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Crew Systems and Flight Station Concepts for a 1995 Transport Aircraft

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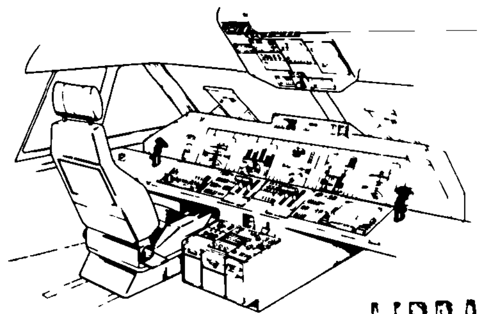

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FOREWORD

This report presents a description of a conceptual design for a 1990's transport aircraft; descriptions and operating procedures for the crew systems; and a discussion of the philosophy, methodology, and rationale used to arrive at the design. The work reported on in this document was performed by the Lockheed-Georgia Company for the National Aeronautics and Space Administration (NASA) Langley Research Center at Hampton, Virginia and Ames Research Center at Moffett Field, California.

The project was funded by NASA under Contract Number NAS 1-16199. In addition, in view of Lockheed's long-standing interest in this program area, this document also includes the results of Lockheed's Independent Research and Development Program with respect to performance of mission analysis and design efforts. This additional documentation is furnished over and above the contract effort.

This conceptual design is being incorporated into the Advanced Concepts Simulator (ACS) facility at Langley, the Man/Vehicle Systems Research Facility (MVSRF) at Ames, and the Advance Concepts Flight Station (ACFS) simulation facility at Lockheed-Georgia.

Guidance for the program was provided by Samuel A. Morello, NASA Langley Technical Monitor; Rodger L. Hayes, NASA Ames MVSRF Program Manager; and William R. Paden, Jr., Lockheed-Georgia Advanced Flight Station Technology Program Manager.

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ABBREVIATIONS AND ACRONYMS

1 ENG	ONE ENGINE
4D RNAV	4-DIMENSIONAL AREA NAVIGATION
A	AHEAD
A/C	AIRCRAFT
A/D	AIRDROME
A/S	AIRSPEED
ABN	ABNORMAL
ABBREV	ABBREVIATED
AC	ALTERNATING CURRENT
ACARS	ARINC COMMUNICATIONS ADDRESSING AND REPORTING SYSTEM
ACAWS	ADVISORY, CAUTION AND WARNING SYSTEM
ACFS	ADVANCED CONCEPTS FLIGHT STATION
ACS	ACTIVE CONTROL SYSTEM
ADC	AIR DATA COMPUTER
ADF	AUTOMATIC DIRECTION FINDING
ADI	ATTITUDE DIRECTOR INDICATOR
ADV	ADVANCE
ADVY	ADVISORY
ADV WX	ADVERSE WEATHER
AFCC	AUTOMATIC FLIGHT CONTROL COMPUTER
AFCS	AUTOMATIC FLIGHT CONTROL SYSTEM
AGL	ABOVE GROUND LEVEL
ALDCS	ACTIVE LIFT DISTRIBUTION CONTROL SYSTEM
ALT	ALTITUDE
ALT=	ALTITUDE HOLD
AN or ANT	ANTENNA
ANGL	ANGLE
ANTICOL	ANTICOLLISION
AOA	ANGLE-OF-ATTACK
AP or A/P	AUTOPILOT
AP/FDS	AUTOPILOT/FLIGHT DIRECTOR SYSTEM
APPR	APPROACH
APRT	AIRPORT
APU	AUXILIARY POWER UNIT

ABBREVIATIONS AND ACRONYMS (CONT'D)

AR	AS REQUIRED
ARAS	AUTOMATIC RESOLUTION AND ADVISORY SERVICE
ARINC	AERONAUTICAL RADIO INCORPORATED
A/S	AIRSPEED
ASAS	AIRBORNE SEPARATION ASSURANCE SYSTEM
ASM	AIR SEPARATION MODULE
ATAS	AIRSPACE AND TRAFFIC ADVISORY SERVICE
ATC	AIR TRAFFIC CONTROL
ATCRBS	AIR TRAFFIC CONTROL RADAR BEACON SYSTEM
ATIS	AUTOMATIC TERMINAL INFORMATION SERVICE
ATL	ATLANTA
ATRACK	ALONG TRACK
ATS	AUTOTHROTTLE SYSTEM
ATT CSS	ATTITUDE CONTROL STICK STEERING
AUTO	AUTOMATIC
AUX	AUXILIARY
AVAIL	AVAILABLE
AVG	AVERAGE
AVION	AVIONICS
B	BEHIND
BARO	BAROMETRIC
BAT	BATTERY
BKRS	BREAKERS
BLNK	BLANK
BRG	BEARING
BRT	BRIGHT
BTC	BUS TIE CONTROL
BTL	BOTTLE
CADC	CENTRAL AIR DATA COMPUTER
CAP	CAPTURE
CAPT	CAPTAIN
CAT	CATEGORY

CAUT	CAUTION
CDI	COURSE DEVIATION INDICATOR
CDR	CRASH DATA RECORDER
CDTI	COCKPIT DISPLAY OF TRAFFIC INFORMATION
CDU	CONTROL/DISPLAY UNIT
CDWI	COCKPIT DISPLAY OF WEATHER INFORMATION
CEP	CIRCULAR ERROR PROBABILITY
CG	CENTER OF GRAVITY
CIR	CIRCUIT
CLB	CLIMB
CLD	COLD
CLNC	CLEARANCE
CLR	CLEAR
CMD	COMMAND
CMPRS	COMPRESSOR
COMM/NAV	COMMUNICATION/NAVIGATION
CONT	CONTINUOUS
CRS	COURSE
CRT	CATHODE RAY TUBE
CRZ	CRUISE
CSS	CONTROL STICK STEERING
CTR	CENTER
CVR	COCKPIT VOICE RECORDER
CVSD	CONTINUOUSLY VARYING SLOPE DELTA
D	DEVIATION
DC	DIRECT CURRENT
DEC	DECREASE
DEG	DEGREE
DEPRES	DEPRESSURIZATION
DES	DESCENT
DEST	DESTINATION
DFDR	DIGITAL FLIGHT DATA RECORDER

ABBREVIATIONS AND ACRONYMS (CONT'D)

DH	DECISION HEIGHT
DIR	DIRECT
DIS or DIST	DISTANCE
DISC	DISCONNECT
DLC	DIRECT LIFT CONTROL
DME	DISTANCE MEASURING EQUIPMENT
DOD	DEPARTMENT OF DEFENSE
DP	DESCENT POINT
DSPY	DISPLAY
DSR	DESIRED
DTM	DATA TRANSFER MODULE
ECS	ENVIRONMENTAL CONTROL SYSTEM
EEC	ELECTRONIC ENGINE CONTROL
EFR	ELECTRONIC FLIGHT RULES
EGT	EXHAUST GAS TEMPERATURE
EL	ELECTROLUMINESCENT
ELE OR ELEV	ELEVATION
ELEC	ELECTRONIC
ELM	EXTENDED LENGTH MESSAGE
ELT	EMERGENCY LOCATOR TRANSMITTER
EMER or EMERG	EMERGENCY
EMP	EMPENNAGE
ENG	ENGINE
EP	ENTRY POINT
EPR	ENGINE PRESSURE RATIO
ERP	EYE REFERENCE POINT
EST	ESTIMATED
ETA	ESTIMATED-TIME-OF-ARRIVAL
ETE	ESTIMATED TIME ENROUTE
ETIS	ENHANCED TERMINAL INFORMATION SERVICE
ETP	EQUAL TIME POINT
EXT	EXTERIOR/EXTERNAL/EXTENDED

ABBREVIATIONS AND ACRONYMS (CONT'D)

F	FAST
FD or F/D	FLIGHT DIRECTOR
FAA	FEDERAL AVIATION ADMINISTRATION
FAF	FINAL APPROACH FIX
FCC	FLIGHT CONTROL COMPUTER
FCS	FLIGHT CONTROL SYSTEM
FF	FUEL FLOW
FL	FLIGHT LEVEL
FLT STA	FLIGHT STATION
FM	FROM
FMC	FLIGHT MANAGEMENT COMPUTER
FMS	FLIGHT MANAGEMENT SYSTEM
F/O	FIRST OFFICER
FP	FUEL PRESSURE
FPA	FLIGHT PATH ANGLE
FPM	FEET PER MINUTE
FT	FUEL TEMPERATURE
FWD	FORWARD
G or g	ACCELERATION OF GRAVITY
G-A	GO-AROUND
GCP	GUIDANCE AND CONTROL PANEL
GEN	GENERATOR
GLC	GENERATOR LOAD CONTROL
GMT	GREENWICH MEAN TIME
GND	GROUND
GPS	GLOBAL POSITIONING SYSTEM
GRAD	GRADIENT
GS or G/S	GROUNDSPEED
GPWS	GROUND PROXIMITY WARNING SYSTEM

ABBREVIATIONS AND ACRONYMS (CONT'D)

H or HF	HIGH FREQUENCY
HDD	HEAD-DOWN DISPLAY
HDG	HEADING
HI	HIGH
HNAV	HORIZONTAL NAVIGATION
HSI	HORIZONTAL SITUATION INDICATOR
HUD	HEAD-UP DISPLAY
HZ	HERTZ
IAS	INDICATED AIRSPEED
IC	INTERCOM
ICAO	INTERNATIONAL CIVIL AVIATION ORGANIZATION
ICN	INTEGRATED COMMUNICATIONS/NAVIGATION
IDENT	IDENTIFY/IDENTIFICATION
IFOV	INSTANTANEOUS FIELD OF VIEW
IFR	INSTRUMENT FLIGHT RULES
IGN	IGNITION
ILM	INDEPENDENT LANDING MONITOR
ILS	INSTRUMENT LANDING SYSTEM
IMC	INSTRUMENT METEROLOGICAL CONDITIONS
INBD	INBOARD
INC	INCREASE
INCOMP	INCOMPLETE
INDX	INDEX
INFO	INFORMATION
INOP	INOPERATIVE
INS	INERTIAL NAVIGATION SYSTEM
I/O	INPUT/OUTPUT
IRS	INERTIAL REFERENCE SYSTEM
IRU	INERTIAL REFERENCE UNIT
ISOL	ISOLATION
IWP	INITIAL WAYPOINT

ABBREVIATIONS AND ACRONYMS (CONT'D)

JEPP	JEPPESEN (INSTRUMENT APPROACH INFORMATION)
KBD	KEYBOARD
KTS	KNOTS
KVA	KILOVOLT-AMPERE
L	LEFT
LAT/LONG	LATITUDE/LONGITUDE
LBS	POUNDS
LE	LEADING EDGE
LED/LEU	LEADING EDGE DOWN/UP
LF/ADF	LOW FREQUENCY AUTOMATIC DIRECTION FINDER
LH	LEFT HAND
LND	LAND
LO	LOW
LOC	LOCALIZER
LPC	LINEAR PREDICTIVE CODING
LRU	LINE REPACEABLE UNIT
LSAS	LATERAL STABILITY AUGMENTATION SYSTEM
LSB	LOWER SIDE BAND
LT	LIFT TAILORING
LTG	LIGHTING
MACH or M	MACH NUMBER
MAN	MANUAL
MAST	MASTER
MAX	MAXIMUM
MBCN	MARKER BEACON
MDS	MULTIFUNCTION DISPLAY SYSTEM
MED	MEDIUM
MIC	MICROPHONE
MIN	MINIMUM
MLS	MICROWAVE LANDING SYSTEM
MODE-S	TRANSPONDER MODE FOR SELECTIVE CALL
MVSRF	MAN/VEHICLE SYSTEMS RESEARCH FACILITY

ABBREVIATIONS AND ACRONYMS (CONT'D)

N	NORTH OR NOSE
N-DME	NORMAL L-BAND DME
N1, N2	ENGINE REVOLUTIONS PER MINUTE AT STAGE 1 OR 2
NAV	NAVIGATION
NAVSTAR	NAVIGATION SYSTEM USING TIMING AND RANGING
NDB	NONDIRECTIONAL BEACON
NM	NAUTICAL MILE
OAT	OUTSIDE AIR TEMPERATURE
OBST	OBSTACLE
OBOGS	ON-BOARD OXYGEN GENERATING SYSTEM
OP	OIL PRESSURE
OQ	OIL QUANTITY
OT	OIL TEMPERATURE
OVHD	OVERHEAD
P-DME	PRECISION DME
P1, P2, P3	PILOT 1, 2, OR 3
PA	PUBLIC ADDRESS
PASS	PASSENGER
PIREPS	PILOT REPORTS
PLAD	PITCH LADDER
PM	PERFORMANCE MANAGEMENT
PNL	PANEL
POS	POSITION
PRES or PRESS	PRESSURE
PSAS	PITCH STABILITY AUGMENTATION SYSTEM
PSI	POUNDS PER SQUARE INCH
PWR	POWER
Qc	COMPRESSIBLE DYNAMIC PRESSURE

ABBREVIATIONS AND ACRONYMS (CONT'D)

R	RIGHT OR RADAR
RA	RADAR ALTITUDE
R&D	RESEARCH & DEVELOPMENT
RCR	RUNWAY CONDITION READING
RCS	ROLL CONTROL SPOILERS
RCVD	RECEIVED
RDR	RADAR
RE	RADIAL ERROR
RECIRC	RECIRCULATE
REF	REFERENCE
REL	RELEASE
REM	REMOVAL
RETR	RETRACTED
REV	REVERSE
RH	RIGHT HAND
RL	RUDDER LIMITER
RLL	RUDDER LOAD LIMITER
RMKS	REMARKS
RNAV	AREA NAVIGATION
RNG MKR	RANGE MARKER
RPM	REVOLUTIONS PER MINUTE
RQMT	REQUIREMENT
RSC	RUNWAY SURFACE CONDITION
R/T	RECEIVER/TRANSMITTER
RVDT	ROTARY VARIABLE DIFFERENTIAL TRANSFORMER
RVR	RUNWAY VISUAL RANGE
RWY	RUNWAY
S	SLOW
SAS or STAB AUG	STABILITY AUGMENTATION SYSTEM
SELCAL	SELECTIVE CALLING
SECT	SECTOR
SFO	SAN FRANCISCO

SG	SYMBOL GENERATOR
SID	STANDARD INSTRUMENT DEPARTURE
S/O	SECOND OFFICER
SPD/MACH	SPEED/MACH NUMBER
SPI	SURFACE POSITION INDICATOR
SPL	SPECIAL
SSB	SINGLE SIDE BAND
SSPC	SOLID STATE POWER CONTROLLER
SSR	SECONDARY SURVEILLANCE RADAR
STAB	STABILIZER
STAR	STANDARD TERMINAL ARRIVALS
STOR	STORE
SW	SWITCH
SYNC	SYNCHRONIZE
SYS STS	SYSTEM STATUS
T-CAS	TRAFFIC-ALERT AND COLLISION AVOIDANCE SYSTEM
T-O	TAKEOFF
TAE	TRACK ANGLE ERROR
TAS	TRUE AIRSPEED
TBD	TO BE DETERMINED
TCA	TERMINAL CONTROL AREA
TCMD	THRUST COMMAND MODE
TCS	THRUST CONTROL SYSTEM
TE	TRAILING EDGE
TEMP	TEMPERATURE
TFB	TOTAL FUEL BURNED
TIP CLR	WINGTIP CLEARANCE
TNAV	TIME NAVIGATION
TOLD	TAKEOFF AND LANDING DATA
TRAF or TRFC	TRAFFIC
TRK or TK	TRACK
TRT	TAKEOFF RATED THRUST
TT	TOTAL TIME
TURB	TURBULENCE

UHF	ULTRA HIGH FREQUENCY
USB	UPPER SIDE BAND
V1, V2	VHF RADIO NUMBER ONE OR TWO, OR TAKEOFF DECISION SPEED AND TAKEOFF SAFETY SPEED
V_S	STALL SPEED
VCSS	VECTOR CONTROL STICK STEERING
VF	VIBRATION (FAN)
VFR	VISUAL FLIGHT RULES
VFU	VARIABLE FEEL UNIT
VH	VIBRATION (HIGH PRESSURE TURBINE)
VHF	VERY HIGH FREQUENCY
VLF	VERY LOW FREQUENCY
VMC	VISUAL METEOROLOGICAL CONDITIONS
VNAV	VERTICAL NAVIGATION
VOL	VOLUME
VOR	VHF OMNIDIRECTIONAL RANGE
VORTAC	VOR COLOCATED WITH UHF COURSE AND DISTANCE INFORMATION
VS	VERTICAL SPEED
VSCF	VARIABLE SPEED CONSTANT FREQUENCY
VSL	VERTICAL SPEED LIMIT
VSM	VERTICAL SPEED MINIMUM
VSPD	VERTICAL SPEED
W	WEST
WF	WIND FACTOR
WLA	WING LOAD ALLEVIATION
WT	WEIGHT
WTR	WING TORSION RELIEF
WX	WEATHER

ABBREVIATIONS AND ACRONYMS (CONCLUDED)

XFER	TRANSFER
XMT	TRANSMIT
XPONDER	TRANSPONDER
XTK or XTRACK	CROSSTRACK
YSAS	YAW STABILITY AUGMENTATION SYSTEM

NOTE: There are several instances in the above list where two different abbreviations are used for the same word or where one abbreviation is used to represent more than one word. This was done only when absolutely necessary due to display or labeling space limitations and only when the context of the information should not be confusing to the pilots.

INTRODUCTION

Until recently, aircraft flight station designs have evolved through the incorporation of improved or modernized controls and displays for individual systems. New displays and controls have simply replaced outmoded units. Coupled with a continuing increase in the amount of information displayed, in many instances, this ad hoc process has not only produced a complex and cluttered conglomeration of knobs, switches, annunciators, and electromechanical displays but also has frequently resulted in a high crew workload, missed signals, and misinterpreted information. Now, however, advances in electronic technology offer new concepts in flight station design which provide for safer and more efficient system operation through a reduction in clutter, and through a more orderly, logical control and communication of information to the flight crew.

The Federal Aviation Administration (FAA) estimates in their National Airspace System Plan (Reference 1) that aircraft operations will increase by over 116 percent over the next 20 years. There are several systems under development to deal with the increased traffic including conflict-alert and conflict-resolution advisory systems, traffic-alert and collision avoidance systems, automated en route air traffic control, modernized weather collection and distribution systems, improved communications and navigation systems including the microwave landing system (MLS) and the NAVSTAR Global Positioning System (GPS), and improved radar beacon systems with Mode-S data link. Each of these systems has the potential to influence the aircraft and the aircrew operating procedures.

A design problem is created by the fact that the new airborne systems will not immediately replace any existing systems. The MLS, for example, will continue to have the conventional instrument landing system (ILS) as a companion for years to come since many aircraft will initially be equipped with only one system or the other. The presence of overlapping systems will therefore continue to have a significant impact on flight station design.

Fundamental to the development of an effective flight station configuration is the careful consideration of crew role and performance as affected by design. Because of the dramatic advances in electronic and computer technology, this factor is becoming even more important. The extensive array of highly flexible display devices and the powerful onboard computers available to the designer provide an almost unlimited range of alternatives in establishing the role and tasks of the pilot. Therefore, it is imperative to assess the impact on crew performance of various alternative display devices, formats, procedures, control devices, mode selection switching, and the like, to optimize the flight station design.

The sophistication of the assessment tool can range from something as simple as a soft mockup to something as complicated as a prototype aircraft. The degree of confidence in the design decisions is directly proportional to the sophistication of the testing device and process. While the "proof-of-the-pudding" is in a successful flight test, it involves a very slow, expensive, and inflexible procedure. A full-mission flight simulator which simulates the real world factors that a flight crew would encounter on an operational mission—including, for instance, functional aircraft systems, the air traffic control environment, en route weather, and the cabin crew—is an excellent research, development and testing device. A very realistic environment can be provided for pilots to check the feasibility and acceptability of crew systems before the expensive detailed design process for the aircraft occurs.

The flight station and crew systems must be developed ahead of or at least concurrently with the design of the rest of the aircraft. This is necessary because the flight station is the place where the pilot, as a systems integrator, must interface with virtually all aircraft systems. With the powerful capabilities of electronics, the pilots could become the limiting link in future operations either because they are overloaded with unnecessary information and tasks or bored because of too much automation. It is essential that tradeoffs be made and designs be established early enough in the design process so that proper flight station integration can be accomplished.

Other new technologies, such as advanced aerodynamics, active controls, composite materials, fuel efficient propulsion systems, and supersonic configurations, impact the aircraft design and must be considered while developing the flight station. More importantly, however, the effects of the rapidly changing digital avionics technology must be tested against human performance. Of primary concern is the determination of how much automation is needed and how much is optimum. Resulting decisions on crew systems design can then be accommodated in the design of the remainder of the aircraft.

During this program, commercial transport needs, new technologies, and the air traffic control environment for the 1990s were forecasted. A conceptual design of the entire aircraft was accomplished with heavy concentration on the flight station and crew systems. A soft mockup of the flight station was laid out and the location of crew systems interfaces were tested in a soft mockup. The design was refined and is to be incorporated into full mission flight simulation facilities where the crew systems can be further developed and tested in a very realistic operating environment. Systems evaluated in this more sophisticated testing tool (the flight simulator) can be modified, added to, or deleted as necessary with a higher degree of confidence than through the recently completed mockup testing. The conceptual systems described in this document are by no means the final designs, but make up the baseline design from which to begin further research and development. The design philosophy, methodology, and conceptual systems that make up the flight station for this research simulator are described in the following sections.

DESIGN METHODOLOGY

The flight deck is the mobile office where man, machine and job interface and where decisions are made. The validity of those decisions and the resultant success or failure of the mission are directly related to how well the flight deck is designed to fulfill the needs of the crew considering the mission. The crew's needs vary greatly with the type, length, and urgency of the mission, crew size and complement, and outside operating environment (e.g., geographic location, temperature, time of day, threat, external aides). For these reasons, it is extremely important in the cockpit design process to assure that the cockpit is efficiently designed as a unified system.

