1}(\dot{h}/GSP)$ where: $\gamma =$
flight path angle, $\dot{h}$= vertical speed, GSP= ground speed.
This parameter is particularly useful in monitoring aircraft
performance along multi-segment descent paths defined
in terms of flight path angle. For the 2-segment descent

shown in Figure 56b, a display of flight path angle
provides the pilot with a quantitative measure of his
actual vertical path. If this parameter was easily displayable
with present instrumentation, it would be recommended.
This is not the case, however, on the USAF aircraft studied
for this report. Moreover, sufficient data from the T-39
program does not exist to support the requirement for flight
path angle.

Path Anticipator - One of the most serious deficiencies
with the current T-39 mechanical display presentations has
been the lack of sufficient path anticipation information.
At present, to determine what will occur next, the pilot
must relate his position to the approach plate to obtain
the information. If he could obtain this information
directly from his displays and use the approach plate only
for monitoring, his workload would be reduced. The
ultimate in path anticipatory information can, of course,
be provided with an electronic map display; however, its
presentation on mechanical displays is more difficult
to implement within an overall system's framework. The
following discussion highlights two methods for providing
lateral path anticipation using the HSI. Each method has
possible problems and variations.

The first method involves stepping, or rapidly slewing,
the course pointer at the start of the circular transition
to the course of the next lateral path segment. On the T-39
presently, the course pointer slews at a rate proportional
to the path's radius of turn and the aircraft's true turn
rate. The problem occurs in that the pilot does not immediately
know when it will stop slewing). At the same time, the
lateral deviation indication could be referenced to the
next segment and therefore step to the newly computed
error. The problem with this system operation is that the
circular arc is a definite part of the trajectory and not
just any transition from one straight path segment to another.
Therefore, the deviation shown must be referenced to the
desired circular arc. This criterion is substantiated by
present day approaches such as the Carnarsie approach(Figure
29) at John F. Kennedy International in New York which has a
defined 3.7 nautical mile radius turn on to a 2 nautical
mile final approach leg. In this approach the prescribed
transition between straight path segments is an important
portion of the approach.

A variation of this method would involve stepping, or
rapidly slewing, the course pointer at the start of the
circular transition but keeping the deviation referenced
to the circular arc instead of changing the reference to
the next segment. Therefore, at the transition, no step
would occur on the lateral deviation indicator. The problem
with this method is that ambiguous situation information would
result. For example, if a 45 degree course change occurred
at the transition and the aircraft was on track and turning
to maintain the circular arc, the situation would appear
as a 45 degree (decreasing to a 0 degree) crab angle with
zero lateral deviation.

A second, more desirable, method is to step, or rapidly
slew, the heading bug to the next course to be flown.
and allow the course pointer and lateral deviation indicators
to operate as at present. The bug can be slewed either
at the start of the circular arc or at the completion of
the circular arc. This method will provide the desired
path anticipation without sacrificing the need for accuracy
about the circular arc or introducing confusing situation
indications.

A possible drawback to this second method involves its
relation to missed approach procedures. At present in many
commercial aircraft, the heading bug is normally set to
the missed approach heading when executing ILS approaches.
In the military, however, this is not necessarily standard
procedure. If it is required, a system problem results
since the bug movement is under computer control for a
different function. Although the computer could provide
auto-slewing of the heading bug to the missed approach
heading upon selection of a go-around mode, this would
require increased data entries and would result in further
complication in failure effects analyses and safety consider-
ations.

Aircraft Position Predictor is a display parameter commonly
used with CRT map displays. It is represented in the form
of a "whip-type line" which indicates aircraft movement,
over a fixed time segment (typically 7 to 15 seconds for
MLS approach conditions), with respect to the desired path.
It essentially acts like a flight director roll command
bar. Further information is contained on this subject in
Appendix B.

80

Ground/Wind Speed and Direction, Estimated-Time-To-Go-
These parameters are easily derived within the MLS computer
as part of the aircraft position computation for complex
trajectory flight. They provide the pilot with reference
type information that is not essential during high workload
situations. For present RNAV and OMEGA systems, this infor-
mation is typically selectable for display on a CDU. This
method of display is also recommended for MLS.

3.3.3   MLS Auxiliary Data Parameters

The MLS provides the capability for transmitting many ground-
derived parameters to the aircraft as auxiliary data infor-
mation. This data consists of: status information which
is useable by the pilot for reference; and, geometry data
which describes the layout of the MLS transmitters and is
required by the MLS computer in the complex trajectory flight
computations. Although the final auxiliary data parameters
to be provided have not been defined, the following lists
provide some examples.

3.3.3.1   Auxiliary Data Status Information

Runway Heading	Runway Visual Range
Runway Condition (e.g., wet, dry)	Ceiling
Runway Status (e.g., CAT I, CAT II)	Barometer Setting
Runway Length	Wind Velocity on Runway
Minimum Glide Slope	Wind Direction on Runway
Azimuth Sector Limits	Wind Gust Velocity on Runway
Facility Identification	

3.3.3.2   Auxiliary Data Geometry Information

Elevation Antenna Height
Distance Along Runway from DME Site to GPIP
Distance Along Runway from Azimuth Site to GPIP
Elevation Site Offset from Runway Centerline
Elevation of GPIP Above Sea Level
DME Site Offset from Runway Centerline

3.3.4   MLS Alerts and Warnings

MLS related alerts and warnings shall provide a positive
indication of failures, loss of adequate signal strength,
important ground facility information changes, and upcoming
approach segment transitions. These indications shall be
provided on primary instrumentation and master caution and
warning panels in a manner similar to corresponding ILS
and RNAV information. The alert and warning information
discussed below is readily available for display. The MLS
receiver validity data is also useable in the MLS computer
and autopilot: to enable mode engagement; to cause reversion
to dead-reckoning control; and; to automatically disconnect
the autopilot during autoland control.

The MLS receivers output validity information in both a
standard 28 VDC analog format and a digital format. The
analog format is required to allow interface with standard
electro-mechanical instrumentation and existing autopilot/
flight director systems. The digital format is cost-effective
in interfacing with the digital MLS computer. The receiver
validities - azimuth, elevation, DME and back azimuth - are
a function of received signal strength and receiver self-
testing. Invalid information can be displayed with flags on
the ADI, HSI, and MLS AZ/DME indicator.

In complex trajectory flight, a dead-reckoning mode can be
engaged as a function of loss of receiver validity. Control
equations during this mode are based on position data derived
from the last good MLS and wind speed information. Although
this results in significant inaccuracies as time goes on, on
a short term basis it solves the problem of intermittent
signal strength due to antenna masking. Use of dead-reckoning
during complex approaches to landing for periods of time
greater than 10 seconds should be avoided. Flag information
associated with the raw MLS receiver data provides an indica-
tion o the faulty parameter. A discrete light should be
provided on the CDU for annunciating the mode.

A discrete light is required on the master caution and warning
panel to indicate a change in important ground facility
information per the MLS auxiliary data transmission. Impor-
tant information changes which require review by the pilot
include runway condition, runway status, RVR, ceiling and
significant wind changes. Logic may be required within
the computer to determine when the light should be illuminated.

A discrete light is also required to alert the crew of up-
coming segment transitions in both the lateral and vertical
axes. This should be placed in the primary instrument area
to insure visibility. RNAV annunciations of this alerting
function result in a flashing indication for 15 seconds
immediately preceding each transition point. This method
of annunciation is also useful for MLS.

3.4   Man/Machine Interface Requirements

3.4.1   Control Functions

The man/machine interface with MLS is a variable problem
dependent on the level of MLS capability employed. For
simple straight-in MLS approach paths the procedures involved
with setting up the approach are consistent with those for
ILS. As the approach path complexity increases, so does the
pilot procedural requirements. For an avionics configuration
which contains full MLS complex trajectory capability, the
following MLS-related control functions are required. A
discussion on each of these functions immediately follows.

Data Entry	Antenna Mode Select
Channel Select	Complex Trajectory Mode Select
Audio Volume Adjust	Auxiliary Data Select
ILS/MLS Select	

3.4.1.1   Data Entry

Data Entry involves insertion of the required data into the
MLS computer to totally define the desired trajectory.
Depending on the complexity of the trajectory and the method
of insertion and crosscheck, data entry can be a major source
of pilot workload simply due to the number of entries which
have to be made. The means of data entry traditionally
involves some form of CDU made up of alphanumeric readouts,
pushbuttons, lights, and a keyboard or rotary encoder knob.
Such a CDU is required for MLS complex trajectory flight.

Unlike RNAV operation, where the pilot has a reasonable amount
of time to set up and stay ahead of his flight plan (usually
done on the ground prior to the flight), MLS operation will
require the pilot to enter the trajectory data after obtaining
clearance from approach control. Different methods exist
which can automate or semi-automate this task. These include:

automatic data entry via a card reader; onboard bulk storage
which can be accessed in flight and is modifiable through
a tape reader on the ground; a ground-to-air data link system;
and,manual entry of small amounts of data required to define
a limited set of standardized trajectories. Although the
automatic schemes end up creating expensive logistic problems
and none totally solve the problems created by last minute
changes directed by traffic control, they do require serious
consideration since they drastically reduce pilot workload
levels for a large percentage of the time. The manual entry
scheme with standardized trajectory types also must be
considered since it will reduce both initial purchase cost
and system maintenance costs for the user. Further discussions
on these methods follow:

- Automatic Data Entry Unit (ADEU) - A prepunched
  IBM card, programmed for the desired trajectory,
  is inserted into the ADEU to automatically enter
  the required data. A logistics problem associated
  with this method results from the need to continuously
  carry and maintain a large library of cards corres-
  ponding to all of the possible trajectories at all
  airports and alternates along the route or mission
  structure. It is assumed that each landing field
  will have between 5 and 10 standard trajectories for
  each MLS runway.

- Flight Data Storage Unit (FDSU) - This unit provides
  bulk storage memory which can be altered by tape
  via a self-contained tape reader. In this manner all
  trajectory data for a region of airports is stored
  in memory by trajectory number. To access this
  memory, the pilot must only insert the required
  trajectory number on the CDU. The problems involved
  with this method are similar to those with the
  ADEU.

- MLS Auxiliary Data - Trajectory data could be
  defined on the ground and transmitted to the aircraft
  as part of the MLS auxiliary data information.
  The pilot would only have to verify this data on
  his CDU. The problem with this method lies in the
  fact that the MLS auxiliary data is only available
  inside MLS coverage. Workload and traffic control
  problems would certainly result during the period

of time when the data check was being made and the
MLS was essentially being ignored.

- Discrete Address Beacon System (DABS)- Since this is
  a long-range ground-to-air transmission (50 nm),
  DABS would tend to eliminate the problems associated witn
  the MLS data link. Like MLS, this system is in its
  development stages. Its use for this application
  requires further investigation into the technological
  and cost aspects of its implementation.

- Manual Entry of Standardized Trajectory Type Data -
  This method probably provides the most cost-effective
  near term solution to the data entry problem. It
  requires the definition of standardized trajectory
  types with a limited number of variables required
  for entry. Detailed discussions on this subject
  are included in Section 4.3.

One of the major problems associated with complex trajectory
flight is determining whether the trajectory computed by
the MLS computer is truly the trajectory which the pilot
intended to fly. The two major sources of error are those
introduced by: the pilot in specifying and inserting the
defining data to the computer; and, faults within the computer
itself.

Note that in the alternate method of defining trajectories
discussed in Section 3.1,only one point on the trajectory
was defined with respect to the MLS transmitters - the
touchdown point. The remainder of the trajectory was defined
by laying out the next segment with respect to the touchdown
point, then the next segment was defined with respect to
the previous one, etc. It becomes clear that if a multi-
segmented trajectory is defined in this manner, any error in
specifying one segment will result in the wrong location of
every segment which follows it.

In this manner, a single checkpoint situated on the outermost
inbound leg of the trajectory can be used to check the
validity of the entire trajectory. This checkpoint will be
input to the computer as an along track distance only. From
the trajectory it has defined, the computer can compute
the coordinates of this point in terms of the basic MLS
receiver outputs (i.e.,with respect to the transmitters)

and this information can be supplied to the CDU for presentation.

By comparing these basic coordinates to those shown for the checkpoint on the approach plate, the pilot may now conclude that:

> 1) The data was entered correctly
> 2) The trajectory is correctly computed within tne MLS computer

This is an extremely valuable confidence check and obviates the need for the pilot to check each data insertion independently. It thereby represents a significant decrease in pilot workload in interfacing with the CDU.

Having once visually checked that the trajectory is correct, the pilot may now cause the displayed checkpoint data to be stored in the MLS computer. The computer will now periodically recompute the trajectory and checkpoint data and compare the results to those previously verified by the pilot. In this manner, a subsequent failure can be detected by the computer and an automatic alarm can be issued.

Data entry equipment, for USAF aircraft retrofitted for MLS complex trajectory flight, will probably consist of a dedicated MLS CDU rather than a modified NAV or weapons delivery CDU. This will eliminate the need for extensive redesign investigations and rework of many different existing pieces of equipment. It will also result in an increased amount of MLS commonality within the USAF inventory since the CDU can be standardized for those aircraft requiring full complex trajectory capability. MLS data entry requirements for future USAF aircarft can certainly be integrated into the multifunction keyboard concepts developed under the Digital Avionics Information System (DAIS) program by the Air Force Avionics Laboratory at Wright Patterson Air Force Base.

3.4.1.2 Channel Select

Setting of the MLS angle and DME frequencies involves selection of the proper MLS channel number. Although to the pilot this only involves selecting a number from 001 to 200 via a rotary knob, keyboard, or any other device, consideration must be given to implementing this mechanism in a manner which

provides maximum availability of the basic MLS. Part of this consideration must include a reliability analysis tradeoff of the components in the CDU (and computer, if applicable) involved with the channel selection process and those of a simplified tuner completely independent of the CDU. The results of this analysis will determine whether the channel select function should be implemented as part of the complex CDU or in a highly reliable simple tuner. This analysis has not been performed for this study.

3.4.1.3 Audio Volume Adjust

Either two knobs or one dual-concentric knob are required to adjust the volume of the audio identification signals from the angle and DME receivers. This control should be located adjacent to the channel selection mechanism due to its relationship to the tuning process.

3.4.1.4 ILS/MLS Select

For aircraft that contain both ILS and MLS capability, a switch is required to differentiate between the systems. This is used to switch display information and provide interlock logic to the MLS naviagation computer and autopilot/flight director systems.

3.4.1.5 Antenna Mode Select

For those aircraft flying complex trajectories which require more than one C-band and L-band antenna to eliminate masking (as experienced on the USAF T-39 and NASA 737), an antenna switching unit is required. This switch should operate in an automatic mode based on received signal strength for the complex portion of the approach. On final approach it must be locked on to the front antennae to ensure a constant flight path and ground clearance level. This is especially true for large aircraft where the distances between fuselage-mounted front and rear antennae can result in vertical path discrepancies of 12 feet for normal approach pitch attitudes.

An override control may be necessary for the automatic switching unit. This need is dependent on the reliability levels of the switching unit and the receiver electronics used to drive the switching unit. If these levels are sufficiently high, the antenna mode select switch is not required. If not, the switch should be included with the unit which contains the channel select mechanism.

3.4.1.6 Complex Trajectory Mode Select

This switch is required to differentiate between a straight-in ILS-type MLS approach and a complex trajectory. It should be integral to the CDU. The resultant switching external to the MLS computer and CDU should be configured such that straight-in MLS approaches are always possible with a CDU and/or computer failure.

3.4.1.7 Auxiliary Data Select

MLS auxiliary data is necessary for complex trajectory flight due to the runway and ground site geometry information it provides. Its usefulness for display information is questionable especially for direct ILS replacement configurations. For this reason a dedicated auxiliary data panel is not recommended. Instead, it is recommended that this information be provided on a CDU if found to be necessary. Its implementation within the CDU requires a pushbutton to call-up the various pieces of information. Also required, in relation to this data, is a warning light which indicates that a change has occurred in the ground status information. This warning should probably be provided on the aircraft's master caution and warning panel to catch the pilot's attention and direct him to look at his auxiliary data information.

3.4.2 ILS/MLS Procedures

Pilot operational procedures for straight-in ILS-type approaches are essentially identical for ILS and MLS configured aircraft. For MLS complex trajectory flight, data entry and approach situation monitoring are the primary reasons for the increase in pilot workload. Three general sets of procedures are shown below which point out the similarities and differences of the set-up requirements for the three types of approaches.

STRAIGHT-IN

ILS	MLS
1) Tune ILS frequency - (2 knobs)	1) Select MLS channel - (1 knob or 4 keystrokes)
	2) Identify-volume control (1 knob)
	3) Select intercept heading (1 knob)

