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KC-135 CREW REDUCTION FEASIBILITY DEMONSTRATION SIMULATION STUDY VOLUME 2: COCKPIT DESIGN

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This technical report has been reviewed and is approved for publication.

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In support of the KC-135 Avionics Modernization Program, a two-person (no-nav) conceptual cockpit design was developed for use in the man-in-the-loop simulation feasibilty demonstration. This report is Volume 2 of a 3-volume technical report. The report covers the background, rationale, and process used in developing the Crew Station Evaluation Facility's two-person (no nav) conceptual cockpit design. A total of six subsystems were either added to or replaced older archaic systems. These systems included (1) Remote Readout Unit (RRU), (2) Electronic Attitude Director Indicator (EADI), (3) Electronic Heading Situation Indicator (EHSI), (4) Control Display Unit (CDU), (5) Color weather radar, and (6) Warnings and Cautions Advisory Panel (WCA). A detailed description is provided for each piece of new equipment/ subsystem. Recommendations of the functional requirements determined from the feasibility demonstration (Volume 3) are also discussed.

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TABLE OF CONTENTS

LIST OF FIGURES vi

ABBREVIATIONS AND ACRONYMS viii

INTRODUCTION 1

CSEF Tasking 2

Function Analysis Phase 2

Cockpit Design Phase 2

Test and Evaluation Phase 3

DESIGN DESCRIPTION 3

Electronic Attitude Director Indicator (EADI) 4
1. Horizon Line and Pitch Scale 4
2. Roll Scale and Roll Pointer 7
3. Aircraft Symbol 7
4. Command Bars 7
5. Vertical and Lateral Deviation Displays 7
6. Indicated Air Speed (IAS) 7
7. Angle of Attack (AOA) 7
8. Barometric Altitude (BALT) 7
9. Vertical Velocity (VV) 8
10. Decision Height (DH) Annunciator and Indicator 8
11. Radio Altitude (RALT) 8

Electronic Horizontal Situation Indicator (EHSI) 8
1. Display Formats 8
2. Digital Displays 13
3. Primary Navigation Aid Indicator 16
4. Bearing Indicator 16

EHSI/EADI Display Control Panel 16
1. HSI-ARC-MAP Format Switch 16
2. Course Active (CRS ACT) Button 16
3. Select/Range (SEL/RNG) Knob 18
4. Course Preset (CRS PRE) Button 18
5. Bearing (BRG) Button 18
6. Course Transfer (CRS XFR) Button 19
7. Decision Height Set (DH SET) Knob 19
8. Dim Knobs 19
9. Radar Test (RA TST) and Radar (RDR) Buttons 19

Heading/Course Panel 19
1. Course Control (CRS CTL) Button 19

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2. Course (CRS) Select Knob 19
3. Heading (HDG) Select Knob 19
4. Navigation Data (NAV DTA) Button 20
5. Elapsed Time (ET) Button 20

Map Overlay Panel 20
1. Waypoint (WYPT) Button 20
2. Navigation Aids (NAID) Button 20
3. Airport (ARPT) Button 21
4. Radar (RDR) Button 21

Radar Control Panel 21
1. Gain Control Knob 21
2. Tilt Control Knob 21
3. Radar Range Selection Buttons 21
4. Radar Mode Selection Buttons 23
5. Ground Clutter Suppression (GCS) Button 23
6. Hold (HLD) Button 23
7. Stabilization (STB) Button 23

Mission Management System (MMS) 23
1. Symbol Conventions 26
2. Function Select Keys 27
3. Indexed Functions 31
4. Communications (COM) Functions 37
5. Navigation (NAV) Functions 41
6. Identification Friend or Foe (IFF) Functions 43
7. Mode 3 (M3) Function 44
8. Integrated Navigation (INAV) Functions 44
9. Flight Plan (FPLN) Functions 47
10. Hold and Rendezvous (RZ) Functions 51

Digital Warning/Caution/Advisory (WCA) Display 54

Remote Readout Unit (RRU) 54

Other Design Changes 54
1. Standby ADI 54
2. Radar Control Panel Location 54
3. Ground Map Update Capability 54
4. Landing Gear Lights 56

SUMMARY OF RECOMMENDATIONS 57

Navigational Systems 57

Communication Systems 59

Radar Systems 59

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Flight Control Systems 59

Additional Recommendations 60

BIBLIOGRAPHY 61

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LIST OF FIGURES

Figure 1. KC-135 Conceptual Cockpit Simulator 5

Figure 2. EHSI Display 6

Figure 3. EADI Full Compass Rose Display 9

Figure 4. EADI Full Compass with INAV Bearing 10

Figure 5. EADI Arc Display with Radar Off 12

Figure 6. EADI Map Display with 5-mile Range 14

Figure 7. EADI Map Display with Waypoints 15

Figure 8. Overhead Control Panels 17

Figure 9. Radar Control Panel 22

Figure 10. WCA Display Between CDUs 24

Figure 11. Control Display Unit 25

Figure 12. Sample Symbols 26

Figure 13. Index Page 31

Figure 14. Power 1 Page 31

Figure 15. Power 1 Page with Confirmation Message 32

Figure 16. Power 2 Page 32

Figure 17. Start 1 Page 33

Figure 18. Start 2 Page 33

Figure 19. Loader Page 34

Figure 20. TOLD Page, Take Off Mode 35

Figure 21. TOLD Page, Landing Mode 35

Figure 22. Timers Page 35

Figure 23. Lock/Zeroize Page 36

Figure 24. Communications (COM) Page 37

Figure 25. UHF1 Control Page 38

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Figure 26. UHF1 Presets Page 38

Figure 27. VHF Control Page 39

Figure 28. VHF Presets Page 40

Figure 29. HF Control Page 40

Figure 30. HF Channels Page 41

Figure 31. Navigation Page 41

Figure 32. VOR/LOC1 Presets Page 42

Figure 33. IFF Page 43

Figure 34. IFF Mode 4 Page 44

Figure 35. Integrated Navigation (INAV) Page 45

Figure 36. Global Positioning System (GPS) Page 45

Figure 37. Inertial Navigation System 1 (INS1) Page 46

Figure 38. INS1 Update Page (Overfly Mode) 47

Figure 39. INS1 Update Page (VORTAC Mode) 47

Figure 40. Flight Plan (FPLN) Page 48

Figure 41. FPLN Page After Down Scrolling 49

Figure 42. "Direct To" Function 49

Figure 43. Edit Page 50

Figure 44. FMS Approach Page 50

Figure 45. Entering FMS Waypoints into Flight Plan 51

Figure 46. Waypoint Page 51

Figure 47. Hold/Rendezvous Orbit Page 52

Figure 48. Hold/Rendezvous Rendezvous Page 53

Figure 49. Hold/Rendezvous Intercept Page 53

Figure 50. Remote Readout Unit 55

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ABBREVIATIONS AND ACRONYMS

A/A	Air-to-Air
AAR	Air-to-Air Receive
AATR	Air-to-Air Transmit and Receive
ACC	Accuracy
ACT	Active
ADI	Attitude Director indicator
ADV	Advance
AFB	Air Force Base
AFWAL	Air Force Wright Aeronautical Labs
AGL	Above Ground Level
ALN	Alignment
ALT	Altitude
AM	Amplitude Modulation
AMP	Avionics Modernization Program
AOA	Angle of Attack
APP	Approach
APPR	Approach
ARPT	Airport
ASD	Aeronautical Systems Division
ATCA	Advanced Tanker/Cargo Aircraft
AUD	Audio
AUTO	Automatic
BALT	Barometric Altitude
BEACN	Beacon
BIT	Built-in Test
BNCO	Beacon Code
BRG	Bearing
CDU	Control Display Unit
CEP	Circular Error Probability
CLR	Clear
COM	Communication
CRS	Course
CRT	Cathode Ray Tube
CSEF	Crew Station Evaluation Facility
CTL	Control
CW	Continuous Wave
DAT	Data
DCA	Drift Angle
DEG	Degrees
DEGRAD	Degraded
DEV	Deviation
DF	Direction Finder
DH	Decision Height
DIR	Direct
DME	Distance Measuring Equipment

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D/M/Y	Day/Month/Year
DTA	Data
EADI	Electronic Attitude Director Indicator
EHSI	Electronic Horizontal Situation Indicator
ELEV	Elevation
EMER	Emergency
EMERG	Emergency
ENAB	Enable
ENECH	Human Factors Branch
ERR	Error
ET	Elapsed Time
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FLT	Flight
FMS	Flight Management System
FSA/CAS	Fuel Savings Advisory/Cockpit Avionics System
FSK	Function Select Key
ft	Feet
FPLN	Flight Plan
GCS	Ground Clutter Suppression
GPS	Global Positioning System
G/SLOPE	Glideslope
GSP	Ground Speed
GSPD	Ground Speed
GWT	Gross Weight
HDG	Heading
HF	High Frequency
HLD	Hold
HSI	Horizontal Situation Indicator
IAF	Initial Approach Fix
IAS	Indicated Air Speed
ICAO	International Civil Aviation Organization
IDENT	Identify/Identification
IDX	Index
IFC	Instrument Flight Center
IFF	Identification Friend or Foe
INAV	Integrated Navigation
INBND	Inbound
INIT	Initial/Initialization
INS	Inertial Navigation System
INTCPT	Intercept
kts	Knots
L	Left

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LAT	Latitude
LD	Load
LD	Lower Data
LOC	Localizer
LONG	Longitude
LSK	Line Select Key
LT	Light
LV	Lower Voice
M	Mode
MAN	Manual
MFD	Multi-Function Display
MIC	Microphone
MLS	Microwave Landing System
MMS	Mission Management System
MOA	Memorandum of Agreement
MOA	Military Operating Area
MSN	Mission
NAID	Navigation Aids
NATO	North Atlantic Treaty Organization
NAV	Navigation
nm	Nautical Miles
NORM	Normal
OFLY	Overfly
OFST	Offset
PRE	Preset
PSN	Position
PWR	Power
R	Receive
R	Right
RA	Radar
RAD	Radiation
RALT	Radio Altitude
RDR	Radar
RDU	Remote Display Unit
RDY	Ready
REC	Receiver
RNG	Range
RPLY	Reply
RRU	Remote Readout Unit
RTN	Return
RZ	Rendezvous
SAC	Strategic Air Command
SATS	Satellites
SDB	Directorate of Bomber and Tanker Programs

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SEL	Select
SIF	Selective Identification Feature
SON	Statement of Need
SPO	System Program Office
SQL	Squelch
STAT	Status
STB	Stabilization
STBY	Standby
STR	Steering
SYS	System
TACE	Tanker Avionics Aircrew Complement Evaluation
TACAN	Tactical Air Navigation
TAS	True Air Speed
TCN	TACAN
TM	Time
TOLD	Take Off and Landing Data
TR	Technical Report
T/R	Transmit and Receive
TR+G	Transmit/Receive and Guard
TST	Test
TTG	Time-to-Go
TTI	Time to Intercept
UD	Upper Data
UHF	Ultra High Frequency
UPDT	Update
UTC	Universal Coordinated Time
UV	Upper Voice
VHF	Very High Frequency
VOL	Volume
VOR	VHF Omnidirectional Radio
VORTAC	VHF Omni Range and TACAN
Vr	Rotate Speed
Vs	Stall Speed
VV	Vertical Velocity
VVI	Vertical Velocity Indicator
WCA	Warning/Caution/Advisory
WX	Weather
WPTS	Waypoints
WYPT	Waypoint
XFR	Transfer

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INTRODUCTION

The USAF currently foresees the continuing need for the KC-135 aircraft fleet and, consequently, has embarked on an avionics modernization program. The Strategic Air Command (SAC) issued a Statement of Need (SON, 1987) addressing its need for modernizing the KC-135 cockpit avionics. SAC stated the avionics systems currently installed need updating since a large percentage of the current avionics are late 1950s and early 1960s technology (e.g., vacuum tubes, mechanical analog displays). Consequently, the outdated technology has degraded the efficiency, reliability, maintainability, and safety of the KC-135 mission.

The Avionics Modernization Program (AMP) represents a shift in philosophy from reacting to urgent deficiencies to planning for anticipated requirements. The long-range goal of AMP is to develop a systematic time-phased avionics integration by means of modification blocks (Mod Blocks) that will ensure all avionics upgrades are installed in a manner that will optimize follow-on upgrades. This integration plan emphasizes the use of modern technologies while maintaining commonality with other Air Force weapon systems.

Current technology allows the KC-135 to be updated with avionics that have significantly higher levels of reliability and maintainability, thereby reducing life-cycle costs and increasing mission reliability. An integrated avionics system can also allow for increases in mission management efficiency and automation, simplified crew interfaces, as well as enhanced navigation, and reductions in overall crew workload. Accordingly, the reduction of the current crew configuration (pilot, copilot, navigator, and boom operator) to that of a crew with no navigator might be feasible resulting in an additional savings in manpower costs.

The possibility of a KC-135 crew reduction has also been addressed several times in the past. Geiselhart, Schiffler, and Ivey (1976) conducted a series of flight tests with dual Inertial Navigational Systems (INSs) installed aboard a test aircraft. They concluded workload was too excessive for the exclusion of the navigator. Schiffler, Geiselhart, and Ivey (1976) reviewed task analysis documents and performed flight tests before similarly concluding that a four-person crew was necessary with the available equipment.

However, other efforts in other aircraft have shown that crew reduction can be accomplished effectively. For example, Schiffler, Geiselhart, and Griffin (1978) used flight tests to demonstrate the C-141 aircrew could be reduced from its crew of five to four without significant mission degradation. Accordingly, the C-141 aircrew was reduced in size and currently has no navigator on board. In 1981, Barbato, Sexton, Moss, and Brandt used a KC-135 cockpit design study to determine avionics control and display criteria needed to successfully accomplish a mission. Their study used complete state-of-the-art systems to conclude a KC-135 crew reduction was feasible given a completely updated and redesigned cockpit. Madero, Barbato, and Moss (1981) used the previous study and subsequent system evaluations to develop a composite configuration that was evaluated in a full mission simulation. They

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concluded the KC-135 mission could successfully be accomplished using a three-person crew. Although, the studies cited indicate mixed results, the more recent studies call for a completely redesigned cockpit as necessary for mission accomplishment given a crew reduction.

CSEF Tasking

The Crew Station Evaluation Facility (CSEF) operated by the Aeronautical Systems Division's Human Factors Branch (ASD/ENECH) conducts real time engineering simulation evaluations in support of weapons system development. System Program Offices (SPOs) use the CSEF as an engineering tool for quantitatively and qualitatively assessing the flight crew's performance as a function of crew complement, crew station configuration, and operational mission.

As part of the KC-135 Avionics Modernization Program, a Memorandum of Agreement (MOA) between the Directorate for Bomber and Tanker Programs (ASD/SDB) and the CSEF was signed in October 1990. The CSEF was tasked with exploring the feasibility of a reduced crew size by developing an advanced cockpit design and avionics update, then demonstrating the feasibility of that design in a full mission simulation environment. The CSEF accomplished this tasking in a three phase effort: (1) function analysis phase (Vol. 1), (2) cockpit design phase (Vol. 2), and (3) test and evaluation phase (Vol. 3). The task analysis, design, and evaluation efforts were, by intent, separate efforts conducted to identify items of interest such as workload bottlenecks, safety-critical tasks, etc.

Function Analysis Phase

The function analysis phase focused on breaking up tasks into categories and describing the who/what/where/why/how of each function/task (Ward, Dudley, Hassoun, Hughes, Rueb, Conroy; 1991). Tasks were broken up into duties, large segments of work performed by an individual crew member (e.g., celestial navigation) or into tasks, distinct work activities carried out for a specific purpose (e.g., alter heading line entry in the navigator's log). Additionally, high workload segments of the mission were identified to aid the design team in determining areas to focus on. This information was gathered via literature searches, questionnaires, interviews, and observations. Based upon the information gathered, a working group composed of two pilots, two navigators, two human factors engineers, and one industrial psychologist recommended how the various duties and tasks should be reallocated and/or automated (functional requirements). The recommendations of this phase were used during the design phase for determining which systems/displays should be used.

Cockpit Design Phase

This phase focused on designing a two-person conceptual cockpit to eliminate the navigator from the cockpit. The design effort used the functional requirements identified above supplemented by a number of other

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sources. User/customer requirements were a major consideration, while vendors of Cockpit Display Units, flight computers, etc., were also consulted to ensure current innovative technologies were considered. In addition, several of the design team members were experienced participants in earlier KC-135 (and other aircraft) advanced developmental projects.

The final design used a SAIC developed approach as its baseline with significant modifications implemented by the CSEF team. These modifications were based upon sound human engineering practices and comments from preliminary "quick looks", where several KC-135 crew members were shown different design configurations and asked to comment and make design and location recommendations. These items were provided to the test and evaluation team for their consideration.

This report describes the method and results of the design effort, and provides functional, crew information and control requirements for each major aircraft system. Design recommendations, lessons learned, trade-offs and other considerations are also included to provide guidance to SPO engineers and managers when developing human factors and crew station requirements for KC-135 improvement programs, especially those involving crew reductions. The approach used to develop the cockpit design for simulation, including the ground rules and assumptions for this development, is also discussed. A goal of the design team was to provide rationale and an audit trail for all design decisions made, while allowing sufficient flexibility in implementing improvements and suggestions. This report is Volume 2 of a 3-volume technical report.