A classic three phase approach was used to arrive at the recommended flight station design: mission analysis, design, and test. Since the phases are very much interactive in a program of this nature, no attempt was made to draw lines of separation among the functional tasks that define the methodology, which is shown in Figure 1. The various steps included in the three major phases are discussed below.

MISSION ANALYSIS PHASE

The mission analysis phase consisted of obtaining, forecasting, and determining information on 1990s transport aircraft with respect to user needs, operating environment and procedures, and electronic technology. Mission scenarios using this information were developed and validated by operationally qualified personnel. Detailed mission scenario time lines were used to develop aircraft functional requirements and to determine aircrew information and control requirements.

The forecast of user needs revealed that the need during the mid-1990s can be filled by a 200-passenger, wide-body transport, powered by twin turbofan engines, and having a range of 2500 nautical miles. Using 1995 technologies, this aircraft will interface with air traffic control systems of that vintage and be operated by a crew of two pilots. It will have the capability for worldwide operation in or around all types of weather conditions.

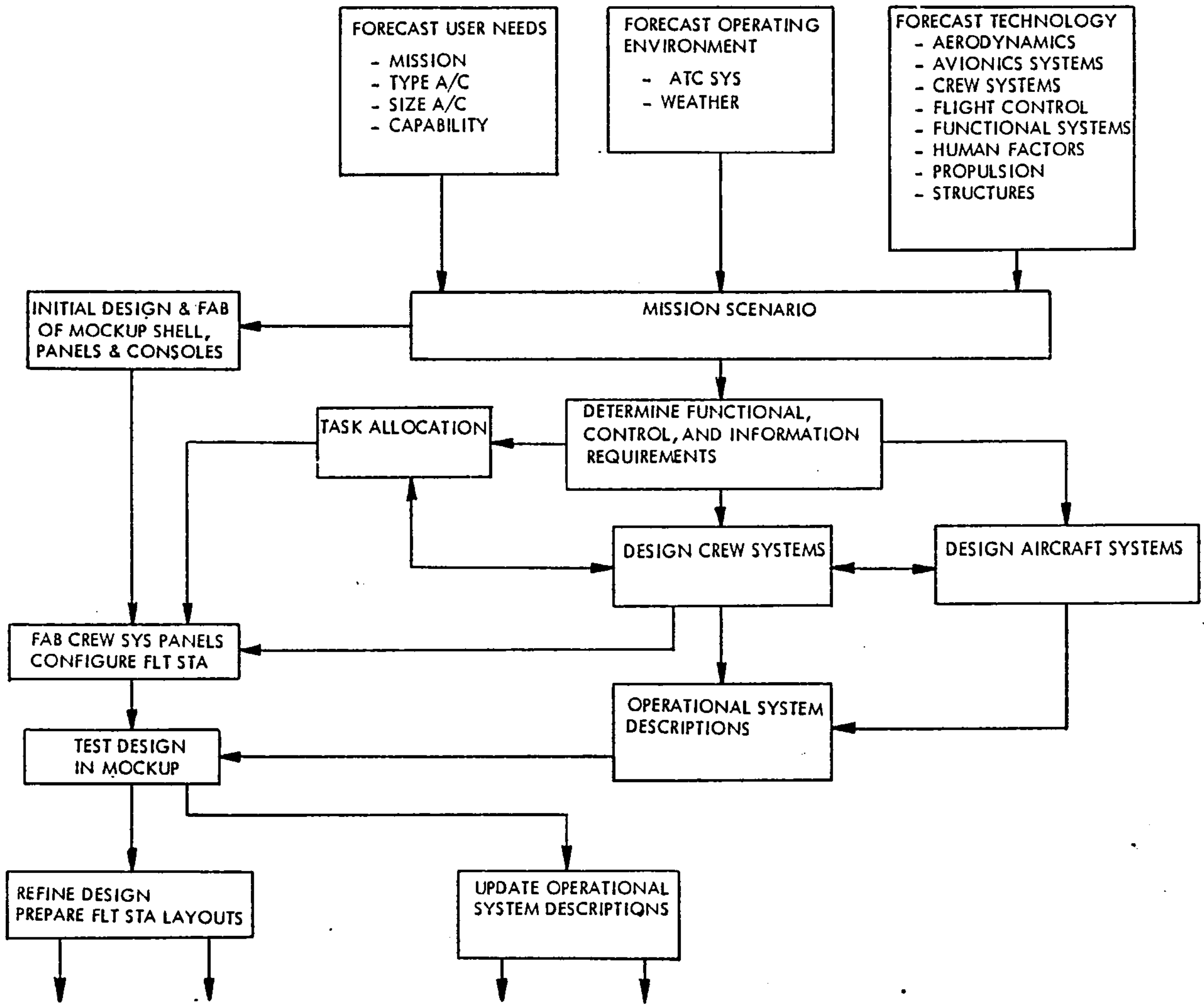


Figure 1. Total System Design Methodology

The air traffic control operating environment for the 1990s and beyond requires that the aircraft not only retain many existing systems (such as VOR/DME, ILS and Omega), but also at the same time add new systems. This is demonstrated by the information shown in Figure 2, which is a table published in the National Airspace System Plan (Reference 1).

Engineers from each of the following design disciplines forecasted what the technology level will be in the 1990s for their specific area of concern: aerodynamics, avionic systems, crew systems, flight controls, functional systems, human factors, propulsion and structures. The information provided from forecasts in the three areas described above—user needs, operating environment and technology—was used during the remainder of the analysis to assure that the pilots have the proper amount of information and control at the correct time within each flight phase to adequately and safely perform the designated mission. Very detailed mission scenarios were developed to reflect civil transport aircraft operating in the 1995 environment. These were plotted against a time line, a portion of which is shown in Figure 3. Tasks were allocated to the crewmembers or to the aircraft for automation. The projected scenarios were validated and checked for authenticity by airline pilots. This documentation then became the benchmark against which the design was measured.

To assure that information and control requirements were considered for each functional requirement, a Functional, Information and Control Requirements Table, a portion of which is shown in Figure 4, was developed. The data in the table were used to trace the origin of design requirements and to assure completeness.

A Crew Functions Table, a portion of which is shown in Figure 5, was developed. It is task oriented by phase of flight and shows the content, source, and recipient of information. The table was used during the design of individual controls and displays as well as the configuration of the overall flight station.

The Display/Control Usage Table, a portion of which is shown in Figure 6, provides a very detailed listing of all information and control parameters in 1970s aircraft and those projected for 1990s aircraft. A further breakout indicates during which phase of flight the information or control is necessary, and whether it needs to be continuous or can be called up on

	1981	1985	1990	2000
NAVIGATION				
VOR/VORTAC	W	W	W	W
SATELLITE NAV			L	L
DME	W	W	W	W
INS	L	I	I	W
LORAN C	L	L	L	L
OMEGA/VLF	L	L	L	L
DOPPLER	L	D	D	D
NDB	W	W	W	W
RNAV	W	W	W	W
4D RNAV		L	W	W
MAPPING	L	I	W	
COMMUNICATION & DATA LINK				
VHF COMM	W	W	W	W
UHF COMM	W	W	W	D
HF COMM	W	W	W	E
MODE S			L	W
ACARS	W	W	W	W
SATELLITE			L	I
VHF Wx Data Broadcast (VOR)		L	W	W
HF DATA LINK			L	W
AIRCRAFT SEPARATION				
EFR				L
TCAS II		L	W	W
TCAS I			L	I
ATAS (TERMINAL)			L	I
CDTI			L	I
ALTIMETRY			L	W
ATCRBS	W	W	D	D
MODE S			W	W
FMS	L	I	W	W
LANDING SYSTEMS				
MLS			W	W
ILS	W	W	W	D
ADF	W	W	W	D
VOR	W	W	W	W
RNAV	L	L	I	W
CAT IIIA	L	I	W	W
CAT IIIB		L	W	W
HUD		L	I	W
ADVANCED HDD		L	I	W
ELEC. APPR. PLATE			L	I

LEGEND:

L-LIMITED USE
I-INCREASING USE
W-WIDESPREAD USE
D-DECREASING USE
E-ELIMINATED

Figure 2. Projected Schedule for ATC Systems

GMT ELAP	CAPTAIN	FIRST OFFICER	AIRCRAFT	ATC SYS
0949 01:09 (DESCENT)	INITIATES DESCENT. SELECTS A DESCENT MODE. COMMANDS ALTITUDE AND AIRSPEED PARAMETERS. NOTES THRUST ADJUSTMENT. CALLS FOR DESENT CHEKLIST. RESETS ALTIMETER TO LOCAL PRESSURE. PERFORMS DESCENT CHEKLIST.	ACKNOWLEDGES WASHINGTON CENTER MESSAGE TO DESCEND TO INTERMEDIATE EN ROUTE ALTITUDE. RESETS ALTIMETER TO LOCAL PRESSURE. PERFORMS DESCENT CHEKLIST.	RECEIVES DATA LINK MESSAGE. BEGINS DEFINED DESCENT. PROVIDES "DECENT-TAILORED" CONTROLS AND DISPLAYS. PROVIDES AURAL CHEKLIST.	MODE-S DATA LINK TRAFFIC ADVISORY. AUTOMATIC CLEARANCE DELIVERY VIA DATA LINK.
0955 01:15	RESPONDS TO INTERIM APPROACH CLEARANCE. COMMANDS AND MONITORS FLIGHT TRAJECTORY TO ARRIVE AT WAYPOINTS ON ALTITUDE AND ON TIME.	ACKNOWLEDGES WASHINGTON CENTER MESSAGE TO MONITOR WASHINGTON APPROACH CONTROL. CHANGES COMM FREQUENCY. MONITORS APPROACH CONTROL. RECEIVES INTERIM APPROACH CLEARANCE. SELECTS APPROPRIATE NAVIGATION INFORMATION.	RECEIVES DATA LINK MESSAGE TO CHANGE COMM FREQUENCY. FLIES VERTICAL, HORIZONTAL AND TIME PROFILE TO ARRIVE AT WAYPOINTS ON ALTITUDE AND TIME. RECEIVES AND DISPLAYS INTERIM APPROACH CLEARANCE VIA DATA LINK	MODE-S DATA LINK - COMM FREQ. AUTO CLNC DEL - MODE-S DATA LINK CLNC. VOICE COMM WITH APPROACH CONTROL.
0958 01:18 (APPROACH)	SELECTS APPROACH MODE. COMMANDS APPROACH PARAMETERS. CHECKS DISPLAYS OF FLIGHT INFORMATION. RECEIVES TRAFFIC ALERT SIGNAL. MONITORS DISPLAY OF TRAFFIC INFORMATION TAKES EVASIVE ACTION.	ACKNOWLEDGES FINAL APPROACH CLEARANCE FROM APPROACH CONTROL. CONFIRMS WITH CAPTAIN.	MAINTAINS FLIGHT TRAJECTORY. RECEIVES AND DISPLAYS T-CAS SIGNAL. PROVIDES "APPROACH-TAILORED" CONTROLS AND DISPLAYS.	DATA LINK OF TRAFFIC INFO TO COCKPIT DISPLAY. AUTO CLNC DEL SYS - DATA LINK. VOICE COMM WITH APPROACH CONTROL.

Figure 3. Portion of Timeline within Mission Scenario

DRIVER	FUNCTIONAL REQUIREMENT	INFORMATION REQUIREMENT	DISPLAY LOCATION	CONTROL REQUIREMENT	CANDIDATE SYSTEM
ICAO AIRWAYS	SHORT RANGE NAV & COMM	SAME AS CONUS AIRWAYS (GPS WILL ELIMINATE THE NEED FOR LF/ADF)	FRONT INSTRU PANEL & FLT MGT SYS		
TERMINAL AREA (STATE-OF-ART FACILITIES)	SHORT RANGE NAV & COMM	SAME AS CONUS AIRWAYS EXCEPT TO ADD: PRECISION LATERAL COURSE AND COURSE DEVIATION, PRECISION VERTICAL FLIGHT PATH AND PATH DEVIATION, LOCATION AND IDENT OF APPROACH MARKERS	NAV, FLT, & HUD	NAV MODE SELECT HUD CONTROLS FLT/FLT DIRECTOR MODE SELECT	VOR/DME, ILS, MARKER BEACON, MLS, TRANSPONDER VHF COMM, FLIGHT DIRECTOR
			PILOT & COPILOT INSTRUMENT PANELS	MARKER BEACON LIGHT AND AUDIO CONTROL	
			TBD	ILS AND MLS TUNING, AND SPL FUNCTIONS CONTROL	
	PLANNING	CURRENT STATUS, WEATHER WINDS AND ATC PROCEDURES FOR AIRFIELD	VISUAL - TBD AURAL - TBD	TBD	ATIS
GLOBAL OPERATION-OVERWATER & UNCONTROLLED AIRSPACE	LONG RANGE NAV	AIRCRAFT POSITION	NAV	NAV MODE SELECT	INS OMEGA GPS
		DESIRED COURSE & COURSE DEVIATION	NAV & FLT	FLIGHT DIRECTOR MODE SELECT AND COURSE SET	
		TRUE HEADING AND DRIFT	NAV	TRUE/MAG HEADING SELECT HEADING SET	
		GROUNDSPEED	NAV & FLT MGT SYS	CDU	
		WIND DIRECTION & VELOCITY OR MEAN EFFECTIVE WIND		TBD	
		DISTANCE TO WAYPOINT	NAV		
		TIME TO WAYPOINT	NAV		
		FORECASTED EN ROUTE WEATHER	TBD	TBD	CDWI
	AIRCRAFT CONTROL	IMC FLIGHT PARAMETERS (SAME AS LISTED UNDER ADVERSE WX-IMC)			
	LONG RANGE COMM WITH ATC AND COMPANY SELECTIVE PAGING	COMM FREQ	TBD	HF COMM TUNING, AUDIO SELECTION MONITOR, & SPL FUNCTIONS CONTROL	HF (SSB)
		DATA LINK CODE		DATA LINK CONTROLS	MODE-S TRANSPONDER, ACARS
		PAGING ALERT SIGNAL	TBD	SELCAL CONTROLS	SELCAL
					VOICE INPUT/OUTPUT

Figure 4. Portion of Functional, Information, and Control Requirements Table

FLIGHT PHASE: TAKEOFF & CLIMB	INFORMATION				FUNCTION
TASKS	CONTENT	SOURCE	DESTINATION		
			TWO CREW	Δ FOR THREE CREW	
33. Receive departure instructions, Note 4	(SID clearance or vectoring)	Departure Controller	P1, P2		Communications
34. Initiate "after takeoff/ climb checklist"	Checklist items	Checklist/display/voice	P2		Communications
35. Complete after takeoff/ climb checklist	Checklist items	Checklist/display/voice	P1, P2, respond	P3	Systems control/ status
36. Contact company*	See note below	Systems displays, cabin crew	Company, ACARS, voice command	P3	Communications
*This is a continuing function covering items such as: needed maintenance, fuel usage, needed fuel, passenger info, etc.					
37. Select desired hdg/select flt director mode	Departure hdg	Departure controller	P1 - operates		Systems control
38. Select VS or FPA mode/ assigned altitude	Mode, altitude	Company procedure	P1 - operates		Systems control
39. Engage autopilot	A/P status	Company procedure & P1	P1, A/P control		Systems control
NOTE: (1) FMS automatically captures/holds 250 Kts IAS. (2) At this point, P1 may or may not replace heading with HNAV. If there are avoidable thunderclouds, he will stay on hdg and request a deviation from ATC. (HNAV would provide guidance from the stored SID					
40. Engage autothrottle	Autothrottle	P1 company procedure	Autothrottles control		Systems control
41. Engage flight mgt sys	Control status	Flight manual	P1 - selects		Systems control
NOTE: FMS automatically captures/holds 250 Kts IAS below 10,000', then best IAS.					
42. Confirm arriving at checkpoints	Checkpoint arrival - ETA next checkpoint	P2	P1, flight log		Communications, admin
43. Monitor climb/level off - intermediate altitude	Thrust, acceleration, airspeed, altitude, attitude	Flt/engine instruments	P1		Aircraft guidance/ control
44. Departure/enroute handoff, Note 4	"Contact enroute control - freq XXXX"	Departure controller	P2		Communications
45. Receive and confirm altitude clearances, Note 4	Clearance instructions	ARTC	P2		Communications
46. Notify ATC leaving intermediate altitude, Note 5	Aircraft identity - "leaving altitude"	P2 - altimeter	ATC		Communications

Figure 5. Portion of Crew Functions Table

DISPLAY / CONTROL USAGE TABLE

Page 1

SYSTEM/SUBSYSTEM	TIME FRAME		FLIGHT PHASE										
	1970'S	1990'S	CONTINUOUS	PRE-FLIGHT	ENGINE START	AFTER ENGINE START	TAXI OUT	TAKEOFF AND CLIMB	CRUISE	CRUISE/ DESCENT TRANS.	DESCENT	APPR LAND	TAXI IN
FLIGHT DISPLAY													
Controls													
Power	X	X		X									X
Brightness/Contrast		X	AR										
System Test		X		X									
Barometric Pressure Set	X	X		X				X	X		X		
Alternate Computer		X	AR										
Alternate Signal Generator		X	AR										
Alternate Display		X	AR										
Alternate Air Data Computer	X	X	AR										
Alternate Flight Director		X	AR										
Alternate Attitude Source	X	X	AR										
Display Format Controls													
Flight Mode Select													
Takeoff		X		X			X	X					
Go Around		X	AR										
Climb		X						X					
Cruise		X							X				
Descent		X								X	X		
Approach		X										X	
Land		X										X	
Time/Path (4-D)		X						X	X	X	X	X	
Mach/IAS Bugs	X	X		X				X	X	X	X	X	
Radar Altimeter Set	X	X		X							X	X	
Flight Path Angle Set		X						X	X	X	X	X	
Information to be Displayed													
Attitude	X	X		X				X	X	X	X	X	
Attitude Reference	X	X		X				X	X	X	X	X	
Mach	X	X		X				X	X	X	X	X	
IAS	X	X		X				X	X	X	X	X	
Bank Pointers	X	X		X				X	X	X	X	X	
Pitch Reference	X	X		X				X	X	X	X	X	

Figure 6. Portion of Display/Control Usage Table

an as-required basis. These tables were particularly useful in developing electronic display formats tailored to the flight phase.

Preliminary decisions were made on task loading and allocation of function between crew members, and between the crew and the machine. This process was iterated numerous times during the design and testing phases.

Note: Figures 3, 4, 5, and 6 are examples from Reference 2, "Mission Analysis Documents for Development of 1995 Flight Station," which contains the scenario and tables in their entirety.

DESIGN PHASE

The design process started by making general decisions on the projected air vehicle. The aircraft was characterized during a series of workshops where forecasts of technology from each discipline were examined by all team members, along with how each was affected by the mission scenarios and operating environment. This procedure is depicted in Figure 7. The resulting conceptual design has the characteristics described in the following paragraphs. The specifics on each system are described in detail later in this report.

Aerodynamics

Aerodynamically, the selected aircraft is configured with conventional planform, high aspect ratio wings, advanced airfoils, and winglets (for aircraft with restricted ground operating space). Laminar flow control technology was considered, but it was determined that it will not mature until the late 1990s.

Avionics

Data buses for the aircraft include dedicated buses for critical functions, fiber optic transmission, multiplex data buses for communication between the computers and the aircraft functional systems, and very high speed buses for radar/video data. Computers in the 1990s will be smaller and faster with more memory, fewer components, very high speed integrated

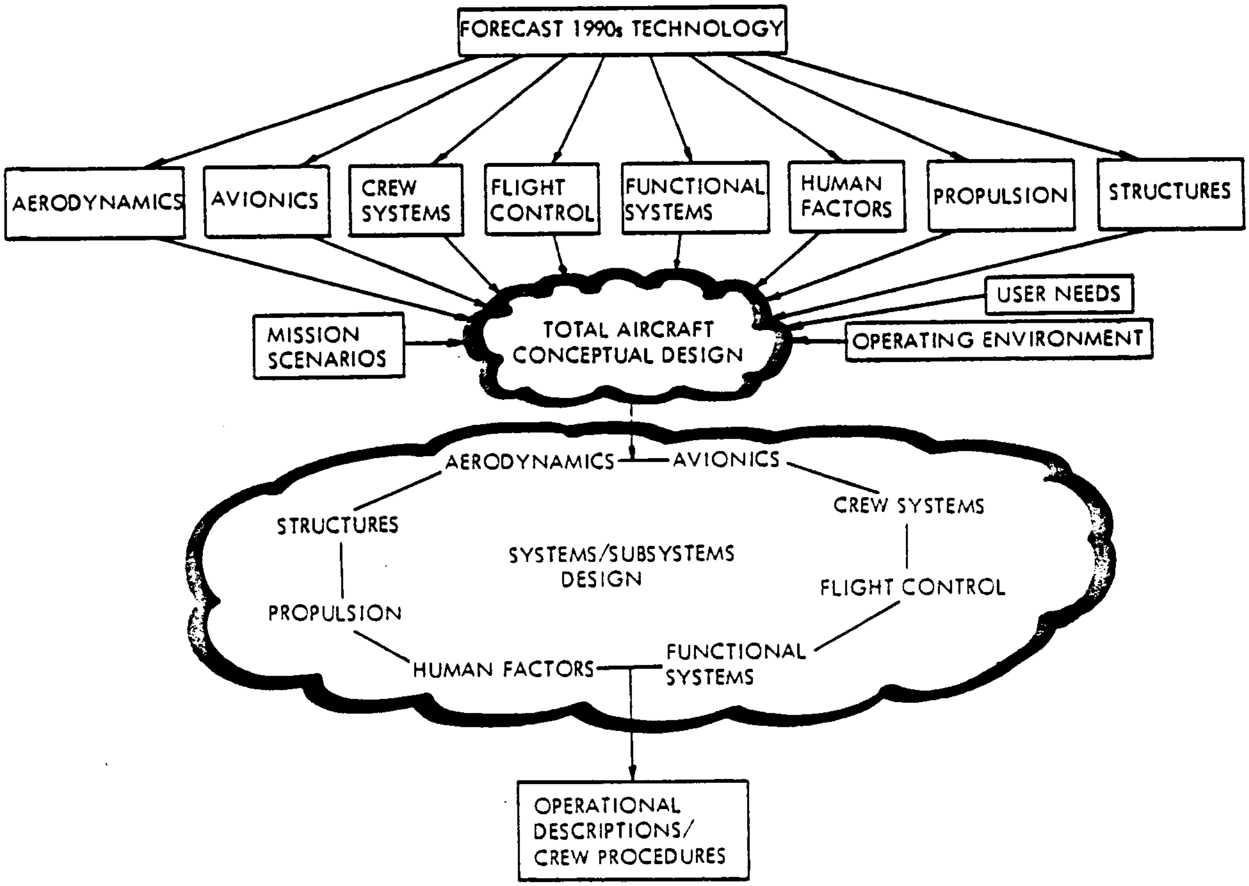


Figure 7. Design Team Functions and Interactions

circuitry, and customized large scale integration circuits. The displays are a combination of large screen color CRTs, small monochromatic flat panels and projected or holographic head-up displays. Navigation systems include VOR/DME, ILS, MLS, Laser Inertial, GPS, and 4D RNAV. Communications systems include VHF and HF voice and data, ARINC communications addressing and reporting system (ACARS), and transponder Mode-S with data link. The flight management system integrates flight control, navigation, propulsion, performance management, air traffic control systems, cockpit alerting and warning systems, and air data.