88

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                            4) Select final approach course
                                ( 1 knob)
5) Select ILS mode:               5) Select MLS mode:
   a) Set ILS/NAV/ TAC switch        a) Set ILS/NAV/TAC switch
      to ILS                            to ILS *
   b) Depress ILS pushbutton         b) Set ILS/MLS switch to MLS
                                     c) Depress ILS * pushbutton
```

* ILS nomenclature should be changed to APPR (approach)

COMPLEX TRAJECTORY

1) Select MLS channel - (1 knob or 4 keystrokes)
2) Identify - (dual concentric knob)
3) Enter trajectory data - (1 pushbutton and 12 entries of
   up to 4 keystrokes each * to define a trajectory with
   3 lateral and 2 vertical segments)
4) Check trajectory data - (1 entry and reading and comparing
   3 numbers versus those on the approach plate)
5) Select complex trajectory MLS mode
   a) ILS/NAV/TAC switch to ILS**
   b) ILS/MLS switch to MLS
   c) Depress complex trajectory mode pushbutton
   d) Depress ILS** pushbutton

* Based on third CDU candidate described in Section 4.3
** ILS nomenclature should be changed to APPR (approach)

In comparing these procedures, the only difference for the
straight-in ILS and MLS approaches is the additional ILS/
MLS switch operation. This is insignificant in terms of
workload.

For the complex trajectory procedures, however, data entry
and check requires 13 additional operations of up to 4 key-
strokes each and the actuation of two additional pushbuttons.
These numbers are based on what is probably the most complex,
and yet still practical, approach that will be used (i.e.
3 lateral and 2 vertical segments). They are also based
on a specific CDU which is not optimized for the lowest
number of entries. For a less complex approach consisting
of two lateral and one vertical segment, only six rather than
13, additional entries are required. It should be noted
that these numbers of entries include runway heading and
runway height above sea level. Although this information

will be included as MLS auxiliary data, it must be entered
into the computer prior to entering signal coverage to allow
performance of the data entry check procedure.

Although workload levels for the complex trajectory approach
are obviously much higher than those for the straight-in,
no problem is expected in two-seat aircraft if approach
definition is obtained from traffic control a sufficient
distance from the approach initiation point. If this time
is not provided or if the approach requirements are altered
close to the airport, the new approach must be sufficiently
simple to allow rapid entry or the pilot will be required to
enter a holding pattern to complete his data entry. If this
occurs for a single-seat aircraft, the procedures must allow
for a rapid reversion to a straight-in approach.

4.0 MECHANICAL/ELECTRONIC CONTROL-AND-DISPLAY CANDIDATE CONFIGURATIONS

4.1 General MLS Configurations and Electro-Mechanical Display Candidates

Four general MLS configurations have been defined as an aid
in analyzing the overall MLS requirements for all classes
of USAF aircraft and in performing the aircraft studies
of the C-130A/D, F-111A/E, A-7D, F-15A, and KC-10A. The
intent is to recommend one of the four general configurations
for each of the specific aircraft. Recommendations will
be based on present aircraft systems' capabilities, complexity
of retrofit, and anticipated pilot workload levels with
the associated cockpit controls and displays. The four
general configurations have been labelled as follows:

- MLS-1 Direct ILS Replacement

- MLS-2 Selectable Azimuth and Elevation

- MLS-3 Selectable Intercept of Final

- MLS-4 Complex Trajectory

Configuration complexity increases significantly from
the direct ILS replacement system to the complex trajectory
system. The increased complexity is evident in the control/
display design requirements, resulting hardware require-
ments, and increase in pilot workload for operation.
Highlights of these configurations follow. A detailed
discussion of these configurations is included in the
following sections.

- MLS-1, Direct ILS Replacement Configuration:

    - Angle receiver, C-band antenna, and tuner required
    - DME function optional depending on usage of marker
      beacon
    - Auxiliary data function optional
    - Raw azimuth and elevation deviation outputs
      identical in format to present ILS receiver
      outputs to insure compatibility with present
      USAF autopilot/flight director equipment and
      instrumentation
    - Raw deviation outputs referenced to extended
      runway centerline and nominal glide slope

91

of field
- No selectable azimuth and/or elevation angles
- Useful for all classes of aircraft

● MLS-2, Selectable Azimuth and Elevation

- Required and optional equipment same as for MLS-1
  (i.e., angle receiver, antenna and tuner
  required; DME and auxiliary data functions
  optional).
- MLS tuner requires selection mechanisms for
  selecting desired azimuth and elevation angles
  as in Phase III MLS design
- No low altitude IFR use seen for selectable
  azimuth function
- Selectable elevation function useful for STOL
  and rotary wing aircraft in performing steep
  final descents. No use seen for CTOL aircraft.

● MLS-3, Selectable Intercept of Final

- Angle receiver, DME interrogator, C-band and
  L-band antennae, and switching unit required
- Also requires MLS navigation coupler, simple
  control panel, and azimuth/DME display
- Auxiliary data functions optional
- Provides precise low altitude IFR control along
  a selectable heading intercept and to a selectable
  final approach segment length
- Provides 2-segment glide path capability
- Allows close-in (< 2 nm) final approach captures
  not possible with typical present day ILS
  approaches (7-10 nm)
- Useful for all classes of aircraft
- Particularly useful for providing limited complex
  trajectory capability while maintaining sufficient
  operational simplicity for single-seat aircraft.

● MLS-4, Complex Trajectory Configuration

- Requires angle receiver, DME interrogator, and
  switching unit as in MLS-3
- Requires fore and aft antenna installations and
  antenna switching unit, if desired trajectories
  warrant

- Requires more complex MLS navigation computer
- Requires azimuth/DME display
- CDU replaces control panel and contains auxiliary data functions
- Provides precise low altitude IFR control along any complex trajectory
- Increase in capability results in increase in pilot workload for trajectory selection and monitoring approach progress
- Use for single-seat aircraft without automatic approach coupler and some form of automatic trajectory selection is doubtful due to workload requirements.

4.1.1   MLS Interface Analysis

Although only five different types of USAF aircraft were studied in detail for this investigation, this interface analysis is a comprehensive assessment of the MLS integration problem for most aircraft in the USAF inventory. Detailed discussions for the five aircraft studied are presented in Section 5.0 of this document.

The basic MLS airborne system (as defined for this study) results in a direct replacement for ILS. As various "options" are added additional capabilities are realized, of which, the most sophisticated is complex trajectory flight. Figure 31 shows a generalized representation for the basic system. It consists of a C-band antenna, an angle receiver, a means to tune frequency channels, and a volume control to adjust the audio identification signal. To complete the loop, means must be provided to display and utilize the MLS receiver outputs (deviations, validities and audio signals). In general, these means are available in all existing USAF aircraft equipment systems.

The MLS angle receiver must provide analog deviation and validity signals with interface characteristics identical to those of the localizer and glide slope signals of the present ILS system. This is required so that a retrofit involving the minimum MLS capability requires no modifications to existing autopilot/flight director computers (i.e., changes to control law gains, input impedances, etc.) and/or cockpit instruments. Additionally, the MLS receiver provides a digital output data bus with full coverage aircraft position
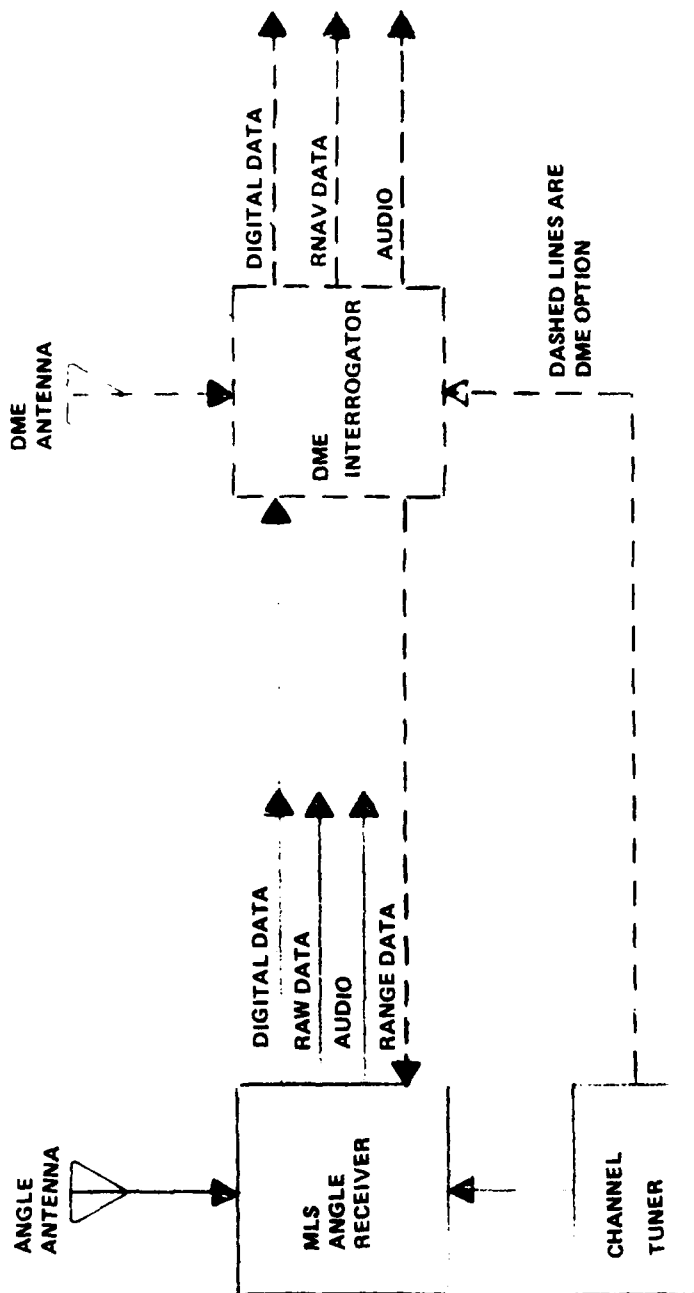
Figure 31 Basic MLS System With DME Option

94

and auxiliary data information for those aircraft which will more fully utilize the MLS capabilities.

If a DME antenna and interrogator are added to the basic MLS system to increase capability, range and altitude information are available on a digital data bus. This information can be displayed on a cockpit indicator for the basic system, and/or can be processed with the angle receiver data by a suitable computer to provide precise aircraft position in rectangular coordinates for complex trajectory flight.

The overall implementation considerations, for the interface of the equipment and systems associated with any level of MLS retrofit capability, can be classified in the following categories:

- Additions
- Modifications
- Replacements

"Additions" include new ship's wiring, new MLS equipment, and the physical location and mounting details of the new units. "Modifications" include the re-routing and re-termination of existing wires, and the modification of existing units. "Replacements" include replacement of existing units in the cockpit and the equipment bay.

For any aircraft, the general MLS interface illustrated in Figure 32 is applicable. Functions of the MLS are shown in their logical relationship with each other and with the existing system. MLS receiver outputs are: routed through the MLS interface for further computation and/or signal formatting; applied to any new MLS displays; and, via the existing interface, applied to the flight controls, instruments, and audio system.

Typical equipment associated with each function is listed in the tables adjacent to each function block. All equipment associated with the MLS functions are additions. Equipment listed under the existing interface function are exclusively in the modification category since ship's wiring associated with these units may be altered. Most of the remaining equipment listed under flight control, instruments and audio will be left intact since the MLS shares these with other systems that may have a higher
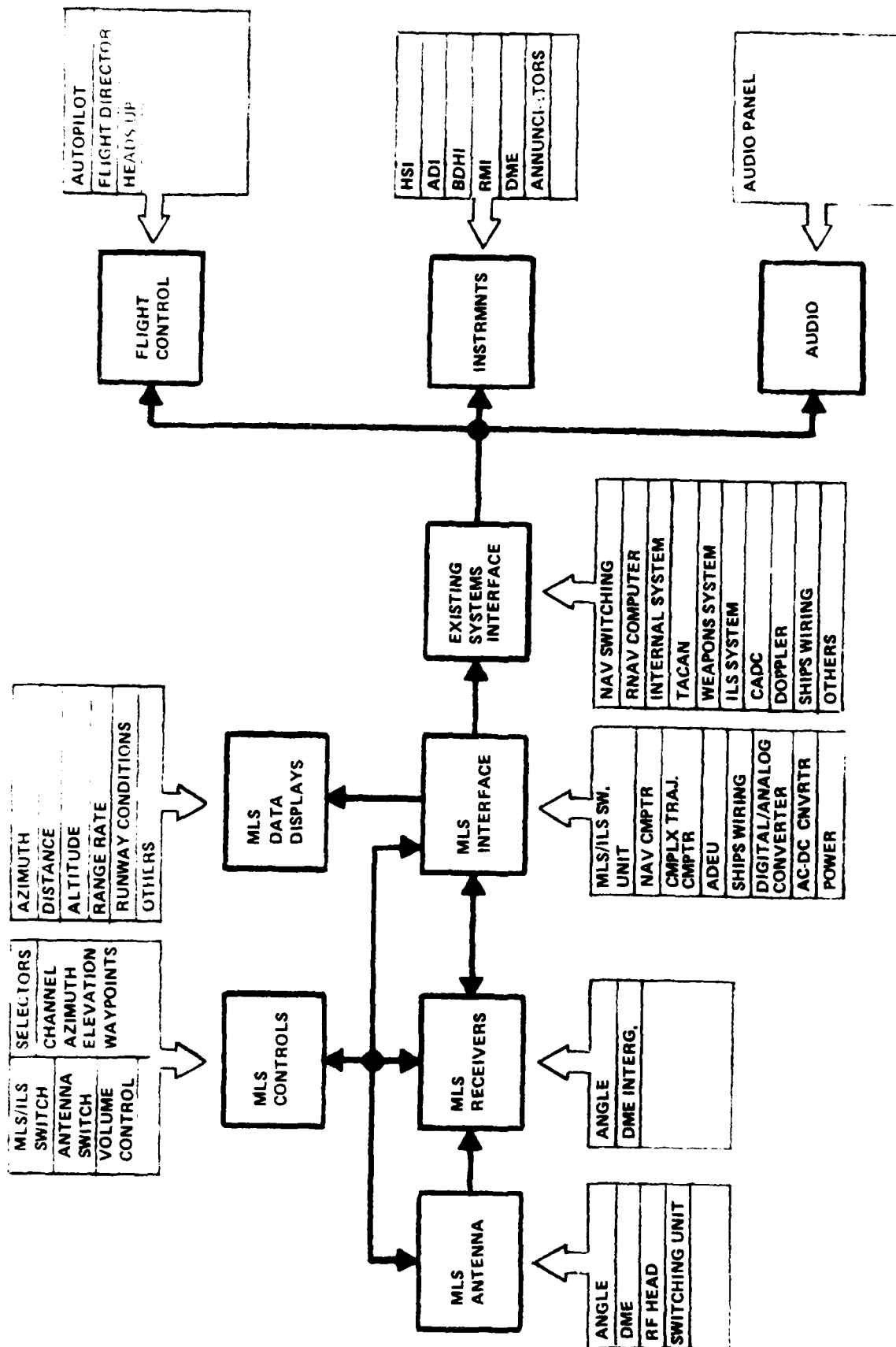
Figure 32 MLS General Interface

mission priority. Simple modifications may be required for a few of these units and replacements will be confined to updated or more sophisticated units required to perform the MLS task.

The analog MLS outputs are useable "as-is" by the existing system, while the digital signals require either conversion or must be combined with other signals and then modified for flight path control. All DME interrogator output signals are in digital form and a digital-to-analog converter is required for analog display interfacing. Since the raw deviation data outputs of the MLS angle receiver are compatible with the existing ILS system, these outputs can be utilized as a function of MLS selection. Normal "ILS type" approaches can be made using the present flight controls and instruments.

If an MLS-controlled complex approach capability is required, an interface unit is necessary to process the full-coverage digital outputs, and, thereby, provide deviation signals for the instruments and steering signals for the flight controls. Two interface possibilities are feasible. The first is to provide a dedicated (new) digital MLS navigation computer, and the second is to modify a suitable computer already installed (major modification) in the aircraft.

Providing an MLS navigation computer is advantageous since a common computer can probably be used for all aircraft which require complex trajectory capabilities. Furthermore, some aircraft are not equipped with digital computers or have computers that cannot be easily modified due to space, power, memory or real-time limitations.

Modification or a functional replacement of existing computers is advantageous since a new unit need not be installed. For aircraft with space and weight limitations, this may be the only choice. Some of the disadvantages of this approach to retrofit are as follows:

- Many different types of computers will have to be studied and modified
- Each modification will require coordination with a different manufacturer
- Test equipment and specifications associated

- with each computer must be modified
- As a result of the above, the USAF management task is greatly increased

Because of its disadvantages, the computer modification approach is not generally recommended except for aircraft types with severe space limitations. As a consequence of eliminating this approach, only minor equipment changes and ship's wiring are involved in the "modifications" category. Wherever possible, even minor equipment changes will be avoided. The "modification" task is to provide MLS outputs to the audio system, flight controls and instruments.

Since the DME and angle receiver audio signals are "paralleled" on a common audio output and individual signals are introduced by dedicated on-off switches and volume controls; the existing wiring need not be interrupted, and the audio wires can be considered as "additions." A separate switch (on, off) is required for each audio signal. If space is available on existing audio panels, the switches should be added there. If space is not available, a simple panel must be added somewhere in the cockpit.

The sensor information applied to the flight controls and instruments is time shared by the various navigation systems installed on the aircraft. All aircraft utilize ILS and TACAN systems and, as required, more sophisticated navigation systems. Switching of the navigation references can be a function of a separate switching unit or as part of some other unit of the existing interface.

Since the MLS and ILS systems will never be used simultaneously, and the output signals have the same characteristics; the MLS signals will be substituted for the ILS signals when the MLS mode is selected. If both MLS and ILS are to be accommodated on a particular aircraft, an MLS/ILS switch and remotely located switching unit will be added. The existing switching will be left intact, and only the required wires will be interrupted. A typical interface is illustrated in Figure 33. If the ILS system is removed, MLS signals are substituted directly. Switching from MLS raw deviation data to complex trajectory MLS signals will be a function of the MLS interface which is unique for each of the four MLS configurations.

Figure 33 Typical Interface

99
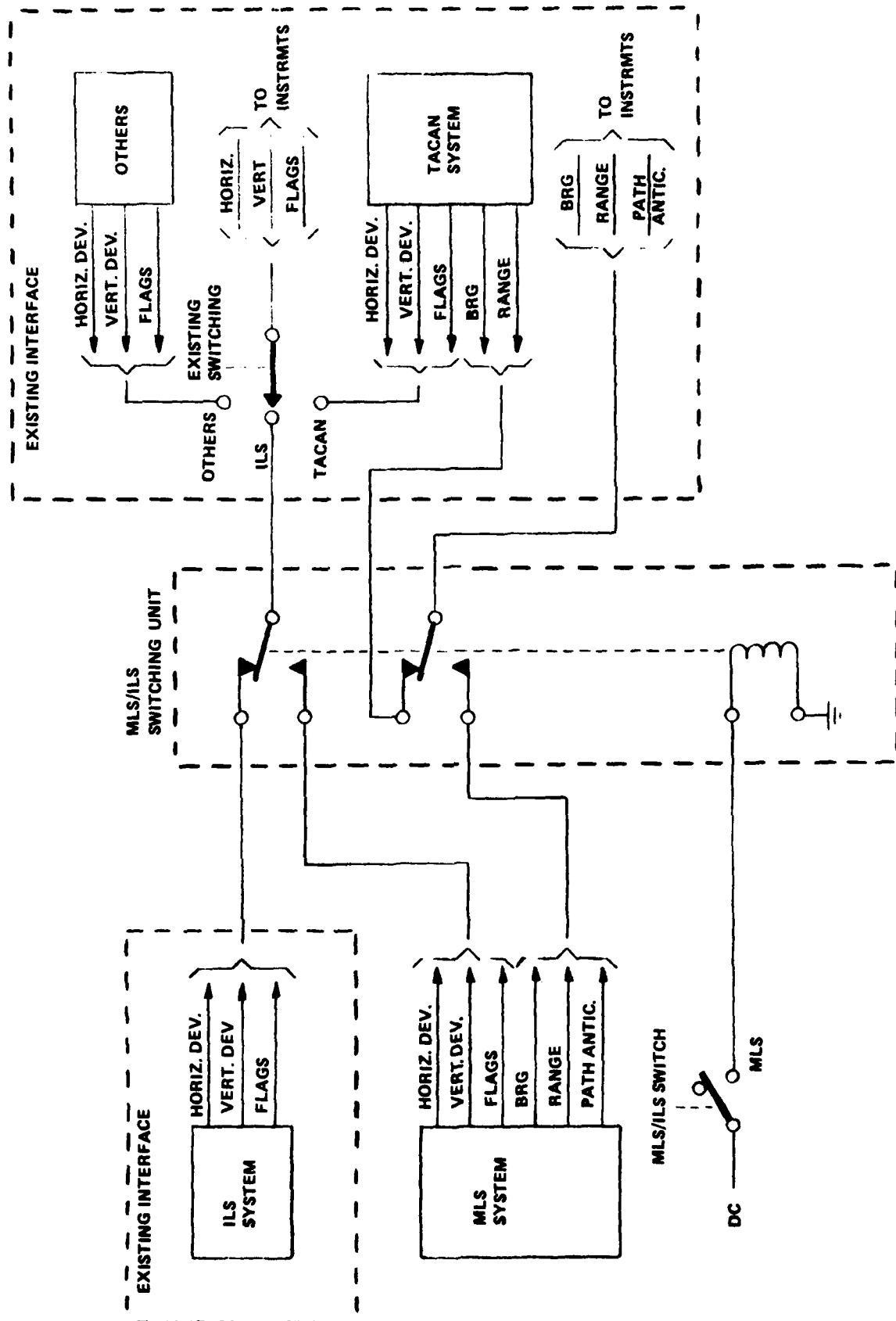
4.1.2   MLS Configurations

Dependent on the desired requirements and/or the inherent
capabilities of a particular aircraft, at least one of the
MLS system configurations can be incorporated. The selected
configurations are as follows:

        MLS-1   Direct ILS Replacement

        MLS-2   Selectable Azimuth and Elevation

        MLS-3   Selectable Intercept of Final

        MLS-4   Complex Trajectory

All configurations utilize the basic MLS system (see Figure
1). The channel tuner is absorbed by the MLS control
panel or CDU as the system's sophistication is increased.
The basic MLS system is as follows:

Basic	Basic Options
MLS Angle Antenna	AZ/DME Display
MLS Angle Receiver	Aux Data Display
MLS/ILS Switch	DME Interrogator
MLS/ILS Switching Unit	DME Antenna
MLS Audio Panel	
Channel Tuner	

DC power must be supplied to the MLS components via circuit
breakers. Dual MLS installations will require two separate
circuit breakers connected to two independent power sources.

The MLS/ILS Switch can be incorporated on the same panel as
the tuner.

A typical audio panel (see Figure 34) must be added for all
configurations if the MLS on-off audio switches cannot be
accommodated on the existing audio panel(s).

The following is a brief description of each of the four
configurations, the equipment required and a general

	1	3	4	2*

ON	ON	ON	ON
ANGLE-1	ANGLE-2	DME-2	DME-1
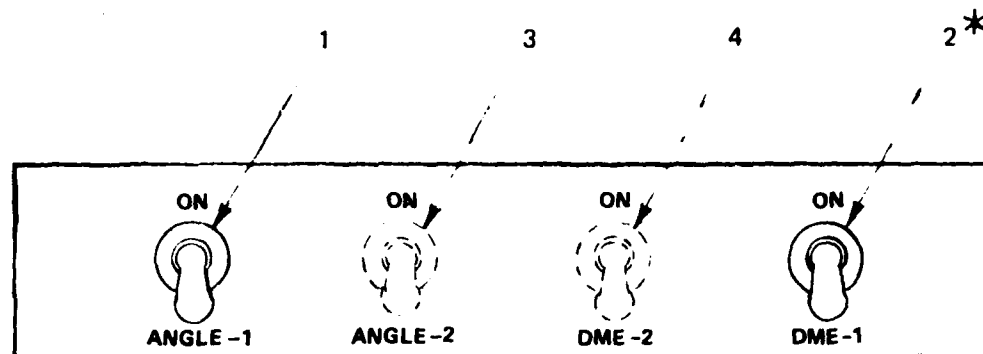
NOTE: FOR DUAL INSTALLATIONS EITHER DASHED SWITCHES OR ADDITIONAL PANEL ADDED.

* NOT REQUIRED FOR BASIC MLS SYSTEM RECEIVER

1. MLS ANGLE-1 SWITCH COUPLES AUDIO SIGNAL FROM ANGLE RECEIVER NO. 1 TO AUDIO SYSTEM.

2. DME-1 SWITCH COUPLES DME AUDIO SIGNAL FROM DME INTERROGATOR NO. 1 TO AUDIO SYSTEM.

3. MLS ANGLE-2 SWITCH COUPLES AUDIO SIGNAL FROM ANGLE RECEIVER NO. 2 TO AUDIO SYSTEM (SEE NOTE).

4. DME-2 SWITCH COUPLES DME AUDIO SIGNAL FROM DME INTERROGATOR NO. 2 TO AUDIO SYSTEM (SEE NOTE).

Figure 34 Typical MLS Audio Panel

101

discussion of the interfacing. In the description, the
equipment added is for a single Category I installation.
Category II and III installations require certain dual units.
Table 5 lists the equipment complement for Category
I,II. and III versions of the four MLS configurations.

Category I systems require either an autopilot or flight
director coupler. With this system IFR approaches can be
made down to an altitude of 200 feet. Most older types of
aircraft fit into this category.

Category II systems require the following:

- Two independent flight director couplers or
- Two independent autopilot couplers or
- Independent flight director and autopilot couplers

All other equipment needed for the approach such as receivers,
instruments, etc., must be dual. In addition, the couplers
must have certain performance characteristics relating to
path tracking under various wind conditions. Equipment
on older aircraft does not have these capabilities; and,
if Category II capabilities are required, the couplers
must be updated. Category II IFR approaches can be made
down to an altitude of 100 feet.

Category III systems require the same complement of equipment
as Category II systems, and in addition, the autopilot
must have automatic flare capabilities. Category III
coupled approaches can be made to touchdown and beyond.
Various levels of Category III configurations (Category IIIa,
IIIA, IIIB, IIIC) are generally defined but these do not
affect the MLS system complement of equipment.

4.1.2.1 MLS-1 Direct ILS Replacement Configuration

This is the minimal (basic) MLS system and is a direct
replacement for the present ILS system. The required
equipment and approach considerations are illustrated in
Figure 35. Only the raw data analog outputs of the
angle receiver are utilized. It is proposed that the
raw data be permanently referenced to the 0 degree azimuth
angle and the nominal field elevation angle so that a
pilot selection is not required. An option to provide this

TABLE 5
MLS Equipment

MLS AVIONICS		MLS AVIONIC CONFIGURATION							
		MLS-1		MLS-2		MLS-3		MLS-4	
		ILS REPLACEMENT		SELECT AZ & ELEV		SELECT INTERCEPT & GS		COMPLEX TRAJECTORY	
		CAT		CAT		CAT		CAT	
		I	II/III	I	II/III	I	II/III	I	II/III
ANTENNA	ANGLE	1	2	1	2	1	2	1	2
	DME	1	½	1	½	1	2	1	2
		-	-	-	-		-	1	2
RCVR	ANGLE	1	2	1	2	1	2	1	2
	DME INTERROGATOR	1	½	1	½	1	2	1	2
CONTROLS — SWITCH	MLS/ILS SWITCH	1	1	1	1	1	1	½	½
	MLS/ILS UNIT	1	2	1	2	1	2	1	2
	MLS AUDIO	1	2	1	2	1	2	1	2
CONTROLS — SELECT	TUNER	1	1	-	-	-	-	-	-
	TUNER/SELECTOR	1	1	1	1	1	1	-	-
	CONTROL/DISPLAY UNIT	-	-	-	-	-	-	1	1
	AUTO DATA ENTRY UNIT	-	-	-	-	-	-	1	1
DISPLAY	AZIMUTH/DME	1	½	1	½	1	½	½	½
	AUX DATA	1	½	1	½	1	½	-	-
CMPTRS	NAVIGATION	-	-	-	-	1	2	-	-
	NAV (COMPLEX TRAJ)	-	-	-	-	-	-	1	2
MISC	AC-DC CONVERTER	1	2	1	2	1	2	1	2
	DIGITAL/ANALOG CONV.	1	½	1	½	-	-	-	-
	REMOTE RF HEAD	-	-	-	-	-	-	1	2

OPTIONAL

MISC. ONLY IF REQUIRED DEPENDING ON SPECIFIC AIRCRAFT

103

MLS EQUIPMENT

BASIC

MLS ANGLE ANTENNA
MLS ANGLE RECEIVER
MLS/ILS SWITCH
MLS/ILS SWITCHING UNIT
MLS TUNER
MLS AUDIO PANEL

OPTIONS

AZ/DME DISPLAY
AUX DATA DISPLAY
DME INTERROGATER
DME ANTENNA

Figure 35 MLS-1 Configuration Direct ILS Replacement

104
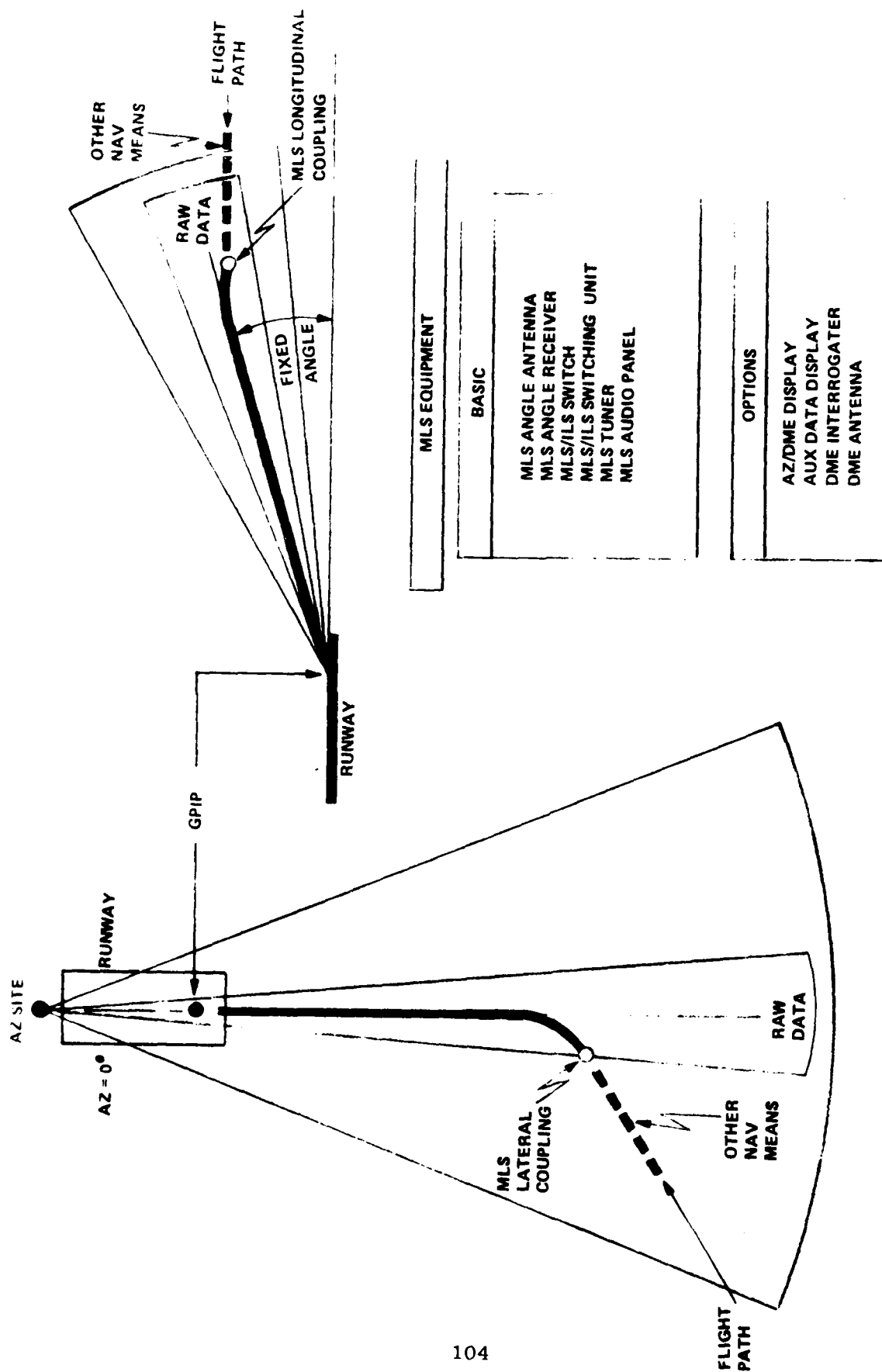
fixed selection capability should be incorporated in the
angle receiver such that several ship's wires will key a
standard receiver to this configuration. A typical MLS-1
configuration tuner is illustrated in Figure 36.

Except for the channel tuning and MLS selection (MLS/
ILS switch), the operational MLS procedures for this
configuration are the same as those for the ILS system.
The aircraft is maneuvered to the desired beam intercept
angle using other navigation means, the runway heading
is selected on the HSI course pointer (for autopilot and
flight director computations), and the present autopilot
and/or flight director ILS mode is then activated. Since
the MLS interface in this configuration is identical to
that of ILS, the flight control system and cockpit displays
behave as if the ILS mode is engaged.

To realize a significant advantage of MLS, the DME function
can be added to this configuration as an option. The
DME interrogator outputs can be switched to the existing
range readouts as a function of selecting the MLS mode.
If the range readout device is an analog interface (commonly
3 synchros to drive 3 digit wheels), an analog to digital
converter must be installed. As an alternate a digital
MLS DME, or AZ/DME, display can be added (see Figure
37)   which is compatible with the digital outputs of the
DME and angle receivers, thus providing indications of the
full azimuth and DME coverage.

A block diagram of the MLS-1 (and MLS-2) configuration
appears in Figure 38.   Components of the existing system
are on the right of the illustration. All others are MLS
additions, and the dashed components are MLS options.

Figure 39   is an illustration of a typical MLS Auxiliary
Data display. This unit was built by Bendix Avionics
Division as part of the Phase III MLS airborne equipment
package. As noted in the figure, it allows presentation
of only a few of the many auxiliary data parameters discussed
in Section 3.4 of this report.

4.1.2.2 MLS-2 Selctable Azimuth and Elevation Configuration

This configuration is a minor modification of the basic
MLS-1 system and is, in fact, the system provided as part

1.125" X 5.75"
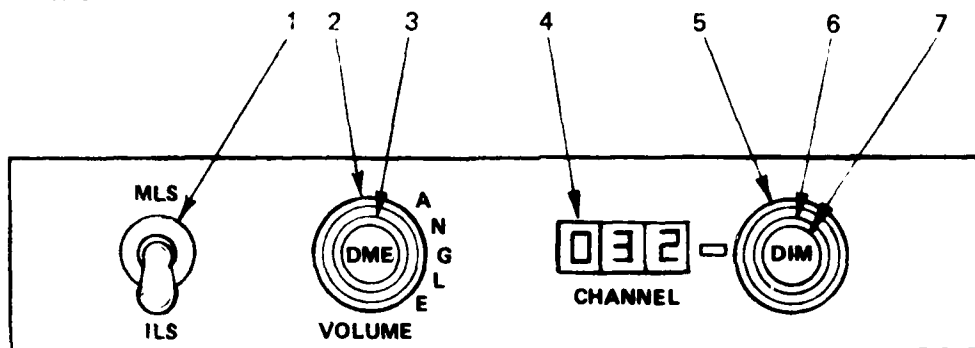
1. MLS/ILS SWITCH SELECTS EITHER MLS OR ILS APPROACH MODE.

2. CONTROLS VOLUME OF MLS ANGLE RECEIVER AUDIO CODE.

3. CONTROLS VOLUME OF DME INTERROGATOR AUDIO CODE.

4. DISPLAYS MLS CHANNEL SELECTED

5. CONTROLS HUNDRED (0-2) AND TENS DIGITS OF DISPLAY.

6. CONTROLS UNITS DIGIT OF DISPLAY

7. DIMS DISPLAY

Figure 36 Typical   MLS-1   Tuner

1. RANGE INDICATOR

2. AZIMUTH INDICATOR

3. INDICATOR DIMMING CONTROL

4. SELF TEST SWITCH
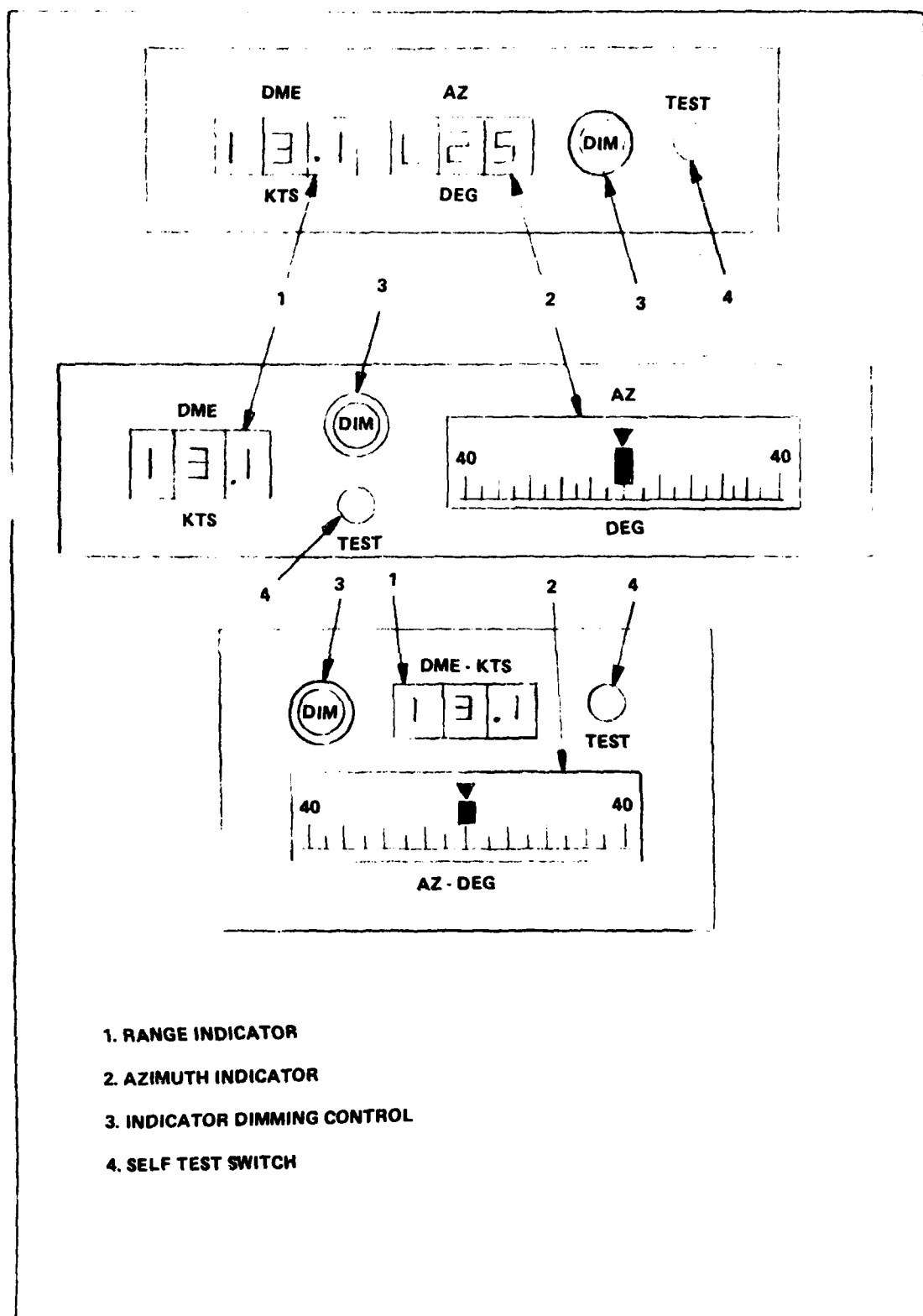
Figure 37 Typical Azimuth/DME Indicators

107
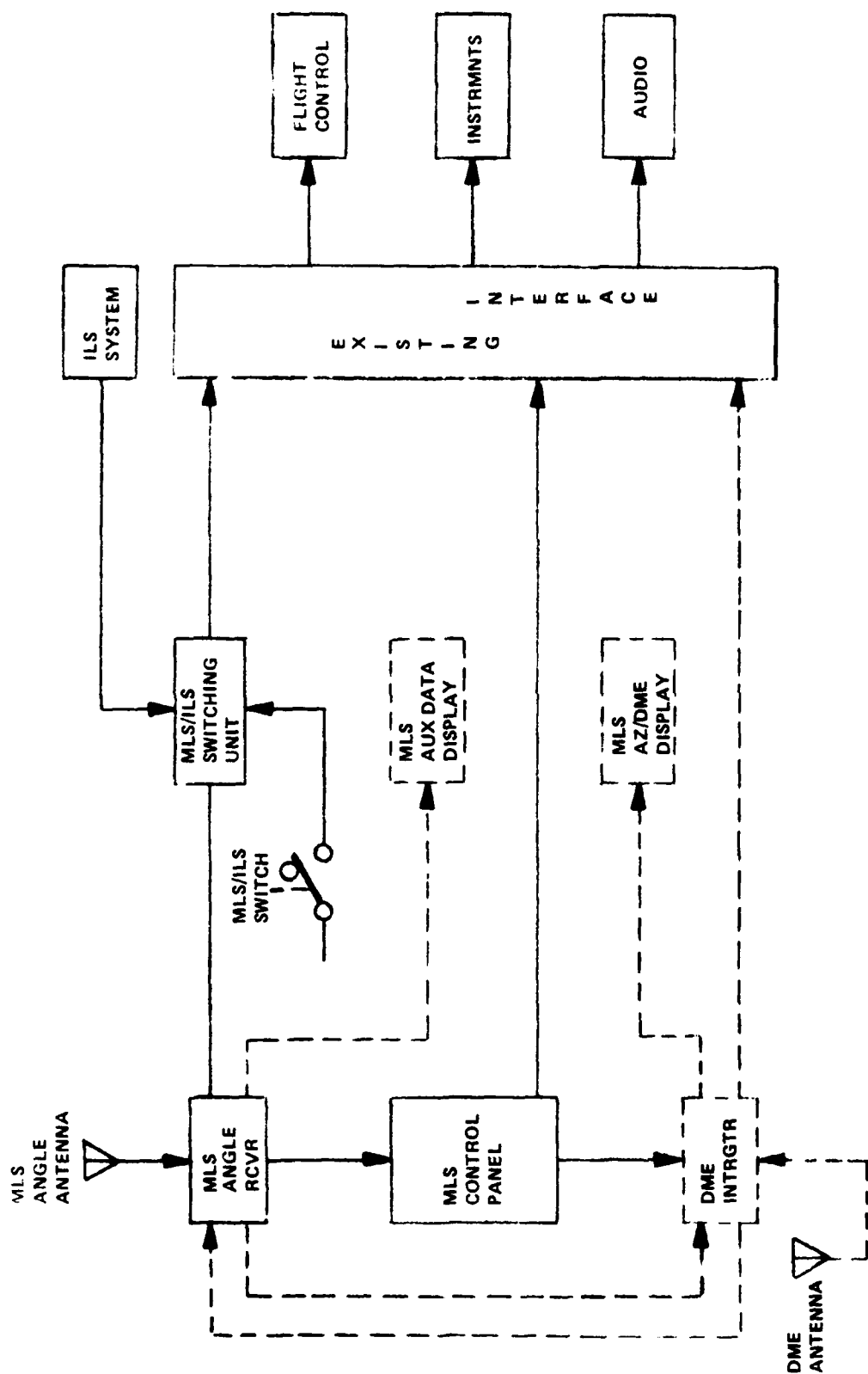
Figure 38 Block Diagram MLS-1 & MLS-2 Configurations
(Direct ILS Replacement & Selectable Azimuth & Elevation)

108

3" x 5.75"
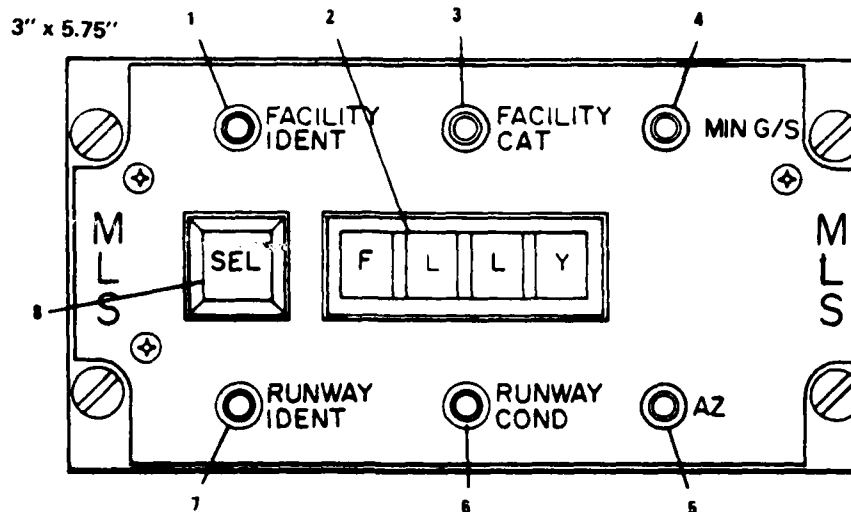
NO.	FUNCTION
1	When pressed selects the FACILITY IDENT function for display when SEL is pressed. The display appears in the framed area to the right of SEL (item 2). The display is a three-letter combination such as IDL or FTL etc.
2	The display area for the various selected functions. The display may be a combination of letters and/or numbers when pressing SEL. Display disappears after a few seconds or after another function is selected.
3	When pressed selects the FACILITY CAT (category) function for display when SEL is pressed. Display is I, II or III. These categories relate to weather-handling capabilities of the ground facility. The using aircraft must have the proper equipment to comply with the conditions existing.
4	When pressed selects the MIN/GS (minimum glide slope) function available at that facility when SEL is pressed. Display will be in degrees. First digit can be either 0 or 1, second digit 0 to 9 and third digit .0 or .5.
5	When pressed selects AZIMUTH function for display when SEL is pressed. The display is initially L or R followed by two digits. This figure is the number of degrees the aircraft is L (left) or R (right) of the runway center-line. As aircraft approaches the centerline, this reading decreases numerically to 00.
6	When pressed selects the RUNWAY COND (condition) function for display when SEL is pressed. Display is WET, ICE etc.
7	When pressed selects the RUNWAY IDENT function for display when SEL is pressed. Display is a two digit runway heading with L (left) or R (right) direction indicator such as 15L or 15R and 33L or 33R etc.
8	When pressed selects each of the above functions for display.

Figure 39 Typical MLS Auxiliary Data Display

109

of Phase III MLS. The same basic MLS-1 equipment is required;
however, a tuner/selector must be substituted for the
MLS-1 tuner. The required equipment and approach consider-
ations are illustrated in Figure 40. A typical MLS-2
tuner/selector is illustrated in Figure 41.

Although this configuration is more versatile than MLS-1,
it is not recommended for CTOL or STOL aircraft because of
the obvious operational limitations involved in approaching
a runway along a radial not aligned with the runway center-
line. To take advantage of the desirable capability of
selecting a non-standard glide slope, especially for
STOL aircraft, a configuration allowing only this selection
is more practical for USAF mission requirements. Since
this last configuration is just a simplification to the
more general MLS-2 configuration, it will not be covered
in any more detail.

To utilize the MLS-1 configuration, the MLS/ILS switch on
the tuner/selector is placed in the MLS position; the
appropriate channel, azimuth and elevation (GS) angles are
selected; and the magnetic heading of the desired azimuth
is selected on the HSI course pointer (for flight director
and/or autopilot coupler computations). The ILS mode
is then activated, and the system behaves as if the ILS
mode is engaged with an azimuth reference that need not
be zero. If a 0 degree azimuth has been selected, the
lateral axis capabilities are identical with the MLS-1
configuration and with ILS. As in MLS-1, the analog raw
deviation outputs from the MLS angle receiver are applied
directly to the existing couplers and instrumentation.
The deviations are referenced to the selected angles and
no new computer is required.

The operational limitation of this configuration is that
if an azimuth angle other than zero is selected, the refer-
enced flight path is not coincident with the center of the
runway. At some point in the approach, at an altitude much
higher than the Category I limit (200 feet), the pilot
must decouple the MLS system and, using visual ground cues,
align the aircraft with the runway. For azimuth angles
other than zero, this configuration is not capable of
Category I system performance for low approaches during
limited weather conditions.
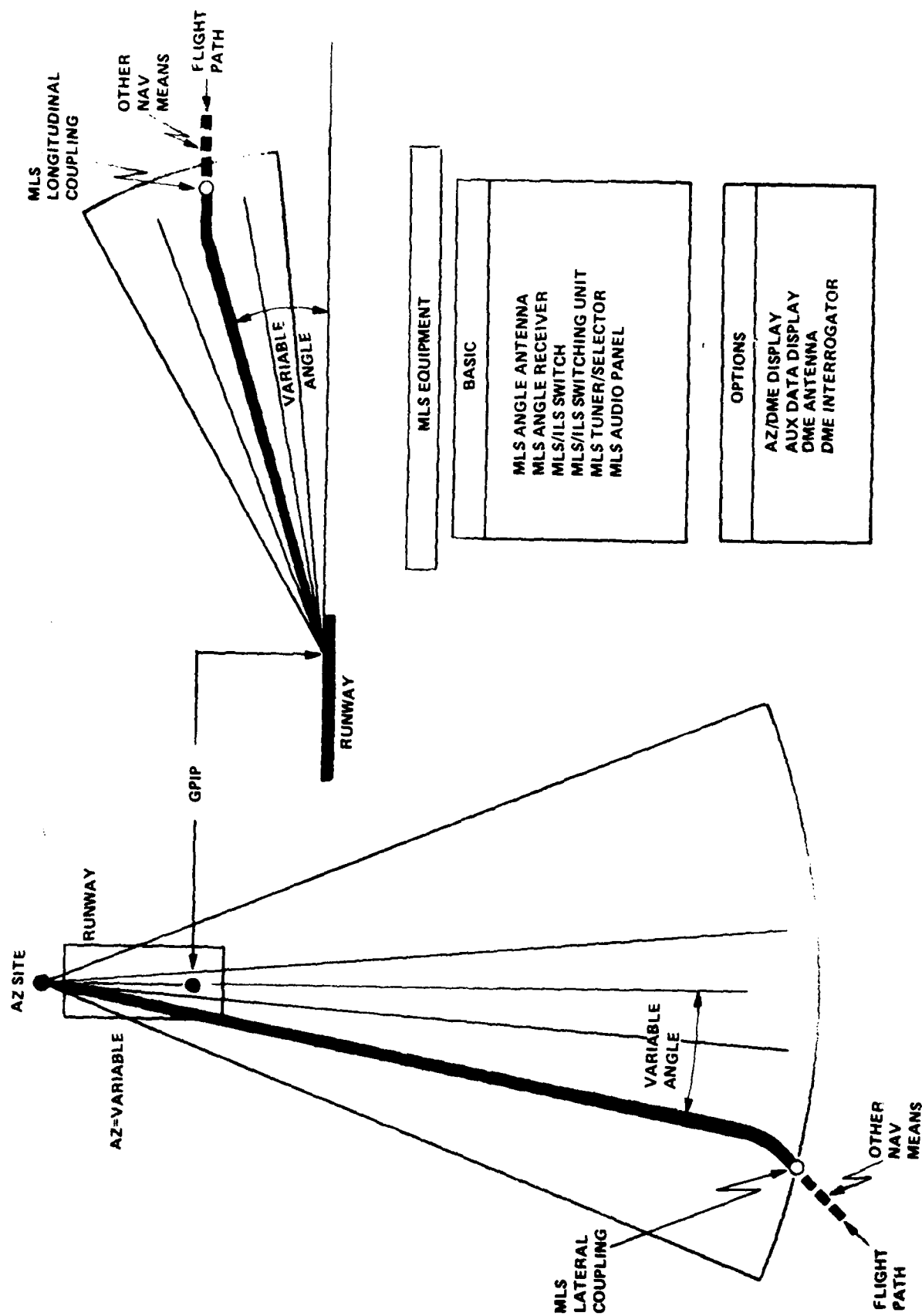
Figure 40 MLS-2 Configuration Selectable Azimuth & Elevation

MLS LONGITUDINAL COUPLING

OTHER NAV MEANS

FLIGHT PATH

VARIABLE ANGLE

RUNWAY

GPIP

MLS EQUIPMENT

BASIC

MLS ANGLE ANTENNA
MLS ANGLE RECEIVER
MLS/ILS SWITCH
MLS/ILS SWITCHING UNIT
MLS TUNER/SELECTOR
MLS AUDIO PANEL

OPTIONS

AZ/DME DISPLAY
AUX DATA DISPLAY
DME ANTENNA
DME INTERROGATOR

AZ SITE

RUNWAY

AZ=VARIABLE

VARIABLE ANGLE

MLS LATERAL COUPLING

OTHER NAV MEANS

FLIGHT PATH

111

5.75" x 6.25"
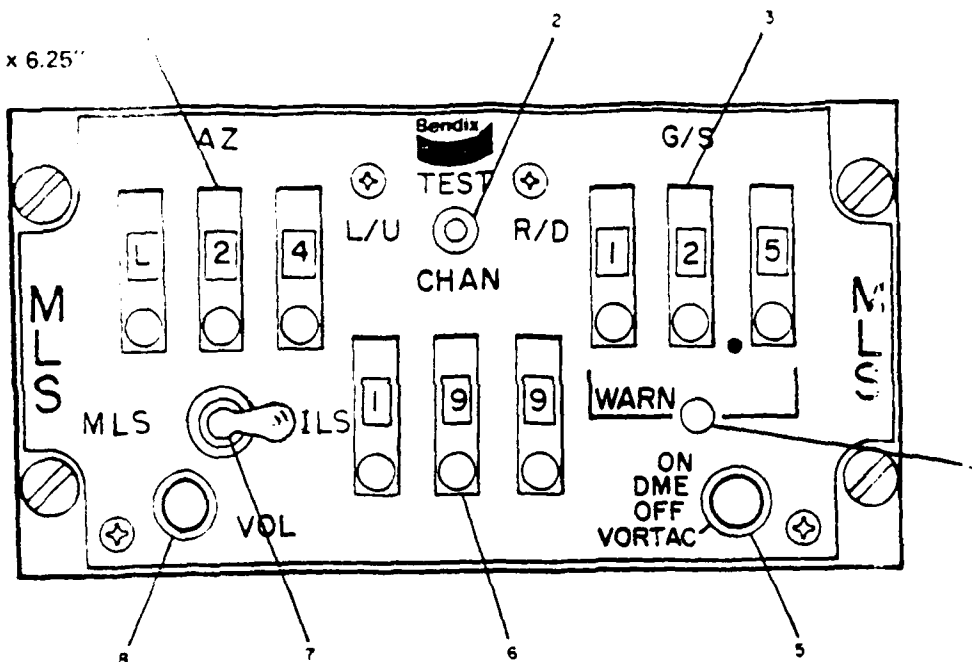
NO.	FUNCTION
1	These three pushbutton digital switches select the azimuth radial used to compute azimuth angle deviation. They range from L00 to L49 and R00 to R49 in one degree increments. Only angles between L40 and R40 are usable. Angles that exceed this range are converted to either L40 or R40. L/R means left or right.
2	Test junction that generates a L/U (left/up) or R/D (right/down) indicator deflection on the CDI.
3	These three pushbutton digital switches select the glide slope used to compute elevation angle deviation. They range from 00.0 to 10.5 degrees in increments of 0.5 degrees. Only angles between 2 and 15.5 are usable. Angles exceeding this range are converted to either 2 or 15.5 degrees.
4	If a glide slope is selected that is below 2° or the minimum selectable or greater than 15.5°, or if azimuth is selected that is greater in magnitude than ±40°.
5	This switch in VORTAC sets the DME in a standard operating mode. VORTAC removes all power to the Angle Receiver. DME OFF reserved for future use. On applies power to Angle Receiver and transfers the DME from the VORTAC mode to a precision approach MLS mode.
6	These three pushbutton digital switches select the channel that the MLS angle receiver is on. Their range is from 000-199 dedicated to commerical channels. These are coded in standard 2 of 5 coding.
7	This switch selects either the MLS or ILS approach system.
8	This 500 ohm potentiometer adjusts the audio volume of the morse code (station identification).

Figure 41 Typical MLS Control/Display Unit

Figure 38 is a block diagram of the MLS-2 configuration.
The DME function is again noted as optional, and its consider-
ations are the same as for the MLS-1 configuration. DME
is recommended to provide increased progress and situation
information, especially if marker beacons are not provided
at all desired landing sites.

4.1.2.3 <u>MLS-3 Selectable Intercept of Final Configuration</u>

This configuration is the basic MLS-1 system with: a tuner/
selector substituted for the tuner; DME equipment; and
an MLS navigation coupler. Operationally, this configuration
permits selection of intercept angles (lateral and longitu-
dinal) to the final approach via a simple, fast selection
process. The required equipment and approach considerations
are illustrated in Figure 42. A typical MLS-3 tuner/
selector is illustrated in Figure 43.

The MLS navigation coupler required for this configuration
accepts the digital outputs from the angle receiver and
DME interrogator. These outputs are processed by the coupler
in conjuction with the selected lateral and longitudinal
intercept data to provide computed deviation and situation
information to the flight controls and instruments. At
some point in time soon after the transition to the final
approach, MLS raw deviation data (equivalent to ILS data)
is coupled to the flight controls and instruments. For
this configuration, the final approach azimuth angle (0
degrees) and elevation angle are set to field nominal values
via aircraft wiring. They are not selectable by the
pilot.

Referring to Figure 43, the MLS approach set-up procedure
is as follows:

> 1) Pilot arms MLS mode by placing MLS/ILS switch
>   (ref.3) to MLS position.
> 2) Select switch (ref. 8) is placed in "CHAN"
>   position, and appropriate channel is selected
>   by manipulation of select knobs (ref. 5 and 6)
>   using display (ref. 4) as visual reference.
> 3) Select switch (ref. 8) is then placed in
>   "HDG" position, and select knobs (ref. 5 and 6)
>   are manipulated to adjust to the desired intercept
>   heading.

113

OTHER NAV MEANS
FLIGHT PATH

MLS LONGITUDINAL COUPLING

MLS LONG RAW DATA COUPLING

RAW DATA

VARIABLE ANGLE

FIXED ANGLE

RUNWAY

VARIABLE INTERCEPT POINT

GPIP

MLS LATERAL RAW DATA COUPLING

MLS EQUIPMENT

BASIC

MLS ANGLE ANTENNA
MLS ANGLE RECEIVER
MLS/ILS SWITCH
MLS/ILS SWITCHING UNIT
DME ANTENNA
DME INTERROGATOR
MLS NAV COUPLER
MLS AUDIO PANEL

OPTIONS

AZ/DME DISPLAY
AUX DATA DISPLAY

AZ SITE
RUNWAY

FINAL AZ=0°

VARIABLE INTERCEPT DISTANCE

VARIABLE INTERCEPT

MLS LATERAL RAW DATA AVAILABILITY

RAW DATA

VARIABLE ANGLE

MLS LATERAL COUPLING

OTHER NAV MEANS

FLIGHT PATH

Figure 42 MLS-3 Configuration Selectable Intercept Of Final

114

5.75" X 1.75"

Figure 43 Typical MLS-3 Tuner/Selector
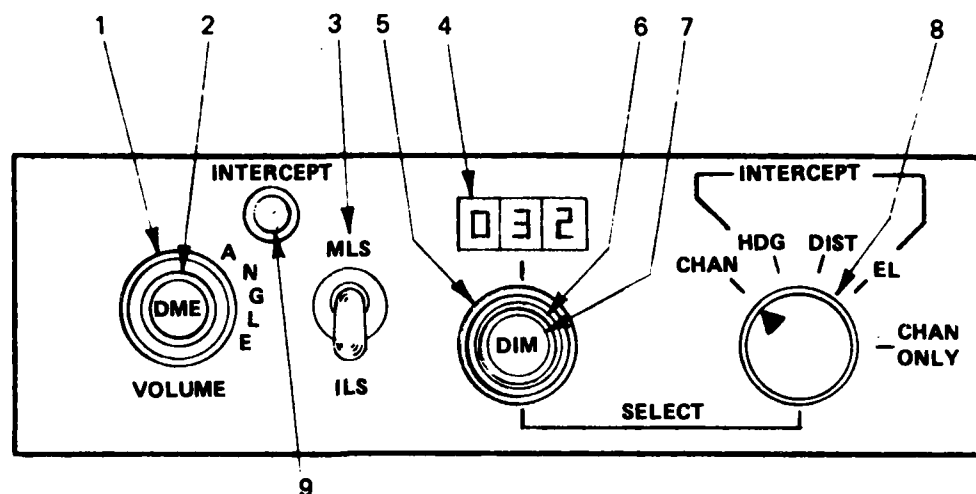
1. CONTROLS VOLUME AT MLS ANGLE RECEIVER AUDIO CODE.

2. CONTROLS VOLUME OF DME INTERROGATOR AUDIO CODE'

3. MLS/ILS SWITCH SELECTS EITHER MLS OR ILS APPROACH MODE.

4. DISPLAYS NUMERICAL VALUE OF FUNCTION SELECTED BY SELECT SWITCH.

5. CONTROLS HUNDREDS AND TENS DIGITS OF DISPLAY

6. CONTROLS UNITS DIGIT OF DISPLAY

7. DIMS DISPLAY

8. SELECTS FUNCTION TO BE DISPLAYED OR BASIC ILS TYPE APPROACH (CHAN ONLY SELECTED)

9. LIGHT WHICH ILLUMINATES WHEN MLS INTERCEPTS MODE IS ENGAGED. NOT LIT ON FINAL.

Figure 43 Typical   MLS-3   Tuner/Selector

115

(Note: Runway heading is part of ground site-
transmitted data).
4) Select switch is then moved to "DIST" position
   and the variable intercept distance in nautical
   miles (see Figure 42) to the GPIP is selected.
5) Select switch is then moved to "GS" position,
   and the longitudinal intercept angle to the
   final is selected.
6) If a "straight-in" approach (no intercept)
   is desired, the select switch (ref. 8) is placed
   in the "CHAN ONLY" position, and only the
   channel must be selected. The system will
   then behave as the direct ILS replacement
   (MLS-1).

A block diagram of the MLS-3 configuration is illustrated
in Figure 44.   Options include the MLS AZ/DME and
Auxiliary data displays.

Operational capabilities of the MLS-2 configuration are
available by: setting the "HDG" to the desired intercept
heading; setting the "GS" to the desired elevation angle;
and setting the "DIST" to a 0.0 nautical mile intercept
offset distance.

To safely perform to this level of MLS capability during
IFR conditions, automatic control may be necessary (especially
for single-seat aircraft) to make pilot workload acceptable.
This requires further study in the simulation phase.
The display requirements for the MLS-3 configuration include
the means to monitor approach progress and maintain situation
orientation while on the final approach intercept segment.
It is felt that this can definitely be accomplished using
the conventional electro-mechanical navigational instrumenta-
tion found on all present-day USAF aircraft because the
MLS intercept is merely a precise ILS intercept.

With ILS, the pilot is vectored by ATC to a heading which
will intercept the localizer beam. Due to beam width
and bank angle constraints, localizer capture normally
occurs 7 to 10 nm from the runway threshold. During the
intercept prior to capture the pilot is following the
compass card on the HSI, or is in a coupled autopilot or
flight director heading mode. The CDI and course pointer
information on the HSI provide him with his angle of

116
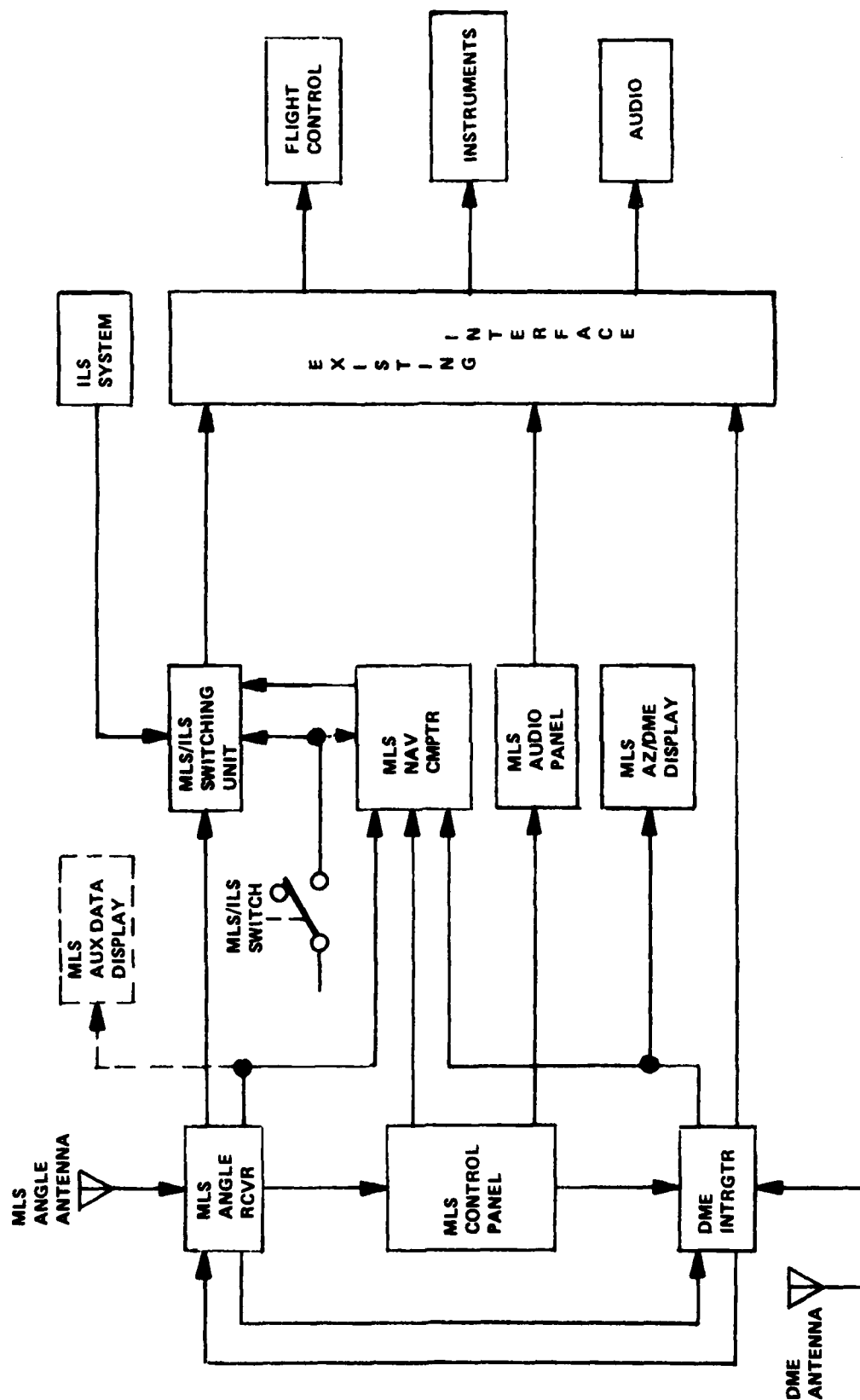
Figure 44 Block Diagram MLS-3 Configuration (Selectable Intercept)

117

intercept only. He cannot easily tell where he is in relation
to his localizer capture point because his CDI is "pegged"
to one side of the case. He also has no means of flying
an accurate ground track during this intercept leg.

With the MLS-3 configuration, the MLS navigation coupler
calculates a specific ground track from the pilot-entered
data and outputs data to the navigation displays as shown
in Figure 45. Deviation information, calculated about
the ground track, is displayed on the CDI (lateral deviation):
the course pointer is automatically rotated to the intercept
heading (desired track angle); the heading marker is
rotated to the runway heading (path anticipator); the
bearing pointer is rotated according to the relative
bearing of the aircraft with respect to the azimuth site;
and, the DME wheels are positioned as a function of the
range to the final approach transition point. In addition,
it is recommended that an AZ/DME display be provided to
allow MLS digital raw data monitoring and manual control
on a third approach segment.

Since the navigational coupler in use with this configuration
utilizes the full coverage MLS data, routinely successful
final approach captures can be achieved less than 2 nm
from the runway threshold. Because existing autopilot and
flight director ILS control law gains are normally optimized
for captures at longer ranges, it is recommended that the
MLS coupler remain coupled until the capture is complete
and the aircraft is tracking the final segment. Switchover
to the existing ILS control laws can then occur without
oscillatory performance. The actual implementation of
this logic operation and MLS control through the autopilot/
flight director computers requires a very detailed investi-
gation of the computer hardware for each specific aircraft.
Although the final result of such an investigation will
probably result in a fairly simple modification to the
autopilot/flight director computers (as discovered in
Reference 21), further analysis of this issue was not
within the scope of this study.

Control-and-display requirements in the vertical axis are
effectively identical to those in the lateral axis. On
the initial descent leg the MLS coupler calculates deviation
with respect to the desired flight path defined by the
pilot in terms of the final approach length and the initial

N

AZ/DME XMTR

30°

5.6NM

000°

40°

045°

3.1NM

RANGE-TO-TRANSITION
= 3.1nm

POSSIBLE
THIRD SEGMENT
(30° RADIAL)

BEARING TO
STATION
= 40°

NEXT COURSE =
RUNWAY HEADING
= 000°

TRANSITION
ALERT LIGHT

RANGE-TO-GPIP
= 5.6 NM

AIRCRAFT AZIMUTH
ANGLE = 30 TO LEFT

DME   AZ
5.6   L 3 0

GLIDE PATH
DEVIATION
= ¼ DOT
BELOW

FLIGHT
PATH =
5° DOWN

3 1   045

DESIRED
TRACK
ANGLE
= 45°

LATERAL
DEVIATION
= ½ DOT
LEFT
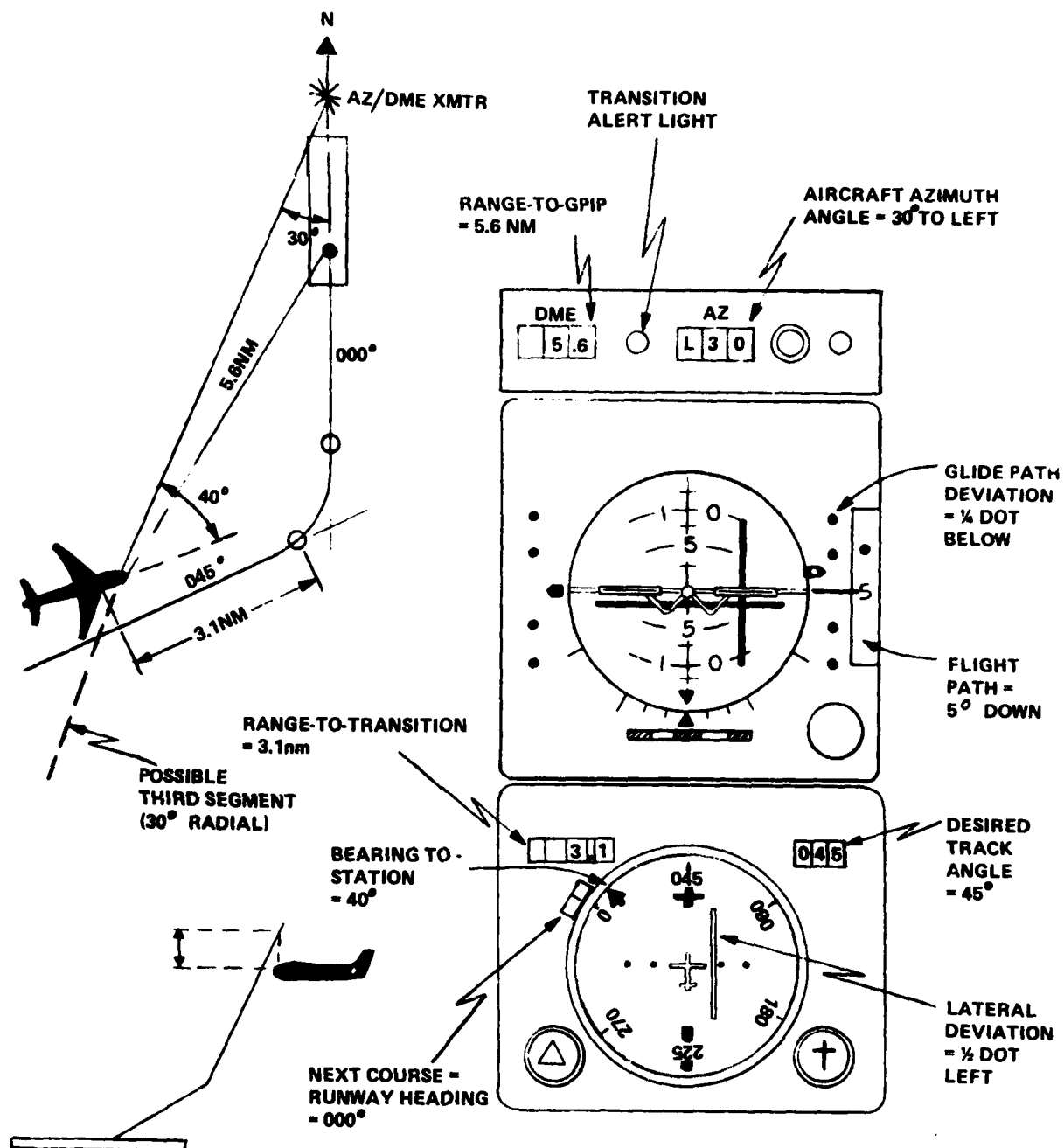
Figure 45 MLS-3 Displays

119

descent flight path angle. This deviation information is
displayed on the GSI and utilized for control. Approach
progress monitoring is provided by his altitude indicators,
rate-of-climb indicator, MLS range-to-transition indicator
on the HSI, and the range-to-station indication on the
AZ/DME display. As for the lateral control, it is recommended
that the MLS coupler remain coupled to perform the transition
to the final descent angle.

4.1.2.4 MLS-4 Complex Trajectory Configuration

This configuration is the most sophisticated and permits
selection of complex lateral and longitudinal approach
paths. A control and display unit (CDU) and an MLS navigation
computer are substituted for the tuner/selector and naviga-
tion coupler of the MLS-3 configuration. The required
equipment and approach considerations are illustrated in
Figure 46.   A typical CDU appears in Figure 47.
Detailed discussions on this CDU and other candidate units
are contained in Section 4.3.

Like the MLS-3 configuration, digitally formatted infor-
mation from the DME interrogator and angle receiver is
utilized, in conjunction with the desired trajectory data,
to provide computed deviation and situation information to
the flight controls and instruments. The desired complex
trajectory approach path is entered into the navigation
computer via the CDU. Other functions absorbed by this
unit include channel selection, antenna selection, and all
of the display functions of the MLS auxiliary data display.
An automatic data entry unit is indicated on the MLS-4
configuration block diagram, shown in Figure 48   as
an option. This unit, if required, permits rapid entry
of complex trajectory definition data.

As discussed in other areas of this report, the display
requirements for complex trajectory flight must provide
the pilot with sufficient clear information to allow him
to control his aircraft, monitor his approach progress, and
maintain orientation with respect to his desired path and
the runway. Moreover, this must be done in an integrated
manner to result in acceptable levels of pilot workload.

Flight test results from the T-39 program have indicated
that a pilot cannot perform the control function, even via

120

FLIGHT PATH

MLS LONGITUDINAL COUPLING

OTHER NAV MEANS

MLS LONGITUDINAL RAW DATA COUPLING

RAW DATA

RUNWAY

GPIP

RUNWAY

AZ SITE

MLS LATERAL RAW DATA COUPLING

MLS LATERAL RAW DATA AVAILABILITY

RAW DATA

FLIGHT PATH

OTHER NAV MEANS

MLS LATERAL COUPLING

MLS EQUIPMENT

BASIC

MLS ANGLE ANTENNA
MLS ANGLE RECEIVER
MLS/ILS SWITCH
MLS/ILS SWITCHING UNIT
DME ANTENNA
DME INTERROGATOR
MLS CONTROL/DISPLAY UNIT
NAV (COMPLEX TRAJECTORY) COMPUTER

OPTIONS

AUTO DATA ENTRY UNIT

Figure 46 MLS-4 Configuration Complex Trajectory

121

5.75" x 6.25"
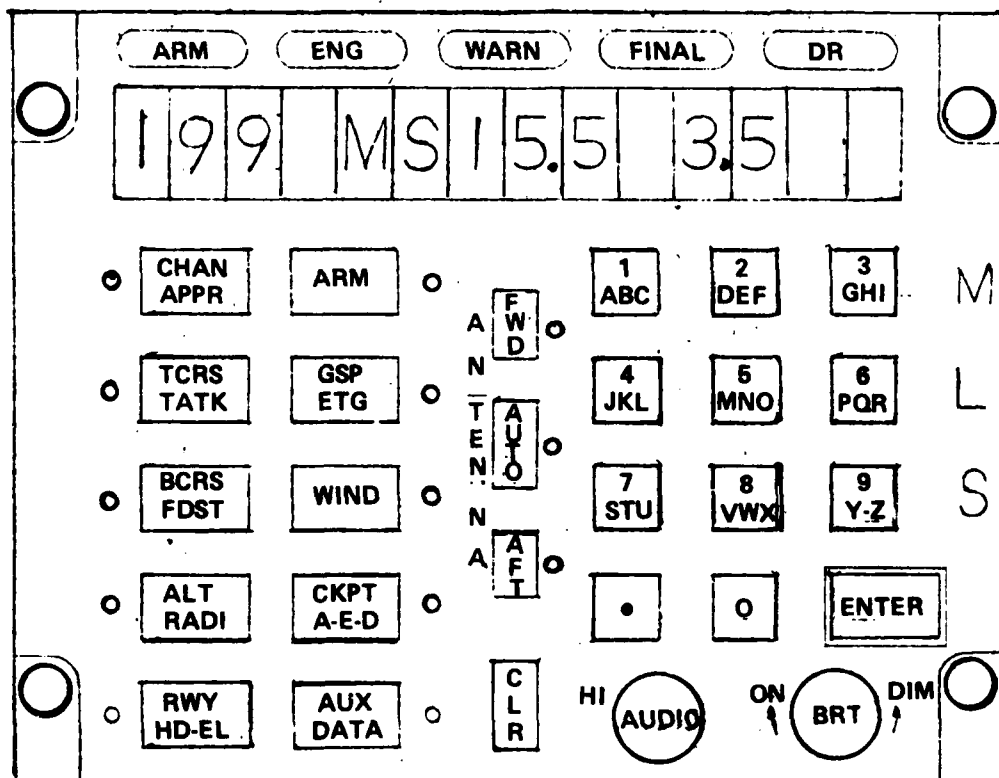
Figure 47 Typical MLS Control/Display Unit
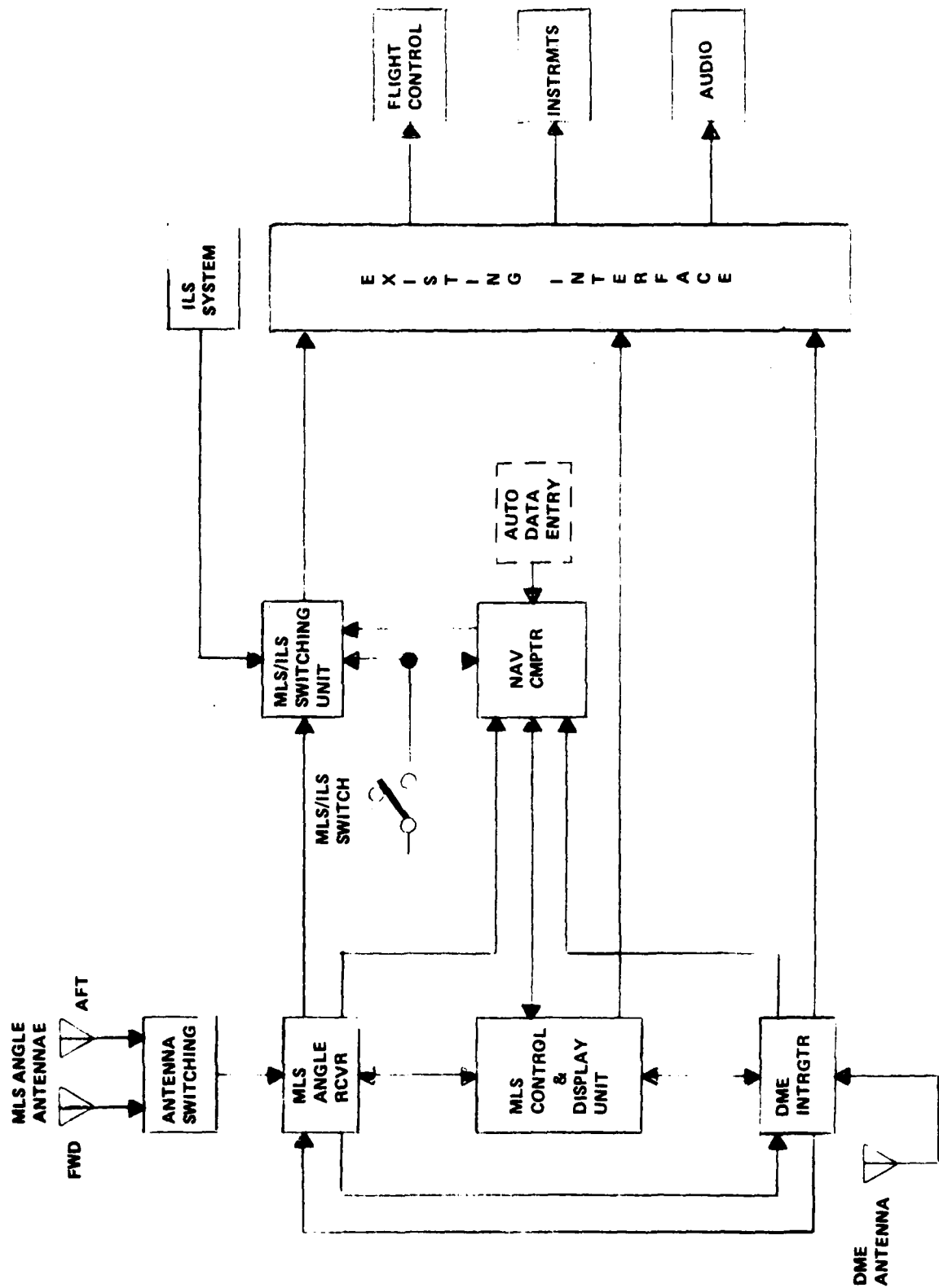
Figure 48 Block Diagram MLS-4 Configuration (Complex Trajectory)

the flight director, and still adequately monitor the complex approach and continuously assess his rapidly changing situation with present electro-mechanical instrumentation. Performance of this task is even doubtful when the aircraft is under automatic control. For this reason, Section 4.2 has been dedicated to defining candidate complex trajectory flight display presentation for a state-of-the-art electronic color CRT indicator.

Attempts to improve the electromechanical instrumentation for complex trajectory flight should continue, however, for the simple reason that the vast majority of present-day aircraft contain only this type of equipment. To expect that fleets of aircraft will be modified to add new electronic navigational instruments and their associated symbol generation computer hardware appears to be quite unreasonable. For this reason, a minor modification to the display scheme discussed previously for the MLS-3 configuration (see Figure 45) should also be considered as a candidate for complex trajectory flight. This scheme involves displaying the following parameters on the following instrumentation:

- Desired track angle -- On HSI course pointer. The MLS navigation computer automatically slews the pointer to the course of the lateral segment. It smoothly rotates about the prescribed circular arc during the transition from one lateral segment to another.

- Lateral deviation from desired track -- On HSI course deviation indicator. The MLS navigation computer drives the CDI during the complex portion of the approach and the MLS angle receiver drives it during the final approach segment.

- Range-along-track-to-GPIP -- On HSI DME readout. The MLS navigation computer drives the readout based on the distance from the aircraft to the touchdown point assuming the aircraft flies along the selected path.

- Relative bearing-to-station -- On HSI or RMI bearing pointer. The MLS navigation computer drives the pointer to indicate the aircraft's

bearing to the azimuth ground transmitter.

- Path anticipator -- On HSI preset heading marker. The MLS navigation computer automatically slews the marker to the magnetic course of the next lateral segment.

- Vertical deviation from desired glide path -- On ADI (or HSI) glide slope indicator. The MLS navigation computer drives the GSI during the complex portion of the approach and the MLS angle receiver drives it during the final approach segment.