Test and Evaluation Phase

During this phase, the CSEF personnel attempted to demonstrate the feasibility of the two-person conceptual cockpit developed during the design phase (Rueb, Barnaba, Hassoun, 1991). The final design configuration was demonstrated in a simulated environment using operational aircrews. Each aircrew flew four different simulation missions with varying levels of crew workload. Pilot performance data, as well as subjective questionnaires and oral responses, were collected. Given the feasibility of the two-person cockpit configuration, this phase would also determine the functional requirements necessary to keep workload levels manageable for successful mission accomplishment. A final objective was to attempt to identify possible deficiencies and improvements to the conceptual baseline design.

DESIGN DESCRIPTION

After conducting a search of current hardware that could fill the automation and reallocation needs of this demonstration, a conceptual simulator cockpit design was developed which had heavy emphasis on Rockwell/ Collins avionics and system features. The design baseline, as modified for the KC-135, assumed the use of a color weather radar, dual INS, and Global Positioning System (GPS). Further assumptions were that celestial navigation would not be required; all mode 1, 2 and 4 Selective Identification Feature

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and Identification Friend or Foe (SIF/IFF) settings were assumed to be set and correct; current Federal Aviation Administration (FAA) and SAC regulations and directives were followed; and the Fuel Savings Advisory/Cockpit Avionics System (FSA/CAS) would not be integrated.

A picture of the conceptual cockpit baseline design is shown in Figure 1. The cockpit included an Electronic Attitude Director Indicator (EADI) and an Electronic Horizontal Situation Indicator (EHSI) for both the pilot and copilot with associated controls. A Mission Management System (MMS) was interfaced through pilot and copilot Control Display Units (CDUs). In addition, a color weather radar could be overlaid on the EHSI; a digital Warning, Caution and Advisory (WCA) display was provided with master caution lights; and a Remote Readout Unit (RRU) was provided for quick access to communication and navigation information.

Electronic Attitude Director Indicator (EADI)

Three possible EADI display designs were considered for the CSEF conceptual cockpit. The first was being considered by the Instrument Flight Center (IFC) for standardization into bomber and tanker cockpits. The display resembled a head-up display presentation in a head-down location and incorporated a dual cue flight director. The second was a three-dimensional display designed for potential application to the F-15 and other fighter aircraft. The third was a Rockwell/Collins baseline design pictorially similar to the FD-109 currently in the C/KC-135 aircraft. The Collins design was unanimously selected by eight of eight KC-135 pilots during a pre-study "quick look" analysis. The pilots stated the IFC design was too cluttered and the F-15 design provided a range much greater than needed.

The EADI (Figure 2) was a 5" by 5" color cathode ray tube (CRT) with the standard attitude director indicator (ADI) convention of blue for sky and brown for ground. The EADI location was not changed from the current analog ADI. There were many other functions overlaid in white, unless otherwise stated, onto this display such as:

1. **Horizon Line and Pitch Scale:** The horizon line was a solid line representing the ground/sky separation. The pitch scale used 10-degree increments with 5-degree hash marks.

    a. A 2-degree of radius circle appeared on the horizon line for climb and descent cues. This cue was added based on pilot recommendations as an aid for maintaining level flight.

    b. A short dotted line appeared at 8 degrees nose high as a takeoff rotation guide when the gear were down, disappearing when the gear were up. Again, this aid was added based on pilot recommendation.

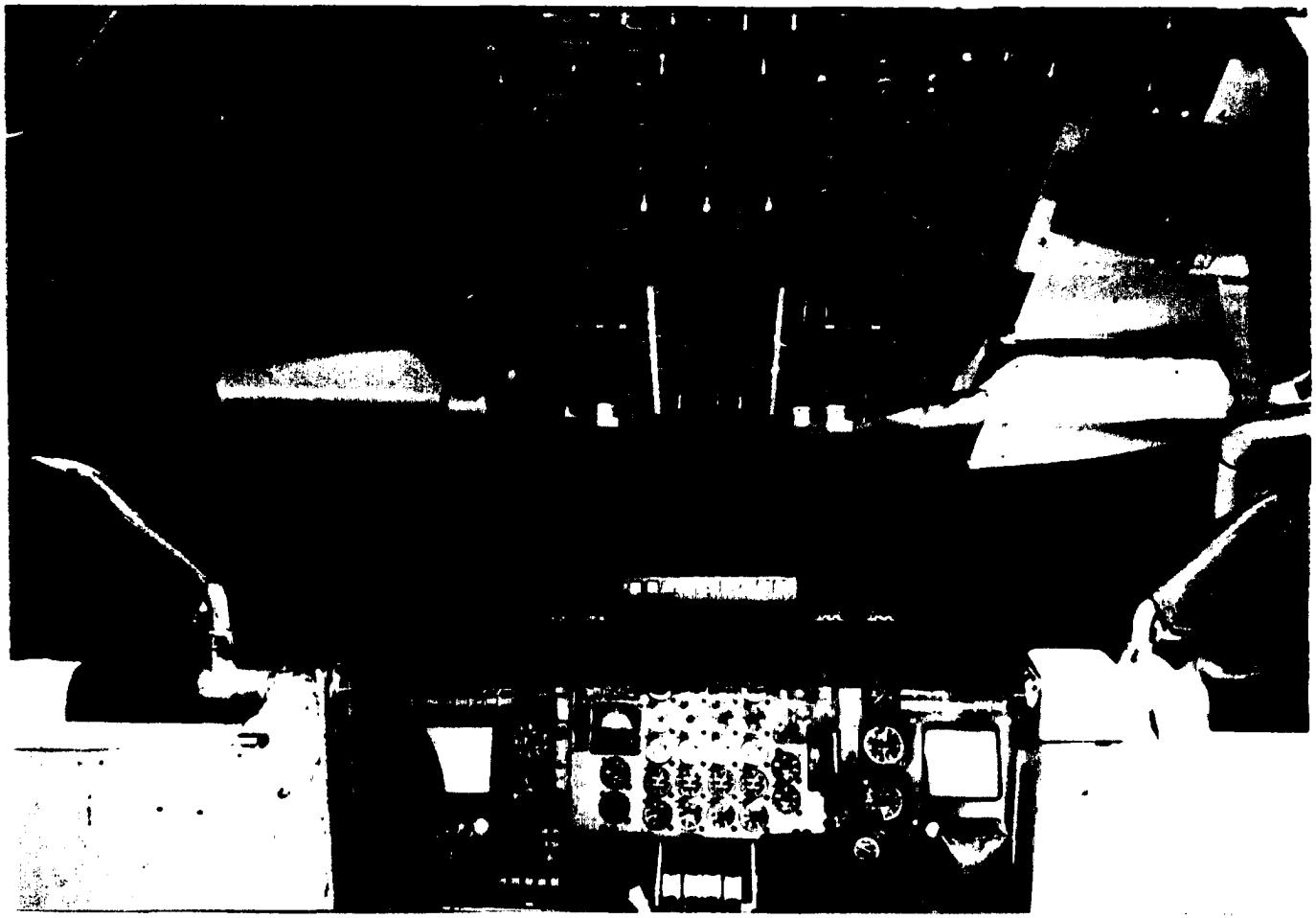

Figure 1. KC-135 Conceptual Cockpit Simulator

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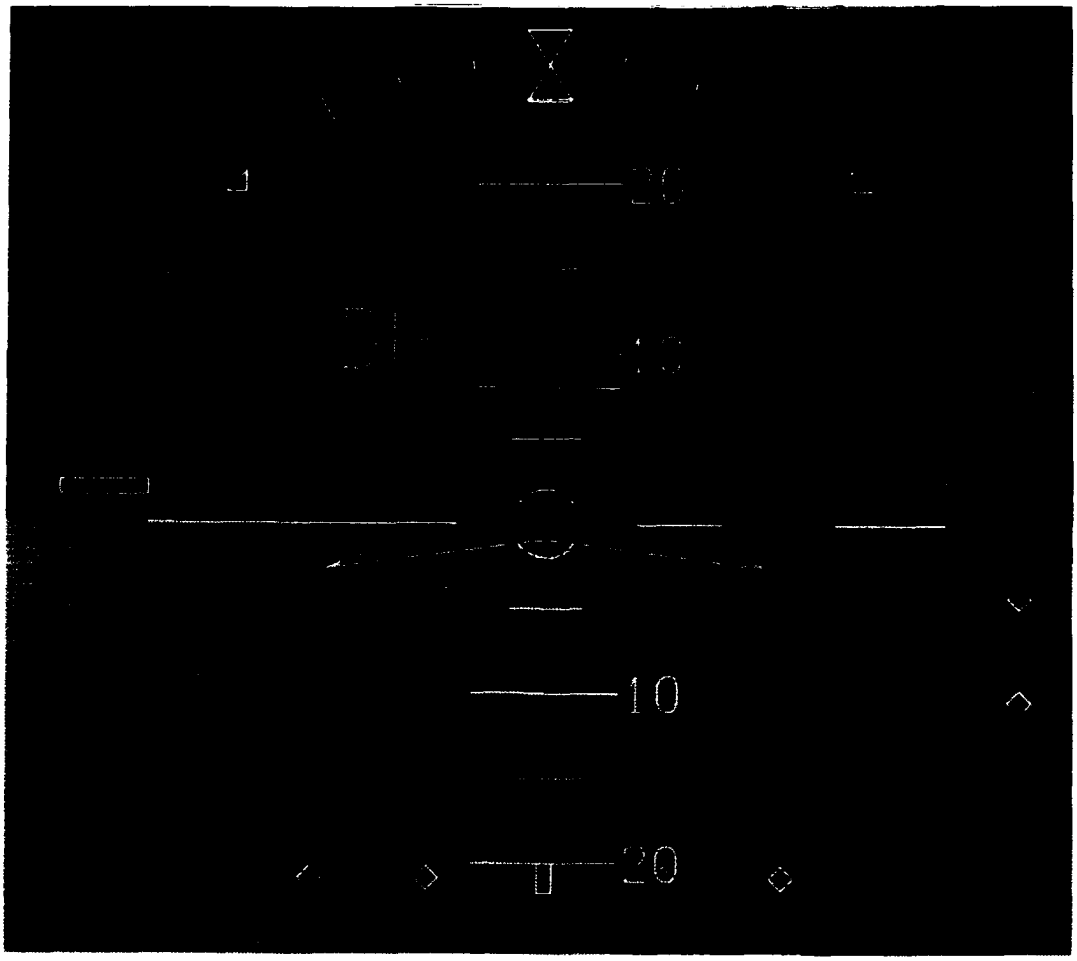

Figure 2. EHSI Display

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2. **Roll Scale and Roll Pointer:** The scale was an arc of hash marks along the top edge of the "ball," with marks representing 10, 20, 30, and 60 degrees of bank (left and right) and a small triangle at 45 degrees. The aircraft roll was indicated by an upward pointing triangle. Zero degree of roll was indicated by a stationary, downward pointing triangle causing an hourglass shape to be formed when the aircraft was at zero degree bank (see Figure 2).

3. **Aircraft Symbol:** The aircraft attitude was represented by a black elongated wedge, outlined in yellow.

4. **Command Bars:** Solid, magenta command bars, driven by the flight director, provided the pilot with the roll command necessary to acquire and maintain the selected heading, course to waypoint, or course across a tactical air navigation (TACAN) or VHF omnidirectional radio (VOR) station. They also provided localizer tracking and pitch commands to maintain selected attitude or altitude or to track and maintain a glide slope. The command bars were filled in, as opposed to outlined, for better visibility and closer resemblance to the analog instrument.

5. **Vertical and Lateral Deviation Displays:** The vertical deviation display was a scale on the right side of the CRT used for glideslope indication. The display provided diamonds representing every 0.25 degrees of vertical deviation and a rectangular center point. The vertical deviation pointer was two green or yellow, concentric, hollow triangles. The vertical deviation display only appeared when localizer was selected and the signal was valid. The lateral/course deviation was displayed at the bottom, using 5-degree increments (diamonds) with a center point (except in localizer where 0.75 degree increments were used). The lateral deviation pointer varied color and shape according to the current navigation mode selected. The color of the pointer was the same as the primary course arrow (described below for the EHSI), while the shape resembled a small basketball or, when integrated navigation (INAV) was selected, a white "saint's cross" (see head of bearing pointer in Figure 4).

6. **Indicated Air Speed (IAS):** IAS in knots appeared in the top left corner of the display in a green digital format (Figure 2 "I170"). (Note: The green/blue contrast in Figure 2 is not representative of the actual color CRT.) This feature was added based on pilot comments.

7. **Angle of Attack (AOA):** The AOA was presented, also in green, just below the IAS (Figure 2 "α0.57"). The value was normalized from zero to one based on percentage of lift available. This feature was added based on pilot comments.

8. **Barometric Altitude (BALT):** BALT was presented in the top right corner of the display in green digital format rounded to the nearest

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10 feet to prevent jitter in the final digit (Figure 2, "350"). This feature was added based on pilot comments.

9. **Vertical Velocity (VV):** VV was presented, also in green, just below the BALT using the same approach (Figure 2, "0"). This feature was added based on pilot comments.

10. **Decision Height (DH) Annunciator and Indicator:** The decision height setting was shown digitally in cyan in the bottom right corner of the display (Figure 2, "DH 200"). A relatively large "DH" annunciation appeared in yellow in the upper left quadrant of the display when the aircraft altitude was lower than the selected decision height setting.

11. **Radio Altitude (RALT):** RALT was presented in the lower right corner above the decision height indication, in green digital format, when the aircraft was below 2500' above ground level (AGL) (Figure 2, "141").

Electronic Horizontal Situation Indicator (EHSI)

The EHSI was a 5-inch by 5-inch color CRT display positioned in the same location as the current horizontal situation indicator (HSI). This size of display was chosen over a smaller display (i.e., 3.5-inch by 3.5-inch) due to pilot preference in the quick-look analysis. The pilots stated that the larger display allowed information to be placed in the corners while still avoiding any interference from the primary information and the yoke. The EHSI was partially controlled by the Display Control Panel. Integrated into the EHSI display was the color weather radar display. The radar display was mainly controlled by the radar control panel.

1. **Display Formats:** There were three selectable presentation formats for the EHSI display: the HSI presentation, the arc presentation and the map presentation.

   a. HSI presentation: This format was a full compass rose (360°) presentation (Figures 3 and 4). Overlaid on this compass were the following:

      1) Primary Course Indicator: The primary course was represented by a segmented arrow. The arrow was green when the source was from the operator's radio and under the operator's control for VOR or TACAN (Figure 3). It was yellow when the operator did not have direct control over that navigation aid (the pilot controlled NAV 1 settings and the copilot controlled NAV 2 settings) (Figure 4). It was white when the INAV solution for navigation was selected. Also included were:

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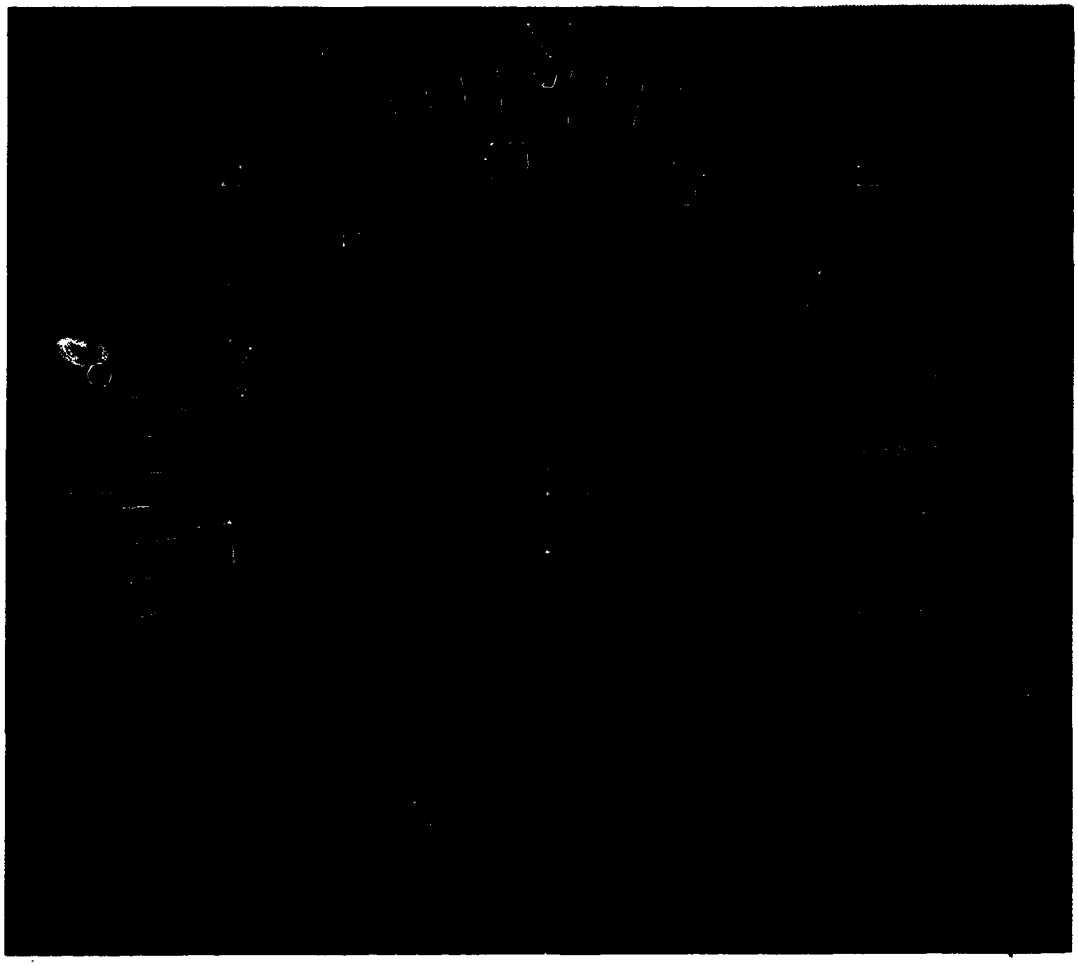