Flight Controls

The advanced active controls provide load alleviation, automatic tailored lift, and flutter mode stabilization. A digital fly-by-wire/light system with all-electric flight surface actuators is employed. Although forecasts did not identify this technology as maturing by 1990 due to insufficient funding (since so many issues are involved with its ultimate implementation), it is included in the design so that these research issues may be addressed in simulation.

Functional Systems

Electrically powered environmental systems rather than bleed air provide air conditioning, heat, and anti-ice/deice capabilities. Even though hydraulic system technology is forecast to become more lightweight through the use of very high pressure systems using very high density fluid, hydraulic systems were not included in the design. This is made possible by great strides in the application of electrical power. All functional systems operate from an electrical system with the following characteristics: variable speed AC generating system; high efficiency power conversion for regulated power (AC-115 volt, 400 Hz, 3 phase and DC-270 volt, 28 volt and low voltage); distribution through remote controlled solid state r -
controllers; and automatic priority load shedding through digital con
The fuel system uses dense JP type fuel, full authority digital fuel
trol, and has an integral fuel heating system. The landing gear syst

electrically operated and has carbon composite brakes. An on-board generating system provides crew breathing oxygen and fuel inerting nitrogen, and at the same time provides heat for the fuel system.

Propulsion

The aircraft is powered by an advanced technology turbofan propulsion system, which uses full authority digital electronic engine control.

Structures

Greater use of composite materials lightens the aircraft structure. New technology in windshields makes them moisture repellent and reduces the requirement for windshield wipers during the takeoff and landing phases of flight.

Human Factors

The conceptual design incorporated human factors principles wherever possible to assure an optimal baseline of crew performance. In the 1995 timeframe, this objective will be aided by the use of computer aided design and evaluation techniques.

The basic geometry of the flight station was laid out so as to maximize both internal and external visibility and locate all controls and displays in the flight station within the normal cones of vision and reach. The anthropometric ranges of the design will accommodate from the fifth percentile female through the ninety-fifth percentile male. Voice interfaces are also used to reduce anthropometric limitations.

Workload will become increasingly more critical as the two-pilot crew becomes more common and new systems are introduced. The balance between manual and automatic tasks has been allocated to control workload while maintaining a reasonable level of pilot interaction. Provisions were incorporated for software reallocation of tasks as dictated by research findings.

Information presentation was the most extensive area of human factors concern in the design because of the number of electronic displays incorporated in the flight station. Based on extensive analyses, the displayed information was carefully tailored to flight phase and requirements. Specifications for format symbology were carefully assessed so that legibility requirements are compatible with display characteristics. A detailed color coding specification was also developed to ensure that this feature is applied in a manner which aids pilot performance. Provisions have been included to permit the addition of advanced displays.

Crew Systems

Technology advancements in many other disciplines impact the crew systems, making possible the side-stick controller, non-mechanical throttles, large screen color electronic displays, touch panel controls, head-up displays, many applications of voice command and response, multi-legend switches, and control/display units. Aircraft systems management/operation are made easier through the use of tailored logic developed during the design process.

Since the resulting design is being installed in a full mission research and development flight simulator, heavy emphasis was placed upon the design of crew systems and the development of operational systems descriptions. Crew systems are defined as the interface between the aircrew and aircraft systems including controls, displays and operational procedures/logic; that portion of the aircraft systems/subsystems that are affected by the aircrew. All other aircraft functional systems terminate as their own entity when they arrive at the cockpit, at which point they become part of the crew systems. The control and display of crew systems are designed to provide the operator with the optimum amount of information to perform a given mission, controlled in the most effective way for the operator.

As with the other systems, the requirements for crew systems were developed after an indepth analysis of the proposed aircraft missions, operating environment, and available technology (avionics, hardware, software). The systems were first described by operationally oriented personnel (mainly pilots) in terms of what functional requirements must be performed, what information the pilots need, and the best type and amount of control. Manual versus automatic was considered, and the logic used in operating the system to perform the mission was described. It was through this analytical process that design criteria were developed and crew systems integration requirements were defined.

The design of the crew systems included defining dedicated and multifunction panels as well as developing formats for electronic displays. In conjunction with this, very detailed descriptions of the operational logic and procedures used by the crewmembers were prepared.

MOCKUP FABRICATED AND CONFIGURED

In a parallel and closely coordinated effort, the size and geometry of the major flight station components such as the panels, consoles, controls, and displays were determined and the components fabricated. Relatively inexpensive soft mockups were then constructed from wood and Fome-Cor, with panels and consoles laminated with a thin ferrous sheet. Control or display representations mounted on magnetic backed 1/4-inch Fome-Cor were attached to the panels. This full scale mockup of the major components was then enclosed in a shell representative of a generic wide-body flight station. Paper and pencil studies on reach and vision, performed earlier in the process, were checked in the mockup. The mockup was also used during the design of individual crew systems panels to check the configuration for visual and physical accessibility and ease of operation.

DESIGN EVALUATED AND REFINED

The design was tested using a very structured evaluation process that caused the test subjects to consider all aspects of the design in a mission context. Figure 8 depicts an evaluation scenario which was developed to address all facets of a transport mission that the crew might encounter. The mission was divided into a series of small units which, when examined individually, became a slice-in-time. Aircrew operating procedures and checklists were defined. Flight mission materials were obtained or prepared including charts, flight plans, Jeppesen flight publications, simulated weather briefings and performance data for takeoff and landing.

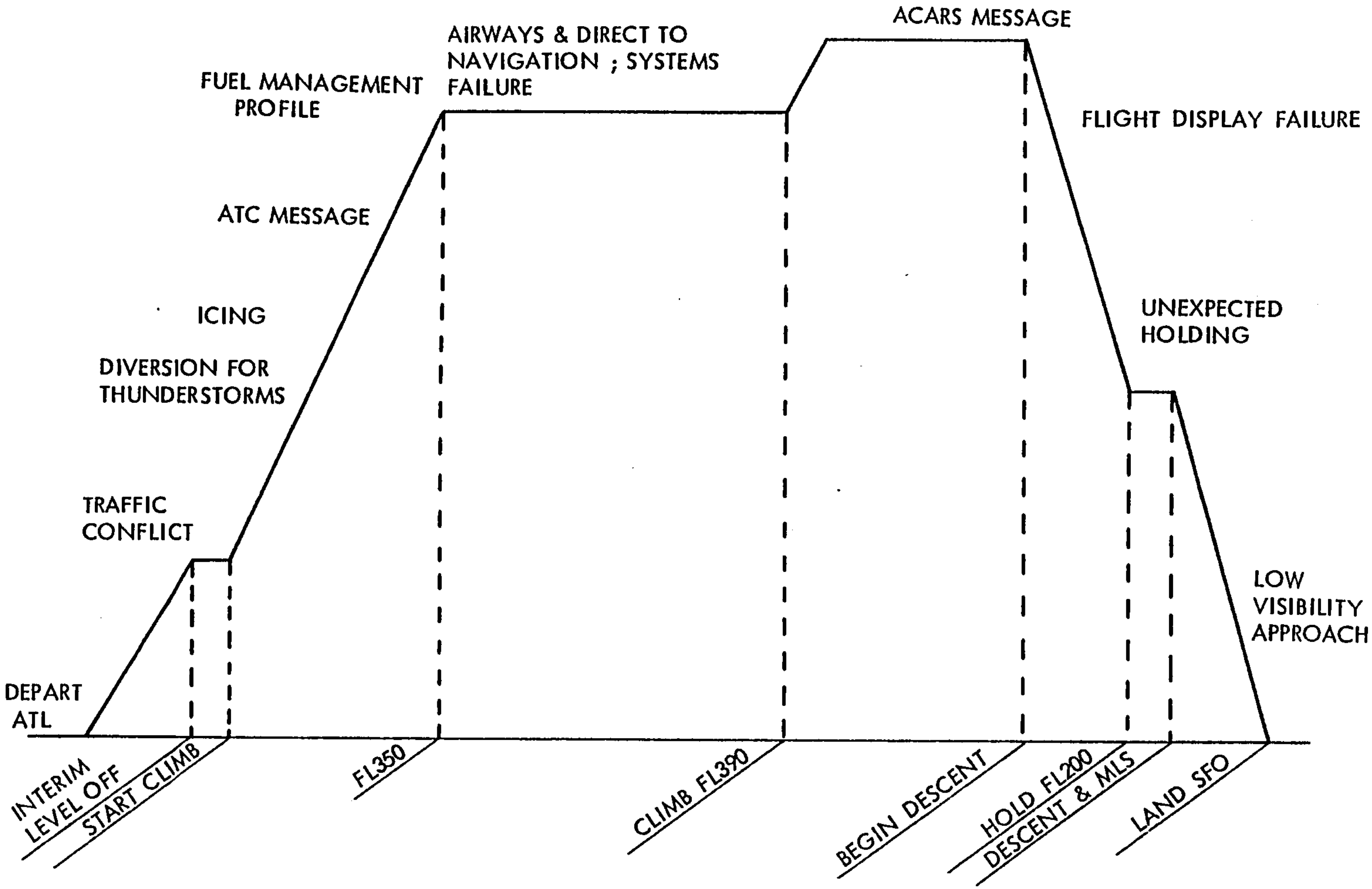


Figure 8. Mission Scenarios Flight Profile

Five two-pilot crews made up of experienced line pilots currently flying commercial transport aircraft, NASA test pilots, and Lockheed flight operations pilots were test subjects. Their qualifications and experience are shown in Figure 9. They received comprehensive classroom training on the new systems and were briefed on the mission to be flown including route, weather, and payload. They evaluated the design by "flying" slice-in-time mission scenarios by pretending to operate the Fome-Cor controls and displays in the flight station as shown in Figure 10. The flying sessions were structured to expose them to all elements of a 1995 transport mission. Very detailed questionnaires were developed which addressed comprehensive design and workload issues. Comments and critiques, recorded during the two-to-three-day-per-crew evaluation and on the questionnaires, were used to refine the design. The design, as refined, and the operational systems descriptions constitute the body of this report.

EMPLOYER	QUALIFICATION	TYPE A/C	FLYING HOURS
NASA	CAPT	B 737, G 159	7,000
NASA	CAPT	B 737, G 159	7,000
DELTA	CAPT	DC-9, B 727	10,000
DELTA	F/O	L-1011, DC-8	10,000
DELTA	CAPT	B 727, DC-9	18,000
EASTERN	CAPT	A 300, B 727	11,000
EASTERN	CAPT	B 727, L-1011	15,000
EASTERN	S/O	B 727, KC-135	5,000
LOCKHEED	CAPT	C-130, KB-50	6,000
LOCKHEED	CAPT	C-130, RC-135	4,000

Figure 9. Test Subjects

Figure 10. Flight Station Evaluation

DESIGN CRITERIA, PHILOSOPHY AND RATIONALE

The flight deck design criteria give primary consideration to placing the crew members in an environment where they can efficiently, effectively, safely, and comfortably perform their duties. The pilots must receive the proper amount of information at the right time to permit them to make necessary decisions and perform the operational mission. The necessary information must be presented adequately (i.e., easily interpretable and readily available). The accessibility of the information and controls must be proportionate to the frequency and criticality of use. The cockpit environment must physically and psychologically aid, rather than reduce, the pilots' efficiency.

Since this flight deck will be part of a research facility, it will be used to investigate different methods of providing information and control of various aircraft systems and other systems with which the aircraft interfaces. Integration of information from the various sources will be examined, including that from the improved air traffic control systems and the national airspace system.

The research facility must provide the capability to examine these integration issues as they pertain to the flight deck and the flight-deck layout must be flexible enough to permit this research.

CREW COMPLEMENT AND FLIGHT STATION CONFIGURATION

The flight station for the advanced concepts flight simulator was designed for safe and efficient operation by a two-pilot crew during the 1990s. The criteria for configuring the flight station were that all controls pertinent to operation of the aircraft should be accessible for operation by both pilots for three reasons. First, this permits the aircraft and all systems to be operated by the pilot sitting in either seat; second, it provides the flexibility for either pilot to perform any or all functions in event of overload or incapacitation; and third, it provides flexibility necessary for "normalizing" operation as much as possible during degraded mode operation. For instance, if a front panel electronic display fails, information/touch panel control from that display can be readily transferred to another display where it can be used by either pilot.

SWITCHES

Most of the controls are of the lighted pushbutton variety, which are easy to use; offer a clean, less cluttered appearance; and eliminate protrusions on which to bump the head, knees, or other body parts. While the switch labels are readable under any lighting conditions, the circuits are designed so that the switch lights are only illuminated for abnormal conditions. This provides for a dark cockpit with all systems/switches normal.

TAILORED LOGIC

The displays are mainly multifunction with the information presented being tailored to the needs of the pilot for the specific phase of flight or task that is being performed. The specified information presented is preprogrammed by event; however, the pilot has the capability to change, add, or delete from that as he deems necessary. The computer system has tremendous monitoring capability and also provides automatic switching in event of some malfunctions, where the course of action can consistently and safely be preprogrammed. The general philosophy, however, is to keep the pilot in the loop by presenting him with information and possible courses of action, and letting him make the decisions.

FLIGHT DECK SYMMETRY AND PRIMARY CONTROLLER LOCATION

Several different arrangements of controls and displays were evaluated to determine the best candidate for the pilot's desk flight station. The arrangement of information on the front panel CRTs is detailed in the section on that subject. As with present-day transports, during normal operation the flight display is directly above the navigation display, located on the captain's and first officer's centerline. Depending upon the weather conditions and air traffic environment, approximately 70 to 90 percent of each pilot's time is concentrated on those formats. In this design the information on each CRT (captain's and first officer's flight and nav) is formatted the same; that is, the airspeed, altitude, attitude, flight path, and all other symbology are identical between the two positions, not a mirror image. The other information is displayed inboard from the primary flight display, much the same as with all modern transport aircraft where engine instruments and cautions and warnings typically occupy the center instrument panel. Flexibility permits the pilots to switch total information formats between the second and fourth displays (depending on which pilot is flying the aircraft), while information critical to both pilots on the center display (caution and warning) would not normally be transferred, unless a display failure had occurred.

In determining the best arrangement for the primary flight controllers, five different designs, sketched in Figure 11, were evaluated against the criteria listed below. The number and location of the primary controllers vary between designs; but, with one exception, the front panel displays remain constant.

- o Symmetry - the design similarity in the arrangement of controls and displays between the captain and first officer positions
- o Operational Utility - the degree to which all mission requirements can be performed by either pilot
- o Display Visibility - the degree to which the primary and secondary controllers do not obstruct the vision of the CRT and other displays
- o Clutter - the degree of crowding caused by the number of controls and displays
- o Cost - cost relative to a lower-cost candidate

Design A is a side-by-side configuration of two single-pilot flight stations, each equipped with controls for thrust, flaps, gear and virtually all other functional systems; three CRT displays; and dual primary controllers. While this symmetrical design meets the operational flexibility requirements, requires less cross-training between pilot seats, and may require less workload than an asymmetrical design, crew coordination and communication are degraded because the configuration would probably require

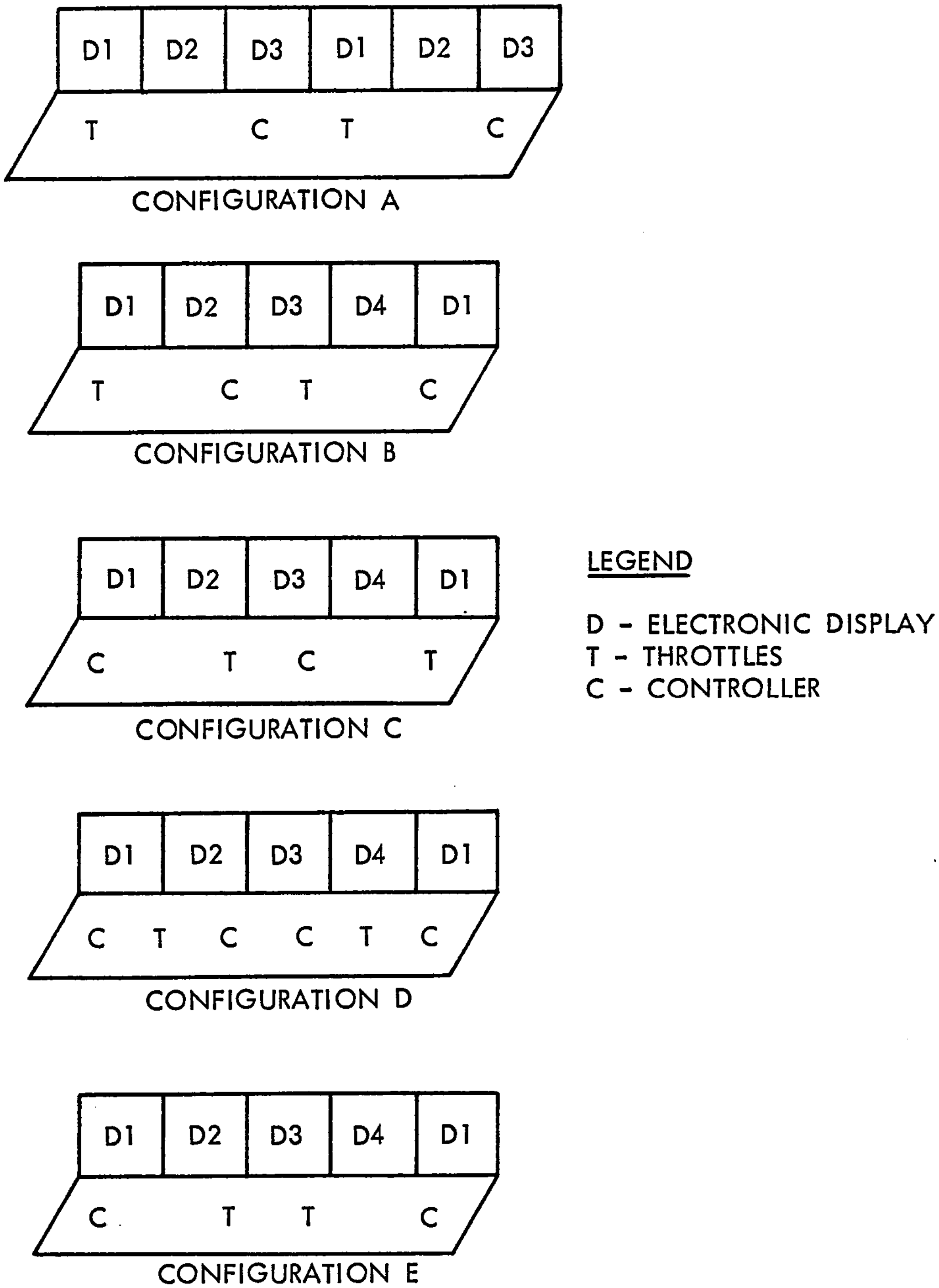


Figure 11. Sketches of Configuration Tradeoffs

that the displays be positioned so that all six could not be observed by both pilots simultaneously. This, then, would require additional communications between the pilots to coordinate information. In addition, although this interesting concept appears operationally feasible, it is thought to be unrealistic because of cost. The penalties of this design include higher initial cost of hardware, as well as the operating costs imposed by the extra weight, and a much higher degree of clutter in the flight station. There may also be difficulty in providing adequate over-nose vision.

Design B provides each pilot with a right-hand controller, left-hand throttles, and identical flight/nav displays. It divides the remaining controls and displays according to the tasks allocated for each pilot. Although this design works well for aircraft with some military missions (such as F-111), it does not provide the operational flexibility required for commerical airline operation. The left-seat pilot cannot conveniently reach the secondary controls allocated to the first officer without releasing the primary controller, and the secondary controls allocated to the left-seat pilot are completely out of reach of the first officer. An additional problem is that the captain's right-hand controller obstructs his vision of the lower portion of the center CRT.

Design C has a left-hand controller, right-hand throttles, and identical flight/nav displays for each pilot. The remaining controls and displays are shared. The major disadvantage of this design is that the right-seat pilot cannot operate the shared controls without releasing the primary controller. This unnecessarily restricts normal activities of an instructor pilot while performing flight demonstrations and a copilot while performing flight control tasks. Additionally, in this configuration the copilot's left-hand controller will obstruct his vision of the center CRT.

Design D has dual controllers and a set of throttles for each pilot as well as identical flight/nav displays. All other controls are shared. This design proved to be very cumbersome to use because it was frequently necessary to switch hands between the controller and throttle, and vice versa, in order to operate secondary controls. It was not operationally acceptable for either the captain or the first officer. The dual controllers for each pilot contribute specifically to the clutter in this configuration.