- Flight path angle -- On ADI flight path angle scale, if one exists. Although not essential if the existing cockpit does not contain a suitable display of this parameter, it is especially useful during multi-segmented descents. It is driven from the MLS navigation computer.

- Azimuth angle and range-to-GPIP -- On the MLS AZ/DME indicator. The AZ/DME display is driven directly from the MLS angle receiver and thus presents a continuous readout of raw data information throughout the approach.

- Transition alert -- On the MLS AZ/DME indicator. This shall be provided in the form of an amber light which shall flash for approximately 15 seconds to alert the pilot of an upcoming segment transition. It shall be driven from the MLS navigation computer.

4.1.3   Miscellaneous Interface Requirements

Certain aircraft may require special interface units when MLS is incorporated. These units are as follows:

- AC-DC Converter -- This unit is required only if inadequate DC or no DC is available for the MLS system.

- Digital/analog converter -- This unit is required

to interface digital range data to analog-controlled displays if a navigation coupler or computer is not provided.

- Remote RF Head -- This unit transforms the microwave frequencies to L-band prior to subjecting the signal to long cable runs. This allows use of relatively inexpensive flexible coaxial cable with acceptable line loss. For small aircraft not requiring long cable runs, an RF head integral to the receiver eliminates the need for this unit. Large aircraft configured for the MLS-3 and MLS-4 configurations are the only candidates for this unit since they may require front and aft antennas.

- Antenna Switching Unit -- This unit is required for aircraft which use fore and aft antennas to maintain signal coverage during complex trajectory flight. Without this unit, antenna "masking" during turns can result in invalid data for significant periods of time (typically 10 seconds for T-39 approaches). This results in a dead-reckoning mode and a consequent degradation in control accuracy.

4.1.4   Considerations Regarding Replacement of Existing Equipment

Certain aircraft utilize flight director and/or autopilot couplers which may not be adequate for MLS flight path control. These should be replaced with updated units if MLS is incorporated. An example is the autopilot installed aboard the C-130 aircraft. Presently, the operational manual for this aircraft recommends either not using or closel monitoring the autopilot below 1000 feet. If this system is left intact, incorporation of a complex MLS system is not justifiable.

If, in a particular aircraft, an MLS system is required and cockpit space is not available for adding MLS components (particularly displays), equipment may be substituted which is compatible with the MLS and existing systems. If certain existing instruments do not have provisions to

126

accept required MLS information, and other instruments in
the USAF inventory do, then a substitution may be recommended.
An HSI with a remotely-slewable course pointer for display
of complex trajectory situation is an example of a unit
which falls in this category.

4.1.5 Mode Annunciation and Logic Switching Considerations

As part of the pilot's display information during coupled
approaches, most aircraft installations provide means to
annunciate the associated ILS modes. Examples are : LOC,
LOC ARM, LOC ENG, LOC TRK,GS, GS ARM, GS ENG, and GS TRK.
In general, the annunciations are controlled by logic
generated in the couplers (autopilot or flight director)
which utilize raw data in conjunction with other data to
switch from one submode to another (e.g., LOC ARM to LOC
ENG). Since a straight-in MLS approach is equivalent to
an ILS approach, no change in the label of these annunciations
is contemplated for an MLS retrofit. Although it may be
argued from a human factors standpoint that ILS mnemonics
is certainly not the ideal annunciation for MLS flight,
it is felt that its use would be acceptable to minimize
retrofit costs if no safety of flight problem is created.

Pilot selection of an MLS approach versus an ILS approach is
different in that for MLS he selects a channel and for
ILS tunes a frequency. It would be very unlikely for the
pilot to mistake one procedure for the other. For aircraft
installations which include both MLS and ILS, the second part
of the pilot procedure in selecting an MLS straight-in
approach is to position the MLS/ILS switch to the MLS
position. Failure to perform this task, however, may not
be immediately apparent if no annunciation change is made.
Under certain coincidental conditions of a nearby ILS
frequency being tuned or an ILS receiver failure, pilot
error in not selecting the MLS switch position could
result in the pilot mistakenly flying active, or even inactive,
ILS data instead of MLS data. This could definitely compro-
mise safety of flight.

Due to the above argument, it is felt that some form of
MLS annunciation is required. As an alternate to all new
annunciation mnemonics, a small light can be installed
on the instrument panel to indicate the selection of MLS.

For the four MLS configurations, the final approach utilizes raw MLS deviation data for control and for existing coupler logic to control annunciations. The MLS-3 and MLS-4 configurations utilize navigation couplers and computers, respectively, to control the flight path prior to final. The normal ILS logic within the existing couplers will be armed when the MLS approach mode is selected. When the aircraft is controlled via the MLS navigation coupler or computer within the levels of the existing ILS threshold logic, the existing ILS coupler will automatically engage and consequently cause the MLS coupler to disengage.

MLS annunciations prior to final are accommodated by the CDU (see Figure 47, top of panel) for the MLS-4 system. In the MLS-3 system, a light is provided on the tuner/selector (Figure 43, ref. 9) to annunciate that the intercept mode is active. Logic is provided by the MLS navigation coupler to illuminate the light when the MLS mode is first selected and to extinguish it when the final is engaged.

4.2   Electronic Display Candidate Configurations

Presenting information to the pilot in a coordinated, readily interpreted format while exploiting the full capabilities of the MLS system requires a display medium having flexibility and capacity beyond that possible with electro-mechanical indicators. The CRT currently is the most logical candidate although LED and/or LCD matrix panels may replace the CRT in the future. The proposed display concepts would apply in any case. Use of a programmable color CRT display will provide an avenue to easily evaluate numerous variations of display parameters leading toward an optimum combination. A description of 2-D and 3-D displays are included herein and these displays are proposed as candidates for further evaluation.

4.2.1   Implications of the Shift from Electromechanical to Electronic Displays

The shift from electromechanical displays to electronic displays for primary command, control, performance, and navigation information constitutes a potential for a quantum jump in the effectiveness of cockpit displays as a result of the following:

- It is possible to present much more information on electronic displays.

128

● There is much more freedom for the display designer,
  particularly in the opportunity to associate a
  number of display elements moving with respect to
  each other.

It is important in this shift to have the early generations of
electronic displays be designed as well as possible. Traditions
and expectancies form rapidly and later modifications in design
principles may be difficult to accomplish.

There are some characteristics inherent in electromechanical
flight display design which can carry over to limit or distort
what might be done with electronic displays. Two of these are:

● The erroneous assumption that we have been pushing
  the limit in the amount of information which can
  be processed by a pilot.

● The erroneous assumption that the pilot's task can
  be simplified by reducing the amount of information
  displayed to him.

The first assumption is erroneous in that it applies only to
electromechanical displays as we have known them. By the use
of advanced pictorial quality, the speed with which a pilot
can derive information from a display can be increased
enormously.

The second assumption is based on a misinterpretation of the
pilot's task. Figure 49   shows a diagrammatic representation
of the pilot's task in terms of information flow. The left half
of the diagram shows information which must be processed by the
pilot in flying an aircraft. By providing a display allowing
him to assimilate each of the parameters on that left side,
his task is relatively simple. If any of those parameters is
not displayed, the pilot's task is made more complicated since
he must now derive that parameter by mental differentiation,
integration, or other relatively complex processes.

In short, the only way to simplify the pilot's task is to provide
him all the information he needs and do it in such a way that
the information is readily perceived and intepreted. The
electronic display can help this process greatly because it
provides great design freedom. This design freedom can result
in much faster information transfer to the pilot, particularly
through allowing a number of display elements to move relative
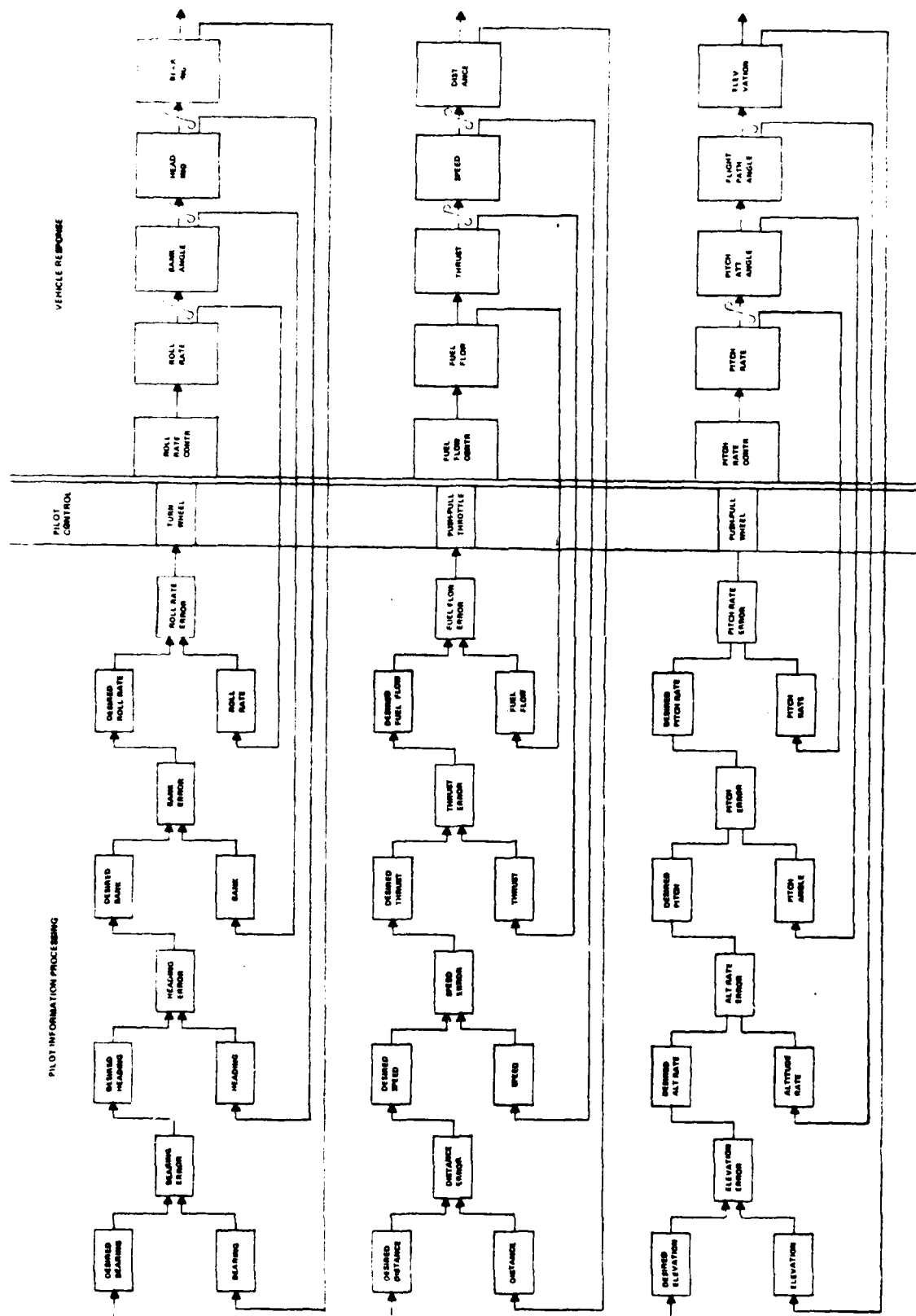
Figure 49 Information Flow Diagram Depicting The Processing Required For Manual Control

130

to each other in concert.

4.2.2 Baseline Rationale for the Selection of Displayed Parameters for the Electronic Display

The fundamental result of the Microwave Landing System relative to cockpit display systems, is to inform the pilot of his position at any moment in time relative to a specific path in space extending up from the runway on which he intends to land. For information synthesizing purposes it is not nearly enough to provide that data in two dimensions (right-left or up-down). In each of these dimensions he needs to see the trend of relative motion of that line in space and see how his present flight vector relates to that trend. In mechanical display systems the pilot has been forced to derive large portions of situation and control information which has added greatly to his mental workload at just the time when he is in the most critical and dangerous phase of all normal flight operations.

For these reasons the design of the proposed 2D and 3D displays is intended to maximize the pilot's ready interpretation of his situation. That situation is further defined precisely as being the relation of his flight vector in horizontal and vertical dimensions to the vector of his desired path in those same dimensions.

The horizontal relations between actual and desired flight vectors used by the pilot to decide what heading he should fly, and that in turn relative to actual heading, is used to decide what bank angle he needs to achieve or maintain. The display of these parameters needs to be associated in a manner enhancing ready interpretability. For purposes of achieving a path in space it is desirable for the pilot to see desired track angle in addition to heading. Heading should also be considered part of an attitude display, particularly during flight involving large pitch angles.

The vertical relations between actual and desired flight vectors are used by the pilot to decide what flight path angle to fly, and from that to decide on the momentary pitch attitude. The pilot has seldom had flight path angle information available to him in the past and has usually had to approximate it by using a displayed rate of descent.

131

For each of the control parameters extending from the characteristics of desired path through space back to attitude rate, the pilot must either see or derive three aspects; (1) desired value, (2) actual value, and (3) the direction and magnitude of the difference between them (error). Wherever a display can provide all three, the pilot's workload will be reduced correspondingly.

The third dimension of the pilot's task is the control of velocity, for which he usually uses air speed during an approach. In the interest of having the display help the pilot in his total task, the integration into the display of the information used for this control task will further alleviate the pilot's workload.

It is the thesis of the present design rationale that no pilot ever suffered from having too much information available, but he has often suffered as a result of having too little information. In those cases where it has been considered that a pilot had too much information, it can usually be shown that the real problem was bad display design in which some information occluded other information and thus reduced the amount available. Every pilot wants as much information about his control situation as is possible as long as it can be used on his own terms. That means having the information when he wants it and not having it intrude when he does not. That is the real challenge for display design.

4.2.3 Symbology and Colors for the Candidate

As stated previously, the use of electronic displays driven by digitally processed information, has made possible a quantum jump in the ratio of display-provided information to pilot-derived information. In fact the set of possible information that can be provided to the pilot has become so large that the limit is now determined by display interpretability rather than signal processing and space for the instruments.

Common Reference Lines

The most general aspect of the design of the displays for interpretability has been that of tying together visually those parameters which, in an information sense, belong together. Consider first the reference lines for reading attitude, track, airspeed, altitude and flight path angle. Whenever these parameters are shown by separate instruments it takes a separate

132

indication to establish the frame of reference for reading each parameter. In both the 2-D and 3-D displays, as shown in Figure 50, only two lines are required to provide a common "reading" reference for all of these displayed variables. To provide maximum area for the "map" situation symbol on the 2D display, the pitch/path angle and the airspeed altitude references are offset downward shown as bulges which grow out of these reference lines. This latter technique eliminates the requirement for additional discrete elements in the display. By extending these lines toward the edges of the display this reference tends to become a part of the "background" in the sense of Gestalt psychology, and thus does not compete visually in the perception of "figure" in the display. They tend to behave much like dividers in the windshield through which the pilot is looking to see the world beyond.

Attitude Display

Consider the attitude scale provided to show pitch angle and bank angle relative to the common reference. For the following symbology descriptions refer to Figures 51 and 52. Only two or three of these lines will appear at any one time - enough to enclose the reference symbols for fuselage centerline extension and flight path angle. These pitch lines are simple lines extending across the display space so that one line will appear as only one visual object. By that fact they reduce the amount of information in each line to a minimum from the standpoint of the pilot's visual information processing and consequent clutter.

The coding of the pitch lines has been chosen to simplify the amount of information which must be shown and to speed up interpretability. Solid lines are used each ten degrees for negative pitch angles and dashed lines each ten degrees for positive angles. Short indica marks are inserted at two degree intervals. A heading scale, traveling along the horizon line as part of attitude (as well as being a part of situation), is provided for the smooth interpretation of control at large pitch attitude angles. Experiments have shown that when attitude indicators become more pictorial in nature pilots begin to expect movement along the horizon with heading change.

A unique operational feature of the horizontal reference line is provided relative to the attitude-scale aircraft angle of attack increases from 0° the reference line separates to form a

133
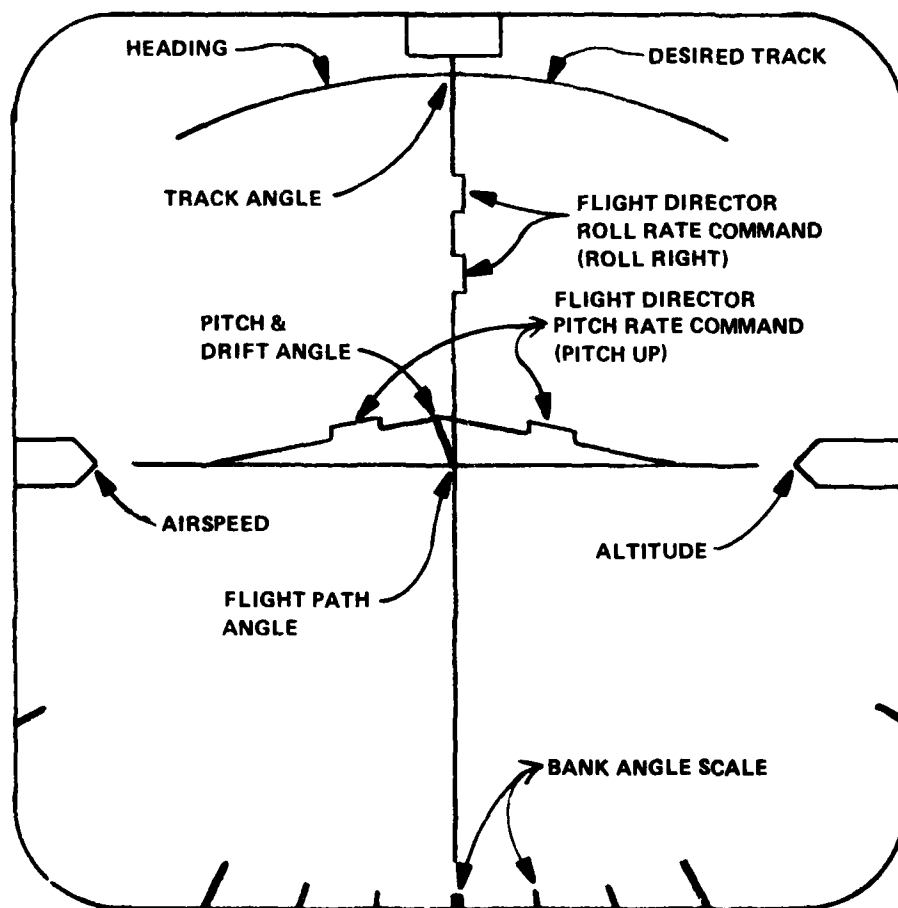
Figure 50 Common Reference Lines For Candidate Displays
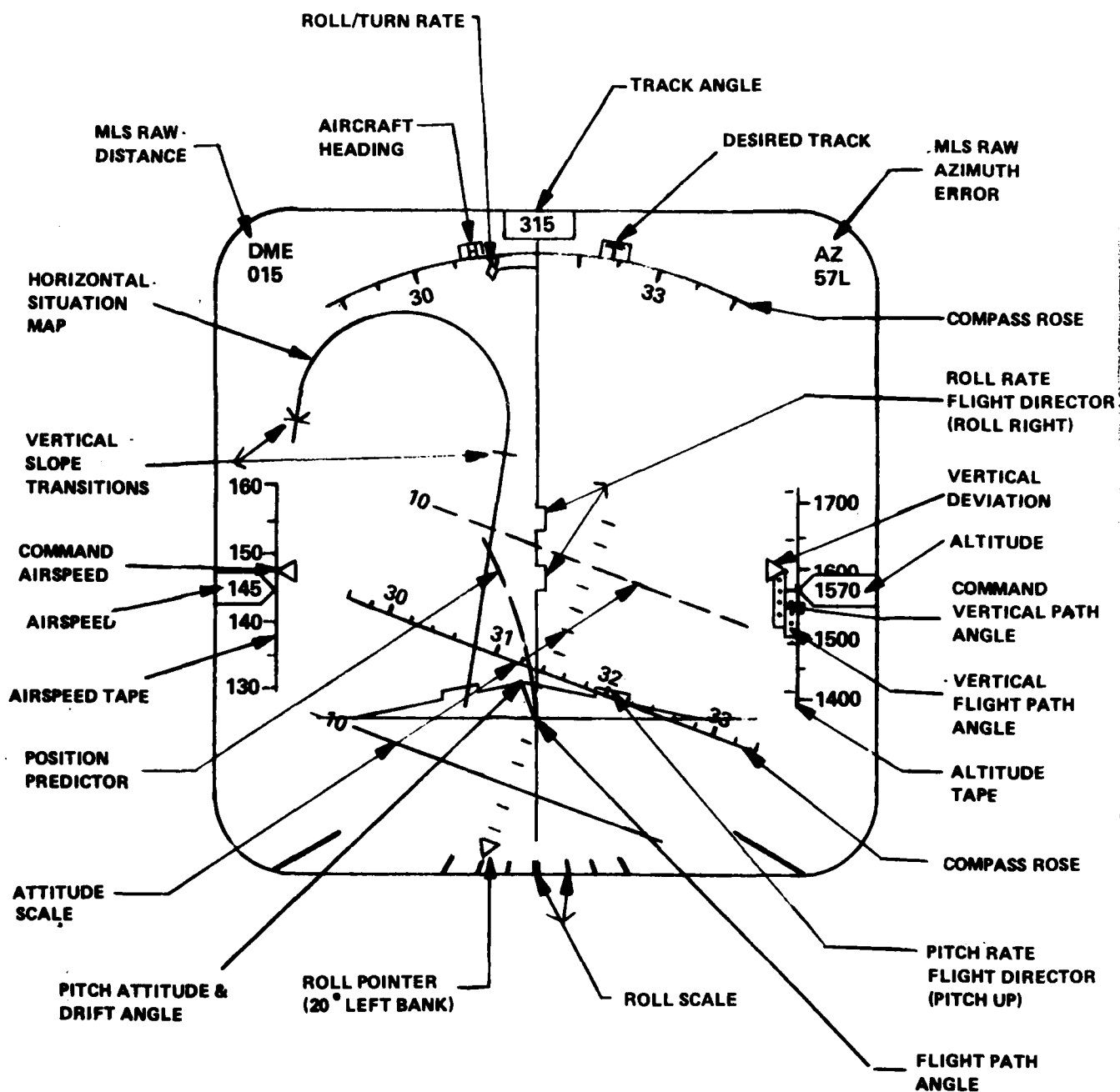
Figure 51 2D Display Symbology

135
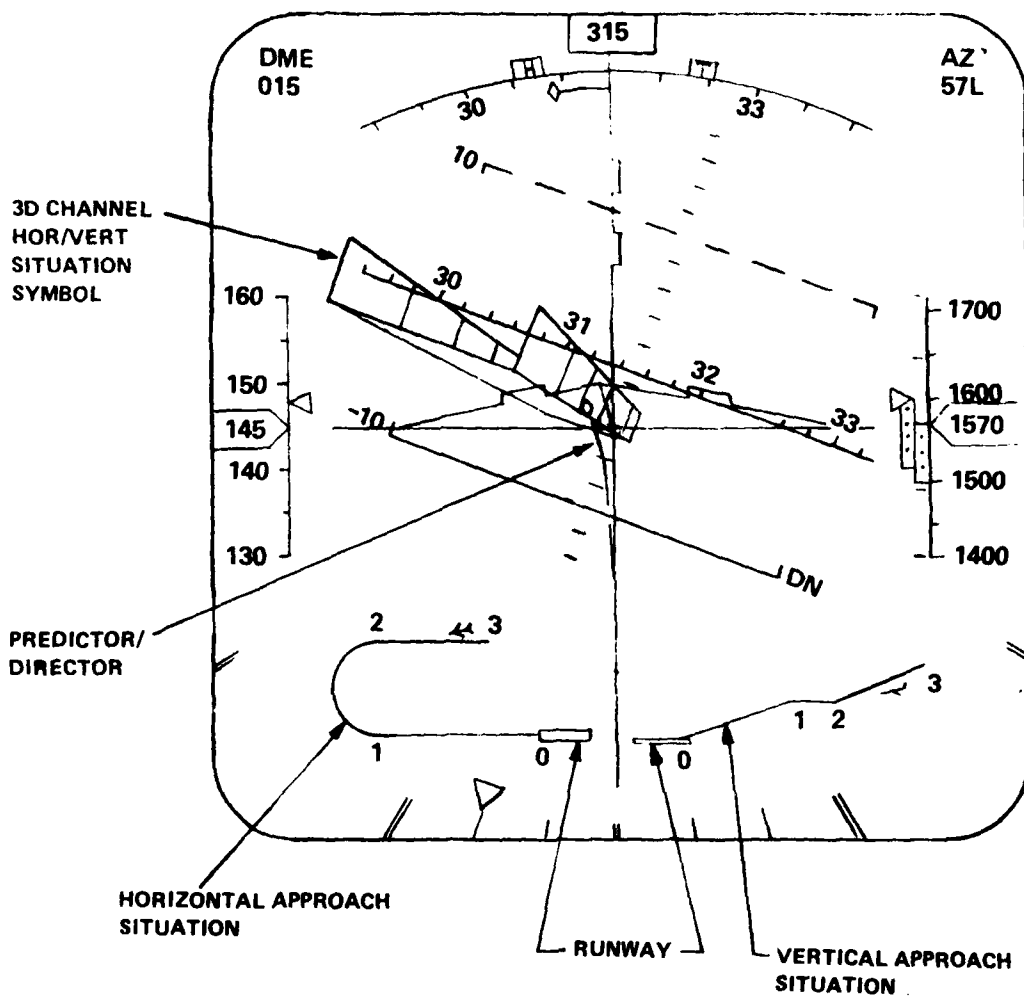
Figure 52 3D Display Symbology

136
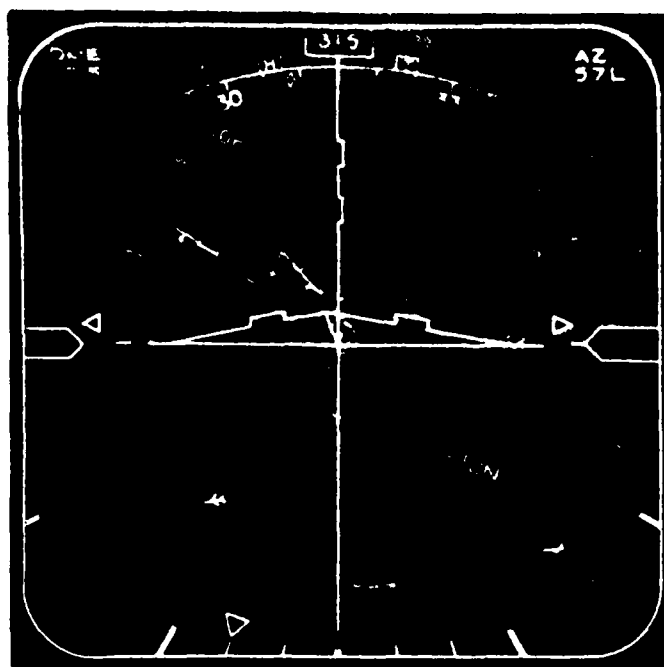
Figure 54 3D Color Display
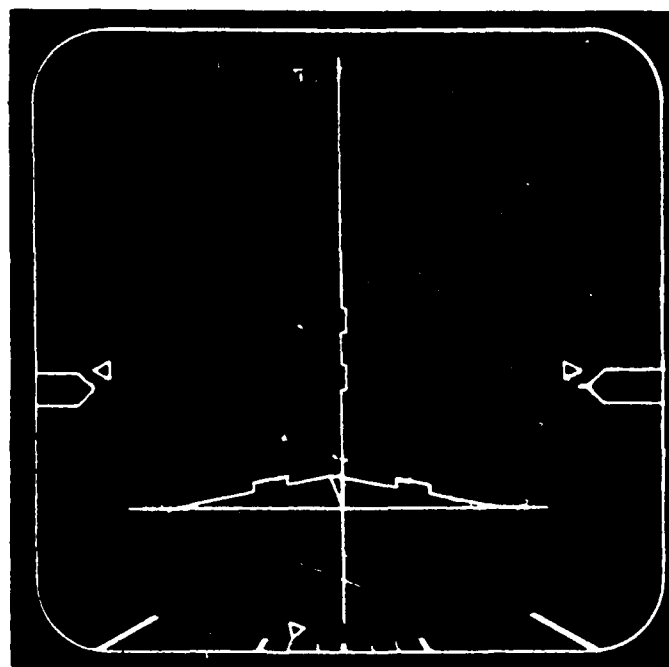
Figure 53 2D Color Display

triangle resembling a delta wing aircraft as viewed from the rear. The horizontal base of the triangle, read against the attitude scale, indicates vertical flight path. The apex of the triangle indicates pitch attitude. Thus, the height of the triangle is proportional to angle of attack. The apex is also displaced laterally as a function of drift angle and thus provides a qualitative indication of that parameter. Roll attitude is indicated by observing this symbol relative to the attitude scale. Actual roll angle is also read via the roll pointer against the fixed roll scale.

Airspeed/Altitude

A moving tape-type scale is used for both airspeed and altitude on the left and right side of the display, respectively. A pointer-shaped box serves as both an index against which the scale may be read and an enclosure for a corresponding digital readout.

Command airspeed is indicated by a second pointer moving with that scale adjacent to the selected value. Thus, airspeed error is indicated by a displacement between the two pointers. The command pointer is limited at the upper and lower extreme of the scale whenever the error exceeds the visible portion.

2D Horizontal Situation

In the case of the 2D display, mapping of the horizontal situation is passed on a track-up display with range and azimuth defined up from the center of the reading reference. At its upper end, the reference constitutes a lubber line for reading ground track against the moving compass rose. A digital readout of track is also provided. Aircraft heading and desired track are indicated on the compass rose with specific pointers. In a display sense, the airplane is always moving up this line in its momentary direction. During turns, the situation rotates under this line. With range and azimuth defined in display space, the horizontal components of the path of the desired vector can now be shown directly in the same coordinates. That portion of the horizontal view of the MLS approach path, within the scaling of the display, is presented in a map situation format with symbols provided along the path to cue the pilot to vertical slope transitions as the approach proceeds toward touchdown. The actual scaling of the display may be variable in the MLS terminal area depending upon the type and phase of approach. A lateral position predictor is provided in this

139

same display space to indicate further aircraft positions as a function of bank angle, drift angle and airspeed. Each sector corresponds to the next 5 seconds of flight, thus expanding the pilot's comprehension of the horizontal situation and providing an alternate means by which the pilot can couple asymptotically to the desired path.

Digital readouts of raw MLS distance and azimuth error data are provided in the upper corners of the display. This data can be used to continuously cross check the map situation during the various segments of a complex approach. It will also correspond in distance to touchdown and cross track angular error during final.

3D Horizontal/Vertical Situation

The 3-D display uses the same display mapping for attitude as the 2-D. For position information, the 3-D uses up-down and right-left as angles and depends upon the use of perspective to create the illusion of depth as the third dimension for mapping distance. The perspective treatment is limited to the depiction of a channel into which the aircraft is flying. The amount of distance which can be shown in this manner is limited and at present is expected to correspond to the distance that will be covered in 20 seconds at current velocity.

During the final phase of the approach, a runway image will appear in full perspective at the far end of the channel and will appear to grow and vary in shape as a function of distance to touchdown and lateral and vertical displacement relative to the derived path.

A combined lateral and vertical predictor is provided to indicate the future aircraft position as a function of bank angle, drift angle, airspeed and rate of change of vertical flight path. By centering the circular end of this symbol within the far end of the channel, the aircraft will couple to the derived flight path. Thus, its use is an alternate to the flight director bulges in the reference lines.

A plan and elevation view of the specific MLS approach is displayed with the current aircraft positions shown, thus providing the pilot with an overall evaluation of his status during the entire approach.

140

4.2.4 Vertical Flight Path Angle/Deviation

The most interpretable place for showing relative and quantitative flight path angle is at the altitude lubber line. Closest to the altitude scale is a segmented tape-like symbol which emanates from the lubber line position either up or down. Each segment represents one degree of flight path angle.

To the left of the segmented flight path angle display is a triangular pointer which indicates vertical deviation from the desired path. Growing out of the center of that triangle is a segmented tape which shows the slope of the commanded path. Again each segment represents one degree. With the efficiency of shared references, the pilot can readily see the comparison of actual and desired vertical position and the comparison of actual and desired vertical flight path angles. All these parameters are read at the point at which he reads his altitude. In this form they can all be read clearly while providing a minimum of interference with the rest of the display.

Roll/Turn Rate

Emanating from the vertical reference line close to the compass scale is a thin tape which displays turn rate. At the active end of the turn rate tape is a green diamond which displays roll rate. When roll rate is at zero, the green roll rate diamond is at the active end of the green turn rate tape.

The compass rose at the top of the display is a major element in pilot situation control. With regard to this scale, he is flying (tracking) straight up the display. In the 2-D display features to the right or left of his path are shown in the same relative position as in the outside world. Thus there are some very important reasons for having these major display elements in just this orientation.

Designing the moving compass scale to achieve these major relationships induces a cost in pilot reading errors. A moving scale such as this must violate one or more principles of human engineering design. One such principle is that a progression of numbers should increase from left to right. Another is that when things move they should be arranged so that movement to the right or clockwise means an increase.

It is readily apparent that a moving scale must violate one or the other of these principles if it is read at the top. And this one does. The consequences as stated in human engineering design terms is that violation of the principles leads to operator error. In a series of studies in 1956 and 1957, published in 1957 and 1958, Ritchie and Bamford established that the moving card compass does indeed lead to pilot control reversals. They also published an experimentally determined way to alleviate the problem.

That method of reducing the number of control reversals from the use of the moving card compass involved the association of the place at which the compass was read with a display of turn rate and quickened turn rate. By putting them in the relations in which they are shown on the 2-D and 3-D display, they reduce to a marked degree the number and duration of control reversals.

The reasons these two elements reduce control reversals is that they respond much more quickly than heading to aileron movement and their direction is compatible with the direction of aileron control movement. Being in the relation shown to the heading lubber line they act like a vernier and they allow asymptotic roll outs to specific headings by pointer matching.

The presence of these two displayed elements provides additional correlated flight parameters for those occasions when the pilot does systematic cross checking to verify that some of his data inputs are accurate.

Further rationale and details of the various symbology are contained in Appendix

Summarizing The Systematic Use Of Color On The Displays

One color is used in the display to represent the aircraft reference, i.e., those things which remain fixed or nearly fixed relative to the bezel. The crossed reference lines are made as long and as continuous as possible to function similar to window pane dividers - you look past them to see objects. This accounts for most of the use of yellow in the display.

Of the two remaining colors, green has been assigned to attitude and those parameters that belong in the time frame of attitude.

142

Red has been assigned to those functions dealing with position.

In some cases,there has been a departure from strict adherence to these rules in order to minimize confusion. The scale on the bottom of the display quantifies bank angle and strictly speaking should be green. In the case of the 2-D display,the proximity to the pitch reference lines is such that use of another color makes the display less confusing. Yellow was chosen since the scale is fixed on the bezel and is related to the aircraft reference. Yellow was chosen for a similar reasons for airspeed command and the vertical deviation scale.

There are two scales and two colors used for compass information. The one along the horizon is green because heading belongs as a part of attitude control, especially at large pitch angles where it is necessary to include the third dimension in attitude reference to allow smooth control based on straight forward interpretability. The red compass scale at the top of the display is that color because it is involved in position control as opposed to attitude control. That may best be emphasized by noting that the primary mode in which this display is read is the direction of the ground track. The marker for heading is in a secondary position on this scale.

The channel needs to be visually separable from the yellow aircraft reference lines and from the green attitude display. Since it is involved with aircraft position, the choice of red is consistent and also provides the necessary color separation.

4.2.5   The 2-D/3-D Display Concepts

In the color 2-D display shown in Figure 53, the vast amount of information displayed to the pilot has been achieved by having a dual mapping of the same display space in conjunction with the availability of color right-left and up-down in display space is defined as azimuth and elevation for the green set of attitude data and as azimuth and range for the red set of track data.

The systematic use of color and other design techniques has been employed to minimize interference between these two mappings of the same display. It is expected that simulator evaluations will verify the merits of this approach.

143

An alternate concept, the color 3-D display, utilizes
a second major design approach to preserve the
consistent mapping of the display space into azimuth and eleva-
tion and to map distance by creating the illusion of depth
in the display. The most powerful single tool for generating
the illusion of depth is linear perspective.

This approach to display design has been implemented as shown
in Figure 54. In the same display space,the fixed
reference is shown in yellow, the attitude display in green,
and the perspective picture of the commanded flight path
(with predictor) in red.

The form of the major perspective feature is the channel concept,
which was examined experimentally by Kraiss and Schubert in Ger-
many, and by others in this country. Perceptually,it presumes
that the pilot will position his aircraft in height even with
the top of the channel sides and laterally over the center line
of the channel. The predictor originates as if from a point
on the fuselage slightly below eye level. The channel extends
to a point in space corresponding to approximately 20 seconds
of flight time. The path predictor will extend through the
same time figure.

Two total view situation displays are provided to enable the
pilot to assess his overall position relative to the complete
approach profile.

4.2.6 The Relative Advantages And Disadvantages Of The 2-D And 3-D Displays

In comparing the 2-D and the 3-D displays, one must look first
to what is maximized in each and what is compromised most in
each.

In the case of the 2-D display,the pictorial view of the
horizontal situation is maximized. With most of the display
space available for the purpose,it allows him to visualize
directly the situation in its geographical coordinates relative
to his own velocity vector. He sees in some detail the
situation in which he will operate in the next several minutes.
He has the information required to put himself and other
features into conceptual relation with his path over that time.

The 3-D display maximizes the visualization of the situation to be encountered in the next 20 seconds. As such, it is something of an extension of the attitude control loop. With that extension, the pilot should find his attitude control task easier and more effectively performed.

The comparison of 2-D and 3-D is that the former gives the best aid to situation interpretation and path planning while the latter gives the best aid to attitude control and short-time path control.

The major theoretical problem for the 2-D display is that it combines azimuth-elevation and azimuth-range coding in the same display space. It does that to maximize the sensitivity of situation display.

The major theoretical problem for the 3-D display is that its effect depends on creating the illusion of depth within the azimuth elevation coordinates. There is a limit to the useful perception of this depth, and a limit to how accurately the pilot can derive the information he needs for control. An attendant cost is the considerable amount of computation which must be done to present the channel in perspective in real time at the required up-dating rate.

The 3-D display evolves naturally out of control engineering while the 2-D comes more naturally from task analysis and operational pilot comments

4.2.7   The Choice of "Inside-Out" Displays

The "inside-out" configuration for attitude is recommended for both the 2-D and 3-D displays for the following reasons:

  • Complex Display Simplification

Each of the proposed displays incorporates two crossed lines serving as a common reference for several primary displayed variables. This characteristic has greatly simplified the display when compared to other methods of displaying an equal number of parameters.

The common reference lines cannot be used with an "outside-in" format. In "outside-in" the coordinates of the cockpit and instrument panel represent earth-reference coordinates

145

for display-mapping purposes. Each displayed parameter must have its scale fixed somewhere in this space and have a moving element in that space denote the indexed value of the parameter. It seems necessary then for each scale to have a relatively independent coordinate system, thus increasing the number of display indices when compared with the complex displays as shown.

The opportunities for simplification through common references is illustrated in Figure 50. Note that the pitch rate and roll rate commands of the flight director are a part of the two reference lines for reading attitude. No separate indications are required, thus reducing clutter or visual noise.

In a similar manner the horizontal reference line splits into two parts to show both pitch attitude and flight path angle. The center of the pitch reference also moves laterally with drift angle.

The resultant image pictorially resembles a delta wing aircraft whose "nose to tail" projected height corresponds to angle of attack and whose lateral nose displacements is a function of drift angle.

- Other ways to obtain control-and-display compatibilities

There are indeed a number of experiments in which some advantages have been shown for a moving airplane or "outside-in" concept. However, there are two main disadvantages to this concept. One is that the displays have tended to be quite ambiguous from the standpoint of interpretability. The other characteristic is that they depended upon motion in the display to confirm that the control was moved in the right direction.

In the proposed displays, it will be seen that great care has been taken to keep the display from being ambiguous. There can be very little doubt on the part of an experienced pilot about the major elements of motion relations.

One element of these displays, the moving scale compass, has been shown experimentally to be misinterpreted occasionally resulting in control reversals. On both the 2-D and the

146

3-D display a turn and roll rate symbol is displayed at the reading reference for the compass. Both roll rate and turn rate respond more quickly to aileron control movement than does the heading scale. The two rate symbols, therefore, set the direction for aileron control movement and are compatible with the control in motion relations.

- Compatibility with the Head-Up Displays

Head-up displays are already common in high performance aircraft. As their technology matures and costs decrease, much more wide-spread usage can be expected.

It is inherent that head-up displays are used while the pilot is looking at the outside world and simultaneously observing images reflected off the combining glass. It is necessary that they be inside-out to fit into this framework of use. A predictable penalty will result in performance if pilots who have an inside-out reading habit developed by the use of a head-up display are provided an outside-in head down attitude display.

- Existing "Inside-Out" Perceptual Habits

Most aircraft flying in this country today have "inside-out" attitude displays. Thus, at present most trained pilots have developed a reading habit to fit the inside-out format. Displays involving competing reading habits should not be mixed without a cautious consideration of the penalties.

- Compatibility with All-Attitude Indicator

A.l-attitude indicators in service today employ the "inside-out" concept. Even if desired, it appears to be quite impossible to build an "outside-in" attitude indicator which will operate through all attitudes with smooth linear motion. The reason is that the pilot has a fixed viewing position in cockpit space and thus loses one degree of freedom in that space. The mapping of attitude onto display space for outside-in assumes that the coordinates of the cockpit represent earth-reference space. Since he has lost a degree of freedom in that space he will sometimes see his representation as flying toward himself, sometimes away, etc.

4.2.8   Extension of the 3-D Channel Near End to the Display
         Extremes

The 3-D display is a complex display designed to provide a
great deal of information to the pilot which is critically
useful to him. The several elements of the display must be
carefully designed to provide the information required by the
pilot and to do that without unnecessarily increasing his
perceptual workload.

One of the ways to calculate the amount of information in
a display is to count the number of discrete elements shown.
The effect of visual noise on the part of the pilot follows
somewhat the calculation of "bytes" first used by Shannon
and Weaver.

The simples calculation of bytes of information presumes that
the elements are uncorrelated. In matters dealing with dis-
plays upon which humans can impose meaning, the calculation
of information transmitted can be influenced to a phenomenal
degree. The Gestalt psychologists showed some fifty years
ago that human perceivers can organize a scene into percep-
tual units by grouping and handle a large number of now-
related elements as if they were one unit. Another way to
say this is that pictorial quality in a display can serve
to make a massive change in the apparent information-handling
ability of the perceiver.

In the 3-D display there are three different sets of elements
sharing the same display space: (1) the reference lines
representing the viewing frame, (2) the pitch lines which
allow attitude angles to be read, and (3) the channel.
The channel has been carefully designed to provide the illusion
of distance looking into the display. By providing the
illusion of distance the channel allows the depiction of
future desired path changes.

The illusion of distance suffers somewhat if the channel
ends somewhere in front of the pilot and there is no good
clue for him to be able to judge how far away it is. By
being some distance away it also tends to be seen as an
object, and as such not necessarily a three-dimensional
reference.

If the lines of the channel extend to the limits of the

148

display space, there is less doubt on the part of the pilot
about what his relation to it is. Like the difference between
being on the runway and approaching it, there is a good bit
of difference in the accuracy and assurance of perceived
relations.

It is probably true that extending the channel at the near
end will reduce the apparent perceptual workload in inter-
preting it. The pilot will tend to see it as a whole as one
of the references for flight. If it is only out in front
of him he will likely take more time to interpret it in
relation to himself, and there will be more of a tendency
to examine its parts separately to evaluate its orientation
relative to himself. That adds up to more perceptual workload.

There may be some details (e.g. apparent thickness of stroke
lines) which will change the predicted perceptual response.
Simulation of the display in the extended form should provide
a test of this hypotheses and allow a comparison with the
truncated version.

4.3   Electronic CDU Candidate Configurations

Three MLS CDU candidates are described in the following paragraphs which integrate all of the control functions required for MLS complex trajectory flight. These units have been designed for mounting on either the center pedestal or side console. Each candidate is adaptable to accept and display data from an automatic entry source. For manual operation, each candidate requires approximately 50 key strokes to enter all the frequency and geometry data required to fully define a complex trajectory consisting of three lateral and two vertical path segments. Less key operations are required for trajectories with fewer segments. Less key operations are required for trajectories with standard turn radii.

These units combine the functions of the Phase III MLS control panel and auxiliary data panel. By integrating the channel select function in the CDU an availability problem could result. This will depend upon a reliability comparison of the CDU and a simple channel selector. No such analysis has been made for this study.

The two major human factor problems associated with the T-39 CDU have been corrected with these designs. These are as follows:

- A keyboard has been substituted for the non-detented incremental encoder knob to provide faster and more positive data insertion.

- Logic has been provided to visually prompt the pilot and lead him to his next piece of data to be entered.

This has essentially eliminated the need to memorize procedures and has eliminated the resultant loss of place due to distractions. This, in turn, results in less errors and/or the time-consuming reinitiation of a procedural sequence.

Of the three designs, Candidate Number 3 appears to be the most attractive. It provides for relatively easy operation and utilizes pilot relatable data and push-button terminology. Simulation is required, however, to

150

determine if any of these designs is truly acceptable from
a pilot workload aspect. It is doubtful that any of these
(or any other design for that matter) are useable for
manual data entry in a single-seat aircraft.

4.3.1 CDU Candidate Number 1

A candidate MLS configuration for data entry, described
herein, has been devised to provide maximum capability and
versatility with minimum equipment. The functions previously
associated with the MLS Control Panel and the MLS Auxiliary
Data Panel are all handled by a new CDU shown in Figure 55.

A wide variety of approaches can be accommodated including
U's, intercepts, Z's, multiple segments, direct and straight-
ins as shown in Figure 56.   Data defining the particular
approach path required by the MLS computer can be retrieved
from internal storage; or entered manually via the CDU.
The system can be adapted to accept approach path data
received via the MLS ground to air data link or any other
ground-to-air link such as the newly proposed Discrete
Address Beacon System (DABS), or entered via an automatic
card/tape reader.

To simplify the manual entry of data, a procedure has been
established requiring a minimum of pilot activity. Several
standard type approaches have been established and are
recognized by the computer via a pilot selected identification
code. Depending upon the particular approach type, other
pilot inputs are made to adjust the intercept angle,
final distance, turn radius, and other parameters as necessary.
Table   6   summarizes the inputs required for each type
approach. A maximum of ten input parameters are required
to tune, identify, and define the most complex multiple
segment trajectory handled by the system. The most simple
straight-in approach requires only two. These parameters
are defined as follows:

      CHAN   - Channel code associated with