Figure 3. EADI Full Compass Rose Display

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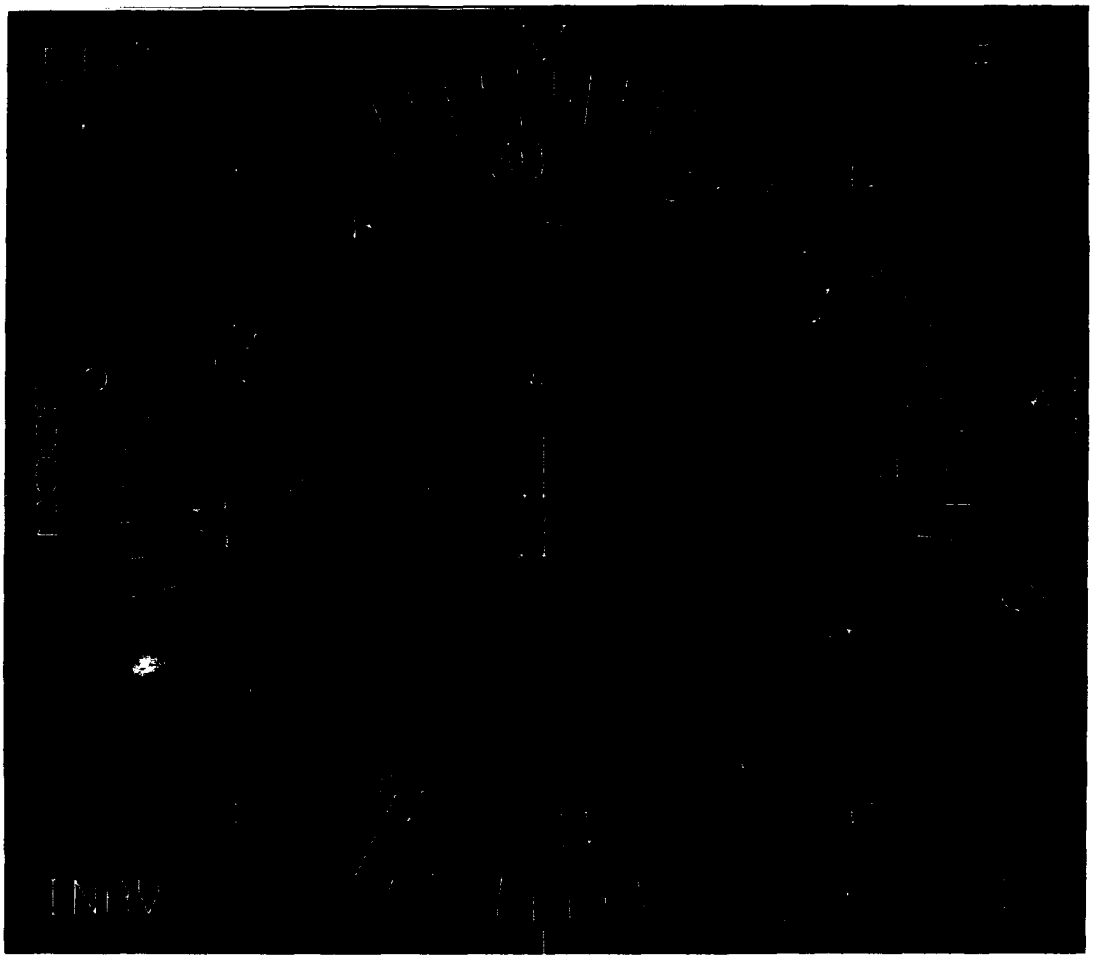

Figure 4. EADI Full Compass with INAV Bearing

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a) To-From Indicator: The to-from indicator was a small triangle on the centerline of the primary course indicator that pointed in the direction of the selected navigation aid (Figure 3).

b) Course Deviation Indicator: The course deviation indicator had small white diamonds every 5 degrees (0.75 degree for localizer deviation) off course of selected navigation aid. Midsection (segmented section) of primary course arrow showed deviation (Figure 3).

2) Secondary Course and Course Deviation Indicator: The secondary course (or preset) was represented by an outlined cyan (light blue) arrow of dashed line (= = =)(Figure 3). Deviation was shown again using the midsection of the arrow, in this case, without a scale.

3) Bearing Pointer: The bearing pointer was a thin magenta arrowhead with a tail of equal size at the other end (Figure 3). If INAV was selected as the bearing source, the head of the arrow would be a "saint's cross" (Figure 4).

4) Heading Marker: The heading marker was represented by a pair of magenta rectangles (captain's bars) with the space between them being the desired heading. The heading bug was filled in solid, instead of outlined, for better visibility.

5) Vertical Deviation Indicator: This indicator appeared on the EHSI when localizer was selected and the signal was valid. Its appearance is the same as that for the EADI (Figure 4).

b. Arc presentation: This format was an expanded compass segment, approximately 40 degrees left and right of heading, across the top of the display with the aircraft symbol centered at the bottom (Figure 5). Overlays on this arc were:

1) Primary Course and Course Deviation Indicator: As described for the HSI presentation above, without the to/from indicator.

2) Bearing Pointer: As described for the HSI presentation above. If the bearing was off of the 80-degree arc, the bearing was displayed digitally in magenta next to the bearing indicator, described on pg. 16 (Figure 5, "BRG 204").

3) Heading Marker: As described for the HSI presentation above. If the heading marker was off the 80-degree arc, the marker remained at the nearest edge of the arc with the actual heading presented digitally directly adjacent (Figure 5, "269").

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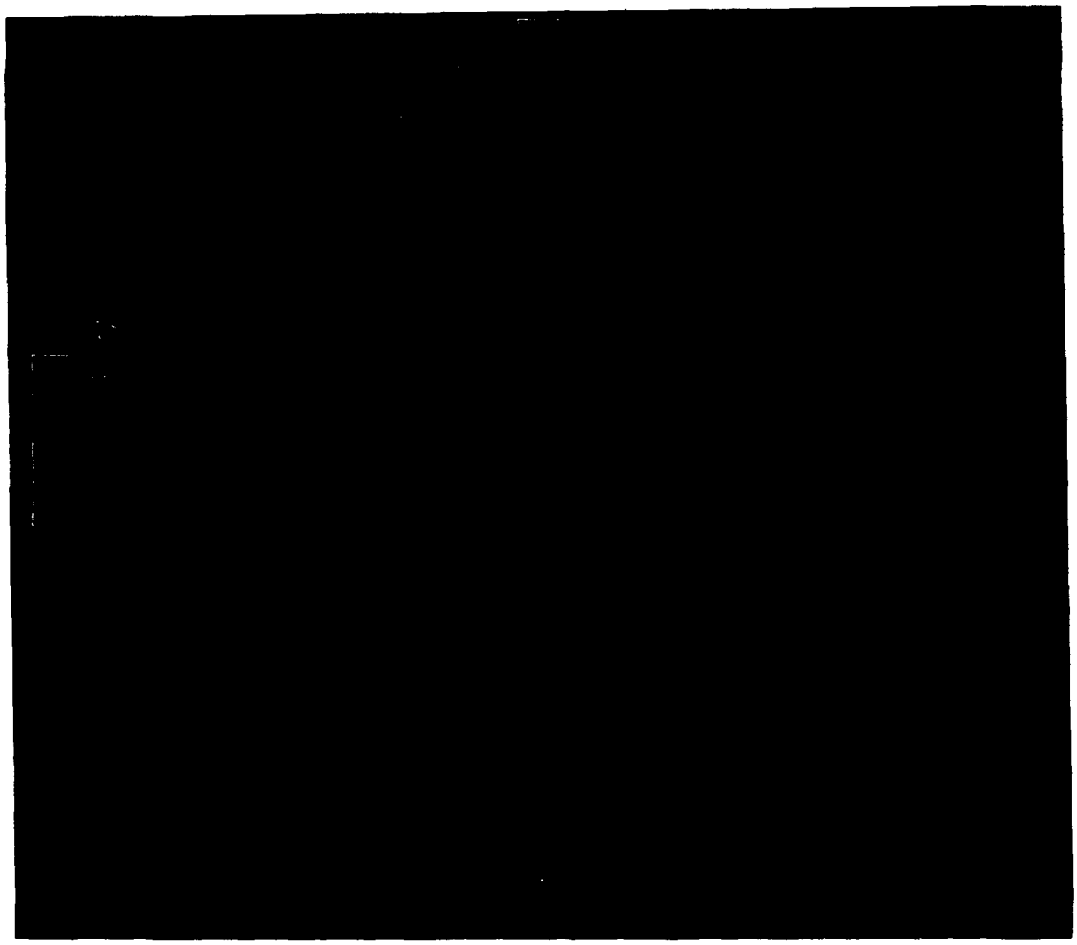

Figure 5. EADI Arc Display with Radar Off

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4) Range Indication and Radar Tilt: Several ranges were selectable from the EHSI/EADI control panel without radar or from the radar control panel when radar was active. A cyan arc appeared midrange and was the half-range scale marker. The half-range distance was digitally labeled at its right end (Figure 5, "37.5"). The compass arc represented the full range. The marker was hash marked when not in radar mode (Figure 5) and solid when in radar mode (Figures 6 and 7). Presented digitally below the midrange distance, on the right end of the arc, was the tilt angle of the radar (Figure 7, "-3.3"). In the 5-mile range, a range marker appeared at 1-mile intervals as an aid for cell departure, join-up and rendezvous activities (Figure 6).

5) Weather radar: Weather information was displayed in this EHSI arc format when selected. Green represented light rain, yellow was a thunderstorm of light to moderate intensity and red was a thunderstorm of moderate to severe intensity (Figure 7).

6) Radar Mode: The mode of the radar, as selected on the radar control panel, was displayed on the left end of the midrange arc in cyan (Figures 6 and 7, "MAP" and "NORM").

7) Beacon and Skinpaint: The location of the receiver aircraft was displayed, depending on the radar mode, via beacon or skinpaint. The beacon display is shown in Figure 7 (receiver has a 1 - 1 - 1 setting on the beacon) and the skinpaint is shown in Figure 6 (white mark at 4 miles and 307 degrees).

c. Map Presentation: This presentation (Figures 6 and 7) was similar to the ARC presentation. However, VOR, TACAN, waypoint, and/or airport symbols could have been overlaid in proper range and bearing position with respect to the airplane symbol and selected range (Figure 6). The tuned TACAN station was highlighted by presenting its symbol in magenta as opposed to white when navigation aids were displayed (Figure 6). The preplanned course through the waypoints was shown with a solid white line. Offsets to that course, when selected, were shown with a dotted white line (Figure 7). Also shown were planned orbit and rendezvous symbols and military operating areas (MOAs) (Figure 7). The primary and secondary course arrows were not displayed in the map mode.

2. **Digital Displays:** Displayed in the upper left corner of the EHSI was the distance to the selected navigation aid (Figure 6, "16.8"). Displayed in the upper right corner was the current course (Figure 6, "309"). By displaying the course indicator in the top right corner

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Figure 6. EADI Map Display with 5-mile Range

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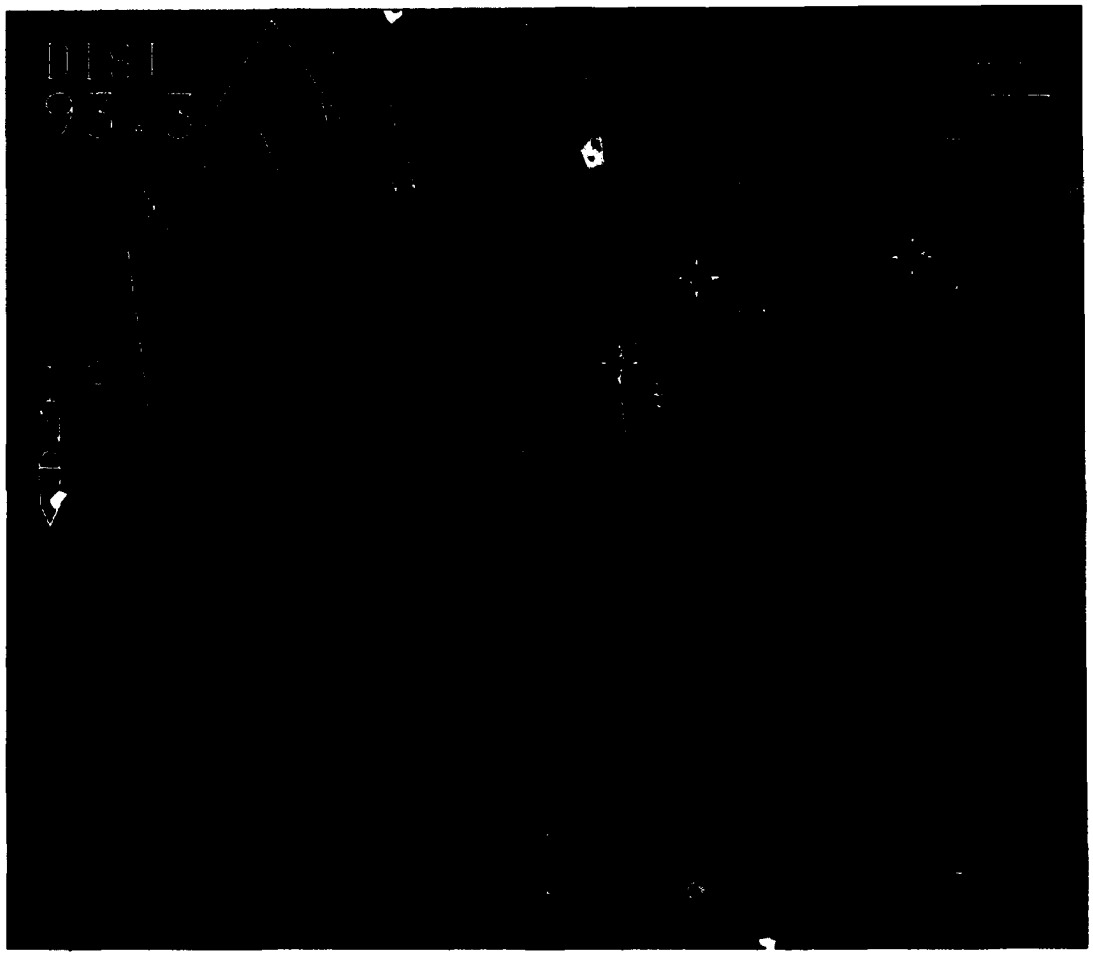

Figure 7. EADI Map Display with Waypoints

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of the display, as opposed to the bottom right, the bottom right could then be used to display time to go, wind direction/speed/drift angle, ground speed/drift angle, true air speed or elapsed time.

3. **Primary Navigation Aid Indicator:** The primary navigation aid was indicated vertically along the left side of the display (Figure 6, "INAV"). The same color conventions used for the primary course arrow applied to these text displays. The indicator was green when the source was from the operator's radio and under the operator's control for VOR or TACAN (Figure 3). It was yellow when the operator did not have direct control over that navigation aid (Figure 4). It was white when the INAV solution for navigation was selected (Figure 6). The various options for display were TACAN (TCN), Localizer (LOC1, LOC2), VOR (VOR1, VOR2), and INAV.

4. **Bearing Indicator:** The navigation aid for bearing information was shown in the bottom left corner of the display using the same color conventions as the primary navigation aid indicator. In the arc and map modes, a bearing off of the compass arc was also presented digitally in this location. The same navigation aids were available for bearing as for primary/secondary navigation.

EHSI/EADI Display Control Panel

The EHSI/EADI display control panel, shown in Figure 8, was one of three added panels located in the overhead control panel of both the pilot and the copilot. This panel, along with the heading course panel, represented the primary means of controlling the main EHSI functions. In addition, the brightness of both displays and the decision height setting on the EADI were controlled from this panel. The display control panel had the following control functions:

1. **HSI-ARC-MAP Format Switch:** This three position rotary switch was used to select the following display formats:

   a. HSI: The EHSI full compass rose (360°) format was displayed similar to that of a conventional HSI (Figure 3).

   b. ARC: An expanded compass segment (80°) was shown across the top of the display with the aircraft symbol centered at the bottom. Weather radar could also be displayed in this format (Figure 5).

   c. MAP: An expanded compass segment was displayed with VOR and/or waypoint symbols for active course in proper range and bearing position with respect to the aircraft symbol and selected range. Weather radar information, navigation aid locations and airport locations could be displayed in this format (Figure 6).