Furthermore, vision of the center CRT is obstructed for both pilots by the inboard controller in each position.

Design E has a left-hand controller for the captain, a right-hand controller for the first officer, dual sets of throttles, and identical flight/nav displays; all other controls and displays are shared. This design has high operational utility and low clutter at baseline cost. In addition, the controller location provides both pilots with an unobstructed view of all CRT and auxiliary displays.

The mirror image primary flight controllers on the desk top are not far different in principle from those proven in today's transport aircraft. In both cases, the pilot in the left seat controls the aircraft with his left hand while operating throttles and other systems controls with his right hand. The first officer, when controlling the aircraft, does so with his right hand, while operating throttles and other systems controls with his left hand. Pilots, whether naturally left handed or right handed, quickly adapt to operating from either seat; but, if necessary, this transition can be aided through training in a flight simulator. While the chosen design is not ideal in every way, the rationale for location of the controls is as follows:

- One of the pilot's hands should be available continuously for primary controller operation. Any other time-critical control to be operated by this hand must be located so that the hand does not need to be removed from the primary controller for operation. Controls that do not require immediate access (non-time-critical) may be located for operation with the primary-controller hand.
- The throttle hand may be used for operation of throttles as well as any other controls.

In determining that only a single controller is required, the following considerations were made. In today's transport aircraft, where massive controllers may be required for mechanical leverage during normal or degraded flight control mode operation, two-handed or right-handed operation is sometimes necessary in order to obtain maximum muscle force from the majority of the pilot population. The all-electric flight control system in this design does not require or have a mechanical backup system. Even the "manual" flight control modes are augmented, so the question becomes one of dexterity, not strength. The simplicity of the system design permits either left-handed or right-handed pilots to operate it regardless of their dexterity. The grip chosen for the controllers is primarily to house switches such as trim, autopilot disconnect, microphone, voice command activate, and trim disconnect. Additional research may identify a more suitable controller such as a trackball, slim stick, or one that resembles those used for remote controlled model aircraft if the necessary switching functions can be accommodated.

Figure 12 presents a rating matrix of the five designs, rated against the five criteria; the lowest score is best. Design E, which had the lowest score, was selected for the configuration.

CODING FOR CRT FORMATS

With the advent of large-screen color displays into the flight station, criteria were developed for the basic formats for the five front-panel CRTs. Guidelines were developed to define color coding: symbology; font characteristics (i.e., sizes, stroke widths, etc.); and symbol logic. In each case the scheme is simple to learn and understand, and is applied in the same manner to all formats. An explanation of the color coding, symbology, and symbol logic guidelines is presented below.

Color Coding

Three special-purpose colors and four primary coding colors are the maximum recommendation in any format to avoid the overuse and degradation of the benefits of color. The color assignments reflect the level of importance of coded information. Special-purpose colors used are black for background; cyan for flight display sky; and desaturated orange as a segmenting color. The primary coding colors are red for warning, time-critical messages, and failures; amber for caution, non-normal situations, high-level information, and critical settings; white for advisory, moderate-level information, and fine details where high legibility is required; and green for safe, normal, general or low-level information.

	SIDE BY SIDE DUPLICATE	DUAL RIGHT HANDED CONTROLLERS AND LEFT HANDED THROTTLES; OTHER CONTROLS ALLOCATED BY TASK	DUAL LEFT HANDED CONTROLLERS AND RIGHT HANDED THROTTLES; OTHER CONTROLS SHARED	DUAL CONTROLLERS FOR EACH PILOT PLUS SET OF THROTTLES; OTHER CONTROLS SHARED	PILOT: LEFT HANDED CONTROLLER COPILOT: RIGHT HANDED CONTROLLER DUAL THROTTLES; OTHER CONTROLLS SHARED
	(A)	(B)	(C)	(D)	(E)
SYMMETRY	1	2	2	2	3
OPERATIONAL UTILITY	2	3	3	4	1
DISPLAY VISIBILITY	2	3	3	4	1
CLUTTER	5	2	2	4	2
COST	4	1	1	2	1
TOTAL SCORE	14	11	11	16	8

NOTE: SYMMETRY, OPERATIONAL UTILITY, DISPLAY VISIBILITY AND CLUTTER USE SCALE I; COST USES SCALE II.

SCALE I

1 - EXCELLENT
2 - GOOD
3 - FAIR
4 - POOR
5 - BAD

SCALE II

1 - BASELINE
2 - SLIGHTLY HIGHER THAN BASELINE
3 - MODERATELY HIGHER THAN BASELINE
4 - SIGNIFICANTLY HIGHER THAN BASELINE

Figure 12. Rating Matrix for Controller Location

Symbology

The major coding requirement for symbology is the need for consistency, especially when there is a large group of related formats in the design, such as the functional systems formats. It is also necessary for the symbology to be compatible with the color-coding scheme and the symbol logic. Several examples of the applied symbology consistencies are:

- o Touch-panel menu switches are single squares color-coded green.
- o Touch-panel switches on functional systems formats are double squares with the outer box color-coded white.
- o Primary sources on functional system formats are represented by circles color-coded white.

Figure 13 illustrates additional symbology used in developing the various functional systems formats. Aspects of the symbol logic are inherent in the switch representations for ON and OFF illustrated in the figure.

Symbol Logic - The following examples of the symbol logic are used across the various display formats. It should be noted that, in many cases, there is a direct interaction between the symbol logic, symbology, and color coding.

One example pertains to the touch panel menus on formats where the legend for the switch that has been selected is highlighted. The rationale is to readily identify the choice that has been made.

A second example is in the difference between flow and nonflow in fuel, electrical or environmental system lines. Nonflow conditions are represented by nonfilled lines, and flow conditions are represented by filled lines. Color coding of the lines indicates the status of the pressure or voltage in the lines. The following convention is used:

- o White unfilled flow line - no flow, current, pressure, or voltage in line.
- o Green unfilled flow lines - normal pressure or voltage in lines but no flow or current.

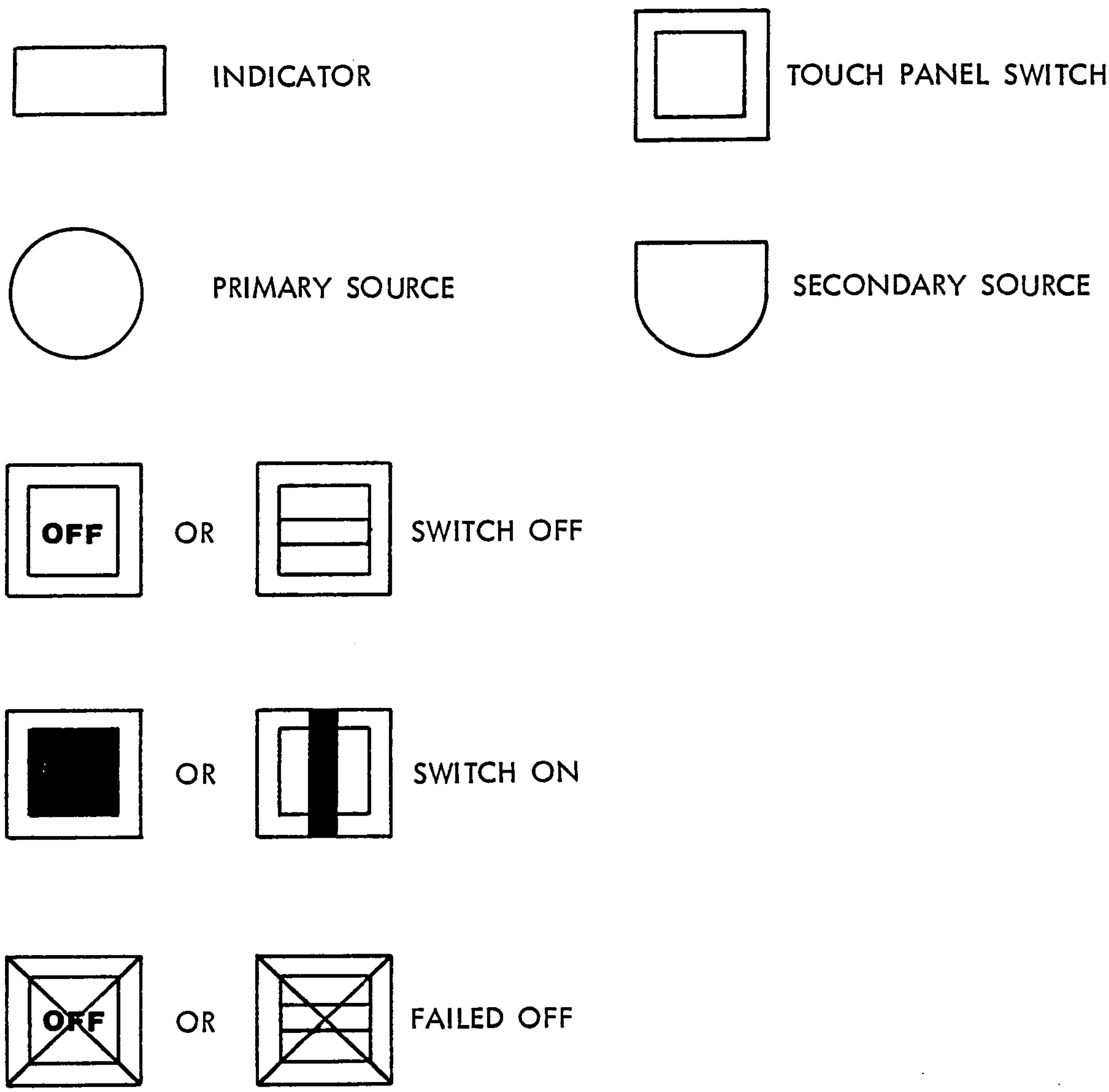


Figure 13. Examples of Symbology on Functional Systems Formats

- <u>Green filled flow line</u> - normal flow or current in line under pressure or voltage.

- <u>Amber filled flow line</u> - normal flow or current in line, but low pressure or voltage.

- <u>Amber unfilled line</u> - no flow or current and low pressure or voltage.

VOICE COMMAND AND RESPONSE SYSTEM

The voice command and response system in the baseline design has a single mode of speech recognition and three types of speech synthesis. The three types of speech synthesis are continuously varying slope delta (CVSD) modulation, linear predictive coding (LPC) speech, and text-to-speech.

The voice systems requirements are listed in Tables 1 and 2. Table 1 lists the voice input and output requirements for the baseline design, and Table 2 lists those functions which may have voice requirements in post-baseline refinements.

TABLE 1

BASELINE VOICE REQUIREMENTS

Voice Input (Control)

1. Call up of formats/information on the three center displays, i.e., redundant to touch panel menus
2. Comm/nav tuning and frequency entry
3. Rain removal, e.g., on/off
4. Landing lights, e.g., on/off
5. Call up of control/display unit (CDU) pages
6. Enter navigation waypoints

Voice Output

Automatic

1. Barometric altitude alerts
2. Radar altitude alerts
3. Airspeed readouts
4. Time critical messages
    a. Positive action collision avoidance commands
    b. Windshear and windshear/go-around alerts
    c. Ground proximity warning system (GPWS) messages
    d. Landing gear warnings

Selectable

1. Readout of mode-S messages
2. Readout of ARINC Communications Addressing and Reporting System (ACARS) messages
3. Readout of Advisory, Caution and Warning System (ACAWS) messages
4. Takeoff and landing data (TOLD) information readout
5. Echo of voiced entries

TABLE 2

POST-BASELINE VOICE REQUIREMENTS

Systems Which May Require Voice Interface

1. Radar Panel - mode select, i.e., weather or turbulence (Wx-Turb)
2. Nav Display Panel - range selection, display symbology
3. Com/nav - transponder ident, active/standby transfer
4. CDU - scratch pad entry of text messages
5. Global Positioning System (GPS) - waypoint entry
6. Guidance and Control Panel (GCP) - Altitude, flight path angle, track, course, mach, and indicated airspeed set
7. Head-Up Display (HUD) - declutter modes, on/off
8. Cabin Advisory - seat belts, no smoking on/off
9 Landing Gear and Brakes (LDG/BRKS) - auto-brake on/off
10. Lights - taxi lights on/off
11. Systems display - all switches
12. Checklist display - item checkoff
13. Entry of mode-S transponder messages
14. Entry of ACARS messages

Systems Which May Require Voice Output

1. Echo of above items
2. Checklist - readout
3. Systems display - quantity readouts, status readouts
4. Engine display - parameter readout

AIRCRAFT DESCRIPTION

A generic transport aircraft was formulated and sized based upon projected user needs for 1995 and a forecasted technology cutoff date of 1990. A major variation in these projections exists however, because, although technically feasible and possible, whether an all-electric flight control systems will be certified by the FAA for civil transport aircraft by that date remains a question. In the interest of performing research on this subject, the design does incorporate this system.

The preliminary design culminated in an aircraft, shown in Figure 14, with the following characteristics:

- Wide-body
- Twin engine - 30,000 pounds thrust each
- Tee tail
- Low wing
- Max gross weight - 224,000 pounds
- Payload - 60,000 pounds at 2.5g
- Capacity - 200 passengers
- Speed - 0.78 Mach
- Range - 2500 nautical miles
- All-electric airplane (no hydraulics)
- Primary and secondary composites
- Fly-by-wire/light
- Negative static margin
- Supercritical wing
- Active flight controls
- Load alleviation
- High density fuel - 42,500 pounds useable
- Two-person flight station crew with center observer seat

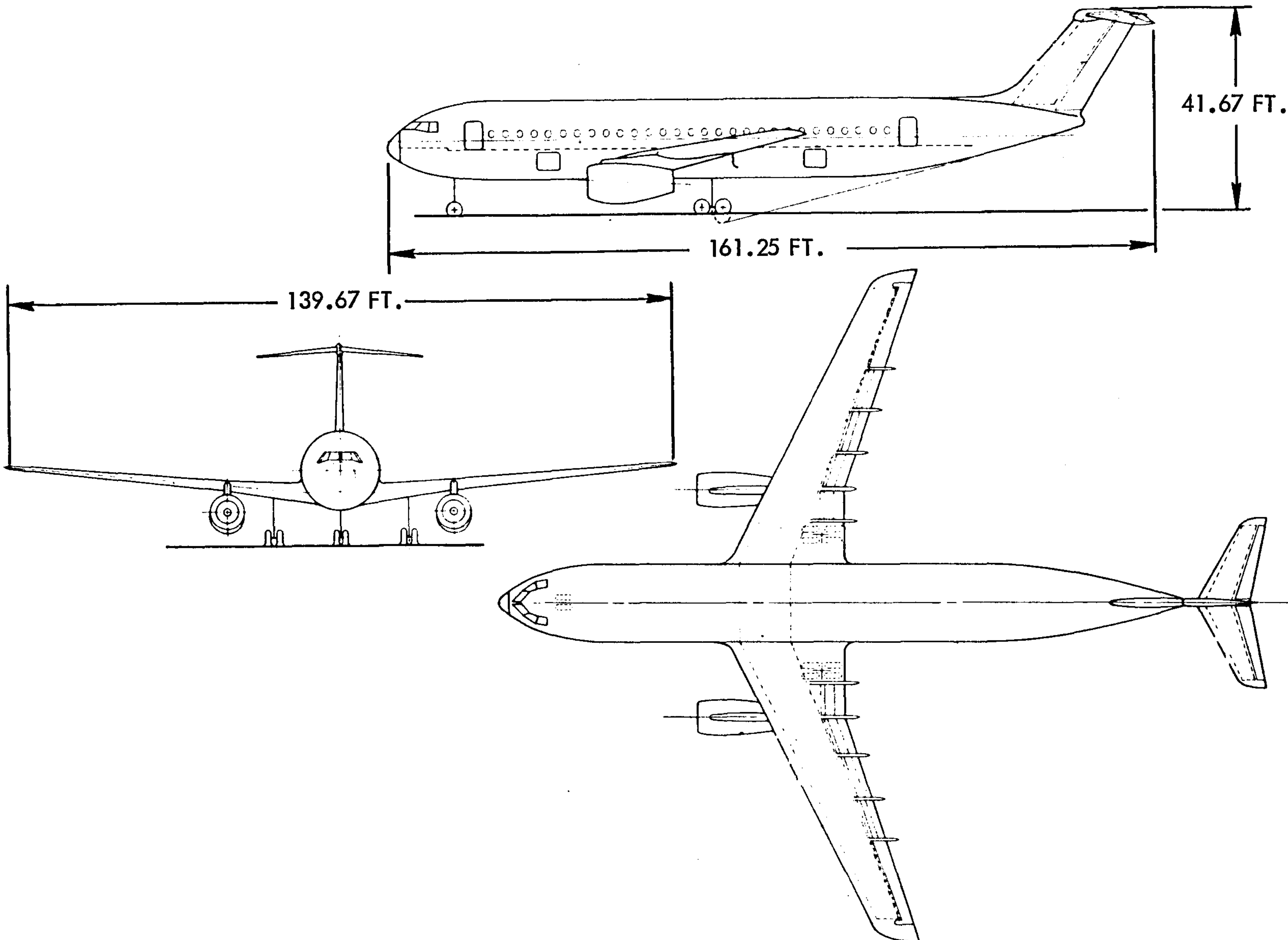


Figure 14. Generic Aircraft Being Simulated

CREW SYSTEMS DESCRIPTION

Crew systems were designed concomitantly with the design of the functional aircraft systems. During this process, descriptions of the systems and their operations were prepared.

The controls and displays are placed in the most convenient location for the pilots. Since the systems are so highly integrated, it is not feasible to present them according to their location in the flight station, such as main instrument panel, desk top, glareshield, center console, overhead console, and side pedestals. Therefore, an overview of the major components, by location, is provided here, but the systems descriptions are grouped more or less by function. Figure 15 shows the layout of the various components that make up the flight station, and Figure 16 is a photo of the pilot's desk flight station mockup.

MAIN INSTRUMENT PANEL

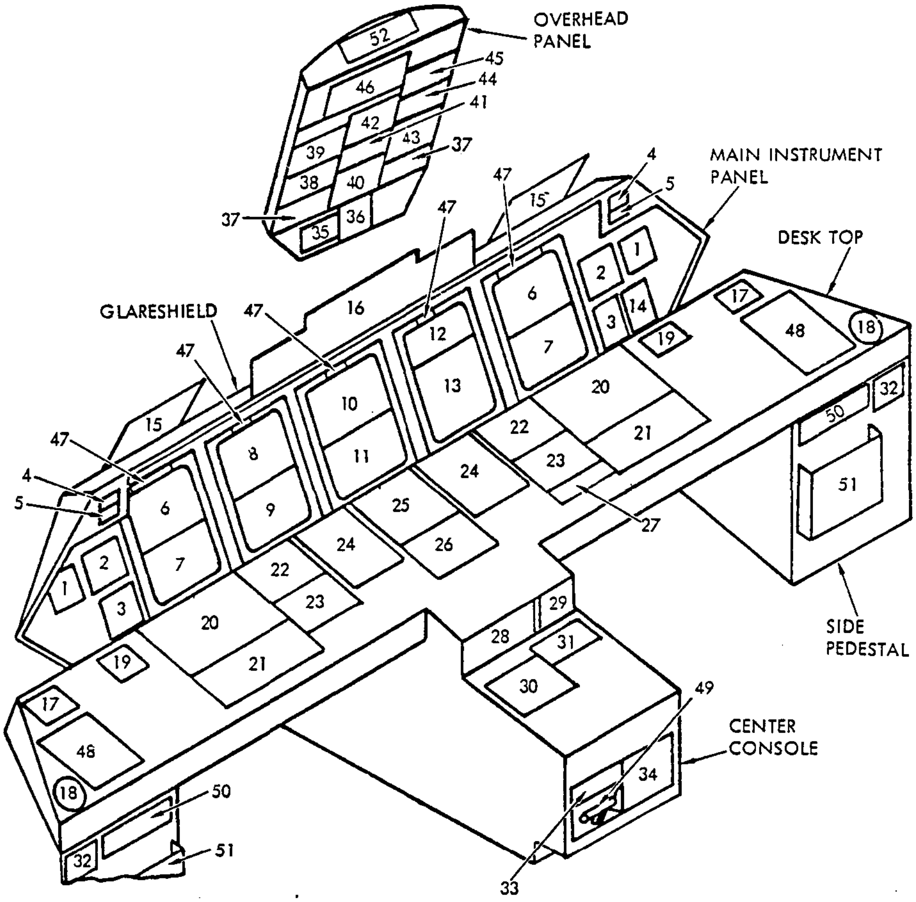
The main instrument panel contains five multifunction electronic displays (three center displays with touch panel overlays) upon which the majority of information for the pilot is presented and much of this information is controlled. Outboard of the multifunction displays on each side are a digital clock, a wing flap position indicator, and a CRT master brightness control. Additionally, there is a fuel quantity indicator on the right-hand side.

DESK TOP

The desk top contains the nosewheel steering controls, side-stick controllers, control/display units, integrated comm/nav system, throttles, parking brake, rudder pedal adjust, coffee cup holders, and ashtrays.