                                      frequency selection for a
                                        particular MLS installation

      APPR   - Approach type identifier
                                        (see Figure 2 & 3). Numerics
                                        in code indicate vertical path
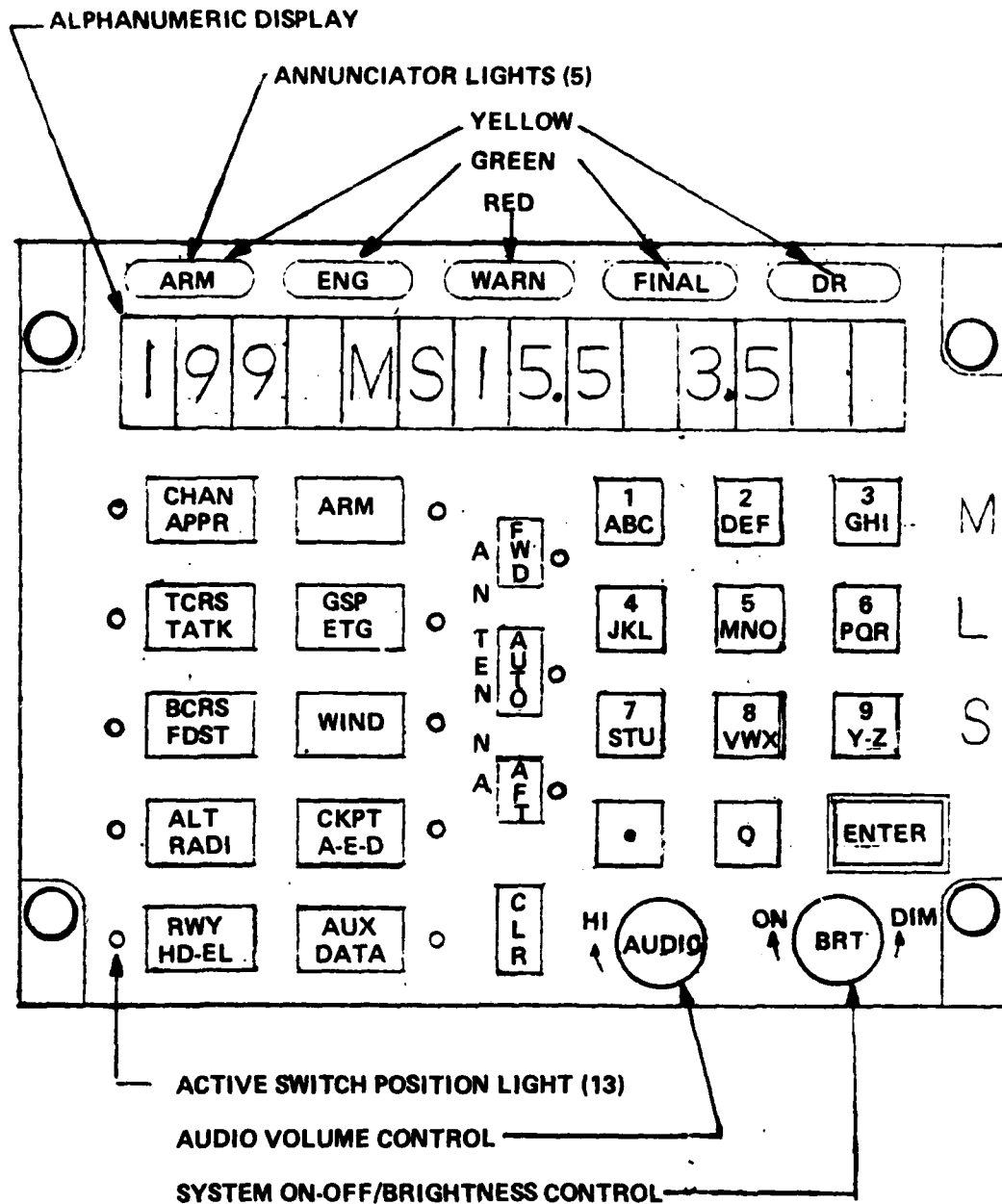
Figure 55 MLS CDU Candidate Number 1
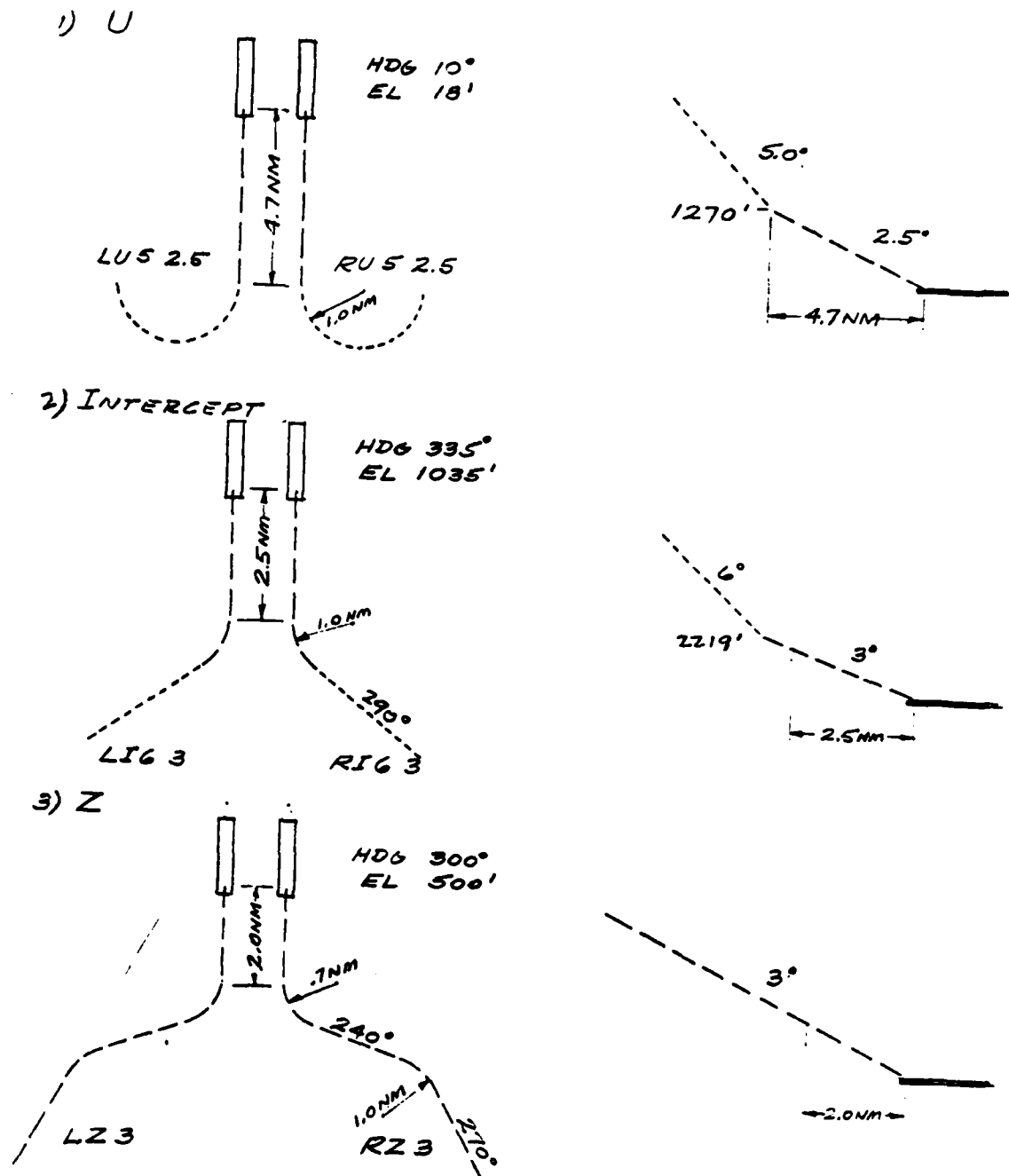
152

1) U

HDG 10°
EL 18'

4.7NM

LU 5 2.5   RU 5 2.5

1.0NM

5.0°

1270'   2.5°

4.7NM

2) INTERCEPT

HDG 335°
EL 1035'

2.5NM

1.0NM

290°

LI6 3   RI6 3

6°

2219'   3°

2.5NM

3) Z

HDG 300°
EL 500'

2.0NM

.7NM

240°

LZ 3   RZ 3

1.0NM

270°

3°

2.0NM

Figure 56 Typical Approach Types

153

4) MULTIPLE SEGMENTS

HDG 30°
EL 720'

4.0 NM

.7 NM

TATK

5.7°

2632'

340° .9 NM 255°

.1

TATK

1995'

3°

2 IMS 5:3

4.0 NM

8.4 NM

IMS 5:3

5) DIRECT

HDG 45°
EL 407'

6°

2000'

3°

D 5:3

5.0 NM

6) STRAIGHT IN

HDG 45°
EL 407'

3.5° FIELD NOMINAL

S
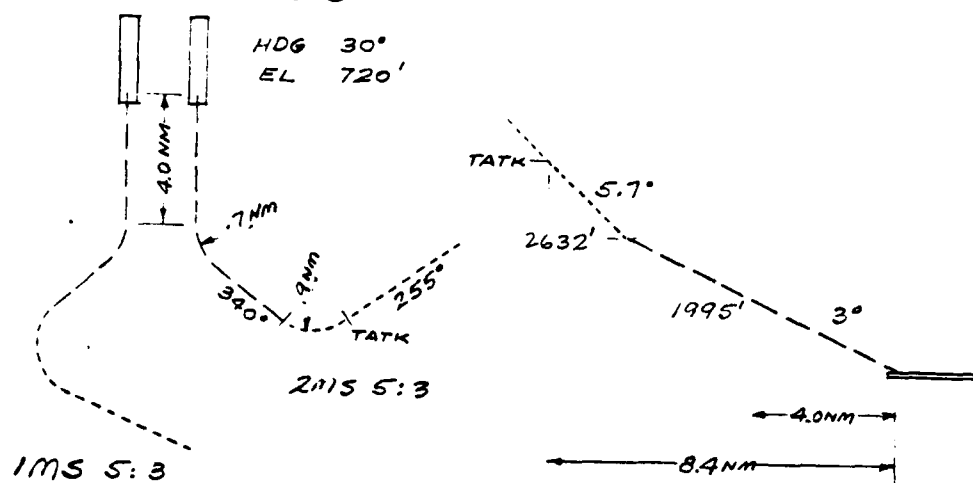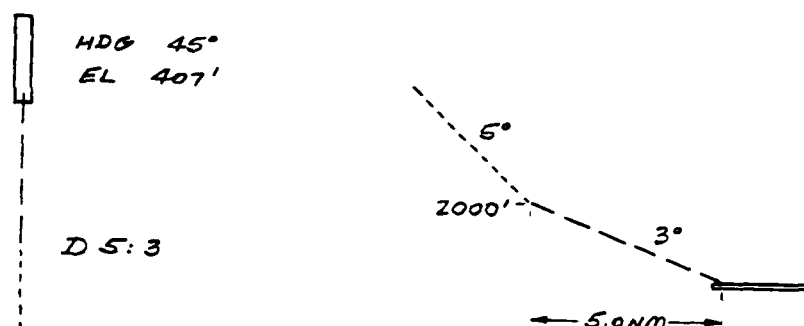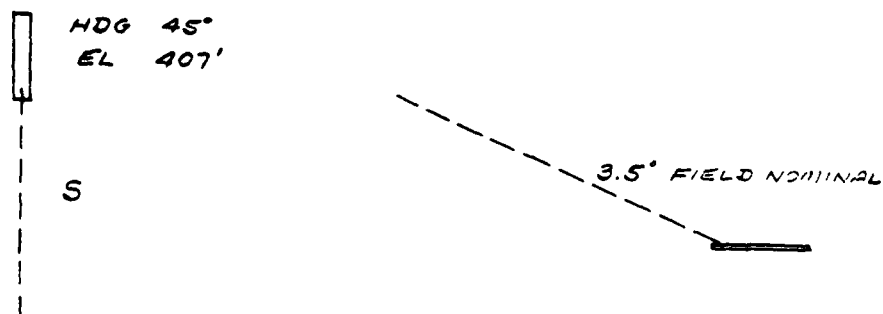
FIGURE 3 - APPROACH TYPES

Figure 56 Typical Approach Types - Continued

154

TABLE 6

Input Parameters to Define Approach

APPROACH TYPE	SWITCH POSITION	CDU DISPLAY			
		INITIAL			SET
1)	CHAN/APPR	SET	SET	199	RU 5 2.5
	TCRS/TATK	NR	NR	NR	NR
	BCRS/FDST	NR	SET	NR	4.7
	ALT/RADI	SET	SET	1270	1.0
	RWY HD/EL	SET	SET	10	18
2)	CHAN/APPR	SET	SET	163	RI 6 3
	TCRS/TATK	NR	NR	NR	NR
	BCRS/FDST	SET	SET	290	2.5
	ALT/RADI	SET	SET	2219	1.0
	RWY HD/EL	SET	SET	335	1035
3)	CHAN/APPR	SET	SET	131	RZ 3
	TCRS/TATK	SET	NR	270	NR
	BCRS/FDST	SET	SET	240	2.0
	ALT/RADI	NR	SET	NR	1.0 0.7
	RWY HD/EL	SET	SET	300	500
4)	CHAN/APPR	SET	SET	129	2MS5.7 3
	TCRS/TATK	SET	SET	255	8.4
	BCRS/FDST	SET	SET	340	4.0
	ALT/RADI	SET	SET	2632	0.9 0.7
	RWY HD/EL	SET	SET	30	720
5)	CHAN/APPR	SET	SET	115	D5 3
	TCRS/TATK	NR	NR	NR	NR
	BCRS/FDST	NR	NR	NR	NR
	ALT/RADI	SET	NR	2000	NR
	RWY HD/EL	SET	SET	45	407
6)	CHAN/APPR	SET	SET	085	SI 3.5
	TCRS/TATK	NR	NR	NR	NR
	BCRS/FDST	NR	NR	NR	NR
	ALT/RADI	NR	NR	NR	NR
	RWY HD/EL	SET	SET	45	407

* NR -- Not Required

155

angles (two maximum)

TCRS   – Course of first MLS segment
following enroute navigation
for three (3) segment approach.

TATK   – Distance from start of the
first transition within MLS
coverage to GPIP

BCRS   – Course of base leg to final

FDST   – On course distance of final
approach segment

ALT   – Transition altitude from
first vertical descent path to
final descent path

RADI   – Radius of turns (two selectable
maximum)

RWY HD   – Heading of MLS runway

RWY EL   – Runway elevation at GPIP

- ● SYSTEM DESIGN PARAMETERS

    - A maximum of two vertical paths and three
      horizontal segments may be selected with the
      system

    - Resolution established for selectable parameters
      is as follows:

Heading/Track Angles	1°
Vertical Path Angles	0.1°
Along Track & Final Distance	0.1 NM
Turn Radii	0.1 NM
Transition Altitude	1 FT
Runway Altitude	1 FT

156

- All control & display functions required for
  MLS operation can be accomplished via one
  CDU including channel select, auxiliary data
  monitoring, antenna control, etc.

- All test and maintenance information is provided
  via the CDU switches and display

● CDU DESCRIPTION

The CDU in conjunction with eight instruments, is the
pilot's total interface with the MLS system. Its operation
is described in the following paragraphs. Following the
description, step by step operational examples are given
for minimum and maximum complexity approaches.

- Data Input/Verification Switches, Controls and
  Indications

Within the group of 10 pushbuttons on the left side of the
CDU, nine are provided to accommodate the data input/
verification function. All are electronically interlocked
such that only one may be active at a time. With the
exception of the AUXILIARY DATA switch, any one of the nine
in the active state may be deactivated by repushing that
switch or any of the remaining eight. When all nine switches
are deactivated, the alphanumeric display reverts to its
normal operating mode.

- AUX DATA Switch

The AUX DATA switch, when pushed will deactivate any of
the remaining eight. However, multiple pushes of this
switch are necessary to cycle through the various data
which then appears sequentially on the alphanumeric display.

This switch is also used in conjunction with the ENTER
pushbutton to accept data from an external source such as a
card or magnetic tape reader.

- ARM Switch

Activating the ARM switch places the system in a state of
readiness to engage once the received MLS signal strength
is adequate for operation. Several conditions have to be

met before it's possible to ARM such as 1) all input data
must be in memory for the particular approach contemplated
2) the computer must have satisfactorily solved the navigation
equations 3) all data link information must have been received.

- Alphanumeric Keyboard

The Alphanumeric Keyboard and decimal key are used to manually
enter all required MLS approach data as described elsewhere.
As presently envisioned, the full alpha keyboard is not
required, only approximately the nine being used. The computer
can recognize the single push of a specific key and deter-
mine whether a numeric or alpha is required at a particular
location in the input sequence. At this point in the program,
however, it is recommended that the potential for full
alphanumeric capability be available to accommodate changes
that may occur during the simulation and/or flight test
phases. As an example, in conjunction with the AUX DATA
switch, specific navigation, flight, test, etc. data could
be called up to be displayed by keying in the necessary
alphanumeric code.

- CLR Switch

The Clear switch is used to correct data entry errors
and/or modify stored data by clearing the unwanted character(s)
allowing new data to be entered. A single rapid push of this
switch (held less than 1 second) will clear one character
to the left of the cursor as seen on the alphanumeric
display. Holding the switch in longer than 1 second will
clear all data to the left of the cursor.

- ENTER Switch

The ENTER switch is used to enter the data, set up on
the alphanumeric display, into memory. It is also used in
conjunction with the AUX DATA switch to enter data from an
external source if the system is so equipped.

By keying in a specific approach identity code and pushing
ENTER,the computer will search memory to extract the required
data. If the data is contained in memory, this will eliminate
the necessity of manual entry.

- Annunciators

Five annunciator lights are provided to indicate ARM,
ENGage, WARNing, FINAL approach, and Dead Reckoning status.
Additional annunciators may be provided along the left
and right edges of the panel if simulator and/or flight
tests prove their necessity or desirability.

- Antenna Control

Three pushbuttons are provided to control the antenna
mode. Normally, when the system is turned ON, the antenna
automatically enters the AUTO mode. In the event of an
actual or suspected failure of the AUTO mode, the receiver
may be switched to the Forward or AFT antenna using the
appropriate pushbutton. Electronic interlocking will allow
only one of the three switch positions to be active at one
time.

- Audio Control

The AUDIO Control, consisting of two concentric knobs,
is used to adjust the volume of the MLS angle and DME
receiver audio identifying codes.

- On-Off/BRT Control

The Brightness Control with its integral ON-OFF Switch
allows the pilot to activate the system and control brightness
of all lighted elements on the CDU.

- Alphanumeric Display

A choice of alphanumeric display will be based upon the
following preliminary requirements:

- Characters   Alphanumeric
  - Number   14 nominal
  - Height   0.3" approx.
- Display size   4 5/8" W x 5/8" H
- Type   LC, Incandescent, or LED
- Color   White
- Brightness   Sunlight readable

- Operational Features

All switches and keys are momentary type with positive feel. Hold and interlocking functions as described later, are accomplished electronically.

"Jewel" lights are provided adjacent to each control switch to indicate when a particular switch has been activated.

- Approach Parameter Selection Ranges:

Initial Vertical Descent Path Angle	$0\text{-}19.9^{\circ}$
Final Vertical Descent Path Angle	$1\text{-} 9.9^{\circ}$
Course/Heading	$0\text{-}359^{\circ}$
Final Approach Distances	1.5-15 NM
Transition Along Track Distance	1.5-30 NM

PILOT ACTIVATED SW.	DISPLAY	COMMENTS
ON	ALL LIGHTS & TEST CHARACT-TERS ON FOR 2-3 SECONDS	ANTENNA TO AUTO
	& THEN CHAN/APPR SW. ON	CHAN/APPR LIGHT ON
	C H A N A P P R	
0	0 - A P P R	CURSOR(-) BLINKS AT NEXT INPUT LOCATION
8	0 8 - A P P R	
2	0 8 2 A P P R	
S	0 8 2 S -	
ENTER	BLANK FOR ½ SECOND	COMPUTER SEARCHES FOR NOMINAL VERT. PATH FOR STRAIGHT IN APPROACH RCVD. VIA DATA LINK
	0 8 2 S 3.5	
RWY HD·EL	H D G E L E V	CHAN/APPR LIGHT OUT
0	0 - E L E V	
4	0 4 - E L E V	
5	0 4 5 ° E L E V	
4	0 4 5 ° 4 -	
0	0 4 5 ° 4 0 -	
7	0 4 5 ° 4 0 7 -	
°	0 4 5 ° 4 0 7 '	
ENTER	BLANK FOR ½ SECOND	
	0 4 5 ° 4 0 7 '	READ BACK FROM MEMORY
ARM		ARM ANNUMCIATOR ON
RWY HD·EL	NORMAL OPERATION	RWY HD·EL LIGHT OUT

EXAMPLE OF CDU OPERATION
STRAIGHT IN (MINIMUM COMPLEXITY)

PILOT ACTIVATED SW.	DISPLAY	COMMENTS
ON	ALL LIGHTS AND TEST CHARAC-TERS ON FOR 2-3 SECONDS & THEN CHAN/APPR SW. ON	ANTENNA TO AUTO. CHAN/APPR LIGHT ON
	C H A N A P P R	
1	1 - A P P R	CURSOR (-) BLINKS AT NEXT INPUT LOCA-TION
2	1 2 - A P P R	
9	1 2 9 A P P R	
ENTER	BLANK FOR ½ SECOND	COMPUTER SEARCHES FOR APPROACH DATA. IF IN MEMORY DATA WOULD APPEAR IN PROPER LOCATION & NO FURTHER PILOT ENTRY RQD.
	1 2 9 A P P R	
2	1 2 9 2 -	
M	1 2 9 2 M -	
S	1 2 9 2 M S -	
5	1 2 9 2 M S 5 -	
•	1 2 9 2 M S 5.-	
7	1 2 9 2 M S 5.7 -	
3	1 2 9 2 M S 5.7 3.-	COMPUTER RECOGNIZES NEED FOR DECIMAL. COMPUTER WILL ASSUME ZERO FOLLOWING DEC-IMAL READ BACK FROM MEMORY
ENTER	BLANK FOR ½ SECOND	
	1 2 9 2 M S 5.7 3.0	
TCRS/TATK	T C R S T A T K	CHAN/APPR LIGHT OUT
2	2 - T A T K	
5	2 5 - T A T K	
5	2 5 5 ° T A T K	

EXAMPLE OF CDU OPERATION
MULTIPLE SEGMENTS (MAXIMUM COMPLEXITY)

PILOT ACTIVATED SW.	DISPLAY	COMMENTS
8	2 5 5^{o} 8 -	
.	2 5 5^{o} 8.-	
4	2 5 5^{c} 8.4 NM	
ENTER	BLANK FOR ½ SECOND	READ BACK FROM MEMORY
	2 5 5^{o} 8.4 NM	
☀BCRS/FDST	B C R S F D S T	TCRS/FDST LIGHT OUT
4	4 - F D S T	
4	4 4 - F D S T	
0	4 4 0^{o} F D S T	COMPUTER RECOGNIZES ERROR. 4^0 BLINKS CLR HELD >1 SEC. CLEARS LAST CHARACTER ENTERED
CLR	- F D S T	
3	3 - F D S T	
4	3 4 - F D S T	
1	3 4 1^{o} F D S T	
CLR	3 4 -$_{o}$ F D S T	
0	3 4 0^{o} F D S T	
4	3 4 0^{o} 4 -	
.	3 4 0^{o} 4.-	
0	3 4 0^{o} 4.0 NM	
ENTER	BLANK FOR ½ SECOND	READ BACK FROM MEMORY
	3 4 0^{o} 4.0 NM	
☀ALT/RADI	A L T R A D I	BCRS/FDST LIGHT OUT
2	2 - R A D I	
6	2 6 - R A D I	
3	2 6 3 - R A D I	
2	2 6 3 2- R A D I	

EXAMPLE OF CDU OPERATION
MULTIPLE SEGMENTS (MAXIMUM COMPLEXITY) (CONTINUED)

163

PILOT ACTIVATED SW.	DISPLAY			COMMENTS
•	2 6 3 2 .' R A D I			COMPUTER RECOGNIZES •AS END OF ALT INPUT
•	2 6 3 2 ' 0.-			
9	2 6 3 2 ' 0.9,-			
•	2 6 3 2 ' 0.9,0.-			
7	2 6 3 2 ' 0.9,0.7 NM			
ENTER	BLANK FOR ½ SECOND			
	2 6 3 2 ' 0.9,0.7 NM			READ BACK FROM MEMORY
✷RWY HD•EL	H D G	E L E V		ALT/RADI LIGHT OUT
0	0 -	E L E V		
3	0 3 -	E L E V		
0	0 3 0	E L E V		
7	0 3 0	7 -		
2	0 3 0	7 2 -		
0	0 3 0	7 2 0 -		
•	0 3 0	7 2 0 '		
ENTER	BLANK FOR ½ SECOND			
	0 3 0	7 2 0 '		
✷CKPT A•E•D	3 5 0°	4.1°	1 7.1 NM	RWY HD•EL LIGHT OUT
✷ARM	3 5 0°	4.1°	1 7.1 NM	ARM ANNUNCIATOR ON

EXAMPLE OF CDU OPERATION
MULTIPLE SEGMENTS (MAXIMUM COMPLEXITY) (CONTINUED)

PILOT ACTIVATED SW.	DISPLAY	COMMENTS
AUX DATA	E X T E R N A L L O A D ?	USED WITH AUTOMATIC DATA ENTRY UNIT. IF YES PUSH ENTER
AUX DATA	N W K 1 0 R C A T 2	FACILITY IDENTIFICATION CATEGORY
AUX DATA	R W Y 3 2 7° 1 5 0 0 0'	RUNWAY HEADING AND LENGTH
AUX DATA	R V R 3 0 0 0 ' W E T	RUNWAY VISUAL RANGE & STATUS
AUX DATA	C L I 5 0 0 0' B 2 9.9 2	CEILING, BAROMETER SETTING
AUX DATA	R W Y W D 3 2 7° 5 0 G 7 0	RUNWAY WIND DIRECTION, SPEED & GUSTS
AUX DATA	A Z L I M 3 5 0 L Z 8 0 R	AZIMUTH SECTOR LIMITS
AUX DATA	V P M I N 1.8°	MINIMUM VERTICAL PATH
AUX DATA	T E S T C O D E ?	USED IN CONJUNCTION WITH A/N KYBD FOR TEST & MAINT.
AUX DATA	E X T E R N A L L O A D ?	SEQUENCE REPEATED

EXAMPLE OF CDU OPERATION
AUXILIARY DATA

4.3.2 CDU Candidate Number 2

A "general case candidate for entering MLS approach
parameters uses data in a format such as that shown on
approach chart RWY13-257, Figure 57.   Any conceivable
complex trajectory approach can be handled in this manner.
With the exception of turns, each segment from transition
to transition, horizontally or vertically, is defined in
terms of course, along track range, and vertical path
angle. For turns, the direction and radius are entered.
The information is entered exactly as shown on the chart,
and during verification, is displayed exactly as on the
chart. As is evident from Figure 58, the same CDU
as previously described can be adapted to perform this
"general case" operation. An example of pilot/CDU inter-
action follows.
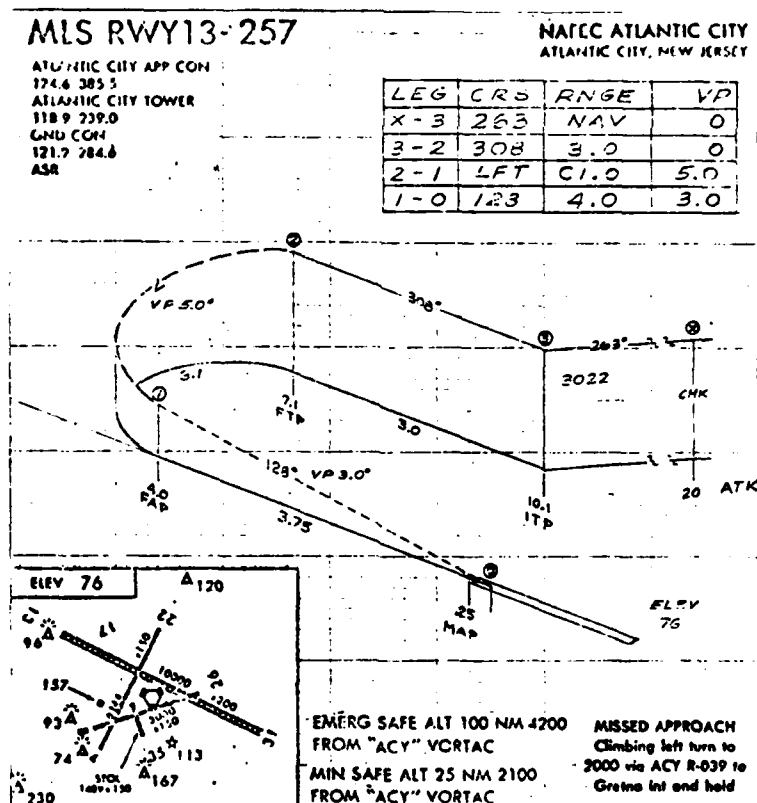
Figure 57 MLS RWY 13-257 Approach Chart
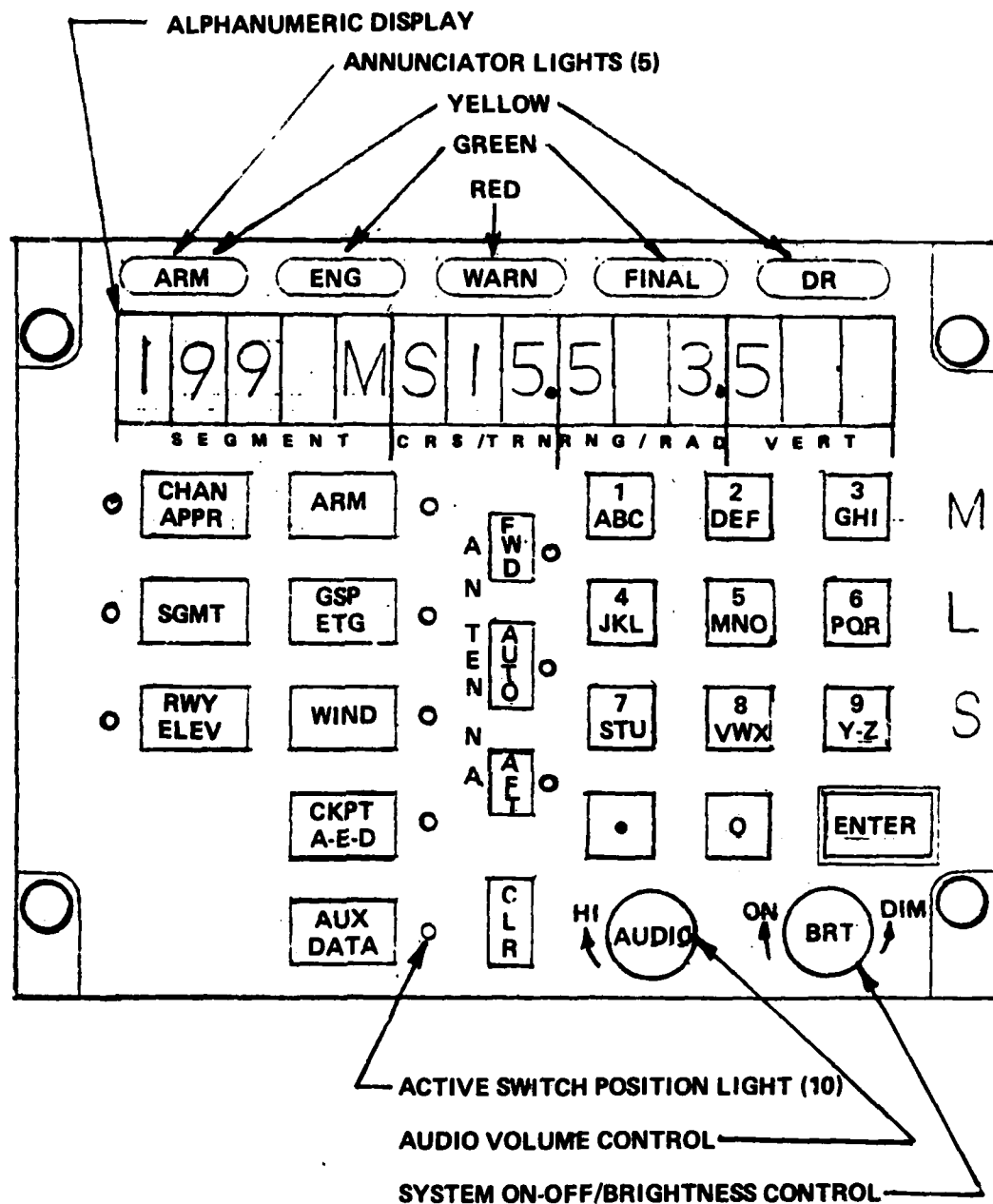
Figure 58 MLS CDU Candidate Number 2

167

PILOT ACTIVATED SW.	DISPLAY		COMMENTS
ON	ALL LIGHTS & TEST CHARACTERS ON FOR 2-3 SECONDS & THEN CHAN/APPR SW. ON		ANTENNA TO AUTO CHAN/APPR LIGHT ON
	C H A N	A P P R	
1	1 -	A P P R	CURSOR (-) BLINKS AT NEXT INPUT LOCATION
9	1 9 -	A P P R	
9	1 9 9	A P P R	
M	1 9 9	M -	
S	1 9 9	M S -	
1	1 9 9	M S 1 -	
5	1 9 9	M S 1 5.-	COMPUTER RECOGNIZES NEED FOR DECIMAL
5	1 9 9	M S 1 5.5 -	
3	1 9 9	M S 1 5.5 3 -	
•	1 9 9	M S 1 5.5 3.-	
5	1 9 9	M S 1 5.5 3.5	
ENTER	BLANK FOR ½ SECOND		
	1 9 9	M S 1 5.5 3.5	READ BACK FROM MEMORY
SGMT			CHAN/APPR LIGHT OUT COMPUTER SEARCHES FOR DATA ASSOCIATED WITH IDENT. & DISPLAYS HIGHEST SEGMENT. IF NO DATA
	S G M T	C R S R N G V R T	
3	X - 3	- N A V V R T	CURSOR (-) BLINKS AT NEXT INPUT LOCATION
2	X - 3	2 - N A V V R T	

EXAMPLE OF CDU OPERATION
(GENERAL CASE)
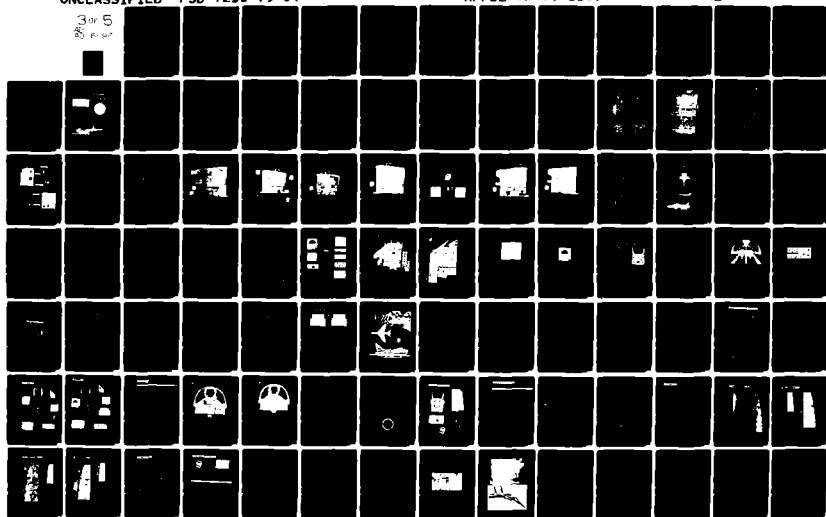
PILOT ACTIVATED SW.	DISPLAY		COMMENTS
6	X - 3	2 6 - N A V V R T	
3	X - 3	2 6 3 N A V V R T	
0	X - 3	2 6 3 N A V 0.-	
ENTER	BLANK FOR ½ SECOND		
	X - 3	2 6 3 N A V 0	READ BACK FROM MEMORY
✳SGMT	3 - 2		IF COMPUTER DID CONTAIN DATA NEXT INNER SEGMENT WOULD BE DISPLAYED
	3 - 2	-	
3	3 - 2	3 -	
0	3 - 2	3 0 -	
8	3 - 2	3 0 8 -	
3	3 - 2	3 0 8 3.-	COMPUTER RECOGNIZES 3 NOT 10s DIGIT & NEED FOR DECIMAL
0	3 - 2	3 0 8 3.0 -	
0	3 - 2	3 0 8 0. -	
ENTER	BLANK FOR ½ SECOND		
	3 - 2	3 0 8 3.0 0	READ BACK FROM MEMORY
·SGMT	2 - 1	-	
L	2 - 1	L F T C -	
1	2 - 1	L F T C 1 -	
·	2 - 1	L F T C 1.-	
0	2 - 1	L F T C 1.0-	
5	2 - 1	L F T C 1.0 5. -	COMPUTER RECOGNIZES 5 NOT 10s DIGIT & NEED FOR DECIMAL
0	2 - 1	L F T C 1.0 5.0	
ENTER	BLANK FOR ½ SECOND		

EXAMPLE OF CDU OPERATION
(GENERAL CASE) (CONTINUED)

PILOT ACTIVATED SW.	DISPLAY		COMMENTS
	2 - 1	L F T C 1.0 5.0	READ BACK FROM MEMORY
SGMT	1 - 0	-	
1	1 - 0	1 -	
2	1 - 0	1 2 -	
8	1 - 0	1 2 8 -	
4	1 - 0	1 2 8 4.-	COMPUTER RECOGNIZES 4 NOT 10s DIGIT & NEED FOR DECIMAL
0	1 - 0	1 2 8 4.0 -	
3	1 - 0	1 2 8 4. 3.-	COMPUTER RECOGNIZES 3 NOT 10s DIGIT & NEED FOR DECIMAL
ENTER	BLANK FOR ½ SECOND		COMPUTER ASSUMES 0 READ BACK FROM
	1 - 0	1 2 8 4.0 3.0	MEMORY
RWY ELEV	R W Y	E L E V -	SGMT LIGHT OUT
7	R W Y	E L E V 7 -	
6	R W Y	E L E V 7 6 -	
ENTER	BLANK FOR ½ SECOND		
	R W Y	E L E V 7 6	READ BACK FROM MEMORY
CKPT A·E·D	3 5 0°	4.1° 1 7.1 NM	RWY ELEV LIGHT OUT
ARM	3 5 0°	4.1° 1 7.1 NM	ARM ANNUNCIATOR ON

EXAMPLE OF CDU OPERATION
(GENERAL CASE) (CONTINUED)

4.3.3 CDU Candidate Number 3

Another alternate CDU configuration which minimizes pilot
workload, when manual data entry is required, is shown in
Figure 59.   Similar to the previous CDU, this design
can be used to define a wide variety of trajectories from
the most simple straight-in approach to the most complicated
trajectory, consisting of several lateral and vertical
segments. It is considered to have advantages over both
previous CDU candidates since it combines the virtues of
minimizing entries while at the same time utilizing common
pilot terminology for the displayed data requirements and
control actuations. The overall system design is applica-
ble to both a CRT-type CDU and a discrete alphanumeric
segment CDU. It differs from the previous designs in the
following ways:

> 1. Data is displayed in a vertical "page" format
>   instead of a horizontal "line" format.
>
> 2. More data can be read out per control actuation.
>
> 3. Operation is easier.
>
> 4. Cost is higher.

The philosophy of this CDU for trajectory definition, MLS
mode selection, and data readout is very similar to the
previous designs. The main difference is that a distinction
is made between lateral and vertical segments and that the
number of lateral and vertical segments of this trajectory
must be immediately defined to the computer following
MLS channel selection. With this information, the computer can
sequentially direct the pilot entering the required data to
totally define and check the desired approach.

The "pages" of information to be entered and displayed
are defined in Table 7.   These pages appear auto-
matically as the pilot enters data in the normal sequence,
or they can be called up manually if the pilot wishes to
alter data. Ground speed/wind speed and auxiliary data
pages can also be called up by actuation of their respective
pushbuttons. It should be noted that only three lateral
segment pages are shown. This was done to allow comparison
with the first CDU design discussed. For the CDU Candidate
Number 3 design, however, a limitation in trajectory segments

does not exist.

A description of the data and pushbutton mnemonics is contained in Tables 8 and 9, respectively.

Descriptions of typical pilot procedures for entering, checking and altering trajectory data follow. The data entered is based on the approach path shown in Figure 60.

Data Entry Procedure

     I. Depress DEF APPR pushbutton

    II. Page 1 appears with last entered approach data.

       A. CHAN mnemonic flashed if not CRT, cursor flashes under number if CRT (for rest of procedure non-CRT CDU is assumed).

       B. Insert MLS channel of runway = 182 ("inserting" data involves keying in desired value and depressing ENTER pushbutton).

       C. APPR mnemonic flashes.

       D. Insert approach number and direction = 422L

          1. If approach number is in memory, HDG and ELV will replace LSEG and VSEC, respectively.

            a. HDG mnemonic flashes.

            b. Insert runway heading = 000.

            c. ELV mnemonic flashes.

            d. Insert runway elevation above sea level = 156.

            e. Profile entry is complete.

            f. Page 1 remains for 3 sec., then automatically advances to Approach Check Point Page.

g. Insert check point along track distance = 8.0.

h. Display automatically advances to Check Point Data Page.

i. Pilot verifies check point azimuth, altitude and DME data on CDU versus that on approach plate.

2. If approach number is not in memory, LSEG mnemonic flashes

a. Insert number of lateral segments = 3

b. VSEG mnemonic flashes

c. Insert number of vertical segments = 2

III. Page 1 remains for 3 seconds, then automatically advances to Page 2 (RWY DATA) if approach number not previously in memory.

a. HDG mnemonic flashes

b. Insert runway heading = 000

c. ELV mnemonic flashes

d. Insert runway elevation above sea level = 156

IV. Page 2 remains for 3 seconds, then automatically advances to Page 3 (LAT SEG 1)

a. DIST mnemonic flashes

b. Insert final approach length = 4.2

c. RAD mnemonic flashes

d. Insert radius of turn on to final = 1.0

V. Page 3 remains for 3 seconds, then automatically advances to Page 4 (LAT SEG 2).

173

VI. This procedure continues until all data has been entered and the profile data entry has been checked via the check point. Data will appear on each page as in Table 7.

If the automatic checkpoint test fails or if the entered data must be altered slightly due to a change in traffic control clearance, a means of manually sequencing through the approach definition data is required. The procedure for this operation involves:

I. Depressing CHK APPR pushbutton.

II. Sequencing through the pages of definition data by repeatedly depressing the ADV PAGE pushbutton.

III. Checking the data until the error, or the parameter desired to be changed, is reached.

IV. Depressing the ADV LINE pushbutton until the mnemonic of the erroneous value is flashing.

V. Inserting the correct, or new, value.

Use of the other pushbuttons, annunciator lights and switches is similar to that described for CDU Candidate Numbers 1 and 2.

Figure 59 MLS CDU Candidate Number 3

175

TABLE 7

CDU Candidate Number 3 -- Pages of Information

PAGE 1

    CHAN 182

    APPR 422L

    LSEG 3

    VSEG 2

PAGE 2

    RWY DATA

    HDG 000

    ELV 156

PAGE 3

    LAT SEG 1

    DIST 4.2

    RAD 1.0

PAGE 4

    LAT SEG 2

    DIST 3.0

    CRS 045

PAGE 5

    LAT SEG 3

    CRS 030

PAGE 6

    VRT DATA

    GSI 3.0

    ALT 1000

    GS2   5.0

PAGE 7

    APP CHK PT

    DIST 8.0

PAGE 8

    CHK DATA

    AZ 15.6 L

    ALT 3739

    DME 9.4

PAGE 9

    (GROUND SPD/WIND SPD)

    GSP 145

    WSP 12

    WBG 210

    ETG 1.2

PAGE 10

    (TYPICAL AUX DATA)

TABLE 8

CDU Candidate No. 3 Data Mnemonics

MNEMONIC	DEFINITION	RANGE	UNITS
CHAN	MLS Channel Number	0-200	-
APPR	MLS Approach Number L=from left of runway centerline R=from right of runway centerline	0-999	-
LSEG	Number of Lateral Segments	1-9	-
VSEG	Number of Vertical Segments	1-2	-
RWY DATA	Runway Data Page	-	-
HDG	Runway Heading	000-359	Degrees
ELV	Runway Elevation	0-9999	Feet
LAT SEG 1	Lateral Segment #1 Page	-	-
LAT SEG 2	Lateral Segment #2 Page		
LAT SEG 3	Lateral Segment #3 Page		
DIST	Length of Segment	0-99.9	Nautical Miles
RAD	Radius of Turn on to Segment	0-9.9	Nautical Miles
CRS	Course of Segment	000-359	Degrees
VRT DATA	Vertical Data Page	-	-
GSI	Final Approach Glide Path Angle	1.0-9.5	Degrees
ALT	Glide Path Transition Attitude	000-9999	Feet
GS2	Initial Glide Path Descent Angle	0-20.0	Degrees
APP CHK PT	Approach Check Point Page	-	-
DIST	Check Point Along Track Distance from Touchdown	0-99.9	Nautical Miles

MNEMONIC	DEFINITION	RANGE	UNITS
CHK DATA	Check Point Data Page	–	–
AZ	MLS Azimuth Angle of Check Point	0–60.0	Degrees
	L=left of runway centerline R=right of runway centerline		
ALT	Check Point Altitude	0–20,000	Feet
DME	Check Point DME	0–30.0	Nautical Miles
GSP	Ground Speed	0–999	Knots
WSP	Windspeed	0–999	Knots
WBG	Wind Bearing	000–359	Degrees
ETG	Estimated Time-to-Go to Touchdown	0–99.9	Minutes

CDU Candidate No. 3 Data Mnemonics
TABLE 8 – Continued

TABLE 9

CDU Candidate No. 3 Pushbutton Mnemonics

PUSHBUTTON	DEFINITION	ACTUATION RESULTS
DEF APPR	Define Approach	Activates automatic sequencing through pages as data is entered.
CHK APPR	Check Approach	Allows manual sequencing through pages to check and/or modify data.
ADV PAGE	Advance Page	Causes advancement to next page of data.
ADV LINE	Advance Line	Causes uppermost mnemonic on page to flash. Repeated depression advances flashing to mnemonic of next lower line of data.
ENTER	Enter Data	Data inserted is entered into computer memory.
CLR	Clear	Causes reversion back to previous data if depressed with mnemonic flashing.
ARM	Arm	Arms MLS mode for engagement.
AUX DATA	Auxiliary Data	Calls up auxiliary data information. Repeated actuation causes sequencing through several auxiliary data pages.

179

3.14 NM

3.0°

5.0°

1000'

MLS CHAN   182
ELV   156
APPR   422L

4.2 NM

N

045

3.0 NM

030

CHK PT
DIST = 8.0
AZ = 15.6L
ALT = 3739
DME = 9.4
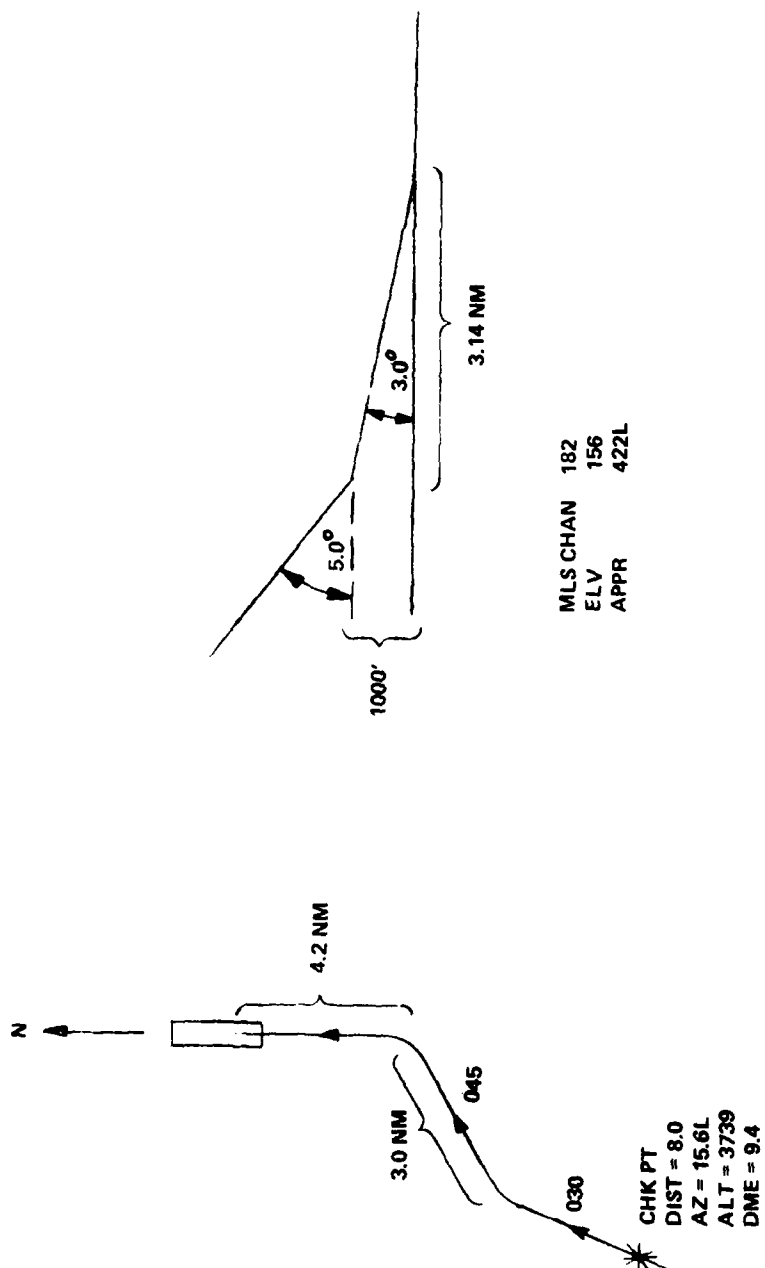
Figure 60 Approach Path Example For CDU Candidate No. 3

5.0 RETROFIT OF MLS INTO EXISTING USAF AIRCRAFT

5.1 Summary of Aircraft Studies

In this section, study results are presented for five aircraft which were chosen to represent a cross-section of the USAF inventory. These aircraft are the C-130A/D; F-111A/E; A-7D; F-15A; and KC-10A. For the first four of these aircraft, Technical Orders on the pertinent systems were obtained from the Air For Flight Dynamics Laboratory. Since no T.O.'s exist, as yet, on the KC-10, information on this aircraft was obtained directly from the Douglas Aircraft Company Division of the McDonnell-Douglas Corporation.

The studies consisted of a review of the basic aircraft systems which would be logically affected by the integration of MLS; and then, an adaptation of one of the four general MLS configurations defined in Section 4.1 which the analysis tended to recommend. No detailed analysis was made of mission requirements, space or weight limitations since this was considered to be outside the scope of this study. No tradeoffs were conducted to determine if MLS computations were more cost-effectively incorporated in an existing computer or a new computer. The recommended MLS configuration for each aircraft was based on the control-and-display capabilities of that aircraft and the anticipated pilot workload levels to perform the various levels of complex trajectory flight.

The studies resulted in the following recommendations:

AIRCRAFT	RECOMMENDED MLS CONFIGURATION
C-130A/D	MLS-1 (DIRECT ILS REPLACEMENT)
F-111A/E	MLS-1 (DIRECT ILS REPLACEMENT)
A-7D	MLS-3 (SELECTABLE INTERCEPT OF FINAL)
F-15A	MLS-3 (SELECTABLE INTERCEPT OF FINAL)
KC-10A	MLS-4 (COMPLEX TRAJECTORY)

the airplane

C-130A AND C-130D-6

Hercules
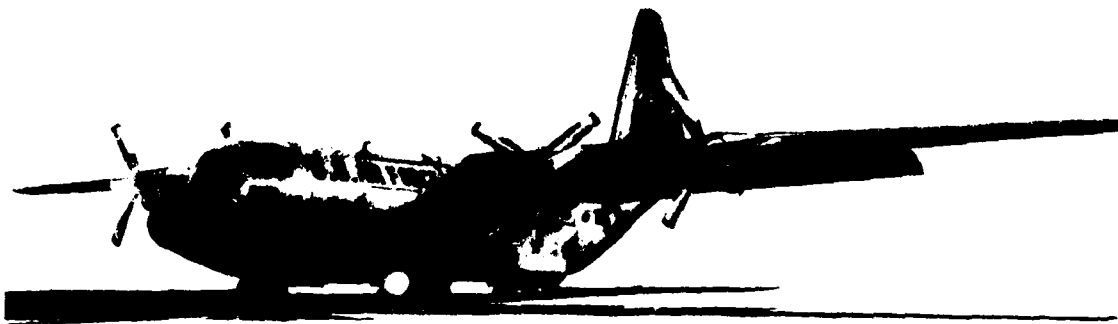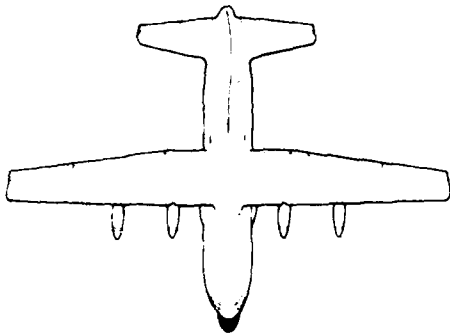
130A-1-33-002-1

v

5.2   C-130A/D

5.2.1   General/C-130A/D Information

The Lockheed C-130 is a high-wing, all-metal construction,
medium-range, land-based monoplane. The mission of the airplane
is to provide rapid transportation of personnel or cargo for
delivery by parachute or landing.   The airplane can be
used as a transport carrying 92 ground troops or 64 paratroops
and equipment, and can be readily converted for ambulance
or aerial delivery missions. The C-130 can land and take off
on short runways and can be used on landing strips such as
those usually found in advance base operations.

A block of the C-130 airplanes was modified to add skis and
designated as C-130D. A part of the C-130D fleet has skis
removed, and these airplanes are designated C-130D-6.

Crew stations are provided for a pilot, copilot, flight engineer,
and navigator. The pilot and copilot are seated on left and
right sides, respectively, of the control pedestal in the
forward section of the flight station. The navigator is
seated behind the copilot on the right side of the flight
station, facing outboard. The flight engineer is seated in
the center of the flight station, behind the pilot and copilot.

Presently, ILS approaches can be made only by certain aircraft,
utilizing either the flight director or autopilot. Flight
Directors are not installed on all C-130 aircraft, and the auto-
pilot is inoperative on some aircraft (see T.O. IC-130A-2-1,
Page 9-42, Section 9-57).

The flight director system provides roll steering commands to
the ADI for localizer path control. When the ILS mode is
selected, the miniature aircraft on the ADI is slaved to a
2.5^{o} preset position above the horizon bar. This is the extent
of the glide path control.

Autopilot coupled approaches must be continuously monitored
(see T.O. IC-130A-1, Page 4-94, Normal Autopilot Operation); and,
with the exception of ILS, the autopilot should be disengaged
below 1,000 ft.

Since all C-130 aircraft utilize only single LOC/VOR and Glide
Slope receivers and because of autopilot and flight director
deficiencies, the C-130 has a category I approach system.

Integration of an MLS system into the C-130 aircraft involves consideration of existing navigation equipment (units or systems) which can be time shared or modified. The following is a list of this equipment.

TYPE	QTY.	DESIGNATION
Radio Compass	2	AN/ARN-6
LOC/VOR Receiver	1	AN/ARN-14
Tacan	1	AN/ARN-21
Glide Slope Receiver	1	AN/ARN-18 or -31
Direction Finder	1	AN/ARN-25
*Talar System	1	AN/ARN-97
Indicator (Deviation)	1	ID-48/ARN or ID-525 ARN
Indicator (Deviation)	1	ID-249/ARN
Indicator (RMI)	5	ID-250/ARN
Indicator, Azimuth	1	ID-307/ARN
Indicator, Range	1	ID-310/ARN
Autopilot	1	E4
Beam Guidance Coupler	1	MB-4
*Flight Director System:	1	MA-1
Gyro Monitor	1	327B-2
Approach Horizon	1	329B-3
Course Indicator	1	331A-3
Vertical Gyro	1	332D-6
Steering Computer	1	562A-3B

* Not installed on all aircraft.

Some aircraft have TALAR systems installed which receive low level microwave signals and process them into steering and deviation signals for use as a landing approach aid. If TRSB MLS is installed on USAF aircraft, it is expected that the TALAR system will be removed.

Some aircraft utilize an MA-1 flight director system which substitutes an HSI and ADI for the pilot's ID-249 (deviation indicator).

Five ID-250 (RMI) Indicators and an ID-307 (Azimuth) Indicator are used to present bearing information. Three ID-250 instruments are dedicated to the ARN-6 radio compass system. The No. 2 pointers of the other two ID-250 instruments can be switched via the TAC/VOR/ILS switch to the respective navigation references. The ID-307 (single pointer) is dedicated to Tacan.

The TAC/VOR/ILS switch controls relays which transfer the audio, bearing and deviation signals of the various navigation references to the appropriate elements. Tacan range signals are applied directly to a pilot's indicator.

A block diagram of the existing navigation system is illustrated in Figure 61. Only those elements involved with the MLS installation or possible MLS usage are shown. Although the existing installation includes an independent doppler system which utilizes a dedicated computer, controls and instruments, none of these is adaptable for MLS. The block diagram also shows the functions which must be interrupted and switched to install the recommended direct ILS replacement MLS-1 configuration (see Section 4.1). Details explaining this recommendation follow.

5.2.2   C-130A/D MLS Recommendations

Since only single LOC/VOR and Glide Slope receivers are used on the studied C-130-A and -D aircraft, the low approach system is Category I. Furthermore, due to the age of the aircraft, the present autopilot is of an early vintage and is not recommended for use below 1,000 ft. unless the controls are continuously monitored. Although certain aircraft have an MA-1 flight director system installed, only localizer (lateral) flight path steering control is provided. No glide slope flight path steering is available. At glide slope engagement, the pitch

steering bar is displaced to command the 2.5° nose-down
attitude needed to maintain the glide path.   Crude path
control is maintained by keeping the pitch steering bar
opposite the glide slope deviation indicator.

Like the autopilot and flight director systems, the display
technology included in these aircraft is also of a primitive
nature.   Many individual indicators are provided throughout
the cockpit with very little display integration.

Based on the above considerations, only the MLS-1 configuration
(direct ILS replacement) is recommended for the C-130-A or
-D aircraft.   If the complex trajectory, MLS-3 and MLS-4,
configurations are to be considered, the following avionics
improvements must be made:

1. Update present autopilot and/or add modern flight
   director system.

2. Replace present ID-249 or HSI (flight director
   system) with an HSI which allows remote slewing
   of the course carriage and pointer.

Installation of a minimum MLS-1 configuration (see Figure 38
Block Diagram, MLS-1) in this type aircraft involves the
addition of the following units:

UNIT	QUANTITY
MLS Angle Receiver	1
MLS Switching Unit	1
MLS-1 Tuner	1
MLS Angle Antenna	1

Because the C-130-A or -D aircraft mission involves usage at
forward operating bases, where marker beacons may not be
provided, it is also recommended that the MLS DME system be
installed.   This requires the following additional units:

UNIT	QUANTITY
MLS DME Interrogator	1
Digital-to-Analog Converter	1
MLS DME Antenna	1

The first two units in each grouping can be remotely located. Ample room is available on the existing radio racks to accommodate these units (see Figure 62).

Space is available on the existing overhead panel (see Figure 63 lower right) to accommodate the MLS-1 tuner.

The MLS angle and DME antennas can be mounted on the underside of the nose of the aircraft (see Figures 64 and 65), aft of the radome, just forward of the access door.

The instrument select switch is used to select the desired navigational reference. When a particular reference is selected, relays in the radio junction box transfer the proper audio reference to the VHF NAV on-off switch (see Figure 66, lower right). Since MLS signals will be substituted for the present ILS signals when the MLS mode is selected, the present VHF NAV switch provides the interface to the audio system. Therefore, an MLS audio on-off switch is not required. Volume control is provided by a knob on the MLS-1 tuner.

Holes exist on the radio junction box panels to accommodate the MLS system circuit breaker. Figure 67 shows a typical location for aircraft utilizing an MA-1 flight director. For installations without the MA-1 system, six holes are available at the same location.

The following is a brief description of the existing instruments available for MLS (time-shared) usage. In addition, the type of interface required by each instrument is discussed and the location of each instrument is pin-pointed.

ID-249 Deviation Indicator (see Figure 68, Panel B)

This instrument is installed only on aircraft which do not utilize the MA-1 flight director system. It includes the same functions as the ID-48/ID-525 unit and, in addition, displays deviations from a pre-set course which is selected by a knob on the front of the instrument. A numerical readout is provided for setting the pre-set course. Coupled to the pre-set course selector shaft is a synchro which supplies pre-set course deviation to the autopilot coupler for flight path control computations.

This instrument must interface with analog and discrete signals. Thus, it is only compatible with the raw data outputs of the

MLS system. Since the pre-set course indicator and readout are not remotely-slewable, aircraft with this instrument can only accept the MLS-1 configuration.

The ID-249 instrument is located on the pilot's instrument panel and is shown on Figure 69, Ref. No. 5.

ID-48/ID-525 Deviation Indicator (see Figure 68, Panel A).

The ID-48 and ID-525 Indicators are interchangeable and either one can be installed on the C-130 aircraft. The indicator is used to display lateral and longitudinal deviations from navigational references and also includes on-off flags to display the validity of these references. Lateral deviations (LOC, VOR and Tacan) are displayed on the vertical needle and longitudinal deviations (glide slope) are displayed on the horizontal needle.

This instrument must interface with analog and discrete signals. Accordingly, it is only compatible with the raw data outputs of the MLS system.

The ID-48/ID-525 instrument is located on the copilot's instrument panel and is shown on the Figures 70 and 71 (Ref. No. 5) and Figure 72, Ref. No. 34.

331A-3 Course Indicator (See Figure 67, Panel D)

The course indicator (HSI) is part of the MA-1 flight director system (see Figure 73). This instrument provides a display consisting of a compass card, course deviation indicator and a pre-set course indicator. The deviation indicator is used to display lateral deviations from a navigational reference. A knob is provided for positioning the pre-set course bug relative to the compass card. A synchro is connected to the shaft end of the knob and it provides preset course deviations to the flight director and autopilot couplers.

This instrument must interface with analog signals and accordingly is only compatible with the raw data outputs of the MLS system. Furthermore, the course carriage and pre-set course indicators are not remotely slewable; therefore, the present installation is not compatible with the MLS-3 and MLS-4 configurations. A replacement instrument must be used if MLS-3 or MLS-4 approach performance is required.

The 331A-3 HSI is located on the pilot's instrument panel and is shown on Figures 74 Pef. No. 32 and 104, Ref. No. 6.

329B-3 Attitude Direction Indicator (See Figure 67 Panel D)

The attitude direction indicator (ADI) is part of the MA-1 flight director system (see Figure 73). This instrument provides a display consisting of glide slope deviation indicator, glide slope and localizer validity flags, attitude references and a bank steering. The bank steering bar is used during ILS approaches for localizer flight path control. No flight path control for glide slope (pitch steering) is available.

This instrument must interface with analog and discrete signals. Thus, it is only compatible with the raw data outputs of the MLS system.

The 329B-3 ADI is located on the pilot's instrument panel and is shown in Figures 74, Ref. No. 34 and 104, Ref. No. 8.

ID-310 Range Indicator (See Figure 75, Panel E)

This instrument provides a numerical readout of range (kts) to station and is presently dedicated to the Tacan system. Since its interface is analog and since range is only available in digital form from the MLS system, the display is not directly compatible with MLS. To provide compatibility, a digital-to-analog converter unit is required.

The ID-310 instrument is located on the pilot's instrument panel and is shown on Figures 69 and 74, Ref. No. 13, and 104 Ref. No. 16.
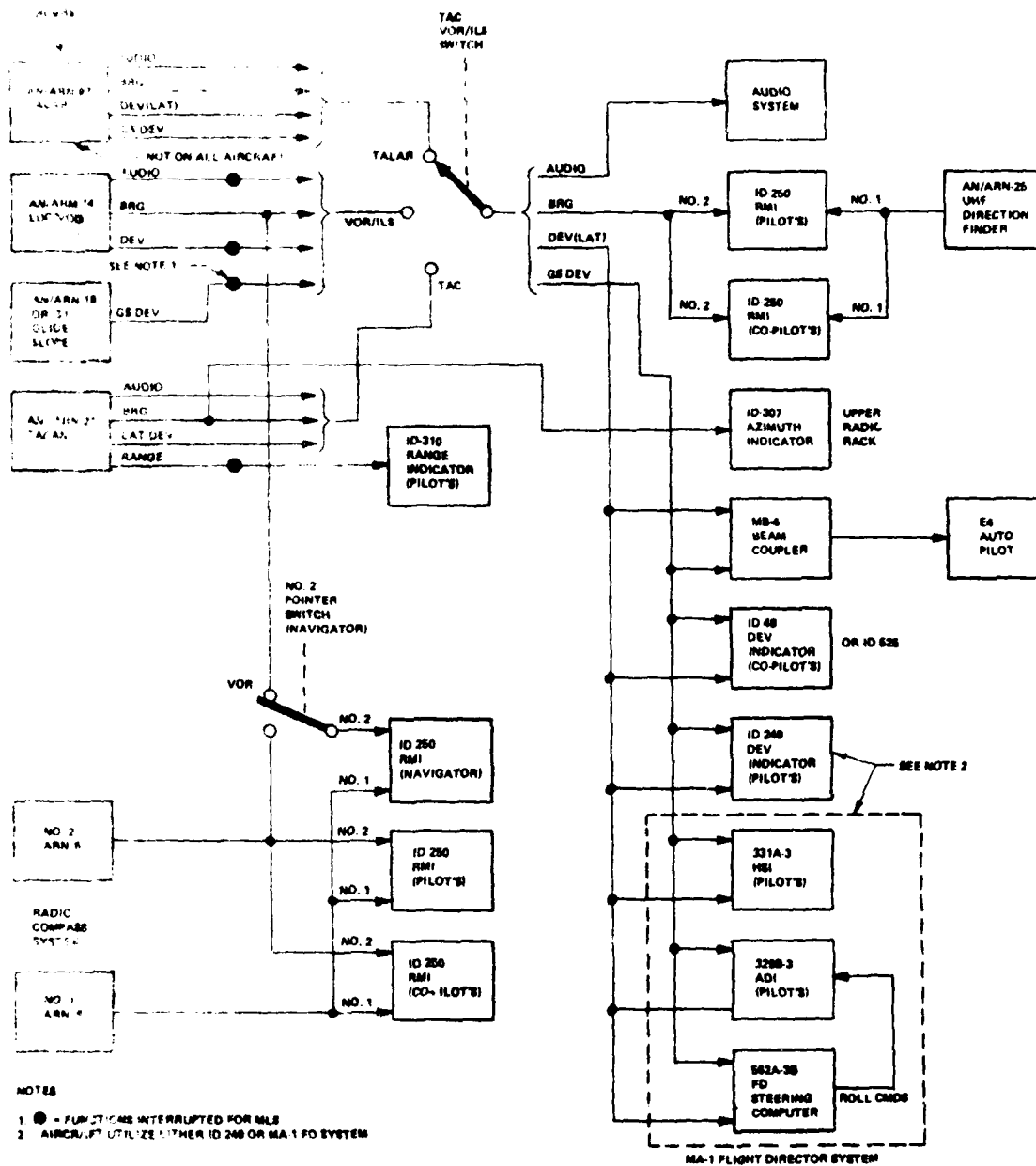
Figure 61 Block Diagram C130A & C130D-6 Navigation System

UPPER RADIO RACK

LOWER OUTBOARD RADIO RACK

LOWER INBOARD RADIO RACK
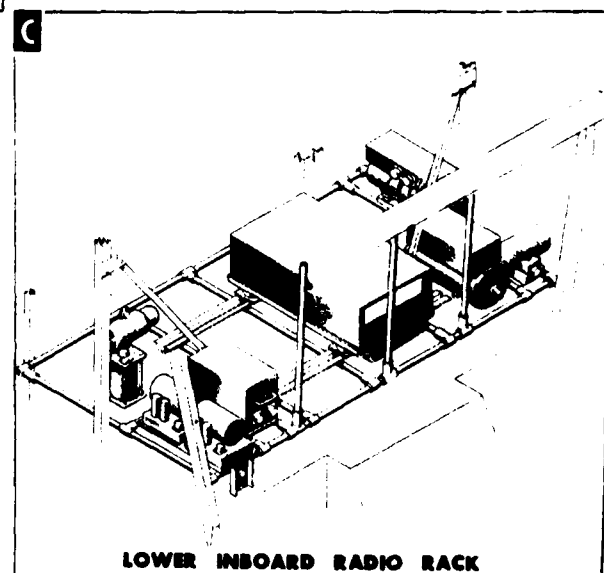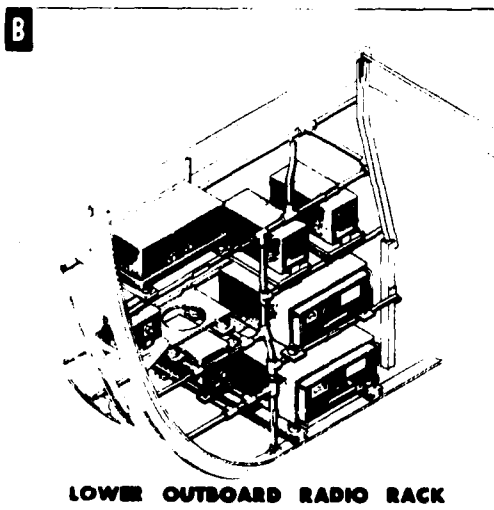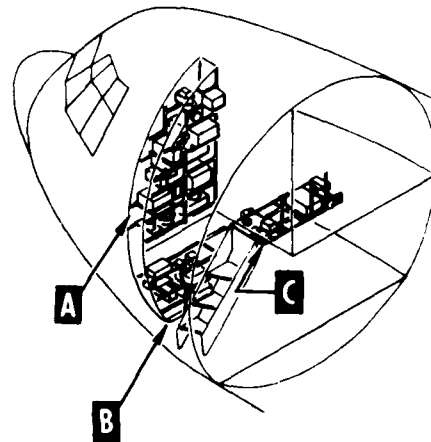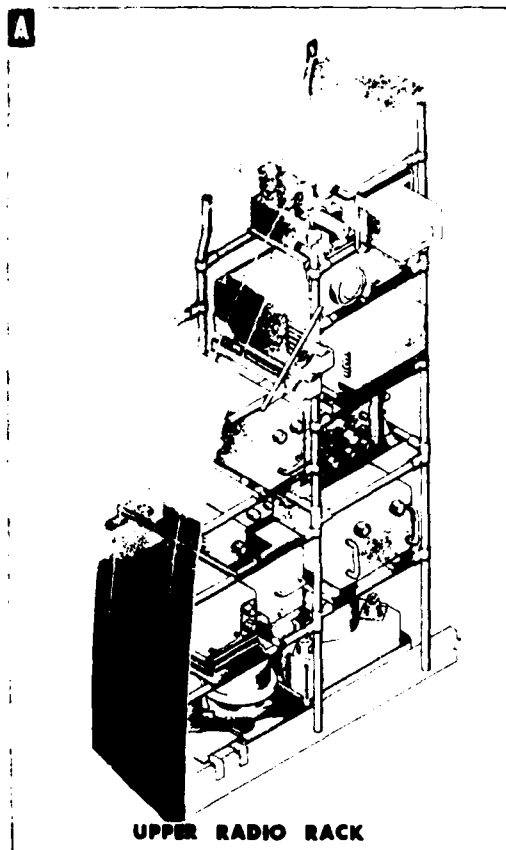
Figure 62 Radio Racks Location

overhead control panel
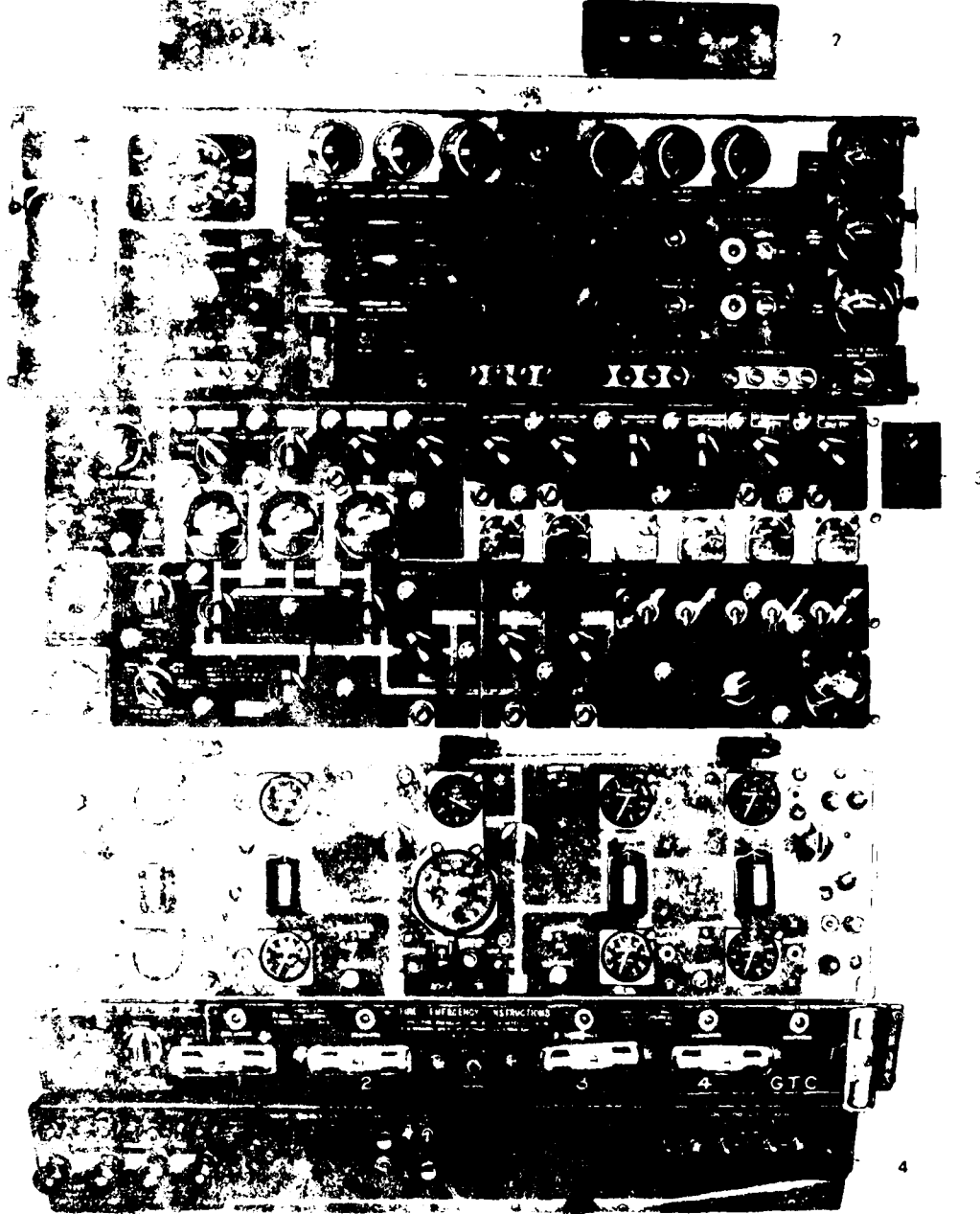
Label	Description
1.	ANTI-ICING TEST PANEL
2.	CYCLONE TANK PANEL
3.	
4.	GTC CONTROL, FLAPS SWITCH PANEL SELECTION PANEL STARTING PANEL CONTROL PANEL
5.	
7.	FUEL CONTROL PANEL
8.	ELECTRICAL CONTROL PANEL
10.	GTC DOOR SWITCH AND LIGHT (SOME AIRPLANES)
11.	AIR CONDITIONING CONTROL PANEL

130A--33-007

AVAILABLE SPACE

Overhead Control Panel

SEARCH RADAR
ANTENNA

GLIDE PATH
ANTENNA

**MLS ANGLE AND DME
ANTENNA LOCATIONS**
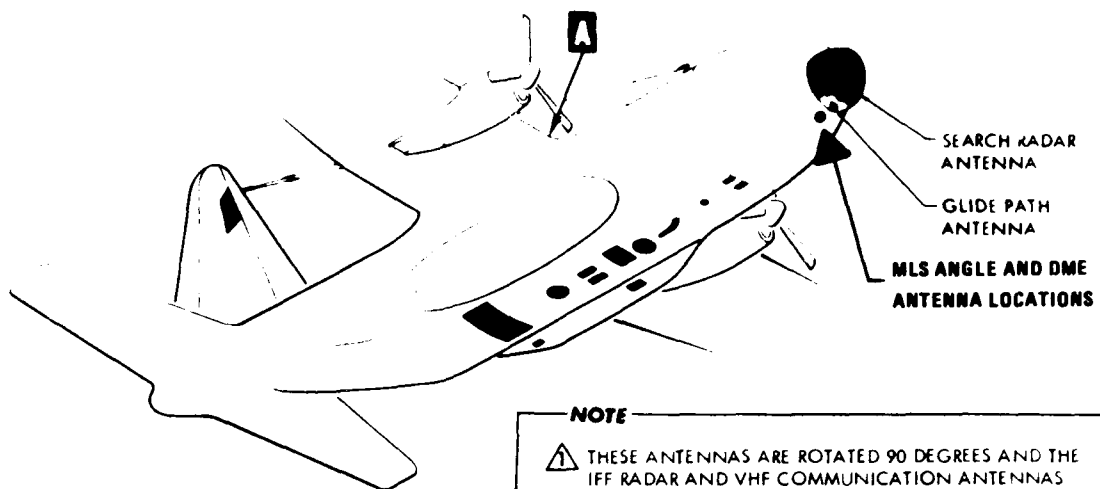
**AIRPLANES AF55-001 THROUGH
55-020, 55-022 THROUGH 57-483,
AND 57-496 AND UP**

NOTE

⚠1 THESE ANTENNAS ARE ROTATED 90 DEGREES AND THE
IFF RADAR AND VHF COMMUNICATION ANTENNAS
ARE MOVED AFT 20 INCHES ON AIRPLANES AF54-1635
THROUGH 54-1640.

2. ALL ANTENNA LOCATIONS SHOWN ABOVE ARE THE
SAME AS THOSE SHOWN BELOW, EXCEPT AS NOTED.

⚠3 AIRPLANES AF53-3129 THROUGH 57-509 IF MODIFIED
BY T.O. 1C-130-538.

⚠4 AIRPLANES AF52-3129 THROUGH 56-551 IF MODIFIED
BY T.O. 1C-130A-659, 57-453 THROUGH 57-509 IF
MODIFIED BY T.O. 1C-130A-757, AND 57-510 AND
UP.

⚠5 AIRPLANES MODIFIED BY T.O. 1C-130-838.

LIAISON NO. 1
ANTENNA

LORAN AND LIAISON
NO. 2 ANTENNA

VHF NAVIGATION
ANTENNA

GLIDE PATH
ANTENNA

SEARCH RADAR
ANTENNA

TACAN BOTTOM
ANTENNA

HIGH-RANGE RADAR
ALTIMETER RECEIVING
ANTENNAS ⚠1

IFF RADAR ANTENNA

VHF COMMUNICATION
ANTENNA

UHF COMMUNICATION
ANTENNA

MARKER BEACON ANTENNA

HIGH-RANGE RADAR ALTIMETER
TRANSMITTING ANTENNAS ⚠1

UHF DIRECTION
FINDER ANTENNA

RADIO COMPASS SENSE ANTENNAS
(LOOP ANTENNAE MOUNTED DIRECTLY ABOVE)

LOW-RANGE RADAR
ALTIMETER ANTENNA

AIRPLANES AF53-3129 THROUGH 53-3135, AND 54-1621 THROUGH 54-1640

Figure 64 Antenna Locations

TACAN TOP ANTENNA

IFF TOP ANTENNA

TACAN BOTTOM ANTENNA

VHF COMMUNICATION ANTENNA

IFF ANTENNA

SEARCH RADAR ANTENNA

GLIDE PATH ANTENNA

MLS ANGLE AND DME ANTENNA LOCATIONS

LIAISON NO. 1 ANTENNA

LORAN AND LIAISON NO. 2 ANTENNA

NAVIGATION ANTENNA

HIGH-RANGE RADAR ALTIMETER, RECEIVING ANTENNA

LOW-RANGE RADAR ALTIMETER ANTENNA

UHF COMMUNICATION ANTENNA

HIGH-RANGE RADAR ALTIMETER, TRANSMITTING ANTENNAS

MARKER BEACON ANTENNA

RADIO COMPASS LOOP AND SENSE ANTENNA

UHF DIRECTION FINDER ANTENNA

Airplanes AF55-021 and 57-484 through 57-495

Figure 64 Antenna Locations (cont'd)

intercommunication controls

FLIGHT CONTROL OVERHEAD PANEL

CALL

NORMAL

AUX LISTEN

VOLUME

FORWARD CARGO DOOR

LEFT HAND PARATROOP DOOR

FLIGHT CONTROL PEDESTAL

NAVIGATORS CONTROL PANEL
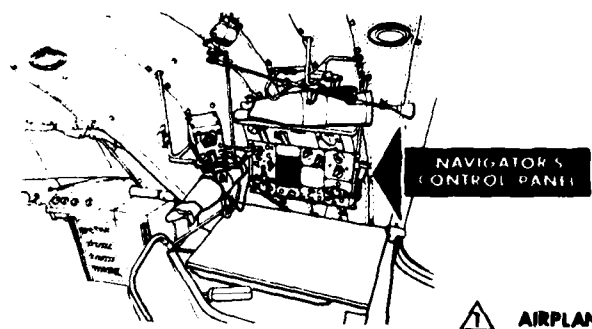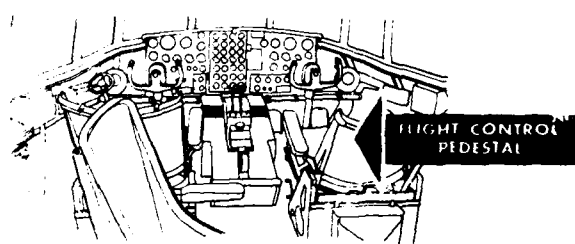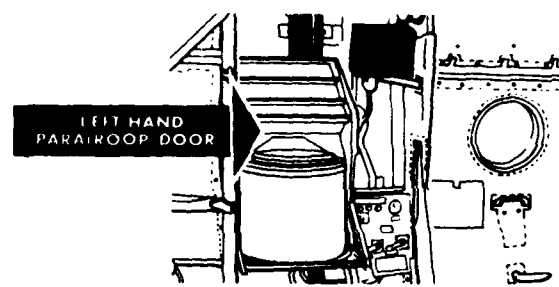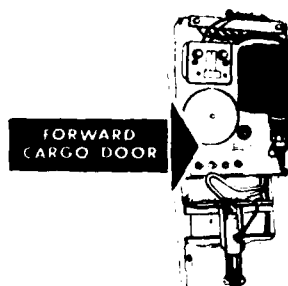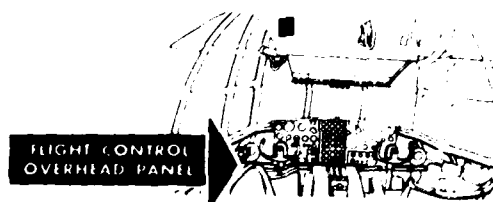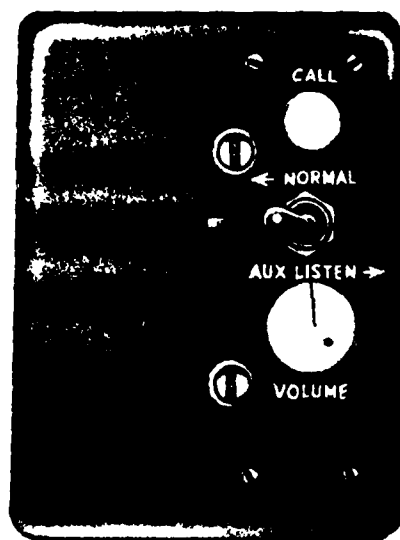
⚠ AIRPLANES MODIFIED BY T.O. 1C-130A-793   130A-1-33-109-1

Figure 66 Intercommunication Control

C

ID-525/ARN
INDICATOR

FWD

COPILOT'S
INSTRUMENT
PANEL

D

327B-2
GYRO
MONITOR

VERTICAL GYRO

329B-3
APPROACH
HORIZON

HDG

ILS

331A-3
COURSE
INDICATOR

FWD

PILOT'S
INSTRUMENT
PANEL

AVAILABLE FOR MLG CIRCUIT BREAKERS

A

CIRCUIT
BREAKER

FLIGHT DIRECTOR

FLIGHT STATION
RADIO
JUNCTION BOX

FWD

B

562A-3B
STEERING
COMPUTER

332D-6
VERTICAL
GYRO

LOWER
OUTBOARD
RADIO RACK

FWD

350YA-1A SHOCK MOUNT

E

MA-1
FLIGHT DIRECTOR
2 AMP - 115V -

POWER

400 ~

SIGNAL

MAIN POWER DISTRIBUTION BOX

Figure 67 Flight Director Systems Components Locations
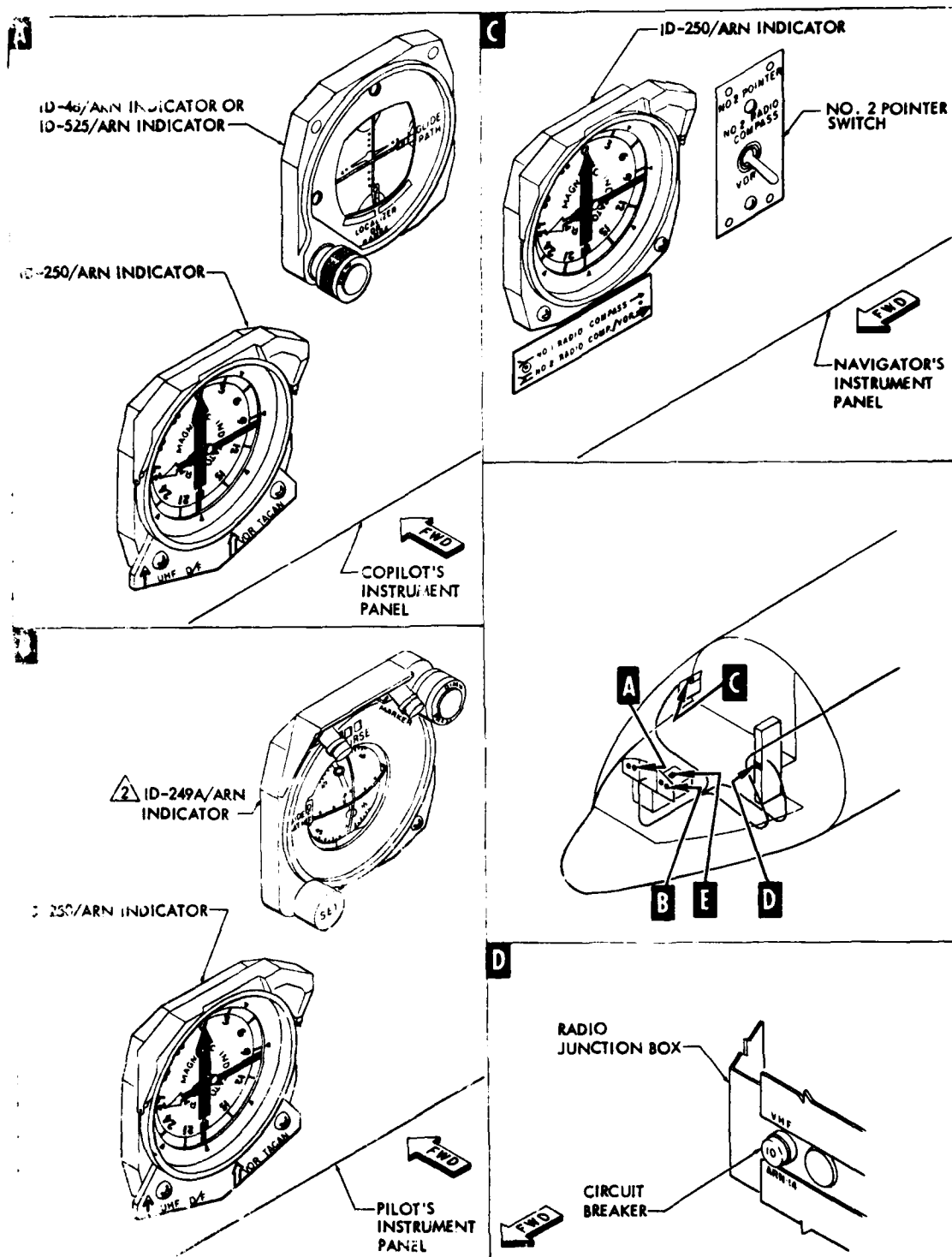
Figure 68 AN/ARN-14 VHF Navigation Receiver
Components Locations

A pilot's instrument panel (TYPICAL)

AIRPLANES AF53-3129 THROUGH 57-0473

1. DOOR WARNING LIGHT

2. MAGNETIC COMPASS

3. AIRSPEED INDICATOR

4. ALTIMETER

4A. ALTIMETER ENCODER

5. COURSE INDICATOR

6. N-1 COMPASS REPEATER INDICATOR

7. VERTICAL VELOCITY INDICATOR

8. ANGLE OF ATTACK INDICATOR

9. ATTITUDE INDICATOR
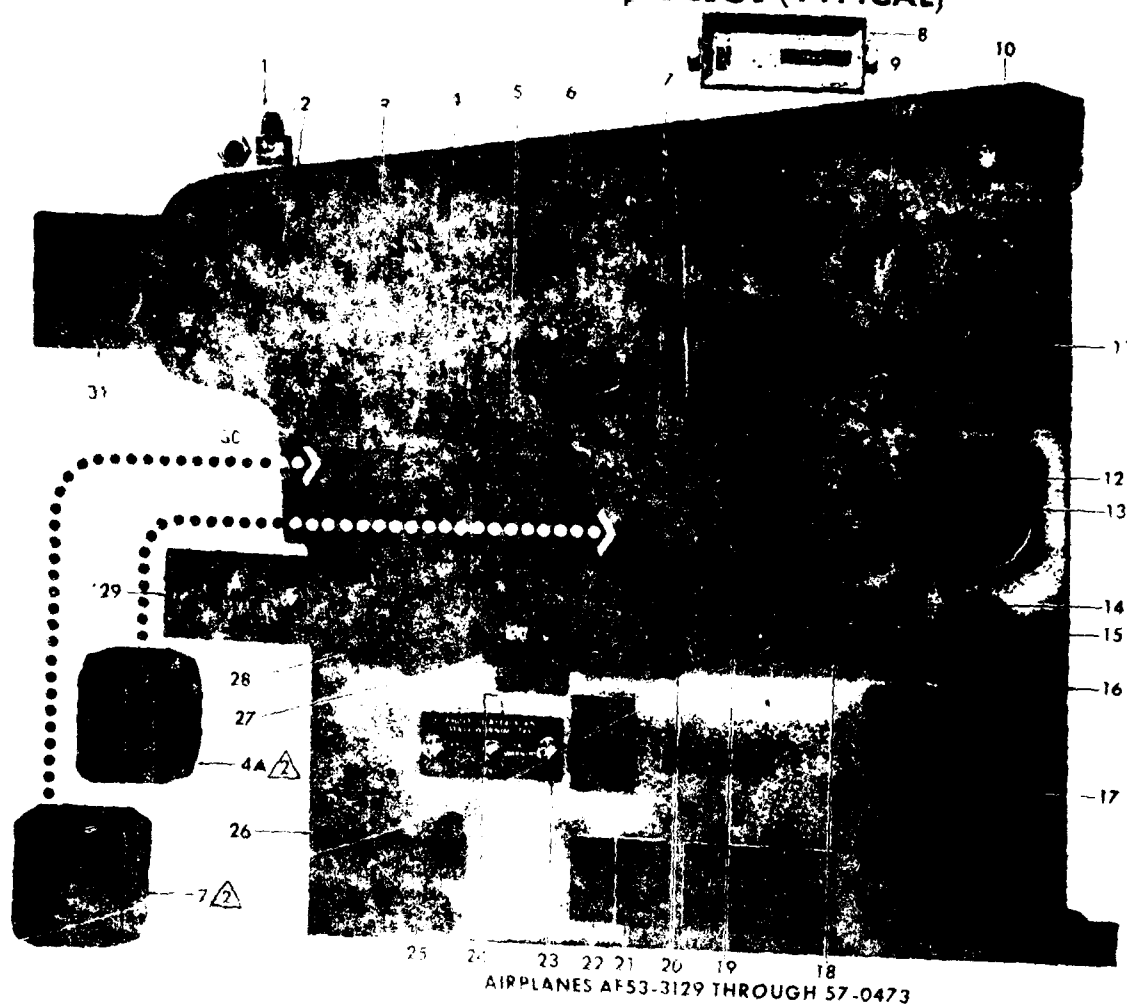
10. MASTER FIRE WARNING LIGHT PANEL

11. RADAR ALTIMETER

12. RADIO MAGNETIC INDICATOR

13. TACAN RANGE INDICATOR

14. ELEVATOR TRIM TAB POSITION INDICATOR

15. WING FLAP POSITION INDICATOR

16. LOW OIL QUANTITY LIGHT

17. ENGINE AND PILOT'S INSTRUMENT LIGHT CONTROL PANEL

18. AILERON TRIM TAB POSITION INDICATOR

Figure 69 Pilot's Instrument Panel (Typical)

A copilot's instrument panel typical
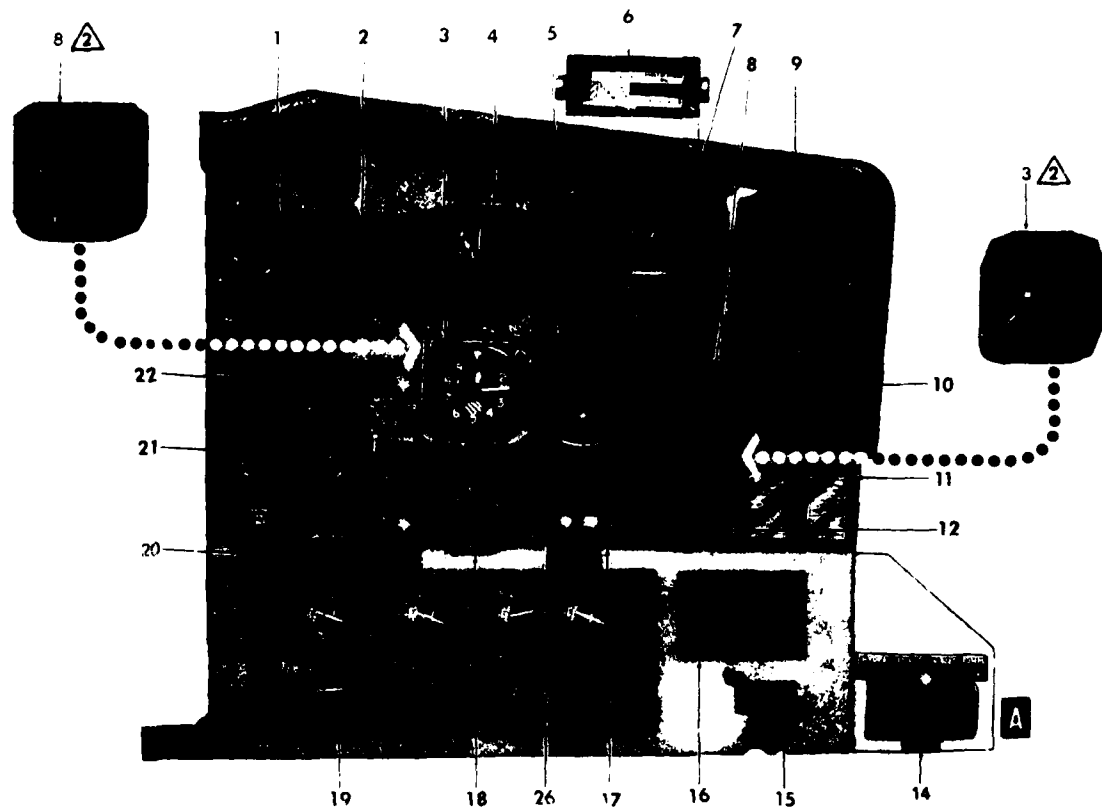
NOTE

⚠1 AIRPLANES MODIFIED BY T.O. 1C-130-708.

⚠2 AIRPLANES MODIFIED BY T.O. 1C-130-838.

AIRPLANES AF53-3129 THROUGH 57-0473

1. CABIN PRESSURE ALTITUDE INDICATOR
2. CLOCK
3. ALTIMETER
4. AIR SPEED INDICATOR
5. COURSE INDICATOR
6. ANGLE OF ATTACK INDICATOR ⚠1
7. HEADING INDICATOR
8. VERTICAL VELOCITY INDICATOR