2. **Course Active (CRS ACT) Button:** The course active button was used with the select/range (SEL/RNG) knob (top right of panel) to control

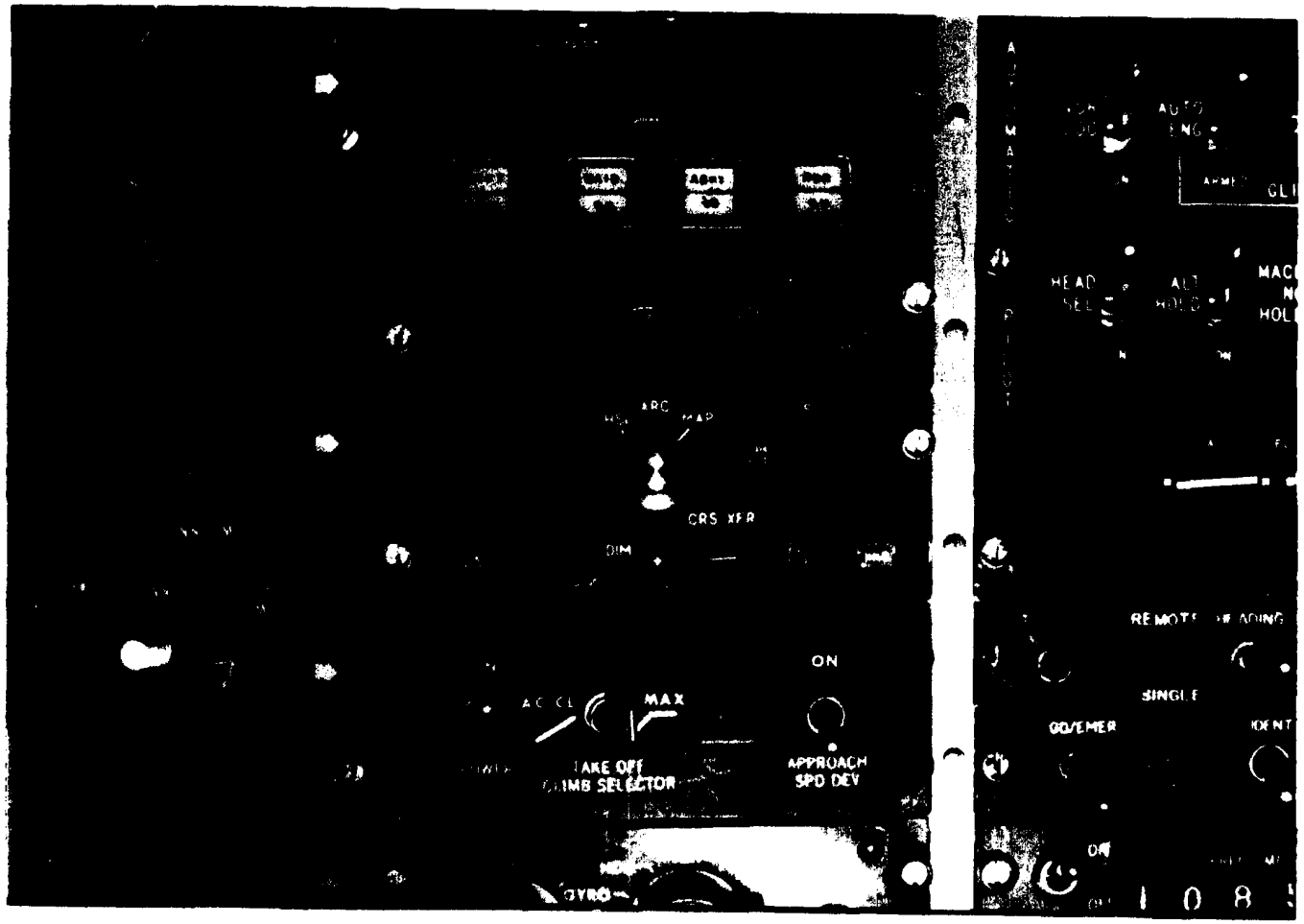

Figure 8. Overhead Control Panels

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the selection of navigation sensors to be connected to the EHSI active selected course arrow and lateral deviation bar. Pressing the CRS ACT button displayed the current navigation sensor on the left side of the display. If this display was already present, the next press selected the "menu" mode. In menu mode, the last selected navigation sensor appeared in a white box at the left center of the EHSI (Figure 5, "VOR1"). Rotating the SEL/RNG knob at that time selected the available navigation sensors and caused the sensors to appear in the white box. The possible selections were INAV, VOR1, LOC1, VOR2, LOC2 and TCN. When the desired sensor was displayed, pressing the button again selected that sensor as the active course navigation sensor; the white box disappeared. If the CRS ACT button was pressed twice without rotating the SEL/RNG knob, the sensor display and course arrow were removed from the EHSI.

3. **Select/Range (SEL/RNG) Knob:** Rotating this knob selected available navigation sensors (SEL function discussed in 2 above) or ranges (RNG function) when a map or arc format was displayed and radar was not active.

   a. SEL: When a Navigation (NAV) "menu" was selected via the CRS ACT, Course Preset (CRS PRE), or Bearing (BRG) buttons, rotating the SEL/RNG knob sequenced through the available navigation sensors as applicable to the button pressed.

   b. RNG: When the ARC or MAP format was selected, the weather radar mode was not selected, and the CRS ACT or CRS PRE sensors were not boxed, rotating the SEL/RNG knob selected the range on the EHSI. Half-scale range was annunciated at the right-hand end of the range arc (hash marked) on the EHSI (Figure 5, "37.5"). Available full scale ranges were 5, 10, 25, 50, 100, 200, and 300 nm.

4. **Course Preset (CRS PRE) Button:** This button controlled the selection of navigation sensors for the EHSI preset course arrow and lateral deviation bar. The navigation sensors available for the preset course were the same as those available for the active course arrow. The CRS PRE selection procedure was the same as the CRS ACT selection procedure. This feature allowed presetting a course and then recalling it by a single press of the CRS PRE button. The preset course was used for reference only. The preset navigation sensor appeared in cyan at the left of the EHSI immediately below the navigation sensor annunciation for the active selected course (Figure 3, "VOR1").

5. **Bearing (BRG) Button:** This button controlled the selection of navigation sensors for the EHSI bearing pointer. Selecting a sensor for the bearing pointer was similar to that just described for selecting the course active and course preset navigation sensor. When the BRG button was first depressed, a magenta bearing pointer

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and a navigation sensor annunciator for the bearing pointer were displayed. The sensor annunciation was in the lower left of the EHSI with the letters BRG, in magenta, above the sensor type (Figure 5, "204").

6. **Course Transfer (CRS XFR) Button:** When the CRS XFR button was pressed, previous course preset information became the active information and the previous active information became the preset and was not displayed.

7. **Decision Height Set (DH SET) Knob:** Rotating the DH SET knob (top left of panel) set the decision height (AGL) displayed in the lower right corner of the EADI (Figure 2, "DH 200"). The setting offered a range of 0 to 2000 ft AGL.

8. **DIM Knobs:** Rotating the DIM knobs changed the intensity of the EADI and/or EHSI (Figure 8). The knobs were concentric and sized so they could be moved together or turned independently. The larger knob controlled the EHSI and the smaller controlled the EADI.

9. **Radar Test (RA TST) and Radar (RDR) Buttons:** The RA TST and RDR buttons on the panel were inoperative for this simulation.

Heading/Course Panel

The heading/course panel, shown in Figure 8, was located directly above the display control panel on the overhead. This panel provided additional interface to EHSI functions, specifically those related to course and heading. This panel had the following control functions:

1. **Course Control (CRS CTL) Button:** Pressing the CRS CTL button allowed the CRS knob to control either the active selected course arrow or the preset course arrow. A small white circle appeared to the right of the active or preset navigation sensor annunciation on the EHSI (Figure 3) to show which course arrow was controlled by the CRS knob. This symbol switched between the active and preset courses with each press of the CRS CTL button.

2. **Course (CRS) Select Knob:** The CRS knob, located on the right side of the panel, controlled the course arrow for the navigation sensor selected by the course active or course preset buttons on the display control panel. The CRS knob included a PUSH CRS DIRECT button that provided a "direct to" function. When pushed, the selected course automatically rotated until the deviation was zero and the selected course was direct to the VOR or TACAN station. The pilot and copilot controls were used independently.

3. **Heading (HDG) Select Knob:** The HDG knob, located on the left side of the panel, controlled the heading cursor (also called "bug" or "captain's bars"). Rotating the HDG select knob positioned the

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heading cursor on the respective EHSI. The heading cursor could also be controlled via a switch on the pilot or copilot yoke. The HDG knob included a PUSH HDG SYNC button that, when pressed, caused the heading cursor to rotate and match the aircraft heading shown under the lubber line on the EHSI. The HDG select knobs and equivalent yoke control could be used independently or synchronously depending on the position of the Single/Dual switch on the remote heading slew panel (single allowed independent, dual allowed synchronous).

4. **Navigation Data (NAV DTA) Button:** Sequentially pressing the NAV DTA button provided a display of TTG (time-to-go), GSP/DCA (ground speed and drift angle), TAS (True air speed), ET (elapsed time) or wind information (direction, speed and drift angle) in the lower right corner of the EHSI. The capability for digital display of wind direction and speed as well as true airspeed was unique to this design.

5. **Elapsed Time (ET) Button:** After ET had been selected via the NAV DTA button, sequentially pressing this button stepped through the modes of the elapsed timer. The timer had three modes: reset, start, and stop. Each time the ET button was pressed, the timer advanced to the next mode in the sequence. Stopping the timer, held the present count on the display until the timer was reset again. After the timer began counting, TTG, GSP/DCA, TAS or wind could be selected via the NAV DTA button without disturbing the ET count.

Map Overlay Panel

The map overlay panel, shown in Figure 8, was located directly above the heading/course panel. The panel consisted of four white lighted push-buttons whose lower half illuminated with a green "on" indication when depressed. The panel was designed to provide the capability of adding to or decluttering the EHSI display by selecting the various options on or off. The radar function was located on this panel because, as well as activating the radar, it determined whether or not the radar presentation was present on the display. A majority of the pilots surveyed preferred the radar control on the map overlay panel rather than on the EHSI/EADI control panel. The four control functions of this panel follow:

1. **Waypoint (WYPT) Button:** When depressed and the EHSI select knob was in map mode, white lines indicating the current and planned course and all waypoints within the range of the current map display were displayed on the EHSI (Figure 7).

2. **Navigation Aids (NAID) Button:** When depressed, TACAN, VOR and VORTAC stations within the selected range were displayed using the TACAN/VOR symbol along with the appropriate three-letter International Civil Aviation Organization (ICAO) identifier. The current selected TACAN station appeared as a magenta symbol while other stations within the selected range were in white (Figure 6).

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3. **Airport (ARPT) Button:** When depressed, all airports in the MMS database, within the selected range, were displayed using the airport symbol and its ICAO identifier (Figure 6, "KMER").

4. **Radar (RDR) Button:** When depressed, the radar switched from standby into transmit mode. This allowed for weather and beacon capability. (Figure 7).

Radar Control Panel

The radar control panel (Figure 9) was located between the pilot and copilot on the center console just aft of the throttle controls. The panel provided the means of controlling the weather radar functions and display. This panel provided some functions relative to a ground mapping capability, which was not developed for the demonstration. The radar control panel reflected an unwanted limitation for the demonstration. The preferred approach, as indicated by the quick look analysis, was to provide independent pilot/copilot control over displayed radar ranges, and separate panels for pilot and copilot. However, time constraints on the design effort resulted in the use of a single panel, centrally located, which provided only one control. The radar control panel had the following functions:

1. **Gain Control Knob:** The left knob controlled enhancement of the radar video target signature. Adjustment was varied to provide the smallest and sharpest returns on the radar.

2. **Tilt Control Knob:** The right knob was used to vary the tilt of the aircraft radar from +10 to -10 degrees. The tilt value was digitally displayed at the right end of the cyan arc (Figure 7, "-3.3").

3. **Radar Range Selection Buttons:** A row of buttons along the bottom of the panel allowed for selection of either 5-, 10-, 25-, 75- or 150-mile radar range displays as described below:

   a. 5: This display provided a 5-mile radar presentation with a solid cyan arc every mile. This range was useful for cell departure and join-up. Since cell operations are performed at 1-mile increments, 1-mile range markers were displayed instead of the half-range scale found on the other ranges (Figure 6).

   b. 10, 25, 75, and 150: A 10-, 25-, 75-, or 150-mile radar presentation with a solid arc at the midrange point. At the right end of the arc, the midrange was digitally displayed (i.e.; 5, 12.5, 37.5 or 75) as well as the current radar tilt angle. The 10-mile range was chosen for its use in cell departure and joinup as well as air refueling operations, the 25- and 75-mile ranges were determined as useful in air refueling and the 75- and 150-mile ranges were useful in identifying and avoiding weather.

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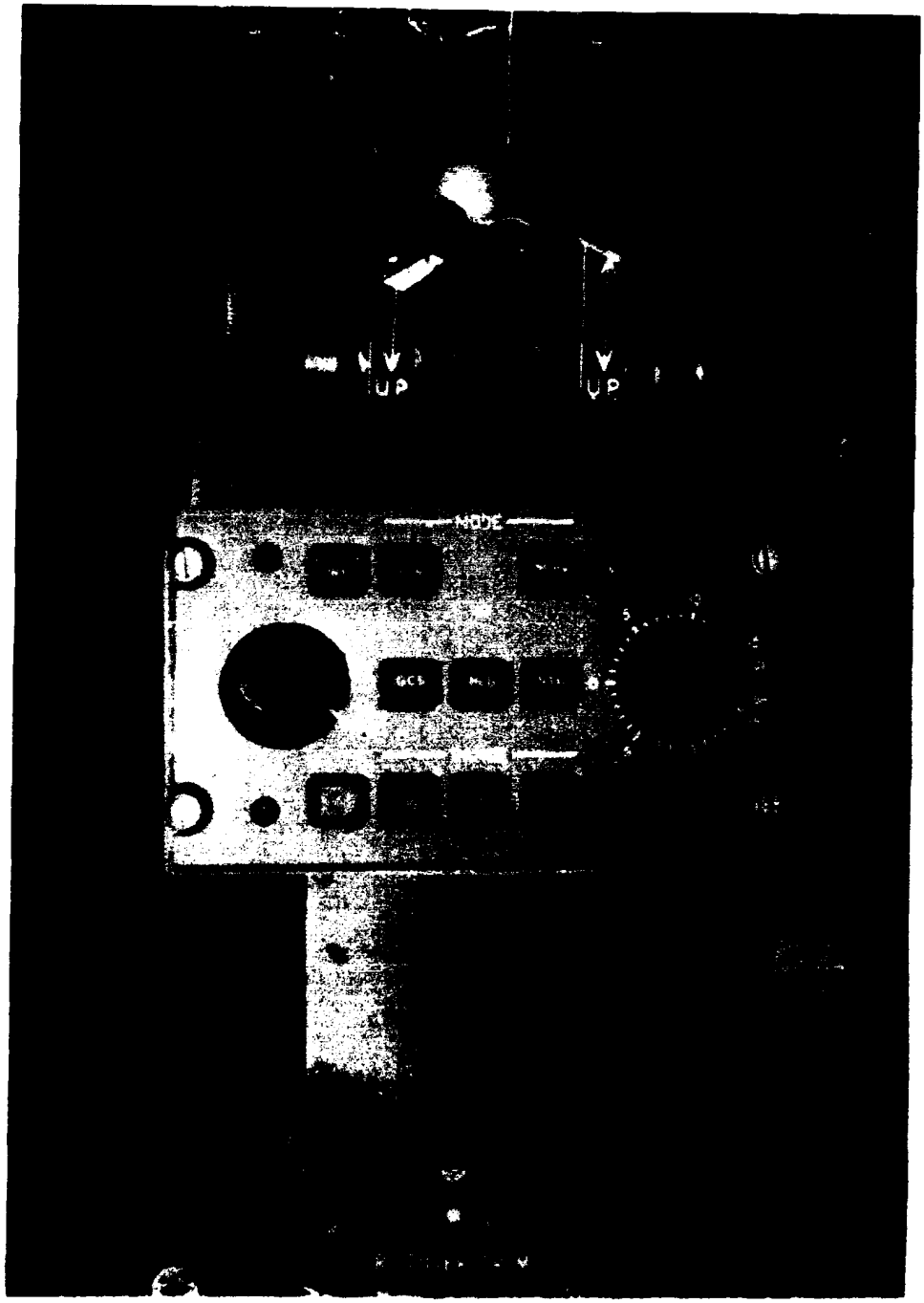

Figure 9. Radar Control Panel

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4. **Radar Mode Selection Buttons:** A row of four buttons along the top of the panel allowed selection of the following modes for the radar:

   a. Normal (NORM) Mode: This mode of operation provided weather radar and beacon capability (Figure 7).

   b. Weather (WX) Mode: This mode provided only a weather radar capability with the option of a much degraded ground mapping capability.

   c. Beacon (BCN) Mode: This mode provided only a beacon capability.

   d. Map (MAP) Mode: This mode provided weather radar, skin painting and an opportunity for a ground mapping capability which was not incorporated for the demonstration (Figure 6).