GLARESHIELD

The controls for the automatic flight control system, autothrottle engage, altitude alerting systems, barometric pressure and radar altimeter



1. MASTER CRT BRIGHTNESS
2. CLOCK
3. WING FLAP INDICATOR
4. MASTER WARNING LIGHT
5. MASTER CAUTION LIGHT
6. FLIGHT DISPLAY
7. NAVIGATION DISPLAY
8. ENGINE POWER
   ENGINE STATUS
9. CDWI
   JEPP
   ENGINE STATUS
10. ACAWS
11. CDTI
    OBSTACLE CLEARANCE
12. CHECKLISTS
13. SYSTEMS SCHEMATICS
    ENGINE STATUS
14. FUEL QUANTITY INDICATOR
15. HEAD-UP DISPLAY
16. GUIDANCE AND CONTROL PANEL
17. COFFEE CUP HOLDER
18. ASH TRAY
19. SIDE STICK CONTROLLER
20. FMC CDU
21. CDU KEYBOARD
22. NAV DISPLAY CONTROL
23. TRANSMIT/MONITOR CONTROL
24. THROTTLES
25. COMM/NAV FREQ DISPLAY
26. COMM/NAV FREQ ENTRY
27. ACARS/SELCAL CONTROLS
28. ALTERNATE TRIM CONTROLS
29. WING FLAP CONTROL
30. GPS CONTROL
31. RADAR CONTROL
32. MIC AND HEADSET JACKS
33. DATA TRANSFER MODULE RECEPTACLE
34. PRINTER
35. LAND LIGHTS AND ADV WX
36. LANDING GEAR CONTROL
37. HEAD-UP DISPLAY CONTROLS
38. FLIGHT CONTROL SYSTEMS CONTROLS
39. ENGINE START CONTROLS
40. LANDING GEAR/BRAKE PANEL
41. CABIN ADVISORY LIGHTS
42. INTERIOR LIGHTING CONTROLS
43. APU/EXTERNAL POWER
44. OXYGEN/EMERGENCY DEPRESS
45. COCKPIT VOICE RECORDER
46. FIRE CONTROL PANEL
47. CRT ALTERNATE SOURCE CONTROLS
48. NOSEWHEEL STEERING & PARKING BRAKE AND RUDDER PEDAL ADJUST
49. EMER GEAR RELEASE
50. STORAGE DRAWER
51. MAP CASE
52. EMER CIRCUIT BREAKERS

Figure 15. Flight Station Configuration

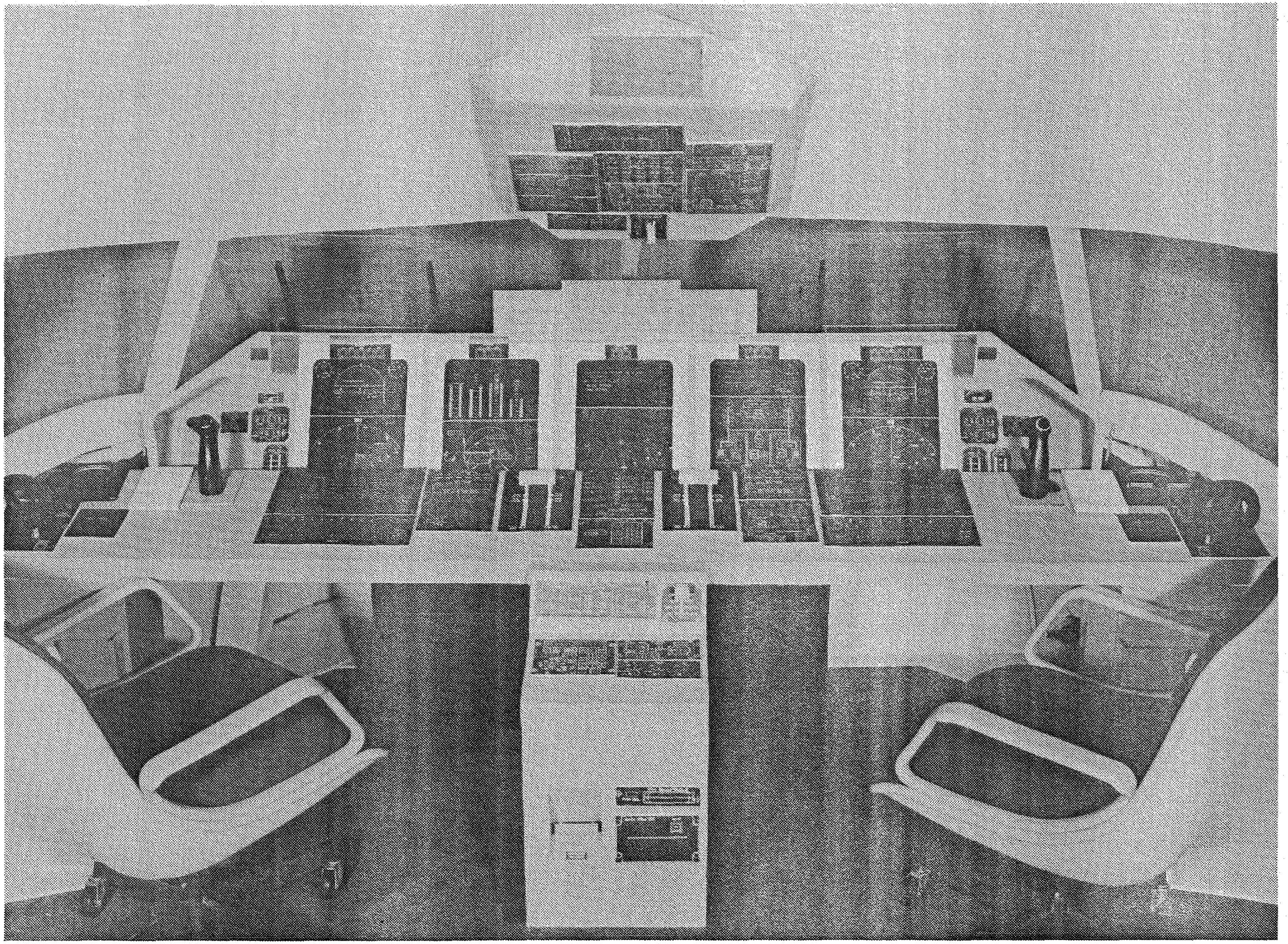


Figure 16. Pilot's Desk Flight Station Mockup

set knobs, and the master caution and warning lights are located on the glareshield.

OVERHEAD CONSOLE

The overhead console contains controls for the fire control system, engine start, flight control system, head-up displays, interior and exterior lights, landing gear, brake system, oxygen system, cockpit voice recorder, auxiliary power unit, adverse weather system, and emergency circuit breakers.

CENTER CONSOLE

The center console contains controls for the alternate trim system, wing flaps, global positioning system, radar, printer, data transfer module, and emergency landing gear release.

SIDE PEDESTALS

The side pedestals contain oxygen controls, smoke and oxygen mask storage, microphone and headset jacks, a drawer for storing papers, and a chart and map storage area.

FRONT PANEL MULTIFUNCTION DISPLAY SYSTEM

The multifunction display system (MDS) consists of five 13-inch diagonal cathode ray tubes (CRTs) with an appropriate number of symbol generators to provide redundancy in case of equipment failure. Control of the MDS is through CRT power/brightness controls, phase of flight switches on the guidance and control panel, two nav display control panels, alternate source select switches, barometric and radar altitude controls, and touch panel control faceplates over the middle three CRTs.

The symbol generators interface with all sensors and systems providing data for display to the pilots via the MDS. These data include flight paramemters; navigation information; engine and aircraft systems parameters; checklists; data-linked ground-to-air information; and advisory, caution, and warning system (ACAWS) information. These data are processed in the symbol generators and formatted into video signals for transmission to the appropriate displays.

Cathode Ray Tubes

The five multifunction displays are identical 13-inch diagonal, stroke/raster, high resolution, shadow-mask color CRTs. They are mounted on the front instrument panel side-by-side, long dimension in the vertical plane, with the outer one on each end centered as nearly as possible to butt line 21, the captain's and first officer's centerline position. The raster sweep for all CRTs is in the vertical plane to reduce the perceived stair-step effect on curved or angled borders of raster-generated areas, particularly the sky/ground area (horizon line) of the flight display. In the aircraft each display will have two light intensity sensors which automatically adjust the display brightness based on ambient light conditions, in addition to a manual override control. These features are not included in the flight simulation.

Symbol Generators

For the simulator, five apparent SGs are employed, one for each CRT, with capability to switch to an alternate SG in case of failure of one. The actual number of SG units which will be on an aircraft is undetermined, since an SG can be designed to have a single output port or multiple output ports. Thus, the term "symbol generator" may refer to a line replaceable unit (LRU) which in actuality contains "X" number of distinct and separate video formatting channels capable of providing "X" number of different flight station displays. Whatever the configuration, all SG LRUs are physically identical. Update and refresh rate goals are yet to be established.

Front Panel Display Formats and Switching Rationale

The CRTs are numbered according to position with number 1 on the left, through number 5 on the right, as shown in Figure 17. The information formats that are to be displayed on them are identified by the letters A through H. Some letters (A through H) are divided into subsets (e.g., A1, A2, A3) to indicate various formats that can be selected onto a specific area of the CRT via touch panel "menu" control or, in the case of the nav display, dedicated switches.

The following criteria are applied in determining which information should be displayed and whether it should be displayed continuously or selectively:

- Primary flight information (A), navigation information (B), and ACAWS information (E) must be displayed continuously.

- During normal operation, flight, nav, ACAWS, and cockpit display of traffic information (CDTI) must always be displayed in the same location.

- During CRT failure mode operation, the lower priority formats are grouped to share space on another CRT. The formats and sequence of information during this mode must remain consistent regardless of which CRT fails.

1	2	3	4	5
A	C	E	G	A
B	D	F	H	B

"FLYING PILOT" IN LEFT SEAT

1	2	3	4	5
A	G	E	C	A
B	H	F	D	B

"FLYING PILOT" IN RIGHT SEAT

Figure 17. Format Locations on Front Panel Displays

- Switching should permit the "flying pilot," whether in left or right seat, to place engine parameter displays adjacent to his flight display. Additionally, the functional systems schematics should be located adjacent to the "nonflying pilot's" flight display.

Formats - The formats which are displayed on the various sections of the CRTs, as shown in Figure 17, are shown below:

A Flight Display (flight-path, attitude, altitude, airspeed, time critical alerts, etc.)

Note: The formats on the captain's and first officer's flight displays are always identical with the exception of flight director symbology which can be individually selected. Information is tailored to phase of flight selected on autopilot panel.

B Nav Display

Note: Formats may be different on pilot's and copilot's nav displays. Information is varied according to selections made on nav mode select panel.

C1 Engine Power

C2 Engine Status

C3 Blank except for Menu

D1 Cockpit Display of Weather Information (CDWI)

D2 Instrument Approach Information (JEPP)

D3 Engine Status (same as C2)

D4 Blank except for Menu

E Advisory, Caution and Warning (ACAWS)

F1 Cockpit Display of Traffic Information (CDTI), which is an airborne display

F2 Obstacle Clearance Detector (TIP CLR), which is a ground display

G1 Checklists

G2 Blank except for Menu

H1 Functional Systems Schematics (electrical, environmental, fuel, flight control surfaces position, lighting, com/nav, adverse weather)

H2 Engine Status (same as C2)

H3 Blank except for Menu

CRT Failure Conditions

Information from a failed CRT may be displayed on a different CRT as shown in Figures 18 and 19 and described below.

Display Switches

The displays are controlled through touch panel switches, hardware switches, and voice command. Each is described below.

Touch Panel Control - Touch panel overlays are used for the three center CRTs (2, 3 & 4) to enable direct interaction between the pilots and the displays. The control logic is tailored to the format being displayed. The display system correlates the grid coordinate of the pilot's finger with the display and, through program logic, determines the action required (e.g., check-off checklist item, send a discrete signal to a switch/valve control, call up a new display). The signal is then sent to the appropriate system processor for action.

	FORMAT	TOUCH PANEL CONTROL
A	Flight	None
B	Nav	None
C1	Engine Power	Menu
C2	Engine Status	Menu
C3	Blank (Menu)	Menu

1	2	3	4	5
FAILED	A / B	E / C, D or F	G / H	A / B
A / B	FAILED	E / C, D or F	G / H	A / B
A / B	E / C, D or F	FAILED	G / H	A / B
A / B	E / C, D or F	G / H	FAILED	A / B
A / B	E / C, D or F	G / H	A / B	FAILED

Figure 18. One CRT Failure - Flying Pilot in Left Seat

1	2	3	4	5
FAILED	A / B	G / H	E / C, D or F	A / B
A / B	FAILED	G / H	E / C, D or F	A / B
A / B	G / H	FAILED	E / C, D or F	A / B
A / B	G / H	E / C, D or F	FAILED	A / B
A / B	G / H	E / C, D or F	A / B	FAILED

Figure 19. One CRT Failure - Flying Pilot in Right Seat

D1	CDWI	Range, Menu
D2	JEPP	Menu
D3	Engine Status	Menu
D4	Blank (Menu)	Menu
E	ACAWS	Menu
F1	CDTI	Range, Data Select, Menu
F2	TIP CLR	Menu
G1	Checklists	Item Check-off, Menu
G2	Blank (Menu)	Menu
H1	Functional Systems Schematics	Switch Functions for all systems Menu
H2	Engine Status	Menu
H3	Blank (Menu)	Menu

Alternate Source/Display Select Switches - These switches, located on the CRT bezel, as shown in Figure 20, are provided to permit the pilot to select an alternate display (DSPY) or an alternate symbol generator (SG) in event of failure of any of those units. Transfer (XFER) switches located on the bezel of displays 2 and 4 permit the pilots to change the location of information formats between CRTs 2 and 4 when all CRTs are operating normally. When pressed after either CRT 2 or 4 has failed, the formats will change to those shown on the figures depicting CRT failure conditions. Additionally, in the case of the flight and nav displays, controls are provided for selecting an alternate air data computer (ADC), flight director (FD) source, and inertial reference unit for source of attitude (ATT):

(1) DSPY - Selecting the appropriate DSPY switch after a CRT failure moves the formats from the failed CRT to a predetermined alternate position as shown previously.

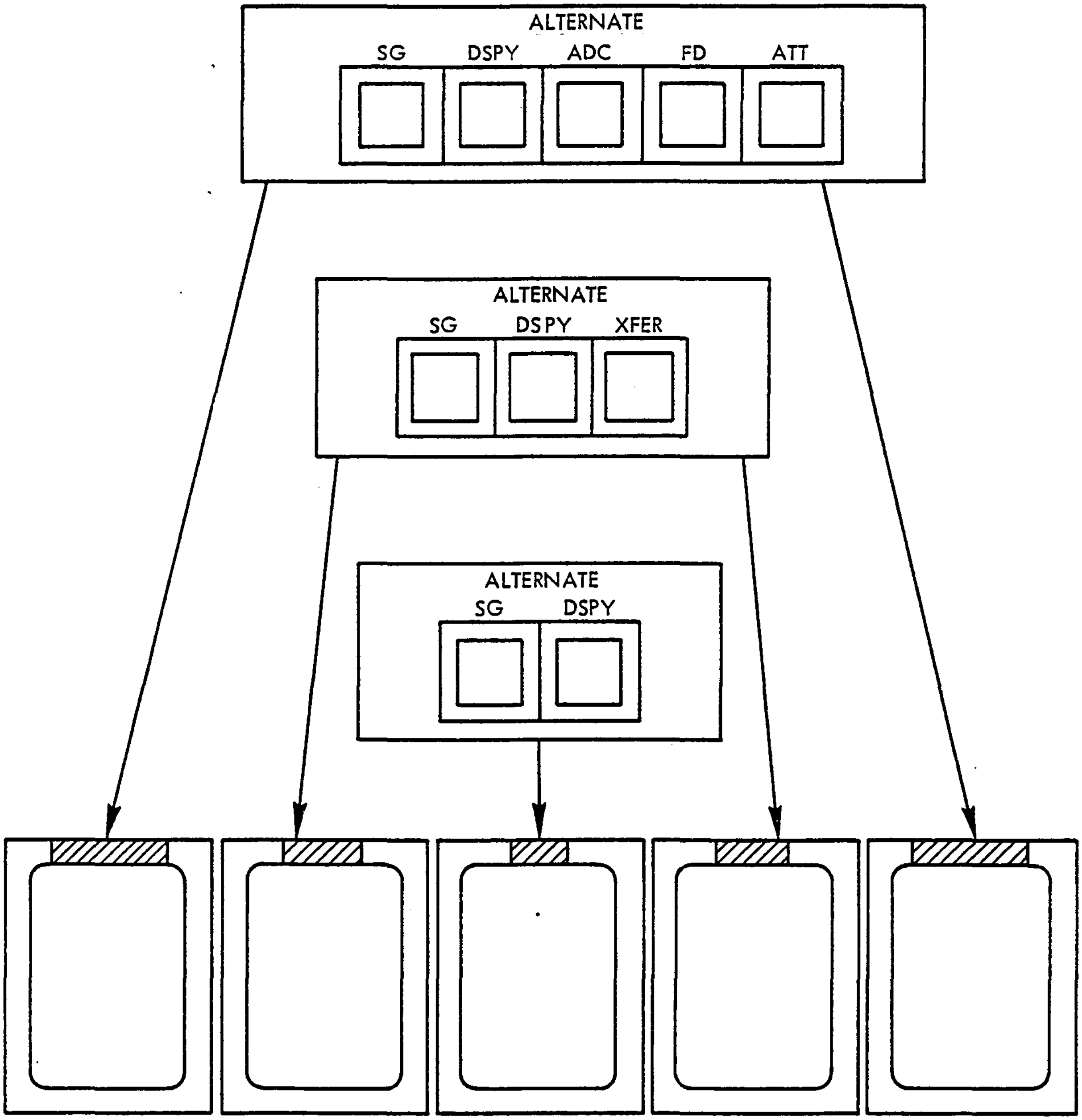


Figure 20. Alternate Source/Display Switches

(2) SG - Selecting the appropriate SG switch after symbol generator failure restores the original format to the same CRT location through use of an alternate symbol generator.

(3) ADC - During normal operation the number one ADC provides air data to the captain's flight and nav displays, and the number two ADC provides air data to the first officer's displays. Selecting ADC will connect the selected side to the number three ADC.

(4) FD - Selecting the alternate FD provides both the captain's and first officer's flight display from the same flight director computer.

(5) ATT - During normal operation the number one inertial system provides attitude information to the captain's flight display and the number two inertial supplies the first officer's attitude information. Selecting ATT will connect the selected side to the number three inertial system.

Display System Controls - Each CRT has a control for power ON-OFF and brightness integrated into one rotary control. All five switches are on one switching panel located on the overhead console and discussed later under Lighting. Additionally, two master brightness controls, one located on each side of the front instrument panel, affect the three right or two left CRTs simultaneously, as appropriate.

Nav Display Controls - Information on the captain's and first officer's nav display formats is controlled with separate switching panels located on the desk top. The functions which are discussed in the navigation display section are: nav mode select - flight management computer (FMC) 1 or 2, VOR/ILS 1 or 2, or GPS; display range - 2.5, 5, 10, 50, 100, and 200 nm; map symbology - nav aids, airports, ground reference points, radar, traffic, and range markers.

Flight Display Controls - Information on the captain's and first officer's displays is identical. It is tailored to the phase of flight selected on the guidance and control panel. Barometric pressure and radar altitudes are displayed and adjusted through set knobs located on each side of the guidance and control panel.

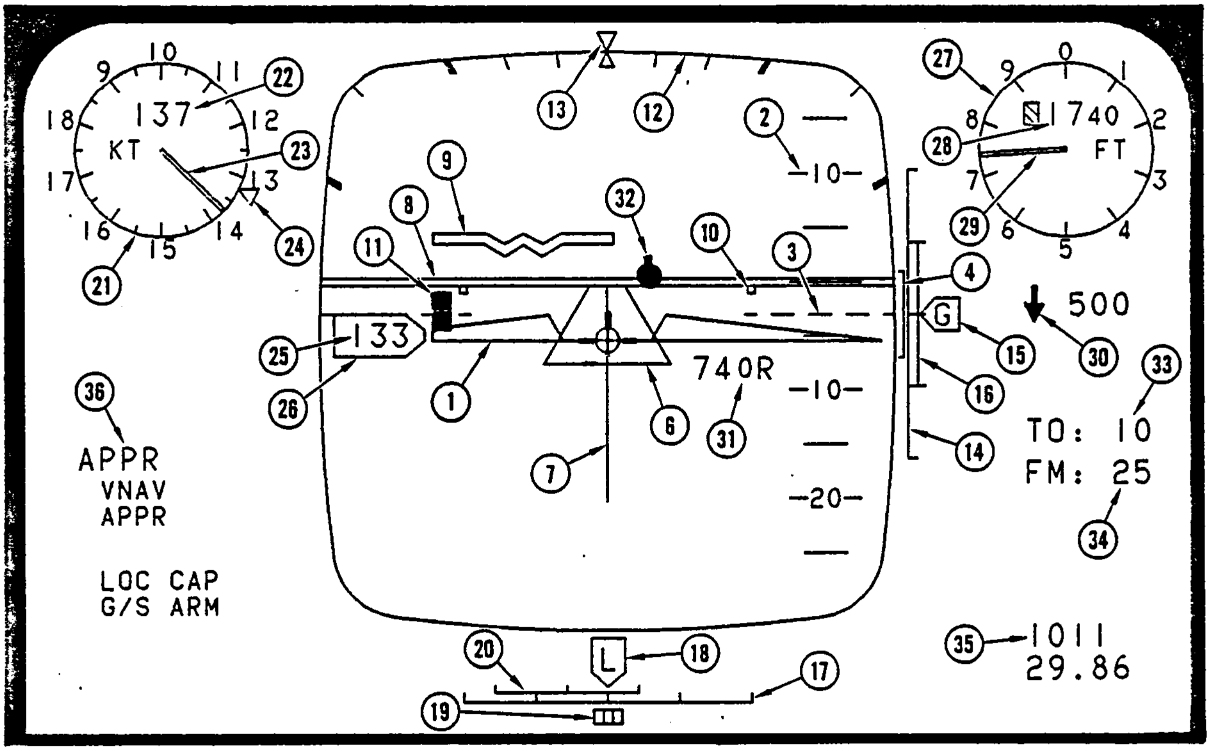
Control Through Voice Command - The voice command and response system may be used to call up any of the various alternate display formats available on CRTs 2, 3, and 4 during either the normal or degraded mode of operation.

Flight Display

The flight display is presented on the upper portion of the CRT located on each pilot's centerline. The information on both the captain's and first officer's flight displays is identical and is controlled as a function of the phase of flight, with the exception of the flight director symbol which can be selected or deselected. The information is tailored so that only information pertinent to the flying task being performed is displayed. The Display/Control Usage Table in Reference 2 summarizes the types of controls, display formats, and the information to be displayed during various flight phases.