9. ATTITUDE INDICATOR
10. RADIO MAGNETIC INDICATOR
11. ALTIMETER AND MAGNETIC COMPASS CORRECTION CARDS
12. FREE AIR TEMPERATURE INDICATOR
13. UTILITY PRIME SWITCH (AIRPLANES AF53-3129 THROUGH 56-0509)
14. HYDRAULIC SUCTION BOOST PUMP SWITCH PANEL (AIRPLANES AF56-0510 AND UP)

Figure 70 Copilot's Instrument Panel (Typical)

199
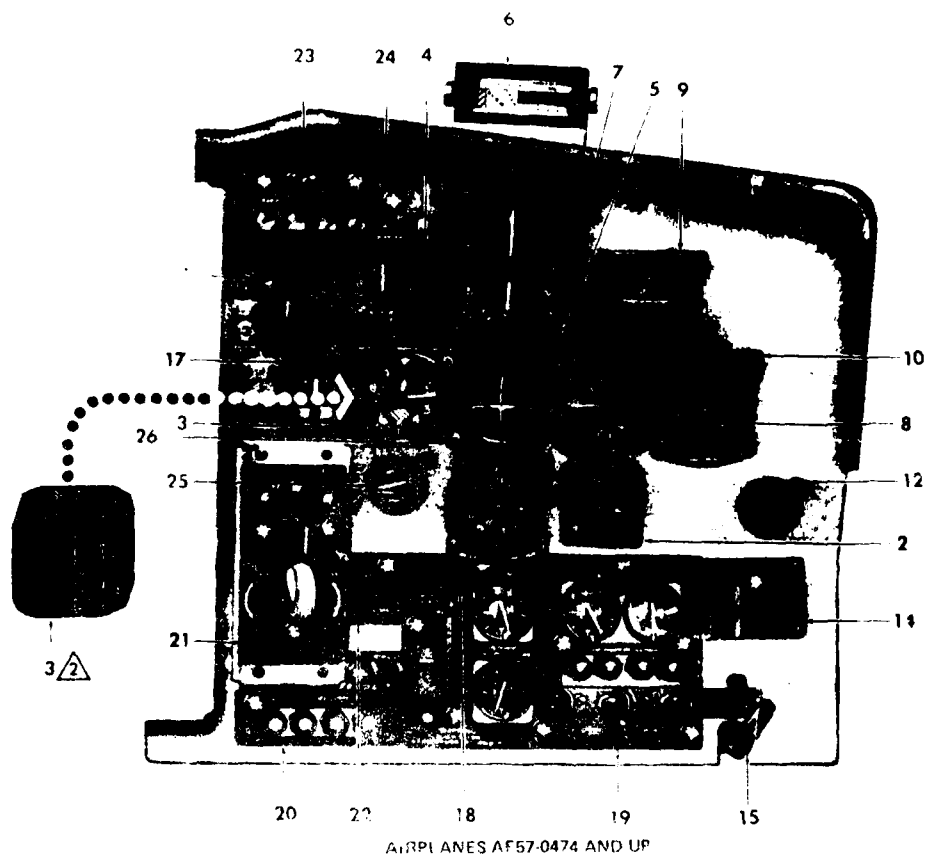
AIRPLANES AF57-0474 AND UP

15. AIR DIVERTER HANDLE
16. COPILOT'S INSTRUMENT LIGHT CONTROL
17. TURN AND SLIP INDICATOR
18. RADIO MAGNETIC INDICATOR
19. HYDRAULIC CONTROL PANEL
20. ELECTRONIC FUEL CORRECTION PANEL
21. LANDING GEAR CONTROL PANEL
22. MAIN LANDING GEAR DRIVE HI-TORQUE SWITCH PANEL
    (AIRPLANES AF55-023 AND UP)
23. NACELLE OVERHEAT WARNING PANEL
24. DOOR WARNING LIGHT
25. WING FLAP POSITION INDICATOR
26. MARKER BEACON LIGHT

Figure 7. Main Instrument Panel

COPILOT'S INSTRUMENT PANEL

23. REMOTE ATTITUDE GYRO SWITCH (ATTITUDE INDICATOR)

24. PILOT'S MULTIPLE INDICATOR

25. ANGLE OF ATTACK S/W TEST PANEL

26. ANGLE OF ATTACK TEST S/W INDICATOR LIGHT

27. AIR DIVERTER HANDLE

28. COMPASS CORRECTION CARD

29. ANGLE OF ATTACK INDICATOR LIGHTING CONTROL

30. RADAR ALTIMETER

31. NOSE SCISSORS EXTENDED INDICATOR

32. NACELLE OVERHEAT WARNING PANEL

33. DOOR WARNING LIGHT

34. COURSE INDICATOR

35. HEADING INDICATOR

36. AIR TURBINE MOTOR HEAT CONTROL PANEL

37. FREE AIR TEMPERATURE INDICATOR

38. HYDRAULIC SUCTION BOOST PUMP SWITCH PANEL

39. HYDRAULIC CONTROL PANEL

40. ANTI-SKID INOPERATIVE LIGHT (DISCONNECTED)

41. ANTI-SKID SWITCH (INOPERATIVE)

42. ELECTRONIC FUEL CORRECTION PANEL

43. LANDING GEAR CONTROL PANEL

44. SKI EMERGENCY-NORMAL PANEL (INOPERATIVE D-6)

45. WING FLAP POSITION INDICATOR

46. SKI CONTROL PANEL (INOPERATIVE D-6)

47. CABIN PRESSURE ALTITUDE INDICATOR

Figure 72 Copilot's Instrument Panel

flight director system indicators

A gyro   monitor

C horizontal situation indicator

B attitude director indicator
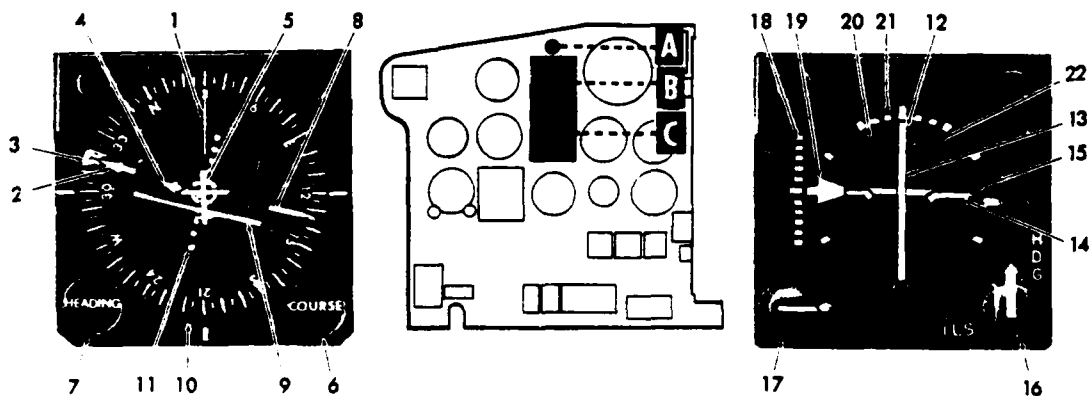
1. LUBBER LINE	12. BANK POINTER
2. COURSE ARROW (HEAD)	13. BANK STEERING BAR
3. HEADING MARKER	14. MINIATURE AIRCRAFT
4. TO - FROM INDICATOR	15. HORIZON BAR
5. AIRCRAFT SYMBOL	16. ILS-HDG SWITCH
6. COURSE SET KNOB	17. PITCH TRIM KNOB
7. HEADING SET KNOB	18. GLIDE SLOPE DEVIATION SCALE
8. COURSE ARROW (TAIL)	19. GLIDE SLOPE INDICATOR
9. COURSE DEVIATION INDICATOR	20. GLIDE SLOPE WARNING FLAG
10. COMPASS CARD	21. BANK SCALE
11. COURSE DEVIATION SCALE	22. COURSE WARNING FLAG

130A-1-33-120

Figure 73 Flight Director System Indicators

202

AIRPLANES AF57-0474 AND UP

19. RUDDER TRIM TAB POSITION INDICATOR

20. CLOCK

21. MARKER BEACON SWITCH

22. REMOTE ATTITUDE GYRO SWITCH (ATTITUDE INDICATOR)

23. ANGLE OF ATTACK S/W TEST PANEL ⚠1

24. ANGLE OF ATTACK TEST S. W INDICATOR LIGHT ⚠1

25. AIR DIVERTER HANDLE

26. COMPASS CORRECTION CARD
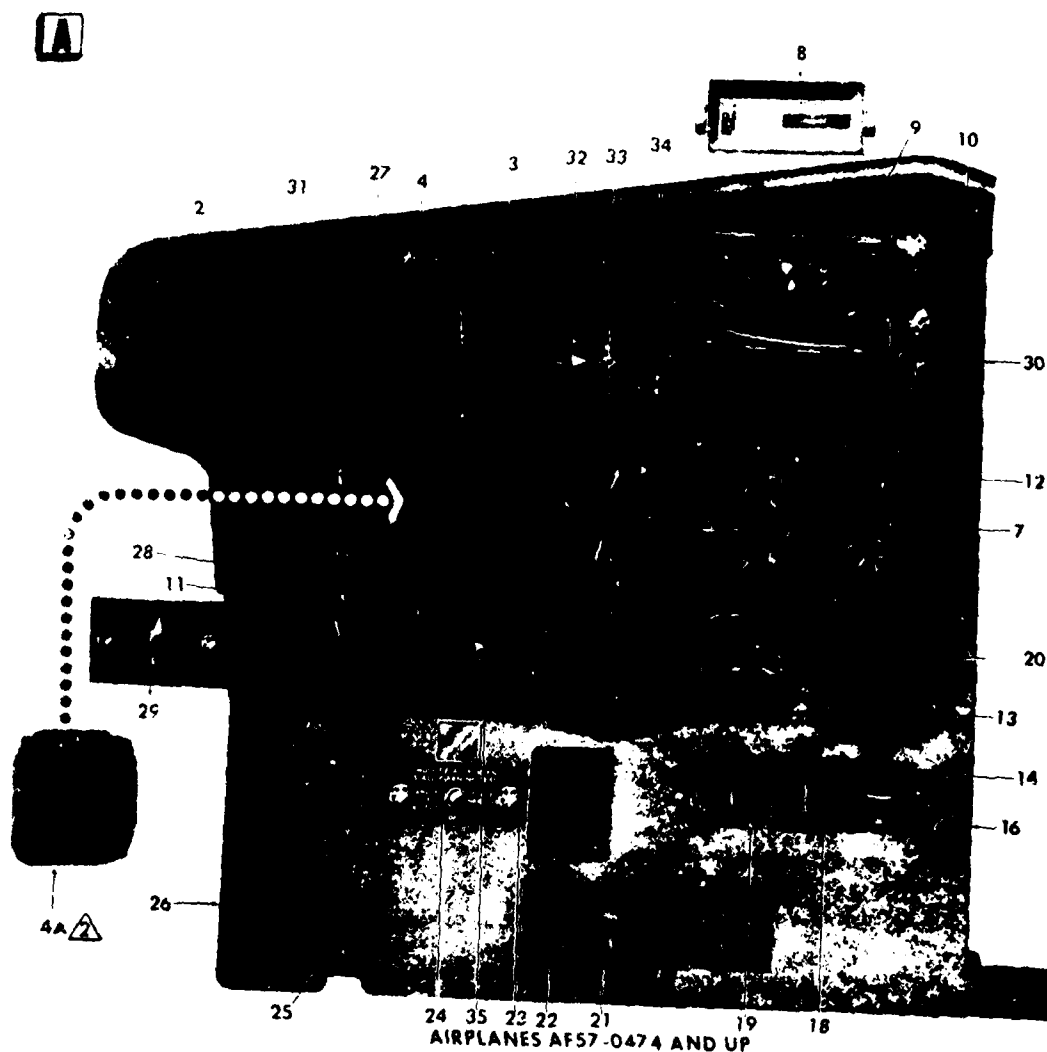
27. TURN AND SLIP INDICATOR

28. RADIO MAGNETIC INDICATOR

29. ANGLE OF ATTACK INDICATOR LIGHTING CONTROL ⚠2

30. MARKER BEACON LIGHT

31. ACCELEROMETER

32. HORIZONTAL SITUATION INDICATOR

33. FLIGHT DIRECTOR SYSTEM GYRO MONITOR

34. ATTITUDE DIRECTOR INDICATOR

35. PILOT'S MULTIPLE INDICATOR

NOTE ⚠1 AIRPLANES MODIFIED BY T.O. 1C 130-708.

⚠2 AIRPLANES MODIFIED BY T.O. 1C 130-838.

Figure 4 Left Instrument Panel

pilot's and copilot's instrument panels

[D] [D-6]

9 **PILOT'S INSTRUMENT PANEL**

1. MAGNETIC COMPASS
2. ACCELEROMETER
3. TURN AND SLIP INDICATOR
4. ALTIMETER
4A ALTIMETER ENCODER △2
5. AIRSPEED INDICATOR
6. HORIZONTAL SITUATION INDICATOR
7. FLIGHT DIRECTOR SYSTEM GYRO MONITOR
8. ATTITUDE DIRECTOR INDICATOR
9. ANGLE OF ATTACK INDICATOR △1
10. ATTITUDE INDICATOR **NOTE**

12. MARKER BEACON LIGHT
13. VERTICAL VELOCITY INDICATOR
14. RADIO MAGNETIC INDICATOR
15. CLOCK
16. TACAN RANGE INDICATOR
17. ELEVATOR TRIM TAB POSITION INDICATOR
18. LOW OIL QUANTITY LIGHT
19. AILERON TRIM TAB POSITION INDICATOR
20. RUDDER TRIM TAB POSITION INDICATOR
21. RADIO MAGNETIC INDICATOR
22. MARKER BEACON SWITCH

△1 AIRPLANES MODIFIED BY T.O. 1C-130-508
△2 AIRPLANES MODIFIED BY T.O. 1C-130-509

Figure 75. Pilot's and Copilot's Instrument Panels

E

ID-249A/ARN
INDICATOR

ID-310/ARN
RANGE INDICATOR

ID-250/ARN
INDICATOR

DISTANCE
NAUTICAL MILES

PILOT'S
INSTRUMENT
PANEL

FWD

F

ID-525/ARN
INDICATOR

G

C-1763/ARN-21A
CONTROL PANEL

ID-250/ARN
INDICATOR

FWD

COPILOT'S
INSTRUMENT
PANEL

FWD

Figure 76 AN/ARN-21 TACAN System Components
Locations

MLS CONSIDERATIONS

The F-111A/E
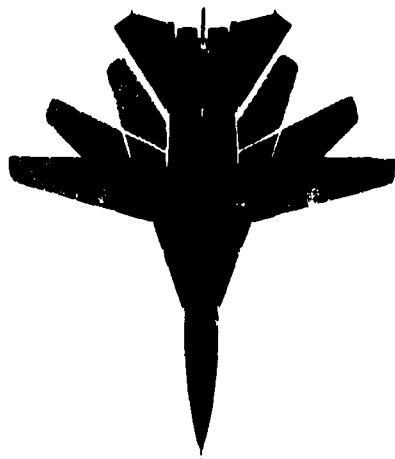
AE-300000-F096A

5.3   F-111A/E

5.3.1   General F-111A/E Information

The F-111A and F-111E are two place (side-by-side) long range
fighter bombers built by General Dynamics, Fort Worth Division.
The aircraft are designed for all-weather supersonic operation
at both low and high altitude, utilizing a choice of missiles,
guns, and bombs. An automatic low altitude terrain following
system enhances penetration capability. Power is provided by
two TF-30 axial-flow, dual-compressor turbo-fan engines equipped
with afterburners. The wings, equipped with leading edge slats
and trailing edge flaps, may be varied in sweep, area, camber,
and aspect ratio, by the selection of any wing sweep angle
between 16 and 72.5 degrees. This feature provides the aircraft
with a highly versatile operating envelope. The empennage
consists of a fixed vertical stabilizer with rudder for direct-
tional control, and a horizontal stabilizer that is moved
symmetrically for pitch control and asymmetrically for roll
control. Stability augmentation incorporates triple redundant
features which enhance system reliability.

The F-111 A and F-111E aircraft equipment consists of a group
of systems which, when functining together, make up a complete
aircraft weapons system. In many cases, the functions of one
system depend upon inputs and loads from other systems. The
aircraft systems are integrated so that maximum use of the
information available within each system can be fully utilized
with other aircraft systems.

The following systems were considered during the MLS interface
analysis:

                Air Data
                Bomb-Navigation
                Flight Control
                Flight Director
                Flight Instruments
                Inertial Bombing-Navigation
                Instrument Landing
                Intercommunications
                Lead Computing Optical Sight
                Radar Homing and Warning
                TACAN
                Terrain Following Radar
                UHF Automatic Direction Finder

All of the systems aboard the aircraft employ analog elements
for computation and interfacing. No digital computers are used.
Of the systems considered, only the Flight Director, Instrument
Landing,and Intercommunications systems are affected by the MLS
installation.

The components of the above systems which are MLS related are as
follows:

> Flight Director System
>
> Instrument System Coupler (ISC)
> Navigation and Attack Panel
> Flight Director Computer
> Horizontal Situation Indicator (HSI)
> Attitude Director Indicator (ADI)
>
> Instrument Landing System (AN/ARN-58A)
>
> Localizer Receiver, R-843/ARN-58
> Glide Slope and Marker Beacon Receiver,
> R844A/ARN-58

Since only single localizer and glide slope receivers are used,
and only flight director approach coupling is available
(no autopilot coupler), the approach avionics is Category I.

A block diagram of the existing navigation interface is illustra-
ted in Figure 77. Only those elements involved with the MLS
installation of possible MLS usage are included. As shown,
the deviation and flag signals from the localizer and glide
slope receiver, TACAN and Bomb-Navigation are applied to the
Instrument System Coupler (ISC) which is mounted on the
left main instrument panel. A mode select switch, integral to
the ISC, (See Figure 78, lower left) is used to select the
desired mode of operation.

When the ILS mode is selected, ISC logic routes the deviation
and flag signals of the Localizer and glide slope receivers
to the Flight Director Computer (FDC). This unit, in turn,
processes the signals and applies lateral and vertical deviation,
flag,and steering signals to the ISC logic. Appropriate switch-
ing in the ISC distributes these signals to the ADI, HSI and
Lead Computing Optical Sight (LCOS, via lead and launch computer)
displays.

When the ILS mode is selected, the position of the switch on the ISC is the only annunciation available during the entire approach. Loc arm and engage and glide slope arm and engage annunciations do not exist.

If the Airborne Instrument Low Approach (AILA) mode is selected, computed localizer and glide slope signals from the Bomb-Nav system (in conjunction with the Attack Radar System) are substituded for the ILS signals.

Referring to Figure 77, the HSI (pilot's side) and the BDHI (copilots side) both receive range and bearing signals from the TACAN system and these instruments can be time-shared by the MLS system.

Instrument landings can only be made by the crew member in the left seat. Only the left instrument panel includes navigation instruments (see Figure 79). With the exception of some basic instruments and a BDHI, the right main instrument panel (see Figure 80) is dedicated to controls and instruments associated with the weapons delivery capabilities of the aircraft system.

The ISC, HSI and ADI are illustrated on the left side of Figure 80) and are located on the left instrument panel. The ISC consists of an integral control panel and computer. Functional details of the HSI and ADI are illustrated on Figures 81 and 82, respectively.

A Lead Computing Optical Sight (LCOS, see Figure 83, is located on the left main instrument panel. This system functions as a heads up display and provides duplicate indications of the information presented on the ADI during operation of the ISC modes. Figure 84 illustrates a typical display presentation.

To integrate the recommended direct ILS replacement configuration (MLS-1) into the aircraft, the outputs of the localizer and glide slope receivers are interrupted (solid circles, Figure 77) and the MLS interface is interposed (see Figure 33, Typical Interface).

Very little space is available in the cockpit area (instrument panels, pedestal and right and left consoles) for new equipment (see Figure 85).

All of the instruments accept only analog interfaces.

5.3.2   F-111A/E MLS Recommendations

The MLS-1 configuration (CAT 1) is the only system recommended
for installation in the F111A/F111E type aircraft. This
conclusion is based on the following:

1.   Present low approach avionics is CAT I.

2.   Only flight director coupled approaches are pos-
      sible. Autopilot coupling is not available.

3.   Only the left side of the cockpit includes low
      approach instruments.

4.   Unused space in the cockpit area is very limited.
      Since a retrofit to a complex trajectory config-
      uration(MLS-3, or MLS-4) would require additional
      controls and displays, an extensive redesign of
      existing control and display instrumentation to
      incorporate the new functions would be required.*

5.   Present HSI course mechanism is not remotely
      slewable and both the MLS-3 and MLS-4 configur-
      ations require such a unit. It is possible to
      utilize a slewable bearing pointer as an alternate
      to course-slewing for MLS-3.

6.   Accomodation of multiple MLS antennas may not be
      possible because of present antennas density.

Because F-111A/F-111E mission requirements do not appear to
necessitate the need for DME during straight-in ILS type ap-
proaches, this added complexity and cost is not recommended.

      *It should be noted that during preparation of this
      report discussions within the USAF were underway re-
      garding an update of the F-111 Bomb Navigation
      system. If this results in a redesign of the existing
      Bomb-Nav Control Panel shown in Figure 86, the incor-
      poration of a more flexible MLS configuration could
      result.

If the proposed bomb-nav system modification is adopted it may
be possible to include additional changes which would provide
an MLS-3 or MLS-4 configuration capability. The bomb-nav control
panel (see Figure 86) must be modified to accomodate the sel-
ected capability. Changes to the Bomb-Nav system are beyond
the scope of this report.

Installation of an MLS-1 system in the F111A/F111E type aircraft
involves the addition of the following units:

UNIT	QTY.
MLS Angle Receiver	1
MLS Switching Unit	1
MLS-1 Tuner	1
MLS Angle Antenna	1

The first two units are remotely-located and these can be ac-
comodated in various aircraft locations.

From the information available in the T.O.'s it is apparent
that no open spaces are available in the cockpit area to
accomodate an MLS-1 type tuner (see Figure 36). Existing
panels will have to be redesigned and shifted. This task is
beyond the scope of this study and cannot be accomplished
without a physical inspection of various F111A/F111E aircraft.

MLS antennas must be mounted in the general area of the present
localizer and glide slope antennas (see Figure 87).   Due
to the density of the various other antennas in this location,
selection of an exact space for the MLS antennas is beyond the
scope of this report.

On the present aircraft, both the left and right crew member
have individual controls to switch on and adjust the volume of
the localizer-identifying audio code. Space is not available
on the existing panels (see Figure 78,   lower right) to
accomodate the MLS audio switches. These can be mounted on the
left and right sidewalls (see Figures 88 and 89).

Figure 90 illustrates the present ILS receiver/ICS interface
and the functions which must be interrupted and routed through
the MLS switching unit are labelled (solid circles).

Figure 91 is an illustration of the present TACAN/HSI/BDHI inter-
face. The wires associated with the range function are labelled
and these must be routed through the MLS switching unit it the
MLS DME is installed.

Empty holes exist on an essential bus panel to accomodate MLS
circuit breakers. This panel is located on the aft console of
the crew compartment. An illustration of this panel appears
on the right in Figure 92.

Figure 77 Block Diagram F-111A/E Navigation System

213

ID UMPING CAPACITORS (4)

RADIO SET CONTROL PANEL

MARKER
BEACON

ATTITUDE DIRECTOR
INDICATOR

MARKER
BEACON
INDICATOR

ANTENNA SELECT PANEL
PRIOR TO T.O. 1F-111A-565
AND T.O. 1F-111A-620

RECEIVER CONTROL PANEL

HORIZONTAL SITUATION
INDICATOR

RADIO SET CONTROL PANEL

INSTRUMENT SYSTEM
COMPUTER

LISTEN

HOT
MIC

TALK

ON AF S/N 65-5708
AND SUBSEQUENT AND
ON AF S/N 65-5701 THRU
AF S/N 65-5707 AFTER
T.O. 1F-111A-550

INTERCOMMUNICATION CONTROL
PANEL ON AF S/N 66-013 AND
SUBSEQUENT AND ON AF S/N 65-5701
THRU 65-5707 AFTER T.O.
1F-111A-519

INTERCOMMUNICATION CONTROL
PANELS (2) PRIOR TO T.O.
1F-111A-519

CHANGE LEGEND

THIS ILLUSTRATION HAS BEEN
EXTENSIVELY CHANGED

NOTE

⚠ ON AF S/N 66-016 THRU 66-024,
67-040 THRU 67-114, AND
ON AF S/N 65-5716, 66-011,
66-011 THRU 66-015, AND 66-025
THRU 67-039 AFTER T.O.
1F-111A-1302

ANTENNA SELECT PANEL
ON AF S/N 66-016 THRU
67-024 AFTER T.O. 1F-111A-920

ANTENNA SELECT PANEL
ON AF S/N 67-058 THRU
67-114 AFTER T.O. 1F-111A-565

Figure 78 Communications and Instrument
Landing Systems Component
Location (Crew Compartment)

Left Main Instrument Panel (Typical)

1. Engine Fire Pushbutton Warning Lamps.
2. Fuselage Fire Pushbutton Warning Lamp.
3. Agent Discharge/Fire Detect Test Switch.
4. External Stores Jettison Button.
5. Landing Gear Control Panel (See fig. 1-18).
6. Pilot's ECM Pod Control Panel (See T.O. 1F-111A1-2)
7. Angle-of-Attack Indexer.
8. Left Warning and Caution Panel.
9. Self Contained Attitude Indicator.
10. Wing Sweep Flap/Slat Position Indicator.
11. Upper Warning and Caution Panel.
12. Gun/Camera Control Switch.
13. Air/Air IR Missile Switch. (E) Rounds Counter. (A)
14. Instrument System Coupler Control Panel.
15. Landing Gear Position Indicator Lamps.

16. Left Main Caution Lamp Panel.
17. Lead Computing Optical Sight and Control Panel, (See fig. 1-89)
18. Upper Warning and Caution Lamp Panel.
19. Integrated Flight Instruments, (See fig. 1-35).
20. Dual Bombing Timer, (See fig. 1-70)
21. Control Surface Position Indicator.
22. Nose Wheel Steering/Air Refueling Indicator Lamp.
23. Radar Altimeter Indicator.
24. Stall Warning Lamp.
25. Radar Altitude Low Warning Lamp.
26. Master Caution Lamp.
27. Bomb Nav Distance-Time Indicator.
28. Takeoff Trim Indicator Lamp.
29. Takeoff Trim Button
30. Right Main Caution Lamp Panel.

31. Engine Tachometers.
32. Engine Turbine Inlet Temperature Indicators.
33. Engine Fuel Flow Indicators
34. Engine Nozzle Position Indicators.
35. Engine Pressure Ratio Indicators.
36. Engine Oil Pressure Indicators.
37. Hydraulic Pressure Indicators.
38. Oil Quantity Indicator Test Button.
39. Oil Quantity Indicator.
40. Air Refueling Receptacle Lights Control Knob.
41. Fuselage Fuel Quantity Indicator.
42. Fuel Quantity Indicator Test Button.
43. Total/Select Fuel Quantity Indicator.
44. Fuel Quantity Indicator Selector Knob.

Figure 79 Left Main Instrument Panel (Typical)

Right Main Instrument Panel (Typical)
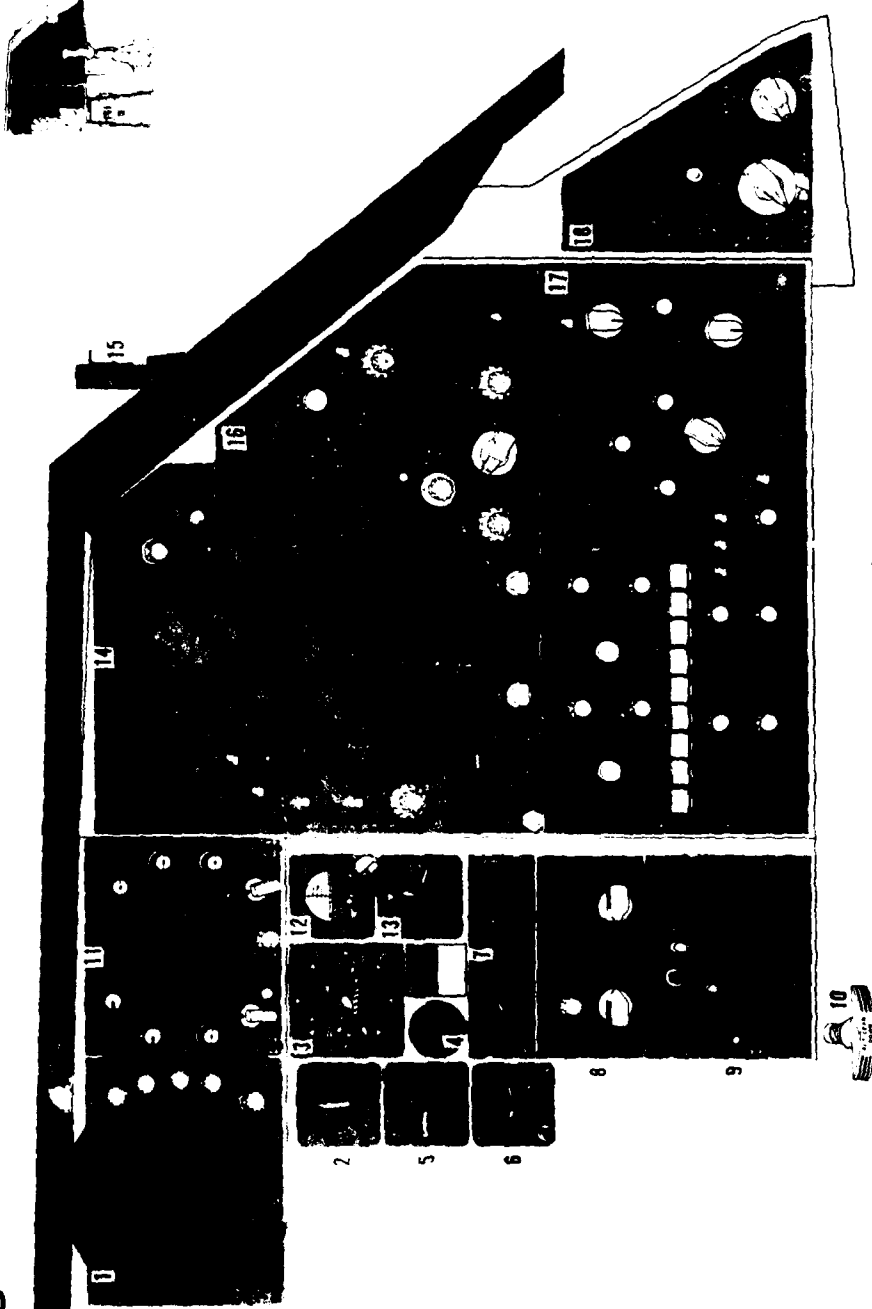
1. Terrain Following Radar
   Scope Panel. (See fig. 1-85)
2. Standby Airspeed Indicator.
3. Bearing-Distance-Heading
   Indicator.
4. True Airspeed Indicator.
5. Vertical Velocity Indicator.
6. Clock.
*7. SAM Sector Indicator/ECM Panel.

8. Offset Aimpoint Panel. (See fig. 1-65)
9. UHF Radio Control Panel. (See fig. 1-54)
10. Landing Gear Emergency
    Release Handle.
*11. Radar Homing and Warning
    Scope Panel.
12. Standby Attitude Indicator.
13. Standby Altimeter.

*Refer to T.O. 1F-111A-1-2

*14. Radar Homing & Warning Threat Panel.
15. Angle-of-Attack Indexer.
16. Attack Radar Scope Panel. (See fig. 1-80)
17. Bomb Nav Control Panel. (See fig. 1-64)
18. Nuclear Weapons Control Panel. (See fig. 1-69)

100000-04-5

Figure 80 Right Main Instrument Panel (Typical)

1-93

216

Figure 81 Horizontal Situation Indicator

HEADING INFORMATION INDICATED
EVERY 5 DEGREES ON
AZIMUTH SPHERE

COURSE WARNING FLAG

PITCH REFERENCE SCALE

GLIDE SLOPE DEVIATION
SCALE

BANK STEERING BAR
(VERTICAL POINTER)

MINIATURE AIRCRAFT

GLIDE SLOPE INDICATOR
(DISPLACEMENT POINTER)

GLIDE SLOPE
WARNING FLAG

PITCH STEERING BAR
(HORIZONTAL COMMAND BAR)

PITCH TRIM INDEX

PITCH TRIM KNOB

ATTITUDE
WARNING FLAG

TURN AND SLIP INDICATOR

BANK SCALE

INCLINOMETER

BANK POINTER

RATE OF TURN POINTER

A5111J00-F0078

Figure 82 Attitude Director Indicator

Lead Computing Optical Sight and Control Panel (Typical)
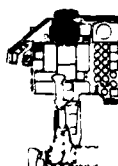
1. Optical Sight.
2. Preset True Airspeed Indicator.
3. True Airspeed Set Knob.
4. Reticle Depression Indicator.
5. Reticle Depression Set Knob.
6. Aiming Reticle Cage Lever.
7. Command Bar Brightness Knob.
8. Mode Select Knob.
9. Aiming Reticle Brightness Knob.
10. Test Switch.
11. Range/Altitude Set Knob.
12. Preset Range Indicator.
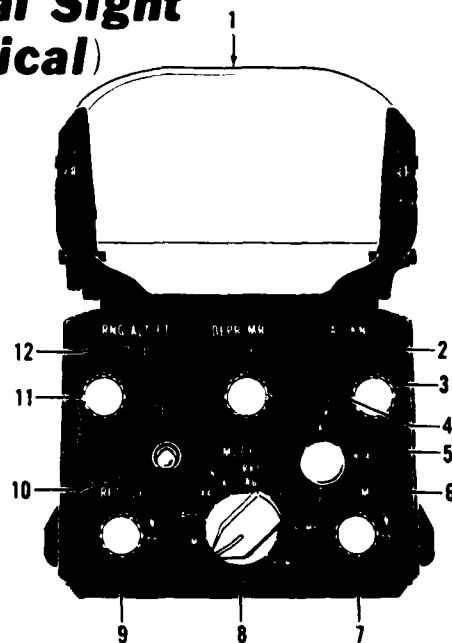
AE000000 I 093

Figure 83 Lead Computing Optical Sight
and Control Panel Typical

Aiming Reticle & Steering Bar Presentations
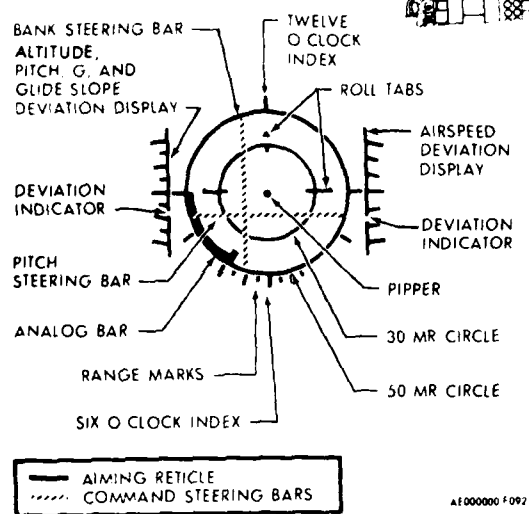
Figure 84 Aiming Reticle & Steering Bar
Presentations

Crew Station General Arrangement (Typical)
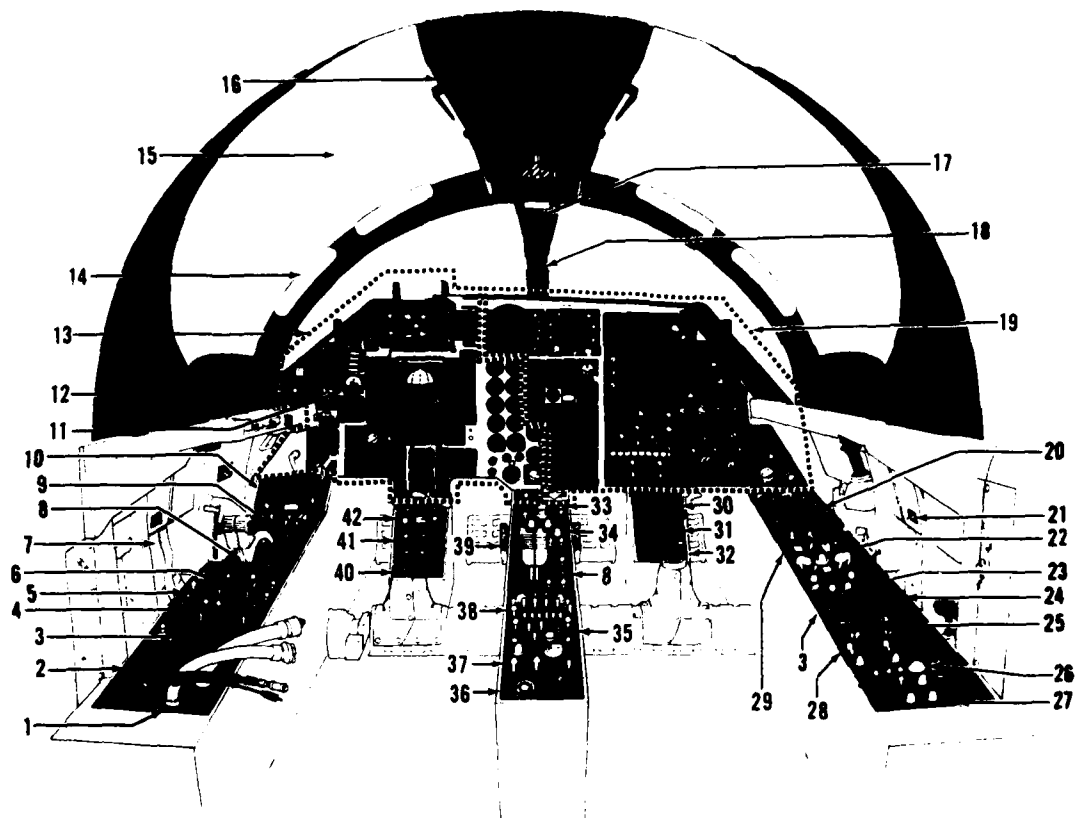
* See T.O. 1F-111A-1-2

1	Left Station Oxygen-Suit Control Panel (See fig. 1-48).	21	Right Sidewall (See fig. 1-45).
2	Oxygen Gage Panel (See fig. 1-49). (E)	22	Attack Radar Control Panel (See fig. 1-78).
	Electrical Power Test Panel (See fig. 1-12). (A)	23	HF Radio Control Panel (See figs. 1-55 or 1-56).
3	Interphone Panel (2) (See fig. 1-58)	24	Strike Camera Control Panel (See fig. 1-74).
4	Auxiliary Flight Control Panel (See fig. 1-28)	*25	ECM Control Panel.
5	Flight Control Switch Panel (See fig. 1-29).	*26	CMRS Control Panel.
6.	Autopilot Damper Panel (See fig. 1-30).	*27	CMDS Control Panel
7	Left Sidewall (See fig. 1-21).	*28	ECM Pod Control Panel
8.	Throttle Panel (2) (See fig. 1-4)	*29	ECM Destruct Control Panel
9	Miscellaneous Switch Panel (See fig. 1-61).	30	Burst Control Panel (Se fig. 1-66).
0	Auxiliary Gage Panel (See fig. 1-17).	31	TACAN Control Panel (See fig. 1-59)
11	Self Contained Attitude Indicator	32	ILS Control Panel (See fig 1-60).
12	Internal Canopy Latch Handles (2)	33	Fuel Control Panel (See fig 1-8)
13	Left Main Instrument Panel (See fig. 1-5).	34	TFR Control Panel (See fig. 1-84).
14	Mirrors (4).	35	Electrical Control Panel (See fig. 1-11).
15	Canopy	36	Scope Camera Control Panel (See fig. 1-76)
16	Thermal Curtain (2).	37	Air Conditioning Control Panel (See fig. 1-43).
17	Canopy Center Beam Assembly.	38	IFF Control Panel (See fig 1-62)
18	Magnetic Compass.	39	Ejection Handles (2)
19	Right Main Instrument Panel (See fig. 1-34).	40	Antenna Select Panel (See fig. 1-63).
20	Weapons Control Panel (See fig. 1-71). (E)	41	Windshield Wash/Anti-Icing Control Panel (See fig. 1-46).
	Armament Select Panel (See fig. 1-68). (A)	42	Compass Control Panel (See fig. 1-33).

Figure 85   Crew Station General Arrangement (Typical)

Bomb Nav Control Panel (Typical)
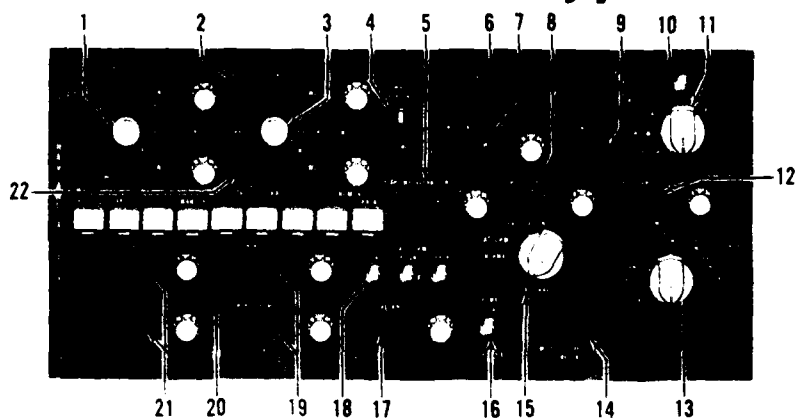
1. Present Position Hold Button.
2. Present Position Counters (2).
3. Present Position Correction Button.
4. Magnetic Heading Synchronization Indicator.
5. Fixpoint Elevation Counter
6. True Heading Counter.
7. Magnetic Variation Counter.
8. Time-of-Fall Counter

9. Ground Track and Groundspeed Counters (2).
10. Go Lamp.
11. Altitude/Test Selector Knob.
12. Trail/Range Counter.
13. Bomb Nav Mode Selector Knob.
14. Destination Distance/Time Counter.
15. Platform Alignment Control Knob.
16. Bomb Release Lamp
17. Glide/Dive Angle Counter.

18. Platform Indicator Lamps (3).
19. Windspeed and Wind From Counters.
20. Bomb Nav Fix Mode Selector Buttons
21. Offset Range and Offset Bearing Counters (2).
22. Destination Position Counters

Figure 86 Bomb NAV Control Panel (Typical)

Antenna Locations (Typical)

1. Glide Slope.
2. ADF.
3. IFF (Upper) and UHF Data Link.
4. Radio Beacon Set
5. UHF #1 and TACAN Upper.
6. HF.
7. IFF Lower.
8. Localizer (2)
9. Low and Medium Frequency Radar Homing (4).
10. Forward Radar Warning (2)
11. High Frequency Radar Homing (4).
12. TFR (2).
13. Attack Radar.
14. AN/ALQ-94 (3).
15. Radar Altimeter.
16. ALR-41
17. AN/ALQ-94 (12).
18. ALR-41 (4).
19. Aft Radar Warning (2).
20. AN/ALQ-94 (6).
21. UHF #2 and TACAN Lower.
22. AN/ALQ-94(3).
23. Marker Beacon.
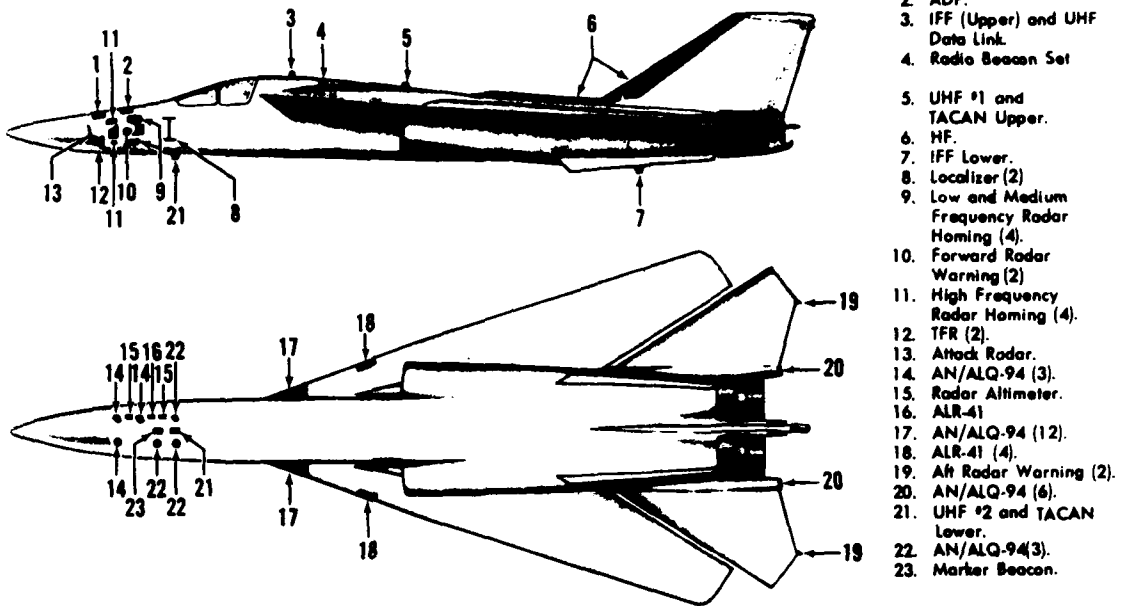
Figure 87 Antenna Locations (Typical)

223

Left Sidewall (Typical)

1. Checklist Stowage.
2. Seat Adjustment Switch
3. Arm Rest.
4. Wing Sweep Handle 26 Degree Forward Gate.
5. Wing Sweep Control Handle
6. Wing Sweep Handle Lockout Controls.
7. Spoiler Reset Button.
8. Ground Roll Spoiler Switch.
9. Map Stowage.
10. Ejection System Safety Pin Stowage.

AE009800.F033A
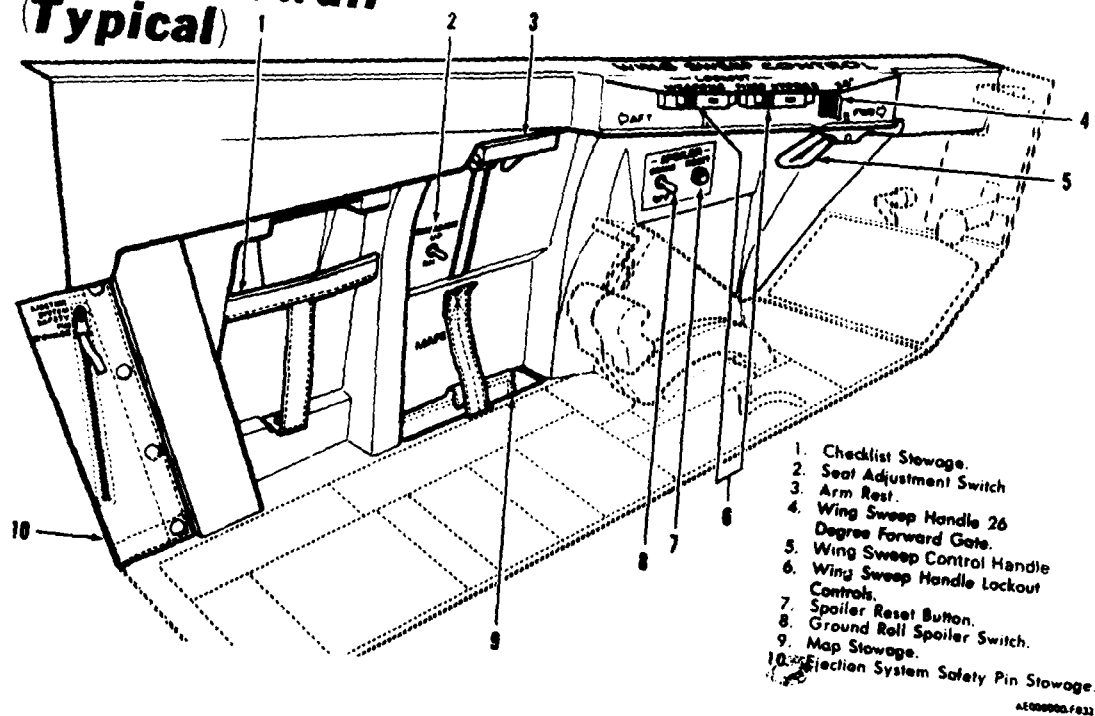
Figure 88 Left Sidewall (Typical)

Right Sidewall (*Typical*)

1. Attack Radar Tracking Control Handle.
2. Arm Rest.
3. Seat Adjustment Switch.
4. Map Stowage.
5. Spare Lamps and Fuses Holder Stowage.
6. Utility Light.
7. Cabin Air Distribution Control Lever.
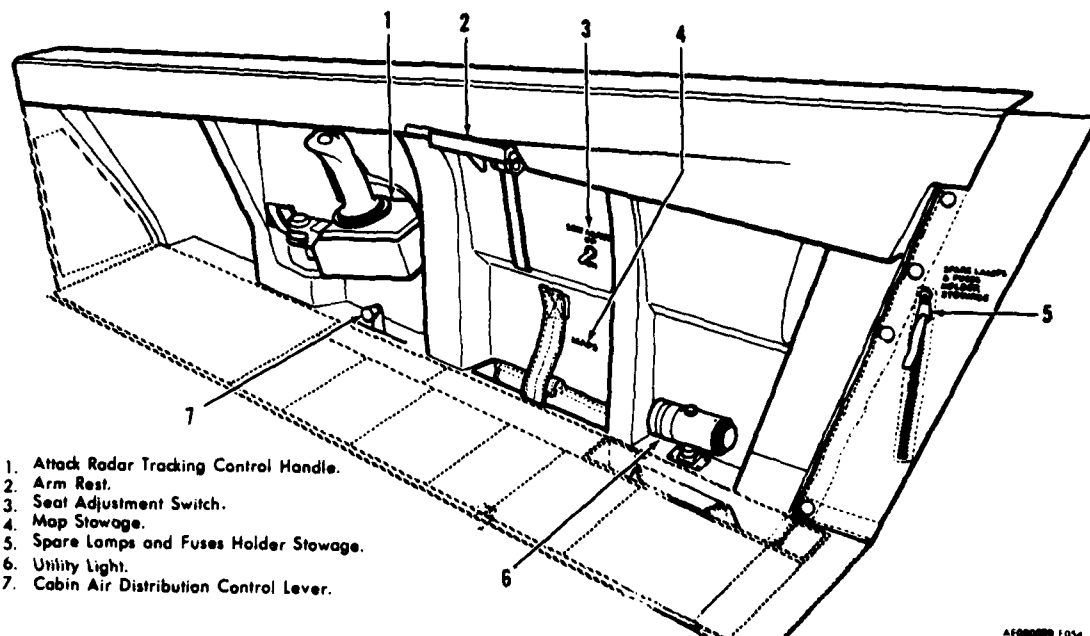
Figure 89 Right Sidewall (Typical)

Figure 90   ILS Receiver/ISC Interface

WHEN INTERFACING MLS
INTERRUPT ILS SIGNALS
AT THESE POINTS

226

Figure 91   Tacan Interface

Circuit Breaker Panel (*Typical*)

(A)

(E)

MOUNTING SPACE
AVAILABLE FOR MLS
CIRCUIT BREAKERS
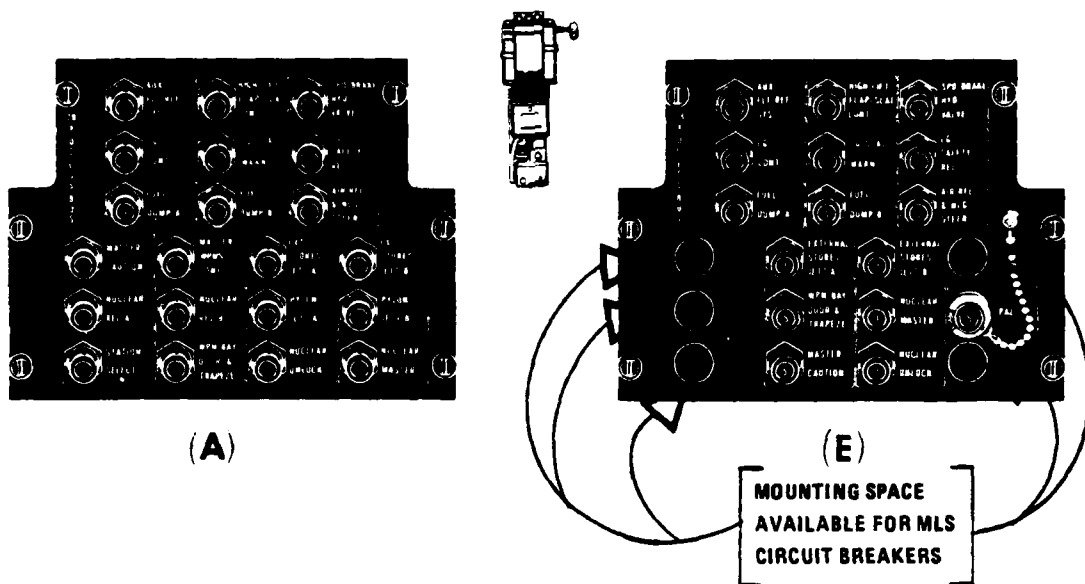
CIRCUIT BREAKER	FUNCTION
AFRS	Provides power to the primary att/hdg caution lamp, the aux/att caution lamp and used as the AFRS good signal.
HIGH LIFT FLAP/SLAT CONT	Provides power to the flap/slat asymmetry system and power to the flap/slat emergency motor.
SPEED BRAKE HYD VALVE	Provides power to the speed brake hydraulic valves.
LG CONT	Provides power to the extend and retract solenoids on the landing gear hydraulic valve.
LG/STALL WARN	Provides power to the landing gear handle warning lamp, gear down and lock indicator lamps, stall warning lamp, and to the warning tone generator.
LG SAFETY RELAY	Provides power to the ground safety switch circuit which inhibits certain aircraft functions.
FUEL DUMP A	Provides power to the fuel dump valve A and C.
FUEL DUMP B	Provides power to fuel dump valve B, dump relays A and B, and auto transfer solenoid valve.
AIR RFL & NLG STEER	Provides power to the air refueling receptacle or nose landing gear steering.
MASTER CAUTION	Provides power to the master caution lamp.

CIRCUIT BREAKER	FUNCTION
MASTER WPNS CONT (A)	Provides power to the master power switch on the armament select panel.
EXT STORES JET A	Provides power to external stores jettison button. (Has no effect on selective jettison.)
EXT STORES JET B	Same as Jett A. (Redundant)
NUCLEAR REL A (A)	Provides power for nuclear release.
NUCLEAR REL B (A)	Same as Rel A.
PYLON JETT A (A)	Provides power for normal jettison of the pylons.
PYLON JETT B (A)	Same as Pylon Jett A. (Redundant)
STATION SELECT (A)	Provides power to energize the station select relays.
WPN BAY DOOR & TRAPEZE	Provides power for operation of the weapon bay door and trapeze.
NUCLEAR UNLOCK	Provides power to monitor the status of the inflight lock on the MAU rack.
NUCLEAR MASTER	Provides source of power and control for the aircraft monitor and control system (AMAC).
PAL (E)	Provides power to PAL for enabling nuclear bombs for pre-arming.

Figure 92   Circuit Breaker Panel (Typical)

5.4   A-7D

5.4.1   General A-7D Information

The A-7D is a single-engine, single-place, transonic, light
attack aircraft, manufactured by Vought Corporation Systems
Division, Dallas, Texas. Equipped with radar, navigational,
communications, and weapon systems, the A-7D has an all-
weather combat capability. The aircraft armament system
includes a single, nose-mounted M61 gun, six wing-mounted
store pylons, and two fuselage-mounted store pylons. A variety
of missiles, bombs, and rockets can be carried and released in
manual or automatic modes. A Navigation/Weapon Delivery System
integrates many of the aircraft's avionic subsystems to provide
for navigation to the target, computed run on target, computed
weapon release, and return navigation. A Head-Up Display (HUD)
System is provided to put all steering and attack displays
between the pilot's eyes and the windshield. A single, large
speed brake is mounted on the bottom side of the fuselage. An
arresting hook retracts under the fuselage aft section.
Stability, control augmentation, trim, and autopilot functions
are provided by an Automatic Flight Control System.

The A-7D Aircraft avionics consists of a number of systems
which, when functioning together, make up an integrated
NAV/Weapon Delivery System (NWDS. see Figure 93).
The subsystems of the NWDS are as follows:

> NAV WD Computer Set
>
> Inertial Measurement Set (IMS)
>
> Doppler Radar Set (DRS)
>
> Forward-Looking Radar System (FLR)
>
> Air Data Computer System (ADC)
>
> Head-Up Display Set (HUD)
>
> Armament Station Control Unit (ASCU)
>
> Projected Map Display Set (PMDS, not installed on all
> aircraft)

Peripheral equipment associated with the NWDS follows:

> Automatic Direction Finder (ADF)
>
> Radar Altimeter

Tacan Navigational Set

* Instrument Landing System (ILS)
* Flight Director Computer (FDC)
* Altitude Director Indicator (ADI)
* Horizontal Situation Indicator (HSI)
* Mode Selection Switches and Relays

Intercommunication System

* Elements of the Heading Mode System (HMS).

Signals from the NWDS, Tacan, ADF and Radar Altimeter
are routed through the HMS.

All of the listed subsystems and peripheral equipment were
considered during the MLS interface analysis. The tactical
computer associated with the NAV WD computer set is a general
purpose, stored-program, digital computer. It interfaces with
the other subsystems via data links and analog elements. All
interfacing with the peripheral equipment and the NWDS is analog.

Of the subsystems and peripheral equipment considered, only the
flight director computer, relaying,and intercommunications are
affected by the MLS installation.

Since only single elements are used for ILS and since approach
coupling is available only via the flight director, the approach
avionics is no better than Category I.

A block diagram of the existing heading (navigation) mode inter-
face is illustrated in Figure 94.   Only those elements in-
volved with the MLS installation or possible MLS usage are
included. As shown, signals from the various elements are
applied to the flight director computer. This computer pro-
cesses these signals and provides inputs to the left avionics
relay assembly and to the pitch channel of the HUD system.
Outputs of the relay assembly are, in turn, applied to the HSI,
ADI and roll channel of the HUD system.

The ILS mode is activated by depressing the landing mode push-
button switch (see Figures 95 a, b,and c, Ref. No. 4).
As a result, localizer and glide deviation signals and flags
are applied to the various instruments. In addition, the
flight director computer provides flight path steering signals
to the ADI and HUD for localizer and glide slope flight path
control.

When the landing mode is selected, the cap of the pushbutton
switch is illuminated and the legend "LDG" is annunciated.
This is the only annunciation available during the entire
approach.

Typical instrument panels are illustrated on Figures 96 and
97.   The HSI and ADI are located in the center of the panel,
and the HUD is located above the panel. Space is not available
for MLS panels.

Functional details of the HSI and ADI are illustrated on Figures
98 and 99 respectively. The course pointer and readout
on the existing HSI is not remotely slewable. Functional details
of the HUD are illustrated on Figures 100a through 100e.

5.4.2   A-7D MLS Recommendations

Since the A-7D type aircraft must operate at forward air bases,
where the benefits of MLS could be used to enhance mission
effectiveness and aircraft survivability, an MLS-3 (Selectable
Intercept of Final) or MLS-4 (Complex Trajectory) configuration
capability is highly desirable. Due to weight and space
restrictions on the aircraft, the lack of autopilot coupling
for approach, and the fact that the MLS-3 configuration provides
a significant reduction in pilot workload in comparison to the
MLS-4 configuration, nothing more complicated than the MLS-3
configuration can be recommended. Moreover, further simula-
tion and/or flight test work is required to prove out the
merits of this level of complexity for a single-seat aircraft.

Installation of an MLS-3 system in the A-7D type aircraft
involves the addition of the following units:

ITEM	UNIT	QTY.
1	MLS Angle Receiver	1
2	DME Interrogator	1
3	MLS NAV Coupler	1
4	MLS Switching Unit	1
5	MLS AZ/DME Display	1
6	MLS Tuner/Selector	1
7	MLS Angle Antenna	1

ITEM	UNIT	QTY.
8	MLS DME ANTENNA	1
9	Audio Panel (Switches)	1

Items 1 through 4 are remotely located in the avionics bay.
If available space is critical, the following are alternate
solutions to conserve space and reduce weight:

1. Replace existing flight director computer with custom
   MLS NAV Coupler which is unique for the A-7D aircraft.
   An adapter may eliminate the need for disturbing the
   existing wiring.

2. Absorb the NAV Coupler functions into the present
   tactical digital computer. This involves a signifi-
   cant program change as a minimum but more importantly,
   it requires a major investigation effort to determine
   feasibility.

3. If neither of these alternate solutions is feasible,
   then only an MLS-1 (direct ILS replacement) configura-
   tion is applicable to the A-7D type aircraft.

The AZ/DME display can be mounted above and to the right of the
HSI on the instrument panel (see Figures 96 and 97).   If
this is not physically possible, the DME readout can be
eliminated and an azimuth readout can be mounted in this
location. If this DME readout is eliminated, the DME infor-
mation on the HSI can be changed from distance-to-transition
to raw MLS DME.

Space is available on the lower portion of the righthand console
in the cockpit to mount the MLS Tuner/Selector and the MLS Audio
panel (see Figures 100 and 102).   Space is not available on the
lefthand console (see Figures 103 and 104).

MLS antennas must be mounted in the general area of the present
g deslope antenna (see Figure 105).   An exact location is
beyond the scope of this report; however, no complications are
expected.

Figure 106   illustrates the present audio controls. Space is
not available to accommodate the two MLS audio switches. As
previously noted, these will be mounted on the right lower
console (see Figures 101 and 102).

Figures 107 and 108 illustrate the present localizer and glide-slope receiver interface and the functions which must be interrupted and routed through the MLS switching unit.

Figure 109 illustrates the present TACAN/HSI interface and the functions which must be interrupted in order to display MLS range, bearing (pointer No. 1) and intercept course (pointer No. 2). Utilizing pointer No. 2 for the intercept course is not the optimum solution; however, it precludes the need for replacing the HSI with one with a remotely slewable course function. The range and bearing functions must be routed through the MLS switching unit. The HSI requires an analog interface for these functions and the MLS NAV Coupler provides the desired converted outputs.

DC power is available for MLS units and space is available on the circuit breaker panel in the avionics compartment to accommodate the MLS circuit breakers (see Figure 110).

NOTE

arrows denote direction of signal flow.

Figure 95 NAV/Weapon Delivery System - NAV Portion
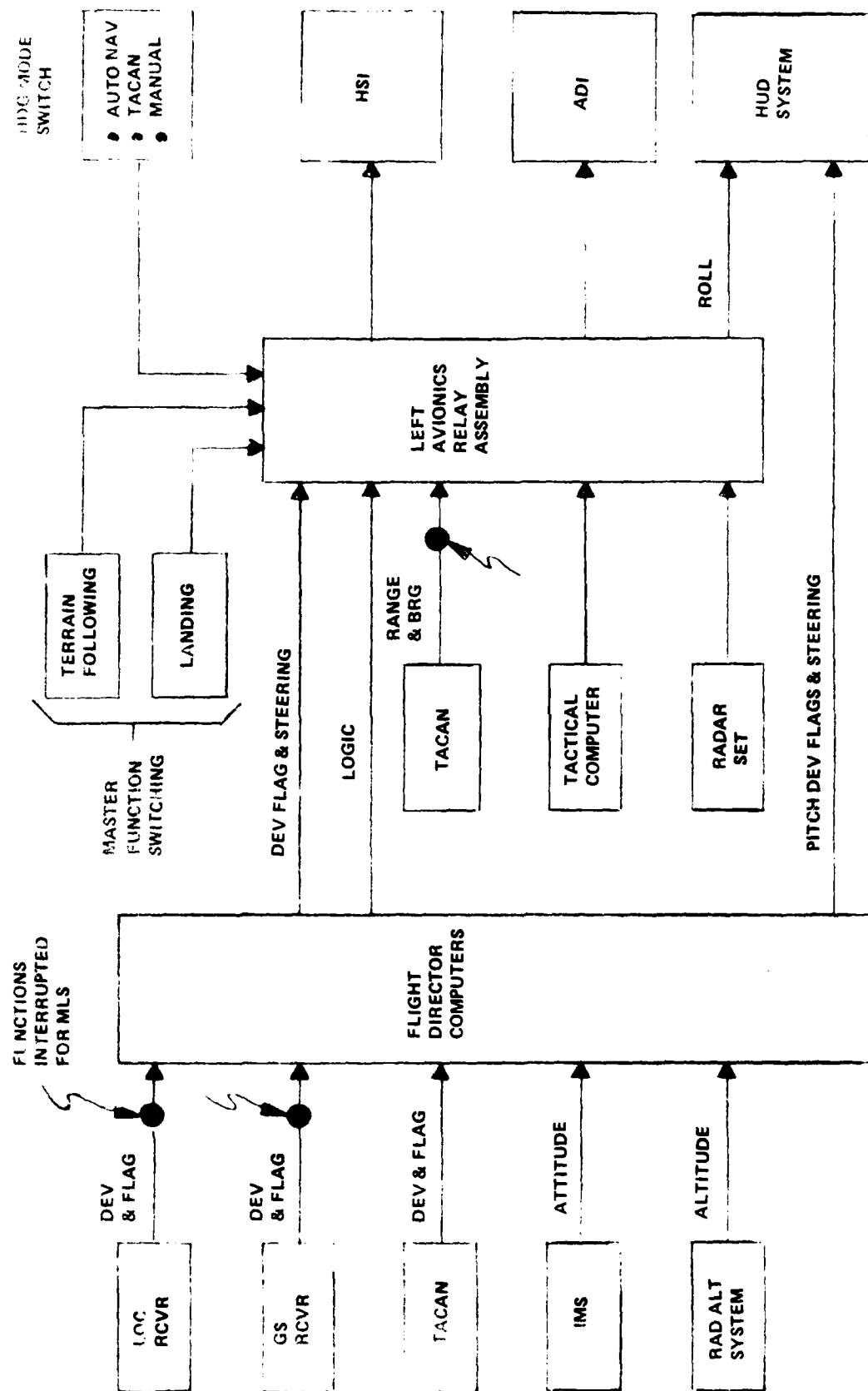
Figure 94 Heading (Navigation) Mode Block Diagram

AIRCRAFT → [16] [18] → [26]
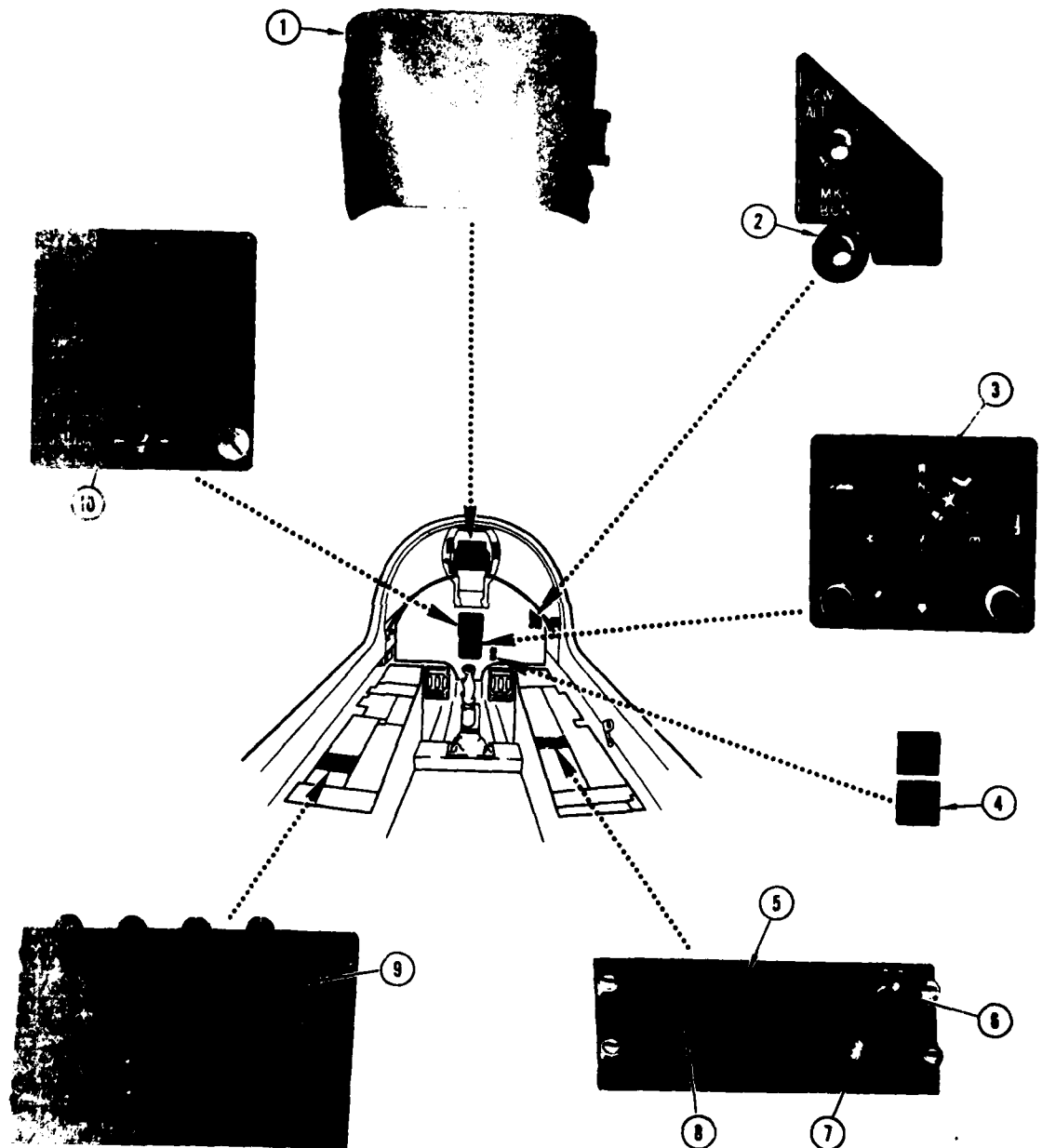
Figure 95a   ILS Controls

AIRCRAFT [17] [27] →

LOW
ALT

MKR
BCN

Figure 95b

238

Control	Function
1. Head-up display	Displays ILS landing symbols and angle-of-attack bracket when LDG mode master function switch is depressed. Indications include raw ILS deviation (landing flight path lines) and flight director computer steering commands (flight director symbol).
2. MKR BCN light	On — indicates passage over a 75.0 megacycle marker beacon.
3. Horizontal situation indicator	Course deviation bar indicates amount and direction of deviation from localizer beam during landing (raw localizer deviation). Course deviation bar flag appears if localizer signal is not adequate for reliable display.
4. LDG mode master function switch	Pressed — energizes landing mode circuitry in Flight Director Computer, heading mode relay, and HUD to enable displays for detection and capture of ILS localizer and glide slope beam.
5. Frequency selector	Used to select the desired localizer and paired glide slope frequencies.
6. POWER switch	POWER — applies operating power to localizer and glide slope receivers.
	OFF — disconnects power to receivers.
7. VOL control	Rotated clockwise increases localizer audio level.
8. FREQ indicator	Indicates selected localizer frequency.
9. Intercommunication panel ILS monitor	Pulled — enables ILS audio to be heard in pilot's headset. Turned to adjust volume.
10. Attitude director indicator	Pressing the LDG mode master function switch permits ILS information to be displayed on the ADI. The Flight Director Computer issues steering commands to the ADI vertical and horizontal pointers and to the HUD landing symbols. Raw glide slope deviation is indicated on the ADI glide slope indicator. Horizontal pointer alarm flag and vertical pointer alarm flag stowed out of view as long as glide slope and localizer signals are reliable and Flight Director Computer operation is normal.

Figure 95c

1. Wheels/Flaps Warning Lights	16. Oil Pressure Indicator	31. Horizontal Situation Indicator
2. Approach Indexer	17. Fuel Flow Indicator	32. Attitude Director Indicator
3. Deleted	18. Oil Quantity Indicator	33. Attack Mode Controls
4. Speed Brake Position Indicator	19. True Airspeed Indicator	34. Clock
5. Master Caution Light	20. Cabin Pressure Altimeter	35. Angle-of-Attack Indicator
6. Head-Up Display Unit	21. Takeoff Check List	36. Mach and Airspeed Indicator
7. Fire Warning Light Press-to-Test Switch	22. Liquid Oxygen Quantity Indicator	37. Armament Select Panel
8. Radar Altimeter Indicator/Warning Light	23. Hydraulic Pressure Indicator	38. Land Check List — Radio Call Placard
9. Threat Lights	24. Fuel Quantity Tank Selector	39. TE Flaps Position Indicator
10. Fire Warning Light	25. Turbine Outlet Pressure Indicator	40. LE Flaps Position Indicator
11. Marker Beacon Light	26. Fuel Quantity Indicator	41. Landing Gear Position Indicators
12. Tachometer	27. Vertical Velocity Indicator	42. Radar Indicator
13. Standby Compass	28. Accelerometer	43. Standby Attitude Indicator
14. Counter Pointer Altimeter (Barometric)	29. Heading Mode Controls	44. UHF Remote Channel Indicator
15. Turbine Outlet Temperature Indicator	30. Armament Release Controls	

Figure 96 Main Instrument Panel

MAJOR CHANGE
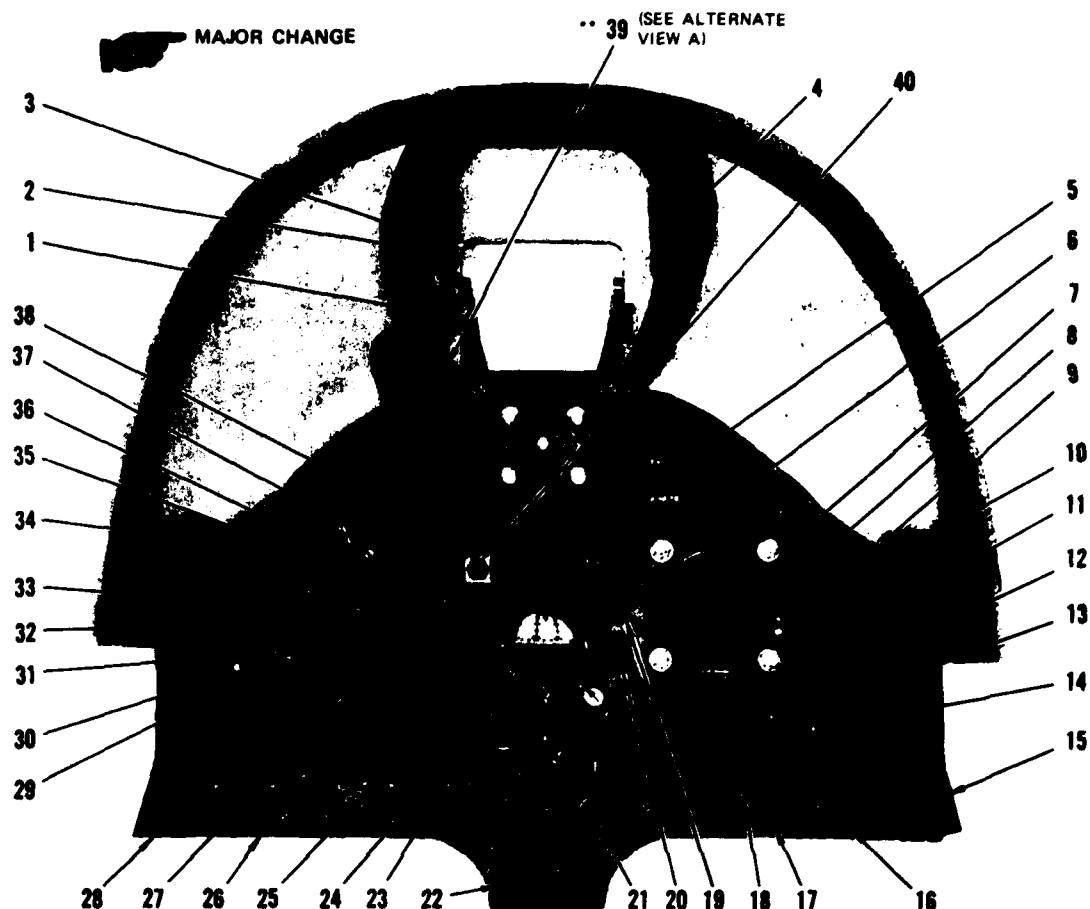
1. Approach indexer
2. IFR and wheel/flaps warning lights
3. Head-up display unit
4. Threat lights
5. Radar set control
6. Oil quantity indicator
7. Radar altimeter warning light
8. Marker beacon light
9. Fuel flow indicator
10. Accelerometer
11. Turbine outlet temperature indicator
12. Oil pressure indicator
13. Tachometer
14. Turbine outlet pressure indicator
15. Takeoff checklist
16. Fuel quantity indicator
17. Projected map display
18. Radar indicator
19. Fire warning light
20. Master caution light

21. Horizontal situation indicator
22. Heading mode controls
23. Attitude director indicator
24. Clock
25. Counter pointer altimeter
26. Armament select panel
27. Angle-of-attack indicator
28. Land checklist — radio call placard
29. Armament release controls
30. Vertical velocity indicator
31. Attack mode controls
32. Speed brake indicator
33. Radar altimeter indicator
34. Standby compass
35. Threat lights and correlate switch
36. Mach and airspeed indicator
37. Standby attitude indicator
38. ECM threat display unit
**39. UHF remote channel indicator
40. Standby gyro erect switch
##41. UHF remote channel indicator
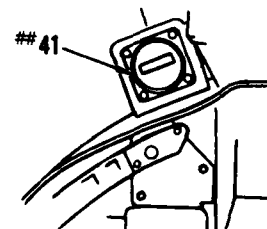
**Airplanes before T.O. 1A-7D-785
##Airplanes after T.O. 1A-7D-785

ALTERNATE VIEW A

Figure 97 Alternate View A

INDEX NO	NOMENCLATURE	FUNCTION
6	Bearing pointer number 2	Indicates ground track to destination in automatic navigation mode. Indicates bearing to station in ADF position or manual heading in TACAN mode.
7	Lubber line	Indicates airplane heading on compass card.
8	Heading marker	Indicates heading selected with heading set knob.
9	Digital course readout	Indicates course selected with course set knob.
10	Course deviation bar and dots	Indicates amount and direction of deviation from TACAN radial in TACAN mode. Indicates amount and direction of deviation of deviation from localizer beam in landing mode. Inoperative and centered in other modes.
11	Power off warning flag	OFF indicates power or or indicator failure. Black when indicator is operative.
12	Fixed marker	Provides fixed airplane reference at 45° points from lubber line.
13	Elapsed time indicator	Records running time of indicator; time is recorded in 4.8 hours up to 9.999.
14	Course set knob	Sets course indicator and selected course pointer. Rotates course datum synchro to provide course signal to flight director computer.
15	Reciprocal bearing pointer number 1	Indicates reciprocal of bearing pointer number 1 indication.
16	Reciprocal heading pointer number 2	Indicates reciprocal of bearing pointer number 2 indication.
17	Reciprocal course pointer	Indicates reciprocal of course pointer indication.
18	Aircraft symbol	Indicates airplane heading and is fixed to lubber line reference.
19	Heading set knob	Positions heading marker. Rotates heading synchro to provide heading signal to flight director computer and automatic flight control system.
20	To/From arrow	Indicates whether selected course is to or from TACAN station in TACAN mode. Out of view in all other modes.
21	Course deviation bar flag	In view if TACAN signal is not adequate for a reliable display in TACAN mode. In view if localizer signal is not adequate for a reliable display in landing mode. Out of view in other modes.

INDEX NO.	NOMENCLATURE	FUNCTION
1	Distance flag shutter	Conceals distance indicator when TACAN distance signal is not adequate for reliable indication. Out of view in automatic navigation mode.
2	Distance counter	Indicates distance to destination in automatic navigation mode. Indicates distance to TACAN station in manual heading and TACAN modes.
3	Bearing pointer number 1	Indicates bearing to destination in automatic navigation mode. Indicates bearing to TACAN station during manual heading and TACAN modes.
4	Compass card scale	Indicates airplane heading in degrees under lubber line.
5	Course pointer	Indicates course selected with course set knob.

Figure 98 Heading Mode System Horizontal Situation Indicator Controls And Indicators

INDEX NO	NOMENCLATURE	FUNCTION
5	Horizontal pointer flag	In view if glide slope signal is not adequate for a reliable display or flight director computer malfunctions in landing mode.
		In view if radar command signal is not reliable in terrain following mode.
		Out of view in other modes.
6	Vertical pointer	Provides steering command to localizer beam in landing mode.
		Indicates tactical computer steering error in automatic navigation mode.
		Provides steering command to selected heading in manual heading mode.
		Provides steering command to TACAN radial in TACAN mode.
7	Pitch trim knob	Adjusts zero-pitch position of horizon bar to compensate for airplane pitch attitude.
8	Rate of turn indicator	Indicates airplane rate of turn about the vertical axis.
9	Slip indicator	Indicates airplane slip or skid when ball is not centered.
10	Power off indicator	OFF – indicates inertial measurement set, indicator, or power failure.
11	Horizon bar	Relationship to fixed miniature airplane indicates airplane attitude with reference to the horizon.
12	Miniature airplane	Relationship to horizon bar indicates airplane attitude with reference to the horizon.
13	Displacement pointer	Indicates amount and direction of deviation from glide slope beam in landing mode.
		Out of view in other modes.
14	Displacement pointer flag	In view if glide slope signal is not adequate for a reliable display in landing mode.