5. **Ground Clutter Suppression (GCS):** Pressing this button would reduce the intensity of ground returns, thereby, making weather returns much easier to see. This feature would only work when operating in the weather mode.

6. **Hold (HLD):** When depressed, it froze (held) the current radar presentation. This allowed the user to evaluate a static, non-changing radar picture.

7. **Stabilization (STB):** When depressed, it locked the stabilization of the radar antennae to that of the aircraft frame.

Mission Management System (MMS)

The MMS baseline was similar to a Rockwell/Collins design for a C-160 autonomous navigation system. The C-160 design was a suite of digital technology avionics hardware and associated computer software for implementing GPS, integrated flight management, mission planning capability independent of the ground, independent mission loading capability, storage and display of Take Off and Landing Data (TOLD), equipment redundancy, Built-In Test (BIT) and monitoring capability, Microwave Landing System (MLS) capability and NATO transponder while maintaining compatibility with a Mil-Std-1553 bus. The MMS represented the key method for automating many of the navigator's tasks, described fully in ASD-TR-91-5005, KC-135 Function Analysis and Function Reallocation. The Control Display Units, located on the pilot's and copilot's center console just above the fuel management panel (Figures 10 and 11), provided the primary means for the crew to interface with the Mission Management System. Data were entered into the CDU with a full alphanumeric keypad, slew keys, function select keys (FSKs), and eight line select keys (LSKs). The CDU was an off-the-shelf design that presented a set limit of function select keys as well as the number of lines and characters on the display page. The multi-function display (MFD) had eight lines of 22 characters each. Lines 1, 3, 5 and 7 were data lines with a line select key

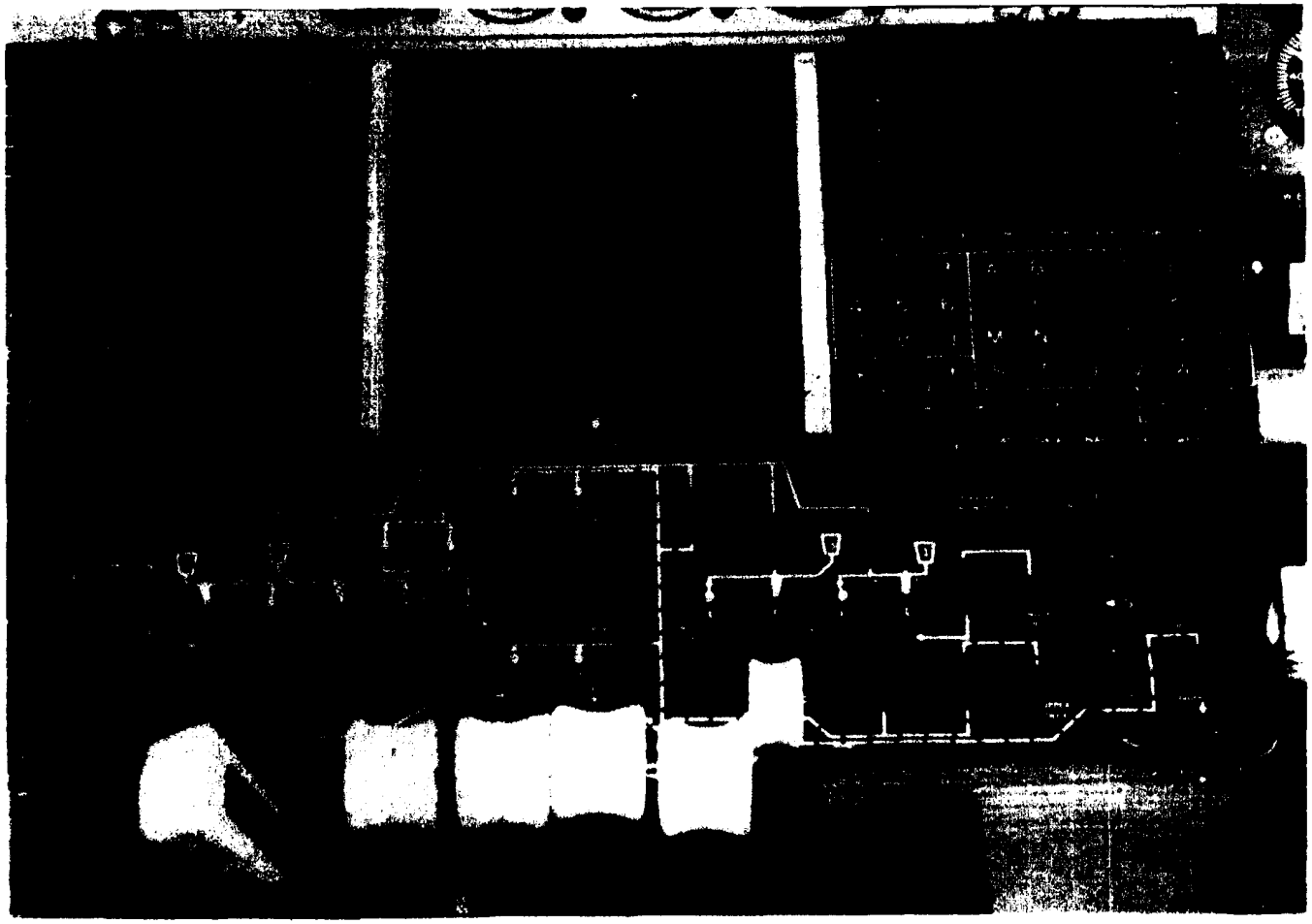

Figure 10. WCA Display Between CDUs

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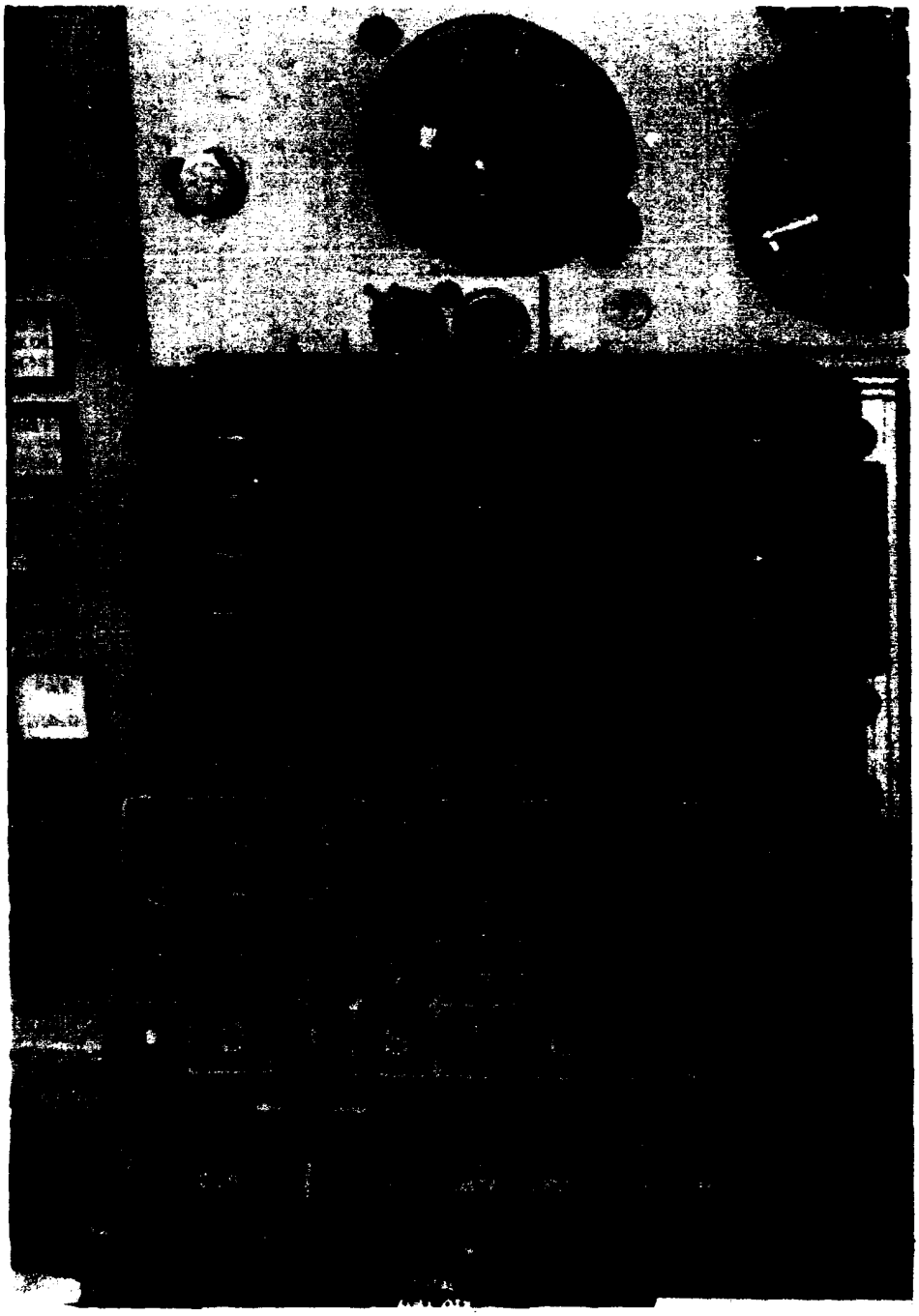

Figure 11. Control Display Unit

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on both the right and left side of the field (indicated by L1 - L4 and R1 - R4 in all subsequent figures). Line 2 was reserved for the page title and line 6 was reserved as an annunciation line. Line 4 was an additional display of data line and line 8 was the scratchpad for holding all keypad entries and messages. The MMS functional menu will be described in terms of "pages," the information contained at any point in time on the CDU display. The high level function pages were selected via the function select keys with the lower level function pages selected via line select keys and/or slew keys.

A simulated capability of the MMS was the navigation database with an external data loading capability. The database had navigation aids accessible using three-, four- or five- letter ICAO identifiers and would automate mission paperwork, Form 200s, TACAN data, air refueling data and instrument approach data. Update of the INS was automatic via the navigation computer or by copilot radar (TACAN and overfly) fixing. In-flight log entries, such as level off time, and mission paperwork, were performed by a flight data recording system. Point parallel rendezvous and turn range information were performed via commands from the navigation system. In the case of a divert, alternate routes of flight were easily accessible through the navigation system.

The following sections provide a complete description of the MMS, its operation and the functions and information contained within the various pages:

1. **Symbol Conventions:** Within the CDU pages, a variety of symbols were used to describe the function of the line select key, denote where information could or should have been inserted, state advisories and show status. A description of the symbol conventions follows:

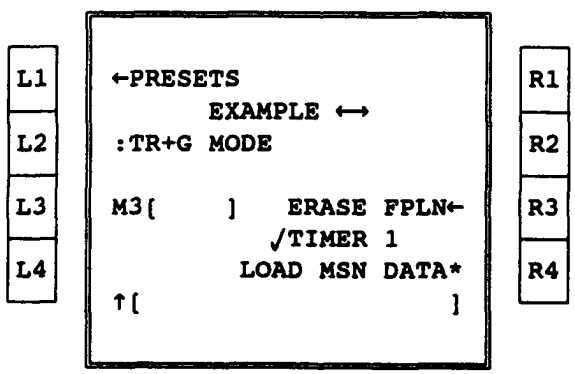

Figure 12. Sample Symbols

a. Outward-pointing arrow (← on left or → on right): An arrow adjacent to and pointing at a line select key indicated that selecting this key would bring up the designated, system related page. In Figure 12, selecting L1 would bring up a Ultra High Frequency (UHF) or Very High Frequency (VHF) presets page.

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b. Inward-pointing arrow (→ on left or ← on right): An arrow adjacent to and pointing inward from a line select key indicated this key would select the feature or enable the designated mode. In Figure 12, selecting R3 would erase the existing flight plan.

c. Asterisk: An asterisk (*) adjacent to a line select key indicated that the feature had been selected. In Figure 12, the asterisk indicated that R4 had been selected and the mission data were being loaded. In this case, the asterisk would have replaced an inward-pointing arrow for the duration of the loading operation. The asterisk would disappear at the completion of the function and revert back to the inward-pointing arrow.

d. Colon: A colon (:) adjacent to a line select key indicated that selecting this key would change the function or operating state. A colon typically indicated a rotary switch where successive executions would eventually return the operator to the starting point. In Figure 12, repeatedly selecting L2 would take the TACAN status from transmit/receive and guard (TR+G), to transmit/receive (T/R), to air to air receive (AAR), to air to air transmit and receive (AATR), and back to TR+G.

e. Dashes: When dashes (- - -) appeared on a line, it meant that no computed data were available or meaningful, or that power was off.

f. Brackets: Brackets ([ ]) adjacent to a line select key, and in the scratchpad, indicated that information entry was possible. In Figure 12, placing a code into the scratchpad and then selecting L3 would enter the IFF mode 3 code.

g. Arrows: Arrows pointing up and down (↑↓) indicated that an additional page or pages of information were available through scrolling within the functional area. Arrows pointing right and left (← →) indicated that slewing was available between related functional areas.

h. Check Mark: A check mark (✓) appearing in line 6 on the MFD identified a potential problem or acted as an advisory. In Figure 12, "✓ Timer 1" alerted the operator that a countdown timer had reached zero.

2. **Function Select Keys:** The use of the function select keys (FSKs) and their locations were designed to emphasize the tanker mission and the need for rendezvous. The final CDU hardware design is shown in Figure 11. The following is a brief description of each function select key and the slew keys on the CDU. A more thorough description of each of the function keys will be provided later.

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The eight primary function select keys were located on a line directly below the MFD. Functions associated with each of these keys were as follows:

a. Communication (COM) Key: Depressing this key accessed the Communication Page. This page provided a summary of the status of the communication radios (frequency and/or channel numbers) and access to control pages for all radios. The COM page options permitted tuning the radios, either manually or by preset channels.

b. NAV Key: Depressing this key accessed the Navigation Page. This page provided a summary of the status of the navigation radios (frequency and/or channel) and access to presets for the VOR receivers. The NAV page options also permitted tuning the radios either through the use of presets, frequency changes, or with ICAO identifiers.

c. IFF Key: Depressing this key accessed the IFF page. This page provided the status of transponder modes 1, 2, 3, C and access to the mode 4 page.

d. M3 Key: Depressing this key with a valid, 4-digit, mode 3 code in the scratchpad changed the mode 3 code. Depressing the key with an empty scratchpad initiated an "ident" (squawk).

e. INAV Key: Depressing this key accessed the Integrated Navigation Display page. This page allowed for the control of information being used in the navigation solution and displayed position discrepancies of the individual sensor solutions (on three other pages accessed by right-left slewing).

f. Flight Plan (FPLN) Key: Depressing this key accessed the Flight Plan Page. This page provided information about the current flight plan. When this page was accessed, it displayed the computed (changeable) course to the next "To" waypoint, course offset (if any), and the selected (manual or auto) waypoint sequencing mode. On this page, waypoints could be added to or deleted from the flight plan. The entire flight plan could be reviewed using the up and down scroll keys.

g. Rendezvous (RZ) Key: Depressing this key accessed the Holding/RZ Page. This page allowed setup of a holding pattern and, if required, the rendezvous geometry. In addition, this page provided access to setup options for the intercept (rendezvous) functions.

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h. Direct (DIR) Key: Depressing this key accessed the direct-to function. The associated page was essentially a flight plan page with "DIRECT TO [ ]" on the top line, allowing entry of the desired point.

The EDIT and INDEX (IDX) keys were located on the next to last line of the keypad, with the last line containing six additional function select keys. The slew keys, scroll keys and minus (-) keys were in the lower left corner of the keypad. Functions associated with each of these keys are as follows:

i. EDIT Key: Depressing this key provided a menu to select pages for the Flight Management System (FMS) approach and waypoints list features.

j. IDX Key: Depressing this key brought up the system index page.

k. Clear (CLR) Key: Three functions were performed with this key:

1) When the system gave an advisory message on line six of the MFD, that message could be removed (acknowledged) using the CLR key.

2) When an incorrect (e.g., out of range, etc.) entry was attempted from the scratchpad , "ERROR" and the entry would flash alternately in the scratchpad. Depressing CLR would clear the scratchpad, allowing entry of a correct value.

3) If the pilot noted that an error had been made during data entry into the scratchpad, depressing CLR once would clear the last character entered. If the key was held down, characters would clear one at a time, right to left, at a rate of approximately three per second. If the key was hit twice, without intervening entries, the first hit would clear the last entered character and the second would clear the entire scratchpad.

l. COPY Key: Depressing this key caused "COPY WHAT?" to be written to the scratchpad. When a point was selected, the contents of that field were transferred to the scratchpad in a format suitable for entry into another field.

m. DATA Key: Depressing this key allowed access to a data page for any selected waypoint in the system. Information on this page included the following:

1) Latitude and longitude of the waypoint.