The displayed information is a function of the phase of flight selected on the guidance and control panel. The selections available are takeoff, climb, cruise, descent, hold, approach, taxi, and go-around. The same switches interface with the flight control system; the performance management system; the advisory, caution, and warning system; and other systems that are flight phase related so that control, computation, and display are entirely integrated.

Two general categories of formats are used, with variations of each to tailor the information to the task. A flight path angle format, similar in many respects to that used on the NASA Transport Systems Research Vehicle aircraft and flight simulator will be researched for its applicability during the various phases of flight. In the baseline it will be used during descent, approach, and go-around. An example of this format is shown in Figure 21. An attitude type format, shown in Figure 22, is used for the other phases of flight. Examples of the information that may be shown on each of the five CRTs during different phases of flight are discussed later in this section following an explanation of the various CRT formats.



#	SYMBOL	COLOR	LOCATION & MOVEMENT
1	AIRCRAFT FLIGHT PATH ANGLE WEDGES & CIRCLE	White	Center of ball. Always stationary. Shows aircraft flight path angle (FPA) in reference to FPA scale and commanded FPA. Represents velocity vector of the aircraft with components in both the horizontal and vertical planes.
2	FLIGHT PATH ANGLE & PITCH SCALE	White	Right center of display. Moves vertically opposite aircraft FPA symbol.
3	COMMANDED FLIGHT PATH ANGLE	Amber	Right center of display. Dashed line through FPA scale to show commanded FPA.
4	FLIGHT PATH ANGLE BRACKET	White	Right center of display. Shows $\pm 3^{\circ}$ from commanded FPA.
5	DELETED		
6	PERSPECTIVE RUNWAY	Green	Overlays real-world runway and comes into view at approximately 3 nm away. Approach is made by keeping circle of aircraft symbol over touchdown point on runway.
7	EXTENDED RUNWAY CENTERLINE	Green	Moves with perspective runway to show relative position in lateral axis.

Figure 21. Flight Display with Flight Path Angle Format, (Sheet 1 of 5)

#	SYMBOL	COLOR	LOCATION & MOVEMENT
8	HORIZON LINE	White	Across the ADI ball. Always stationary in vertical axis but rotates to show roll. Shows aircraft attitude in reference to aircraft symbol and pitch and roll scales. Max climb or descent is 90^o. Max roll is 90^o.
9	AIRCRAFT	White	Top center of ball. Shows aircraft pitch in reference to pitch scale, and roll in reference to horizon. Moves laterally to show drift correction in relation to aim point.
10	CARDINAL HEADING MARKERS	Green	Under horizon line. Move laterally across horizon line to show each 10^o of track change.
11	IAS DEVIATION BAR	Amber (Filled)	Bar grows down from bottom of left wing of the aircraft symbol to show deviation below commanded indicated airspeed (IAS). It grows up from top to the left wing to show deviation above commanded IAS. The length of the bar changes at a rate of ½ inch per 10 KIAS deviation to a maximum of 1.9 inches (38 KIAS). It disappears completely with plus or minus 2 knots deviation.
12	ROLL SCALE	White	Centered above pitch scale. Rotates with the horizon line as the aircraft banks. Scale markers are at 10, 20, 30, 45, and 60 degrees. Angle of bank is shown under the roll index. Max angle of bank is 90^o.
13	ROLL INDEX	White	Centered on outside of ADI ball at the top. Always stationary. Shows angle of bank by pointing to the roll scale.
14	VERTICAL DEVIATION SCALE	White	Centered along right-hand side of ball in fixed position.
15	VERTICAL DEVIATION POINTER	Box-White Letters-Green or Amber	Moves along the vertical scale to indicate vertical deviation from flight plan. Full scale is plus or minus 500 feet when aircraft is outside the FAF. When inside the FAF and within 2.5^o TAE, full scale changes to plus or minus 0.7^o vertical deviation from glide slope. Pointer stops moving when deviation reaches full scale at which time the letters change from green to amber. When inside the FAF the letters change from V to G.
16	INDEPENDENT LANDING MONITOR-VERTICAL SCALE	Amber	Moves vertically along right side of ball to indicate deviation from the vertical path. Taken from an independent source and measured against the vertical deviation pointer.
17	HORIZONTAL DEVIATION & TRACK ANGLE ERROR SCALE	White	Centered below ball in a fixed position. Used with horizontal deviation pointer above and track angle error pointer below.

Figure 21. Flight Display with Flight Path Angle Format, (Sheet 2 of 5)

#	SYMBOL	COLOR	LOCATION & MOVEMENT
18	HORIZONTAL DEVIATION POINTER	Box-White	Moves along the top of the scale. Indicates amount of lateral deviation from flight plan. It is a "fly-to" indicator similar to the CDI on an HSI. Full scale is plus or minus 3 nm while enroute or 1 nm on approach when aircraft is outside the final approach fix (FAF). When inside the FAF and within 2.5° horizontal deviation full scale changes to 2.5°. Pointer stops moving when deviation reaches full scale at which time the letters change from green to amber. When inside the FAF and within 2.5° horizontal deviation, letters change from H to L.
19	TRACK ANGLE ERROR POINTER	Amber	Moves along the bottom of the scale to indicate TAE of aircraft track from desired course. Full scale is plus or minus 20°. Pointer stops moving at max deviation. When aircraft track and desired course are parallel, regardless of whether it is on desired course, TAE pointer is centered. It moves away from center in the opposite direction to which the aircraft track (nose of aircraft with no wind) moves from a position parallel to desired course.
20	INDEPENDENT LANDING MONITOR HORIZONTAL SCALE	Amber	Moves laterally beneath the ball to indicate lateral deviation from flight path. Taken from an independent source and measured against the horizontal deviation pointer.
21	IAS SCALE	White	Occupies fixed position in upper left corner of display. Scaled in 5 knot increments from actual aircraft IAS (shown in digits and under the tip of the pointer). It shows a range of plus or minus 50 knots from actual IAS. The numbers on the scale change at a point 180° from the tip of the pointer. The total range of airspeed is from 0 to 999 knots.
22	AIRSPEED DIGITAL READOUT & LABEL	White	Upper center of airspeed circle. Digits show the IAS of the aircraft and agree with the position of the pointer on the airspeed scale. When acceleration or deceleration is so rapid that the last digit changes too fast to be readable, only the even numbers are displayed. If it gets too fast again, only the 0s and 5s are displayed. Total range is from 0 to 999 knots.
23	AIRSPEED POINTER	White	Extends from center to edge of airspeed scale, pivoting around the center. Tip points to the actual IAS on the scale.
24	COMMANDED AIRSPEED INDEX	Amber	Moves around the circumference of the airspeed scale and points to the commanded indicated airspeed. Difference between the index and the airspeed pointer is shown on IAS Deviation bar. The index disappears from view when the commanded value is more than 50 knots from the indicated.

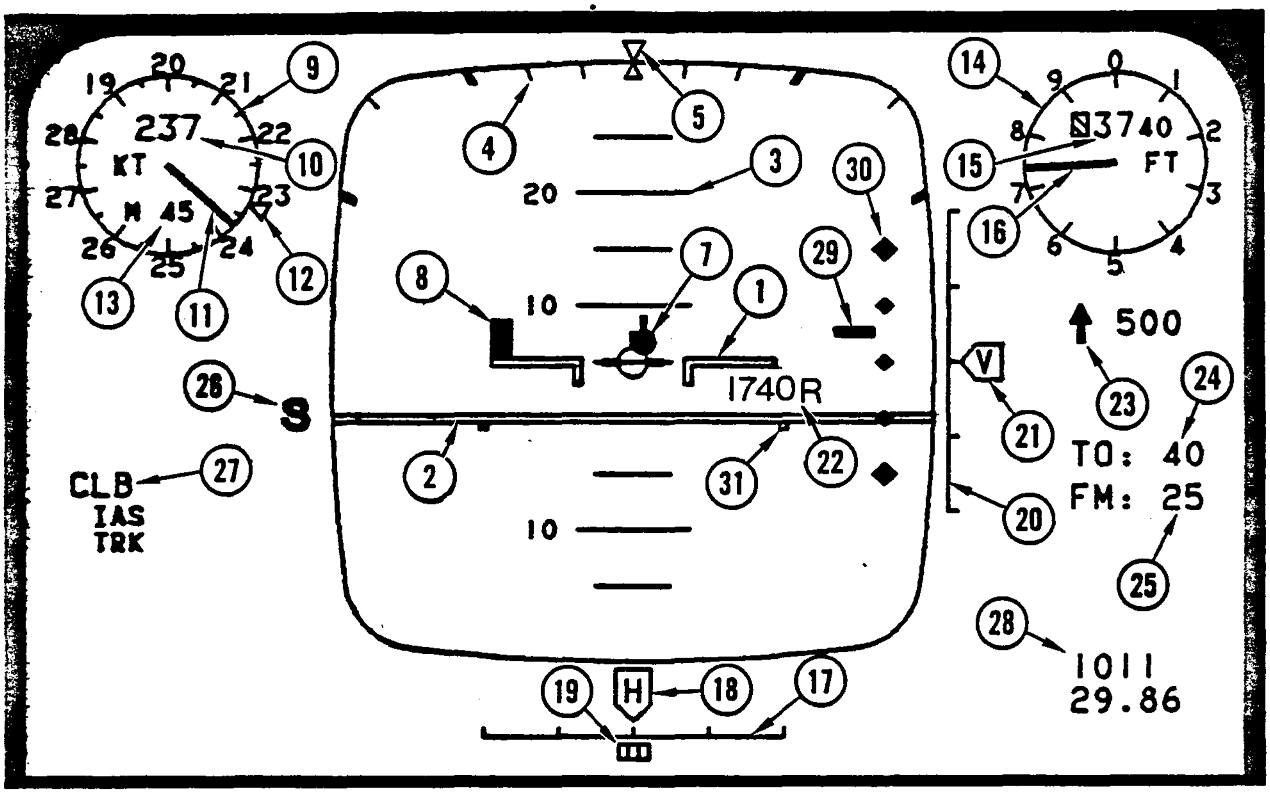
Figure 21. Flight Display with Flight Path Angle Format, (Sheet 3 of 5)

#	SYMBOL	COLOR	LOCATION & MOVEMENT
25	COMMANDED AIRSPEED DIGITAL READOUT	White	Inside potential FPA box. Digital readout of commanded airspeed.
26	POTENTIAL FLIGHT PATH ANGLE BOX	White	Left center of display. Move vertically to show potential FPA for present thrust and drag configuration. To fly the potential, the left end of the FPA wedge is aligned with the right edge of this box.
27	BAROMETRIC ALTITUDE SCALE	White	Occupies fixed position in upper right corner of the display. Scaled in 100 foot increments indicated by single digits from 0 to 9.
28	BAROMETRIC ALTITUDE DIGITAL READOUT	White	Upper center of altimeter circle. Digits show the barometric altitude of the aircraft. The last three digits reflect the position of the tip of the pointer. The total range necessary is from 0 to 50,000 feet. Between 1000 and 9990 the first digit is replaced with a hatched box. Below 990 feet only the 1, 2, or 3 digits are displayed, without hatched boxes. The number is rounded to the nearest 10 feet so that the last digit is always 0.
29	BAROMETRIC ALTITUDE POINTER	White	Extends from center to edge of altimeter scale, pivoting around the center. Tip points to the 100 feet of altitude scale.
30	VERTICAL VELOCITY POINTER & DIGITAL READOUT	White	Right center of display. Indicates descent with a down-arrow or climb with an up-arrow. Digital readout indicates feet per minute of change. Readout shows less than 500 ft/min, nearest 10 foot/min; 500 to 2000 ft/min, nearest 50 feet/min; above 2000 ft/min, nearest 100 ft/min.
31	RADAR ALTITUDE DIGITAL READOUT	Amber	Right center of display under right-hand wedge. Indicates height above ground below 2500 feet. Disappears above 2500 feet AGL. R indicates radar altitude. Reads to the nearest foot when lower than 200 feet; reads to nearest 10 feet above 200 feet.
32	FLIGHT DIRECTOR BALL	Amber (Filled)	Moves left, right, up or down to indicate commanded vertical and lateral track. When aim point is flown so as to encircle the flight director ball, the aircraft will be flying the correct vertical and lateral profile to intercept or remain on desired paths. Disappears when flight director fails or is turned OFF.
33	TO WAYPOINT	Green	Lower right corner of display. Indicates desired altitude of the TO waypoint (the one the aircraft is proceeding towards) in hundreds of feet. Changes to indicate the altitude of the next waypoint when over or 90° abeam the TO waypoint.

Figure 21. Flight Display with Flight Path Angle Format, (Sheet 4 of 5)

#	SYMBOL	COLOR	LOCATION & MOVEMENT
34	FROM WAYPOINT ALTITUDE	Green	Lower right corner of display. Indicates flight planned altitude of the waypoint that the aircraft has just passed (FROM waypoint). Changes when the TO waypoint changes.
35	BAROMETRIC PRESSURE	Green	Lower right corner of display. When barometric set knob is pulled out, altimeter setting is displayed in millibars and inches of mercury. Digits disappear when knob is pushed in.
36	FLIGHT PHASE & MODE ANNUNCIATION	Green	Lower left corner of display. Indicates selected mode of flight and status of that selection.

Figure 21. Flight Display with Flight Path Angle Format, (Sheet 5 of 5)



#	SYMBOL	COLOR	LOCATION & MOVEMENT
1	AIRCRAFT & CIRCLE	White	Center of ADI ball. Always stationary. Shows aircraft attitude in reference to horizon line and pitch and roll scales. Max climb or descent is 90°. Max roll is 90°.
2	HORIZON LINE	White	Across the ADI ball. In relation to aircraft symbol it moves up during descent, down during climb, and pivots around center of aircraft symbol to indicate roll. Left end of horizon line is lower during right bank and higher during left bank. Area inside the ball above the horizon line is shaded cyan; below the horizon line, black.
3	PITCH SCALE	White	Centered above and below horizon line. Remains parallel to horizon line during roll maneuvers. Shows 20° above and below aircraft symbol.
4	ROLL SCALE	White	Centered above pitch scale. Rotates with the horizon line as the aircraft banks. Scale markers are at 10, 20, 30, 45, and 60 degrees. Angle of bank is shown under the roll index. Max angle of bank is 90°.
5	ROLL INDEX	White	Centered on outside of ADI ball at the top. Always stationary. Shows angle of bank by pointing to the roll scale.
6	DELETED		

Figure 22. Flight Display with Attitude Format, (Sheet 1 of 4)

#	SYMBOL	COLOR	LOCATION & MOVEMENT
7	FLIGHT DIRECTOR BALL	Amber (Filled)	Moves left, right, up or down to indicate commanded vertical and lateral track. When the circle is flown so as to encircle the flight director ball, the aircraft will be flying the correct vertical and lateral profile to intercept or remain on desired paths. Disappears when flight director fails or is turned OFF
8	IAS DEVIATION BAR	Amber (Filled)	Bar grows down from bottom of left wing of the aircraft symbol to show deviation below commanded indicated airspeed (IAS). It grows up from top of the left wing to show deviation above commanded IAS. The length of the bar changes at a rate of ½ inch per 10 KIAS deviation to a maximum of 1.9 inches (38 KIAS). It disappears completely with plus or minus 2 knots deviation.
9	IAS SCALE	White	Occupies fixed position in upper left corner of display Scaled in 5 knot increments from actual aircraft IAS (shown in digits and under the tip of the pointer). It shows a range of plus or minus 50 knots from actual IAS. The numbers on the scale change at a point 180° from the tip of the pointer. The total range of airspeed is from 0 to 999 knots.
10	AIRSPEED DIGITAL READOUT & LABEL	White	Upper center of airspeed circle. Digits show the IAS of the aircraft and agree with the position of the pointer on the airspeed scale. When acceleration or deceleration is so rapid that the last digit changes too fast to be readable, only the even numbers are displayed. If it gets too fast again only the 0s and 5s are displayed. Total range is from 0 to 999 knots.
11	AIRSPEED POINTER	White	Extends from center to edge of airspeed scale, pivoting around the center. Tip points to the actual IAS on the scale.
12	COMMANDED AIRSPEED INDEX	Amber	Moves around the circumference of the airspeed scale and points to the commanded indicated airspeed. Difference between this index and the airspeed pointer is shown on IAS Deviation bar. The index disappears from view when the commanded value is more than 50 knots from the indicated.
13	MACH DIGITAL READOUT & LABEL	White	Lower center of the airspeed circle. Digits show the Mach of the aircraft. It has a range from 0.40 to 1.0 Mach. It disappears from view below 0.40.
14	BAROMETRIC ALTITUDE SCALE	White	Occupies fixed position in upper right corner of the display. Scaled in 100 foot increments indicated by single digits from 0 to 9.

Figure 22. Flight Display with Attitude Format, (Sheet 2 of 4)

#	SYMBOL	COLOR	LOCATION & MOVEMENT
15	BAROMETRIC ALTITUDE DIGITAL READOUT	White	Upper center of altimeter circle. Digits show the barometric altitude of the aircraft. The last three digits reflect the position of the tip of the pointer. The total range necessary is from 0 to 50,000 feet. Between 1000 and 9990 the first digit is replaced with a hatched box. Below 990 feet only the 1, 2, or 3 digits are displayed, without hatched boxes. The number is rounded to the nearest 10 feet so that the last digit is always 0.
16	BAROMETRIC ALTITUDE POINTER	White	Extends from center to edge of altimeter scale, pivoting around the center. Tip points to the 100 feet of altitude scale.
17	HORIZONTAL DEVIATION & TRACK ANGLE ERROR SCALE	White	Centered below ball in a fixed position. Used with horizontal deviation pointer above and track angle error pointer below.
18	HORIZONTAL DEVIATION POINTER	Box-White Letters -Green or Amber	Moves along the top of the scale. Indicates amount of lateral deviation from flight plan. It is a "fly-to" indicator similar to the CDI on an HSI. Full scale is plus or minus 3 nm while enroute or 1 nm on approach when aircraft is outside the final approach fix (FAF). When inside the FAF and within 2.5° horizontal deviation, full scale changes to 2.5°. Pointer stops moving when deviation reaches full scale at which time the letters change from green to amber. When inside the FAF and within 2.5° horizontal deviation, letters change from H to L.
19	TRACK ANGLE ERROR POINTER	Amber	Moves along the bottom of the scale to indicate TAE of aircraft track from desired course. Full scale is plus or minus 20°. Pointer stops moving at max deviation. When aircraft track and desired course are parallel, regardless of whether it is on desired course, TAE pointer is centered. It moves away from center in the opposite direction to which the aircraft track (nose of aircraft with no wind) moves from a position parallel to desired course.
20	VERTICAL DEVIATION SCALE	White	Centered along right-hand side of ADI ball in fixed position.
21	VERTICAL DEVIATION POINTER	Box-White	Moves along the vertical scale to indicate vertical deviation from flight plan. Full scale is plus or minus 500 feet when aircraft is outside the FAF. When inside the FAF and within 2.5° TAE, full scale changes to plus or minus 0.7° vertical deviation from glide slope. Pointer stops moving when deviation reaches full scale at which time the letters change from green to amber. When inside the FAF the letters change from V to G.

Figure 22. Flight Display with Attitude Format, (Sheet 3 of 4)

#	SYMBOL	COLOR	LOCATION & MOVEMENT
22	RADAR ALTITUDE DIGITAL READOUT	Amber	Right center of display. Indicates height above ground below 2500 feet. Disappears above 2500 feet AGL. R indicates radar altitude. Readout shows lower than 200 feet - nearest foot; above 200 feet - nearest 10 feet.
23	VERTICAL VELOCITY POINTER & DIGITAL READOUT	White	Right center of display. Indicates descent with a down-arrow or climb with an up-arrow. Digital readout indicates feet per minute of change. Readout shows less than 500 ft/min, nearest 10 foot/min; 500 to 2000 ft/min, nearest 50 feet/min; above 2000 ft/min, nearest 100 ft/min.
24	TO WAYPOINT	Green	Lower right corner of display. Indicates desired altitude of the TO waypoint (the one the aircraft is proceeding towards) in hundreds of feet. Changes to indicate the altitude of the next waypoint when over or 90° abeam the TO waypoint.
25	FROM WAYPOINT ALTITUDE	Green	Lower right corner of display. Indicates flight planned altitude of the waypoint that the aircraft has just passed (FROM waypoint). Changes when the TO waypoint changes.
26	ANGLE-OF-ATTACK	Red (S) Green (C) Amber (F)	Left center of display. Split donut indicates on proper angle-of-attack (AOA) for weight and configuration. "F" indicates too fast or too low AOA. "S" indicates too slow or too high AOA. As AOA changes one-half the donut fades away, as the other symbol comes into view. F or S gets more pronounced as donut completely disappears.
27	FLIGHT PHASE & MODE ANNOUNCIATION	Green	Lower left corner of display. Indicates selected mode of flight and status of that selection.
28	BAROMETRIC PRESSURE	Green	Lower right corner of display. When barometric set knob is pulled out, altimeter setting is displayed in milibars and inches of mercury. Digits disappear when knob is pushed in.
29	FLIGHT PATH ANGLE INDEX	Amber	Right center of display. Moves along flight path angle scale.
30	FLIGHT PATH ANGLE SCALE	Amber	Right center of display. FPA scale is always centered on the aircraft symbol and has a range of $\pm 6^{\circ}$ FPA.
31	CARDINAL HEADING MARKERS	Green	Under horizon line. Move laterally across horizon line to show each 10° of track change.

Figure 22. Flight Display with Attitude Format, (Sheet 4 of 4)

Navigation Display

Navigation information is presented to each pilot on the lower portion of the CRT located on his centerline. This information includes aircraft track, heading, desired course, course deviation, ground speed, proposed flight plan, lateral and longitudinal position, and flight time relative to flight plan waypoints/navigation aids. Symbology for navigation aids, airfields, and ground reference points, weather radar, turbulence radar, and traffic may be displayed as an overlay on the flight plan map to provide the crew with a complete picture of the horizontal situation. The Display/Control Usage Table in Reference 2 summarizes the type of controls, display formats, and the information to be displayed during various phases of flight.