		Out of view in other modes.
15	Horizontal pointer	Provides steering command to glide slope beam in landing mode.
		Provides pitch commands in terrain following mode.
		Out of view in other modes.
16	Displacement pointer scale	Provides scale indexes for displacement pointer.
17	Sphere	In conjunction with miniature airplane indicating airplane attitude in relation to horizon.

INDEX NO.	NOMENCLATURE	FUNCTION
1	Vertical pointer alarm flag	In view if localizer signal is not adequate for a reliable display or flight director computer malfunctions in landing mode
		In view if tactical computer signal is not reliable in automatic navigation mode.
		In view if TACAN signal is not adequate for a reliable display or flight director computer malfunctions in TACAN mode
		In view if flight director computer malfunctions in manual heading mode.
2	Bank angle indexes	Indicates bank angle.
3	Bank angle dial and scale	Indicates bank angle in conjunction with horizon bar.
4	Dial mask and vertical pointer shield	Conceals vertical pointer when pointer is not being used for information display

Figure 99 Heading Mode System Attitude Director Indicator Controls And Indicators

Figure 100a Head Up Display (HUD)
Controls

HEAD-UP DISPLAY (HUD) CONTROLS

Nomenclature	Function
1. IN RNG indicator	On (IN RNG) — indicates when aircraft is within a preselected range of target. Range is set on the RANGE SET thumbwheel control on left console.
2. PNL LTS switch	PNL LTS — turns on HUD panel lights.
	OFF — turns off HUD panel lights.
3. STBY RETICLE power and brightness control	BRT — Clockwise rotation increases standby reticle brightness.
	OFF — full counterclockwise rotation turns off standby reticle lamps.
4. TEST switch	TEST — initiates built-in self-test.
	OFF — disconnects self-test.
5. MILS indicator	Indicates depression angle of standby reticle in milliradians.
6. Standby reticle depression knob	DEPR — clockwise rotation adjusts the standby reticle depression angle from zero to optical reference axis to 210 mils. Two detent positions are provided, one at the zero position and one at approximately 87 mils.
7. BARO ALT/RDR ALT switch	BARO ALT — causes barometric altitude to be displayed on the altitude scale.
	RDR ALT — causes radar altitude to be displayed on the altitude scale when below 5,000 feet, and causes an index mark to be displayed to the lower right of the scale numeral.
8. FILTER knob	DAY — removes night filter from field of view.
	NIGHT — inserts filter in front of lens.
9. SCALES switch	SCALES — displays airspeed, altitude, vertical velocity, and heading symbology.
	OFF — removes scales from display.
10. HUD power and brightness control	BRT — clockwise rotation increases symbol brightness.
	OFF — full counterclockwise rotation turns off the HUD except for the standby reticle.
11. Combiner glass	Reflects HUD symbols from cathode ray tube into pilot's line of vision.
12. Combiner position lever	Permits fore and aft movement of combiner glass. Glass is moved toward pilot in landing mode to enable better view over aircraft nose. Position optional in other modes.
13. HUD FAIL caution light	On (HUD FAIL) — indicates HUD system failure.
14. HUD HOT caution light	On (HUD HOT) — indicates a thermal overload within the system. Continued operation under this condition will result in complete system failure.
15. Thumbwheel control (RETICLE SLEW)	Permits movement of HUD aiming symbol along bombfall line in range only.
16. Bullpup controller	Permits movement of HUD aiming symbol in range and azimuth.

Figure 100b

245

AIRSPEED SCALE
AND INDICATOR
(340 KNOTS INDICATED)

HEADING INDICATOR
(110° INDICATED)

FLIGHT DIRECTOR

AIMING RETICLE

WARNING INDICATOR

ALTITUDE SCALE
AND INDICATOR
(4,750 FT INDICATED)

PITCH ANGLE AND PITCH
LINES (10° LINES SHOWN)
WITH FLIGHTPATH MARKER
AND HORIZON LINES.
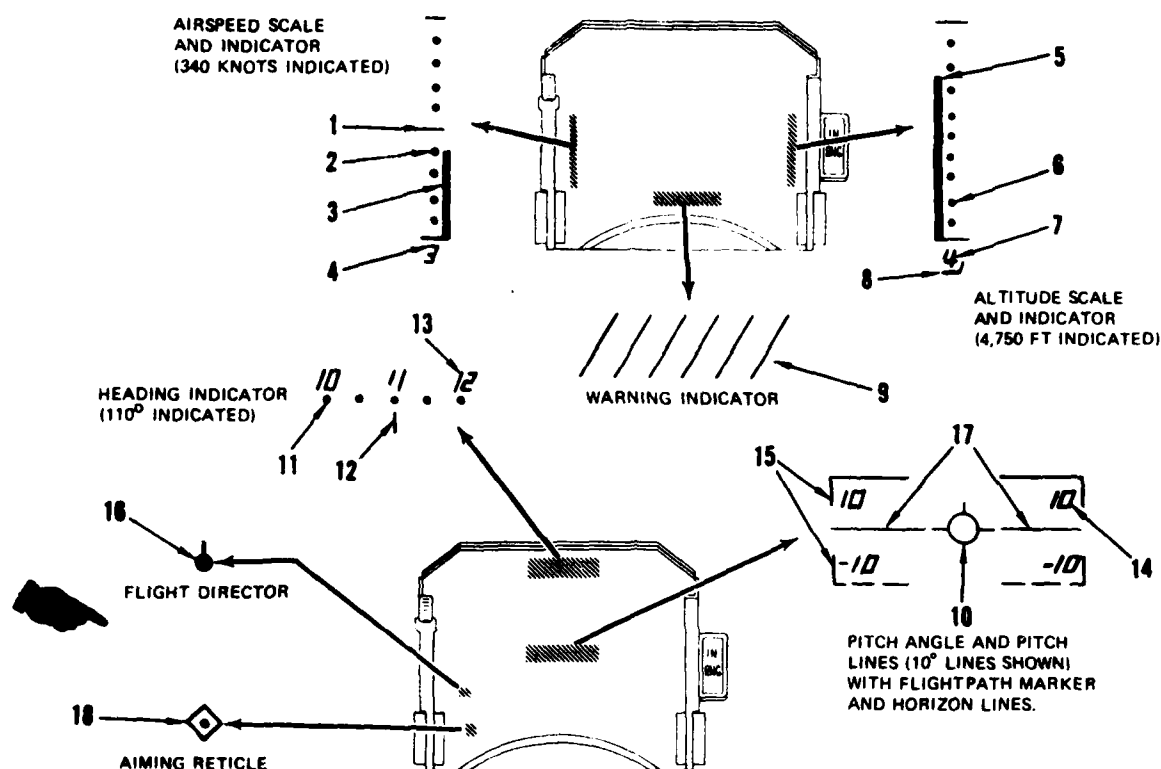
INDEX NO.	NOMENCLATURE	FUNCTION
1	Index lines	Divide airspeed indicator into 50-knot increments.
2	Index dots	Divide airspeed indicator into 10-knot increments.
3	Airspeed column	Rises on increasing airspeed through intervals of 100 knots.
4	Airspeed numeric	Indicates airplane airspeed in intervals of 100 knots.
5	Altitude column	Rises on increasing altitude through intervals of 1,000 feet.
6	Index dots	Divide altitude indicator into 100-foot increments.
7	Altitude numeric	Indicates airplane altitude in intervals of 1,000 feet.
8	Radar altitude advisory symbol	Indicates altitude switch is in RDR ALT.
9	Warning lines	Flashes concurrently with the master caution light, comes on steady concurrently with the fire warning light.
10	Flightpath marker	Represents the flightpath of the airplane.
11	Index dots	Divide the magnetic heading indication into 5° increments.
12	Lubber line	Index for airplane heading.
13	Heading numeric	Indicates airplane heading. (Scale is times 10°.)
14	Pitch angle numeric	Indicates airplane pitch angle. (Scale is times 1°.)
15	Pitch angle lines	Airplane pitch axis index. (End tabs point in direction of horizon.)
16	Flight director	Indicates the relative position of an optimum flightpath.
17	Horizon lines	Represents relative position of horizon to the airplane pitch and roll axes.
18	Aiming reticle	An adjustable aiming or fix point reference indicator.

Figure 100c

PULLUP COMMAND

SOLUTION NUMBER 2 CUE — 28

SOLUTION NUMBER 1 CUE — 20

19

22

21

23

21

24

VERTICAL VELOCITY SCALE AND INDICATOR

25

PULLUP ANTICIPATION CUE

29

LANDING DIRECTOR
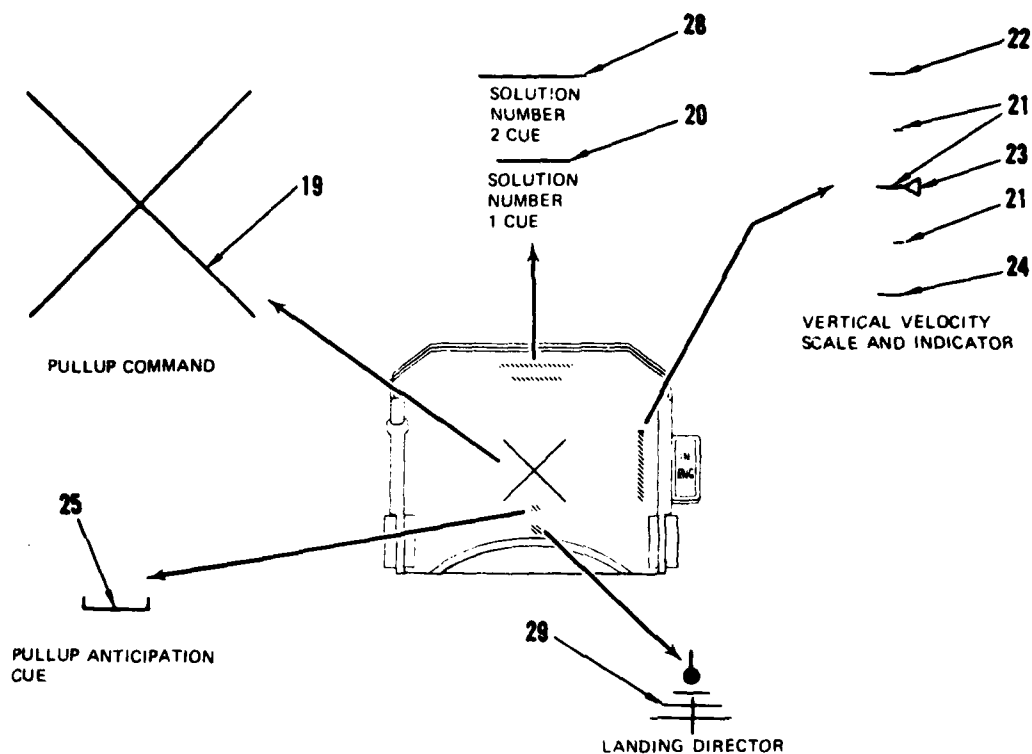
INDEX NO.	NOMENCLATURE	FUNCTION
19	Pullup command	Flashes on to indicate an immediate pullup requirement.
20	Solution number 1 cue	Symbol moves down to indicate an approaching weapon release point.
21	Index lines	Divides the vertical velocity scale into 500-foot increments.
22	Upper index line	Full scale climb index marker.
23	Vertical velocity pointer	Indicates vertical velocity.
24	Lower index line	Full scale dive index marker.
25	Pullup anticipation cue	Symbol moves up to indicate an approaching pullup requirement.
26	Deleted	
27	Deleted	
28	Solution number 2 cue	Symbol moves down the bombfall line to indicate an approaching weapon release point.
29	Landing director	Indicates the relative position of the landing flightpath during a landing approach.

Figure 100d

247

LANDING MODE
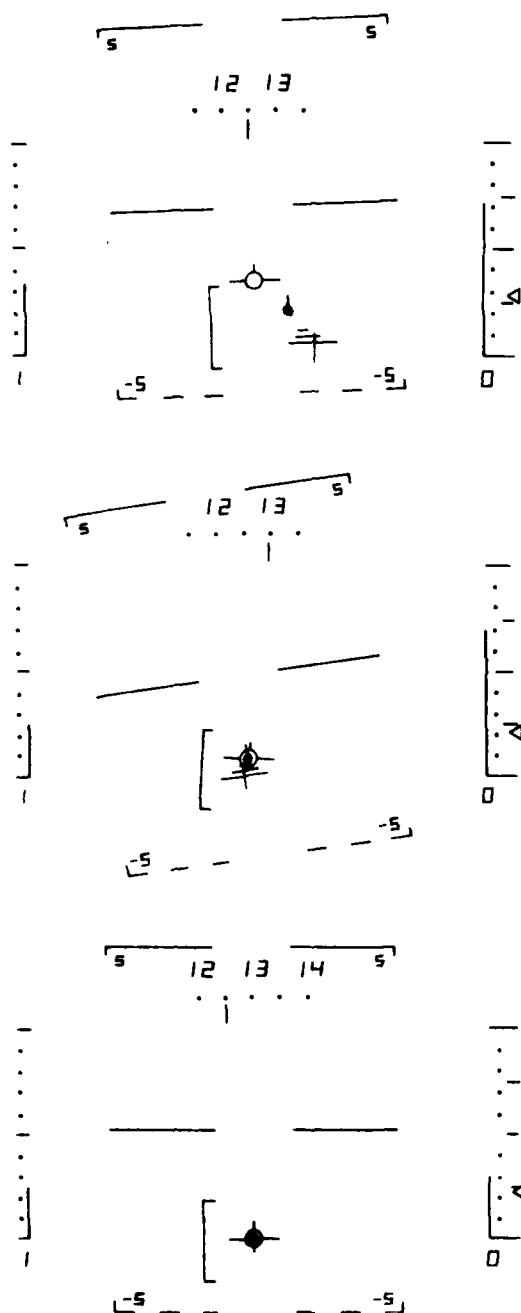
1. Approach too flat.

2. Perspective lines indicate that aircraft is above glide slope and left of centerline.

3. Angle of attack is less than the optimum value of 17.5 units.

4. Airspeed too fast.

5. Landing Director positioned below and right of FPM represents a command to turn right and increase sink rate to effect glide path intercept.

1. Pilot responds by reducing power, increasing angle of attack and banking right.

2. Landing Director centered in the FPM indicates that the pilot has initiated the proper control movements to effect glide path intercept.

3. Perspective lines indicate that aircraft is situated above glide slope and to the right of centerline.

4. Angle of attack is approaching the optimum value of 17.5 units.

1. Aircraft is on glide path with proper sink rate.

2. Angle of attack is optimum at 17.5 units.

Figure 100e
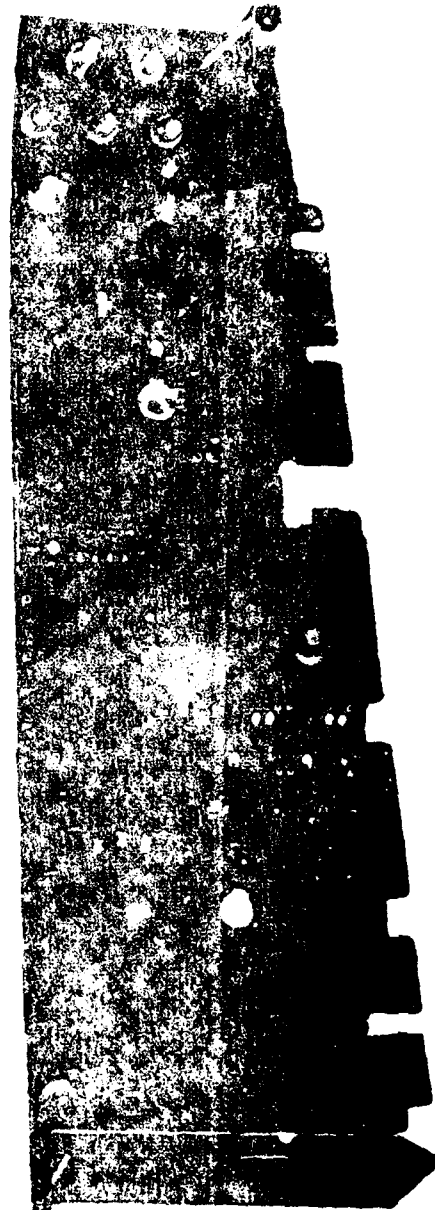
1. INTERIOR LIGHTS control panel
2. DOP control panel
3. OXYGEN REGULATOR
4. NAV WD control panel
5. TACAN control panel
6. ILS control panel
7. FM COMM control panel
8. Speech security control panel
9. RADAR BEACON control panel
10. Blank panel
11 WINGFOLD
12 Map case
13. Blank panel
14. AIR CONDITIONING control
15. IMS control panel
16. ECM pod control panel
17 EXT LIGHTS controls
18 ADVISORY and CAUTION light panels
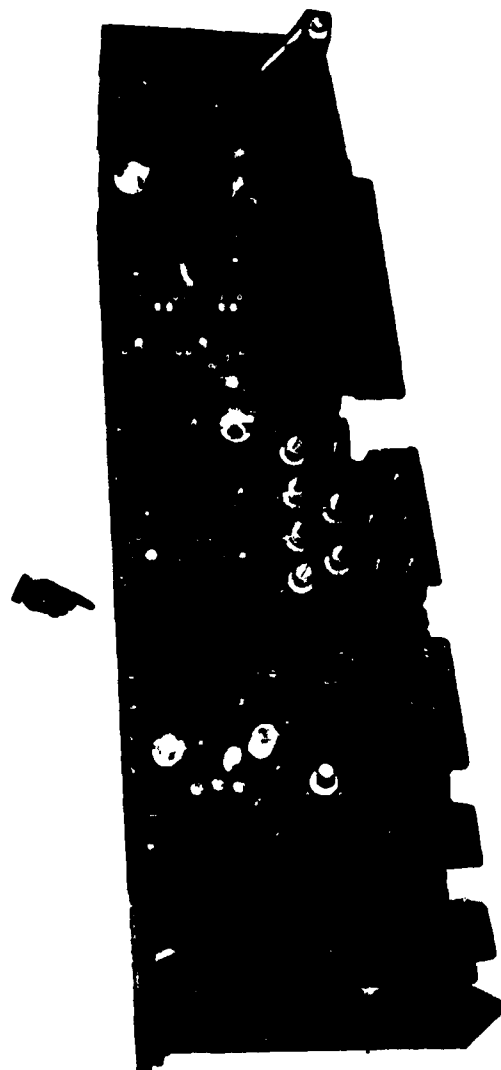
1. Hydraulic pressures indicators
2. Oxygen pressure and TRUE AIRSPEED indicators
3. DOP control panel
4. OXYGEN REGULATOR
5. ECM pod control panel
6. NAV WD control panel
7. TACAN control panel
8. ILS control panel
9. IMS control panel
10. Speech security control panel
11. HOOK control panel
12. ADVISORY and CAUTION lights panel
13. INT and EXT lights control panel
14. FM COMM control panel
15. RADAR BEACON control panel
16. AIR COND control panel
17. WINGFOLD
18. MAP CASE

Figure 102 Right Console [17] [27]
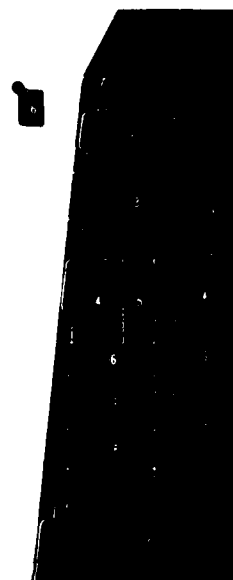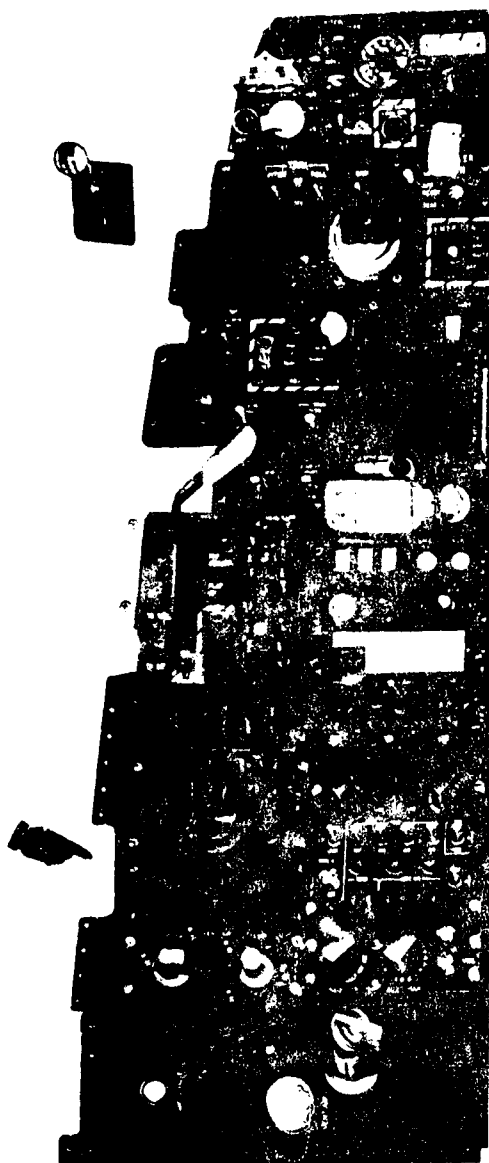
1. Emergency power, EMER WHLS DN,
   PITCH, ROLL and YAW trim indicators
2. Generators, control selector panel
3. Fuel and emergency brake panel
4. Flap control
5. AFCS control panel
6. TER CLR/RANGE SET control
7. INTER control panel
8. DOUBLE DATUM lockout switch
9. Suit temperature panel
10. Pilot services panel
11. ADF radio control panel
12. IFF control panel
13. UHF radio control panel
14. RADAR control panel
15. Throttle, fuel master, rudder trim panel
16. Canopy jettison control handle
    (on left longeron)

Figure 16 Left Console [16] [18] → [26]
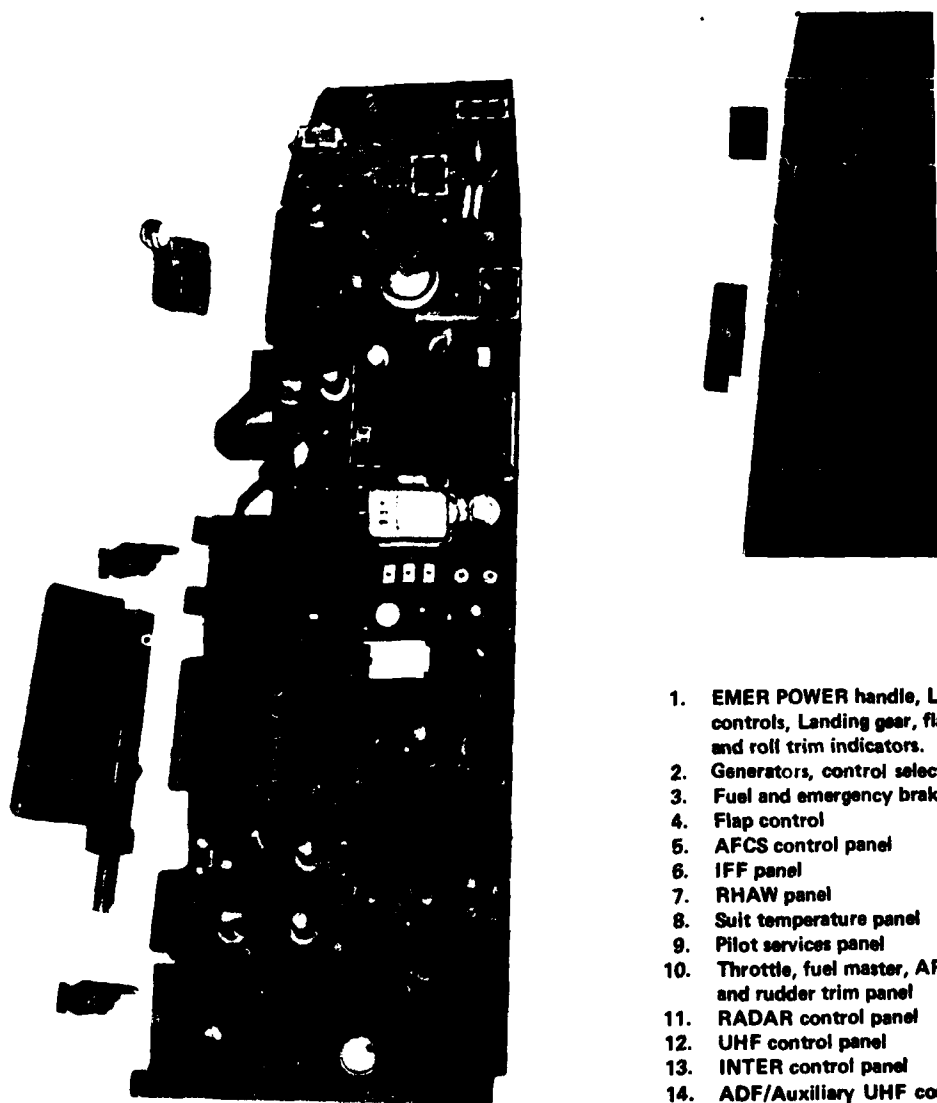
1. EMER POWER handle, Landing gear controls, Landing gear, flaps, and pitch and roll trim indicators.
2. Generators, control selector panel
3. Fuel and emergency brake panel
4. Flap control
5. AFCS control panel
6. IFF panel
7. RHAW panel
8. Suit temperature panel
9. Pilot services panel
10. Throttle, fuel master, AR door, and rudder trim panel
11. RADAR control panel
12. UHF control panel
13. INTER control panel
14. ADF/Auxiliary UHF control panel
15. DOUBLE DATUM lockout switch
16. ALTERNATE FUEL FEED panel (on left longeron)
17. CANOPY JETTISON CONTROL HANDLE (on left longeron)

Figure 101 Left Console |17| |27| →

FORWARD RADAR
AN/APQ-126

GLIDE SLOPE ILS
AN/ARN-58A

RADAR ALTIMETER
AN/APN-141 OR
AN/APN-194

RADAR BEACON
AN/APN-154

UHF/ADF
AN/ARA-50

ECM OMNI
AN/APR-37 OR
AN/ALR-46*

DOPPLER RADAR
AN/APN-190(V)

MARKER BEACON ILS
AN/ARN-58A

TACAN LOWER
AN/ARN-52 OR
AN/ARN-118(V)†

UHF COMM/IFF
AN/ARC-51BX OR
AN/ARC-164(V),**
AN/APX-72

ECM WARNING
AN/APR-38 OR
AN/ALR-46*

LOCALIZER ILS
AN/ARN-58A

VHF/LORAN
FM622A-AN/ARN

TACAN UPPER
AN/ARN-52 OR
AN/ARN-118(V)†

ECM WARNING
AN/APR-38 OR
AN/ALR-46*

*Aircraft after T.O. 1A-7D-760 have the AN/ALR-46 system installed.
**Aircraft after T.O. 1A-7D-785 have the AN/ARC-164(V) UHF radio installed.
†Aircraft after T.O. 1A-7D-806 have the AN/ARN-118(V) TACAN installed.

Figure 105 Antenna Locations

INTERCOMMUNICATION SET CONTROLS
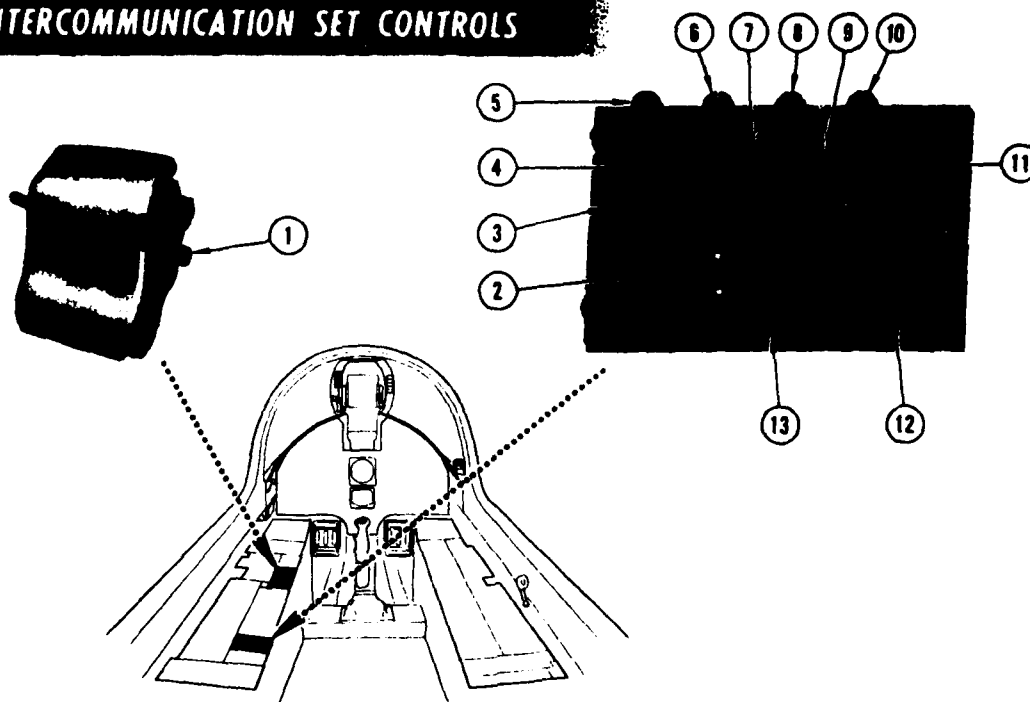
1. MIKE button	Pressed — activates microphone. Also actuates IFF identification replies with IFF in MIC mode.
2. VOL control knob	Adjusts volume of all incoming signals simultaneously.
3. HOT MIC switch	Pulled Out — enables operator to talk to ground crew without depressing MIKE button. Pushed In — disables HOT MIC function.
4. TACAN monitor knob	Pulled Out — connects TACAN station identification signals to headset. Rotated — adjusts volume. Pushed In — disconnects TACAN audio.
5. INTER monitor knob	Pulled Out — connects ground intercom station audio to headset. Rotated — adjusts audio volume. Pushed In — disconnects intercom audio.
6. UHF monitor knob	Pulled Out — permits UHF radio to be monitored while panel selector switch is in VHF or INT. Rotated — adjusts audio volume. Pushed In — disconnects UHF audio (UHF audio continues to be received if UHF is selected on panel selector switch).

Figure 106

254
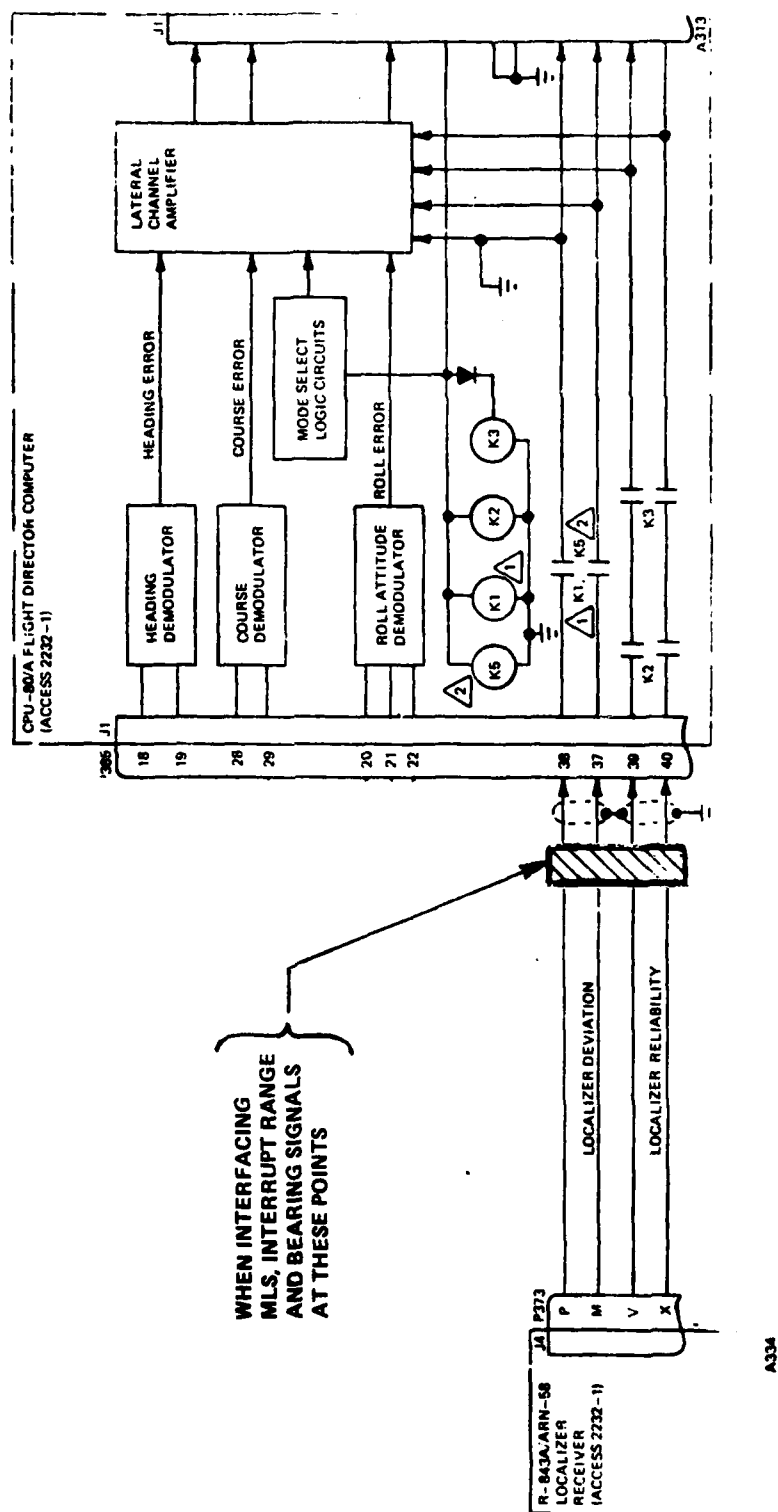
Figure 107 Localizer Receiver/Flight Director Computer Interface
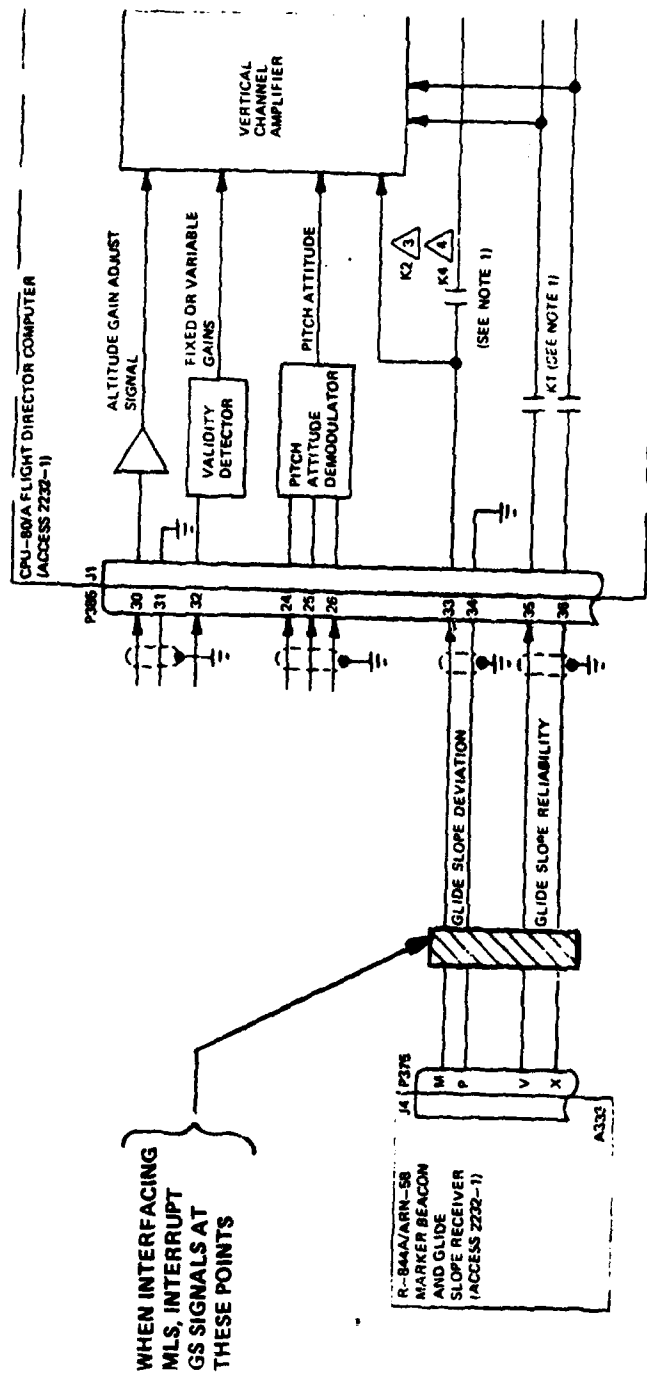
Figure 108 GS Receiver/Flight Director Computer Interface

Figure 109 HSI/Range/Bearing Interface
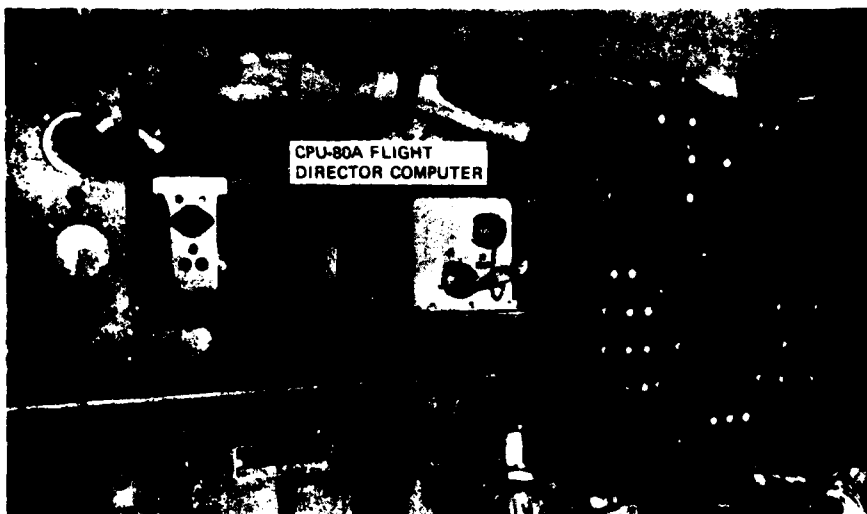
Figure 110 CPU-80A Flight Director Computer

F-15
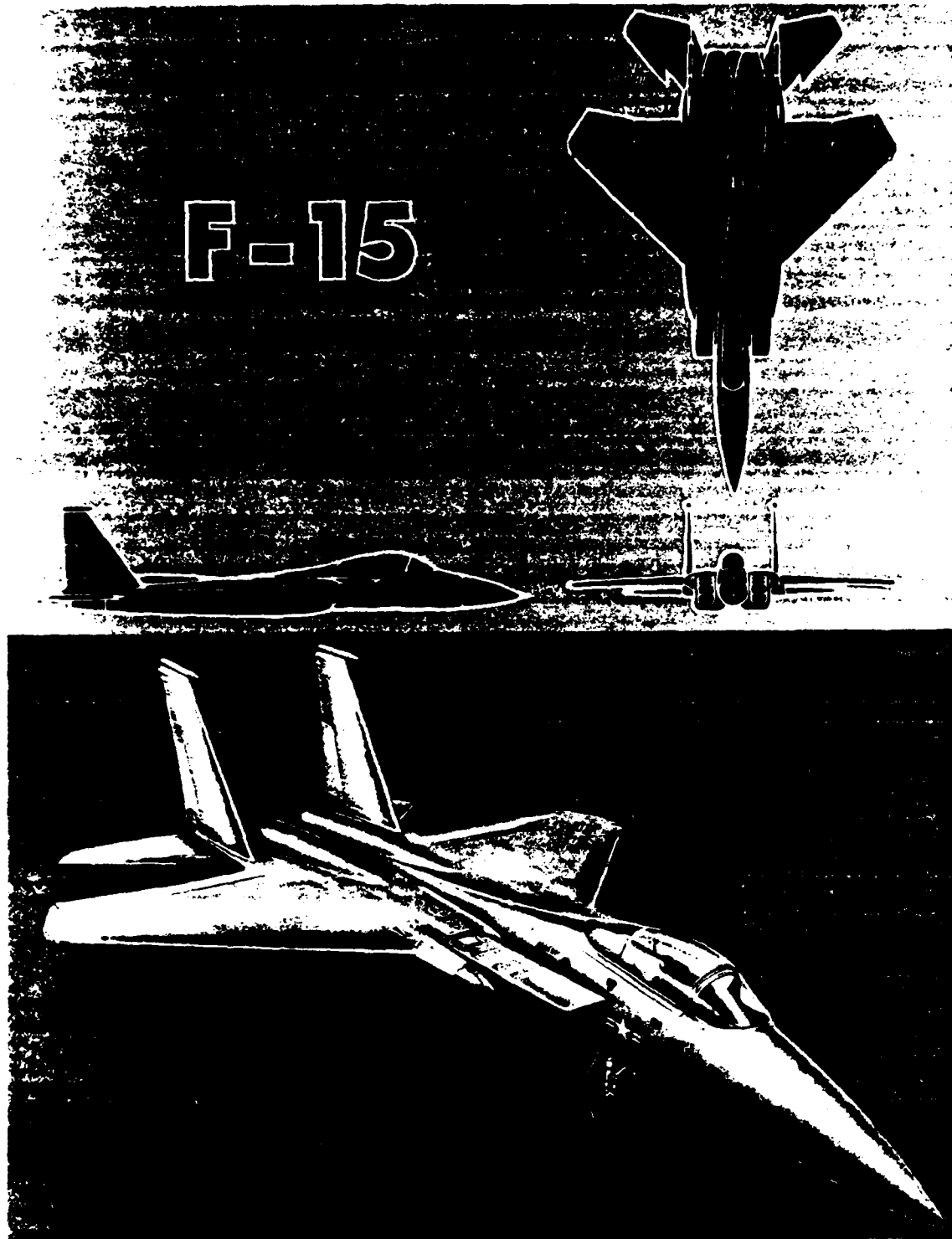
5.5   F-15A

5.5.1   General F-15A Information

The F-15 is a high-performance, supersonic, all-weather air-superiority fighter built by McDonnell Aircraft Company. Its primary mission is aerial combat, but it can also perform ground attack missions. Radar and heat seeking air-to-air missiles and a 20 MM gun are the primary armament. The cockpit is elevated to enhance vibility. Major aircraft systems are designed and conveniently located for high maintainability and reliability.

The avionics equipment aboard the aircraft is integrated and provides weapon delivery, aerial combat, and navigation capabilities. Navigation and associated equipment considered for the MLS interface analysis is as follows:

> TACAN Interrogator
>
> ILS Receiver (LOC/GS)
>
> ILS/TAC Control Panel
>
> Flight Director Adapter
>
> Central Computer
>
> Horizontal Situation Indicator (HSI)
>
> Attitude Indicator (AI)
>
> Integrated Communication System
>
> HUD System
>
> Steering Switch
>
> ADI Switch

A Block diagram of the existing ILS mode interface is illustrated in Figure 111.   Only those elements involved with the MLS installation or possible MLS usage are included. As shown, signals from the ILS receiver and logic from the Steer Mode switch are applied to the Flight Director Adapter. This unit in turn provides deviation and reliability signals to the Central Computer, HSI,and ADI. The Central Computer combines the deviation and other signals and computes pitch and roll steering signals for localizer and glideslope flight path control.

Computed steering signals from the Central Computer are applied to the HUD Data Processor and Flight Director Adapter, and these elements, in turn, provide the steering commands for the

HUD and ADI respectively. In addition, the Central Computer provides converted, localizer and glideslope, deviation and reliability signals to the HUD Data Processor for display on the HUD.

The ILS mode is activated by placing the steering mode switch to the ILS/NAV position (see Figure 112, upper left). As a result, ILS, deviation reliability,and steering signals are applied to the ADI and HSI. To present the same information on the HUD, the ADI switch (see Figure 113, Ref. No. 8) must be activated.

The only annunciation available during an ILS approach is the position (ILS/NAV) of the steering mode switch. An indication is available on the HUD (provided that the ADI pushbutton is activated) when the ILS/NAV mode is selected.

The legend "CSET" flashes on the HUD for 10 seconds to remind the pilot to set the final approach course (via the HSI course set knob). At the end of 10 seconds, "CSET" is replaced with "GSUP" or "GSDN". Interception of glideslope and automatic shift to the approach mode is indicated by extinguishing of the GSUP or GSDN light and by glideslope indications on the HUD and ADI. Except for the above, the only other approach annunciations are provided by the positions of the steering and ADI ILS switches.

On an ILS approach, use of the ILS function is not recommended until approximately aligned with the final approach heading. Bank Steering information on the HUD and ADI automatically switches from 30° maximum bank angle to the final approach mode of 15° maximum bank angle when the glideslope is intercepted. If the glideslope is intercepted with a considerable difference between aircraft heading and final approach course, a 15° bank angle may not be sufficient tc align the aircraft on final approach.

Since the ILS system is non-redundant, the F-15 is a Category I aircraft. ILS approaches can be made only by utilizing the integrated Flight Director System. The autopilot (flight control system) provides three axis control augmentation and pitch and roll attitude hold (pilot relief) modes. Autopilot navigation and approach coupling is not available.

Most of the F-15A avionics is implemented, using digital techniques for the majority of unit interfaces, internal computations, and logic. The ILS receiver outputs, AI, and the inputs to the certain functions of the HSI are analog interfaces. The Flight Director Adapter (FDA) does not provide any computations. It functions only as a converter (A/D and D/A) for interfacing with the Central Computer which does all the flight path computations associated with the navigation modes. In addition, the FDA provides the switching which couples the selected references to the AI and HSI.

The Central Computer is a high speed, stored program digital computer which communicates with the ILS-related equipment via data buses. This unit provides ILS, deviation, steering, and reliability signals for the HUD system and computed ILS steering signals, via the FDA, for the AI.

A typical F-15 cockpit layout is illustrated in Figures 114a B and C. The AI and HSI displays are located on the lower center of the instrument panel. Mounted above the instrument panel is the Heads-Up Display. These three displays are used during ILS approaches in conjunction with the ILS receiver, FDA and Central Computer.

Functional details of the HSI, AI and HUD are illustrated on Figures 115 and 116. See Figure 112 for typical approach symbols displayed on the HUD during an ILS approach.

5.5.2   F-15A MLS Recommendations

Since the F-15A must operate at forward air bases like the A-7D, an MLS-3 (Selected Intercept of Final) configuration capability is highly desirable. For reasons similar to those previously discussed for the A-7D, a full complex trajectory configuration cannot be recommended and even a recommendation of MLS-3 is questionable. Workload levels involved for complex trajectory flight are prohibitive for the operator of a single-seat aircraft flying at high approach speeds without autopilot coupling. Also, space and weight restrictions on the aircraft may preclude the addition of the units required for MLS-3. If subsequent studies indicate that the workload levels associated with this configuration are acceptable, and if space and weight limitations are not a problem, the MLS-3 configuration should be incorporated in the F-15A. If any of these final studies reveals a serious problem, MLS-1 (Direct ILS Replacement)

should be considered. The following paragraphs describe
installation guidelines for the MLS-1 and MLS-3 configurations
in the F-15A.

Installation of an MLS-1 system in the F-15A type aircraft
involves the addition of the following units:

UNIT	QTY.
MLS Angle Receiver	1
MLS Switching Unit	1
MLS-1 Tuner	1
MLS Angle Antenna	1

The first two units are remotely located and these can be
accommodated in various aircraft locations. Panel space is
available on both the right and left consoles (see Figures
114b and 114c to mount the MLS-1 tuner in either location.
The MLS antenna must be mounted in the general area of the
present localizer and glideslope antenna (see Figure 117).
Empy holes exist on the left bus circuit breaker panel (see
Figure 118) to accommodate MLS circuit breakers.

Figure 119   is an illustration of the present ILS/Flight
Director Adapter interface. The wires associated with the
ILS receiver must be interrupted and routed through the MLS
switching unit. This will result in analog raw data MLS
information being used and displayed in exactly the same
manner as is presently done for ILS.

Installation of an MLS-3 system in the F-15A involves the
addition of the following units:

ITEM	UNIT	QTY.
1	MLS Angle Receiver	1
2	DME Interrogator	1
3	MLS NAV Coupler	1
4	MLS Switching Unit	1
5	MLS AZ/DME Display	1
6	MLS Tuner/Selector	1

ITEM	UNIT	QTY.
7	MLS Angle Antenna	1
8	DME ANTENNA (MLS)	1
9	Audio Panel Switches	1

Items 1 through 4 are remotely located in the avionics bay.
If available space is critical, the following are alternate
solutions to conserve space and reduce weight:

- Delete present ILS equipment completely and only
  accommodate MLS-3 (Probably not acceptable).

- Replace the existing Flight Director Adapter with a
  custom MLS NAV Coupler and modify the Central Computer
  to interface with this unit.

- Absorb the MLS NAV Coupler functions into the Central
  Computer (digital). This involves a program and I/O
  change as a minimum, but, more importantly, it is a
  major investigative effort to determine feasibility.

- If none of these alternate solutions is feasible,
  then only an MLS-1 (Direct ILS Replacement) con-
  figuration is applicable to the F-15 type aircraft.

If space, weight, and workload problems are not serious,
MLS-3 can be installed. The display capability of the F-15A
is certainly sufficient for presentation of the MLS-3 display
parameters. As shown in Figure F15-5, the HSI, AI, and HUD
provide for all of the functions described in Sections 4.1.2.3
and 4.1.2.4. Although cockpit space limitations on the main
instrument panel appear to prohibit the addition of the MLS
AZ/DME indicator, these parameters could be programmed for the
HUD. Sufficient space can be found on the instrument panel
for a small alert light.

Figure 111 ILS Block Diagram F-15A

265

ILS/NAV AND ILS/TACAN MODE DISPLAYS

ILS/NAV

STEERING MODE PANEL

ADI
- PITCH STEERING COMMAND
- BANK STEERING COMMAND
- GLIDESLOPE DEVIATION

HSI
- MAGNETIC HEADING
- BEARING TO SELECTED DESTINATION
- DISTANCE TO SELECTED DESTINATION
- SELECTED RUNWAY HEADING
- LOCALIZER DEVIATION

HUD (ADI Mode ILS NAV— Steer 3 – Gear Down)
- INTEGRATED FLIGHT DIRECTOR (Pitch and Bank Steering)
- PITCH SCALE (POS.)
- HEADING SCALE
- ALTITUDE SCALE
- IAS SCALE
- AIRCRAFT SYMBOL
- AOA SCALE
- VELOCITY VECTOR
- HORIZON
- PITCH SCALE (NEG.)

ILS/TACAN

STEERING MODE PANEL

ADI
- PITCH STEERING COMMAND
- BANK STEERING COMMAND
- GLIDESLOPE DEVIATION

HSI
- BEARING TO SELECTED TACAN STATION
- DISTANCE TO SELECTED TACAN STATION
- SELECTED RUNWAY HEADING
- LOCALIZER DEVIATION

HUD (ADI Mode ILS TCN— Gear Up)
- INTEGRATED FLIGHT DIRECTOR (Pitch and Bank Steering)
- AIRCRAFT SYMBOL
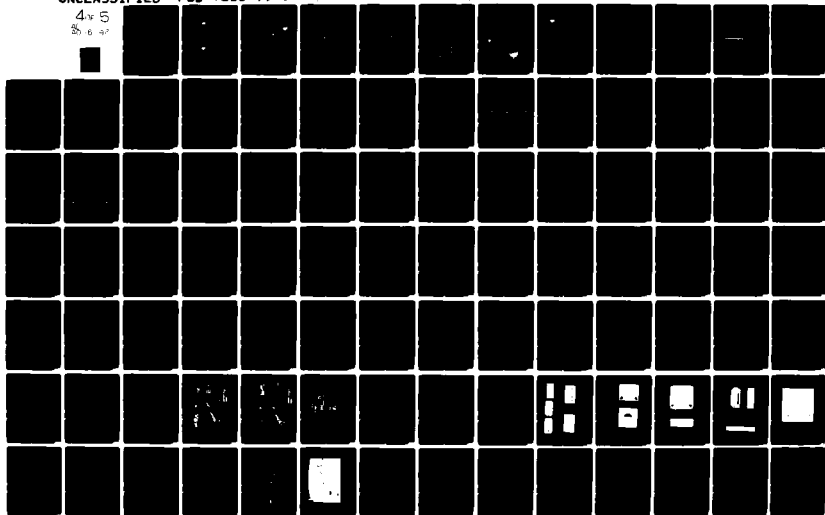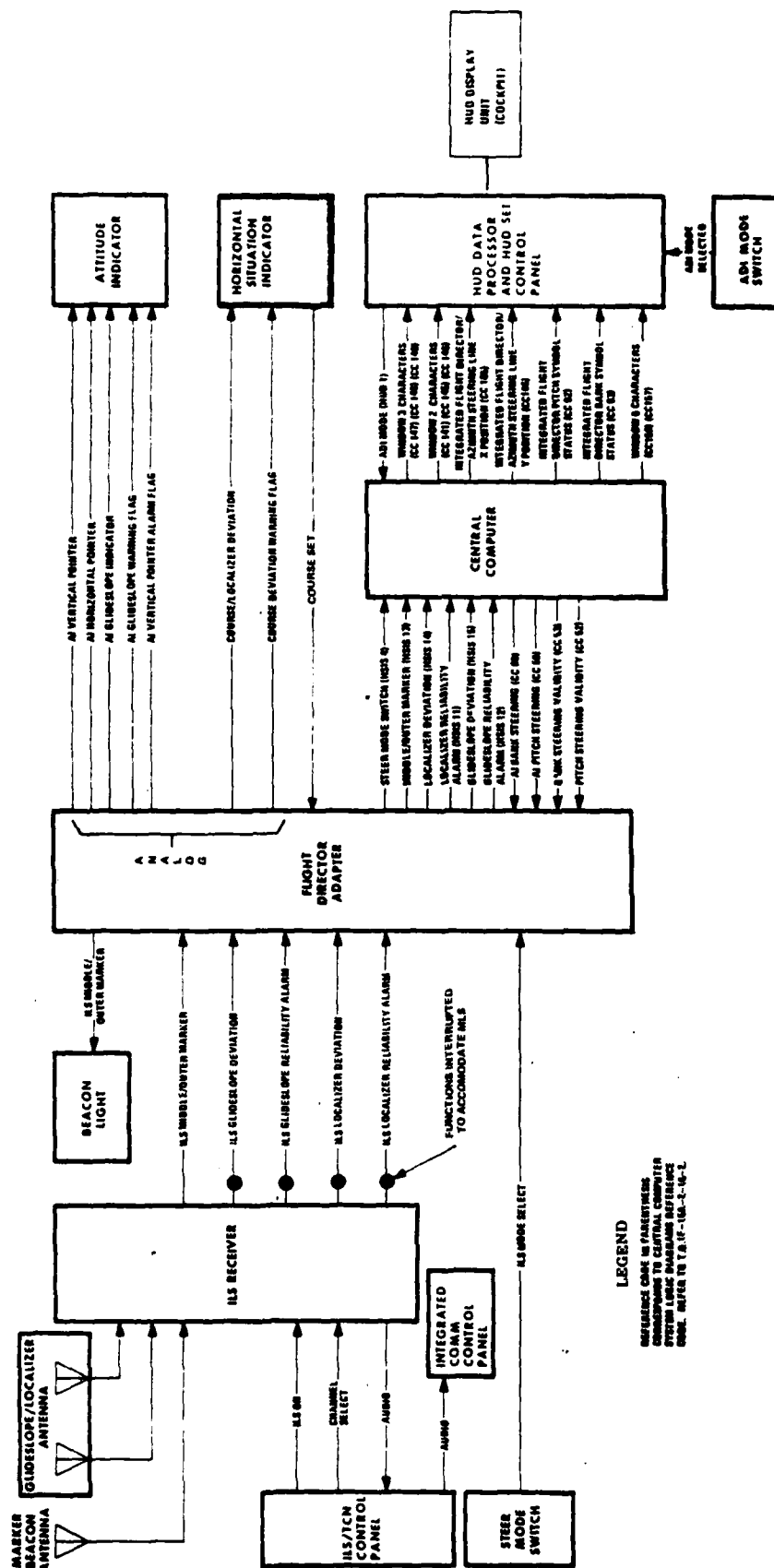
Figure 112   ILS/NAV and ILS/TACAN Mode Displays
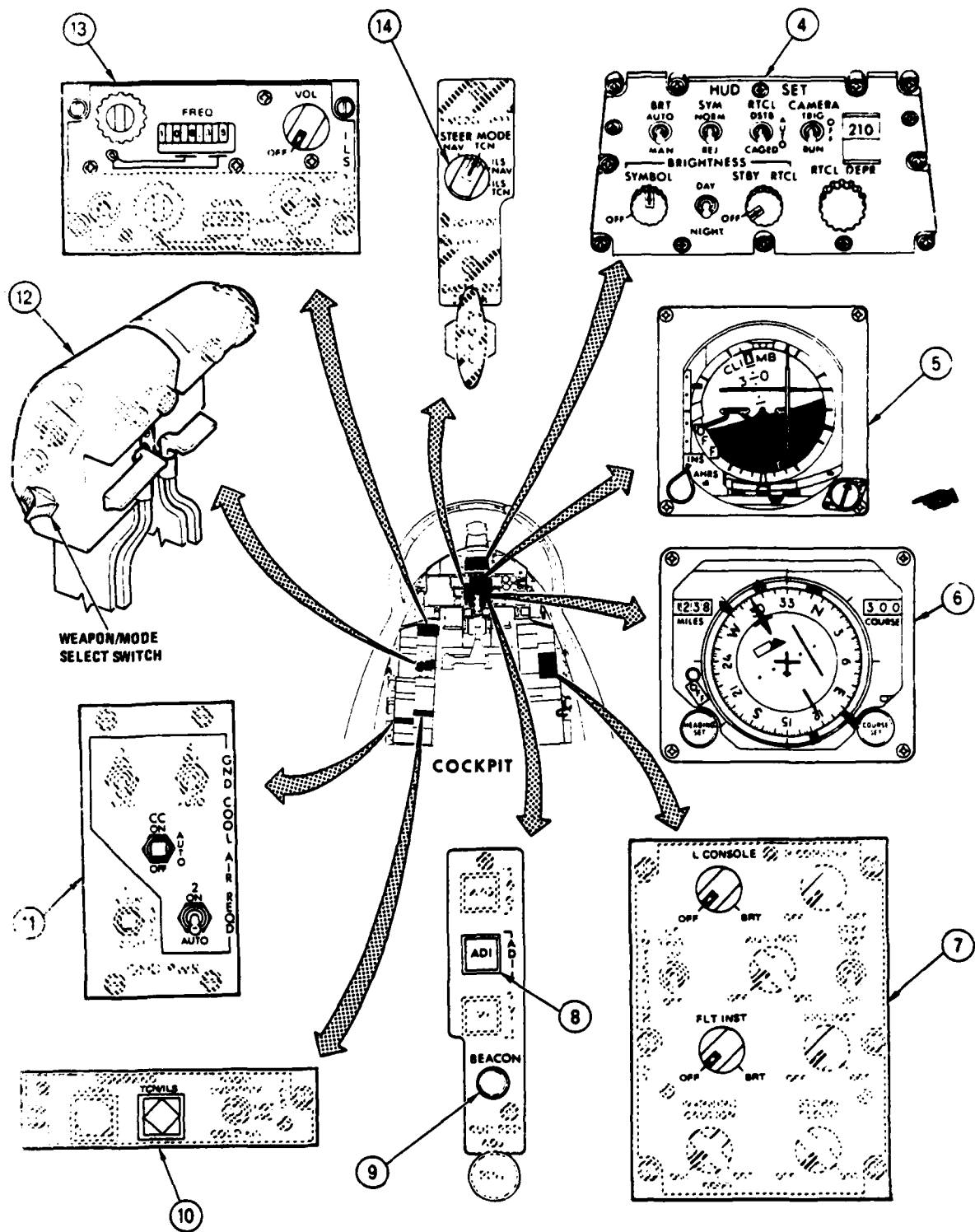
Figure 113   ILS Components, Related Control And Indicators

MAIN PANEL AREA

24. CABIN PRESSURE ALTIMETER
25. CAUTION LIGHTS PANEL
26. EMERGENCY VENT CONTROL HANDLE
27. CIRCUIT BREAKER PANELS
28. COCKPIT COOLING AND PRESSURIZATION OUTLET
29. STANDBY AIRSPEED INDICATOR
30. STANDBY ATTITUDE INDICATOR
31. STANDBY ALTIMETER
32. RUDDER PEDAL ADJUST RELEASE KNOB
33. MASTER MODE CONTROL/EMERGENCY BEACON PANEL
34. ATTITUDE DIRECTOR INDICATOR
35. EMERGENCY ATTITUDE SWITCH
36. STEERING MODE PANEL
37. HORIZONTAL SITUATION INDICATOR
38. ACCELEROMETER
39. ANGLE OF ATTACK INDICATOR
40. AIRSPEED/MACH INDICATOR
41. ARMAMENT CONTROL PANEL
42. PITCH RATIO INDICATOR
43. LANDING GEAR REJECT SWITCH
44. FLAP POSITION INDICATOR
45. EMERGENCY BRAKE/STEERING CONTROL HANDLE
46. EMERGENCY LANDING GEAR HANDLE
47. ARRESTING HOOK CONTROL SWITCH

1. FIRE WARNING/EXTINGUISHING PANEL
2. VERTICAL SITUATION DISPLAY (VSD)
3. RADIO CALL PANEL
4. AIR REFUELING READY LIGHT
4A. LOCK/SHOOT LIGHTS (SOME AIRCRAFT)
5. HEAD UP DISPLAY COMBINING GLASS
6. MASTER CAUTION LIGHT
7. MAIN COMMUNICATIONS CONTROL PANEL
8. HEAD UP DISPLAY CONTROL PANEL
9. GUN SIGHT CAMERA CONTROL PANEL
10. STANDBY MAGNETIC COMPASS
11. TEWS DISPLAY UNIT
12. CANOPY UNLOCKED WARNING LIGHT
13. HYDRAULIC PRESSURE INDICATORS
14. ENGINE TACHOMETERS
15. ALTIMETER

16. FAN TURBINE INLET TEMPERATURE INDICATORS
17. ENGINE OIL PRESSURE INDICATORS
18. FUEL QUANTITY INDICATOR
19. ENGINE FUEL FLOW INDICATORS
20. VERTICAL VELOCITY INDICATOR
21. EIGHT DAY CLOCK
22. ENGINE EXHAUST NOZZLE POSITION INDICATORS
23. JET FUEL STARTER CONTROL HANDLE

Figure 114a Main Panel Area

RIGHT CONSOLE AREA

COCKPIT
TYPICAL

1. OXYGEN REGULATOR
2. ECS PANEL
3. TEMPERATURE PANEL
4. CANOPY CONTROL HANDLE
5. INTERIOR LIGHTS CONTROL PANEL
6. TEWS POD CONTROL PANEL
7. OXYGEN HOSE STOWAGE FITTING
8. BLANK
9. ENGINE START FUEL SWITCHES
10. UTILITY LIGHT
11. STOWAGE COMPARTMENT
12. OXYGEN/COMMUNICATION
    OUTLET PANEL
13. COMPASS CONTROL PANEL
14. TEWS POWER CONTROL PANEL
15. NAVIGATION CONTROL PANEL
16. ENGINE CONTROL PANEL
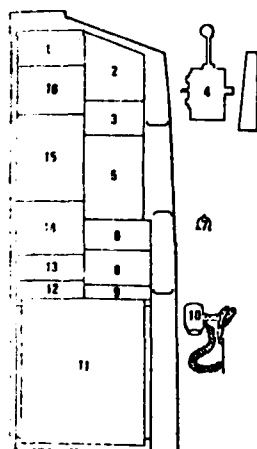
PANEL SPACE
AVAILABLE

Figure 114b

269

LEFT CONSOLE AREA

1. ILS/TACAN CONTROL PANEL
2. CONTROL AUGMENTATION SYSTEM CONTROL PANEL
3. BLANK
4. THROTTLE QUADRANT
5. EXTERIOR LIGHTS CONTROL PANEL
6. INTEGRATED COMMUNICATIONS CONTROL PANEL
7. BLANK (F), TAKE COMMAND/ICS CONTROL PANEL, (TF)
8. BLANK
9. ANTI-G PANEL
10. BOARDING STEPS POSITION INDICATOR
11. BLANK
12. ARMAMENT SAFETY OVERRIDE SWITCH
13. GROUND POWER PANEL
14. BLANK
15. EMERGENCY AIR REFUELING HANDLE
16. BIT PANEL
17. INTERROGATOR CONTROL PANEL
18. IFF CONTROL PANEL
19. IFF ANTENNA SELECT SWITCH
20. TEWS PANEL
21. SEAT ADJUST SWITCH
22. RADAR CONTROL PANEL
23. VMAX SWITCH
24. BLANK
25. FUEL CONTROL PANEL
26. MISCELLANEOUS CONTROL PANEL
27. CANOPY JETTISON HANDLE

NOTE

1 (F) 77-0061 AND UP;
(TF) 77-0154 AND UP.

PANEL SPACE AVAILABLE

PANEL SPACE AVAILABLE

PANEL SPACE AVAILABLE

PANEL SPACE AVAILABLE

PANEL SPACE AVAILABLE

PANEL SPACE AVAILABLE

Figure 114c

270
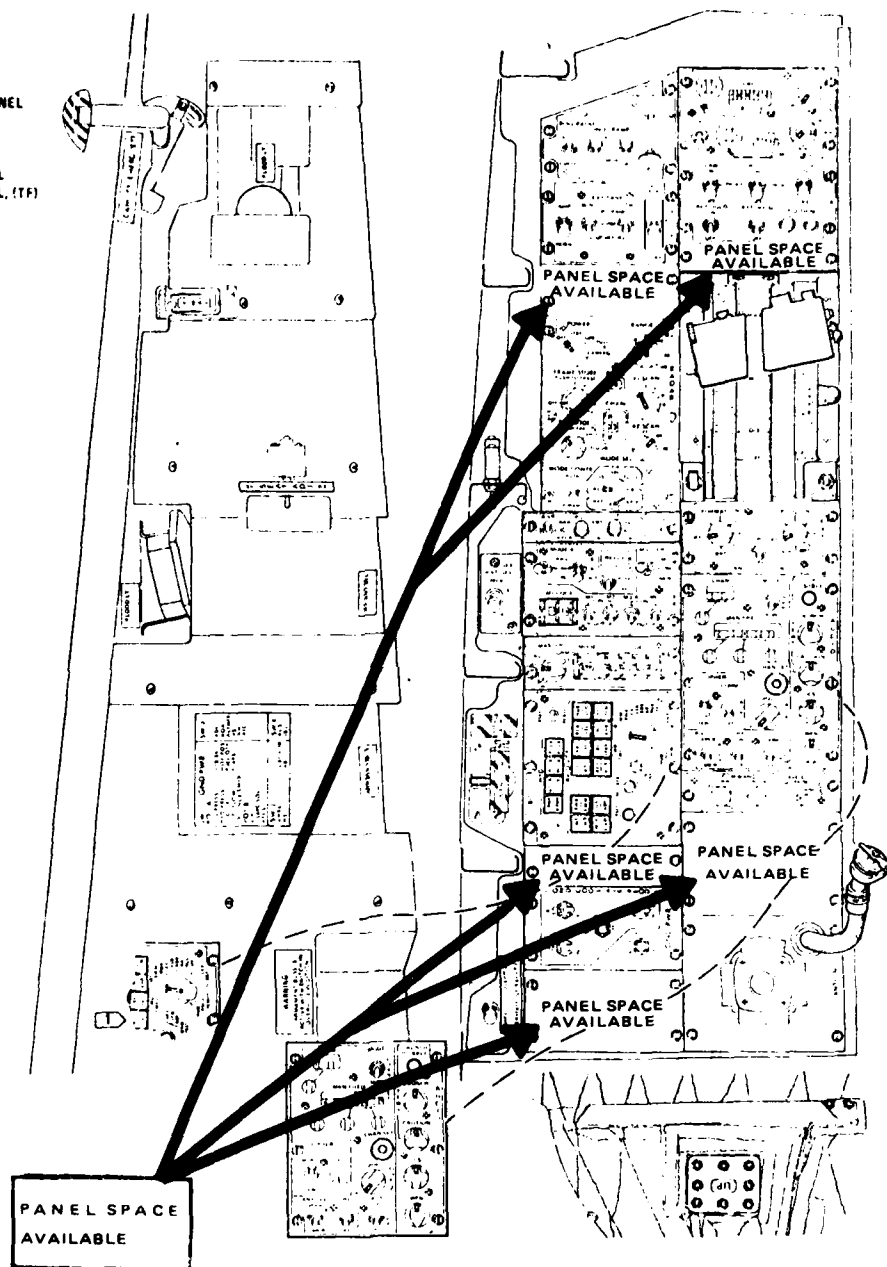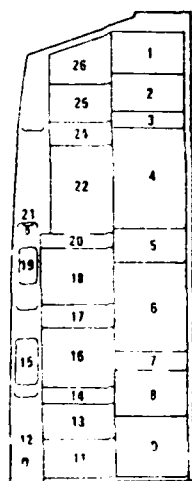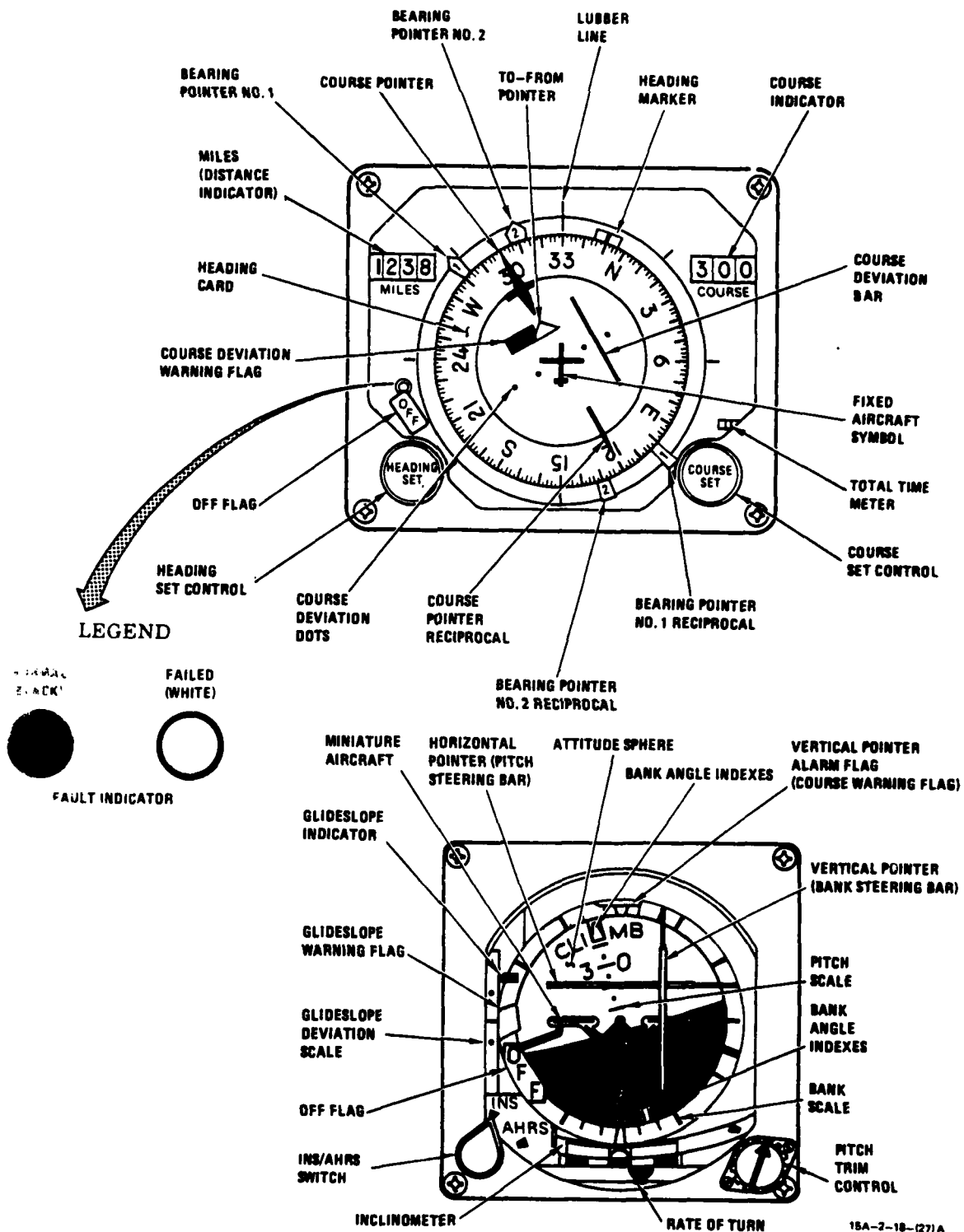
Figure 115 HSI And AI Indicating Devices

271
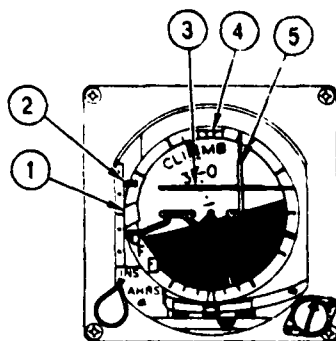
ATTITUDE INDICATOR
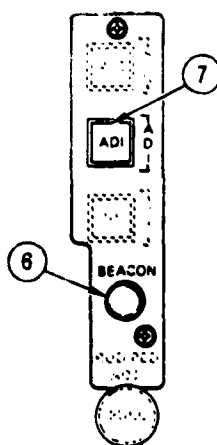
MAIN INSTRUMENT PANEL OR
☐1 REAR MAIN INSTRUMENT PANEL

HORIZONTAL SITUATION INDICATOR
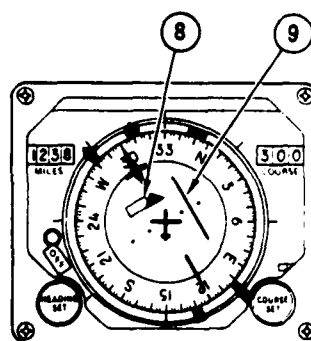
TAKE COMMAND CONTROL PANEL

HUD DISPLAY UNIT
COMBINING GLASS ASSEMBLY

LEGEND

☐1 TF-15A

☐2 ILS-T INDICATION WITH STEER MODE SWITCH IN ILS/
TCN. ILS-N INDICATION WITH STEER MODE SWITCH IN
ILS/NAV.

☐3 GSUP INDICATION WITH AIRCRAFT SITUATION BELOW
GLIDE SLOPE. GSDN INDICATION WITH AIRCRAFT SIT-
UATION ABOVE GLIDE SLOPE.

1.   GLIDESLOPE WARNING FLAG
2.   GLIDESLOPE INDICATOR
3.   HORIZONTAL POINTER
4.   VERTICAL POINTER ALARM FLAG
5.   VERTICAL POINTER
6.   BEACON LIGHT ASSEMBLY
☐1   REAR BEACON LIGHT ASSEMBLY
7.   ADI MODE SWITCH
☐1   REAR ADI MODE LIGHT
8.   HSI COURSE DEVIATION WARNING FLAG
9.   HSI COURSE DEVIATION BAR
☐1 10. TCN/ILS SWITCH
☐3 11. GSUP (WINDOW 6)
☐2 12. ILS-T (WINDOW 3)
13. INTEGRATED FLIGHT DIRECTOR
14. AIRCRAFT SYMBOL
15. MKR (WINDOW 2)
16. VELOCITY VECTOR

Figure 116 ILS Indicators

272

GLIDESLOPE/
LOCALIZER
ANTENNA

GLIDESLOPE/
LOCALIZER
ANTENNA

FWD

ANTENNA
DIRECTORS

COLLAR
(4 REQD)

ANT (REF)

WASHER
(8 REQD)

WASHER
(4 REQD)

BOLT
(4 REQD)

RADOME (REF)

PIN
(4 REQD)
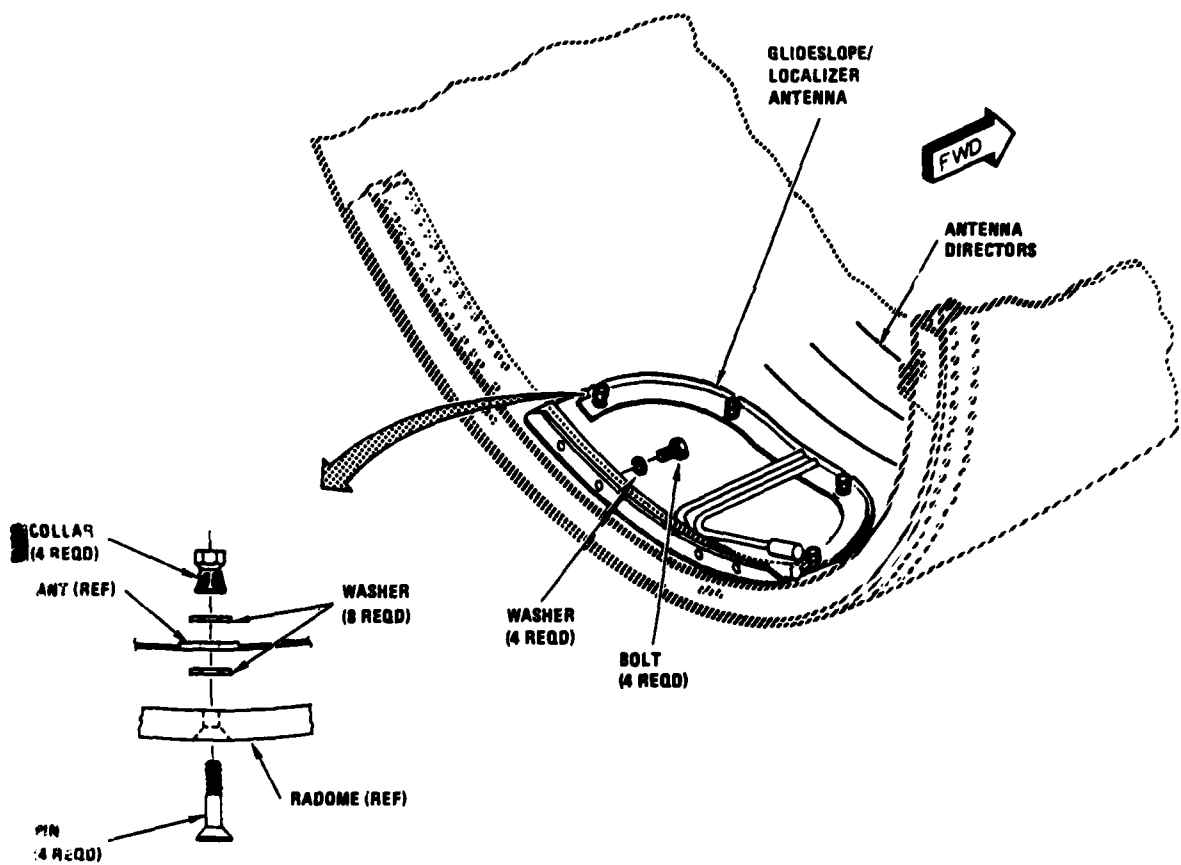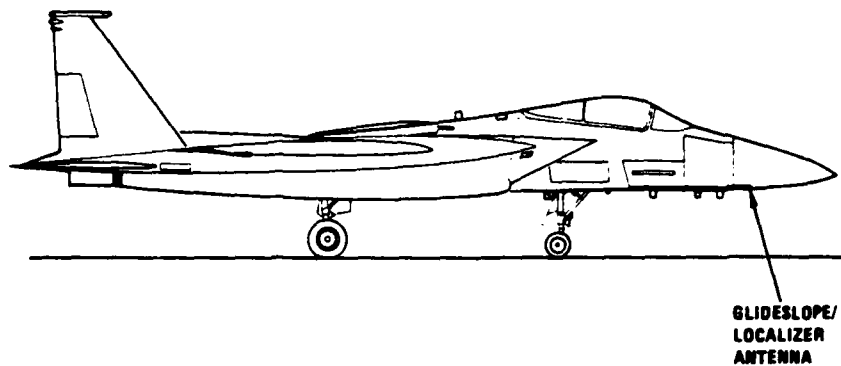
Figure 117 Glideslope/Localizer Antenna Location

273

LEGEND

1. ONLY SYSTEM AND RELATED SYSTEM CIRCUIT BREAKERS ARE SHOWN. POWER DISTRIBUTION SYSTEM CIRCUIT BREAKERS WHICH SUPPLY POWER TO THE CIRCUIT BREAKERS SHOWN ON THIS ILLUSTRATION ARE SET AS PART OF EXTERNAL ELECTRICAL POWER APPLICATION PROCEDURES. REFER TO T.O. 1F-15A-2-2( ).

2 F-15A

3 TF-15A

3 52Z-L230
(REAR COCKPIT, BENEATH RIGHT CONSOLE)

2 52Z-L163
NO. 5 EQUIPMENT COMPARTMENT

52Z-J009
(COCKPIT, BENEATH RIGHT CONSOLE)

52Z-K261 3
(REAR COCKPIT, LEFT SIDE)

52Z-E006
(DOOR 10L)

52Z-C007
(DOOR 6L)
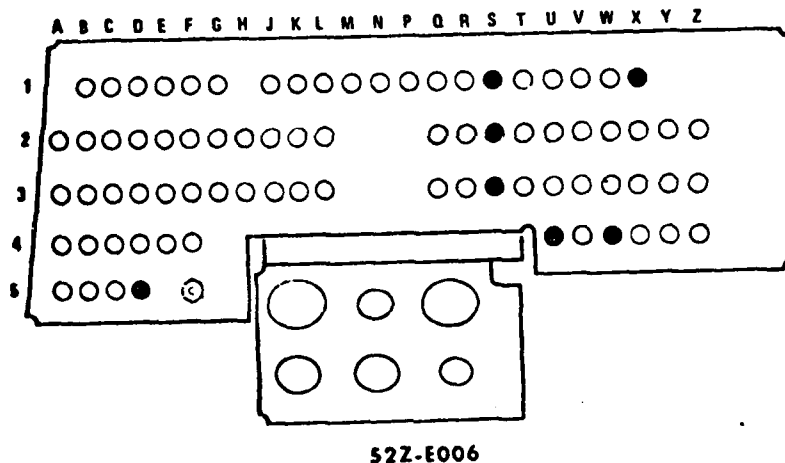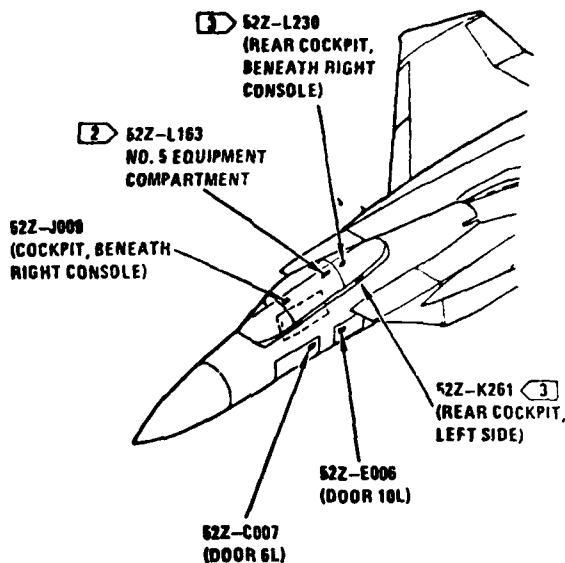
52Z-E006

52Z-E006	LEFT BUS CIRCUIT BREAKER PANEL		
REF DES	ZONE	NOMENCLATURE	BUS
32CBE083	X1	INTERIOR LTS 115V φA	L 115VAC φA
54CBE011	D5	GND PWR/RUD WRN 28VDC	L 28VDC
74CBE003	U4	ILS 28VDC	L 28VDC
90CBE004	W4	HUD 28VDC	L 28VDC
90CBE007	S1	HUD 115V φA	L 115VAC φA
90CBE008	S2	HUD 115V φB	L 115VAC φB
90CBE009	S3	HUD 115V φC	L 115VAC φC

Figure 118 Circuit Breakers Location

274
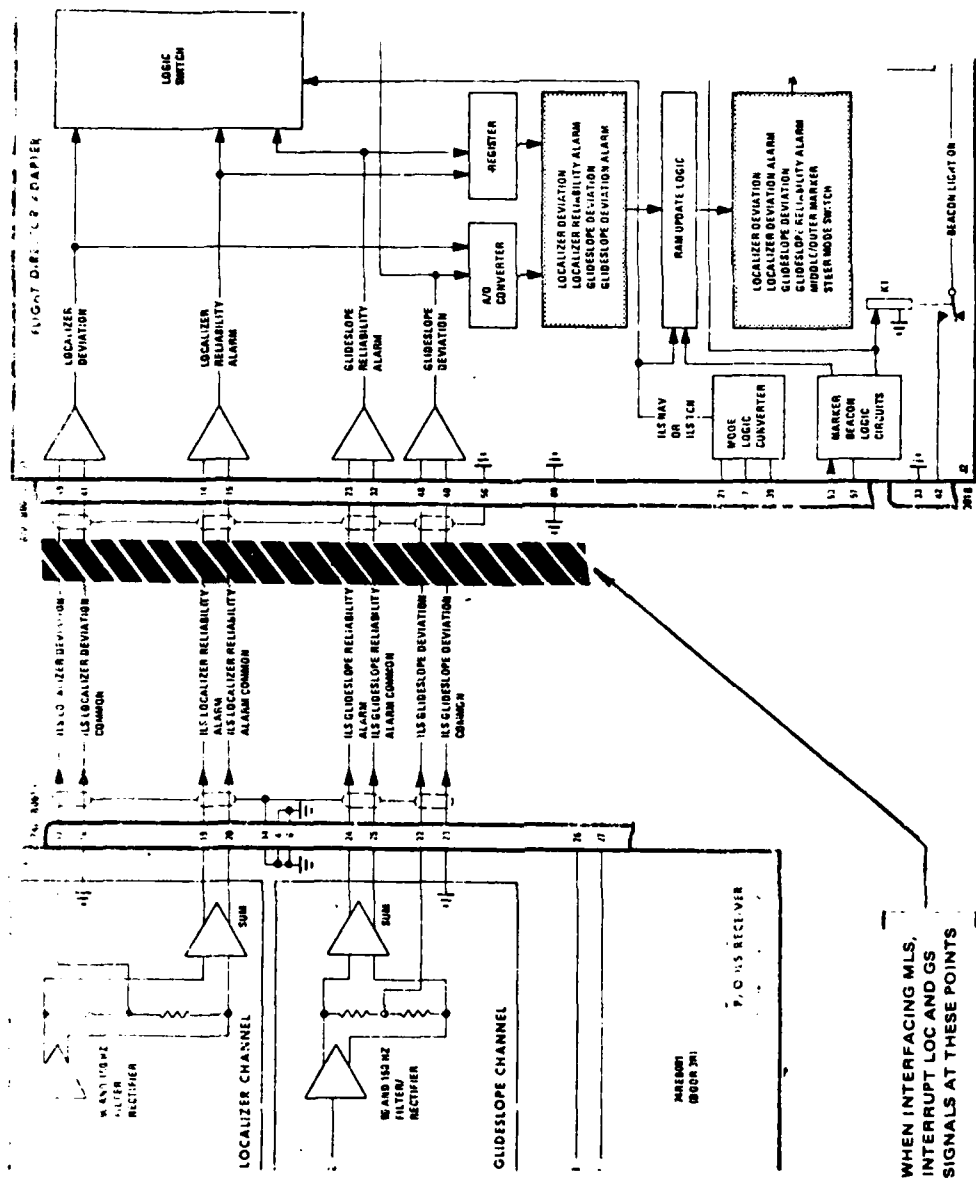
Figure 119 ILS/Flight Director Adapter Interface

275

MLS CONSIDERATIONS

KC-10
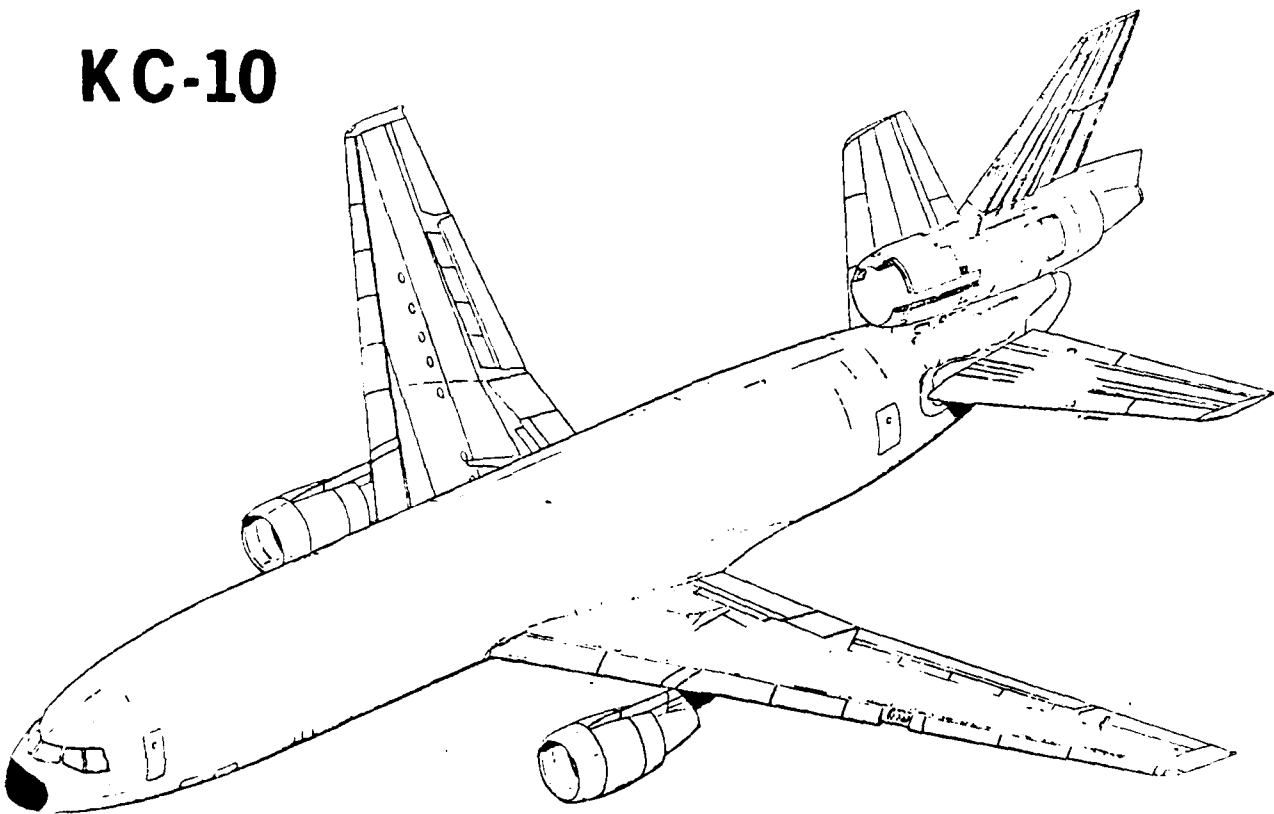
5.6   KC-10A

5.6.1   General KC-10A Information

The McDonnell Douglas KC-10A is a wide-bodied tanker aircraft
used for in-flight refueling of all types of aircraft. It is
a derivative of the commercial DC-10 Series 30 aircraft.

During this study,the KC-10 avionics had not been finalized and
no TO's existed. Information and some preliminary drawings
were obtained from McDonnell Douglas, Long Beach, California,
and internally from the Flight Systems Division of The Bendix
Corporation which designed and manufactured the autopilot/flight
director system for both the military and commercial versions
of the aircraft. The baseline cockpit arrangement is that of
Overseas National Airways (ONA) and the autopilot is a Northwest
Orient Airlines (NWA) version. The ONA cockpit was modified
to add TACAN and single-cue ADI's.

The MLS-related approach equipment is analog and is certified
commercially for Category IIIa fail-operative automatic landings.
As such,the landing system is completely redundant,thus making
the KC-10A one of the few aircraft in the USAF inventory with
Category IIIa capabilities. Because of the autoland avionics
presently aboard the aircraft and due to the absence of weight
and space restrictions, the KC-10A is an ideal candidate for a
MLS-4 complex trajectory configuration if mission requirements
warrant.

Integration of the MLS System into the KC-10A aircraft involves
consideration of the following existing navigation equipment:

KC-10A NAV EQUIPMENT LIST

DISPLAYS

QUANTITY	DESCRIPTION
2	Horizontal Situation Indicator (HSI)
2	Attitude Direction Indicator (ADI)
2	Bearing and Directional Heading Indicator (BDHI)
2	Radio Magnetic Indicator (RMI)
2	Radio Altitude Indicator
2	Distance Measuring Equipment (DME)
2	Flight Mode Annunciator (FMA)
3	INS Control and Display Unit (INS-CDU)

KC-10 NAV EQUIPMENT LIST (Continued)

CONTROLS

QUANTITY	DESCRIPTION
2	ILS/VOR Frequency Selector
2	Preset Course Selector
2	Preset HDG Selector
2	TACAN Frequencey Selector
2	ADF Frequency Selector
3	INS Waypoint Selector (INS-CDU)

SWITCHING UNITS

QUANTITY	DESCRIPTION
1	Attitude Monitoring and Switching Unit (AMSU)
1	Azimuth Switching Unit (ASU)
1	Radio/INS Switching Unit
1	INS Switching Unit
1	VOR/ILS/TACAN Switching Unit

RECEIVERS

QUANTITY	DESCRIPTION
2	ILS
2	TACAN
2	VOR
2	ADF
2	DME
2	Radio ALT

The following pertinent factors regarding the present aircraft systems must be considered in implementing MLS in this aircraft:

- The basic DC-10 system philosophy is duplication of all displays, controls, sensors, receivers, etc. (No. 1 and No. 2 systems).

- The Inertial Navigation System (INS) is triplicated. Attitude information is supplied by the platforms. The third INS system (No. 3 or AUX) is standby and can be substituted for either the No. 1 or No. 2

system. Three INS control and display units are included and provide independent or common waypoint selection for the three computers. INS is capable of accepting information from an automatic data entry unit, however, interfacing provisions have not been included in the aircraft.

- Two separate, identical, autopilot/flight director (AP/FD) systems are installed and each drives separate control surfaces in each axis to provide a high level of availability and the required redundancy for a Category IIIa certification.

- A flight guidance control panel mounted in the center of the glare shield provides the means to engage the autopilot, autothrottle, and flight director systems. Single pushbuttons are provided for each mode and both systems are engaged in the same mode when the pushbuttons are activated.

- Flight mode annunciators (FMA), mounted above each ADI, contain four windows for displaying the various modes of the autothrottle and AP/FD systems. These windows display in left to right order: autothrottle modes; AP/FD arm modes; AP/FD roll modes; and AP/FD pitch modes. Each window is capable of displaying 32 separate legends of up to 8 characters (e.g., LOC TRK, GS TRK, DUAL LAND, MLS TRK).

- Operation in the automatic landing consists of the following events in the following mode sequence:

    1. First autopilot engaged
    2. Land mode armed
    3. Second autopilot armed
    4. Localizer and glide slope beams captured and now being cracked
    5. Preland test initiated
    6. Preland test completed after forty seconds
    7. Second autopilot coupled to surfaces and "DUAL, LAND" mode annunciated
    8. Align mode engages at 137 ft
    9. Flare mode engages at 50 ft
    10. Ground rollout mode engaged when aircraft touches down

- The present DC-10 autoland control laws and logic
  operation have been designed around normal ILS
  approach procedures. To avoid changes in these
  areas: final approach glide slopes must be between
  2.5° and 3.0°; the localizer and glide slope modes
  must be inhibited until a final approach is
  established; and, final approach lengths must be
  greater than 4 nm or else the preland test
  completion altitude detector must be decreased
  below its present 500 ft. level.

Block digarams of the MLS-related interfaces are illustrated in
Figures 120, 121 and 122. Identification numbers have been
assigned to the various elements. Table 10 lists the
equipment, its location, and associated Figure number. The
cockpit is illustrated in Figures 123 through 126.

Figure 120 illustrates the NAV/ILS/HSI interface. Lateral
deviation information from the various horizontal references
can be selected for display on the HSI via two switches, RAD/INS
and VOR/ILS/TAC, mounted on the NAV module of the flight
guidance control panel (see Figure 125).   The RAD/INS switch
is used to select either the INS or one of the radio (RAD)
references for display. In the RAD position, the selected
reference is a function of the VOR/ILS/TAC switch position. In
the TAC position, the TACAN reference is displayed and in the
VOR/ILS position (dependent on the frequency selected), either
the ILS or VOR reference is displayed. Frequency discrimination
is a function of switches internal to the ILS tuning mechanism.

Solid circles on Figure 120 show the functions interrupted
and routed through the MLS switching unit when MLS is installed.

The NAV/ILS/AP-FD/ADI interface is illustrated in Figure
121. If an ILS frequency is tuned and either the ILS
or land mode is selected (see Figure 125) via the control
panel pushbuttons, switching internal to the autopilot/flight
director (AP/FD) computers selects the ILS deviations for flight
path control computations. The AP/FD computer provides the servo
drive and flight director steering commands. Solid circles
on Figure 121 show the functions interrupted and routed
through the MLS switching unit when MLS is installed.

Figure 122 illustrates the course select and DME interface.
The course and heading references presented to the HSI are
a function of the position of the RAD/INS switch. In the
INS position, the INS system provides references and in the

RAD position, the AP/FD control panel provides references. A common actuator on the NAV module of the control panel is used to provide the course select, reference for the AP/FD, TACAN, and VOR receivers. These receivers in turn generate bearing information for the BDHI and RMI (pointer No. 2). The TACAN receiver generates distance information which is displayed on the DME indicator.

Solid circles on Figure 122 show the functions interrupted and routed through the MLS switching unit when MLS is installed.

5.6.2   KC-10A MLS Recommendations

Since the existing KC-10A has Category IIIa capabilities and will operate at fixed air bases with full coverage MLS capability, an MLS-4 complex trajectory configuration is recommended if mission requirements warrant. Workload problems associated with complex trajectory flight should not be serious since the aircraft has a three-man cockpit. Display capability is only a problem if the proposed electro-mechanical instrumentation is found to be insufficient for complex trajectory flight.

Installation of an MLS-4 system in the KC-10 type aircraft involves the addition of the following:

UNIT	QUANTITY
MLS Angle Receiver	2
MLS Angle Antenna	4
DME Interrogator	2
DME Antenna	4
MLS Control/Display Unit	2
MLS NAV (Complex Trajectory) Computer	2
MLS AD/DME Display	2
MLS/ILS Switch	2
MLS/ILS Switching Unit	2
MLS/VOR RMI Switch	2

Space is not a problem on the KC-10A aircraft and all of the units can be accommodated. Ample electrical power is available and MLS circuit breakers can be easily added to the existing panels.

MLS CDU's are the only large units required to be added to the
cockpit and a suggested rearrangement of the forward pedestal
panels is illustrated in Figure 127.   As an alternate,
it may be possible to include the MLS computations in the INS
system and utilize the existing INS CDU's (Item 18, Figure
156)   for trajectory selection. Further study of this
alternate is beyond the scope of this investigation and should
be considered for the final retrofit definition.

MLS/ILS and MLS/VOR RMI switches are added to the instrument
panels and are illustrated on Figures 123 and 124
(Items 19 and 21, respectively).

The MLS will utilize the number 2 pointers of the existing RMI's
to display bearing-to-station when the MLS/VOR RMI switch is
placed in the MLS position. In addition MLS will utilize the
present INS DME indicator on the HSI to display along track
distance to the GPIP when an MLS complex trajectory approach is
being flown.

The MLS AZ/DME displays are added in the space provisions for
the performance and failure assessment monitor display which is
utilized by several commercial airlines.

In order to accommodate the MLS-4 configuration,the pitch and
roll computers of the autopilot must be modified to accept the
pitch and roll complex trajectory steering signals from the
MLS computer. In addition, the present modal logic must be
modified to provide the appropriate control law switching
automatically.

MLS selection will be annunciated by the position of the MLS/ILS
switch and an MLS light mounted in some convenient location on
the instrument panel. The various phases of the MLS control will
be annuciated by the existing approach annunciations; (i.e.,
ILS arm, land arm, LOC capture and track, and glide slope
capture and track). As an alternative, MLS flight can be
annunciated specifically on the flight mode annunciators by
appropriate modification to the FMA tapes and pitch and roll
computers such that MLS legends appear (i.e.,MLS arm, AZ capture
and track, and EL capture and track).

MLS Operation

The sequence of operation and events related to an MLS complex trajectory flight using the proposed controls is as follows:

1) Define trajectory to MLS computer using MLS Control Display Units (both pilot and co-pilot).

2) Place RAD/INS switches on flight guidance control panel to "RAD" position and VOR/ILS/TAC switches to "VOR/ILS" position.

3) Place INS/ILS switches on instrument panel to "MLS" position and MLS/VOR RMI switch to "MLS" position and VOR/AFD-2 switch on RMIs to VOR position.

4) Select INS channel on MLS CDUs.

5) As a result of the above procedure, MLS information is displayed on the following indicators:

Indicator	References
HSI	Lateral deviation, flag, along track distance, desired track angle, path anticipator.
ADI	Vertical deviation, flag, steering.
RMI (Pointer 2)	MLS station bearing.

Azimuth and range to the GPIP will be displayed on the MLS AZ/DME indicators as soon as the MLS channel is tuned. It may be useful to interlock the power to this display through the MLS/ILS switch if the FMA is not modified with MLS legends. In this manner, the absence of azimuth and DME indications will indicate a procedural error.

6) Select ILS or land mode via pushbutton on flight guidance control panel. This action arms the MLS system.

7) Automatic engagement of the MLS trajectory will occur when the capture logic in the MLS computer is satisfied. When the final approach segments are engaged, the MLS system will switch from computed path references to raw data control in azimuth and elevation.

283

TABLE 10

Equipment Identification and Location

ITEM NO.	TITLE	LOCATION PHYSICAL	FIGURE NO.
1	ILS RECEIVER	MAIN RADIO RACK	–
2	VOR RECIEVER	MAIN RADIO RACK	–
3	TACAN RECEIVER	MAIN RADIO RACK	–
4	INS	NAVIGATION RACK	–
5	VOR/ILS/TACAN SWITCH	CONTRL PANEL	154
6	VOR/ILS/TACAN SWITCHING UNIT	MAIN RADIO RACK	–
7	RAD/INS SWITCH	CONTROL PANEL	154
8	RAD/INS SWITCHING UNIT	MAIN RADIO RACK	–
9	HSI	INSTRUMENT PANEL	152 153
10	AUTOPILOT/FLIGHT DIRECTOR COMPUTERS	MAIN RADIO RACK	–
11	AUTOPILOT SERVOS	WINGS AND TAIL	–
12	FLIGHT DIRECTOR CMD SWITCH	OVERHEAD PANEL	155
13	ADI	INSTRUMENT PANEL	152 153
14	NAV MODULE	CONTROL PANEL	154
15	DME INDICATOR	INSTRUMENT PANEL	152 153
16	BEARING/DISTANCE/ HDG INDICATOR	INSTRUMENT PANEL	152 153
17	RMI	INSTRUMENT PANEL	152 153
18	INS CONTROL DISPLAY UNIT	FORWARD PEDESTAL	156
19	MLS/VOR RMI SWITCH	INSTRUMENT PANEL	152 153
21	MLS/ILS SWITCH	INSTRUMENT PANEL	152 153
22	MLS AZ/DME DISPLAY	INSTRUMENT PANEL	152 153
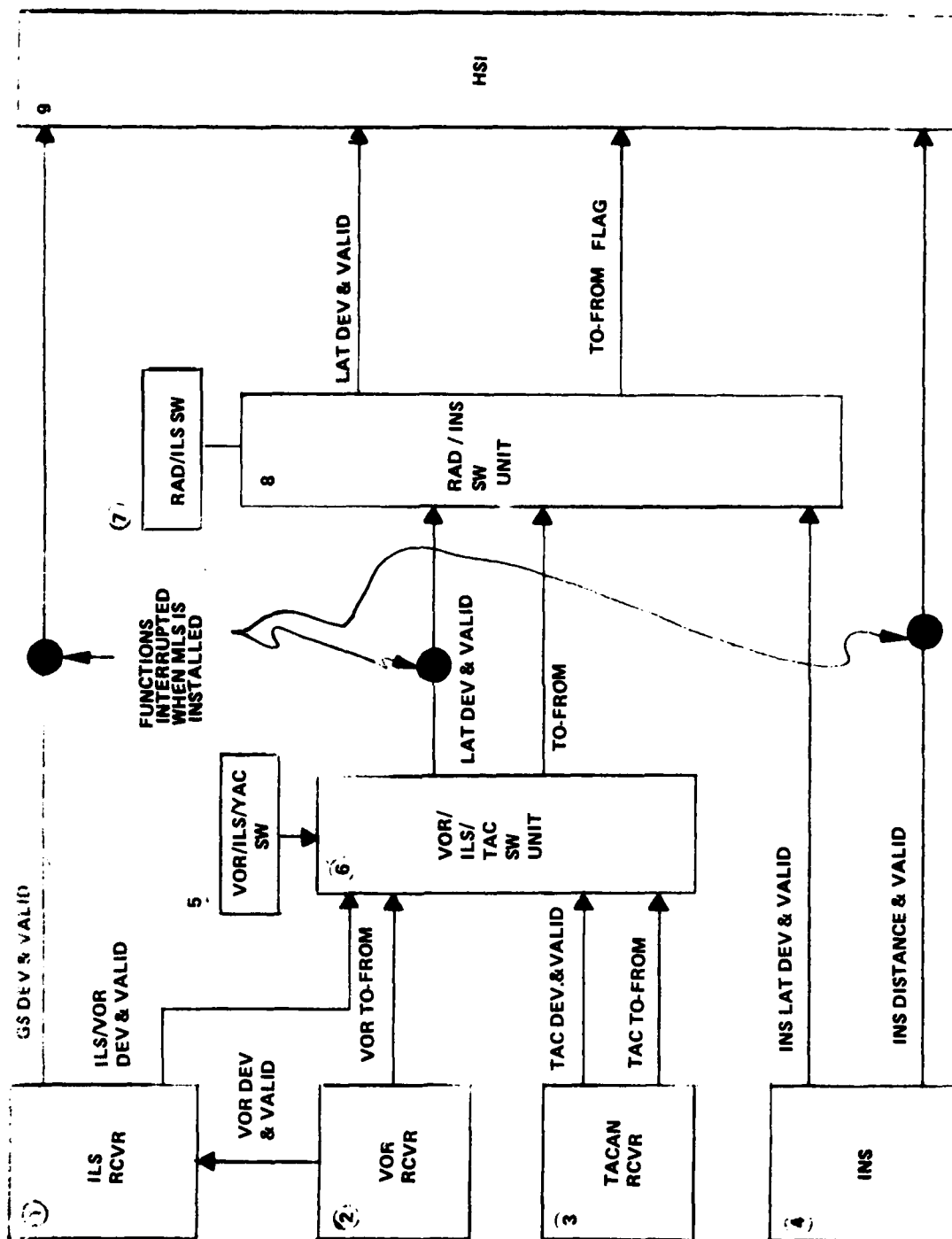
Figure 120 NAV/ILS/HSI Interface

285
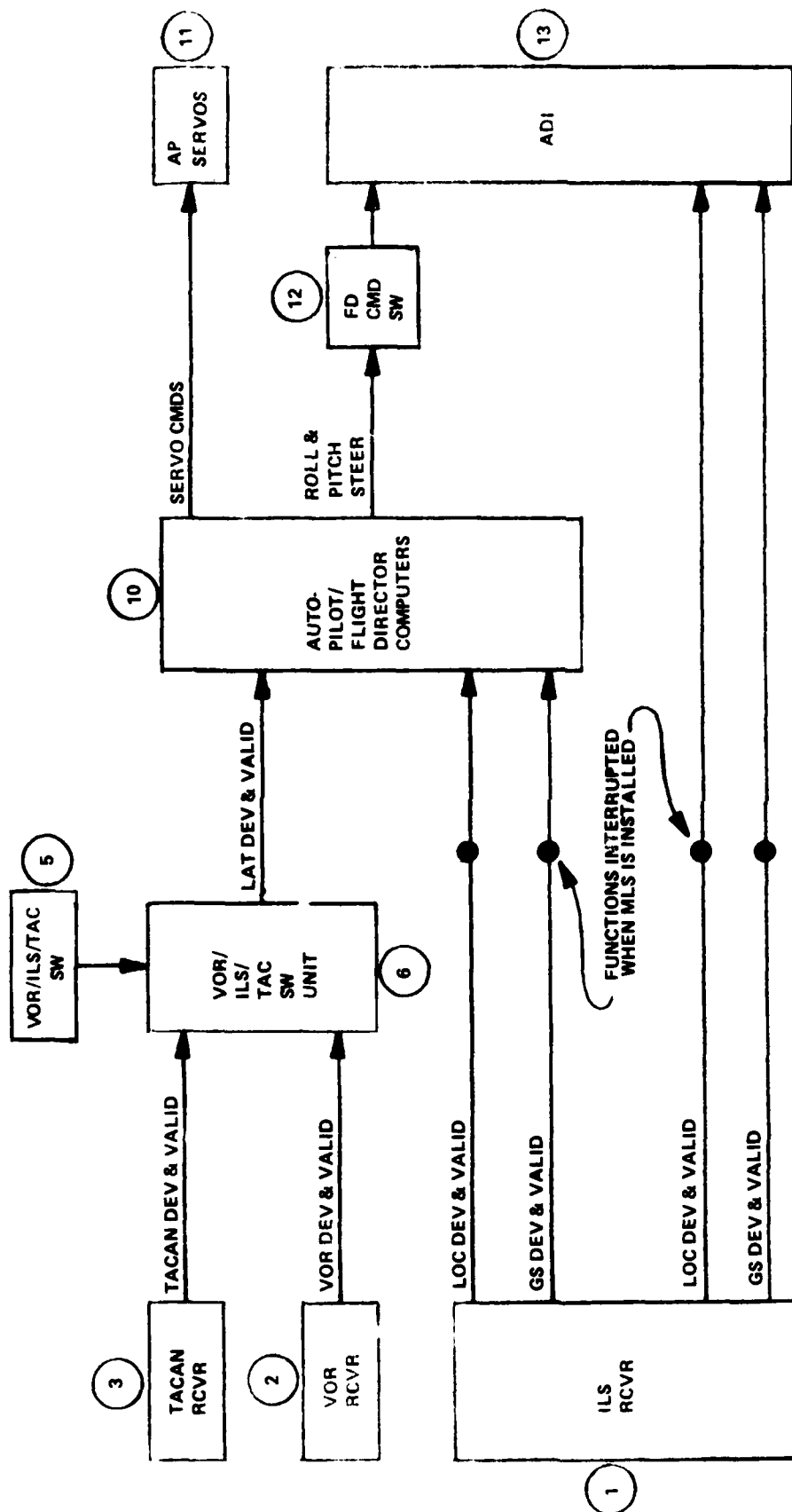
Figure 121 NAV/ILS/AP - FD/ADI Interface
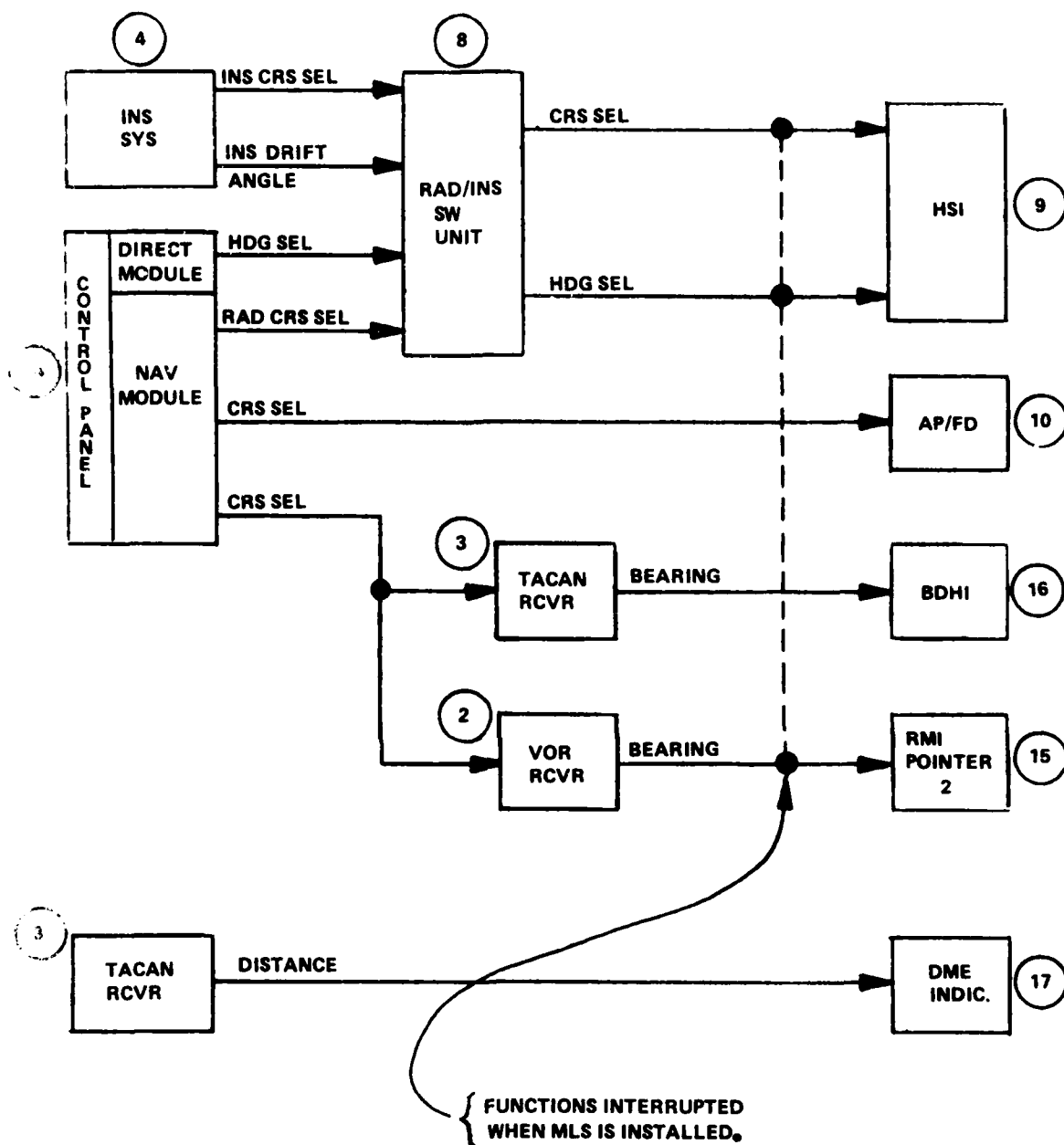
Figure 122 Course Select And DME Interface

287
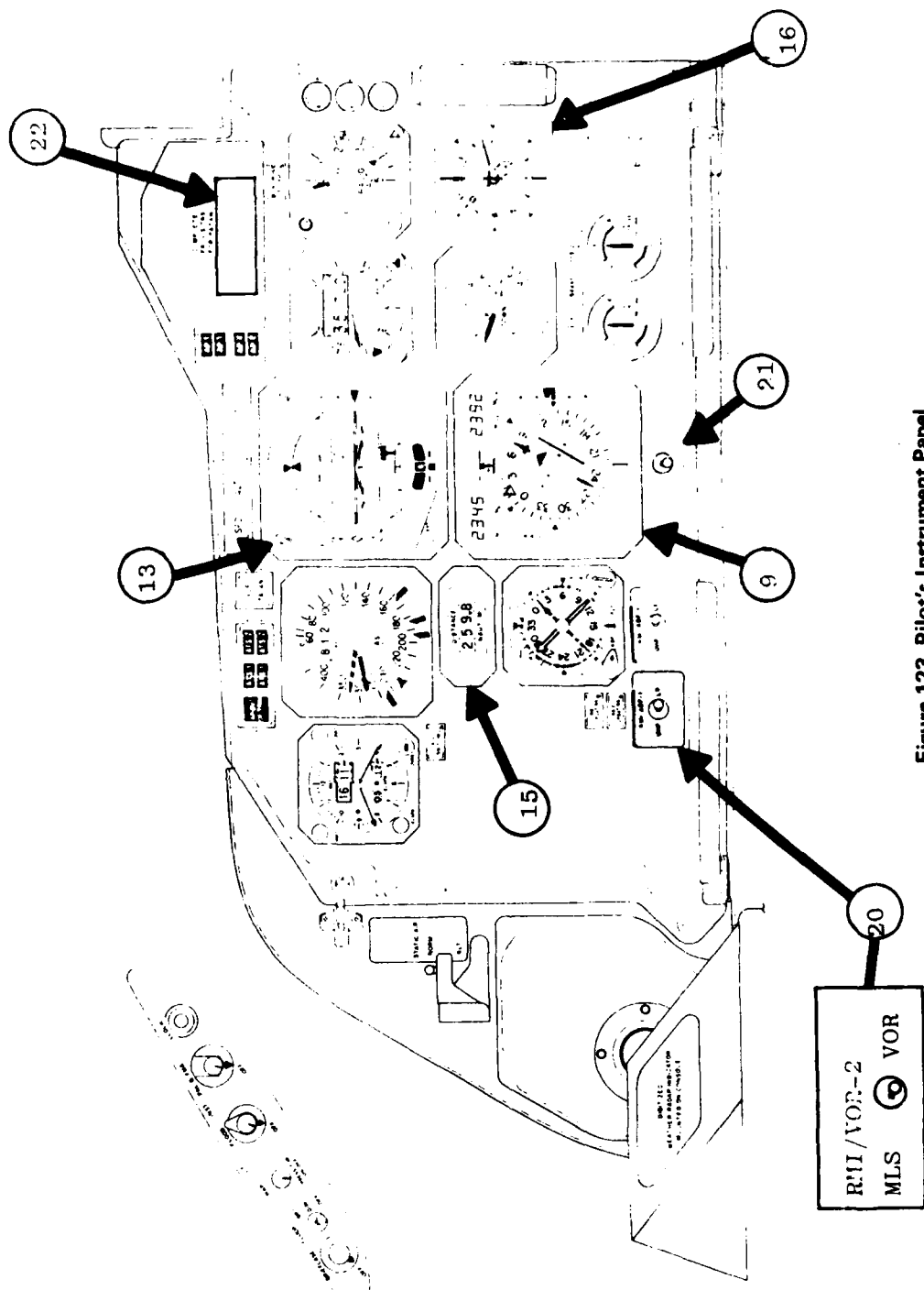
Figure 123 Pilot's Instrument Panel

RMI/VOR-2
MLS VOR
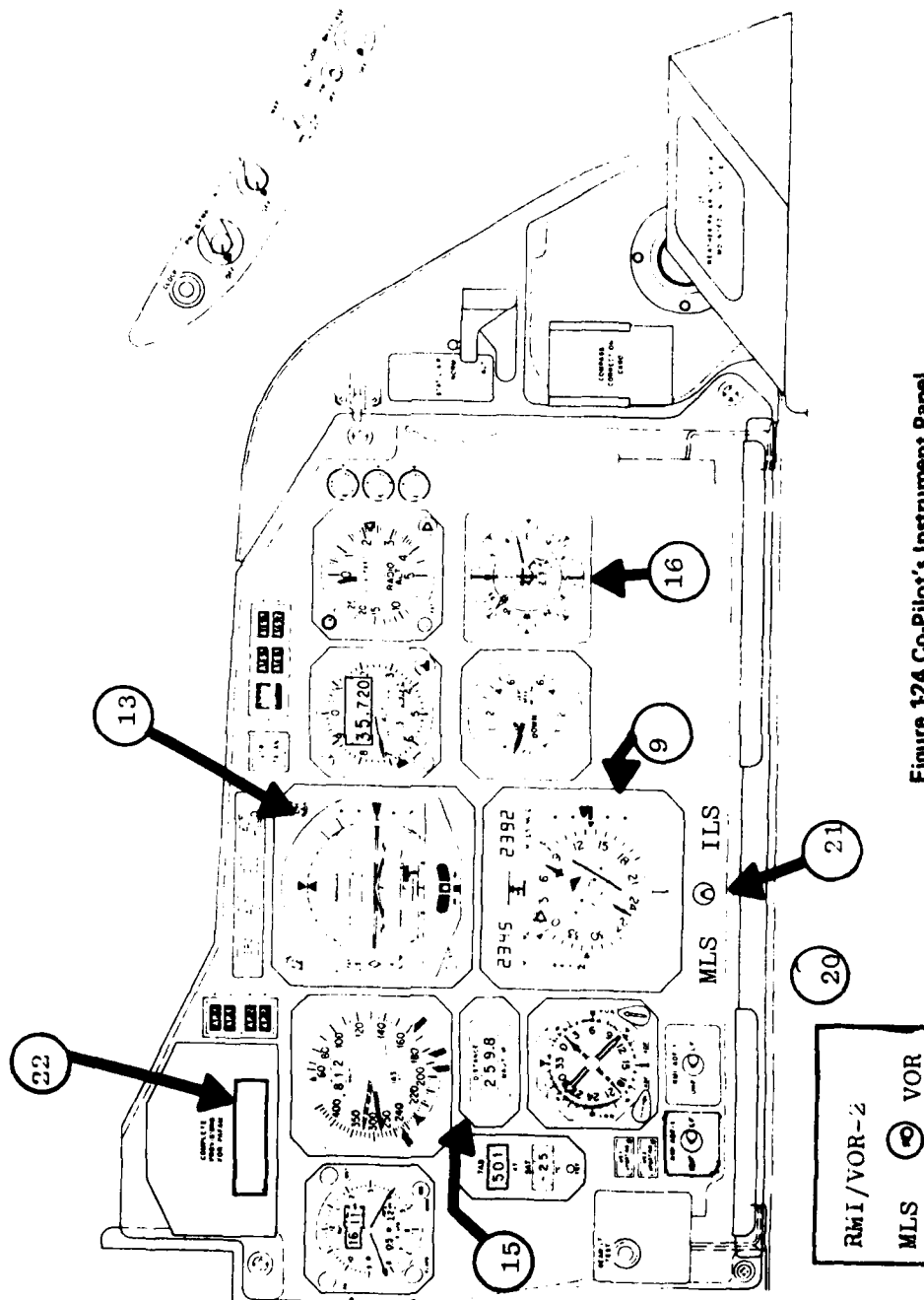
Figure 124 Co-Pilot's Instrument Panel

289
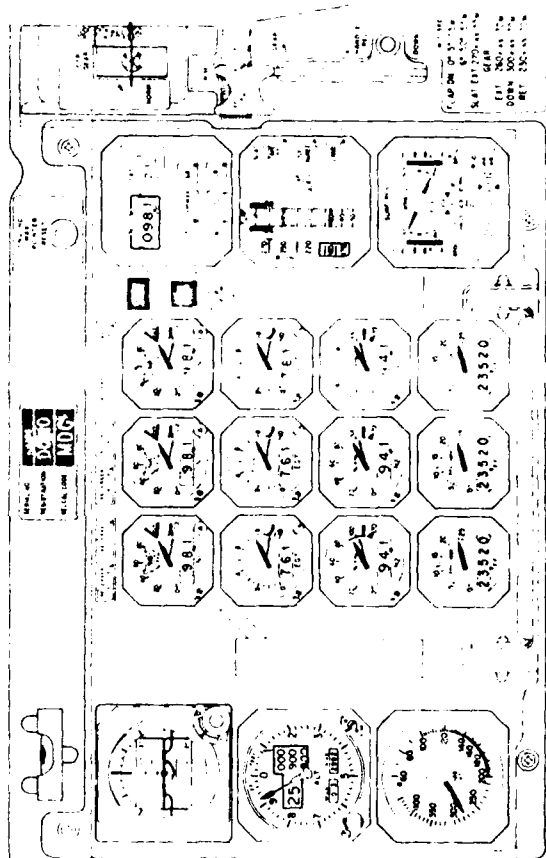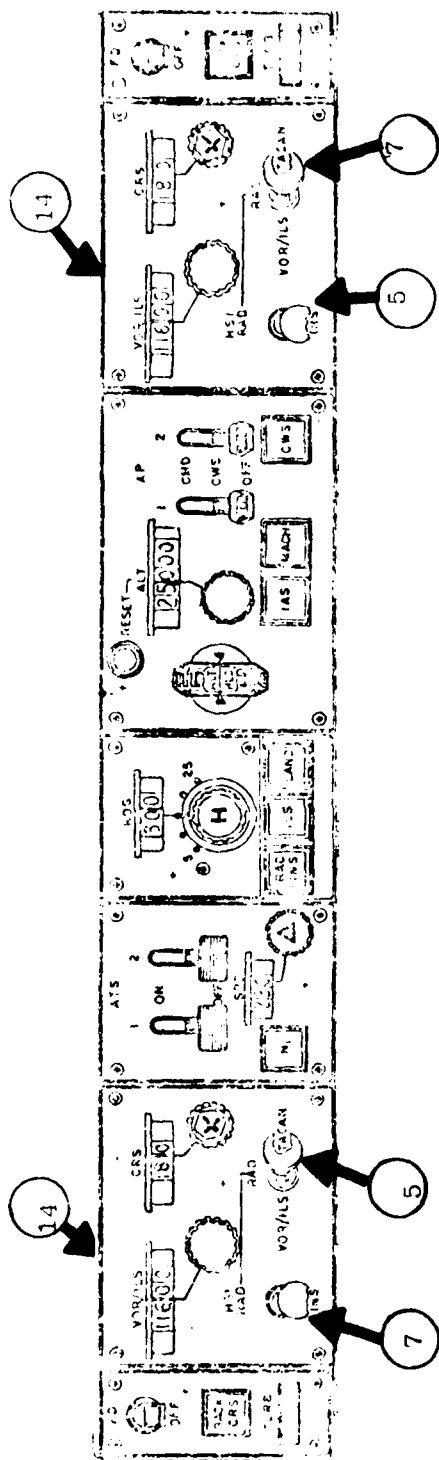
Figure 125 Flight Guidance Control Panel And Center Instrument Panel

290
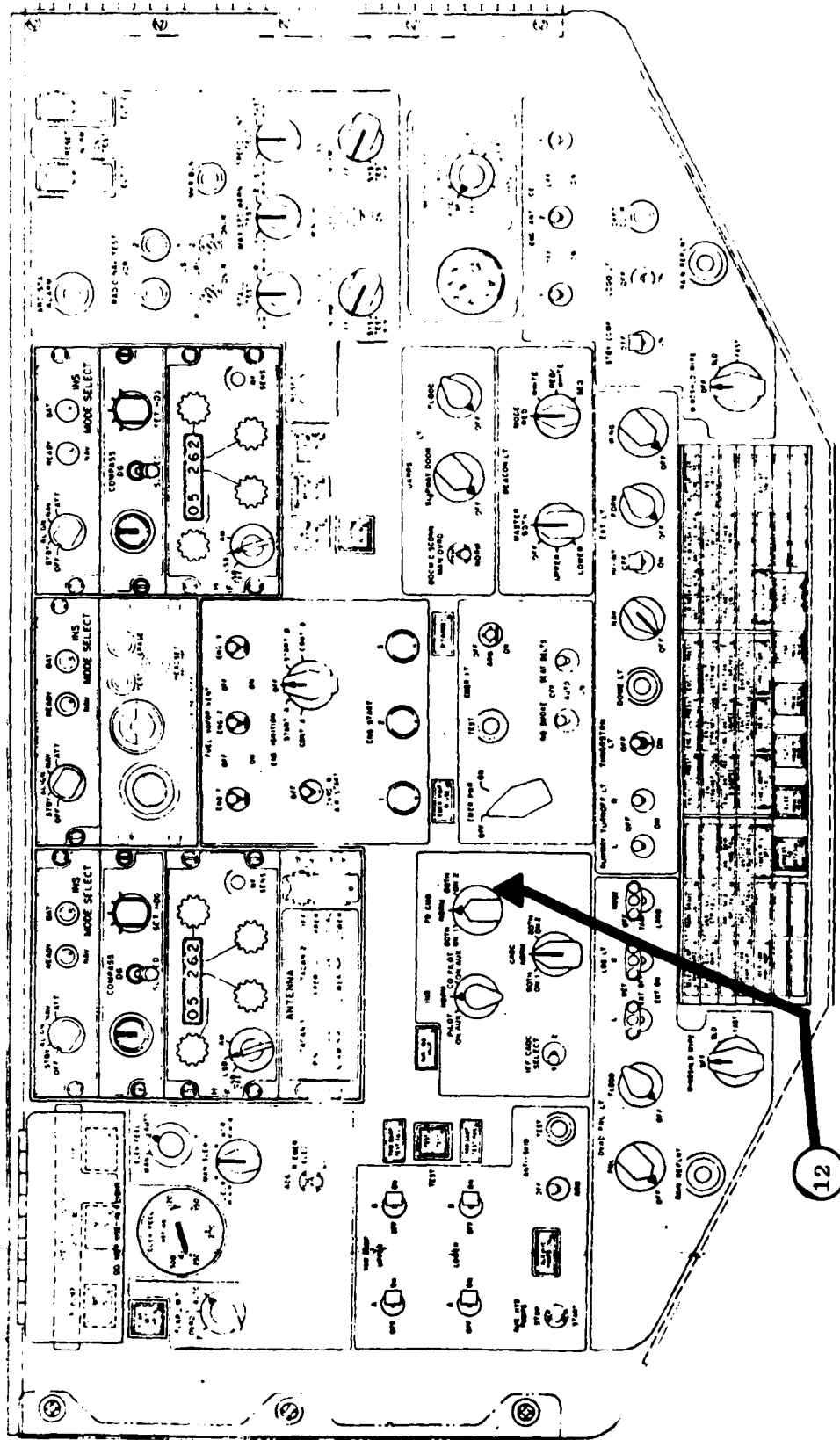
Figure 126 Overhead Panel

291
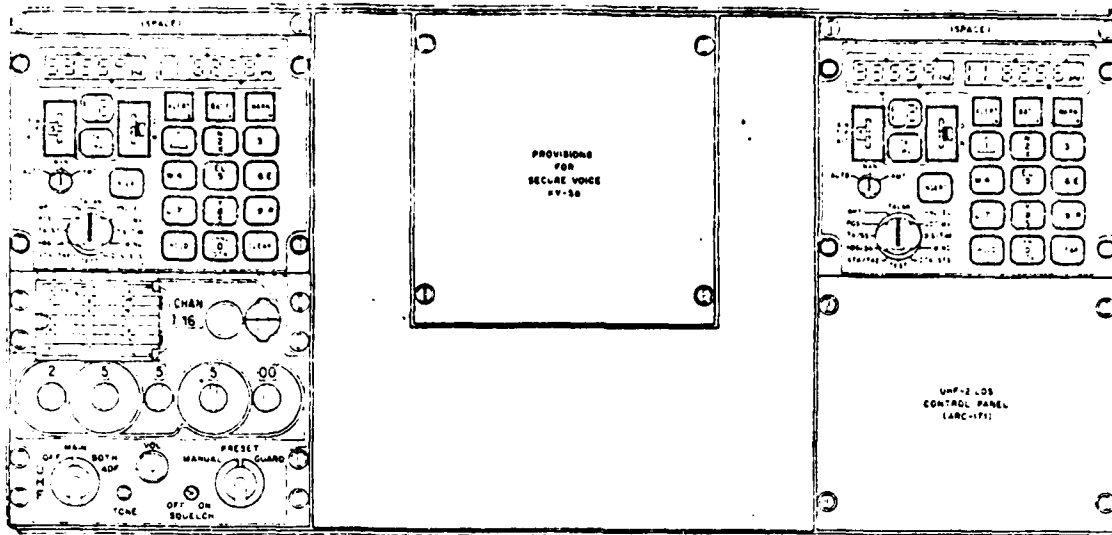
PRESENT
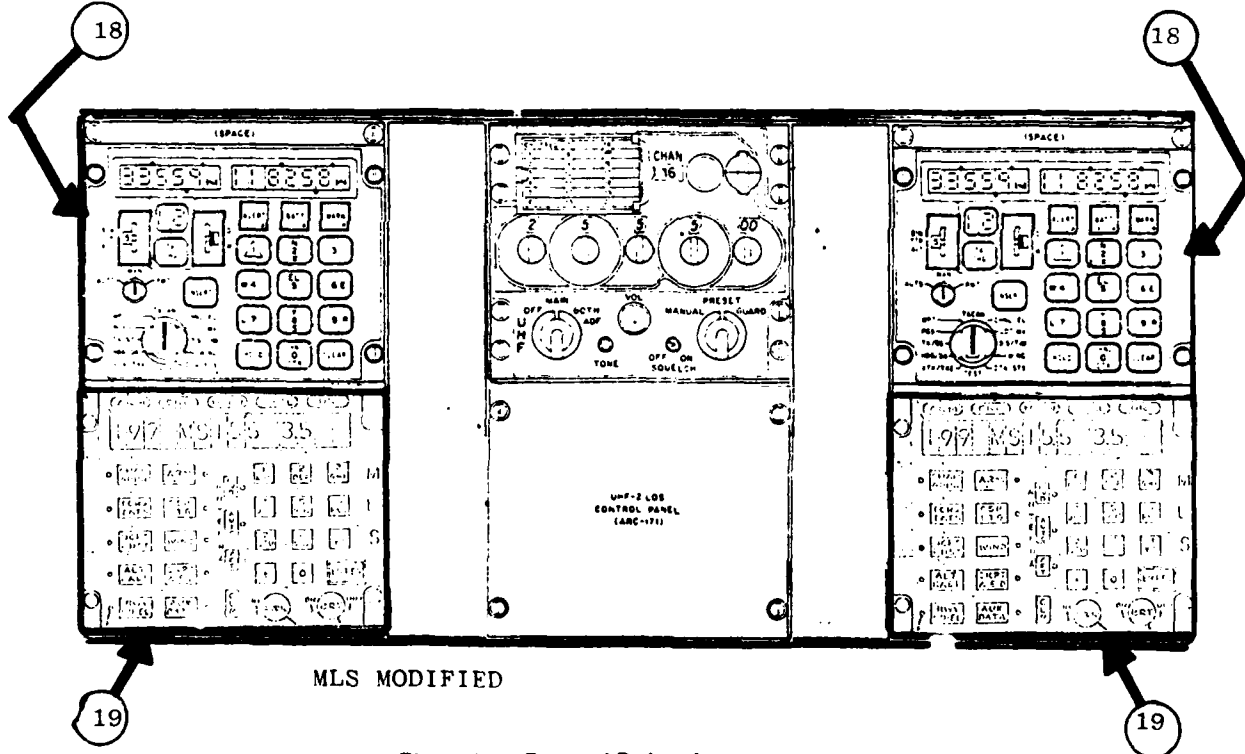
MLS MODIFIED

Figure 127 Forward Pedestal

6.0 DESIGN DEFINITION PHASE ACTIVITIES

6.1   Overall Use of the Cockpit Simulation

The fixed-base cockpit simulator, developed for use in this
program, provides a means for:

- Design Concept Refinement
- Formal Design Tradeoff Studies
- Design Evaluation
- System Demonstration

Each of these functions is discussed in terms of its major
characteristics and its appropriate procedures in the following
paragraphs.

6.1.1   Design Concept Refinement

The simplest use of the simulator is that in which the device
serves as a tool to aid design engineering in narrowing down the
number of possible control-and-display alternatives. This is
particularly true for electronic CRT display development due to
the programmable nature of this equipment.

In the typical environment, provided by the cockpit simulator,
the displays are rendered in the true colors, sizes and
surroundings of the proposed hardware. Most importantly, the
display elements move in a closed-loop, real time fashion which
is representative of actual use.

The simulator can reveal to the designers some advantages and
some limitations which could not be seen in static drawings.
Sometimes it will be seen that things which move together reduce
perceptual clutter because they tend to be seen as one moving
object. Sometimes things in relative motion do not interfere