2) Course, distance, and time to the waypoint via direct or flight plan (if the waypoint existed in the flight plan).

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3) If the waypoint was an ICAO identifier, station variation, elevation, and frequency would be displayed. If station information was not available, magnetic variation would be shown. The above information would not appear immediately on depressing the DATA key. Instead, "DATA FOR" would appear in the scratchpad awaiting pilot entry of a waypoint descriptor.

n. Update (UPDT) Key: Depressing this key accessed the Update Page. This page was used to perform an INAV position update. At initial call up, the system was in the overfly (OFLY) mode with provisions on the page to select the TACAN aided update feature.

o. STAT Key: Depressing this key accessed page one of a series of status pages (13) that reflected the operating status and checks (continuous BIT) of all navigation system components. These were mostly maintenance oriented in nature and would be used primarily for ground checkout and troubleshooting.

p. MARK Key: Depressing this key accessed the mark function and entered the current position in the scratchpad in lat/long coordinates. These coordinates were obtained from the integrated navigation solution, the GPS, or the INS(s) depending on the operational status of the navigation systems and/or sensors. This key was necessary for overfly and TACAN fixing.

q. Scrolling/Slewing Keys: These up/down/left/right keys allowed the operator to move up and down in the flight plan to review/modify the route of flight and, in other areas (i.e., comm/nav radios) to review, select, or modify preset channels and frequencies. In this system, depressing the up arrow on, for example, the flight plan page, moved the display to an earlier portion of the mission and vice versa. Furthermore, up/down scrolling was used to reach additional pages of a particular function while left/right slewing was used to reach a separate and related function. For example, a down arrow, from the Power 1 Page, would access the Power 2 page while a right arrow would access the Start 1 page. Vertical scrolling capability was shown by a double headed arrow to the left of the scratchpad (line 8). Lateral slewing capability was shown by a double headed arrow in the page title line (line 2). Scrolling/slewing conventions were standardized to enhance user interface.

r. Minus (-) Key: This key was used conventionally for data entry. The system assumed positive values for all numeric entries (temperature, pressure, altitude, etc.) unless a minus preceded the entered value. A second function of this key was a deletion function. With a "-" in the scratchpad, a waypoint could be deleted from the flight plan by depressing the line select key adjacent to the "to be removed" waypoint. The flight plan was

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then automatically recalculated with that waypoint removed. This feature could be used in a variety of areas in the system including the removal of a course offset or wind and temperature.

3. **Indexed Functions:** The IDX key provided access to the index page and eight lower function pages. They were, power, start, loader, TOLD, timers, lock/zero(ize), model, and test (Figure 13). All of these functions could be accessed directly through the index page or indirectly through right or left slewing once one of the functions was selected. The function pages accessed through the index page are as follows:

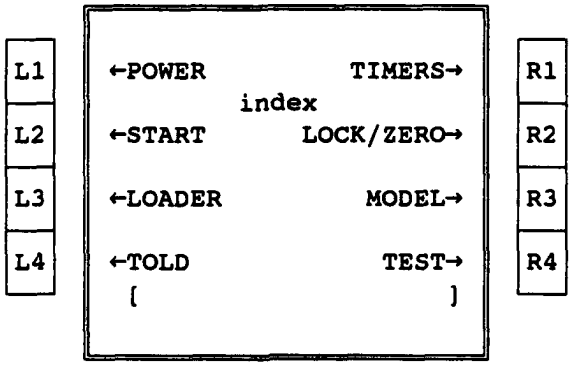

Figure 13. Index Page

a. Power pages: The power pages provided the means for turning on and off communications, navigation and identification systems either individually or simultaneously via the ALL SYS feature. Figure 14 shows the Power 1 page with all systems on. Selecting L4, before changing all indications to off, would require a confirmation by a second depression (Figure 15). Figure 16 shows the Power 2 page with all systems off.

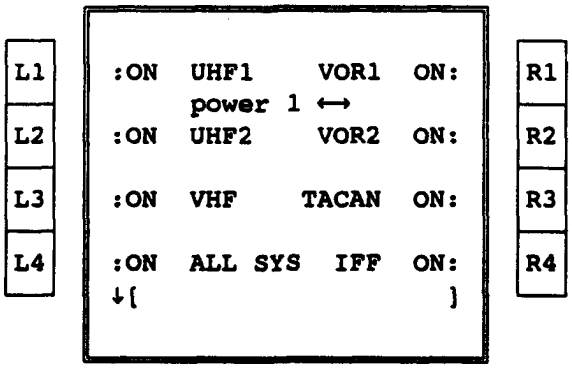

Figure 14. Power 1 Page

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```
L1   :ON  UHF1     VOR1  ON:   R1
     power 1 ↔
L2   :ON  UHF2     VOR2  ON:   R2
L3   :ON  VHF     TACAN  ON:   R3
L4   :ON  ALL SYS  IFF   ON:   R4
     ↓[CONFIRM ALL SYS OFF]
```

Figure 15. Power 1 Page with Confirmation Message

```
L1                              R1
     power 2 ↔
L2   :OFF INS 1    HF   OFF:    R2
L3   :OFF INS 2 BEACN   OFF:    R3
L4   :OFF GPS   RADAR   OFF:    R4
     ↑[                    ]
```

Figure 16. Power 2 Page

b. Start Pages: Once power was applied to the various avionics systems, the start pages could be accessed by using the index page again or by a right slew key. The purpose of the start pages was to insert and/or verify information required for INS alignment and to check the status/currency of data base information in the system. The start pages provided the ability to erase the current flight plan and to load new mission data from the data cartridge. Also provided was the ability to perform a normal or fast alignment of both inertial navigation systems. The Start 1 and 2 pages are shown in Figures 17 and 18. Information regarding the functions of the line select keys follows each figure.

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```
L1   [N39°49.1 E084°03.3   ]   R1
      D/M/Y start 1 ↔
L2   [08/15/91]  UTC[08:23]   R2
      CHART
L3   DATUM[47]  ERASE FPLN←   R3

L4   →GPS INIT  LD MSN DAT←   R4
     ↓[                    ]
```

Figure 17. Start 1 Page

1) Start 1 Page:

a) Line 1: The coordinates on this line were used for INS alignment and could be entered manually using L1 or, if available, automatically by the GPS.

b) Line 3: The current date and time again could be entered manually, using L2 and R2, respectively, or automatically via the GPS.

c) Line 5: Chart Datum for the GPS could be entered using L3. An option is provided to erase the current flight plan, prior to loading a new one, using the R3 key. The erase action required a confirmation.

d) Line 7: The GPS could be initialized using L4. This activity could take up to 20 minutes to perform. Flight plan loading, from a data transfer device, could be initialized using R4.

```
L1   10/06/91  TO  05/08/91   R1
           start 2 ↔
L2   CSEF1       29/08 2335   R2

L3   →NORM INS1 ALIGN FAST←   R3

L4   →NORM INS2 ALIGN FAST←   R4
     ↑[                    ]
```

Figure 18. Start 2 Page

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2) Start 2 Page:

a) Line 1: This line displayed the effective time period for the ICAO data base.

b) Line 3: This line displayed up to 10 characters as a cartridge identifier and the date and time the last information was written to the cartridge.

c) Line 5: An alignment of INS #1 could be initiated from these LSKs. L3 would initiate a normal alignment. The arrow would be replaced by an asterisk while the alignment was in process. Within 2 minutes, the message "DEGRAD RDY 1" would appear in line 6. The system would then be usable, but in a degraded mode. Within 6 minutes, the message "NAV RDY 1" would appear in the same location. The alignment is then complete. R3 would initiate a fast alignment. Within 2 minutes, the "DEGRAD RDY 1" message would appear and the fast alignment would be complete.

d) Line 7: This line and its functions are identical to those of line 5, for the second INS. The advisory messages also appeared in line 6.

c. Loader page: The loader page allowed reading from the data loader cartridge. Although a cartridge was not used in the simulator, loading mission data were simulated. A loader page is shown in Figure 19.

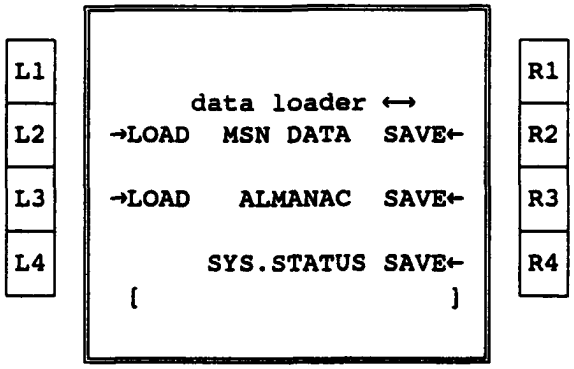

Figure 19. Loader Page

d. Take Off and Landing Data (TOLD) page: This page provided take off and landing performance data, specifically, critical airspeeds. Indications of weight (i.e., aircraft weight) were in pounds, as is standard Air Force convention. Figures 20 and 21 show TOLD pages for take off data and landing data, respectively.

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```
L1   :TAKE-OFF  GWT[185934]   R1
                told ↔
L2   FLAPS:  0°                R2
      Vr        V2     1.25Vs
L3   130       133       145   R3
L4                             R4
      [                    ]
```

Figure 20. TOLD Page, Take Off Mode

```
L1   :LANDING   GWT[107934]   R1
                told ↔
L2   FLAPS:  0°                R2
     1.4Vs    1.3Vs     1.2Vs
L3   134       124       115   R3
L4                             R4
      [                    ]
```

Figure 21. TOLD Page, Landing Mode

e. Timers page: This page provided three timers. Each could have been used as either an elapsed time or a countdown timer with alarm. All timers had the same functions. The page also allowed selection of a clock display in line 6. A timers page is shown in Figure 22, with its functions described below.

```
L1   T1:ON  00:00:25 ↑ LAP←   R1
             timer ↔
L2   T2:OFF 00:01:35 ↓ LAP←   R2
L3   T3:ON  00:00:00 ↓ LAP←   R3
                  /TIMER 3
L4           CLOCK DISPLAY←   R4
      [                    ]
```

Figure 22. Timers Page

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1) Line 1: In Figure 22, Timer 1 is currently an elapsed timer or count up timer. L1 was used to start the timer and could be used again to turn it off. Selecting R1 would freeze the timer display to allow for a reading at a specific point in time, while the timer continued. A second selection would show the timer at its current count.

2) Line 3: In Figure 22, Timer 2 is currently a countdown timer. Placing the desired time value in the scratchpad and then selecting L2 placed the 1:35 value in the timer, a second selection of L2 would start the countdown from that value. Entering a countdown time of zero or allowing the countdown timer to reach zero changes the mode to elapsed time.

3) Line 5: In Figure 22, Timer 3, a countdown timer, has expired resulting in the "/ TIMER 3" message shown in line 6. The message was acknowledged with the CLR key.

4) Line 7: Selecting R4 would cause a digital clock display of Universal Coordinated Time (UTC) to appear in line 6. The clock would remain on all CDU pages until deselected or temporarily overwritten by any advisory messages.

f. Lock/Zeroize page: This page allowed for mass blanking of flight/mission plans, waypoint data base, radio presets, data loader cartridge, INS and GPS inputs. Also provided was a navigation system security lock function. This page was not used during the simulation. A lock/zeroize page is shown in Figure 23, R1 has been depressed once causing the scratchpad message.

```
L1   LOCK[---]    ZERO ALL←   R1
        lock-zeroize ↔
L2   →IFF         CARTRIDGE←  R2
L3   →FLT/MSN PLAN    WPTS←   R3
L4   →COM     PRESETS   NAV←  R4
     [CONFIRM ZERO ALL     ]
```

Figure 23. Lock/Zeroize Page

g. Model Page: This page was used to "play" simulated data as if from INAV into the navigation system while on the ground. This function is not applicable to an actual aircraft system.

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h. **Test Pages:** This series of pages allowed for access to several initiated self tests of navigation system line replaceable units. The test pages provided the capability to perform some in-flight troubleshooting, but was especially designed for ground maintenance and troubleshooting.

4. **Communications (COM) Functions:** The COM page, accessed by pressing the COM key on the CDU, displayed the current frequency settings for the various communications systems (UHF, VHF, High Frequency (HF)) and provided a means to change them. In addition, for each system, a lower level presets page could have been accessed, providing a list of selectable and/or changeable frequencies numbered by standard convention for tower, ATIS, ground, etc. Frequency changes were made, using a frequency or an assigned preset number typed onto the CDU scratchpad and accepted on the COM page or the RRU. Frequency tuning on the RRU could have been done with any page active. The communications page allowed for two UHFs and one VHF radio. Additional human factor inputs allowed for all entries (e.g.; radio/nav frequencies, lat/long etc.) to be entered with or without decimal points, reducing total keystrokes necessary and reducing errors. The COM page is shown in Figure 24.

L1	←UHF1	3	TOWER com	223.00	R1
L2	←UHF2	M		227.00	R2
L3	←VHF	M		122.80	R3
L4	←HF	M		2.3000	R4
	[			]	

Figure 24. Communications (COM) Page

a. **Line 1:** Selecting L1 (Figure 24) with a preset number in the scratchpad tuned the UHF1 radio. If tuned by preset, the preset number was shown on the data line. If tuned manually, an "M" was displayed. If tuned to guard frequency via the emergency panel, a "G" was displayed and the radio could not be directly retuned. Attempting to do so resulted in a scratchpad message "GUARD ENGAGED." Selecting L1 with a blank scratchpad allowed access to the UHF1 radio control page (Figure 25). Selecting R1 with a frequency in the scratchpad transferred the frequency to the data line and tuned the UHF1 radio. If the scratchpad was blank, the previously tuned frequency was recalled.

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```
L1   ←PRESETS                    R1
                uhf1
L2   :TR    MODE                 R2
L3   :ON   SQL                   R3
L4   :OFF DF    TONE             R4
      [                    ]
```

Figure 25. UHF1 Control Page

1) Line 1: Selecting L1 on the UHF1 Control Page allowed access to the UHF1 presets page (Figure 26).

2) Line 3: LSK L2 selected the mode for the UHF1 radio. Two available modes were transmit/receive (TR) and transmit/receive plus guard (TR+G). The TR mode meant the guard receiver was turned off with the main transceiver tuned to a selected frequency. The TR+G mode provided both the UHF transceiver plus the guard/emergency receiver.

3) Line 5: LSK L3 toggled the squelch "on" and "off."

4) Line 7: LSK L4 toggled the direction finder "on" and "off." LSK R4 engaged tone transmission while pressed.

```
L1   ← 5    FLTSRV     255.40   R1
           uhf1 presets
L2   ← 6    OAKHI      327.00   R2
L3   ← 7    OAKLO      319.10   R3
L4   ← 8    PMSV       342.50   R4
     ↑↓[                   ]
```

Figure 26. UHF1 Presets Page

a) Selecting a left LSK, with a call sign in the scratchpad (up to six characters), entered the call sign for the associated preset. Selecting a left LSK, with an empty scratchpad, recalled the COM page (Figure 24) with the

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UHF1 radio then tuned to the preset number (left LSK) selected.

b) Selecting a right LSK, with a frequency entered in the scratchpad, entered the frequency for that preset.

c) Vertical page scrolling was possible via up/down arrow keys through 28 presets presented as seven pages.

d) The smallest incremental frequency that could be entered into the UHF radio was 25 kilohertz (0.025 megahertz). However, the UHF (and VHF) pages were only displayed two digits to the right of the decimal point; thus, the frequency 125.825 would have appeared as 125.82.

b. Line 3: Line 3 in Figure 24 provided the same capabilities for the UHF 2 radio as were just described for UHF1.

c. Line 5: Line 5 in Figure 24 provided similar capabilities for the VHF radio, with fewer options on the VHF control page. The VHF control page is shown in Figure 27 and a VHF presets page is shown in Figure 28.

d. Line 7: Line 7 in Figure 24 provided similar capabilities for the HF radio, with different options on the HF control page (Figure 29).