Display Controls - Each pilot may individually select and display several different formats using the navigation display control panel shown in Figure 23 (Item 22, Figure 15). This panel contains three rows of switches for control of display range, navigation mode, and display symbology. Display switching for alternate information sources, alternate symbol generators, or alternate CRTs in the event of malfunctions, is accomplished through switches on the bezels of the navigation displays as previously described.

Display Range Switches - These mutually exclusive switches are used to select the appropriate maximum range of the navigation display. Six ranges between 2.5 and 200 nautical miles are available.

Nav Mode Select Switches - These switches control which navigation aid is providing information to the display. Only one switch may be selected at a time. All switches are push-button, 2 or 3-position switch-lights which illuminate to indicate which navigation mode is active.

Display Symbology Select Switches - These 2-position (ON/OFF) switch-lights may be selected as needed to overlay information onto the navigation display, thereby cluttering or decluttering the display.

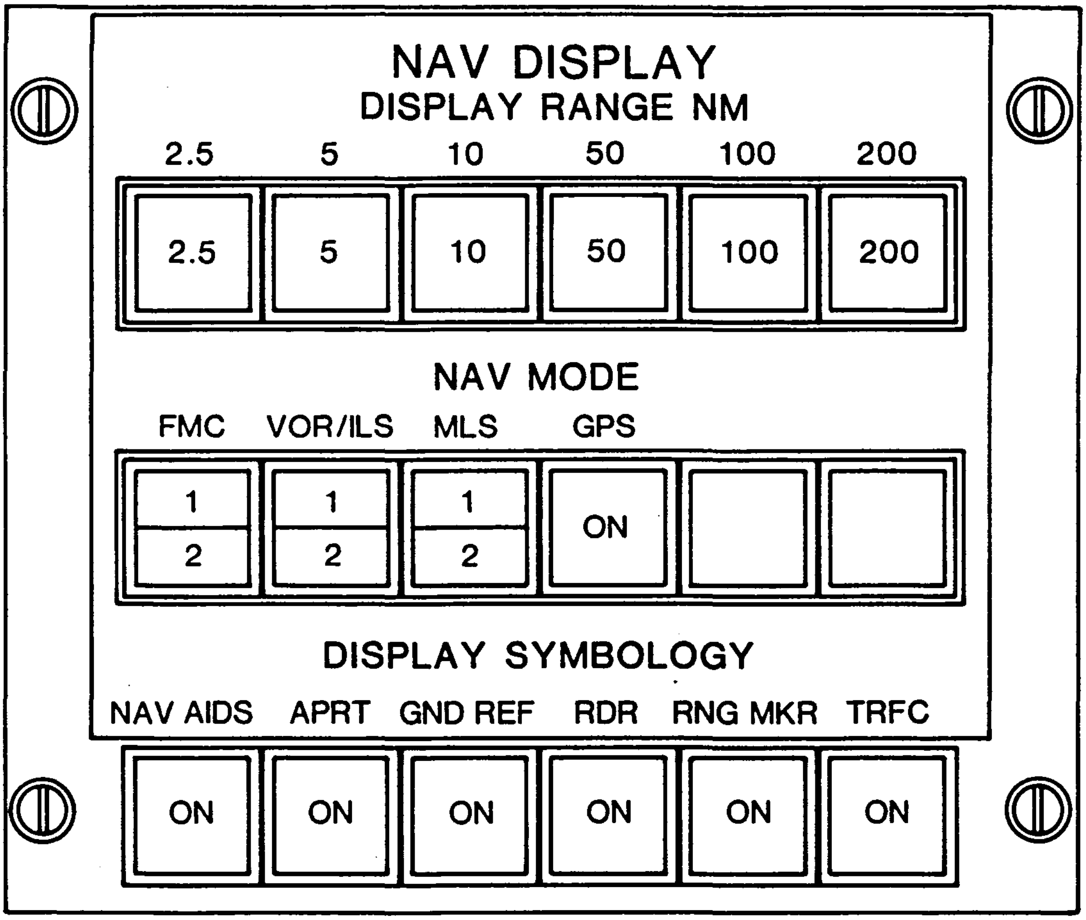


Figure 23. Navigation Display Control Panel

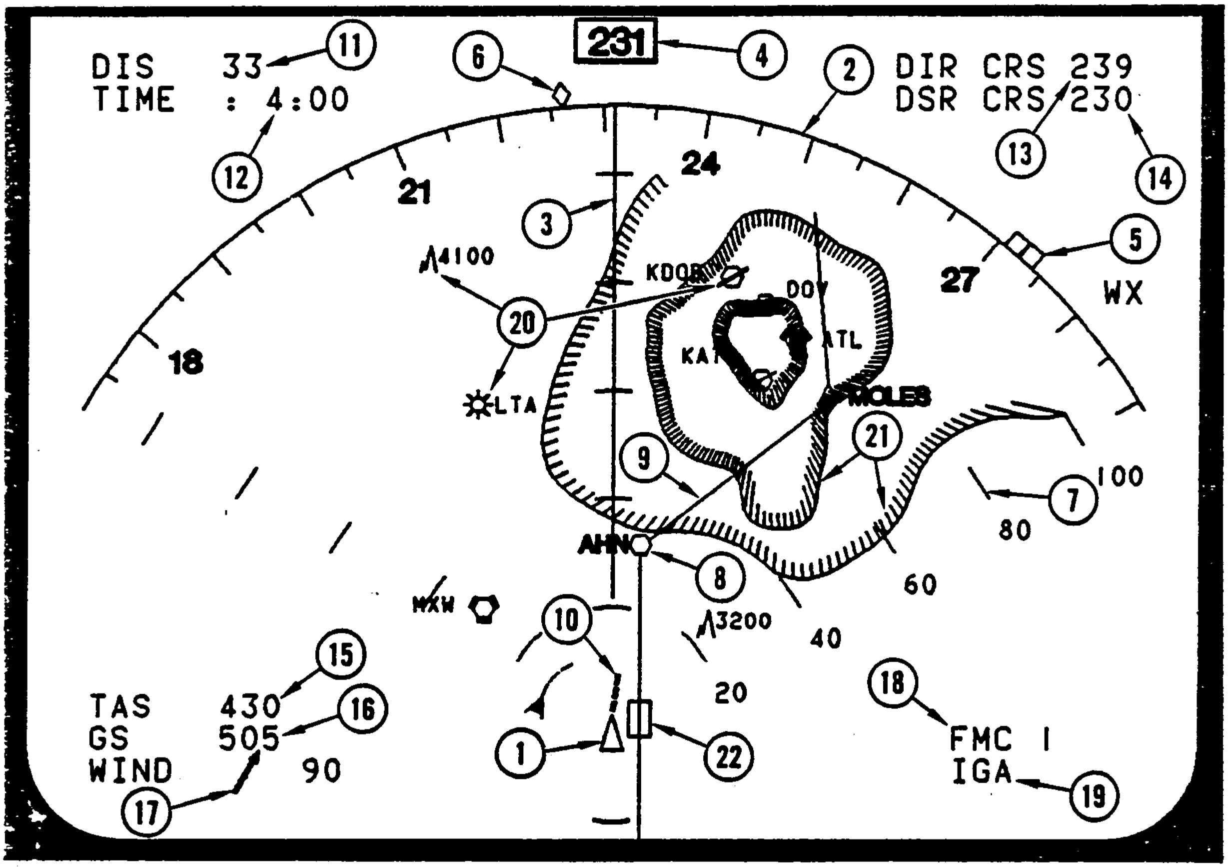
Selection of nav aids causes all nearby navigation aids to be called from storage and overlayed on the map. The ARPT (airport) switch accomplishes the same function for airports within range. Similarly, GND REF (ground reference) causes hazardous terrain and man-made structures to be overlayed. The radar (RDR) switch overlays color digital radar returns on the same navigation display. These returns will be either weather or turbulence, depending on which radar mode is selected on the radar control panel. The switch marked RNG MKR (range marker) removes most of the range markers from the display to declutter the picture. Finally, the traffic switch (TRFC) is used to overlay conflicting traffic. This information is obtained from the CDTI display, but only the more threatening targets are overlayed on the nav display.

An example of the navigation display with all of the display symbology switches selected is shown in Figure 24. The same presentation is shown in Figure 25 except that the display has been decluttered using the same six switches.

Display Formats - Figures 24 and 25 depict the navigation display as it appears when the flight management computer is selected. This is the normal mode of operation in which all navigation aids are processed by the computer to update the inertial-stabilized position. Other display formats are described below.

VOR/ILS Mode - When this mode is selected, information from one or both VOR receivers will be displayed, depending on which sets are operating and tuned to valid VOR stations. If both VOR receivers are tuned to the same station, only the one selected on the appropriate nav mode select switch will be displayed. Normally, VOR1 is used by the captain and VOR2 is used by the first officer.

The display will also vary depending on whether the VOR station has distance measuring equipment (DME). Figure 26 is an example of two VORs with DME. In this case, sufficient information exists to display the VORs on a map-type display. Occasionally, one VOR will not have a DME capability. If that occurs, the VOR with DME will appear in its relative position on the map, but the other VOR will be shown only as a bearing



#	SYMBOL	COLOR	LOCATION & MOVEMENT
1	OWN AIRCRAFT	White	Always remains in a fixed position with the uppermost point of the triangle at the center of the smallest range marker circle.
2	COMPASS ROSE	White	120° arc with aircraft track at top center. Arc is divided into 5° increments with digits each 30° starting at 0°. Arc position does not move but scale changes as aircraft turns.
3	TRACK LUBBER LINE	White	Always oriented vertically from the own aircraft symbol to the compass rose. Shows aircraft track on the scale.
4	AIRCRAFT TRACK DIGITAL READOUT AND BOX	White	Above top center of compass rose. Shows numbers from 001 to 360 degrees and agrees with reading under lubber line on compass rose.
5	TRACK MARKER	Amber	Rotates around circumference of compass rose. It is positioned by pilot.

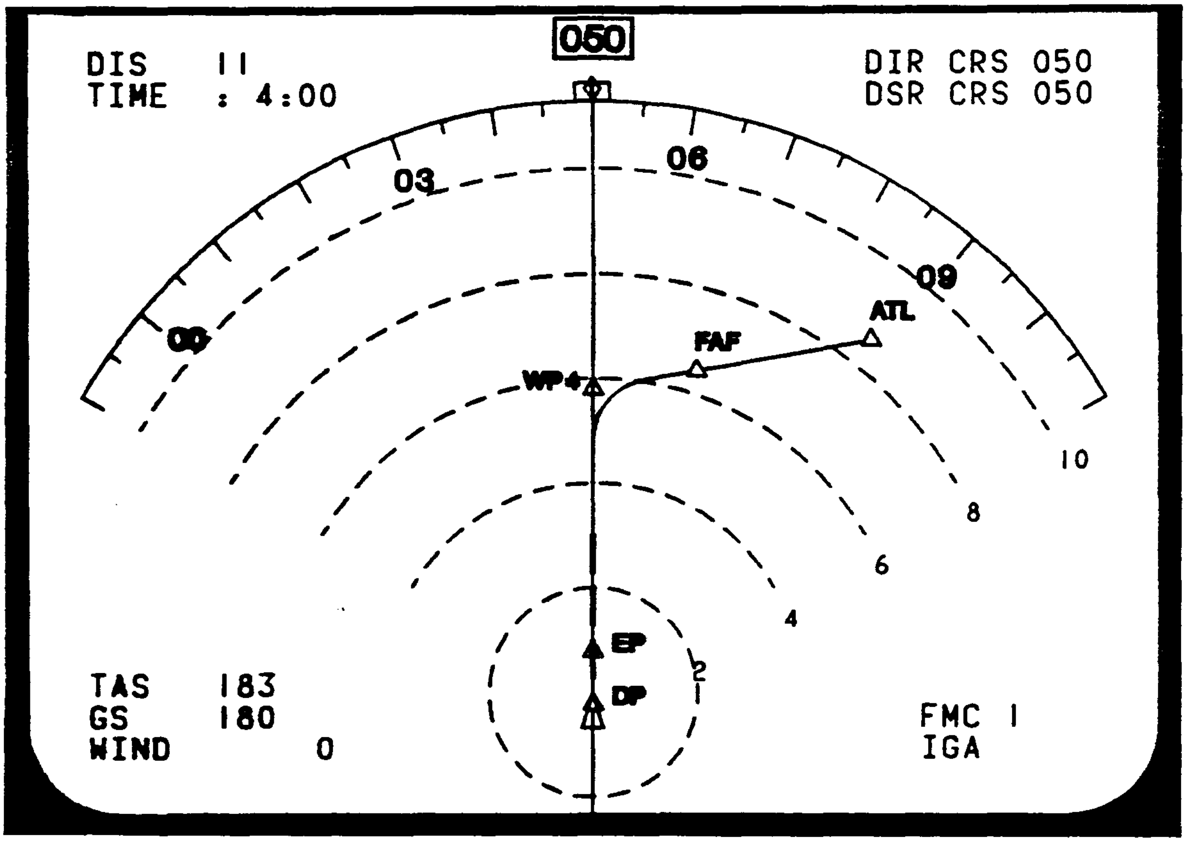
Figure 24. Navigation Display Format, (Sheet 1 of 3)

#	SYMBOL	COLOR	LOCATION & MOVEMENT
6	AIRCRAFT HEADING INDEX	Amber	Rotates around circumference of compass rose. Shows aircraft heading on the compass rose and drift correction angle as the difference between aircraft heading index and track lubber line.
7	RANGE MARKERS	White	Equidistant marks between Own aircraft and maximum range selected. Marks maintain fixed position. Scaled in NM and identified on right hand end.
8	WAYPOINT SYMBOLS AND IDENTIFIERS	White	Three dimensional points defining route of flight. They move with respect to Own aircraft symbol at rate based upon ground speed and range scale selected. When aircraft is on desired track, nearest waypoint is always shown vertically above Own aircraft symbol.
9	PLANNED COURSE LINE	Green	Line between waypoints defining route of flight. Moves with the waypoints. Terminates at largest range marker or furtherest waypoint on one end and bottom of display on other end.
10	POSITION PREDICTOR OR TREND VECTOR	White	Three dashed lines extending from front tip of Own aircraft symbol. The end of each dash shows the predicted position of the tip of the Own aircraft symbol at 20, 40 and 60 seconds from the present time based upon present aircraft course and ground speed. Lines change length with respect to ground speed and display range scale.
11	DISTANCE TO GO DIGITS	Green	Upper left corner of display. Shows nautical miles between tip of Own aircraft and nearest (TO) waypoint. Figure is shown in full miles (no decimal) until under 10 NM; then miles and tenths of miles.
12	TIME TO GO DIGITS	Green	Upper left corner of display. Shows hours, minutes and seconds required to travel from present position to next (TO) waypoint. Leading zeros (insignificant) are not shown.
13	DIRECT COURSE DIGITS	Green	Upper right corner of display. Shows course (typically magnetic) between Own aircraft and next (TO) waypoint.
14	DESIRED COURSE DIGITS	Green	Upper right corner of display. Shows course (typically magnetic) between last (FROM) waypoint and next (TO) waypoint.
15	TRUE AIRSPEED DIGITS	Green	Lower left corner of display. Shows true airspeed of aircraft.
16	GROUND SPEED DIGITS	Green	Lower left corner of display. Shows ground speed of aircraft.

Figure 24. Navigation Display Format, (Sheet 2 of 3)

#	SYMBOL	COLOR	LOCATION & MOVEMENT
17	WIND ARROW AND DIGITS	Green	Lower left corner of display. Shows wind vector (arrow) pointing from the direction that the wind is blowing relative to the aircraft track. Arrow disappears when wind is calm. Digits show wind velocity in knots.
18	NAVIGATION MODE	Green	Lower right corner of display. Shows navigation mode selected for display.
19	NAVIGATION SOURCE		Lower right corner of display. Shows sources of navigation signals being used to obtain navigation display.
20	NAV AIDS, AIRPORTS AND OBSTACLES	Green Amber	Symbols for nav aids, airports and/or obstacles may be selected for display.
21	WEATHER RADAR CONTOURS	Red Green Amber	Weather radar returns may be selected as an overlay to the map.
22	TIME BOX	Amber	Appears when TNAV is selected on GCP. Moves along desired course line of moving map. Indicates the position that the aircraft should be in to arrive at a metering fix at a particular time.

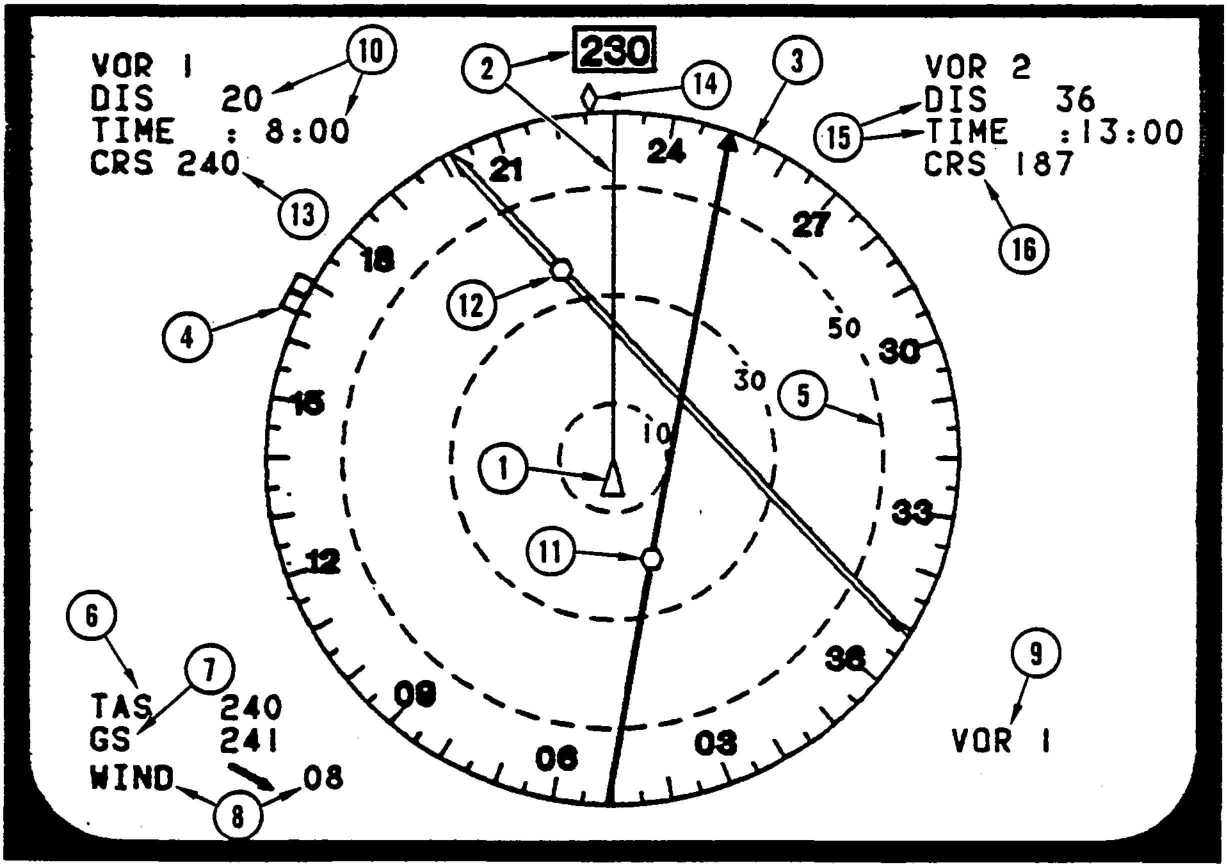
Figure 24. Navigation Display Format, (Sheet 3 of 3)



NOTE:

ALL BUT THE BASIC SYMBOLOGY HAS BEEN REMOVED BY DESELECTION ON THE NAV DISPLAY CONTROL PANEL.

Figure 25. Decluttered Navigation Display



1.	OWN AIRCRAFT	9.	SELECTED NAV MODE
2.	AIRCRAFT TRACK	10.	DISTANCE AND TIME TO VOR 1
3.	TRACK SCALE	11.	RELATIVE POSITION OF VOR 1
4.	TRACK MARKER	12.	RELATIVE POSITION OF VOR 2
5.	RANGE MARKERS	13.	DESIRED COURSE TO VOR 1
6.	TRUE AIR SPEED	14.	AIRCRAFT HEADING
7.	GROUND SPEED	15.	DISTANCE AND TIME TO VOR 2
8.	WIND DIRECTION/VELOCITY	16.	DESIRED COURSE TO VOR 2

Figure 26. Alternate Nav Display with Two VOR/DME Stations

pointer. Figure 27 is an example of a VOR display in which one station has no DME.