visually with each other because they are perceived as lying in
different planes. Sometimes it will be seen that elements do
interfere with each other during motion by masking, causing
distortion, or misleading the pilot.

In this use of the simulator, the persons who are observing the
displays are those who make conceptual drawings and otherwise
engage in design development. They either fly the simulator
themselves or have someone fly it for them while they concentrate
on observing the displays. When an experienced pilot flies the

293

system, the purpose should be to obtain suggestions about the appropriateness of the design features. Neither the aim nor the questions should address the issue of how well the display serves the function, since that issue requires more sophistication in measurement.

6.1.2   Formal Design Tradeoff Studies

After the designs have been narrowed down to a set which represent viable alternatives, formal design tradeoff studies are begun. It is the purpose of the trade study to assign relative figures of merit to each of the candidate designs, and to help select the major contenders. It is important that the candidates represent a range of design alternatives.

The questions to be answered in the design trade study are no longer about design features as in the case of the earlier procedure. The questions now are of the form, "Is pilot performance better with A, or B, or C?" The simulation procedures will answer questions like this and the effects of specific design features can only be inferred from the relative figures of merit.

The design tradeoff study involves the measurement of performance of pilots making landing approaches using the MLS control/display equipment. Enough care needs to be exercised in the selection of pilot subjects, in the simulation of the task, and in the measurement of performance to allow a prediction that the order of merit of the displays in this simulation would be the same as it would be if they were in production and in regular use.

In the design tradeoff studies, performance should be measured only for runs by experienced instrument pilots, who know what it feels like to be groping for the ground by means of electronic aids while managing a fast-moving aircraft that cannot be slowed down in the air and cannot be held up very long. The critical issues for the MLS controls and displays are the way in which they fit into that perceptual habit structure.

6.1.3   Design Evaluation and Validation

The third major category of uses for the simulator is that of design evaluation. The kind of question to be answered by this procedure is whether the MLS landing can be done well with the refined control/display system and whether it can be done well

294

enough to warrant the expenditures for procurement of the new hardware.

The logic of this procedure suggests that two sets of controls and displays should be included in this evaluation and validation experiment:

- A minimum modification of ILS controls and displays, reworked to be driven by the MLS electronics, which provide a limited complex trajectory capability as designated by the MLS-3 System discussed in Section 4.1.

- The set of specially designed controls and displays (including the electronic CRT) which are proposed to take full advantage of the MLS in future aircraft.

This evaluation and validation procedure should be done by measuring the performance of instrument-qualified pilots flying simulated approaches of various types with regard to varying types of local area conditions.

6.1.4 System Demonstration

The fourth category of use for the simulation of the pilot's task using the MLS controls and displays is that of system demonstration. This use involves the communication of technical data to decision makers. It assumes that the engineering and scientific data produced in the technical development procedures do not sell themselves. The critical technical data needs to be illuminated by some additional activities and put into a form in which many participants will be given an understanding of the results of the technical development program. A complex system such as MLS can profit greatly from demonstrations in which the displays are in motion in a real life environment.

6.2 Specific Simulator Activities in Design Definition Phase

This section discusses some of the specific issues associated with the candidate control-and-display configurations, which require further evaluation and concept refinement in the cockpit simulator. These issues include:

- The incorporation of the MLS-3 configuration to
  provide an austere complex trajectory capability
  on a retrofit basis

- The candidate CDU and check-point design
  methodologies affect on pilot workload

- The relative merits of the 2-D and 3-D
  electronic CRT display formats

- The relative merits of the improved electro-
  mechanical display format

- The use of the approach plates in conjunction
  with monitoring

A brief description of the questions associated with these
issues follows.

6.2.1   Incorporation of MLS-3 Configurations

In the USAF FPI Program, serious doubt was expressed regarding the
use of present-day electromechanical control-and-display
instrumentation for complex trajectory flight. This was based on
high pilot workload levels associated with data entry, and
orientation problems while tracking the curved path multi-
segmented approaches.

In this study the MLS-3 configuration was developed to reduce
these problems to a minimum by constraining the complexity of the
trajectory to a maximum of two segments. It results in a
simplified data entry scheme and orientation problems no worse
than those involved with the approach to intercept the ILS
localizer.

The cockpit simulator will be used to observe pilot workload and
operation with this system and to answer the following questions:

- Are pilot workload levels acceptable for data entry?

- Is orientation a problem with the electromechanical
  display information?

- Can these simplified complex trajectories be done
  safely in single-seat aircraft with flight director
  guidance?

296

● Can failures be detected and can missed approaches be executed safely?

6.2.2　Effect on Pilot Workload of Candidate CDU

Software and hardware modifications can be made, in conjunction with the T-39 CDU and digital computer, to simulate one of the proposed candidate CDU configurations. This would also require modifications to the trajectory definition software and the generation of new algorithms to implement the automatic test capability associated with the "check-point." The object of the simulator activity will be to determine if pilot workload is reduced to acceptable levels (by reducing the number of data entries and by eliminating the need for an extensive pilot-conducted test) to obviate the need for automatic data entry.

6.2.3　Relative Merits of 2-D and 3-D Electronic Display Formats

The 2-D and the 3-D displays differ markedly in the way they encode certain parts of the pilot's control information. For purposes of situation planning,the 2-D format shows distance as the vertical dimension of the display. In the 3-D display that distance is shown through an illusion of depth created by the perspective lines.

It is probably true that the 2-D display will do better in providing a view of the situation for planning. The 3-D may provide some advantage in performing the attitude control task. The simulator will be used to compare these concepts and evaluate each against the task requirements of pilots in the terminal area.

The following paragraphs discuss how the simulator will be used to evaluate some of the display elements of the 2-D and 3-D formats.

6.2.3.1　Perceptual Separation of Display Features

It has been observed in previous projects that head-up displays are less interpretable as static pictures than when they are in motion in use. It is similarly expected that this will occur with both the 2-D and 3-D displays. There are a number of display elements to be discriminated and interpreted. Color has been used in these displays to help separate families of display elements. The simulator animation will help considerably in verifying and evaluating the extent to which the designs are perceived as predicted in the analysis.

6.2.3.2   The Systematic Use of Display Color Assignment

Elsewhere in this report it has been stated that color in the
displays has been used systematically to help in the pilot's
interpretation of the displays. In some cases,all three colors
are utilized in the same display space. The simulator will be
highly useful in determining the extent to which the color
assignments aid and do accomplish the design objectives. The
color assignments can be varied easily to provide experimental
aids to analysis.

6.2.3.3   Interpretability of Attitude Pitch Lines

Because of the number of elements in these complex displays, the
number of pitch lines shown for attitude reference has been held
to a minimum. The analysis for this design suggests that two or
three lines are adequate.

The ability to suppress lines and put on only those needed is one
of the things which is possible with electronic attitude displays.
This also means that there is not much actual behavioral
experience behind the performance prediction. It seems necessary
to produce data in the simulator which will verify this concept
or cause it to be changed.

6.2.3.4   Habit Interference in Reading the Bank Scale

The top portion of both the 2-D and 3-D displays is used as the
primary heading or track compass. That information is there for
what are judged to be very important display system reasons. But
that same space can consequently not be used very well for a
scale of bank angle. Therefore,the bank angle display has been
located on the bottom center of the display.

Though its color is different from that of the compass display
and the curvature of the scale different. it is possible that
this scale may sometimes be interpreted to be the reciprocal of
heading. The simulator will be used to help assess the extent to
which this possible interference actually occurs.

6.2.3.5   Variable Scale Factors in the Situation Display

Elsewhere in this report it has been noted that the electronic
display medium now makes it relatively easy to change the scale
factor in displays. It seems quite likely that some important
benefits to performance can be obtained by so doing.

It has been noted that the visual angle in reading a 4-inch
compass scale is only 1/10 of that in an out-the-window display
of direction in the world. This suggests that the ability to
read heading may be enhanced by magnifying the scale by a factor
of 10 when fine control is desired. It has also been suggested
in this report that the area for situation display should in some
cases use the whole space to depict two miles and at other times
20 miles.

The simulator will be used to explore the range of useful scale
factors and whether scale changes should be continuous or
discrete.

6.2.3.6   The Interpretability of Flight Path Angle

At the reference point for reading altitude there are two
displays of flight path angle. Air-defined or ground defined
flight path angle is closest to the altimeter scale depending on
the mode of flight. This angle is the vector sum of true air-
speed (or ground speed) and vertical speed. It is very useful
when descending on a segment which does not terminate on the GPIP.
To the left of the actual flight path angle is a display of the
commanded flight path angle. This display element originates
from the triangle marking vertical deviation from the commanded
flight path. One reason for displaying these parameters in this
relationship is that an asymptotic approach to the vertical
commanded path can be made by aligning the bottoms of the two
FPA indicators.

The utility of these displays will be further evaluated in the
simulator.

6.2.3.7   The Legibility of the Associated Displays of Pitch
             Attitude and Flight Path Angle

One of the ways in which the advantages of the electronic display
media have been exploited is in the display of both pitch
attitude and flight path angle on the attitude indicator.

There is only one calibrated scale for pitch. The reference for
the aircraft has been doubled in order to produce a display of
both angles. That reference which is constant and at the center
of the display is used for reading the flight path angle. The
second aircraft reference symbol rises out of the fixed reference,
as angle of attack increases, to show the pitch attitude angle.
It is this reference line which grows humps to display flight
director pitch rate commands.

299

The legibility of these symbols will be evaluated in the simulator.

6.2.4   Relative Merits of Improved Electromechanical
         Display Format

The proposed improvements to the electromechanical display presentation of the T-39 (i.e., path anticipator on HSI and combined azimuth/DME display) should be evaluated in the simulator to determine if the total information presented provides the pilot with adequate orientation capability for the general complex trajectory. Improving this electromechanical display information to the point of adequacy shall continue to be a goal of the simulation phase since it will open the door of complex trajectory flight to a large number of existing aircraft.

This evaluation must consider autopilot vs. flight director approaches, failure detection, and missed approach execution.

6.2.5   Approach Plate Formats

One of the topics addressed in this study was approach plate design. Several different schemes were presented: the T-39 type with a map view and a profile view; 3-D perspective; and 3-D pseudo-perspective. These presentations could be a subject for evaluation in the simulator.

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        Ripley, Major M.J. (USMC), Dobry, T.E.; Naval Air
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A.9   Specifications

APPENDIX B

ANALYSIS OF THE ROLE OF A PREDICTOR IN A
HORIZONTAL SITUATION DISPLAY

B.1   General

An Electronic Horizontal Situation Display, showing
the position of the aircraft relative to the desired trajectory,
is anticipated to be one of the candidate displays for Phase II
evaluation. The literature indicates that the addition of
a predictor to such a display greatly improves the ease with
which the pilot can capture and track the trajectory.

The purpose of this analysis is to obtain some ana-
lytical insight into the role of the predictor in the capture
and tracking task by equating it to other known control/display
mechanisms, and in particular to attempt to analytically deter-
mine the optimum predictor length.

B.2   Predictor Equations

Figure B-1 illustrates a horizontal map situation at
a particular instant when the aircraft is to the right of, and
flying away from the desired track. The predictor indication
is shown emanating from the aircraft symbol initially in the
direction of the aircraft's present track and forming a
circular arc of length VT. V is the aircraft's ground velocity
and T is the desired prediction time.

The aircraft position error is designated as y. The
difference between the desired and present track angles is
designated the Track Angle Error (TAE). R is the radius of
the predictor arc and A is the enclosed angle.

The distance d represents the displacement of the end
of the predictor from the desired track (measured perpendicular
to the track). It is desired to solve for d in terms of y.

From the geometry one obtains:

$$d = y + 2R \sin \frac{A}{2} \sin \left(\frac{A}{2} + TAE \right) \tag{B-1}$$
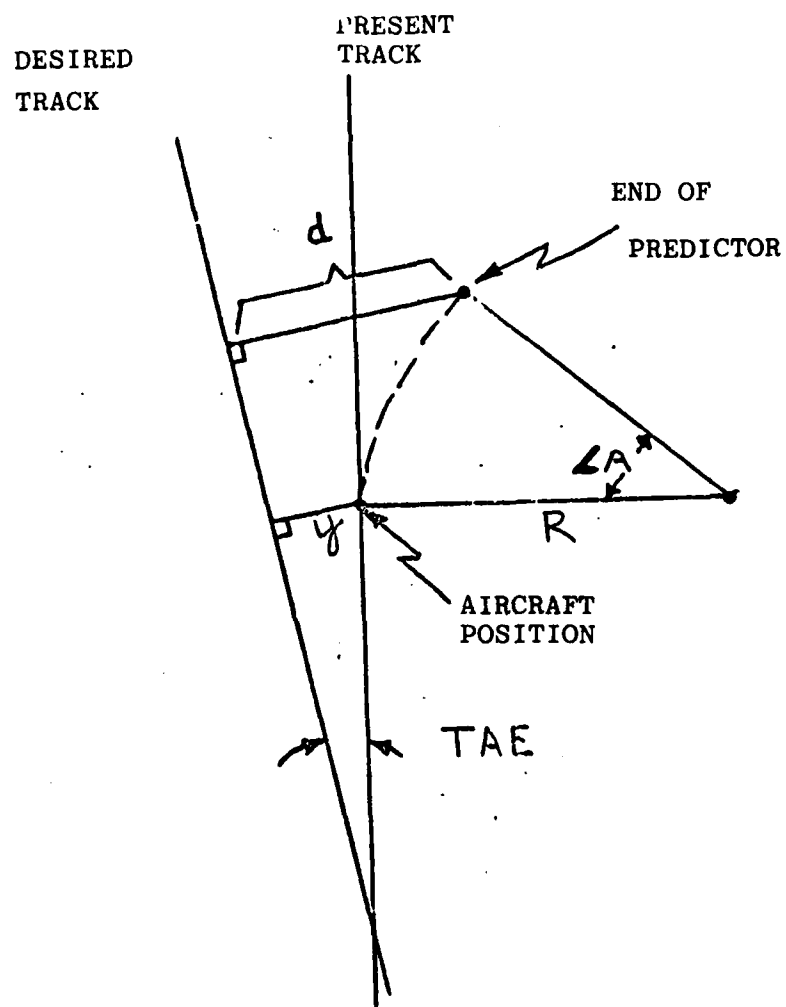
B-1

Figure B-1   Horizontal Situation Display With Predictor

Expanding:

$$d = y + 2R \sin \frac{A}{2} \sin \frac{A}{2} \cos TAE + \cos \frac{A}{2} \sin TAE \qquad (B-2)$$

This equation may be linearized by first assuming that the aircraft maneuvers will be restricted to standard turns or less. In a standard turn the radius of turn R is given by:

$$R = \frac{V \times 120}{2\pi} \qquad (B-3)$$

The enclosed angle A is equal to the arc length divided by the radius, therefore:

$$\frac{A}{2} = \frac{VT}{2R} = \frac{2\pi \times T}{2 \times 120} = \frac{1}{40} T \qquad (B-4)$$

Recognizing that we are concerned with predictor times of about 10 seconds, A/2 will be a maximum of .25 rad and the normal small angle assumptions are then valid. Accordingly, we set:

$$\sin \frac{A}{2} = \frac{A}{2} = \frac{VT}{2R} \qquad (B-5)$$

$$\cos \frac{A}{2} = 1 \qquad (B-6)$$

Substituting 5 and 6 into 2 :

$$d = y + VT \sin TAE + \frac{V^2 T^2}{2R} \cos TAE \qquad (B-7)$$

The radius of the predictor arc will be computed for display as:

$$R = \frac{V^2}{\phi g} \qquad (B-8)$$

where ϕ is the roll angle of the aircraft.

Now, assuming coordinated turns:

$$g\dot{\phi} = V(\dot{TAE}) \tag{B-9}$$

$$\dot{y} = V \sin (TAE) \tag{B-10}$$

$$\ddot{y} = V (\dot{TAE})\cos(TAE) \quad (V = \text{constant}) \tag{B-11}$$

$$= g\dot{\phi} \cos (TAE)$$

Substituting equations 8 through 11 into equation 7 we obtain:

$$d = \ddot{y} \frac{T^2}{2} + \dot{y}T + y \tag{B-12}$$

This is the desired linear differential equation relating the displacement of the end of the predictor (from the linear track) to the aircraft's displacement and derivatives.

B.3   Equivalence to a Flight Director

It is of great interest to note at this point that this is exactly the same form of equation which describes the deflection of the command bar of the conventional Flight Director. It now becomes clear that if the pilot flys the aircraft in a manner so as to maintain d = o; that is, if he places the end of the predictor on the desired track and keeps it there, he will have the same success, and track with the same characteristics, as if he followed an equivalent Flight Director. Since the tracking performance utilizing a Flight Director has historically been proven to be a success, it may be concluded that the proper use of the predictor will prove likewise.

At the same time, the presence of the horizontal situation display allows the pilot the option of not following a flight director if he chooses while being aware of the true horizontal situation.

Let us now probe more deeply into the equivalence (on a quantitative basis) between the predictor and the Flight Director. First, it must be realized that if the pilot succeeds in maintaining d=o (with either a Flight Director or the predictor), equation 12 completely describes the aircraft motion for any set of initial conditions. This is a second order linear differential equation whose characteristics in the time domain are most adquately described in the literature.

The natural frequency of the characteristic equation is:

$$\omega_o = \frac{2}{T} \tag{B-13}$$

and the damping factor is:

$$\xi_o = .707 \tag{B-14}$$

Simply stated, ω_o is a measure of bandpass (or tightness) of the control and ξ_o is a measure of the damping (or overshoot) of that control. Note that the undamped natural frequency is inversely proportional to the predictor time, the damping factor is fixed, and the aircraft velocity is not a factor at all.

The damping factor of .707 is in the optimum range and corresponds to a 4.32 percent overshoot. Most flight directors attempt to achieve damping ratios which are not so high as to cause a slow closure rate and not so low as to cause a large overshoot. Typical values are from 0.6 (about 10% overshoot) to 0.8 (about 1.5% overshoot).

Typical natural frequencies (ω_o) which have been found to be adequate for tracking during the approach phase are between 0.1 and 0.2 radians per second. Lower frequencies result in "sloppy" performance and poor accuracy, while higher frequencies lead to excessive control and surface activity (pilot workload) with no necessary benefits in accuracy.

From Equation 13 it can be seen that this corresponds to predictor times (T) between 7 and 14 seconds. Since the complex trajectories associated with MLS present a more difficult task than conventional approaches, it is probable that the required natural frequency will tend toward the higher end. Hence, the predictor time will be about 7 seconds.

B.4   Path Capture

Figure B-2 shows two of the possible capture options available to the pilot. Each of these methods makes use of the Predictor but in different ways.

In Option 1, the pilot flies the aircraft, with wings level, to some predetermined relationship to the desired trajectory. At a time which he feels is proper, he banks the aircraft and then maintains that bank angle until the aircraft is almost on trajectory, at which time he rolls out.

In Option 2, the pilot treats the end of the Predictor as a Flight Director command. That is, he places it on the desired trajectory, and attempts to keep it there.

The chief difference between the options, in terms of control cues, is that there is no cue in Option 1 to tell the pilot when to start rolling into or out of the turn. For a smooth bank limited turn, the proper turn initiation time is a function of the closure rate, (i.e., the aircraft speed and capture angle). The consequences of initiating the turn too late are either a large overshoot or a compensating large bank angle.

Let us examine this further, on a quantitative basis, to determine the sensitivity of the resulting maneuver to the turn initiation time. For this purpose, we shall assume that the time required to bank up, once initiated, is zero (or small) compared to the total capture time.
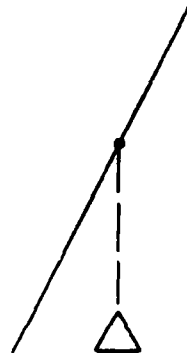
OPTION 1
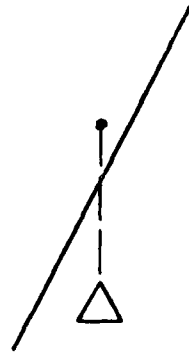
(a)

(b)

(c)

OPTION 2

(a)

(b)

(c)

Figure B-2   Two Capture Control Options

Assume an aircraft speed of 250ft/sec, a capture angle of 45^O, and that the pilot desires a constant bank angle capture at $\emptyset$ nom. From the geometry, the following can be calculated:

1) If the pilot rolls to $\emptyset$ nom late by 1 second, the overshoot will be 176 ft. A 2 second error yields 352 ft overshoot.

2) If the pilot wants to capture with $\emptyset$ nom = 30^O, and rolls 1 second late, he will have to bank 35^O to capture with no overshoot. If he rolls 2 seconds late, he will require 42^O of bank angle.

3) If the pilot wants to capture with $\emptyset$ nom = 45^O and rolls 1 second late, he will have to bank 55^O to capture with no overshoot. If he rolls 2 seconds late, he will require 69^O of bank angle.

The high sensitivity of this type of capture to roll initiation time (for which the pilot has no dedicated visual cue) is now readily apparent. It may be predicted that poor and inconsistent capture performance will result.

With Option 2, the pilot's task is alleviated by the knowledge that a satisfactory capture will consistently result if he maintains a bank angle time history corresponding to keeping the end of the Predictor on the desired track.

A natural question which arises is whether, based upon performance, it is desirable to attempt Option 1 type captures. To attempt to answer this question, the space trajectory for both types of captures were computed, and are illustrated in Figure B-3.

The plots are based upon an initial capture angle of 40 deg. at a speed of 250 ft/sec. Option 2 uses a 7 second Predictor (1750 feet long) and therefore the capture starts 7 seconds before the aircraft would reach the desired track. The maximum bank angle achieved during the Option 2 capture was 30 deg.
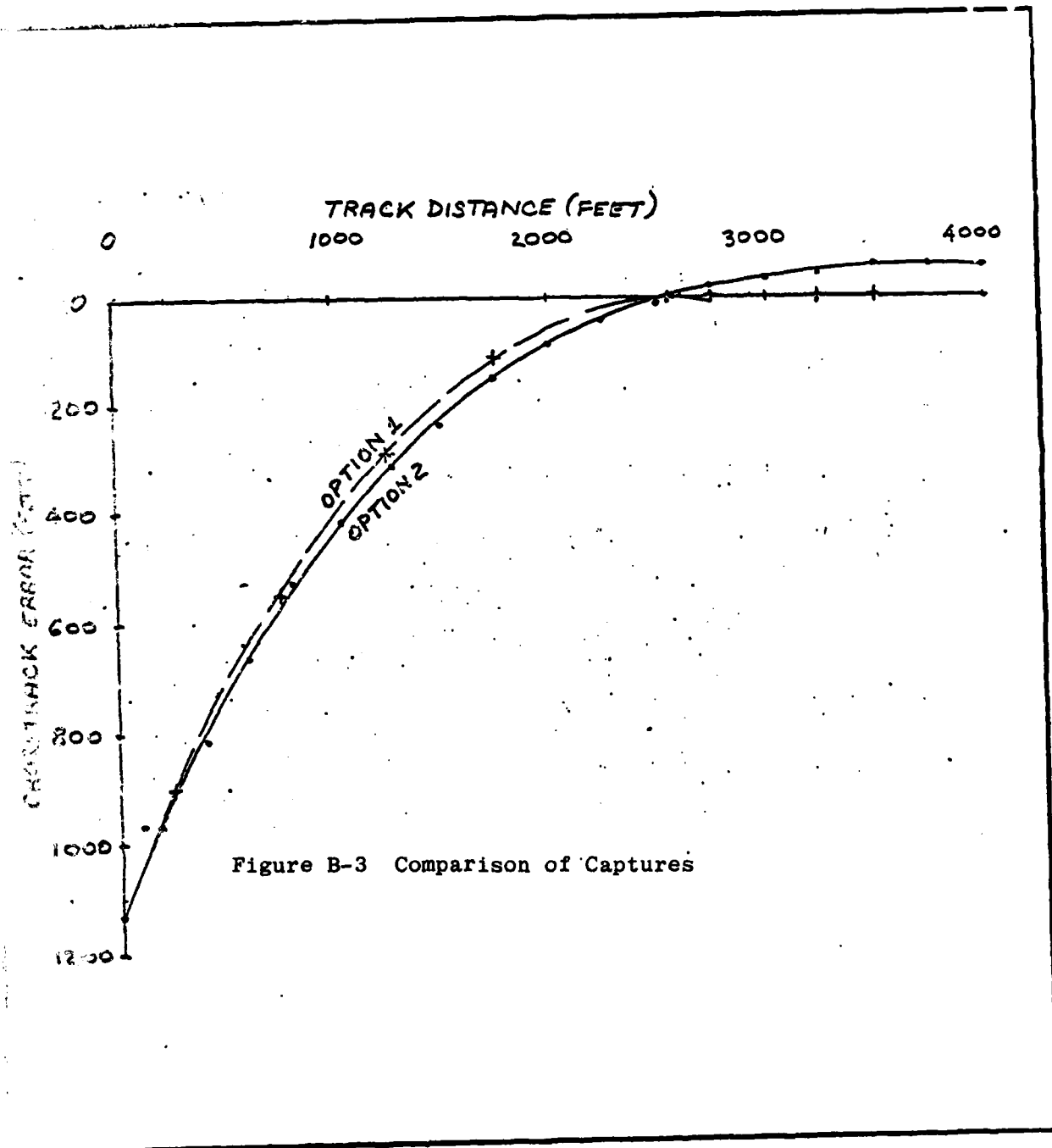
B-8

TRACK DISTANCE (FEET)

Figure B-3   Comparison of Captures

The Option 1 capture corresponds to that achieved with a constant 30 deg. bank angle and is a circular arc in the space reference. In order to make a tangential capture with a constant 30 degree bank angle, the turn is initiated about two seconds after the Option 2 capture.

As shown in Figure B-3, the perfectly executed Option 1 capture trajectory is almost coincident with the Option 2 capture, except that there is the inherent overshoot (60 feet in this case) associated with the latter. Based upon the overshoot consequences previously cited for performing a nonperfectly executed Option 1 capture, one may conclude that Option 2 type captures will yield better results on the average. This is an area that requires further examination in the Phase II simulation studies.

One additional point worthy of note is that Option 1 capture in Figure B-3 cannot really be made by placing and maintaining a 7 second span Predictor arc tangent to the desired track. For the initial conditions selected, and for a 30° bank perfect capture, the length of the circular arc circumscribed by the aircraft is 2360 feet. Since the Predictor is only 1750 feet long, it is not possible to actually place the Predictor tangent to the track at the beginning of the maneuver. It is only possible to estimate that a visual extrapolation of the Predictor arc (extrapolated an additional 610 ft) would be tangent to the circle. This will undoubtedly make the Option 1 type captures exhibit even greater sensitivity to operator errors.

If the pilot waited until he could place the 7 second Predictor arc tangent to the track with no extrapolation required, the resulting bank angle would, of course, be considerably larger. For the case examined here. the bank angle would correspond to 38 degrees.

B.5   Use of the Predictor During Path Transitions

Let us now turn to the problem of transition from a straight track to a circular track and vice versa. Figure B-4 shows two control options for the former case.

Option 1 corresponds to the case where the pilot waits until he reaches, or almost reaches, the transition point, and then rapidly banks the aircraft so that the Predictor arc
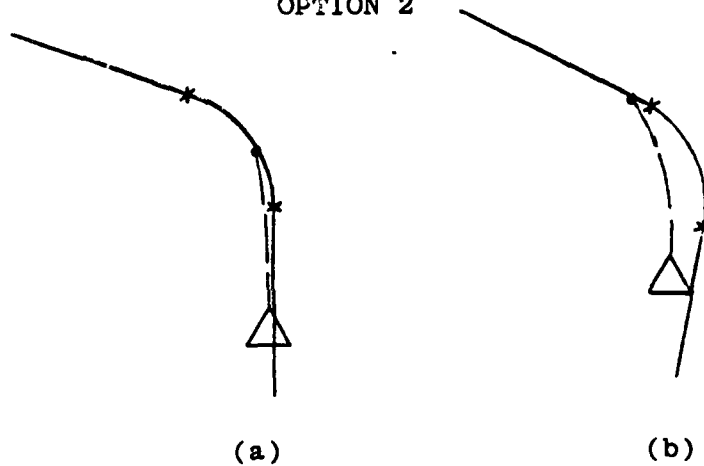
OPTION 1

(a)   (b)

OPTION 2

(a)   (b)
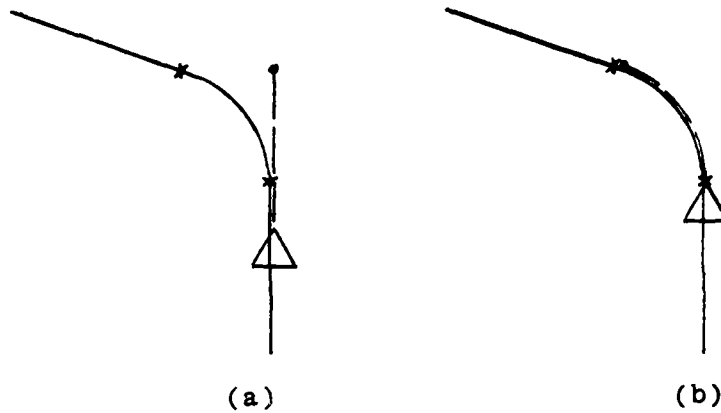
Figure B-4   Two Tracking Control Options/Straight to Circular Path

B-11

becomes coincident with the track arc. If he initiates

the bank too early, he will fly "inside" the turn; and, if too
late, he will fly "outside" the turn. In the latter case: he
must first increase the bank angle; he cannot apply the "tangency"
mode of control; and, he must, therefore,change the method in
which he uses the Predictor.

Option 2 corresponds to the case where the pilot always
keeps the end of the Predictor on the desired track. In this
instance, it is obvious that he will start to bank 7 seconds
before he reaches the transition point and, as a result, will
fly on the "inside" of the the turn. This is a "built-in"
error, inherent in this method of Predictor use, and is exclus-
ive of any other errors involved with how well he uses this
method.

This inherent error was calculated for the conditions
of flight at 250 ft/sec using a 7 second Predictor, and transist-
ioning to a circular arc track of radius corresponding to a
standard turn. The maximum error was 55 ft from the desired
track.

It must be remembered that the use of the circular
arc originated as one means to smoothly connect two linear track
segments intersecting at a waypoint. As such, the circular
arc constituted a considerable error from the two linear seg-
ments. For instance, if two perpendicular linear segments are
smoothed together by a circular arc corresponding to a standard
turn at 250 ft/sec aircraft velocity, the closest the arc
comes to the waypoint is 2000 ft. Thus, in terms of absolute
error, a 55 ft error from the arc is insignificant. However,
an inherent error of 55 ft from the displayed arc may have a
negative psychological effect on the pilot. The final answer
must await the Phase II simulator experiments.

Similar control options exist in the transition from a
circular arc to a linear track segment as shown in Figure B-5.
In Option 1, the pilot controls the aircraft to keep the Pre-
dict r arc tangent to the linear track at the transition point.
Upon reaching (or nearly reaching) the transition point, the
aircraft is rolled out onto the linear segment.

B-12

OPTION 1

(a)   (b)

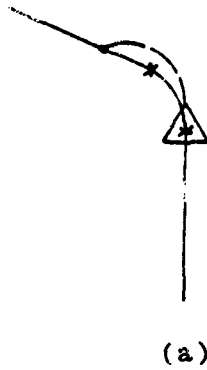OPTION 2

(a)   (b)
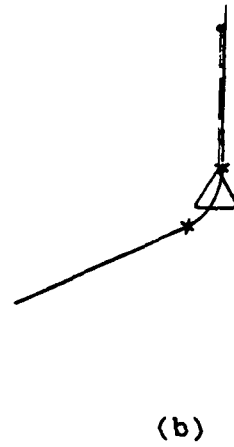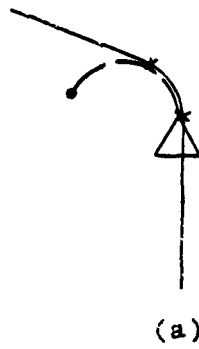
Figure B-5 Two Tracking Control Options/Circular to Straight Path

B-13

Again, the maneuver is sensitive to roll-out initiation time. An early exit results in flying "outside" the turn and a late exit brings the aircraft "inside" the turn. In either case, the aircraft will be heading away from the desired track, and the pilot cannot utilize the "tangency" mode of control.

In Option 2 type of control, the pilot again merely keeps the end of the Predictor on the desired track. Again, the roll activity starts 7 seconds before reaching the track transition point. As a result, the aircraft always flies on the "outside" of the turn, again exhibiting an inherent error due to the control means. The actual magnitude of error was not calculated for this case, but it was assumed to be about the same as previously cited. However, the meaning and consequences of this error may be considerably different.

If, upon exit, the pilot finds the aircraft 55 feet off from the linear segment, it is a true error from the desired track. If this linear segment constitutes the last leg of an approach, the error must be corrected before the decision height window is reached. It's acceptability in terms of touchdown performance will depend to a great extent on the "ground rules" for how long the last linear segment must be. All of these problems must be evaluated in Phase II.

APPENDIX C

RELATED USAF, NASA AND OTHER STUDIES

Many studies have been conducted which relate to the subjects
discussed herein. A complete listing of material received
as a result of the literature search conducted for this
investigation is included in Appendix A. The following
paragraphs present a synopsis of the USAF Flight Profile
Investigation (FPI) Program, NASA Terminal Configured
Vehicle (TCV) Program, and other recent studies which produced
results directly applicable to the subjects of this study.

C.1   USAF T-39 FPI Program

The Flight Profile Investigation was conducted under
the management of the Crew Systems Development Branch of the
Air Force Flight Dynamics Laboratory. The program
focused on the technical and operational aspects related
to performing terminal area instrument approach procedures
using precision guidance from the MLS.

The purpose of the FPI was: to determine which flight profiles
are feasible in the MLS environment with various levels
of aircraft control and display sophistication; and, to
establish a baseline for determining the aircraft controls
and displays required to fully utilize the segmented and
curved approach paths made possible by the use of the
MLS.

The research aircraft for the program were two USAF T-39's,
tail numbers 03478 and 10649, which are military equivalents
of the Rockwell Sabreliner executive jet. These aircraft
were modified by The Bendix Corporation's Flight Systems
Division to include: the latest Phase III MLS receivers,
antenna, controls, and displays; a digital autopilot/
flight director/ navigation computer; a dual analog auto-
pilot/flight director; conventional electromechanical
displays (HSI, ADI); an electronic navigation control-and-
display unit (CDU); a programmable 5.7 in. x 5.7 in. color CRT
display, autopilot/flight director mode progress displays;
an analog autothrottle system; and, a digital data acquisi-
tion system. General arrangements of the equipment in these
two aircraft are shown in Figures C-1 and C-2. A
layout of the instrument panel, side consoles and center
pedestal in aircraft 61-0649 is shown in Figure C-3.
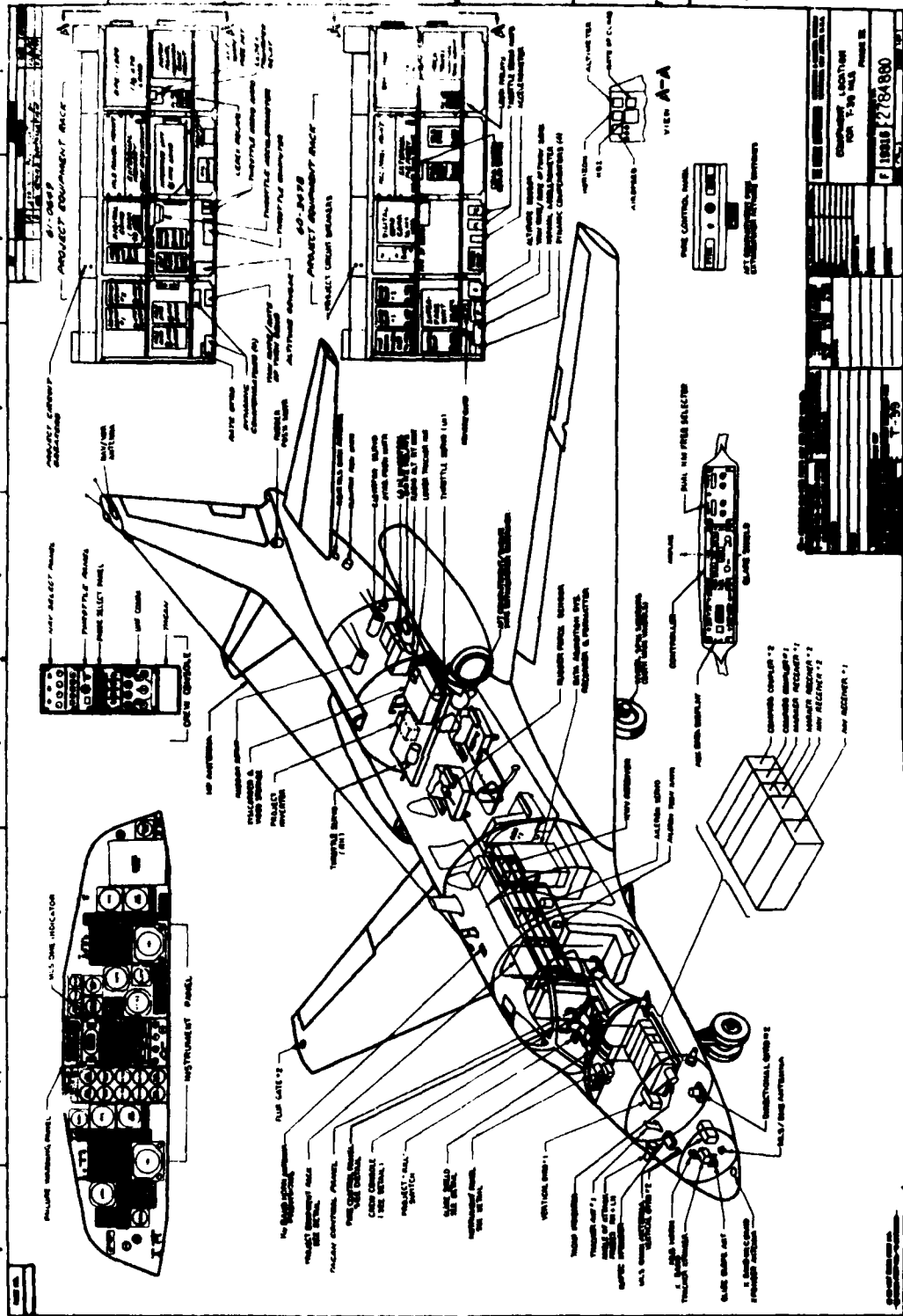
C-1

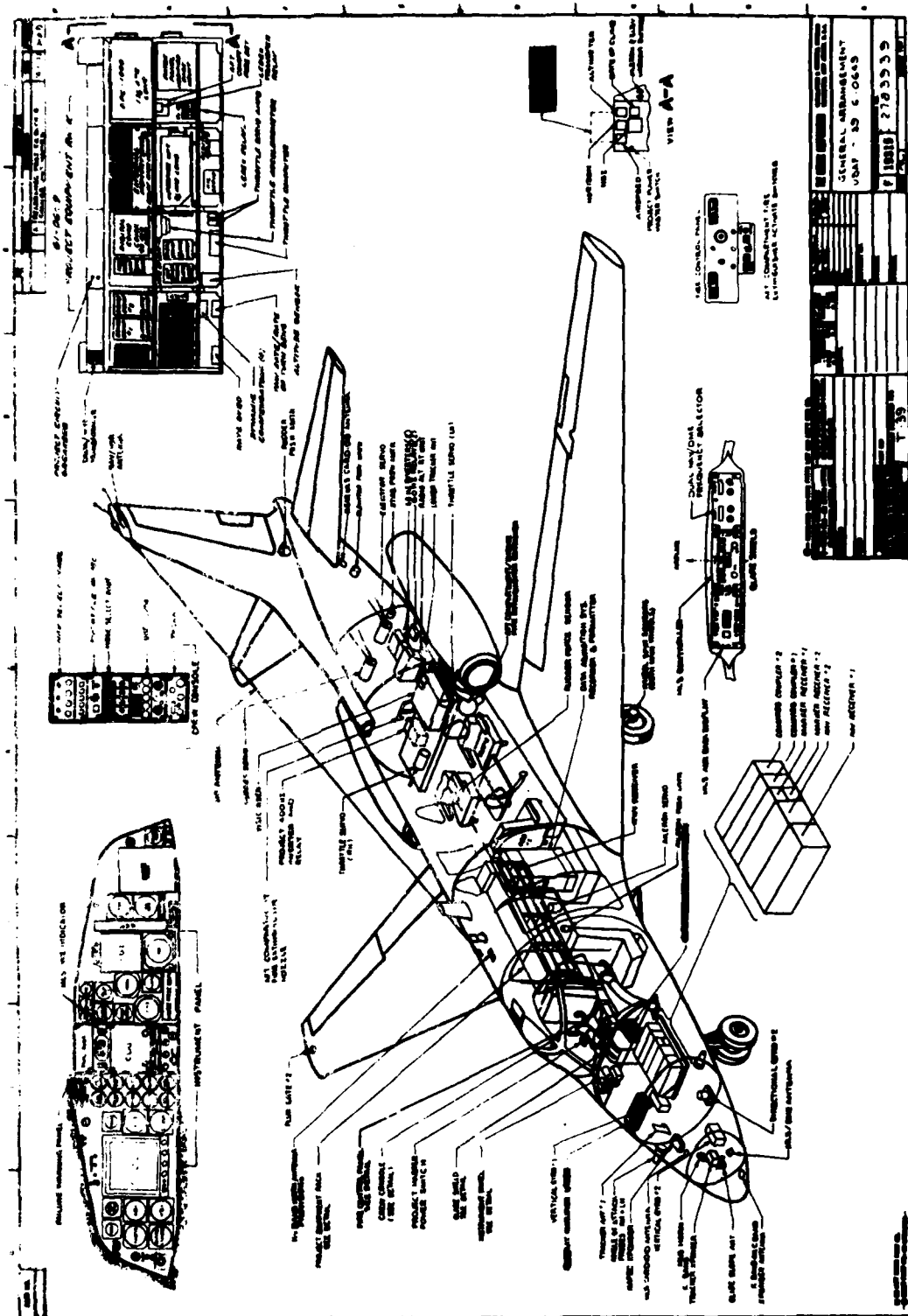Figure C-1 T-39 60-3478 General Arrangement
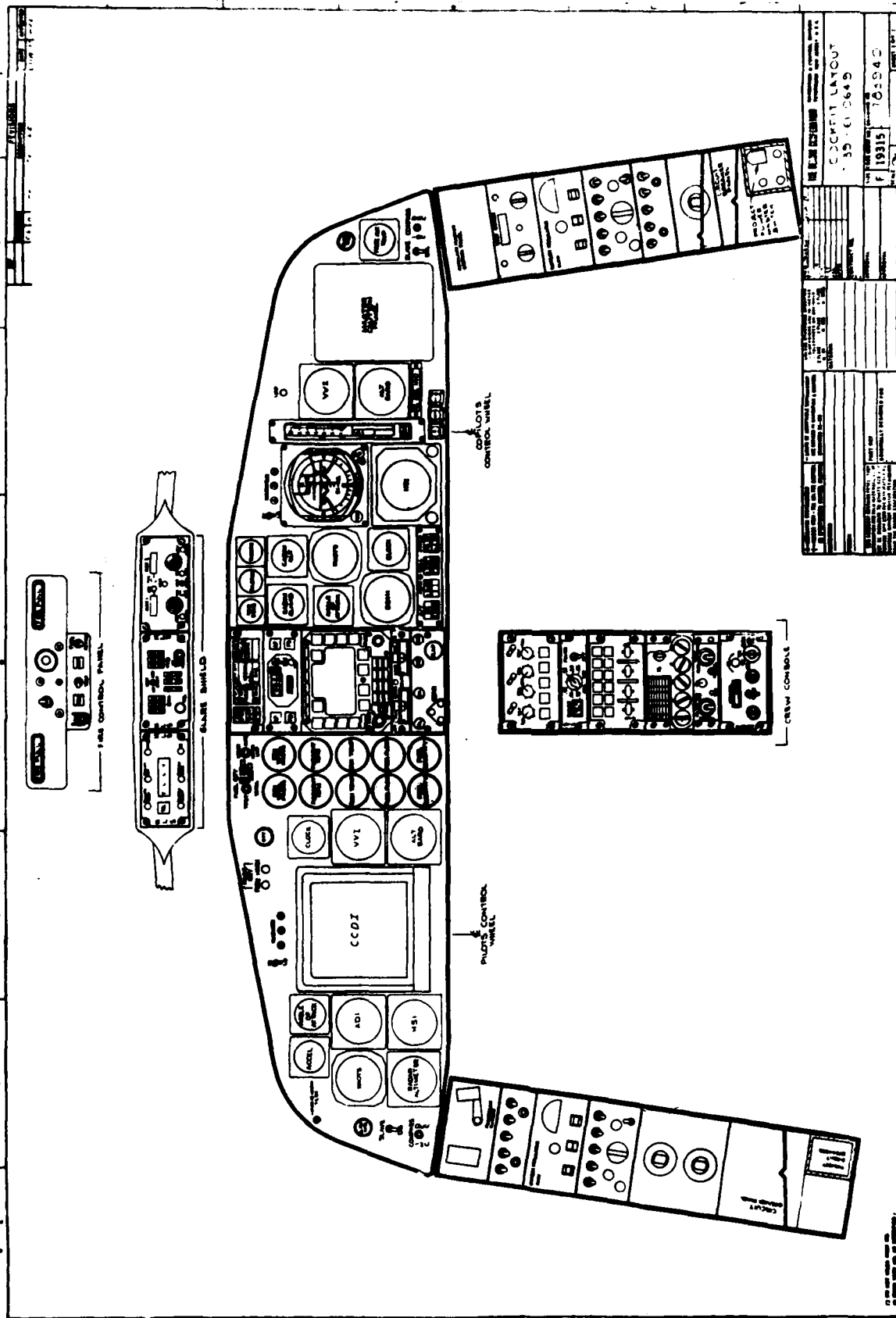
Figure C-2 T-39 61-0849 General Arrangement

Figure C-3 T-39 61-0649 Cockpit Layout

The aircraft were configured to allow investigations of six levels of MLS flight control and display capability. Level 1 was manual flight control with standard electro-mechanical analog displays (ADI, HSI) of course and glide slope deviation. Level 2 included Level 1 with the addition of an analog flight director system. Level 3 added an analog autopilot. Level 4 was manual flight control with a digital flight director system capable of commanding any desired complex trajectory. Level 5 added a digital auto-pilot. Level 6 removed the ADI and HSI from the pilot's instrument panel and added an electronic color CRT indicator.

Reference 31 indicates that flight investigations of Levels 1 through 5, conducted with the MLS at NAFEC and with a radar tracking system used to simulate MLS at Laredo International Airport in Texas, resulted in the following conclusions:

- Aircraft equipped with conventional analog flight control and display systems should be restricted to precision MLS instrument approach procedures similar to existing ILS procedures with final approach intercepts of 7 - 10 nm. This was concluded from tests on profiles as shown in Figure C-4 where the pilot was required to select and fly the azimuth radial corresponding to the initial segment, transition to the intermediate segment at the DME fix and subsequently select the final approach azimuth, and finally capture and track the final approach segment. Many problems were associated with this maneuver. The existing analog autopilot/flight director localizer control law which only looked at raw azimuth deviation could not handle multiple captures (of the initial and final approach segments). No positive guidance other that heading existed on the intermediate segment, therefore, inaccuracies up to 1 nm were experienced. Pilot workload was very high. As a result, it became evident that existing analog systems, unless severely modified, could not be used for complex trajectory flight.

- A digital flight control and guidance system is the most practical method of implementing a complex precision instrument approach capability that fully exploits the volumetric coverage of MLS. With the digital system guidance signals are always computed and accurate tracking

C-5

Figure C-4 10° Left Offset Approach

is always achieved.

- An aircraft equipped with a digital flight control and
guidance system is capable of flying more complex instru-
ment approaches than are acceptable to the pilot and ATC.
MLS Instrument Approach Procedures will be limited
by pilot and ATC acceptance.

- The information available on current aircraft position
and command displays (e.g., ADI and HSI) is inadequate
to accurately monitor the aircraft's position and
progress on a complex terminal area instrument approach.
For this reason further investigations are required to
improve and/or augment the conventional displays and to
study the benefits of the color CRT display of Level 6.
Both of these investigations fall under the scope of
this analysis and are discussed within the main body of the
report. Only very preliminary work has been done to date in
this area of the FPI. Figures C-5 through C-10 show the
MLS-related controls and displays on the T-39.

The control laws and engineering schemes developed for the
T-39 have result in autopilot/flight director performance
which provides accurate and stable control from the transi-
tion into MLS coverage to touchdown. Some of the problems
associated with the MLS transition which occurred during the
flight test program, and their solutions, are discussed
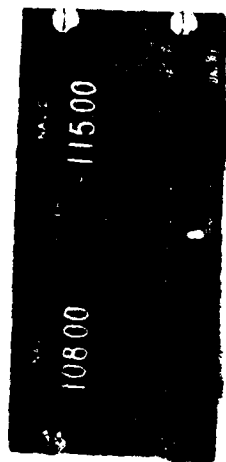below. More discussions on this subject are in Section 2.4.4.

In transitioning from a prescribed RNAV path (the T-39 has a
simple VOR/DME system, or a TACAN radial to MLS, lateral
discrepancies of up to 0.5 nm were experienced. This was
expected due to accuracy differences between the enroute
navigation reference and MLS. For the TACAN transition,
a capture problem occurred whereby the MLS capture mode
(lateral and vertical) would not engage until the aircraft
had been within MLS coverage for more than 15 seconds.
During this time, and depending on the specific trajectory
being flown, errors would accumulate with respect to both
the lateral and vertical paths such that a reasonable
capture maneuver (of especially the vertical path which may
have been falling off at a 5^0 descent for part of this time
while the autopilot was still in the altitude hold mode)
was virtually impossible. The problem was caused by the
operational logic of the T-39 digital navigation system
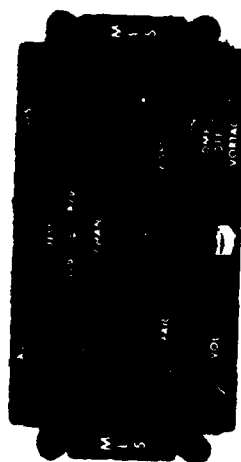
VHF NAV CONTROL
T-39 GLARESHIELD PANEL

PHASE III MLS CONTROL PANEL

PHASE III MLS AUXILIARY DATA PANEL

Figure C-5 T-39 Glareshield Panels
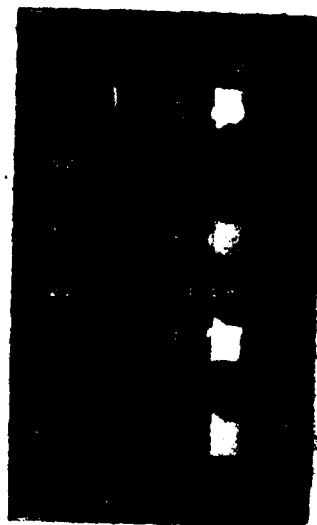
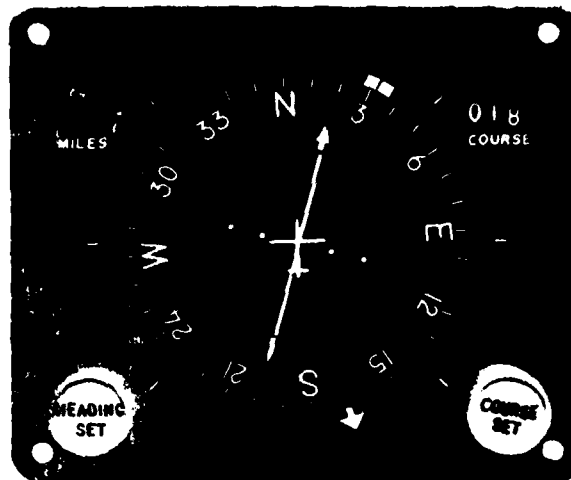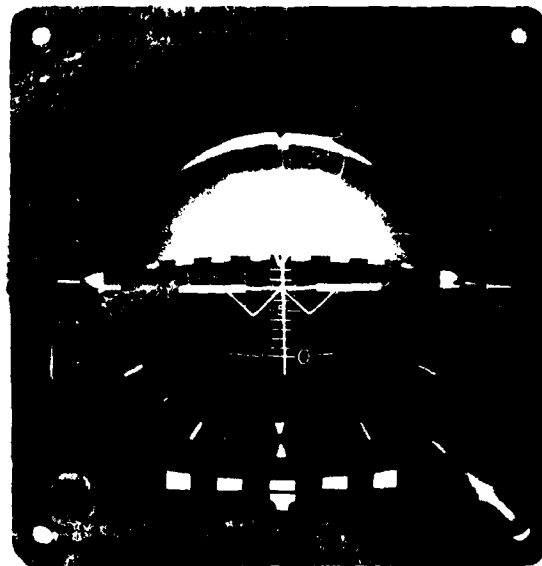MODE SELECT
T-39 PEDESTAL PANEL

NAV SELECT
T-39 PEDESTAL PANEL
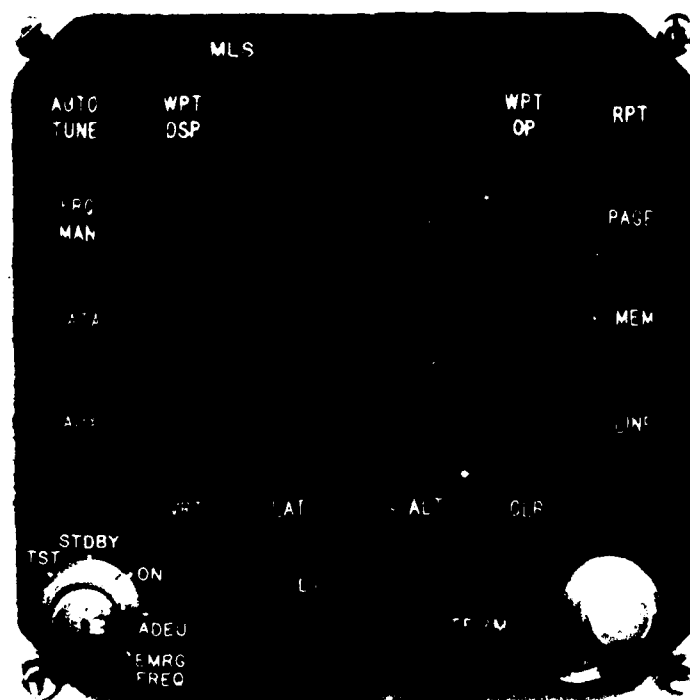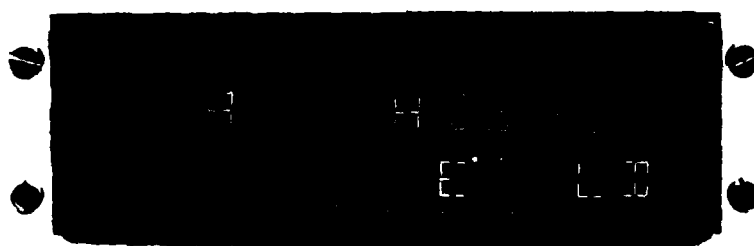
Figure C-6 T-39 Pedestal Panels

HSI

ADI

Figure C-7   T-39 Conventional Displays

NAVIGATION CONTROL-AND-DISPLAY UNIT
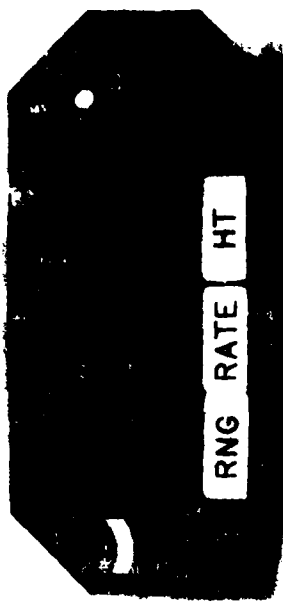T-39 ELECTRONIC DISPLAY

MODE PROGRESS DISPLAY
T-39 ELECTRONIC DISPLAY

Figure C-5. T-39 Electronic Displays

RNG RATE | HT

DME INDICATOR
MLS DATA DISPLAY

AZIMUTH ANGLE INDICATOR
MLS DATA DISPLAY

VERTICAL ANGLE INDICATOR
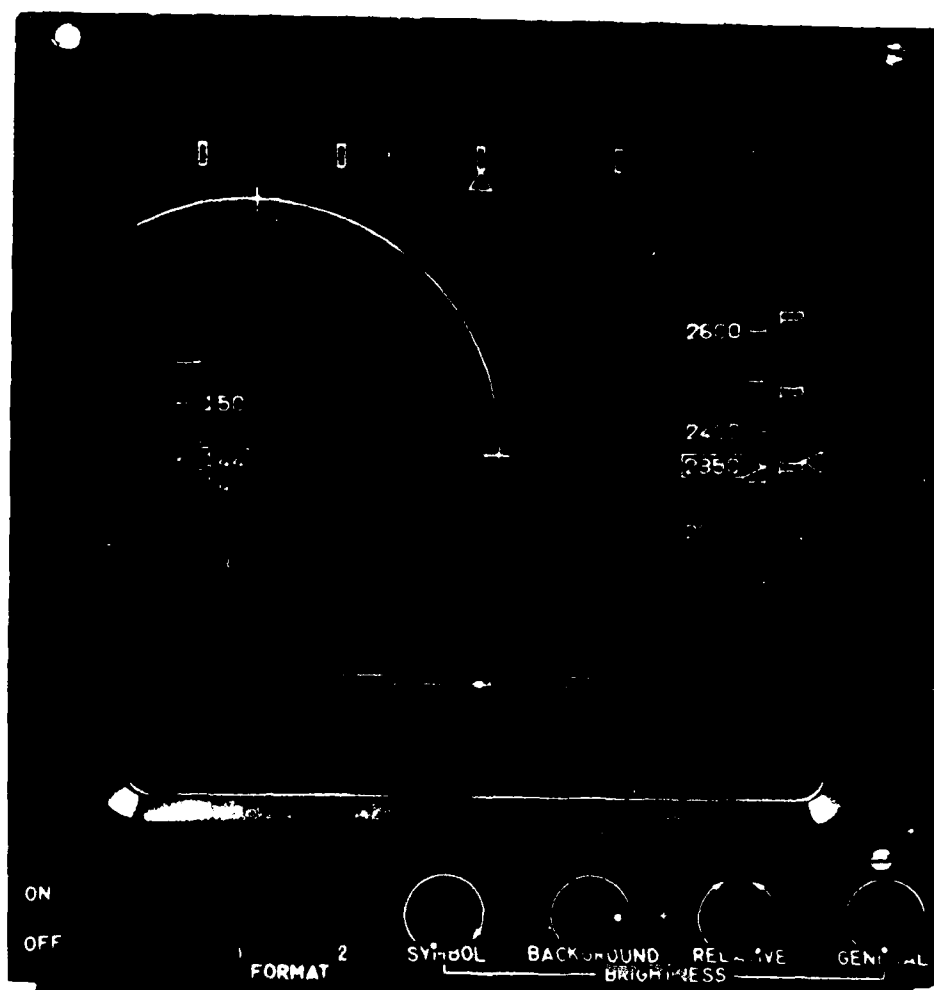MLS DATA DISPLAY

Figure C-9   MLS Data Displays

Figure C-10   T-39 CRT Indicator

which does not allow the MLS mode to be armed for engagement, from any mode except RNAV, until validity signals are received indicating that the aircraft is within MLS coverage. Also, once armed, automatic MLS mode engagement was inhibited until the capture logic was satisfied.

For the TACAN transition to MLS, pilot workload was very high. The pilot was required to: monitor his raw MLS data instruments for validity indications; actuate four push buttons in sequence on two different panels (CDU and MSP) to arm MLS after confirming that he was in coverage; and then, maneuver the aircraft, if required, to engage the MLS capture mode. (A detailed set of T-39 operational procedures for an MLS complex trajectory approach are included in Appendix C).

The overall capture problem was partially solved by opening up the capture logic "window" detector on crosstrack deviation to 1.5 nm; thus, providing an immediate engagement after MLS mode arming. This eliminated the pilot maneuver for all but gross errors greater than the detector level. The pilot workload problem can be completely solved by allowing MLS to be armed when not in coverage (as is done with existing ILS modes in present autopilot/flight director systems). No operational problem occurred with the RNAV system because automatic arming and engagement of MLS was integral to the RNAV logic.

In transitioning from VNAV or altitude hold to MLS, vertical discrepancies of up to 500 feet were experienced. These were due in part to normal inaccuracies of the MLS and barometric altimeter but were primarily due to the different zero references for the two systems caused by the curvature of the earth. Figure C-11 shows the discrepancy between MLS derived altitude, which is referenced to the extended runway, and barometric altitude for various distances from the azimuth/DME ground site.
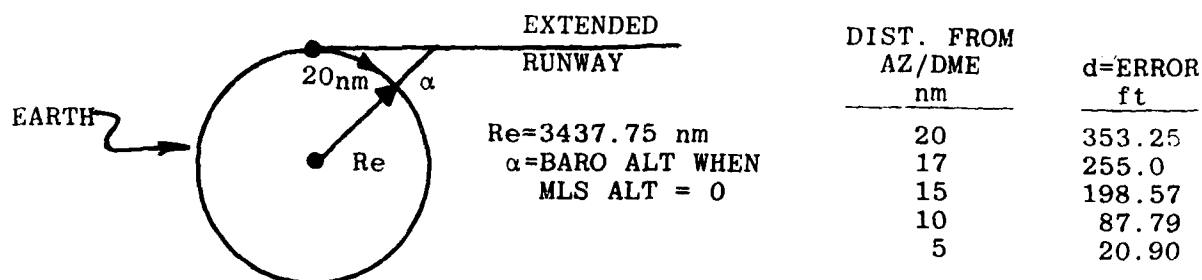
	DIST. FROM AZ/DME nm	d=ERROR ft
EXTENDED RUNWAY		
Re=3437.75 nm	20	353.25
α=BARO ALT WHEN	17	255.0
MLS ALT = 0	15	198.57
	10	87.79
	5	20.90

Figure C-11 MLS/Barometric Altitude Reference Discrepancies

The effect of these errors on the automatic flight control
system resulted in problems similar to those just described
for the RNAV and TACAN transitions. The MLS elevation capture
mode was inhibited with large errors (more than 100 feet)
and a pilot maneuver was required. For small errors, capture
automatically occurred via a smooth automatic maneuver. A
far more reaching effect of these errors results from the
ATC problem of maintaining altitude separation for aircraft
operating in level flight using two different reference systems.

A proposed solution to the MLS vertical transition problem,
utilized on the T-39, is to design all complex trajectories
such that the initial MLS vertical segment is an extension
of the first descent path as shown in Figure C-12.
Operationally, the pilot is required to arm the MLS elevation
mode and fly in any other pitch axis mode (e.g., altitude
hold) to intercept the vertical approach profile. A
smooth capture will automatically occur. This also reduces
pilot workload and increases operational flexibility by
allowing him to approach at any assigned altitude without
reprogramming his computer. Using this procedure, the
aircraft is always referenced to barometric altitude until
the initiation of the published descent. This is completely
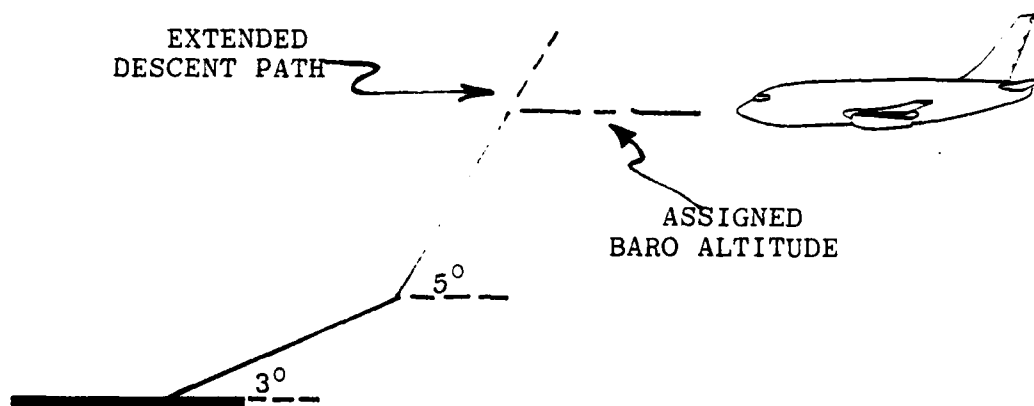compatible with current instrument approach procedures.

Figure C-12 T-39 Vertical Approach Profile Definition

C.2 NASA 737 TCV Program

The National Aeronautics and Space Administration's Terminal
Configured Vehicle (TCV) Program is conducting analytical,
simulator, and flight research which will support civil
air transportation improvements in:

- terminal area capacity and efficiency

- approach and landing in adverse weather

- operating procedures to reduce noise impact

In this research, major emphasis is being placed on the
development of advanced aircraft flight control-and-display
concepts for application to operations in future high-
density terminal-area environments. These terminal areas
will be equipped with new landing systems, navigational
aids, data links and other air traffic control systems
now being developed by the FAA and DOT.

The TCV research aircraft is a Boeing 737-100. It contains
a special research flight deck located about 20 feet aft of
the standard cockpit. From the aft flight deck the aircraft
can be flown in a fly-by-wire mode using advanced electronic
display and digital automatic flight controls. The arrange-
ment of palletized research installations is shown in
Figure C-13. The instrumentation layout of the aft cockpit

is shown in Figure C-14.

Key elements of the NASA MLS are:

- Integrated digital navigation, guidance, display and control system

- Automatic 3-D flight profiles with short (1-1.5nm) final approach segments to touchdown

- Definition of cockpit displays to accurately follow curved approaches--each pilot has 3 monochromatic CRT displays: EADI, EHSI, CDU with keyboard