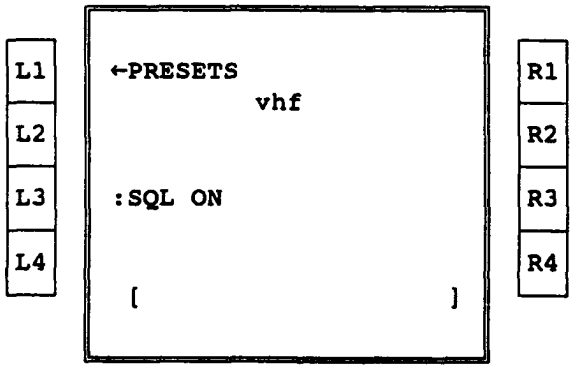

Figure 27. VHF Control Page

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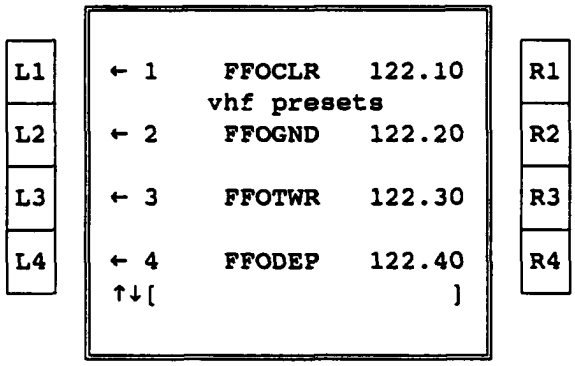

Figure 28. VHF Presets Page

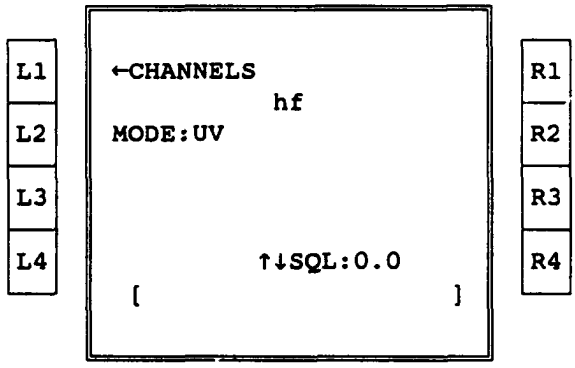

Figure 29. HF Control Page

1) Line 1: Selecting L1 on the HF control page allowed access to the HF channels page. An HF channels page with operations similar to the UHF1, UHF2, and VHF presets pages is shown in Figure 30.

2) Line 3: Selecting L3 on the HF control page toggled the mode through upper voice (UV) sideband, lower voice (LV) sideband, upper data (UD), lower data (LD), continuous wave (CW) and amplitude modulation (AM). Changing the mode, if tuned by a preset, caused the radio to enter a manual mode indicated by an "M" on the COM page (Figure 24).

3) Line 7: Pressing the up/down arrow keys adjusted the squelch from 0 (maximum noise) to 3 (maximum quieting).

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```
L1   ←17 SFRAD6      13.2730   R1
          hf channels
L2   ←18 SFRAD7      1[illegible].28800   R2
L3   ←19 SFRAD8      17.9040   R3
L4   *20 WWV1         5.0000   R4
     ↑↓[                    ]
```

Figure 30. HF Channels Page

5. **Navigation (NAV) Functions:** The NAV page (Figure 31), accessed by pressing the NAV key on the CDU, was similar to the COM page for the various navigation systems (VOR, Instrument Landing System (ILS), TACAN). This function allowed for changing of navigation aid frequencies and access to the preset pages. In addition, input of navigation aid frequencies could also be accomplished by typing the ICAO identifier into the scratchpad and depressing the proper LSK. Finally, the capability was provided to pair up VOR and TACAN frequencies and to set the various modes for the TACAN (receive (R), transmit/receive (TR), air-to-air receive (AAR), and air-to-air transmit/receive (AATR)).

```
L1   ←LOC1   1 IFFO    109.30   R1
              nav
L2   ←VOR2   M         115.80   R2
L3   TACAN:UNPAIRED             R3
L4   MODE:TR             060X   R4
      [                    ]
```

Figure 31. Navigation Page

a. Line 1: Selecting L1 in Figure 31, with a channel or preset number in the scratchpad, tuned the NAV1 radio. The label was toggled between "VOR" and "LOC" based on the frequency, with "LOC" being used for frequencies with odd tenths from 108.1 to 111.9. If tuned by preset, the preset number was shown on the data line. If tuned manually, an "M" was displayed. Selecting L1 with a blank scratchpad, allowed access to the VOR1/LOC1 navigation preset pages (Figure 32). Selecting R1 with a

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frequency or three-letter ICAO identifier in the scratchpad transferred the frequency to the data line and tuned the NAV1 radio. The only VOR identifiers that were recognized were those stored in the data cartridge navigation aid data base. The eight pilot-entered presets could not be called up using an identifier entry, but only by the preset number. If a VOR identifier was not found in the data base, then the CDU scratchpad showed a "NOT STORED" message in the scratchpad alternating with the entry. If the scratchpad was blank, the previously tuned frequency was recalled.

L1	* 1	IFFO	109.30	R1
	vor/loc1 presets			
L2	← 2	FFO	110.80	R2
L3	← 3	DQN	112.20	R3
L4	← 4	MGY	110.00	R4
	↑↓[		]	

Figure 32. VOR/LOC1 Presets Page

1) Selecting a left LSK, with a call sign in the scratchpad (up to six characters), entered the call sign for the associated preset. Selecting a left LSK, with an empty scratchpad, recalled the NAV page (Figure 31) with the VOR/LOC1 radio then tuned to the preset number selected.

2) Selecting a right LSK, with a frequency entered in the scratchpad, entered the frequency for the associated preset.

3) Vertical page scrolling was possible via up/down arrow keys through 20 presets presented in 5 pages.

b. Line 3: Line 3 in Figure 31 provided the same capabilities for the NAV2 radio as were just described for NAV1.

c. Line 5: Selecting L3 in Figure 31, toggled the TACAN between paired with VOR1 and unpaired. Pairing the TACAN toggled the mode to transmit/receive. The TACAN channel changed to the paired VOR1 frequency.

d. Line 7: Selecting L4 in Figure 31, toggled the TACAN mode between R only, T/R, AAR and AATR. LSK R4 entered the TACAN channel. If the TACAN was paired with the VOR1, then it

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automatically reverted to unpaired when a manual TACAN channel was entered. The TACAN defaulted to the "X" suffix (for unpaired ground transmissions) and was changed when the channel, suffixed by a "Y," was entered from the scratchpad or R4 was selected with an empty scratchpad.

6. **Identification Friend or Foe (IFF) Functions:** The IFF page (Figure 33), accessed by pressing the IFF key, allowed the codes for mode 1, mode 2, and mode 3a of the IFF to be set, and modes 1, 2, 3a and 3c to be turned on or off. Transmitter power could have been toggled between standby, normal, and low; the microphone key activated with an ident function; or the emergency IFF mode enabled. In addition, access was provided to the mode 4 page where mode 4 could have been toggled on or off, the mode 4 encrypted code saved, the reply annunciation selected, radiation test selected, or the mode 4 code zeroized.

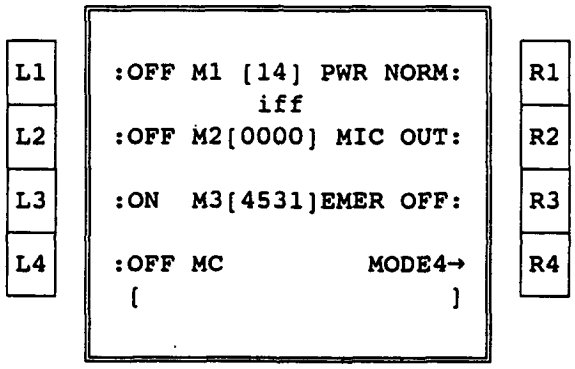

Figure 33. IFF Page

a. Line 1: LSK L1 (Figure 33) transferred a two-digit code from the scratchpad to the mode 1 or toggled the operation "ON" and "OFF" with a blank scratchpad. LSK R1 toggled the transmitter power mode between standby (STBY), normal (NORM) and low (LOW). If the power to the IFF had been selected off on the power pages, data line 1 displayed "OFF" and no selections with R1 were permitted. If the emergency mode (described in 6.c. below) was selected, this field showed "EMER" and attempts to change modes resulted in a scratchpad message "GUARD ENGAGED."

b. Line 3: LSK L2 transferred a four-digit code from the scratchpad to the mode 2 or toggled the operation "ON" and "OFF" with a blank scratchpad. LSK R2 toggled the microphone key between "OFF" and "MIC" (i.e.; IDENT function invoked with each keying of the microphone).

c. Line 5: LSK L3 transferred a four digit code from the scratchpad to the mode 3a or toggled the operation "ON" and "OFF" with a

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blank scratchpad. LSK R3 toggled the IFF emergency mode between "ON" and "OFF." Toggle "ON" required confirmation, indicated by the scratchpad message "CONFIRM EMERG IFF," followed by another L4 key press. Engaging the emergency mode entered the M3 code 7700 and turned on mode 3C.

d. Line 7: LSK L4 toggled mode C "ON" or "OFF." LSK R4 provided access to the mode 4 page (Figure 34).

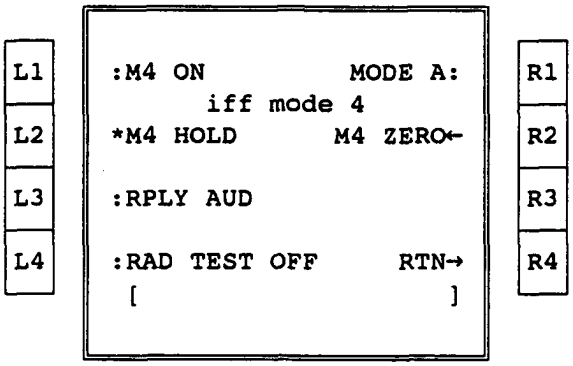

Figure 34. IFF Mode 4 Page

1) Line 1: LSK L1 (Figure 34) toggled mode 4 between "ON" and "OFF." LSK R1 toggled mode 4 operation between "A" and "B."

2) Line 3: LSK L2 commanded the IFF system to save the mode 4 encrypted code. LSK R2 zeroized the mode 4 encrypted code after confirmation, indicated by the scratchpad message "CONFIRM ZERO M4."

3) Line 5: LSK L3 toggled the mode 4 reply capability between light (LT), light and audio (AUD) and "OFF."

4) Line 7: LSK L4 toggled radiation test between "ON" and "OFF." LSK R4 returned to the IFF page (Figure 33).

7. **Mode 3 (M3) Function:** The M3 key provided the means to quickly "ident" (squawk) with a blank scratchpad (an "IDENT" annunciation appeared on the left end of line 6 of the CDU for 10 seconds), or to enter a new mode 3 code from the scratchpad. Any page could have been active during these operations.

8. **Integrated Navigation (INAV) Functions:** The INAV page (Figure 35), accessed by pressing the INAV key, provided the current aircraft coordinates (latitude (lat)/longitude (long)) in line 1, the current mode of the INAV solution in line 3 and the current 95% circular error probability (CEP) INAV error in line 4. The latitude and longitude entries were presented in degrees, minutes, and hundredths

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of minutes, standard for the tanker, as opposed to minutes and seconds. The mode could have been altered by placing INS1, INS2 and/or GPS in or out of the INAV solution (using LSKs L3, R3 and L4, respectively). The mode indicated which systems were providing the reference cues to the integrated navigation activity. Access was provided to the update pages using LSK R4 and, through slew keys, to the GPS, INS1 and INS2 pages. These pages and their functions are described below:

```
L1   N37°36.8   W122°21.7                R1
          ↔ INAV
L2   MODE    GPS/INS                     R2
                  95%ERR=.07
L3   :USE INS1    INS2 OUT:              R3

L4   :USE GPS       UPDATE→              R4
      [                    ]
```

Figure 35. Integrated Navigation (INAV) Page

a. Global Positioning System (GPS) Page: The GPS page (Figure 36) was accessed from the INAV page using a right arrow key. This page provided the current GPS coordinates in line 1, the number of satellites being tracked and the current INAV deviation in line 3 and the current INAV error in line 5.

```
L1   N37°36.8   W122°21.7                R1
          ↔ GPS
L2   SATS 4  DEV/INAV2.73NM               R2

L3             GPS 95%= .07               R3

L4                                        R4

      [                    ]
```

Figure 36. Global Positioning System (GPS) Page

b. Inertial Navigation System (INS1/2) Pages: The INS1 page (Figure 37) and INS2 page were accessed from the GPS page using one or two right arrows or from the INAV page using two or one left arrows, respectively. These pages provided the current aircraft location in line 1; the current status of the INS (i.e.; ORIENT,

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ALIGN, NAV RDY or NAV) and the INAV deviation in line 3; and the alignment circular error probability in line 5. An INS deviation from the INAV solution greater than or equal to 2 nm resulted in the message "INAV ERR" on the right end of line 6, calling for an INS update. Also provided was the ability to enable and air align the INSs using LSKs L3 and L4, respectively. LSK R4 provided access to the update page.

L1	N37°36.8 W122°21.7	R1
	⟷ INS 1	
L2	ORIENT INAV .00NM	R2
L3	→ENAB NAV ALN CEP .80	R3
L4	→AIR ALIGN UPDATE→	R4
	[ ]	

Figure 37. Inertial Navigation System 1 (INS1) Page

c. Update (UPDT) Page: The update page shown in Figures 38 and 39 was accessed from: 1) the INAV page (Figure 35) using the R4 LSK, 2) the INS pages (Figure 37) using the R4 LSK or 3) directly from the CDU using the UPDT FSK. The update page provided the capability to update one or both INSs by either an overfly update or a VORTAC update. For the overfly update, the coordinates of a known ground position were entered into line 1 from the scratchpad. When the aircraft was over the point, the MARK key was depressed and the INAV computed coordinates appeared in line 3 with the comparative error in line 5. Selecting L4 in Figure 38 would update the INS1. This type of update was not very applicable to the high altitude tanker mission. Pressing LSK L3 in Figure 38 toggled the update mode to VORTAC as shown in Figure 39. When selected, the current INAV position appeared in line 1. Depressing the MARK key entered the aircraft position with respect to the tuned TACAN station; a comparison was made and the deviation presented. An update could be performed at this time by depressing the L4 key.

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```
L1   :[N37°36.7 W122°21.6 ]   R1
        UPDATE 1 ←→
L2   [N37°36.8 W122°21.7  ]   R2

L3   :OFLY   ERR=298/ 0.1NM   R3

L4   ←UPDATE                  R4
      [                   ]
```

Figure 38. INS1 Update Page (Overfly Mode)

```
L1    MER  180°/  0.0         R1
        UPDATE 1 ←→
L2   [MER  269°/  0.7     ]   R2

L3   :VORTAC ERR=269/ 0.7NM   R3

L4   ←UPDATE                  R4
      [                   ]
```

Figure 39. INS1 Update Page (VORTAC Mode)

9. **Flight Plan (FPLN) Functions:** The FPLN page, Figure 40, was accessed by pressing the FPLN key. The current course was shown on line 1 as well as any offset to the course (e.g., 22 miles left of course), and the leg sequencing mode (Automatic (AUTO) or Manual (MAN)). Pressing LSK L1 with a new course in the scratchpad would establish a new inbound course to the "to" waypoint. Pressing LSK R1 with an L or R and a numerical value in the scratchpad would enter the offset and display it on the EHSI (Figure 7, dashed line). Pressing R1 with a blank scratchpad would toggle the route sequencing mode. If an offset was entered for the current "direct to" waypoint, then that offset would be applied to all subsequent waypoints. Line 3, Figure 40, shows the current "to" waypoint, which is the first waypoint (Castle AFB/Merced). The 0800 UTC time in brackets is the planned take-off time from the loaded flight plan. The second point (point 1a) was entered using lat/long coordinates, which does not leave enough display space for the time value. The third waypoint time (line 7) is the computer estimated time of arrival (ETA) of the aircraft for the waypoint (no bracket). It was selected by pressing R4 with a blank scratchpad. The computed ETA took into account air

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speed, wind speed and wind direction, but did not account for the turn radius of the aircraft.

```
L1   CRS[273]  [L22.0]AUTO:   R1
     ↓to↓      fpln     ADV
L2    1  MER          [0800]   R2

L3    1a N39"53.1 W121"34.6   R3

L4    2  LIN12210      0815   R4
      [                    ]
```

Figure 40. Flight Plan (FPLN) Page

Also provided was the ability to offset a waypoint from an ICAO identified point using range and bearing information. The waypoints in the flight plan were numbered to match the Form 200 and were similarly numbered on the EHSI display as well. When a new waypoint was typed and entered into the original flight plan display, the new point was numbered by the preceding waypoint number and a lower case letter (e.g., "a" or "b," etc.) in order to maintain the integrity of the flight plan. The waypoint could have been entered to renumber subsequent waypoints by placing a "/" first in the scratchpad before the waypoint entered. The "/" used alone renumbered all subsequent waypoints. A waypoint could also have replaced a given waypoint by typing a "-" first in the scratchpad before the waypoint. The "-" used alone eliminated a waypoint from the list without renumbering. Waypoints were entered using 2-, 3-, 4-, or 5-letter ICAO identifiers, lat/long coordinates, or radial/distance offset from an ICAO identified point.

All information concerning the current flight plan could have been viewed on the page by vertical line scrolling using the up/down arrows. A fast scroll was provided by holding the arrow key down. When the current waypoint was not on line 3, the course, offset, advance line is removed to display more waypoints as shown in Figure 41. Additionally, a direct scroll capability was also added. This allowed the operator to immediately display the desired waypoint in line 3 by inserting the waypoint number into the scratchpad and pressing the FPLN key.

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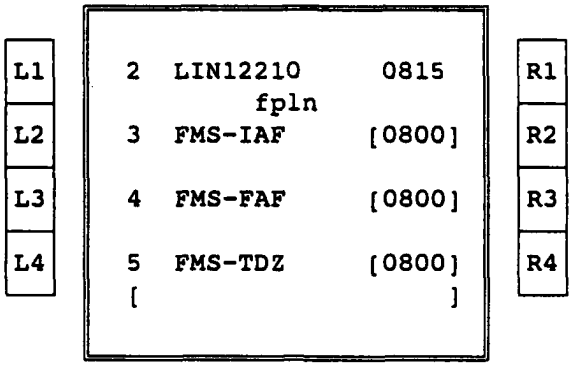

Figure 41. FPLN Page After Down Scrolling

a. "Direct To" Function: This function provided for the comparison of ETAs between flight plan route and present position direct. The DIR key was used to change the current flight path direct to a different waypoint. Depressing this key displayed course, distance and time to the selected waypoint (Figure 42). The function could also be reached by pressing the left LSK adjacent to the desired waypoint on the FPLN page with a blank scratchpad. Any point could have been selected for "Direct to" using previously described designations or flight plan waypoint numbers.

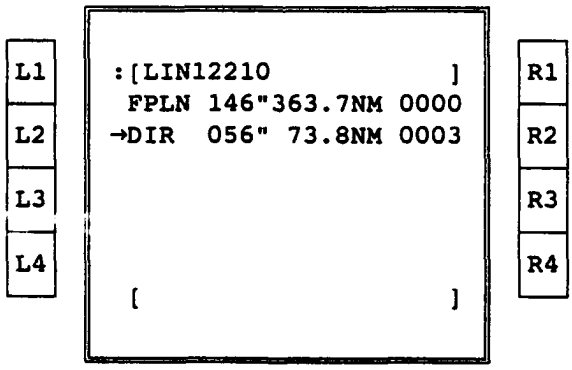

Figure 42. "Direct To" Function

b. Edit Functions: The edit function (Figure 43) provided the ability to edit a FMS approach or to edit waypoints within the waypoint preset list. Selecting LSK L2 provided access to the FMS approach page (Figure 44). Selecting R2 provided access to the waypoint edit page (Figure 46).

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```
L1 |                                  | R1
   |        fpln edit                 |
L2 | ←FMSAPPR          WPTS→          | R2
   |                                  |
L3 |                                  | R3
   |                                  |
L4 |                                  | R4
   |  [                    ]          |
```

Figure 43. Edit Page

1) FMS Approach: This capability provided ILS type steering cues to the touchdown coordinates. Use of this approach assumed the navigation system had at least one functioning INS. If the crew had information about terrain along the approach path, the altimeter would have also been used in the crosscheck. Approach setup required operator entry of the desired touchdown point on the runway, the final approach course and touchdown zone elevation. All other calculations were made by the system from a set of standard defaults. These items were changed by the crew using the FMS approach page, described below.

```
L1 | [N37°36.7 W122°21.6   ]          | R1
   |        fms appr                  |
L2 | APP CRS[220]ELEV[ 961]           | R2
   |                                  |
L3 | G/SLOPE[3.0 ]ACC .07NM           | R3
   |                                  |
L4 | INIT ALT[ 2500]  FPLN→           | R4
   |  [                    ]          |
```

Figure 44. FMS Approach Page

a) Line 1: This line was used to enter the desired touchdown point. Lat/Long entries could have been made to the nearest hundredth of a minute.

b) Line 3: LSK L2 was used to enter the final approach course. R2 was used to enter the touchdown point elevation.

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c) Line 5: L3 was used to enter the desired glideslope angle (default was 3.0°). System sensed position accuracy was also displayed.

d) Line 7: L4 was used to enter the initial approach altitude (default was 1500 feet above touchdown elevation). This altitude was rounded to the nearest 100 feet. R4 returned the user to the FPLN page with the scratchpad message "FMS APPROACH AT" as shown in Figure 45. By scrolling to the desired point for the FMS approach and pressing the appropriate left LSK, the FMS approach would be inserted into the flight plan.

```
L1   CRS[273]  [L22.0]AUTO:   R1
     ↓to↓      fpln     ADV
L2    1  MER          [0800]  R2

L3    1a N39"53.1 W121"34.6   R3

L4    2  LIN12210      0821   R4
      [FMS APPROACH AT     ]
```

Figure 45. Entering FMS Waypoints into Flight Plan

2) Waypoint Edit: This page (Figure 46) provided the capability to list and edit a series of waypoints for future entry into the flight plan.

```
L1   A  N37 36.7 W122 21.6    R1
        waypoint list
L2   B [                  ]   R2

L3   C [                  ]   R3

L4   D [                  ]   R4
      [                   ]
```

Figure 46. Waypoint Page

10. **Hold and Rendezvous (RZ) Functions:** The Hold/RZ pages, accessed by pressing the RZ key, provided setup options for any holding pattern and for point parallel air refueling operations. The page also

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provided access to the enroute intercept page. The selectable rendezvous functions were orbit, rendezvous and intercept.

a. Orbit Function: The RZ function defaulted to the orbit page (Figure 47). The orbit command was linked to a point on the flight plan and appeared on the EHSI as an orbit symbol at that point (Figure 7). When the aircraft was flying direct to that point, the symbol was displayed to scale with proper orientation about the orbit point.

```
L1   :ORBIT            RIGHT:   R1
           hold/rz
L2   INBND[    ]CRS NM[12.0]   R2

L3   REC[    ]TAS BNCO[     ]   R3

L4   RNG/OFST[21/ 7]  FPLN→    R4
      [                    ]
```

Figure 47. Hold/Rendezvous Orbit Page

1) Line 1: LSK L1 (Figure 47) was used to toggle between the rendezvous and intercept pages. R1 was used to toggle between left and right orbits (default was right).

2) Line 3: L2 was used to input the desired inbound course for holding. R2 input the desired holding pattern leg length (default was 12 NM).

3) Line 5: L3 was used to input the receivers true airspeed. R3 input the beacon code for the aircraft.

4) Line 7: L4 was used to input turn range and offset for the RZ turn. When holding and/or rendezvous entries were completed, depressing R4 brought up the FPLN page with the message "Hold At?." The operator could then designate (by pressing the adjacent LSK) the location in the flight plan where the hold/RZ would occur.

b. Rendezvous Function: Options were provided for receiver airspeed, and the turn range and offset for the rendezvous turn. The system displayed a turn range of 21 nm and a default offset of 7 nm for standard refueling speeds. In this configuration, the operator was required to determine and enter offset and turn range using the table of values from the offset/turn range chart. The rendezvous information was also linked to a point in the

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flight plan. A rendezvous page is shown in Figure 48 with the same function as described for the orbit page.

```
L1   :RENDEZVOUS      RIGHT   R1
           hold/rz
L2   INBND[123]CRS NM[12.0]   R2

L3   REC[350]TAS BNCO[ 120]   R3

L4   RNG/OFST[21/ 7]  FPLN→   R4
      [                   ]
```

Figure 48. Hold/Rendezvous Rendezvous Page

c. Intercept Function: Selecting the intercept function allowed for the setup and use of an enroute (receiver) join up.

```
L1   :INTCPT                  R1
           hold/rz
L2   :[N37 36.7 W122 21.6 ]   R2
     --- /   NM     TTI ---
L3   CRS[150] FIX TM[00:00]   R3

L4   :GSPD[280]       FPLN→   R4
      [                   ]
```

Figure 49. Hold/Rendezvous Intercept Page

1) Line 3: LSK L2 was used to input the last known position of the receiver aircraft. This position could be by ICAO identifier or lat/long.

2) Line 5: L3 was used to input the receiver course from the coordinates in line 3. R3 input the receiver time over the fix in line 3.

3) Line 7: L4 was used to input the receiver ground speed. R4 returned to FPLN page allowing for initiation of the intercept by inserting it into the "to" waypoint location.

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Digital Warning/Caution/Advisory (WCA) Display

The WCA display was a 3-inch by 3-inch monochrome CRT positioned above the fuel management panel, between the two CDUs. The WCA display provided a text display of warnings, cautions, or advisories. When a new message appeared on the WCA display, a master caution light, centered above the pilot's and the copilot's EADIs, would illuminate to draw the operator's attention to the main display for the message. Depressing either master caution light would acknowledge the message and extinguish both lights. This approach was used to bring the various warnings, caution and advisories into a central location. By incorporating this technique, and tying it to a master caution light in the primary field of view for both pilots, the effectiveness of the failure alerting system should be improved. Figure 11 shows the location of the WCA display between the two CDUs.

Remote Readout Unit (RRU)

Two Light Emitting Diode (LED) displays were located on the center of the glare shield toward the pilot and copilot sides of the cockpit. The pilot's RRU displayed the current selected COM1 and NAV1 settings and the copilot's displayed the COM2 and NAV2 settings. The display/settings were changed via the CDU scratchpad by frequency or preset number. Activation occurred when the scratchpad setting was selected on the COM/NAV page of the CDU or by the COM1/NAV1 buttons on the pilot's side or the COM2/NAV2 buttons on the copilot's side of the RRU. The RRU was designed to function similar to off-the-shelf equipment using available CSEF hardware (Figure 50).

Other Design Changes

In addition to these major subsystems, there were several other minor changes to the KC-135 cockpit that were incorporated or considered for the conceptual cockpit design.

1. **Standby ADI:** In order to provide the pilot with a secondary analog attitude director indicator, the remote display unit (RDU) was removed from the pilot's center instrument panel. The standby ADI was added due to FAA requirements. All pilots involved with the "quick look" exercise wanted the standby ADI to the right front of the pilot's position. Initial plans involved working around RDU currently in the aircraft, but the final configuration for the demonstration replaced the RDU with the standby ADI due to lack of space.

2. **Radar Control Panel Location:** In order to place the radar control unit aft of the throttle, the warning horn cutout switch and rudder power switch were covered and, therefore, inaccessible. These switches required relocation.

3. **Ground Map Update Capability:** This capability was not included for two main reasons. The first is the high reliability provided by a

Figure 50. Remote Readout Unit

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dual INS/GPS configuration. The second is the fact that current system users, (KC-10 personnel) did not feel this capability was necessary.

4. **Landing Gear Lights:** A change was considered to these lights, but pilot opinion showed a preference for the current configuration.

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SUMMARY OF RECOMMENDATIONS

Many recommendations can be made to individuals involved in the design and development of a system for the KC-135, having the intent of eliminating the need for a navigator. These recommendations are made based upon data collected during the C/KC-135 three-person crew feasibility demonstration (Rueb, Barnaba and Hassoun, 1991) as well as the research and design activity which resulted in the simulator configuration.

Navigational Systems

The navigation system should integrate all navigation information for a single navigation solution. Updating should be virtually instantaneous, so that the aircraft corrects to track automatically when in auto pilot mode or gives commands for return to track in manual modes.

In order for the crew to efficiently and effectively use the navigation information provided by the individual sensors, a navigation management system is necessary. It should incorporate computers, fast access bulk storage memory, an information filtering system and a control display unit to interface the pilot with the navigation system. Generally, the navigation management system must provide precise navigation information worldwide, with and without external navigation aids. Additionally, it must provide the capability for airway navigation, nonprecision approaches, and precision approaches. The navigation database should be large enough to maintain lengthy flight plans in memory, incorporating as many as 200 waypoints into the plan.

An acceptable way of providing this capability is a system consisting of an inertial navigation system (INS), that can be updated by all installed navigation sensors (VHF Nav, TACAN, Radar, GPS). The system should provide the capability to tune the sensors to the appropriate navigation aid station frequencies as the flight progresses. Unreasonable or erroneous information should be automatically filtered out, and only the most accurate information used for updating. Navigation information should be available directly from each individual sensor at the pilot's discretion.

The aircraft should have a navigation database on board that allows for a data transfer system tied to a ground mission planning system. This navigation database should, as a minimum, include the ICAO identifiers and corresponding information for:

1. Navigation aids
2. Refueling tracks
3. Anchor areas
4. Airfields near the route of flight (location, elevation, frequencies, runway lengths, etc.)

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5. Military operating areas and restricted areas

Other desirable information includes:

1. Waypoint information (times, distances, radial/DME, lat/long)

2. Location and information on restricted airspace, (times, altitudes, etc.)

3. Standard instrument departure/approach information (turnpoints, initial approach fixes (IAFs), frequencies, minimun descent altitudes (MDAs), etc.)

4. Preplanned radar fix information (location, elevation)

Based on pilot and navigator comments received during the task analysis phase, any use of celestial navigation was deemed impractical due to pilot workload and the amount of training required to effectively perform celestial navigation. The GPS can provide the capability for accurate navigation and in-flight alignment, and as such, is highly desirable. State-of-the-art INS reliability suggests a dual INS capability is required, in addition to GPS, or a system of greater or equal reliability. In terms of integration of these systems, a filtering system (e.g., Kalman filter) is required to update the navigation solution and filter out erroneous information.

The design of a navigation or mission management system should emphasize easy to understand conventions for symbols, abbreviations and acronyms that are standardized and consistent. In addition, when pages of information are used, logic should be used to allow for left/right scrolling between display pages and up/down scrolling within display pages. Often used functions such as communication, navigation aids, IFF, navigational status, direct to, flight planning, navigation sensor updating, airborne directed approach, fuel management, rendezvous and orbit should each be tied to a dedicated function key. In addition, a mode for receiver identification should be provided and should be fully integrated via the CDU with the radar presentation on the EHSI.

Display of navigation information should emphasize a pictorial representation of flight path, waypoints, navigation aids, airports, and other relevant items from the navigation database such as military operating areas. A mode that allows the operator to modify the flight plan of the aircraft with or without finally accepting it as the active flight plan was determined to be quite useful. The ability to display this modified plan on one or both of the CDU displays would be desirable. The rendezvous and orbit capability must provide the operator with a pictorial view of the route of flight and orbit with associated turn range depicted independent of the air to air TACAN. Offset and turn range should be computer generated to further reduce crew workload during air refueling.

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The navigation system should update and provide constant course, distance, crosstrack error, and time to go readouts for the next waypoint. These data points must take into account true airspeed, and wind speed and direction and update as changes in these inputs occur. Any displayed modifications to the flight plan, before or after their acceptance, should also contain this information as relevant to its specific waypoints.

Communication Systems

Communication requirements are complex. Features include capabilities to talk outside the aircraft only, broadcast with or without other crew members listening, monitor diverse broadcasts, and simultaneously carry out multiple conversations on different frequencies. The communication system must permit selection of the many modes, equipments and frequencies and allow flexibility in participation. Individual volume controls at each station is a must for each radio and communication system. The CSEF task analysis (Ward, et al., 1991) revealed that communications control and voice communications are workload drivers and areas of pilot concern given the elimination of the navigator.

Radar Systems

Display upon demand radar returns of weather, APN 69 beacon, surface terrain features or aircraft "skin paint." The radar return may be selected for the pilot and/or copilot, with or without the symbol generated flight plan map display (overlay), with independent range control between the pilot and copilot. The display must be readable in direct sunlight as well as total darkness. The radar system should have ground map, skin paint, weather modes as well as some type of receiver recognition mode. As a minimum, the recognition mode should allow the copilot to designate a receiver for tracking purposes; this ability should prove useful in skin paint mode as well. Color radar displays are recommended to reduce cognitive processing time. The radar display should be overlaid onto the EHSI map display to allow for a comparison of the current or possible routes of flight with the weather in the area. In this way, the offset utility can be used to determine the best course around weather of concern.

Flight Control Systems

An electronic ADI, which resembles pictorially the FD-109 system currently in the aircraft, would provide the capability for additional display of angle of attack, indicated airspeed, barometric pressure, and vertical velocity. The EADI should also have a radar altitude and decision height readout capability. An electronic ADI, as opposed to the current analog, would provide the benefit of redundancy and reduced pilot crosscheck time by adding additional readouts (such as airspeed, altitude, AOA, VV, etc.) to the display. A larger display, such as the 5-inch by 5-inch display used in the conceptual cockpit accomplishes this more effectively with limited interference.

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An EHSI is recommended for the purpose of overlaying course, heading, map and waypoint data onto one integrated display. The EHSI should allow for a full compass display (360 degrees) as well as an arc (approximately 90 degrees) map display capability. The EHSI should be capable of displaying groundspeed, true airspeed, wind direction and velocity, and drift angle as well as lateral deviation and vertical deviation during approach and landing. An option for presenting radar information while the display is in compass mode merits consideration. Size of the display again is an important consideration.

Additional Recommendations

Some additional items that may prove useful to such a modification are as follows:

The fuel savings advisory system should be integrated through the CDU. This would provide an improvement over the current system and should result in a reduction of workload for the operator.

A remote readout unit should be provided that allows for rapid changes to the radio and navigation aid frequencies. The unit should provide function selection buttons in an easily accessible and logical location. The operator should have the capability to tune the navigation aids with either the frequency or the ICAO identifier. The unit should also have the capability to rapidly recall the last tuned frequency.

A master caution light could be provided to enhance malfunction recognition. To complement this line of thinking, a warning/caution/advisory panel could be used to bring all failure indications to a central location in the cockpit, therefore, reducing recognition time.

The above recommendations are a direct result of the test and evaluation phase of this research effort (Volume III). The test and evaluation phase also provides the procedure and methodology used in arriving at these recommendations. Exact rationale for each recommendation in also covered in detail.

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