- Development of advanced automatic flare control laws to reduce present-day touchdown dispersions

Pertinent results of the TCV research relative to control-and- display follow.

1) Reference 35 presents the results of a flight evaluation of two electronic display formats for the approach to landing under instrument conditions. The evaluation was conducted for a baseline electronic display format shown in Figure C-15 (described in reference 63)and for the same format with the addition of horizontal situation information, consisting of a perspective runway symbol and a relative track angle indicator, on the EADI (see Figure C-16). Flight path tracking performance and pilot subjective comments were analyzed with regard to the pilot's ability to capture and maintain a 3nm straight-in, 3° descent MLS path while flying a flight director approach.

The baseline format on the EADI consists primarily of the aircraft attitudes, flight path information and flight path deviations. The EHSI presents the aircraft symbol, a 30-second trend vector which predicts aircraft position information 30 seconds ahead, an extended runway center line, and a digital readout and scale of the present track angle.

The integrated situation information format contains the addition of the runway symbology and relative track information on the EADI. The EHSI format remained identical to the baseline configuration.
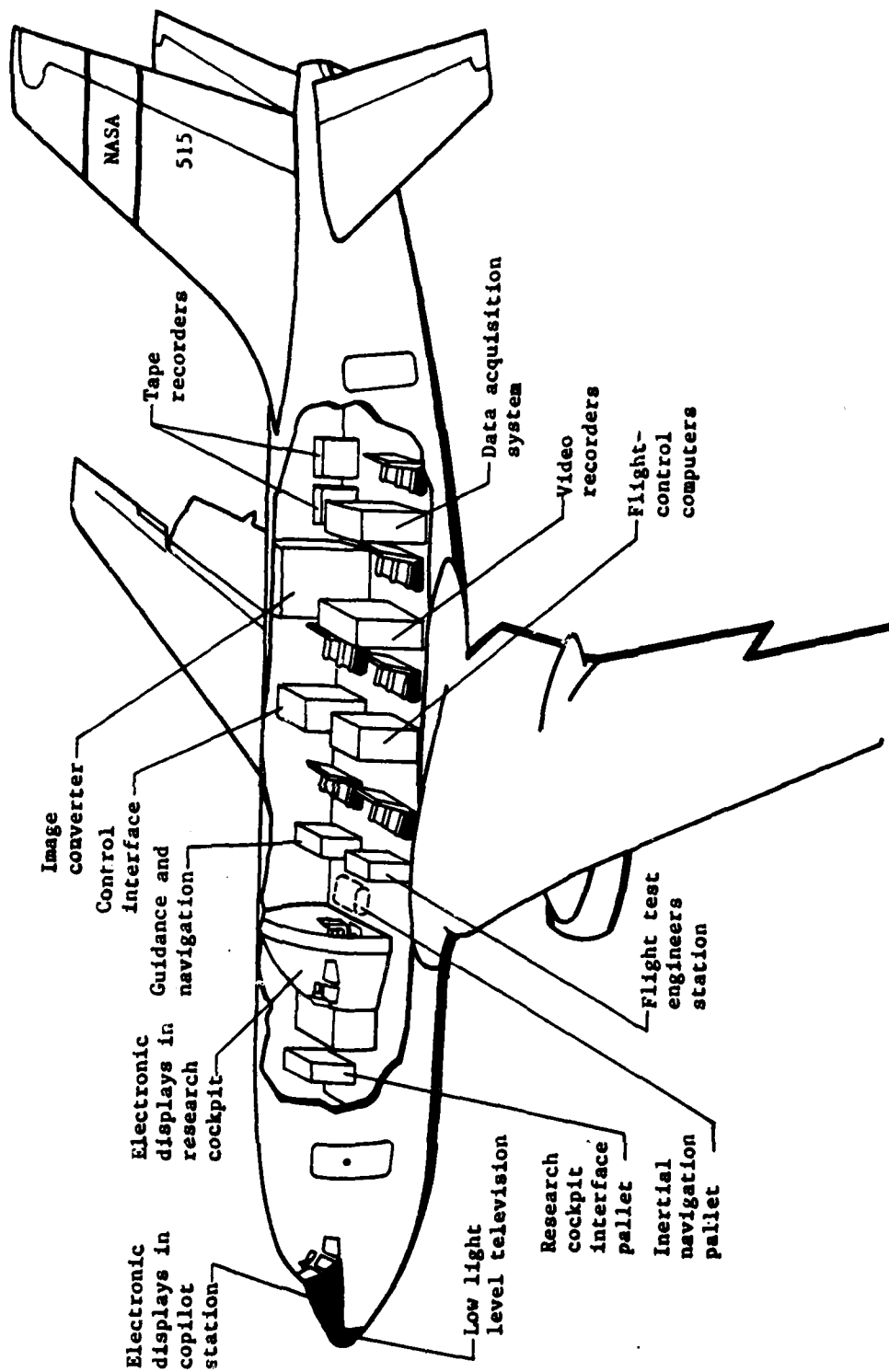
Figure C-13 Internal Arrangement of TCV B-737

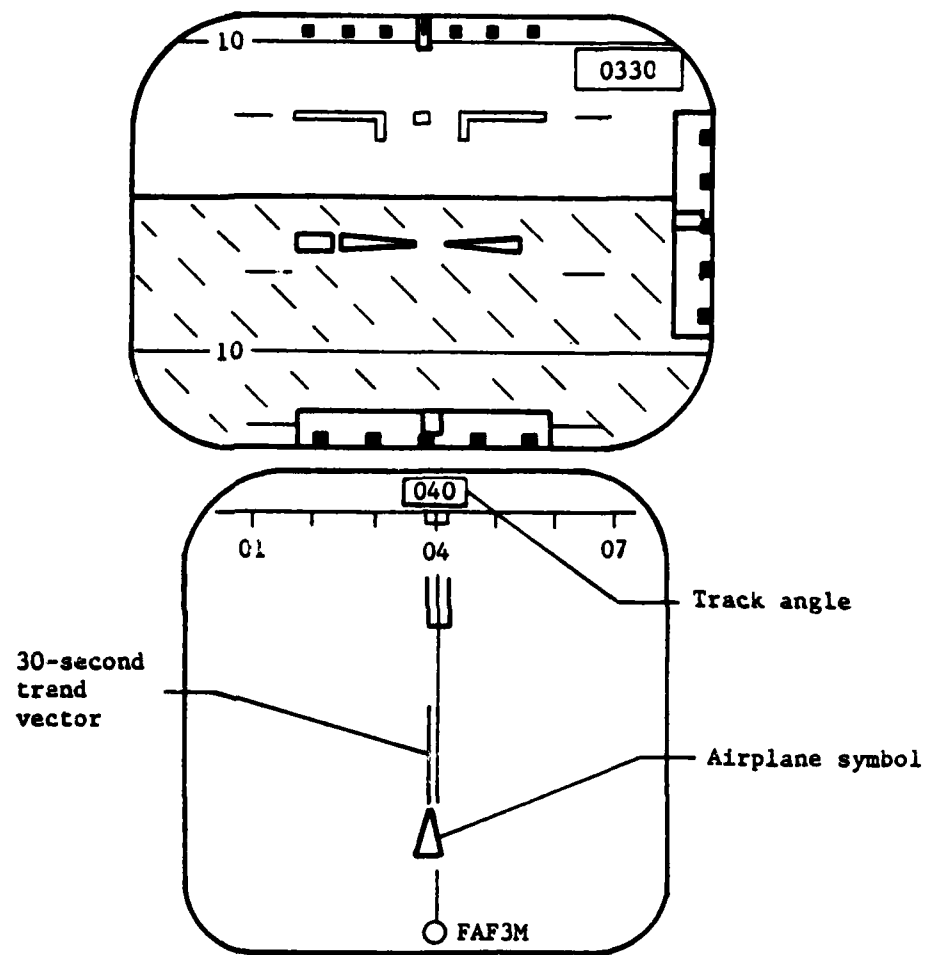Figure C-14 AFT – Flight – Deck Display Arrangement
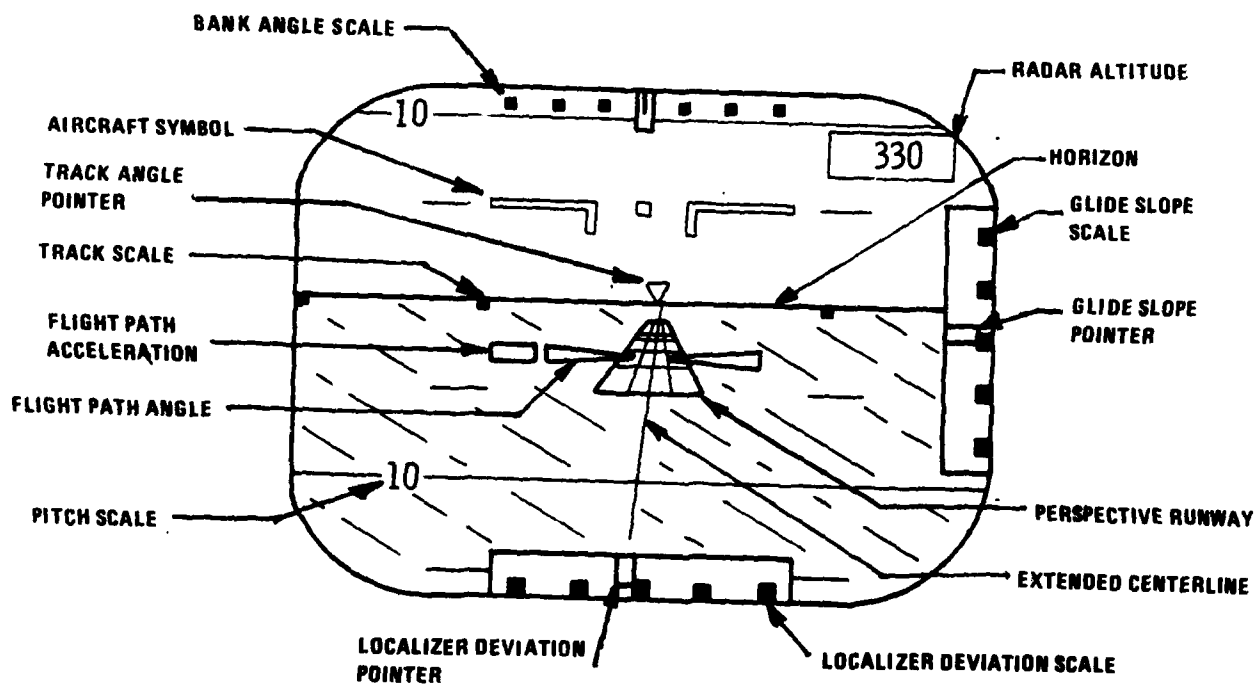
Figure C-15 Base-Line Situation Display Format

Figure C-16 Integrated Situation Display Format

The following labels appear in the figure:

- BANK ANGLE SCALE
- AIRCRAFT SYMBOL
- TRACK ANGLE POINTER
- TRACK SCALE
- FLIGHT PATH ACCELERATION
- FLIGHT PATH ANGLE
- PITCH SCALE
- LOCALIZER DEVIATION POINTER
- RADAR ALTITUDE
- 330
- HORIZON
- GLIDE SLOPE SCALE
- GLIDE SLOPE POINTER
- PERSPECTIVE RUNWAY
- EXTENDED CENTERLINE
- LOCALIZER DEVIATION SCALE
- 10
- 10

The perspective runway symbology, drawn on a $30°$ by $40°$ field of view, includes the basic outline of the runway with an extended center line drawn 1 nm before the runway threshold to the horizon. A magnification factor of 0.3 to 0.5 results, depending on pilot seat position. The runway symbol represents a runway 3048 m (10,000 feet) in length and 45.72 m (150 feet) in width. Four equally spaced lines were drawn perpendicular to the center line of the runway at 304.8 m (1000 feet) intervals that start 304.8 m beyond the runway threshold. Two lines parallel to the center line of the runway were drawn to divide it into equal quarters. The mathematics of drawing the runway symbology are detailed in reference 35.

The relative track angle indicator pictorially shows the inertially reference track angle of the airplane relative to the runway heading. Relative track angle information was indicated by a tab that moved along the horizon line of the EADI. A track scale, referenced to the runway heading in $10°$ increments, was drawn on the horizon line of the EADI. Using the tab and track scale, the pilot could determine the magnitude of the relative track angle of the airplane to the runway.

Figure C-17 depicts the flight profile used to conduct the experiment. Approaches were flown with and without an initial 0.1 nm offset from the final approach segment. The test procedure required the pilot to execute the curved approach by using both the EADI and EHSI. Once the turn was complete, the pilot was instructed to use primarily the display information on the EADI to track the lateral and vertical flight paths.

Test results, shown in Figures C-18 through C-23 indicated that the integrated situation display format increased flight path accuracy.

The pilots commented that the integrated situation format brought about a better understanding of the airplane's position and trajectory relative to the runway and the extended runway center line. This understanding enabled the pilots to more quickly recognize and recover from a large lateral path deviation with confidence. In addition, pilot corrective inputs could be modulated depending on the size of the error and the remaining distance to the runway

threshold. They commented that the integrated situation
display reduced pilot workload for the lateral task by
eliminating the need to scan the EHSI and enabled him to
spend more time on the glide path task. The pilots felt
that the lateral path guidance provided by the map display
was not sufficient for a close-in final approach, even
with the map scale set for greatest resolution (0.394 nm/cm).

These flight test results compare with the simulation
study described in reference 39.

2) Reference 39 presents the results of the pilot simulation
study of the two electronic display formats described above.

Initial display information development indicated that one
of the strongest cues available to the pilot from the
runway geometry is the symmetry (slant) of the runway with
lateral displacement. The pilot may determine from the
runway symmetry, regardless of his altitude or relative
heading, whether his aircraft is on or is displaced to the
left or right of the runway center line. Lateral deviations
outside the width of the runway borders were easily deter-
mined although precise determination of the magnitude of
displacement was not possible.

Aircraft altitude, aircraft range to the runway threshold,
and deviations from the glide path were difficult to assess
solely from geometry cues. While growth rate and runway
size did give the pilot a feel for closure rate at ranges
less than 3704 m (2nm), estimates of range and altitude
were not consistent, particularly when the pilot was
looking at runways of various lengths and widths. The
pilot used objects such as trees, houses, or roads along
his approach path to judge range and altitude.

Another important cue found to be necessary for lateral
approach path tracking is relative heading between the
longitudinal axis of the aircraft and the center line of
the runway. The pilot must know the relative heading since
very small differences cause the aircraft to fly away from
the localizer (or MLS lateral path) course. This situational
information was depicted on the EADI as a track angle
pointer and scale. Track angle, instead of heading, was
used as a reference since this is the desired information
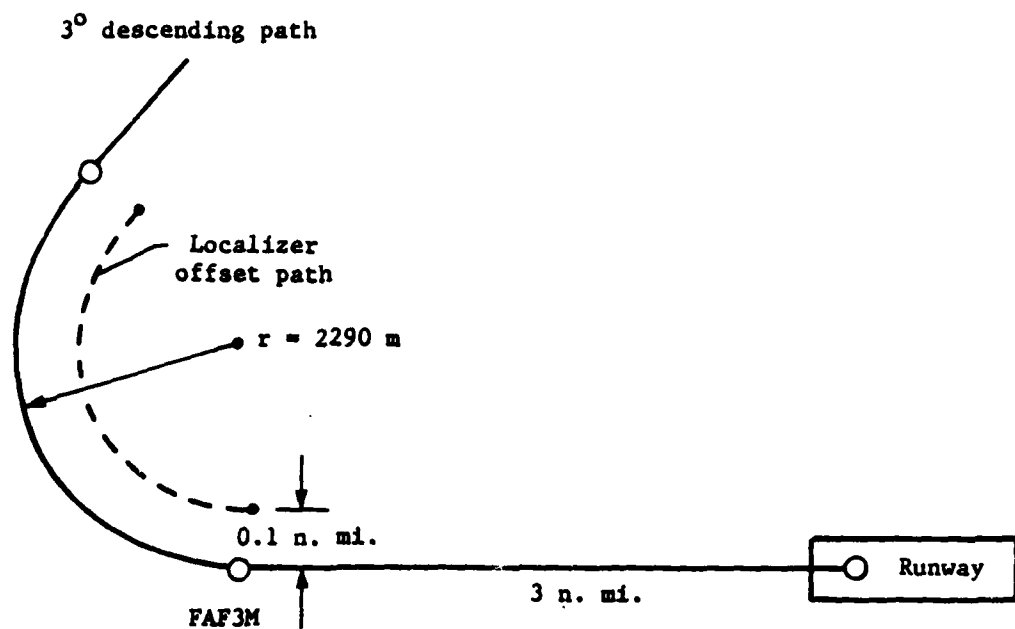for the landing-approach task.

3° descending path

Localizer
offset path

r = 2290 m

0.1 n. mi.

FAF3M

3 n. mi.

Runway

Figure C-17 Plan View Of Approach Path To Runway 04 At National
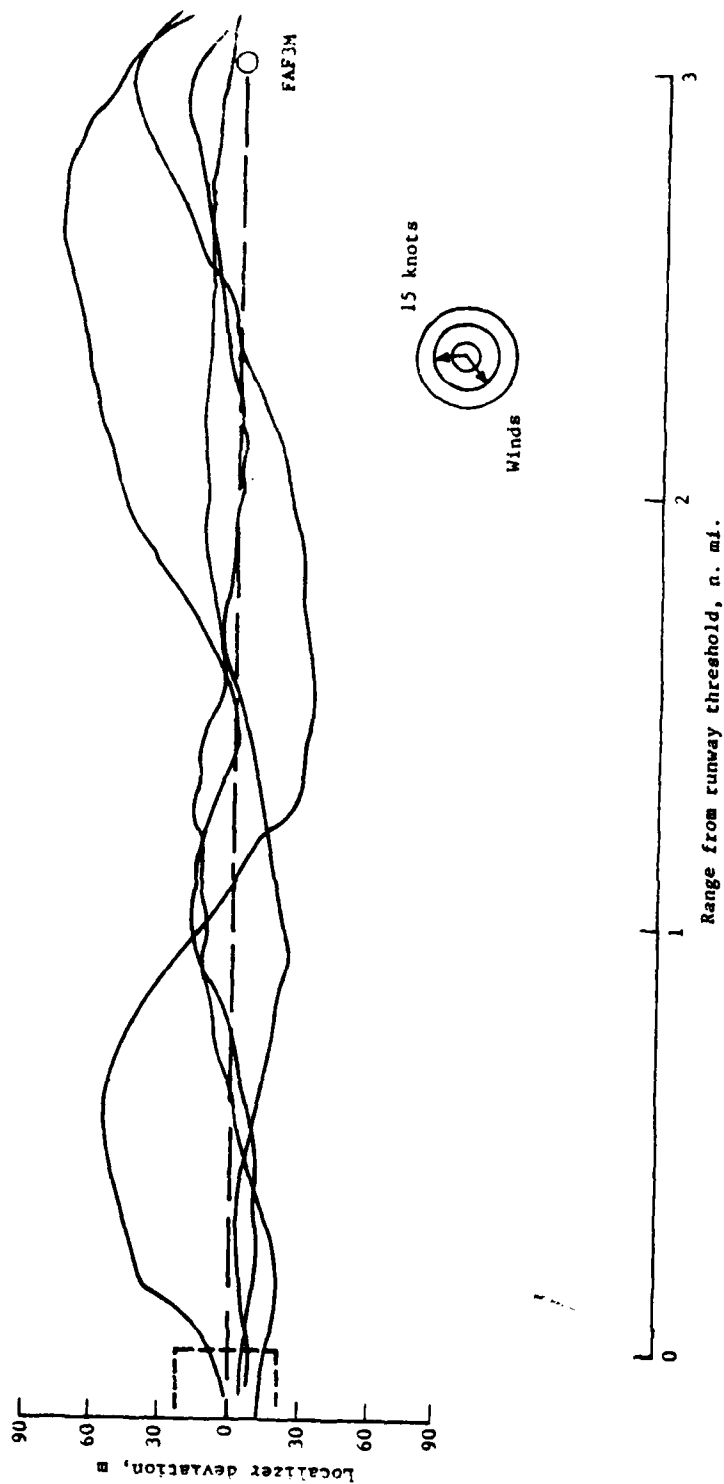Aviation Facilities Experimental Center

C-23

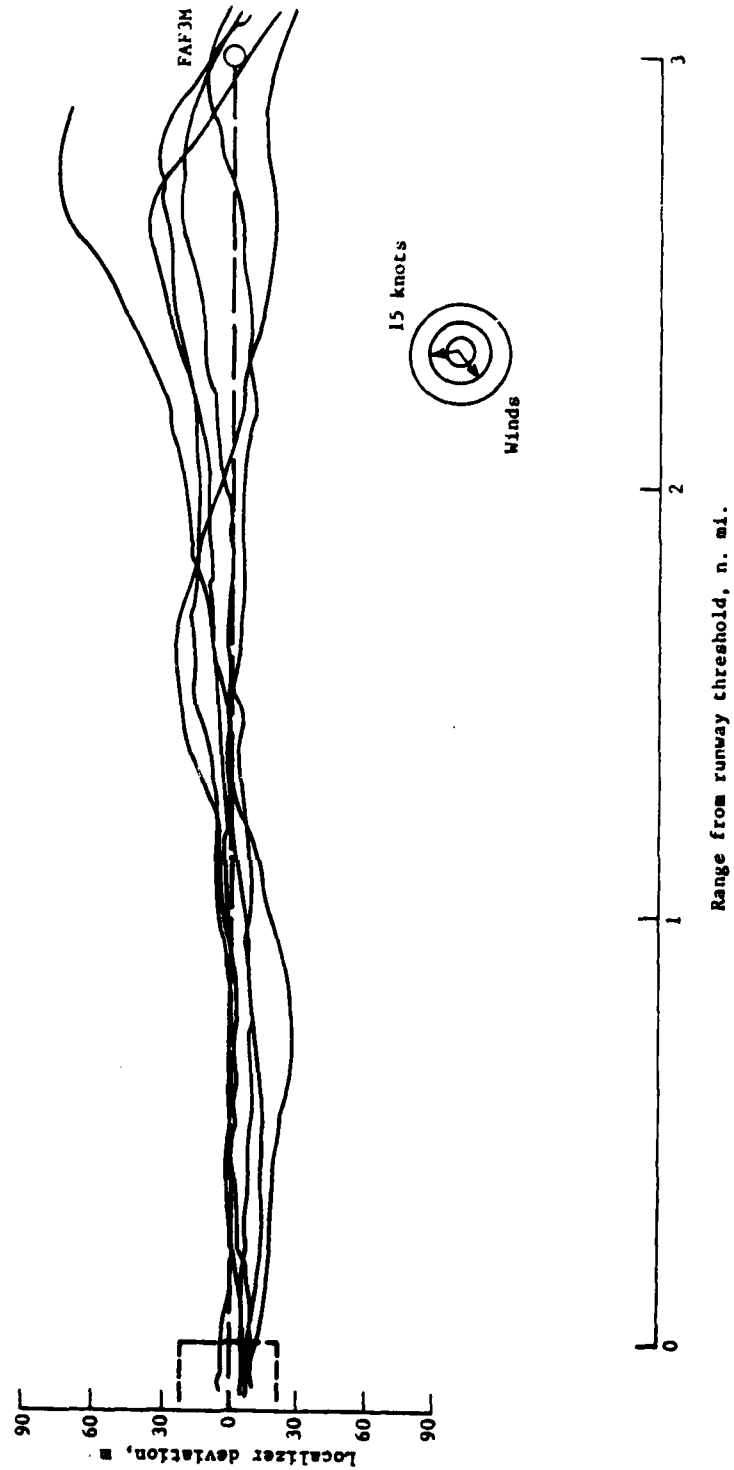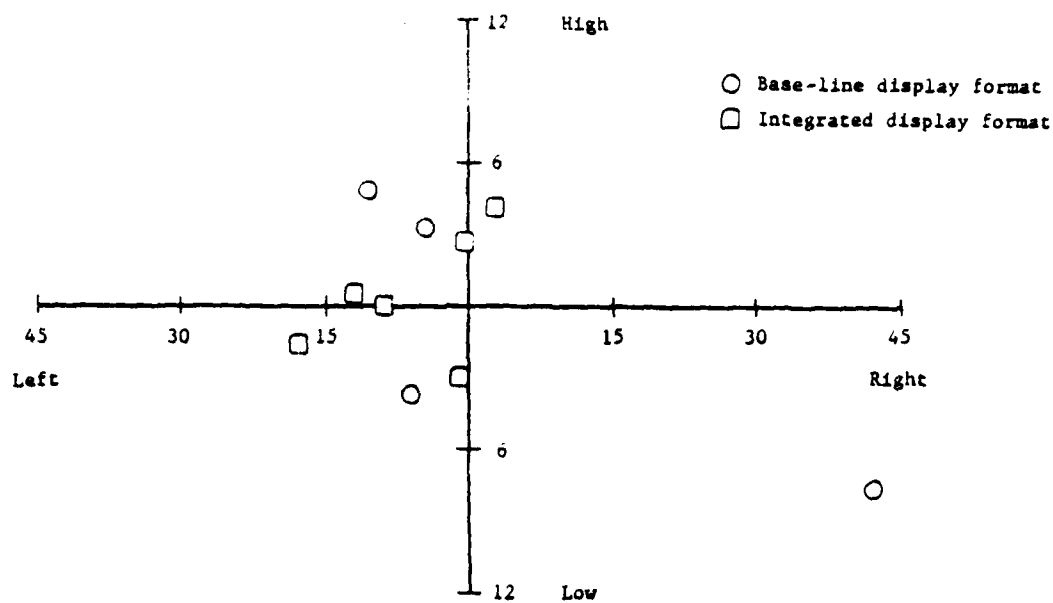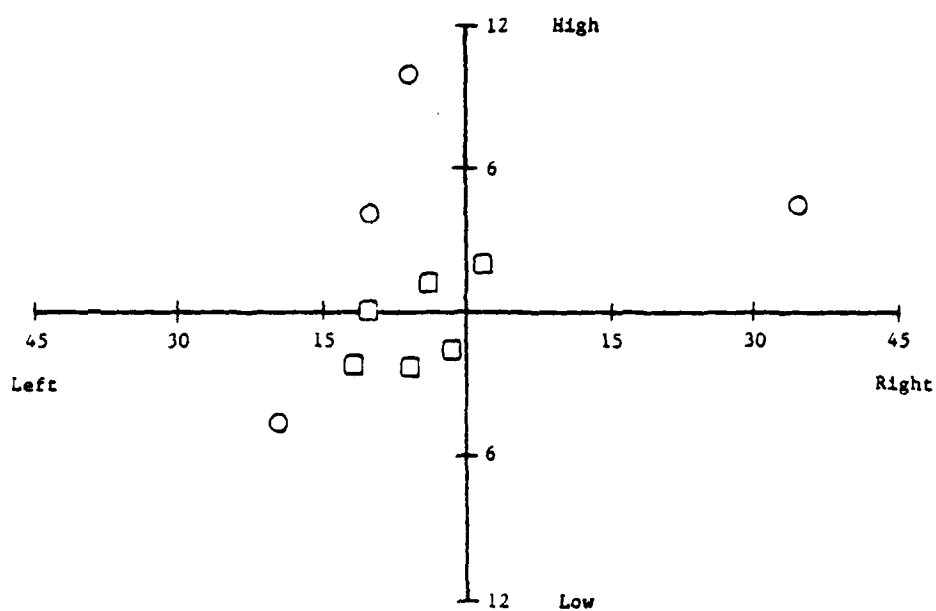Figure C-18 Localizer Tracking Performance Using Base-Line Situation Display Format

Figure C-19 Localizer Tracking Performance Using Integrated Situation
Display Format

(a) 61-m window data.

(b) 30.5-m window data.

Figure C-20 Window Data Of Glide-Slope And Localizer Deviations
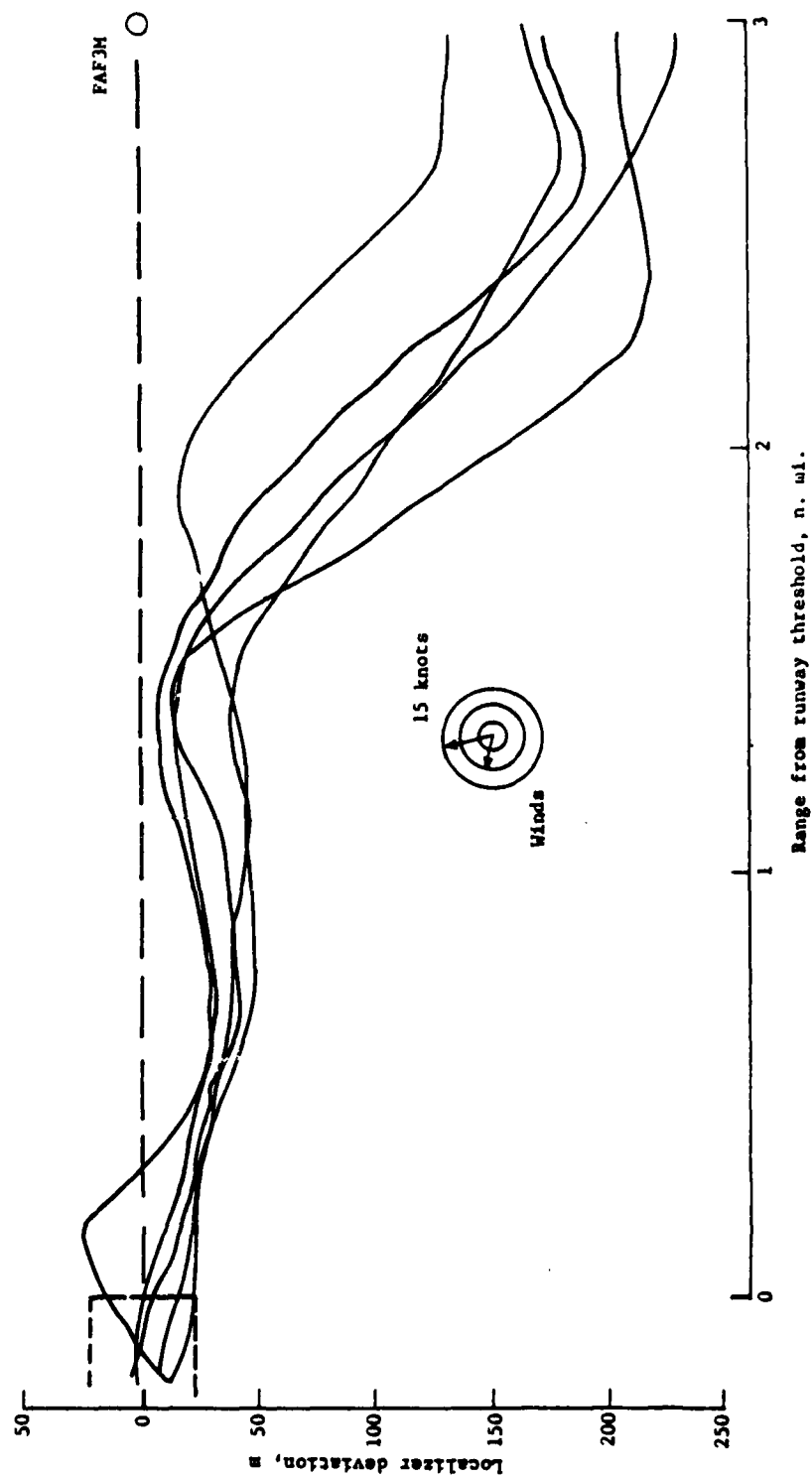**All Scales In Meters**

C-26.

Figure C-21 Localizer Tracking Performance With Initial Offset Using Base-Line Situation Display Format
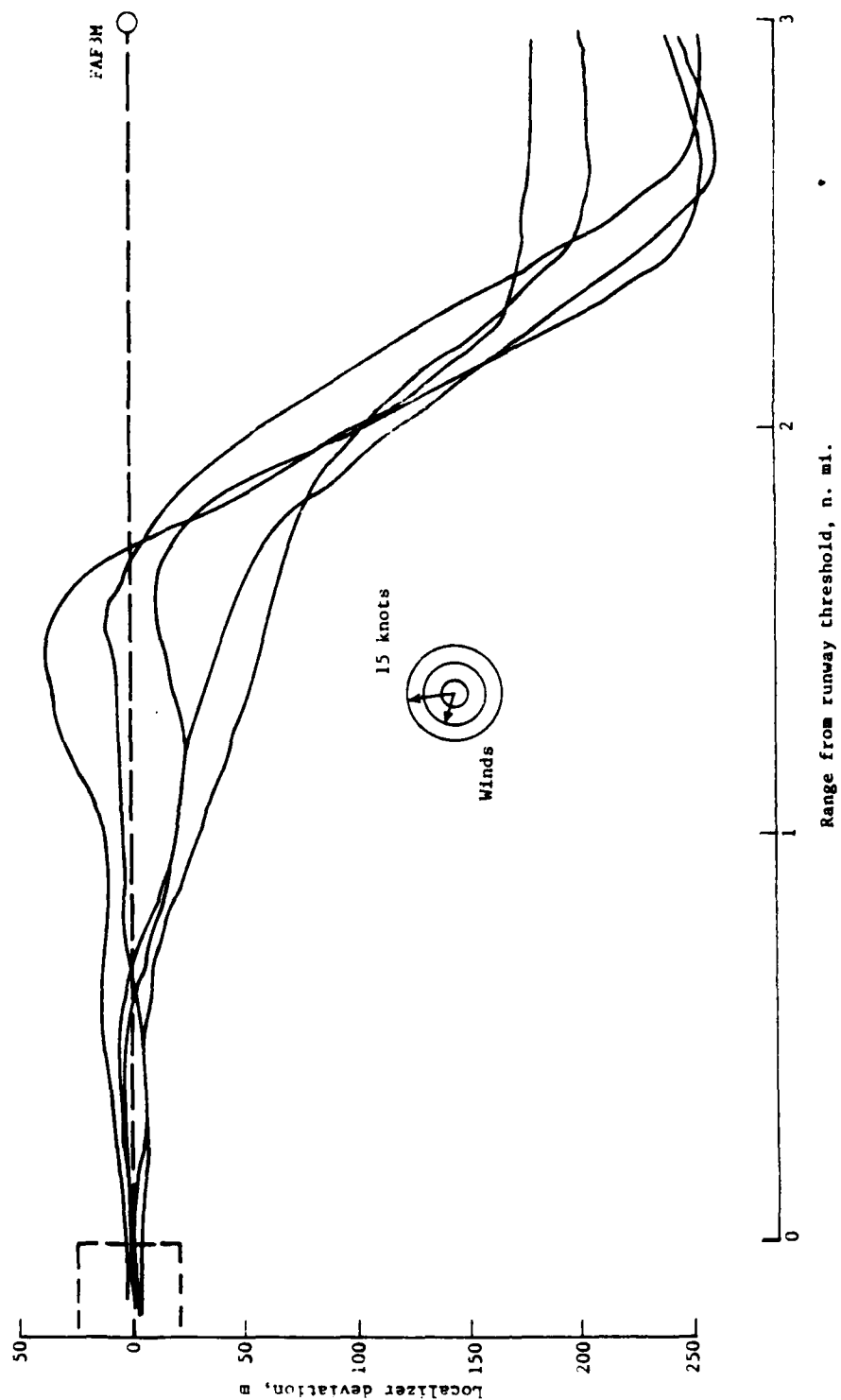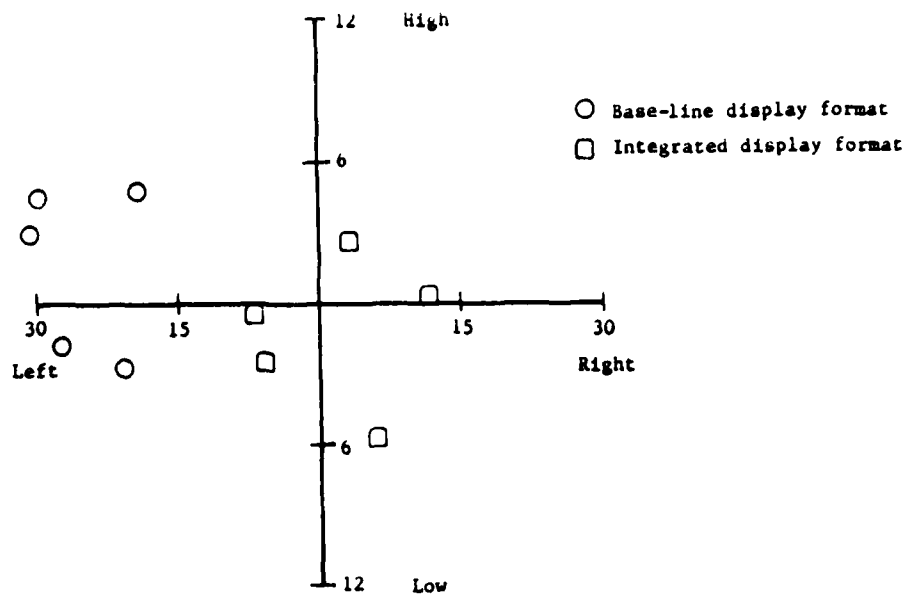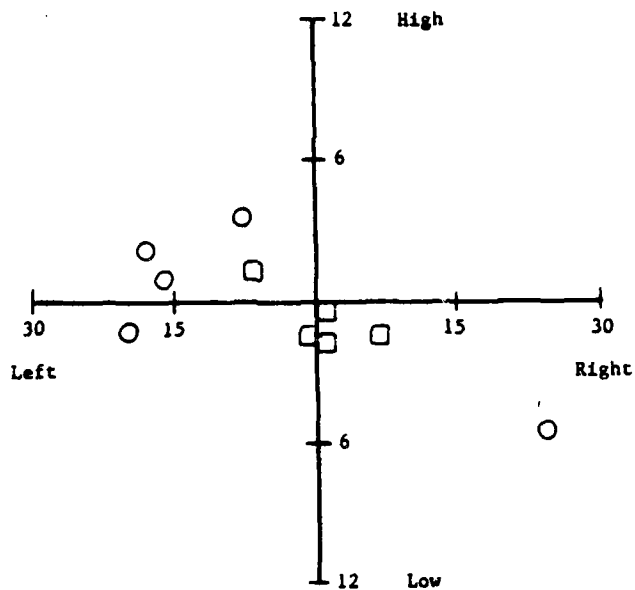
Figure C-22 Localizer Tracking Performance With Initial Offset Using Integrated Situation Display Format

(a) 61-m window data.

(b) 30.5-m window data.

Figure C-23 Window Data Of Glide-Slope And Localizer Deviations
All Scales In Meters

C.3   Other NASA Studies

1) Reference 51 presents the results of a pilot scanning
behavioral study in which a series of approaches were
made by airline-rated Boeing 737 pilots in an FAA qualified
simulator. This simulator contained standard electro-
mechanical instrumentation. A nonintrusive oculometer system
was used to track the pilot's eye-point-of-regard throughout
manual and coupled VFR, Category I and Category II approaches.

All tests were started at 19 km (12 miles) from the runway
threshold and approximately 415 m (1360 feet) above the
ground. The first 6 km (4 miles) were used to stabilize
the aircraft on the flight path and check the oculometer
calibration. At 13 km (8 miles) data recording was started
and continued throughout ground rollout or until the approach
was aborted.

Observation of the pilot scan patterns during the instrument
portion of the test indicated that the pilots used the center
of the flight director (ADI) as the primary look-point
and moved from there to an instrument and then came back
to the center of the flight director. Only rarely did a
pilot check more than one instrument before returning to
the center of the flight director. The bar graphs shown
in Figure C-24 show a comparison of the percent time
spent on the instruments for both the manual and coupled
modes with no atmospheric turbulence. Each contains the
summary data for the entire approach. It was found that
the percent time spent on the various instruments does not
vary by more than a few percent for the different phases
of the approach (straight and level, glide slope capture,
or descent). The clock, radar altimeter, and ADF are not
included in this figure since they were used very little.
Of particular interest is the comparison of time spent on
the flight director (approximately 73 percent in the manual
mode as compared to 50 percent for the coupled mode) and
the airspeed indicator (13 percent in manual and 22 percent
in coupled). It should be noted the throttles were controlled
manually.

The introduction of turbulence did not greatly affect
the pilot's scanning behavior in terms of the percent time
he spent on various instruments. For both the manual
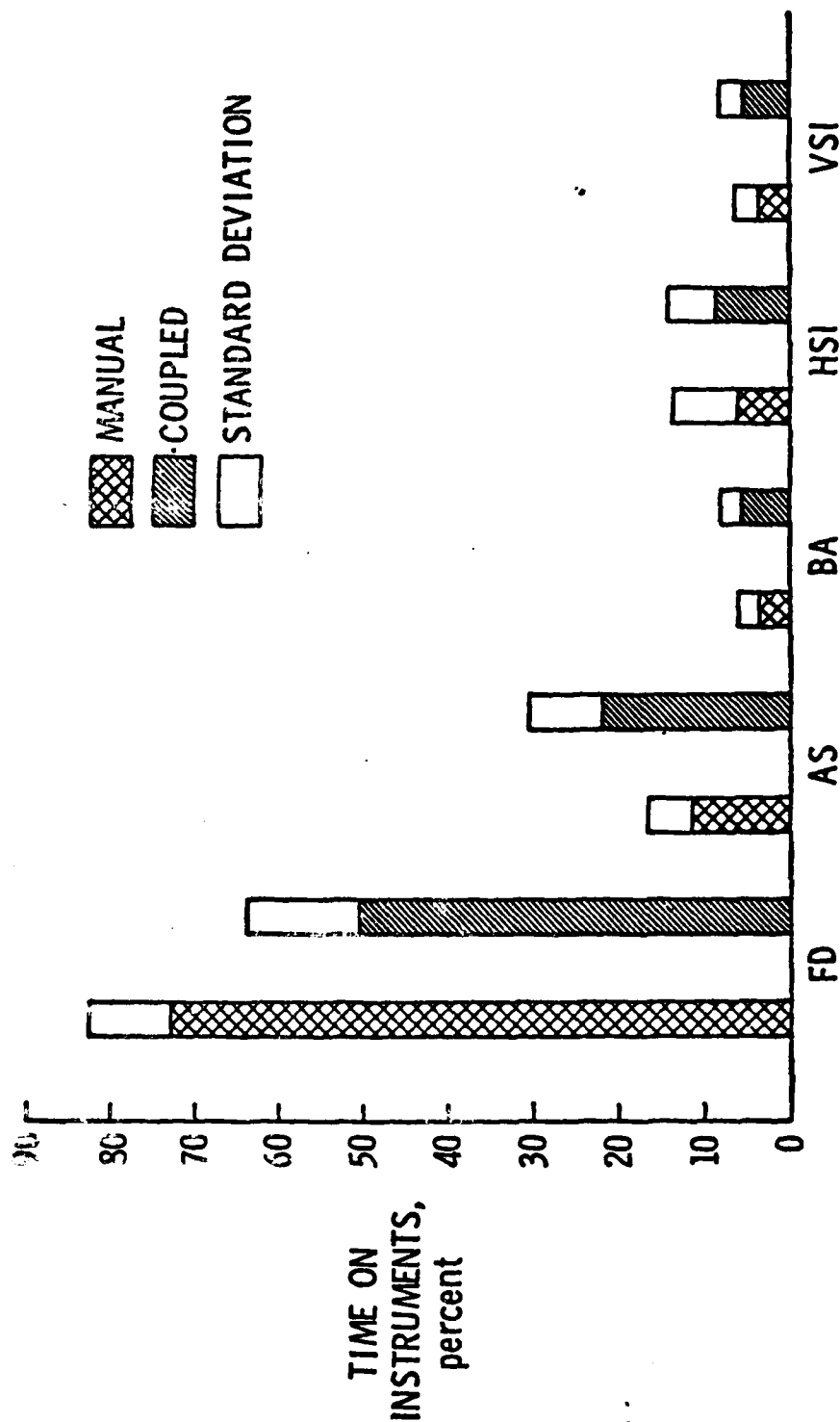and coupled cases the time on the flight director increased

Figure C-24 Percent Time On Instruments For Manual And Coupled Approaches

by about 3% with this being primarily taken away from
airspeed.

Pilot comments indicate that,while they were not necessarily
aware of the differences in scan as a function of the
control mode (manual or coupled),they attribute the change
to the different type of mental picture required. For
the manual mode,they must keep a mental picture of where
they are and where they are going, which is best obtained
from the flight director. Any visual interruption from it require
that they reform that picture upon returning to it. For
the coupled mode,they are primarily checking needle positions
and,consequently,are free to scan more instruments.

2) Reference 46 presents the results of a simulation study
performed at Ames Research Center which investigated:
multiple, curved, descending approaches that merge on a
common final approach within 1 mile of the field; parallel
runways certified for simultaneous and independent operation
during IFR conditions; 1 minute separation at the missed
approach point; and, the use of traffic situation displays
(TSD) in the cockpit coupled with a distributed air traffic
management system between the air and the ground. The
objective was to develop solutions which would evolve
a procedural system that could safely increase air traffic
density. Three groups,each consisting of three commercial
airline pilots and two air traffic controllers,flew a
combined total of 350 approaches. Three fixed-base cockpit
simulators were supplied with computer generated TSD's and
flight instruments, all combined on a 25.6 cm x 25.6 cm
(10 in. x 10 in.) CRT as shown in Figure C-25. The
controllers were supplied with a terminal area map display
and digital status information. The map display consisted
of a 20.7 cm x 20.7 cm (12 in. x 12 in.) CRT upon which
all traffic within 5 nm of the field and the five approach
routes for each of the two runways were displayed (see
Figure C-26). A keyboard and CRT were provided for data
entry and readout of aircraft status (i.e., landing order,
aircraft type and call sign, approach route, speed, heading,
and altitude).

In the study,two divisions of air traffic control responsi-
bility were compared (i) a ground-centralized system
in which controllers were responsible for maintaining
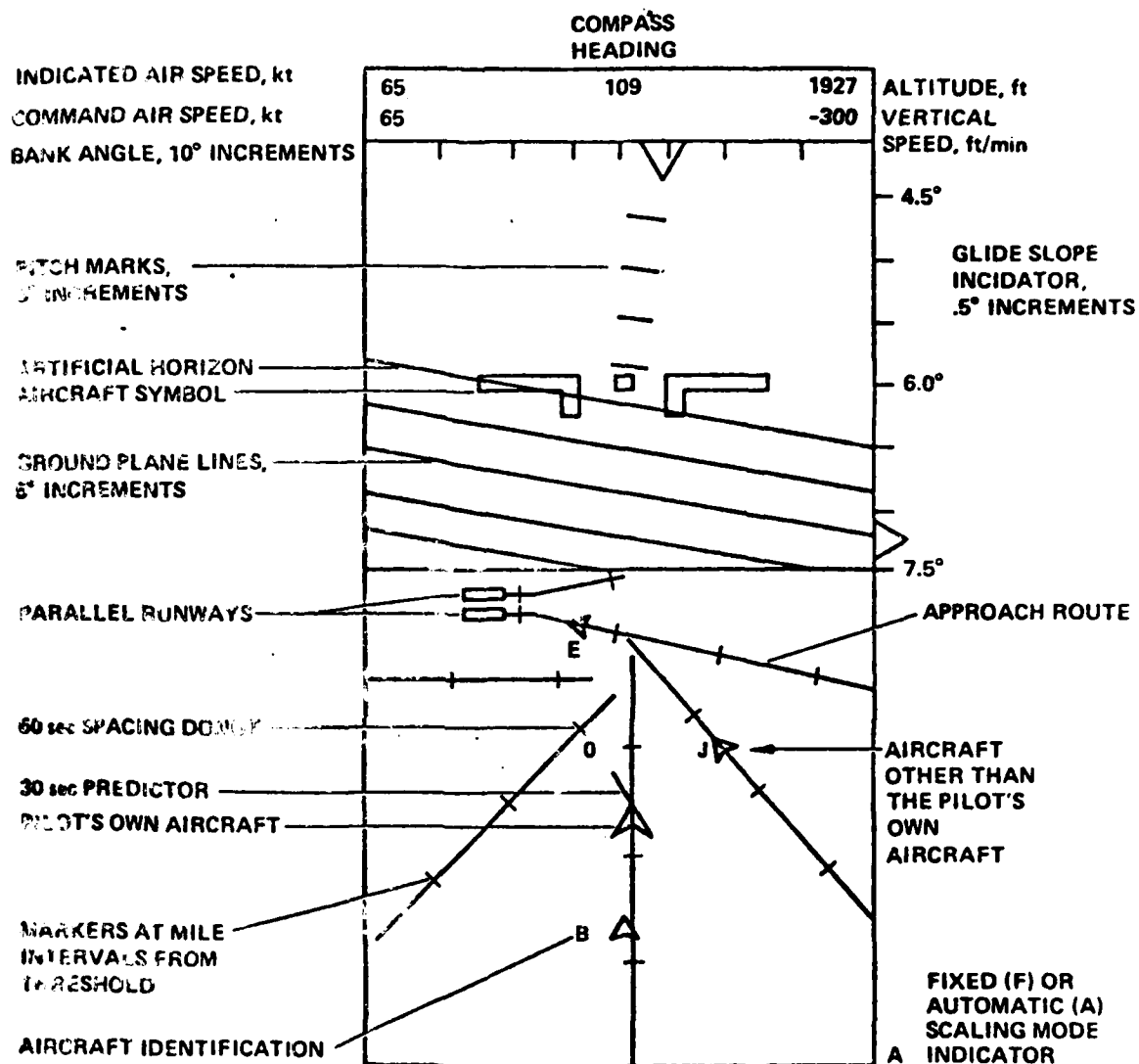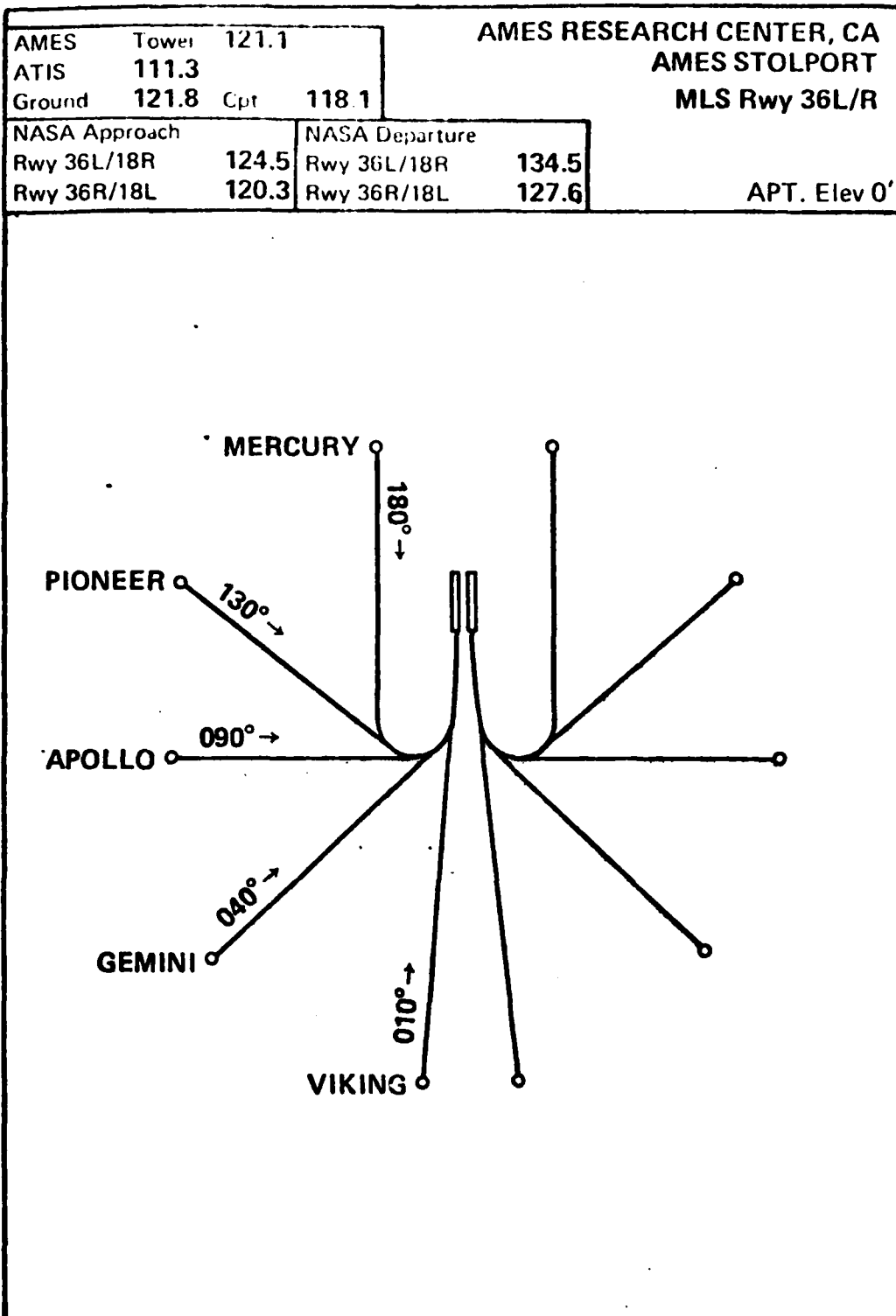separation as well as for issuing sequence commands and

Figure C-25 Vertical Situation Display (Upper) And Traffic Situation
Display (Lower) Serving As The Pilot's Flight
Instruments

C-33

AMES	Tower	121.1	AMES RESEARCH CENTER, CA
ATIS	111.3		AMES STOLPORT
Ground	121.8 Cpt	118.1	MLS Rwy 36L/R

NASA Approach		NASA Departure		
Rwy 36L/18R	124.5	Rwy 36L/18R	134.5	
Rwy 36R/18L	120.3	Rwy 36R/18L	127.6	APT. Elev 0'

Figure C-26 Multiple Approach Routes With Common Final Approach Path
To Two Parallel Runways

(2) a distributed management system in which controllers were only responsible for issuing landing order commands, and individual pilots were responsible for managing their local traffic situation by using their TSD's and by communicating directly with each other.

Study results showed that on the average, aircraft arrived at the Missed Approach Point at 64.5 second intervals. Both pilots and controllers felt that the centralized, ground-based management system was somewhat less safe and orderly than the distributed, pilot-spaced, management system. Pilots felt that the distributed system was more expeditious than the centralized system. The controllers reported the reverse opinion. Since the controllers were able to observe the overall flow of traffic on their display under both systems while the pilots were not, the controllers' judgement might be more relevant to system evaluation.

As expected, localizer and glide slope rms deviation during the last 3 nm of each approach (see Figure C-27). increased as the degree of turn increased. Although the number of missed approaches was low (14 of 350 approaches) the relative frequency was quite high on the Mercury approach. The poorer flight performance on that route could have been due to the steep turn required or the difficulty of reentering the traffic pattern following a previous missed approach. Pilot difficulty and safety ratings were inversely proportional to the amount of turning required. The relatively straight Viking and Gemini approaches were rated as very safe, whereas the Mercury approach was considered somewhat dangerous.

During the final debriefing, pilots expressed mixed reaction to the concept of closer spacing while controller's opinions were evenly divided between for and against. Pilots were much more positive regarding multiple curved descending approaches, particularly if spacing was increased, than controllers were. Managing aircraft merging from different directions was a difficult problem and the controllers indicated the need for additional information, such as estimated time of arrival and indicated air speed, to safely control traffic in this situation. All pilots and all but one controller considered the use of parallel runways, certified for simultaneous and independent operations under IFR conditions, to be a feasible procedure for
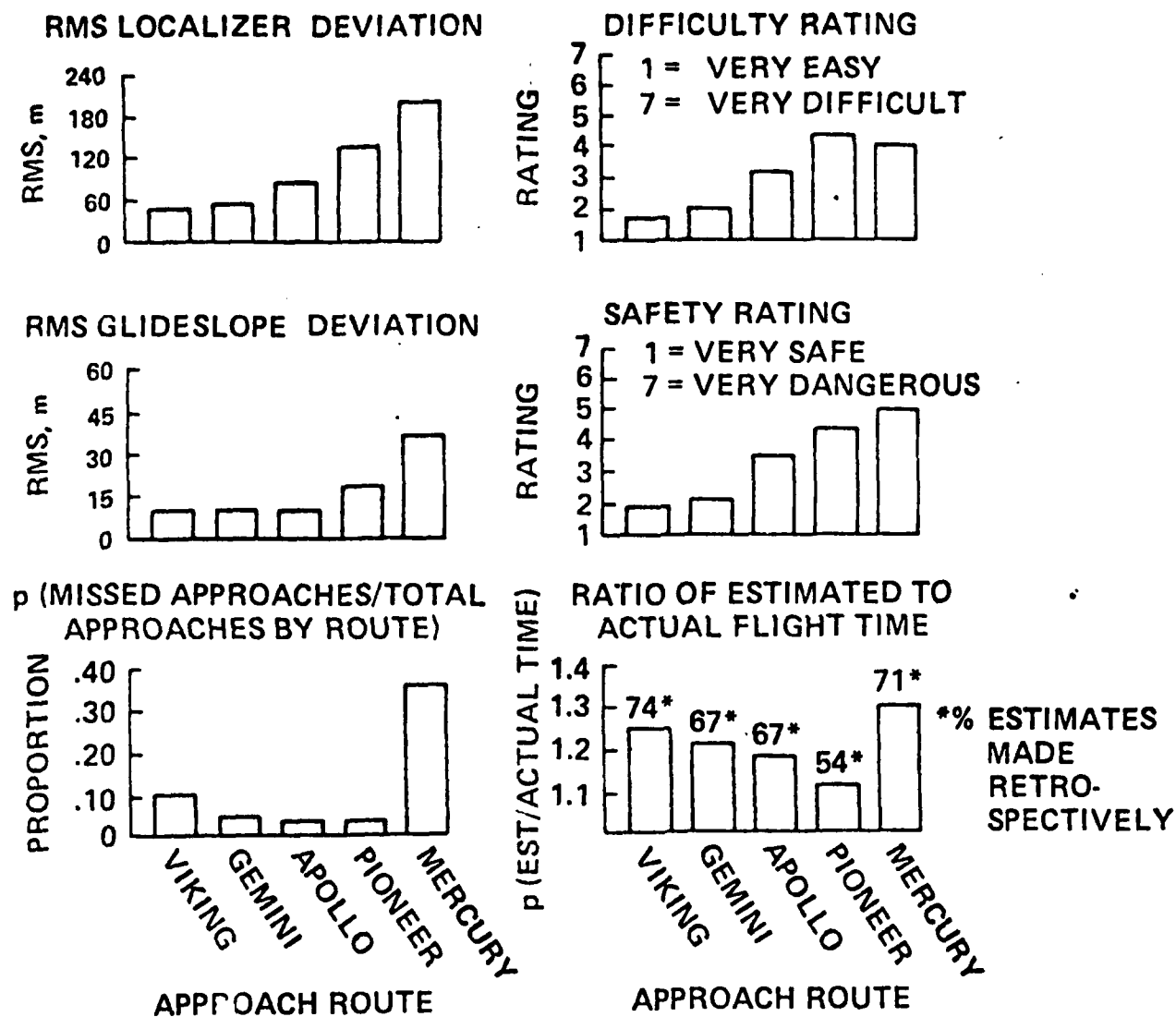
RMS LOCALIZER DEVIATION

DIFFICULTY RATING
1 = VERY EASY
7 = VERY DIFFICULT

RMS GLIDESLOPE DEVIATION

SAFETY RATING
1 = VERY SAFE
7 = VERY DANGEROUS

p (MISSED APPROACHES/TOTAL APPROACHES BY ROUTE)

APPROACH ROUTE

RATIO OF ESTIMATED TO ACTUAL FLIGHT TIME

74* 67* 67* 54* 71*

*% ESTIMATES MADE RETRO-SPECTIVELY

APPROACH ROUTE

Figure C-27 Summary Of Results For Final 3 Miles Of Flight

increasing the rate of aircraft arrivals.

2.4.4   Other Studies

1) Reference 112 provides a detailed discussion on the air-
borne system requirements for transition from enroute
navigation to approach guidance. The paper specifically
addresses the RNAV to ILS and RNAV to MLS transitions in
terms of the following issues: operational requirements and
transitional considerations; computational requirements
and system analysis; performance analysis and simulation
results; and, display requirements. Many of the problems
theorized in this report have been experienced in the
USAF FPI program. Areas of this paper pertinent to the
subject of this report are summarized below.

Due to the mixed airspace environment of navigational
references which exists at the RNAV/MLS transition (i.e.
VOR, DME, barometric altitude, MLS),problems are presented
for both the airborne guidance and control system and the
air traffic controller. Flight control is concerned with
providing adequate performance in transitioning from one
data source to another while ATC is concerned with control-
ling and monitoring flight paths and ensuring aircraft
separation. Erratic maneuvers during transition or lack
of transitional maneuvers may indicate possible system
failure. Unnecessary false alarms would increase controller/
pilot workload and communication channel usage.

A review of mixed airspace separation standards reveals
the need for an increase in vertical but no increase in
horizontal separations. Vertical navigation for departures
must be referenced to barometric altitude since departing
flight will have only partial MLS coverage at best.
Due to typical departure routes which cross arrival paths
and due to the errors between the MLS and barometric
altitude references, an increase in vertical separation
becomes a requirement. Analysis of a typical departure/
arrival crossover 12 nm from the runway touchdown point
(which presently requires 1500 feet separation with all
aircraft using a barometric altitude reference) showed the
need for 1600 to 1800 feet vertical separation from 10 to
30 nm from the MLS elevation site. No increase in hori-
zontal separation standards are required in the mixed
environment because the MLS system azimuth errors are

about 5 to 10 percent of those experienced with VOR (i.e.
0.2 versus 2.0 to 4.0 degrees, 2-sigma). Therefore, present
standards already provide a conservative estimate of route
width requirements in the MLS sector.

Guidance during the horizontal transition involves the
elimination of large errors. Optimal filtering using
VOR, DME, and MLS, whereby the MLS signal is slowly phased
in as a function of distance to the azimuth transmitter,
has been suggested as a method to reduce the effects of
these errors on the maneuver transient. This was not
required on the T-39 program, although variable time constants
were employed in the simple complementary filter schemes
to eliminate the effects of MLS noise at long ranges.

Possible maneuvers for the horizontal transition into
MLS coverage are shown in Figure C-28. Track A,
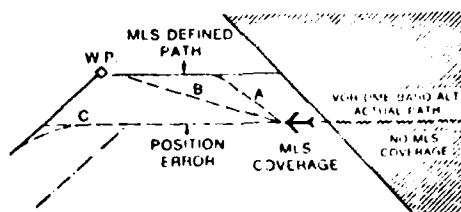
Figure C-28 Flight Path Definition Discontinuity

used exclusively on the USAF FPI Program and typical of
present RNAV systems, results in an immediate corrective
action to reduce the reference switchover error to zero.
Errors in estimated position of 0.2 nm have been observed
at VORTAC station changeover points. For MLS, however,
the discontinuity may be as great as 0.5 nm. Based on
a simulation using the lateral steering equations of the
Collins ANS-70A Area Navigation System, the roll attitude
and heading dynamic responses of an aircraft travelling
at 180 knots ground speed to a 0.5 nm step input are shown

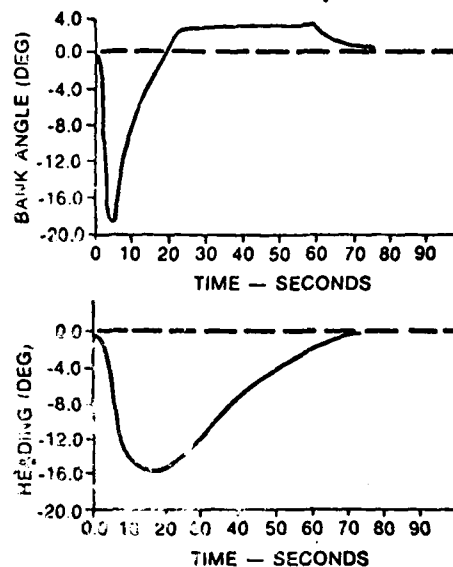in Figure C-29. The responses indicate that the correction

Figure C-29 ANS-70A Response To 0.5-NMI Step In Crosstrack At 180-Knot Ground Speed

is essentially complete after 60 seconds and a maximum
bank angle of 18 degrees is achieved via roll rates of 5
degrees/second or less. From a pilot's standpoint each of
these values are likely to be exceeded in routine terminal
area maneuvering; moreover, if trajectories are flown
such as those flown with the T-39, maneuvers approaching
this will occur during circular transitions about straight-
line segments later on in the approach. A key factor
~ pilot acceptance of such a maneuver is that adequate
warning must be provided so that an unexpected flight
path change does not occur. ATC acceptance should not
be a problem because the maximum heading change is only
15 degrees and is only momentary.

Two other methods to handle the transition are shown in
tracks B and C. Both of these provide a gradual transition

C-39

to the MLS trajectory by sacrificing use of the accurate
MLS data for possibly much longer periods of time.

Whichever transition technique is used, a fixed set of
procedures must be established to reduce pilot and ATC
workload and errors, and to permit automation of the
maneuver. Due to the operational simplicity of the transi-
tion associated with track A and its immediate use of the
MLS, it appears to be most attractive.

Guidance during the vertical transition poses several
problems associated with pilot operational acceptance.
Trajectory design must eliminate the problem associated
with reducing large (500 feet) vertical transition errors
above the desired path which may be descending at a 5 or
3 degree flight path angle. The profile geometry must
provide the pilot with sufficient time to capture the ver-
tical path without disconcerting flight path angle require-
ments. Special consideration must be given to pilot work-
load levels involved with simultaneous turn requirements.
In such a maneuver, the pilot is required to change descent/
ascent path, and lateral path while holding airspeed to
safe levels. A second problem associated with the transi-
tion occurs as a result of errors where the aircraft is
below the desired path. Since climbing to acquire the
path is not normally operationally acceptable (for all but
small errors, i.e., more than 100 feet, on T-39), logic
or procedures are required to prevent a "fly up" to the
path. The trajectory design, logic and procedures used
on the T-39, and described in Section 2.4.1 appear to be
an acceptable solution to these problems.

The paper also provided a cursory look at control/display
requirements for MLS complex trajectory flight. The general
opinion of the author was that, although further investiga-
tion was required, CRT map displays were not necessarily
needed to execute terminal area paths where only minor
impromptu modifications are used to achieve aircraft spacing
and sequencing.

APPENDIX D

THREE-DIMENSIONAL IMAGE REPRESENTATION OF MLS TRAJECTORIES

One graphical entity presented to the pilot on the candidate 3-D Display is the dynamic 3-dimensional computer generated image which represents an MLS flight trajectory. The purpose of this 3-dimensional image is to provide the pilot with a precise, concise, scannable pictorial which allows him to ascertain his position as related to a desired real world MLS flight path.

D.1 Formats

The graphical structure of the image has been a topic of consider-able investigation in recent years. The objectives of the investiga-tions have been aimed at determining the optimal format of the image from a human engineering and computer real time standpoint.

The following criteria have been used to evaluate the displayed image:

1. A non-inverting 3-dimensional image (i.e., the image structure should not allow the pilot to perceive that the front of the displayed image becomes the back and vice versa).

2. The dynamic movement of the image on the display unit, in response to changes in aircraft position, should not be "distracting" to the pilot.

3. The image should retain its integrity for showing an unambiguous situation independent of the aircraft's position in 3D-space (i.e., the "image information content" should not degrade).

4. The image should be capable of indicating:
   a. Cross track and vertical track errors.
   b. Indications of the aircraft position above, below, left or right of his desired flight path.

   c. Future MLS flight path changes in heading and altitude.

   d. Aircraft roll angle.

   e. A desired flight envelope about the desired flight path.

   and implicitly indicate:

   a. Rate of climb or descent.

b. Rate of change in aircraft heading.

c. Rate of turn required to remain on defined flight path.

d. Aircraft speed.

In accordance with item 2, to display a continuous dynamically moving image on the color display unit, the graphical structure must lend itself to airborne computer real time generation. This real time constraint imposes the criterion that the image be comprised of a minimum number of lines, since real time to generate the image is directly proportional to the number of lines when a hidden line algorithm is not used, and exponentially related when a hidden line algorithm is incorporated.

Figure D.1 shows three generically different image display formats (hereafter referred to as a tunnel, channel, and monorail representations) which were conceived as a result of the above criteria. (Note: The figures shown are examples of what the pilot would see on the cockpit display unit if he were exactly flying his desired MLS flight trajectory and no hidden line removal algorithm was incorporated.) The examples presented are pseudo perspective projections of an imaginary MLS "highway in the sky".

The figures which will be presented in this section are hard copies of images generated on a Tektronix 4081. The information shown in the lower left hand corner is a display of the X, Y, Z spatial coordinates (i.e., coordinates with respect to the fixed runway coordinate system) in normalized units (i.e., the values represent distances from the coordinate systems origin) of the aircraft or observation point. The R value shown is the roll angle of the aircraft/observation point in degrees.

The following subsections will discuss the characteristics of the three formats.

D.1.1 Tunnel Format

The tunnel format is comprised of a series of rectangular elements representing planes intersecting the desired MLS flight path at a constant interval along the path. The desired flight path trajectory is not explicitly represented by a line in this type of format, but implicitly represented by the center of each rectangular element.

A major drawback to this approach is its ambiguity in explicitly indicating roll angle. For instance, at a roll angle of 45°, the direction of roll cannot be ascertained from the image presented to him since the rectangular elements are symmetrical. Using elongated elements aids in dispelling this ambiguity, but a similar ambiguity will still exist for certa r angles.
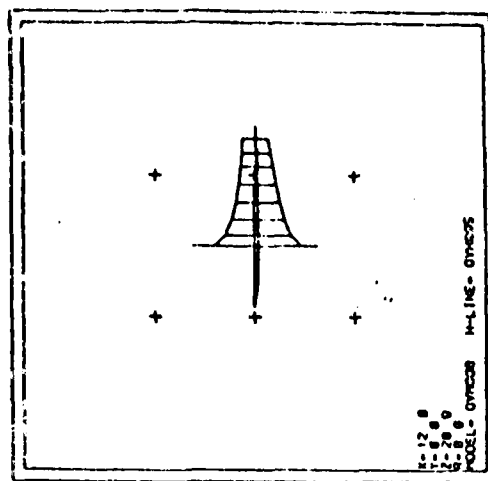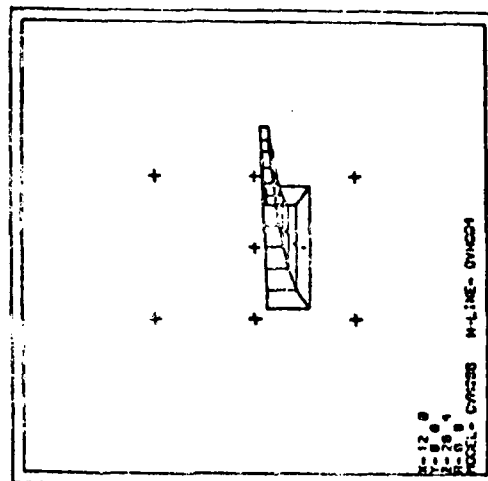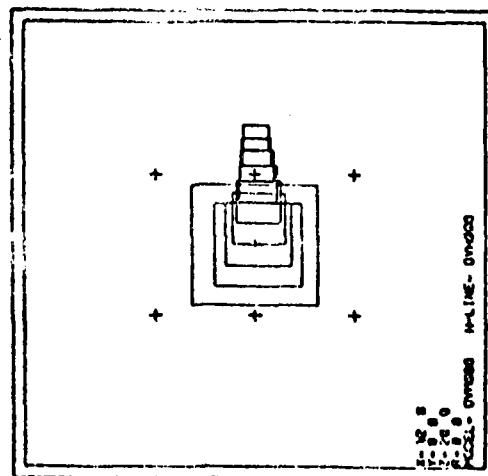
(a) TUNNEL   (b) CHANNEL   (c) MONORAIL

Figure D-1 - Image Display Formats

D-3

D.1.2   <u>Channel Format</u>

Figure D-2 shows the basic graphical structure of the channel format and defines the elements in the structure (i.e., side posts, tar strips, etc.). In this format, the pilot's desired MLS trajectory is again not explicitly represented by a line on the display, but is implicitly located at the top, center of each channel segment. In essence, when the pilot is "on flight path" (as depicted in Figure D-2) the image displayed appears as a "highway in the sky" which extends out in front of the aircraft with the channel bed and center line positioned a channel height distance immediately below the desired flight path.

A major difficulty with the channel format is its tendency to invert or turn inside out in the viewers' eye. An example of this phenomena can be experienced by looking at Figure D-3(a). Employment of a hidden line algorithm and elimination of the center line when the channel is observed from below, improves the situation as demonstrated in Figure D-3(B). In addition to preventing image inversion, the use of hidden line removal in the channel approach, maintains the image integrity as shown in Figure D-4. The images represented in Figure D-4a,b, and c have degraded to a conglomeration of lines and the structure of the "highway in the sky" has been obliterated. Implementing hidden line clarifies the situation as shown in Figure D-4 d,e,and f. However, implementation of hidden line removal dramatically increases the computer real time to generate the image as well as reducing, in certain configurations, the amount of information about future flight path deviations in altitude and heading (refer to Figure D-4).

Since the channel format consists of four primitive graphical structures (side posts, tar strips, side rails, and channel front/ back), each of these primitives can be displayed alone or in combination with other primitives. Figures D-5 and D-6 show some of the possible combinations. It should be noted that one of these channel format variations (Figure D-5(d) tar strips only) is currently being investigated by the Northrop Corporation for the Naval Air Development Center[1]. On the surface, such an image format seems extremely feasible. However, investigation into the dynamics of a "tar strips only" format results in a major inadequacy as shown in Figure D-7. It is apparent that this display format has the characteristic of degrading, in certain situations, to an image which does not meet the criteria stated previously.

1.   W. G. Mulley and J. F. Watler, Jr., "Feasibility Demonstration of the Earth-Referenced Maneuvering Flight Path Display", American Institute of Aeronautics and Astronautics Guidance and Control Conference, August 1977, Paper No. 77-114.
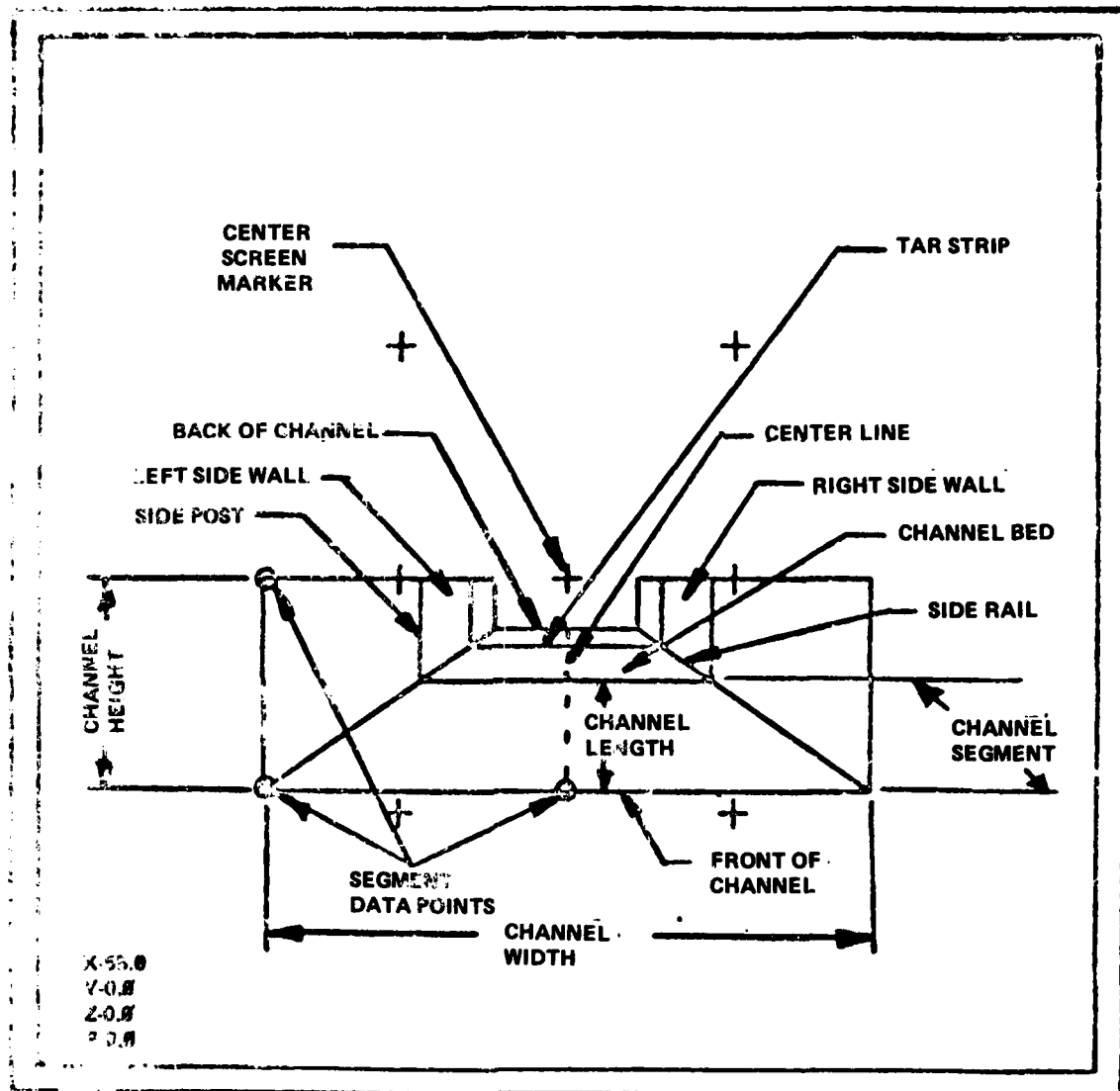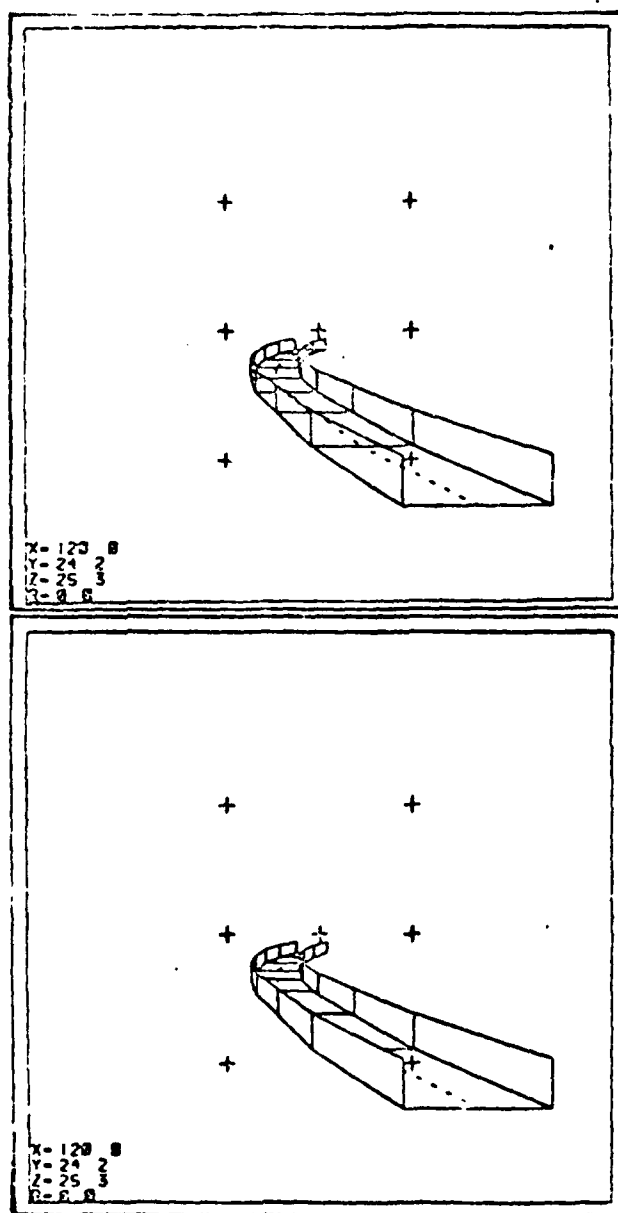
Figure D-2 - Channel Format Definitions

D-5

(a) NO HIDDEN LINE REMOVAL
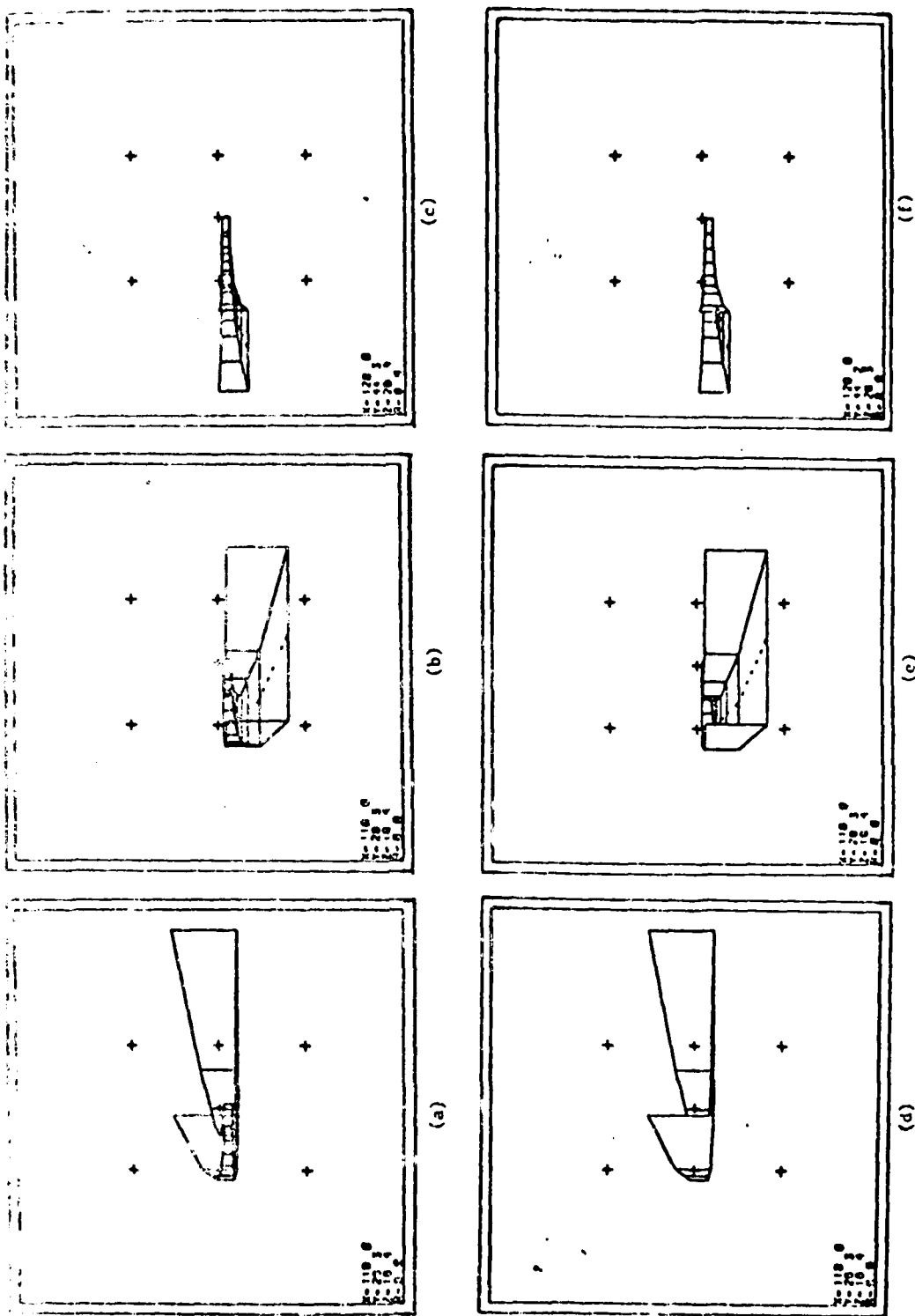(INVERTING IMAGE)

(b) HIDDEN LINES REMOVED
(NON-INVERTING IMAGE)

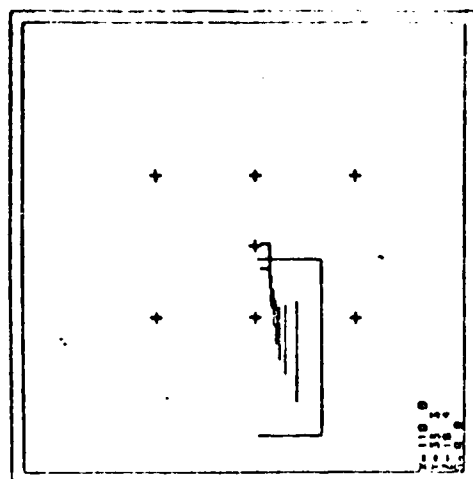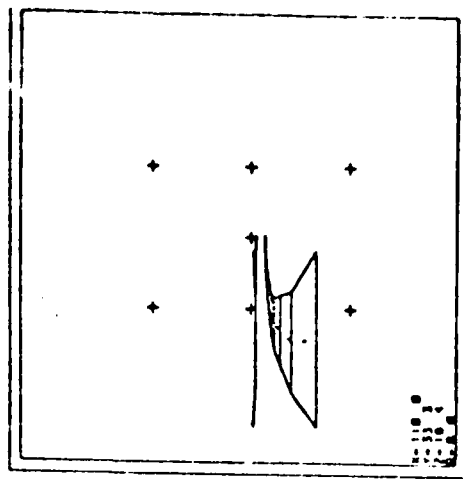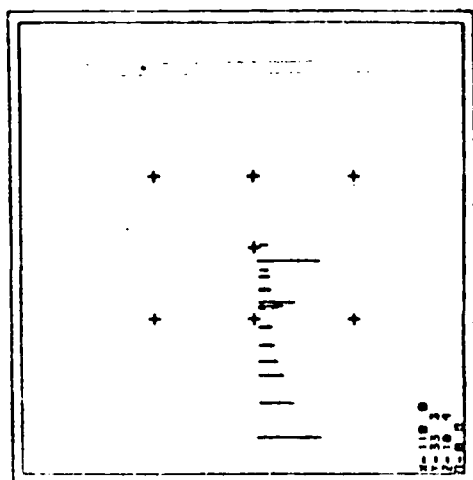Figure D-3   Image Inversion Example

D-6

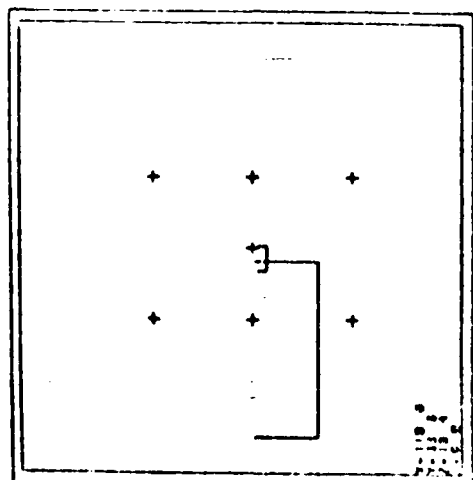Figure D-4 Hidden Line Example
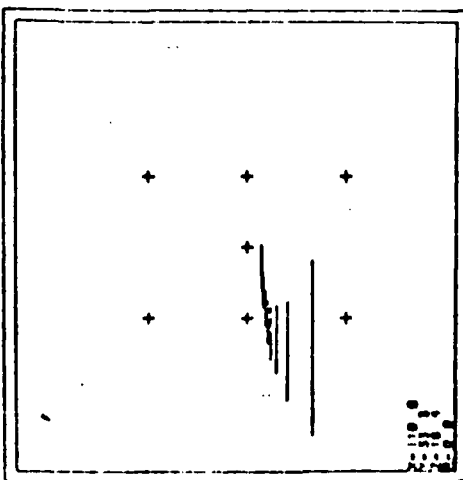
(c) TAR STRIPS AND CHANNEL
FRONT/BACK

(b) CHANNEL SIDE POSTS ONLY
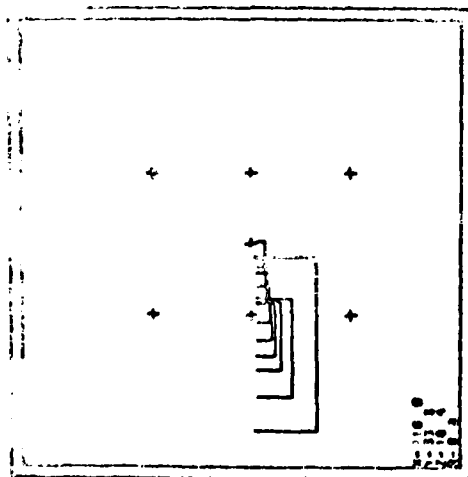
(a) CHANNEL FRONT/BACK ONLY
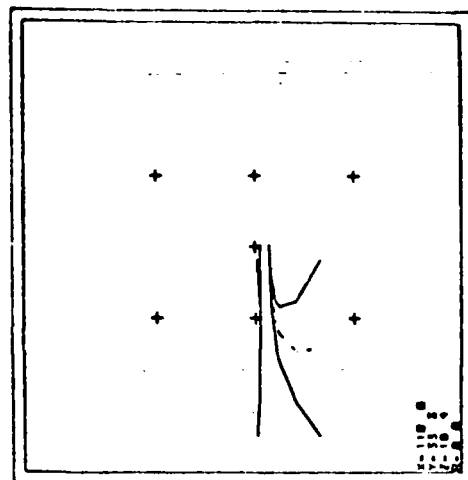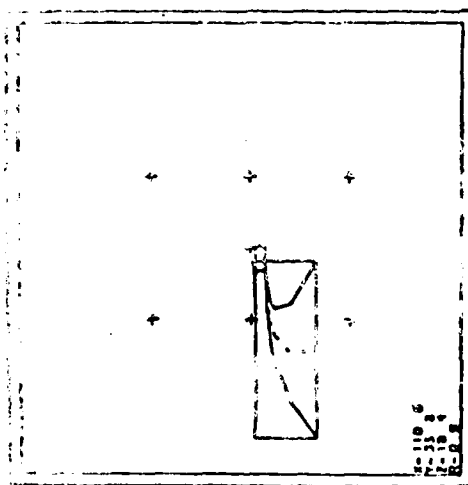
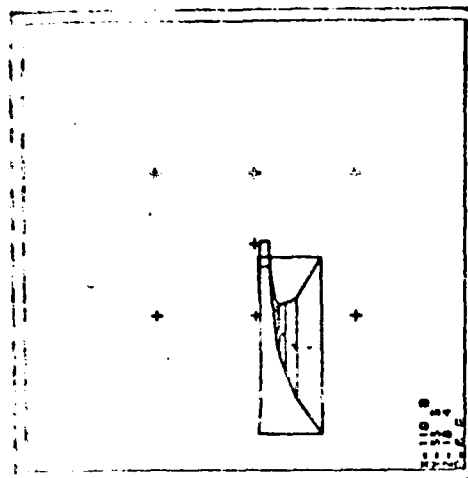(f) TAR STRIPS AND RAILS

(e) RAILS ONLY

(d) TAR STRIPS ONLY

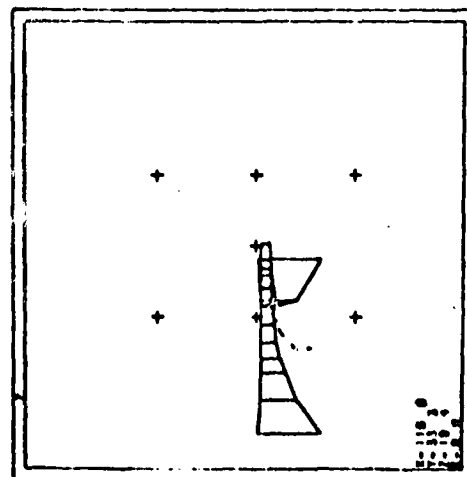Figure D-5   Channel Format Variations
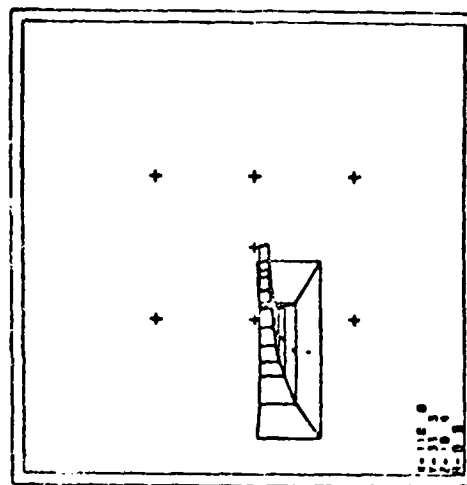
(a) TAR STRIPS AND SIDE POSTS
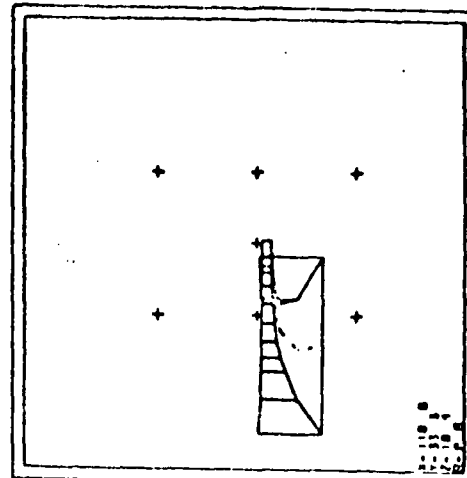
(b) RAILS AND CHANNEL FRONT/BACK

(c) TAR STRIPS, RAILS, AND CHANNEL
FRONT/BACK

(d) SIDE POSTS AND RAILS

(e) SIDE POSTS, RAILS, TAR STRIPS,
AND CHANNEL FRONT/BACK

(f) SIDE POSTS, RAILS, AND
CHANNEL FRONT/BACK

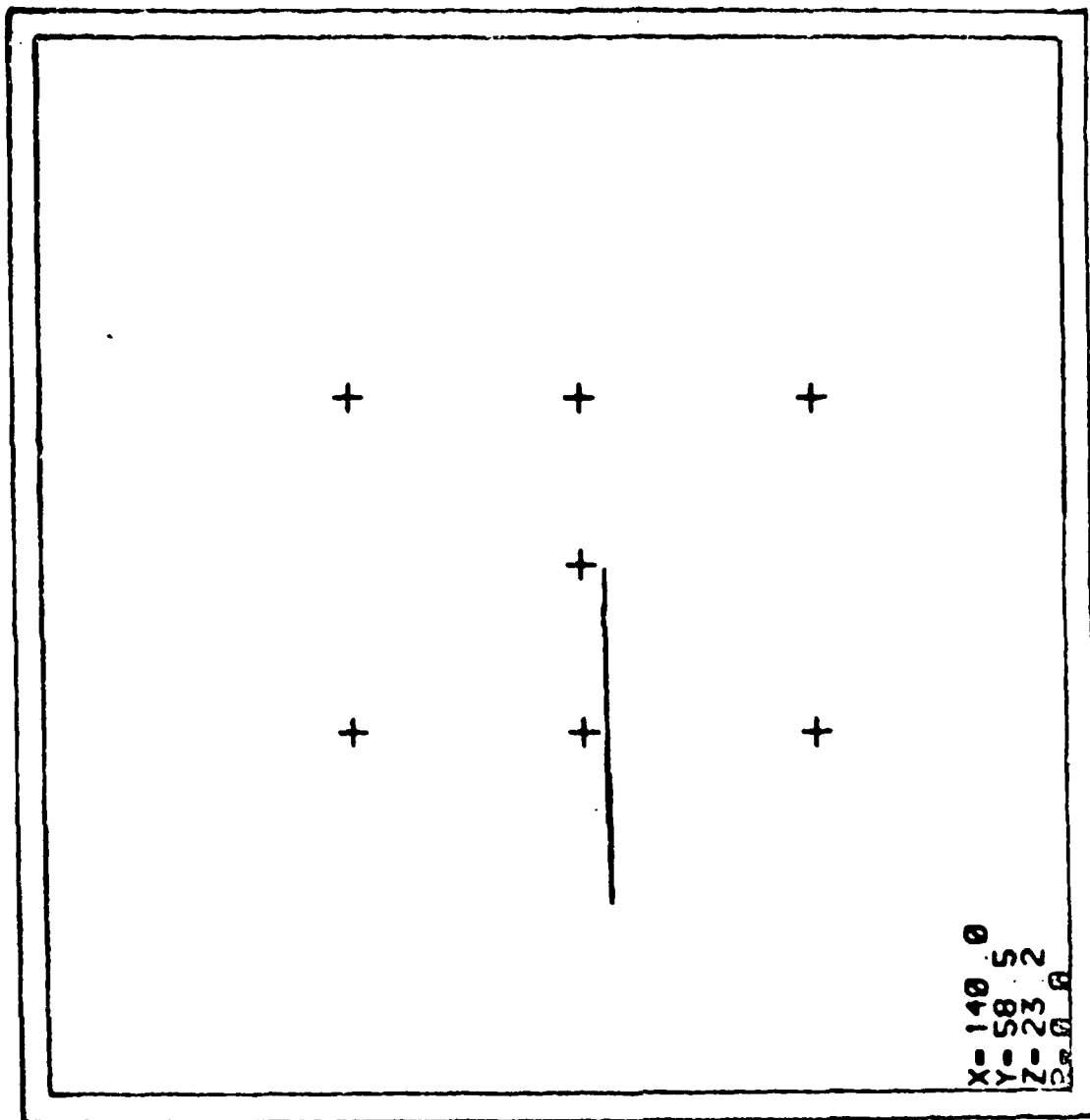Figure D-6 - Channel Format Variations

Figure D-7 Tar Strips Only

X= 140.0
Y= 58.5
Z= 23.2
CR= 0.0

During the investigations into the different channel format variations, it is felt that a channel image comprised of side posts, side rails, and channel front/back primitives with implementation of a hidden line algorithm could be made to meet the human engineering and real time requirements. Figure D-8 is example display images which the pilot would see on the display unit in different flight situations.

The rate of change of cross track, vertical track, and roll angle can be implicitly derived by the pilot by monitoring the rate of horizontal, vertical and rotational changes of the image on the display. For example, if cross track error is increasing rapidly, then the image will move horizontally across the screen at a rate proportional to the aircraft's rate of change in the horizontal direction.

Progress along the flight path is implicitly determined from the movement of the side posts. The side posts increase in size and move as the aircraft proceeds along the flight path producing an illusion of flying down the channel.
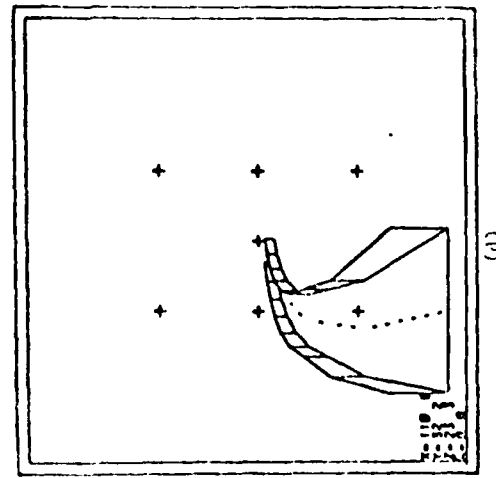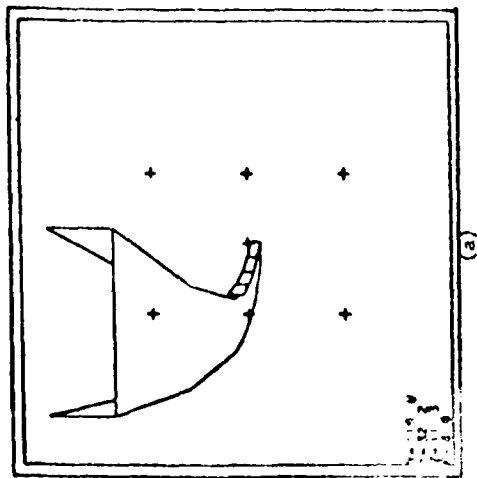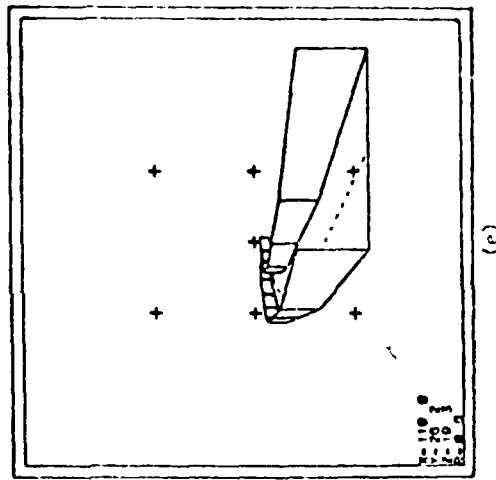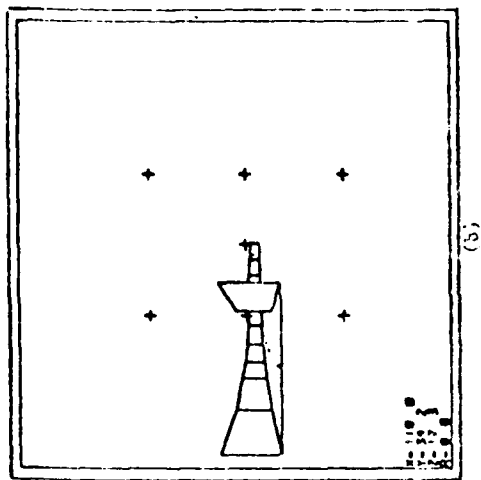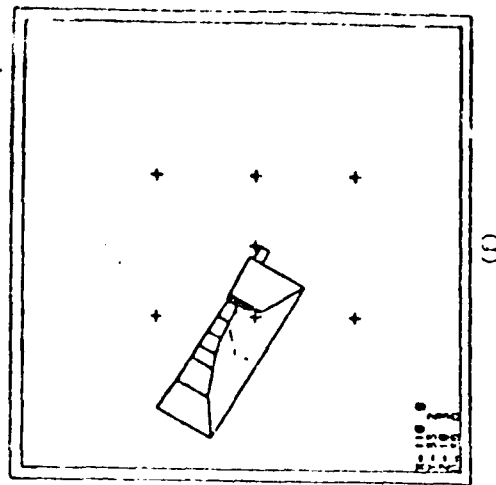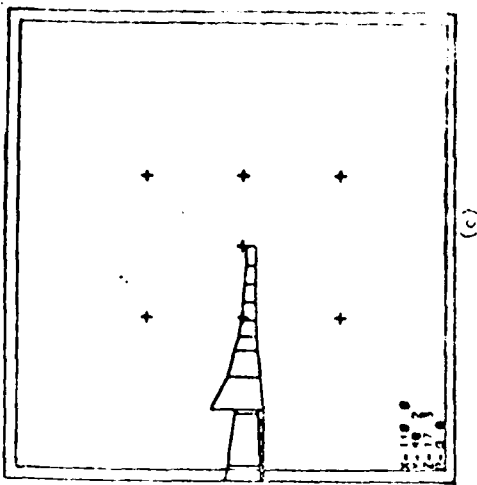
D.1.3   Monorail Format

In a monorail format, an MLS channel segment is represented by two perpendicular, intersecting planes. This format is similar to the "Bendix bull's-eye" presently used on conventional ADI's. Unlike the previous two formats, the MLS flight path is explicitly represented by a line segment in the image. The line resulting from the intersection of the two planes is the MLS flight trajectory.

An interesting characteristic of this type of format is its relative stability with respect to image inversion, even without hidden line removal, the image does not easily invert in the viewer's eye (refer to Figure D.9). The pilot can easily ascertain the front and back of the image. However, without hidden line removal, the image is some-what busy.

The monorail format poses the same major drawback with respect to angle ambiguities as the tunnel format.

Figure D-10 shows example display images which the pilot would see on the display unit in different flight situations if the monorail format were implemented.

D-11
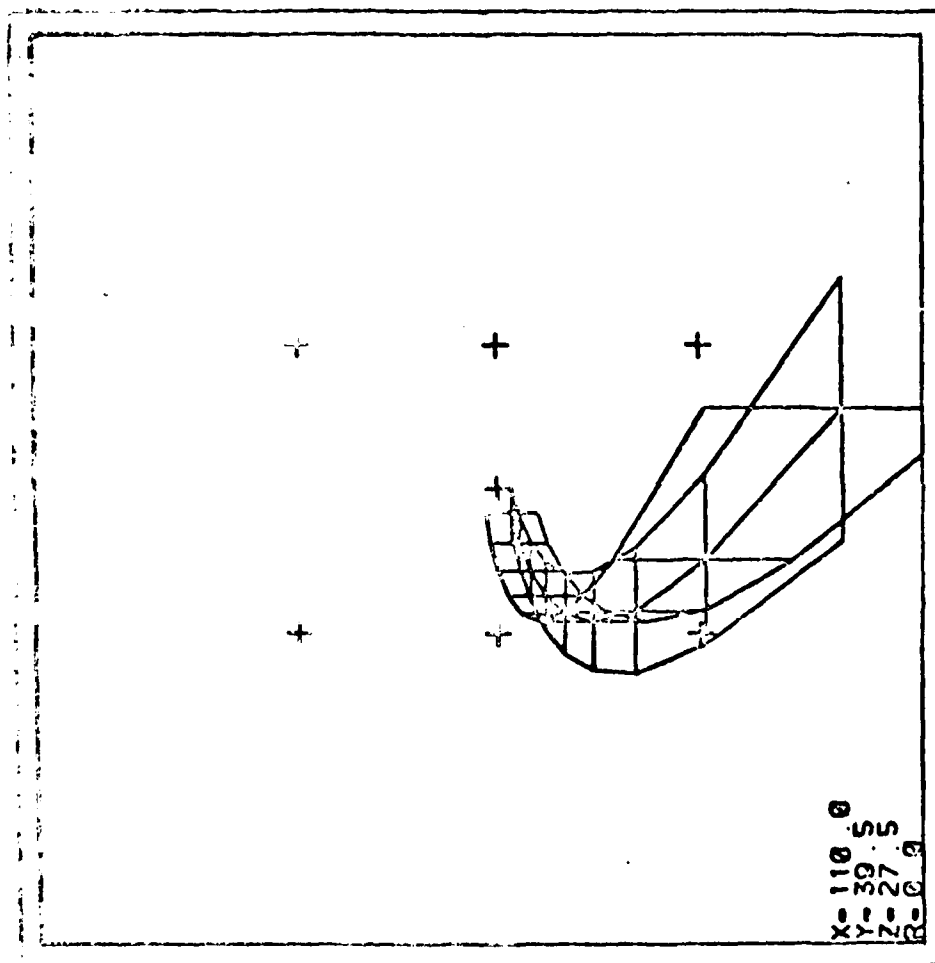
Figure D-8 – Channel Format Examples

X-110.0
Y-30.5
Z-27.5
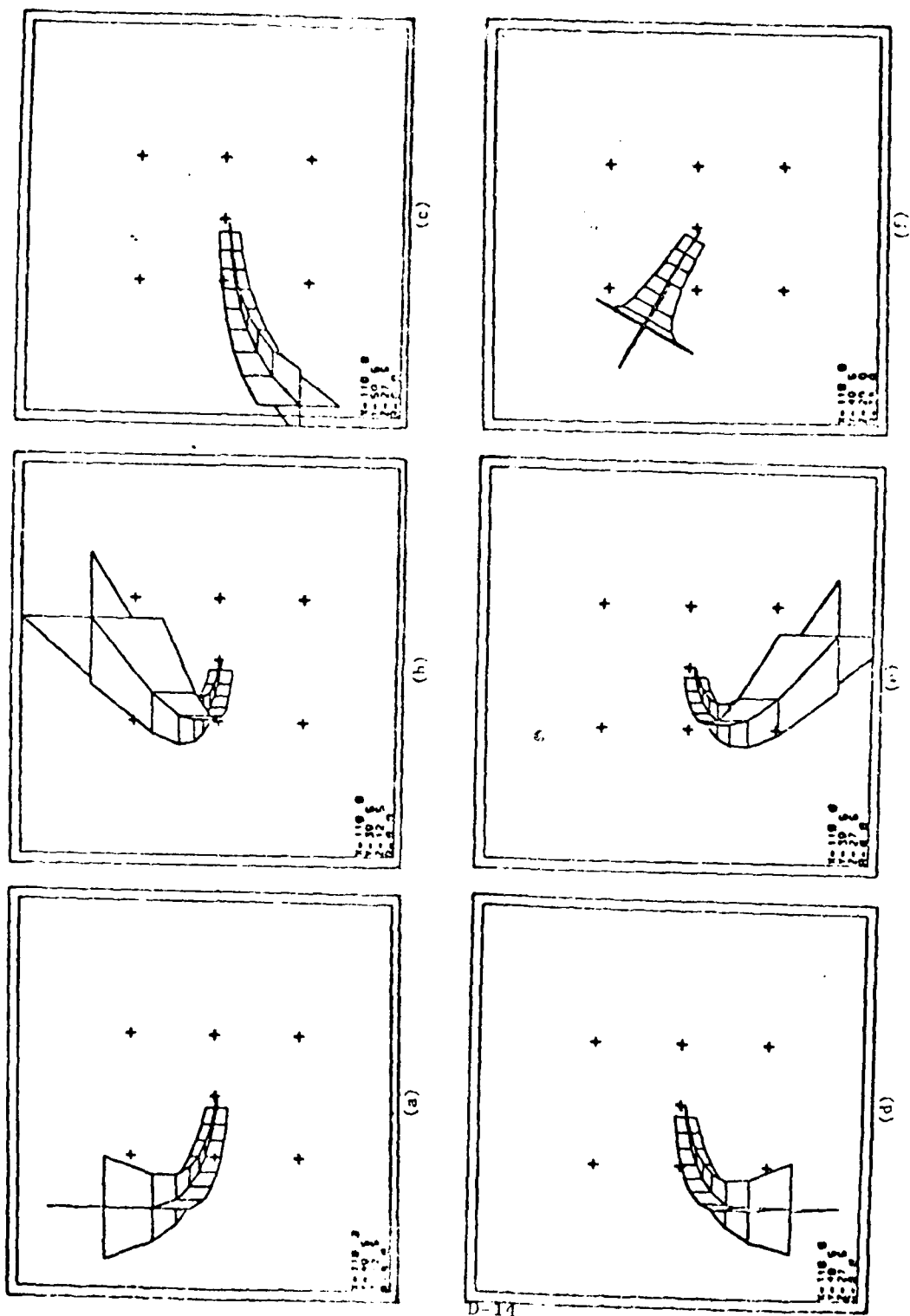R-0.0

Figure D-9 - Monorail Format Examples

D-13

Figure D-10 - Monorail Format Examples

D-11

APPENDIX E

USAF T-39 MLS COMPLEX TRAJECTORY FLIGHT PILOT PROCEDURES

The following typical procedures are involved in flying an autopilot-coupled MLS complex trajectory with the present USAF T-39 control and display configuration. Comments are shown in parentheses following the specific task. Reference should be made to the T-39 panels and displays shown in Section 2.4.1.

Initial Set-Up Prior to Entering MLS Data Coverage

1. Turn on CDU and set barometric pressure and outside air temperature readouts via CDU and MEM pushbuttons and encoder knob. (It would be better if this were done automatically by monitoring the altimeter setting and measuring OAT).

2. Monitor and contact enroute center and approach control frequencies as required. Transmit desired Profile # to approach control and obtain clearance. (Normally ATC will issue an approach path based on current traffic).

3. Select TACAN channel and set up course to intercept first leg of MLS approach on co-pilot's HSI

4. Check and set Nav Select Panel (NSP) switches as follows:

   a. Pilot's DEV switch to CDU   —   SET
   b. Pilot's BRG switch to MLS   —   SET
   c. Copilot's DEV switch to TAC —   SET
   d. Copilot's BRG switch to TAC —   SET
   e. CDU/DME switch to WPT   —   Check
   f. MLS/TKR switch to TKR   —   Check
   g. VERT switch to WPT   —   Check

5. Check and set MLS Control Panel switches as follows:

   a. MLS CHAN selector to desired channel — set three thumbwheel switches.
   b. AZ selector to 000   —   check
   c. GS selector to 3.0   —   check
   d. MLS/OFF/VOR TAC switch to MLS — set

6. Select AZ readout on MLS Auxiliary Data Panel.

7. Set VOR frequency paired with airport's MLS DME frequency on pilot's side of VHF NAV control head. Check that pilot's DME light on control head is illuminated. If not, depress DME transfer pushbutton once. (In the final MLS configuration, the MLS DME frequency will be paired with the MLS channel therby eliminating this step.)

8. Check and set autopilot/flight director Mode Select Panel switches as follows:

    a. Flight director engaged - check for command bars in view on ADI.

    b. AUTOPILOT switch on - check

    c. ROLL and PITCH axes switches in CMD - check

    d. CWS switch in ON position - check

9. Maneuver aircraft via roll CWS to fly TACAN radial which will intercept MLS. (The coupled heading select mode could also have been used).

10. Maneuver aircraft via pitch CWS to obtain desired level flight altitude, then engage altitude hold by depressing ALT HOLD pushbutton on Mode Select Panel.

11. Depress DIG pushbutton on Nav Select Panel to engage digital autopilot. (This could have been on before.)

12. Insert approach profile into computer via CDU*, and check data entry vs. the approach plate, as follows:

    a. Insert desired profile number on "altitude page"

*CDU data entry involves: selecting the desired "page" of informa-tion by actuation of two   pushbuttons; selecting the desired data parameter mnemonics to be changed by repeated actuation of the LINE pushbutton until that mneumonic is flashing; rotating the encoder knob until the desired value appears next to the identifier; and, depressing the MEM (memorize) pushbutton.

_____ "waypoint sequence page" and check the
_____ of waypoint numbers defining the
_____ trajectory.

    c. Select "waypoint display page" for each way-
point (typically 3 or 4 waypoints not includ-
ing GPIP) and check waypoint bearing (azimuth)
and range (DME).

    d. Select "lateral page" for each waypoint and
check inbound and outbound tracks (courses) and
_____ on turn. The inbound track of the initial
___ waypoint may require change.

    e. Select "vertical page" for each waypoint and
check desired altitude and path angles for way-
point. Altitudes, in some cases, will require
_____. Incorrect altitudes will result in
erroneous desired, and next, path angle and
indications.

13. Lower speed brake.

14. _____ power settings for approach speed and control
power as required.

15 Lower landing gear and flaps.

16 Check fuel quantity, fuel heater and hydraulic
pressure.

17. Turn on landing light, seat belt and no smoking
signs.

18. Set decision height bug on radar altimeter indicator.

Monitor the following to Detect Entry into MLS Data
Coverage

1. TACAN lateral deviation and DME data vs. approach
plate indication of MLS entry point data

2. _____ MLS azimuth, elevation and DME data by in-view
indications on MLS Auxiliary Data Panel, Vertical
Angle Indicator and MLS DME Indicators, respectively.
(Too many different displays.)

After Recognition of Valid MLS Data

1. Engage MLS Mode on CDU by the following operations:

    a. Depress LAT and MEM pushbuttons.

b. After 3 seconds observe: LAT green light on
CDU; slewing of Pilot's HSI course to that of
initial MLS approach segment; and, the "to"
waypoint number on the CDU.

c. Depress VERT and MEM pushbuttons

d. After 1 second observe VERT green light
on CDU.
(Could be done using one pushbutton - MLS on.)

* 2. Select autopilot/flight director MLS lateral and
vertical navigation modes via Mode Select Panel.

a. Depress LAT NAV pushbutton

b. Depress VERT NAV pushbutton
(Could be done using one pushbutton - MLS.)

* 3. Observe pilot's or copilot's mode progress dis-
plays for autopilot/flight director MLS arm and/or
engage status.

4. If modes are armed (annunciated by amber AZ and
EL indications in arm window) observe the HSI and
ADI deviation and situation indications described
below:

a. Aircraft below desired glide path and intercept-
ing.

b. Aircraft at an intercept angle to the desired
course.

c. If these situations are incorrect, they should
be attained via. CWS.

*(By modifying the MLS computer logic these steps can be accom-
plished prior to entering MLS coverage. This would greatly
reduce workload levels at the transition point. It would also
eliminate the need to closely monitor for the point where MLS
data first became valid.)

5. When the lateral and vertical navigation modes'
capture logic is satisfied, the individual mode
will be automatically engaged and annunciated by a
green AZ and/or EL in the engage window of the mode
progress display. The aircraft will be maneuvered
by the autopilot in a smooth manner to capture the
transition segment within MLS coverage.

6. Path tracking and approach progress is monitored using the following presentations on the following instruments:

    a. ADI-GS pointer for vertical deviation about the command descent path, pitch and roll attitude, flight director command bars and flight path angle.

    b. HSI - course deviation for lateral deviation about the desired track (i.e., course), desired track angle for the current lateral path segment, DME to waypoint, bearing to waypoint on the bearing pointer and aircraft heading.

    c. MLS DME Indicator - DME to MLS DME site at far end of runway.

    d. MLS Auxiliary Data Panel - Azimuth angle referenced to 0° along the runway centerline.

    e. Azimuth Angle Indicator (AAI) - nonlinear analog display of azimuth angle.

    f. Vertical Angle Indicator (VAI) - non-linear analog display of elevation angle.

    g. CDU "data page 1" - digital readouts of lateral deviation with a resolution of 0.01 NM, vertical deviation in feet, range-to- waypoint with a resolution of 0.1 NM and estimated-time-to-go to the next waypoint with a resolution of 0.1 minutes

    (Again, too many displays.)

7. Circular arc lateral transitions are monitored by observing:

    a. DME to waypoint

    b. Flashing green LAT and ALRT lights on CDU for 15 seconds prior to the turn.

    c. Automatic slewing of the course pointer to the next desired track.

    d. Course on which rollout occurs.

    e. Magnitude of the bank angle during the turn.

8. Vertical position and transitions are monitored using DME to the DME site, baronetric altitude and rate of descent indications.

9. After final approach track (i.e., runway heading and final descent angle) is attained, the lateral and vertical deviation indications on the HSI and ADI automatically switchover from MLS navigation computer data to MLS receiver raw data. This is annunciated by either an amber CATII or ALN/FLR (depending on whether autoland was selected) readout in the arm window of the mode progress display.

10. To determine the time-to-go to touchdown, as is often requested by approach control, the CDU/DME switch on the Nav Select Panel is moved to the ATK position and the ETG is read on "data page 1" of the CDU.

Warning and Failure Indications

1. An MLS receiver failure, or loss of valid MLS data due to antenna masking, is annunciated by a red D/R light on hte CDU. No flags come in view on the HSI or ADI; however, the data which goes invalid or fails is biased out of view or flagged on its specific indicator as described below:

   a. Loss of Azimuth data is indicated by displacing the AAI bar fully to the left and by displaying all dashes on the MLS Auxiliary Data Panel AZ readout.

   b. Loss of elevation data hides the VAI pointer.

   c. Loss of DME data is indicated by displaying all dashes on the MLS DME Indicator.