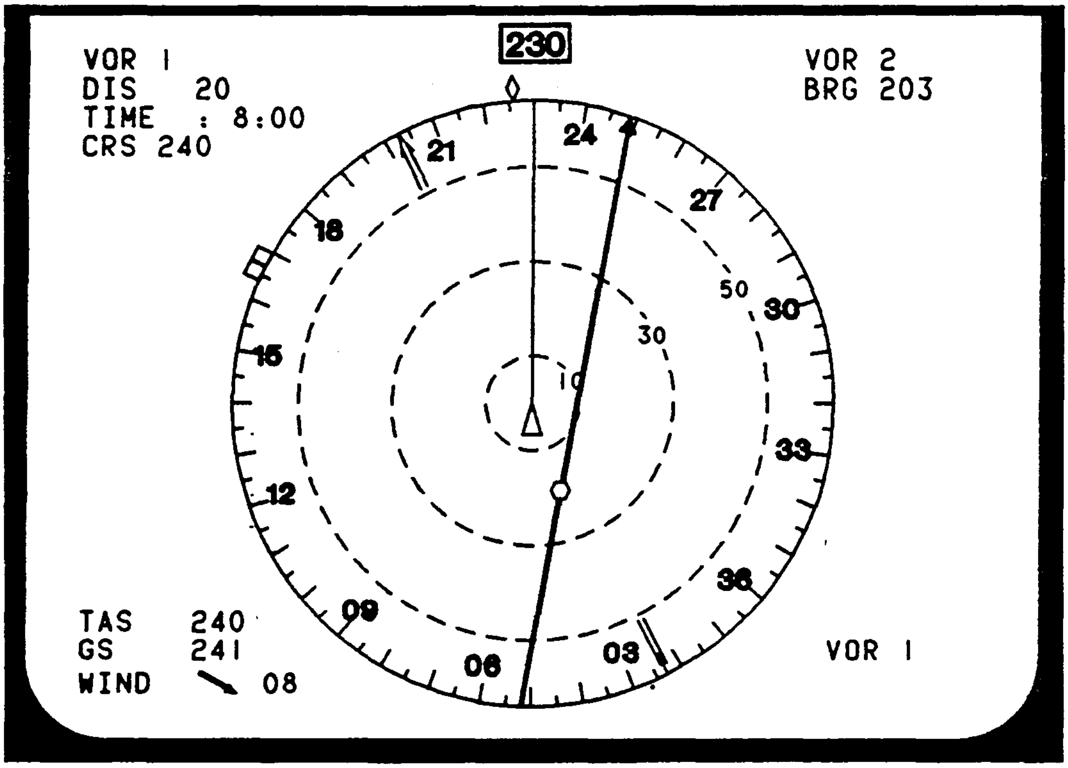
If neither of the VOR stations has DME capability, the display will revert to a more conventional horizontal situation indicator (HSI) as shown in Figure 28. This is also the format when the selected VOR is tuned to an ILS frequency.

MLS Mode - The format for this display is identical to the flight management computer (FMC) except that MLS is the sole nav aid. MLS will appear in the lower right corner of the navigation display.

GPS Mode - The format for this display is identical to the flight management computer (FMC) except that GPS is the sole nav aid. GPS will appear in the lower right corner of the navigation display.

Time Navigation - When the display is being driven by the flight management computer and the time navigation (TNAV) computer mode is selected on the guidance and control panel (GCP), an additional symbol, called the time box, appears on the navigation display. This symbol, shown in Figure 24, indicates the position of the aircraft in order to arrive at a metering fix at a particular time. This rectangle moves along the flight planned track to indicate the scheduled (or desired) position of the aircraft relative to the metering fix. The center of the leading edge of the rectangle represents the scheduled position.

If the actual position of the aircraft (nose of the triangle) is in agreement with the flight plan, the triangle exactly fits within the rectangle. When the triangle is behind the time box, the aircraft is behind schedule. Similarly, if the triangle leads the box, the aircraft is ahead of schedule. The time box is displayed only when it is within range and when TNAV has been selected on the GCP.

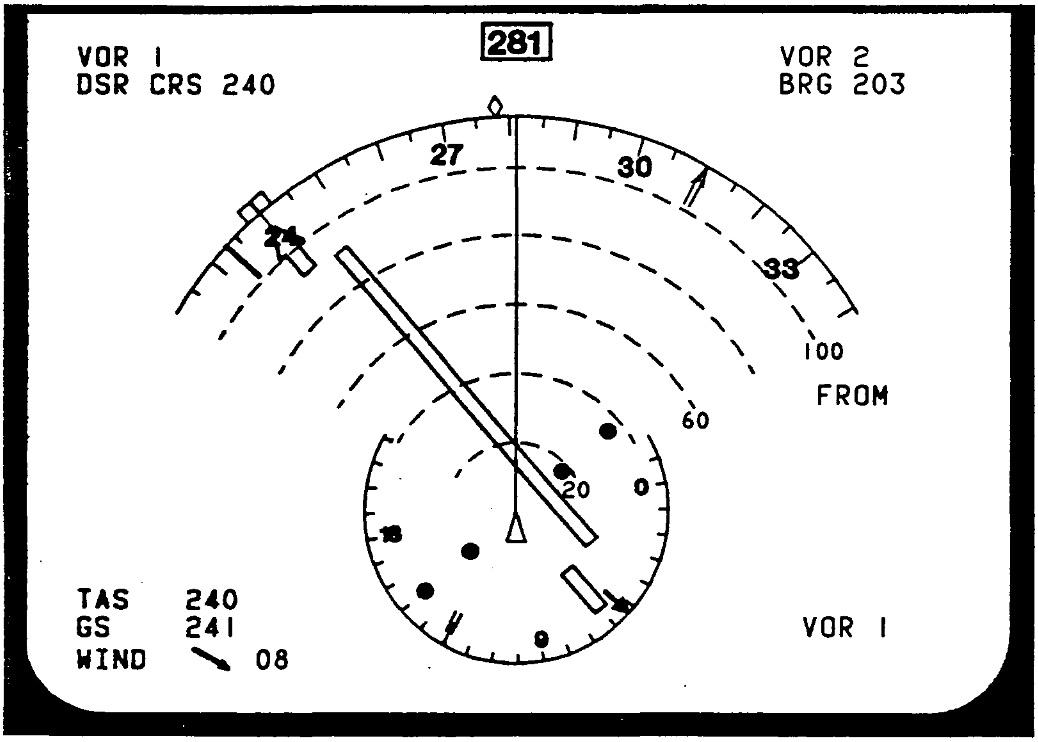


NOTE:

VOR 2 DOES NOT HAVE DME. NUMBER 2 (DOUBLE-BAR) POINTER PIVOTS AROUND CENTER OF DISPLAY. HEAD OF POINTER INDICATES MAGNETIC TRACK FROM THE AIRCRAFT TO VOR 2.

THE RELATIVE POSITION OF VOR/DME 1 TO THE AIRCRAFT IS SHOWN BY THE SINGLE BAR POINTER. THE DESIRED COURSE IS PROJECTED THROUGH THE VOR LOCATION.

Figure 27. Alternate Nav Display when only One VOR Station has DME



NOTE:

UPPER PORTION OF THE COMPASS ROSE IS EXPANDED FOR BETTER RESOLUTION AND MORE AREA TO DISPLAY WEATHER RADAR SYMBOLOGY. DESIRED COURSE IS SHOWN BY THE COURSE BAR; LATERAL DEVIATION, BY THE COURSE DEVIATION BAR; AND THE MAGNETIC TRACKS TO VOR 1 AND VOR 2, BY THE TWO POINTERS.

Figure 28. Alternate Nav Display with Modified HSI Format

Engine Power/Status Display

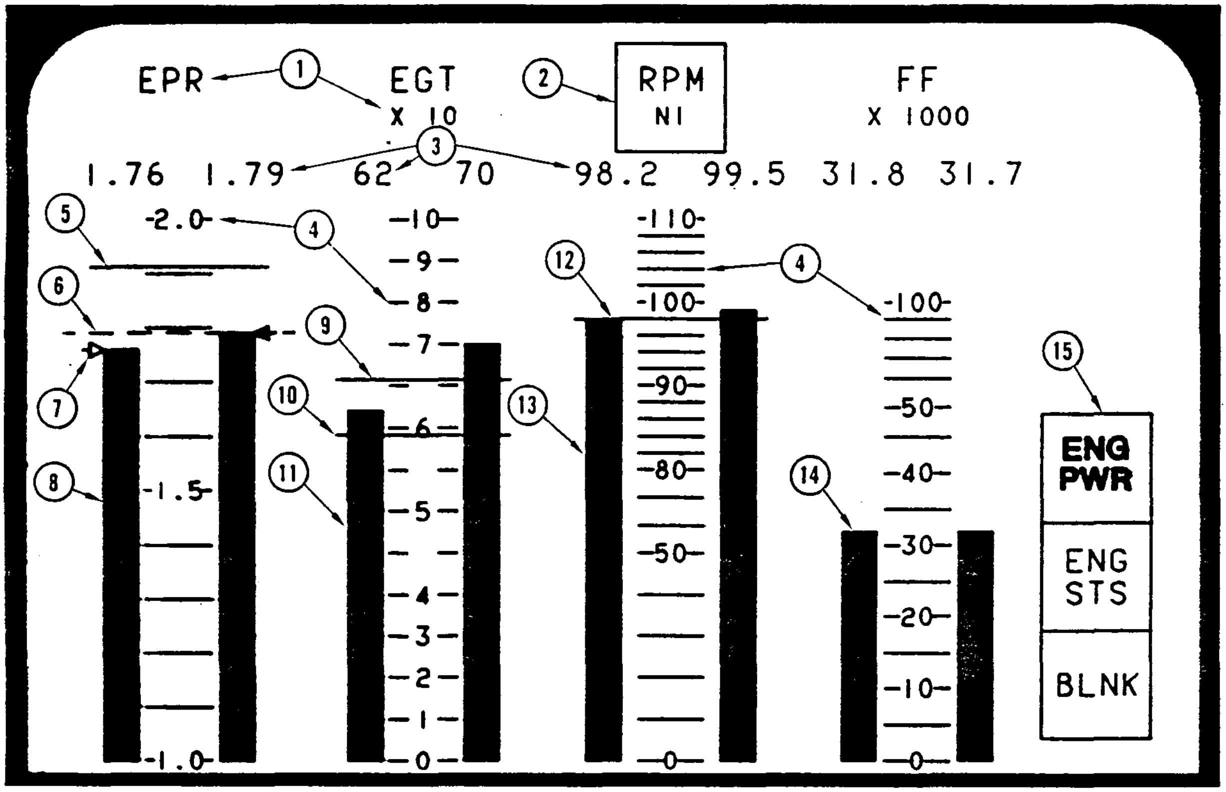
The top portion of the number 2 CRT can display engine power in bar graph form, as shown in Figure 29; or the status of systems associated with the engine plus brake temperatures, as shown in Figure 30. These selections are available through touch switches on the display, as well as the option to blank the display except for the switch legends.

Engine Power Format - The engine power (ENG PWR) format displays engine pressure ratio (EPR), exhaust gas temperature (EGT), either N1 RPM or N2 RPM selectable with the touch switch around the label, and fuel flow (FF).

Engine Status Display - The engine status (ENG STS) format provides digital status readouts of all engine parameters plus several additional aircraft subsystems. The format is called up manually by touching the button area labeled ENG STS on the touchpanel area. If this display area is in the blanked mode (BLNK) and one of the system status parameters departs from tolerance, this format is automatically called up. The ENG STS legend on the touch panel overlay is highlighted when this format is displayed.

The parameters displayed on this format include the following:

(1) EPR - Engine Pressure Ratio
(2) EGT - Exhaust Gas Temperature
(3) N1 - RPM
(4) N2 - RPM
(5) FF - Fuel Flow
(6) OP - Oil Pressure
(7) OT - Oil Temperature
(8) OQ - Oil Quantity
(9) VH - Vibration (High Pressure Turbine)
(10) VF - Vibration (Fan)
(11) FT - Fuel Temperature
(12) FP - Fuel Pressure
(13) BRAKE TEMP - Brake Temperature

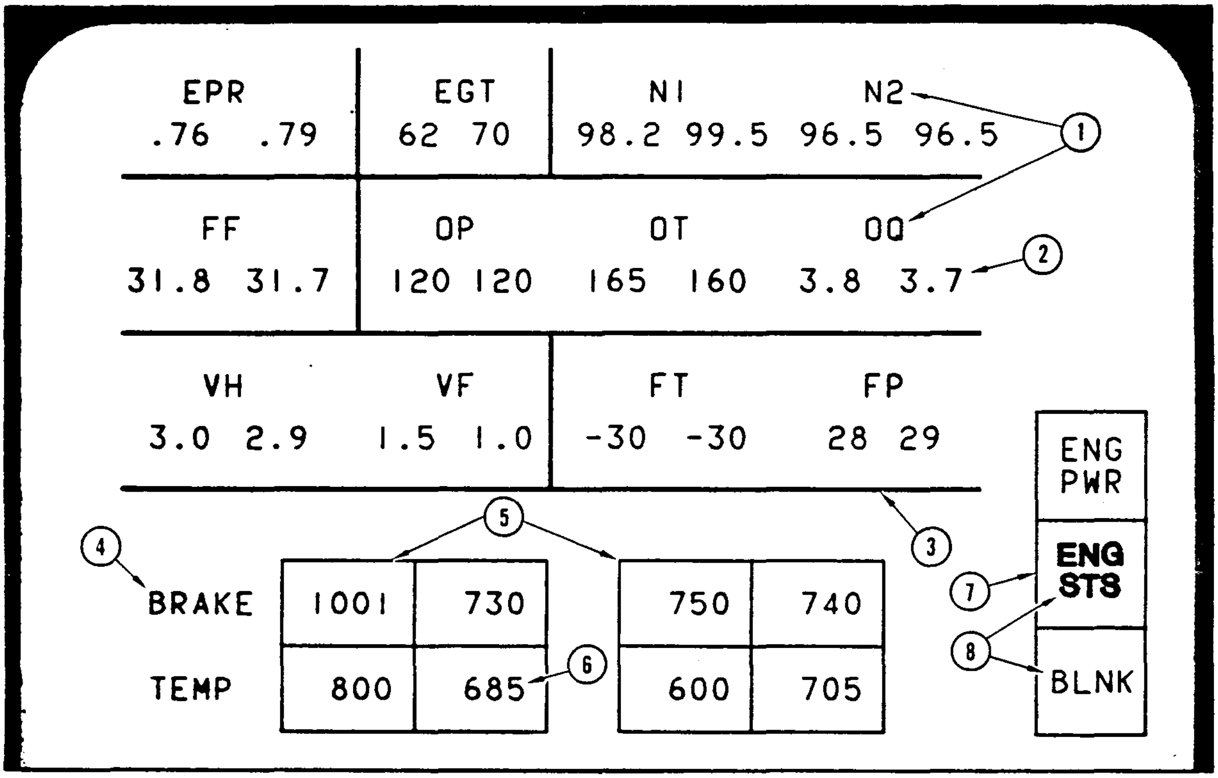


1. ALL PARAMETER LABELS AND UNITS - GREEN
2. RPM TOUCH PANEL SWITCH OUTLINE - GREEN
3. DIGITAL READOUT OF PARAMETERS -
   - EPR - NORMAL, GREEN; WARNING, RED
     EGT - NORMAL, GREEN; CAUTION, AMBER; WARNING, RED
     RPM - NORMAL, GREEN; WARNING, RED
     FF - GREEN
4. ALL SCALES - WHITE
5. EPR LIMIT MARKER - RED
6. COMMANDED EPR MARKER - WHITE
7. THROTTLE EPR SETTINGS - AMBER
8. ACTUAL ENGINE EPR BARS - NORMAL, GREEN; WHEN THE EPR LIMIT IS EXCEEDED, THAT PORTION OF THE BAR ABOVE THE LIMIT LINE PLUS THE INNER HALF OF THE VERTICAL BAR BELOW THE LIMIT LINE TURNS RED
9. EGT WARNING LIMIT MARKER - RED
10. EGT CAUTION LIMIT MARKER - AMBER

Figure 29. Engine Power Display, (Sheet 1 of 2)

11. ACTUAL EGT BARS - NORMAL, GREEN. WHEN EGT EXCEEDS THE CAUTION LIMIT, THAT PORTION OF THE BAR ABOVE THE CAUTION LIMIT LINE PLUS THE INNER TWO-THIRDS OF THE VERTICAL BAR BELOW THE CAUTION LIMIT LINE TURNS AMBER. WHEN EGT EXCEEDS THE WARNING LIMIT PLUS THE INNER THIRD OF THE VERTICAL BAR BELOW THE CAUTION LIMIT TURNS RED; THE OUTER TWO-THIRDS OF THE BAR BETWEEN THE WARNING AND CAUTION LIMITS PLUS THE CENTER THIRD OF THE VERTICAL BAR BELOW THE CAUTION LIMIT REMAIN AMBER; AND THE OUTER THIRD OF THE VERTICAL BAR BELOW THE CAUTION LIMIT REMAINS GREEN.
12. RPM LIMIT MARKER - RED
13. ACTUAL RPM BARS - NORMAL, GREEN; WHEN RPM LIMIT IS EXCEEDED, THAT PORTION OF THE BAR ABOVE THE LIMIT LINE PLUS THE INNER HALF OF THE VERTICAL BAR BELOW THE LIMIT LINE TURN RED
14. ACTUAL FUEL FLOW BARS - GREEN
15. TOUCH PANEL SWITCHES - GREEN
16. SWITCH LEGENDS - WHITE IF SELECTED (SHOWN AS HEAVY FONT), GREEN OTHERWISE

Figure 29. Engine Power Display, (Sheet 2 of 2)



1. PARAMETER LABELS - GREEN
2. DIGITAL PARAMETER READOUTS - FF GREEN; EPR, N1, N2, OP, OT, OQ, VH, VT AND FP, NORMAL IS GREEN AND NON-NORMAL IS RED; EGT, NORMAL IS GREEN, CAUTION IS AMBER, AND WARNING IS RED: FT, NORMAL IS GREEN AND NON-NORMAL IS AMBER
3. DIVIDING LINES - DESATURATED ORANGE
4. BRAKE TEMP LABEL - GREEN
5. BRAKE TEMP BOXES - DESATURATED ORANGE
6. DIGITAL BRAKE TEMP READOUTS - NORMAL, GREEN; WARNING, RED
7. TOUCH PANEL SWITCHES - GREEN
8. TOUCH PANEL LEGENDS - WHITE IF SELECTED (SHOWN AS HEAVY FONT), GREEN OTHERWISE

Figure 30. Engine Status Display

Cockpit Display of Weather and Approach Chart Display

The options available for display on the lower portion of the number 2 CRT are shown in Figure 31. In addition to the menu shown, they include the same engine status format discussed above; cockpit display of weather (CDWI) format, shown in Figure 32 and discussed later along with other ATC systems; and instrument approach information (JEPP) formats.

Jeppesen Chart Display - The information on the various pages of this display replaces or supplements paper copies of Jeppesen approach charts. It is not interactive with the movement of the aircraft, so it provides information and procedures but does not indicate aircraft position.

This information is accessed by touching one of the touch switches under JEPP on the menu page for the display. When any switch is touched, Jeppesen chart information is called up for the destination recorded in the flight plan. Information on alternative airfields may be requested via the CDU when the Jeppesen chart mode is active.

When the top JEPP switch (HORIZ) is selected, the horizontal portion of the approach for the selected airfield is presented. Figure 33 shows a representative horizontal approach format. When the desired horizontal approach is located, touching the advance (ADV) button calls up the vertical approach format for the selected horizontal approach. Figure 34 shows a representative vertical approach, and Figure 35 shows a taxiway diagram. Subsequent touches of the ADV button will page through the file of general information on the specified airfield. The file of general airfield information includes pages for airport information, taxiing, noise abatement, terminal control areas (TCA), standard terminal arrivals (STAR), standard instrument deparatures (SID), etc.

Touching the reverse (REV) button will backpage to the preceding format in the file. For example, when a vertical approach is being displayed, touching the REV button calls up the associated horizontal approach format.

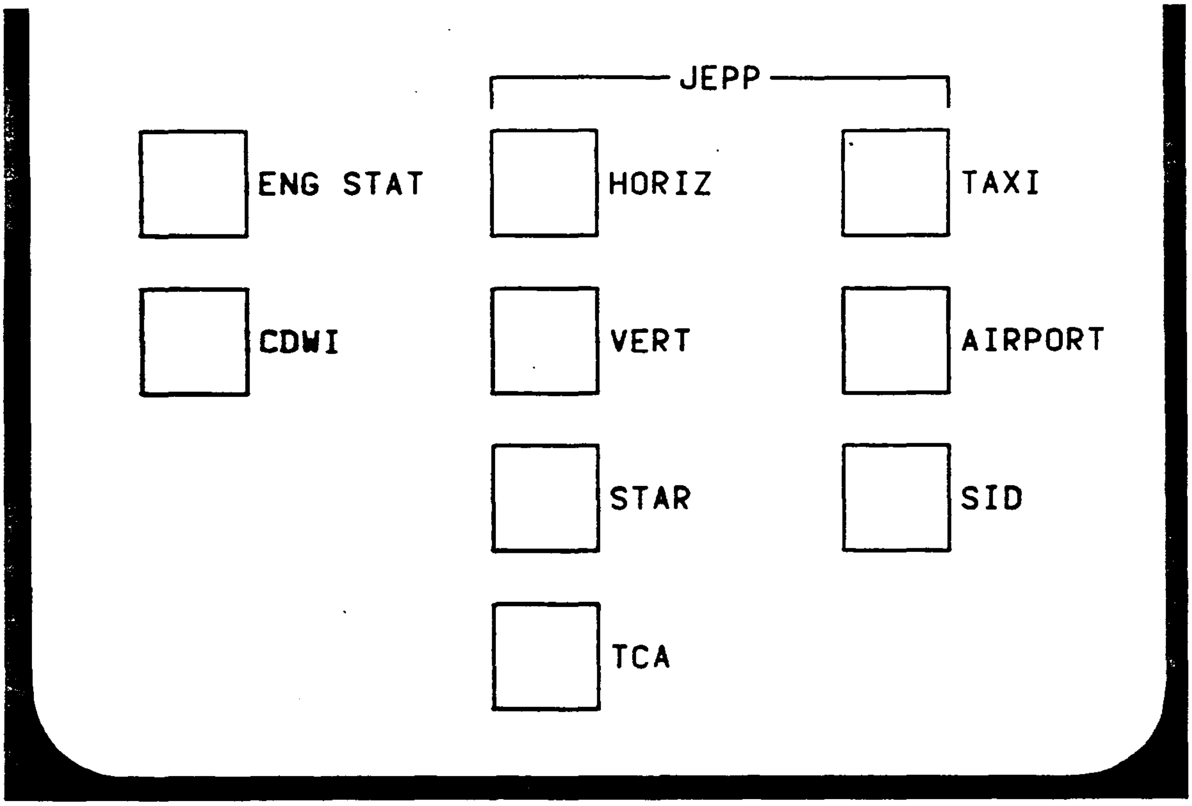
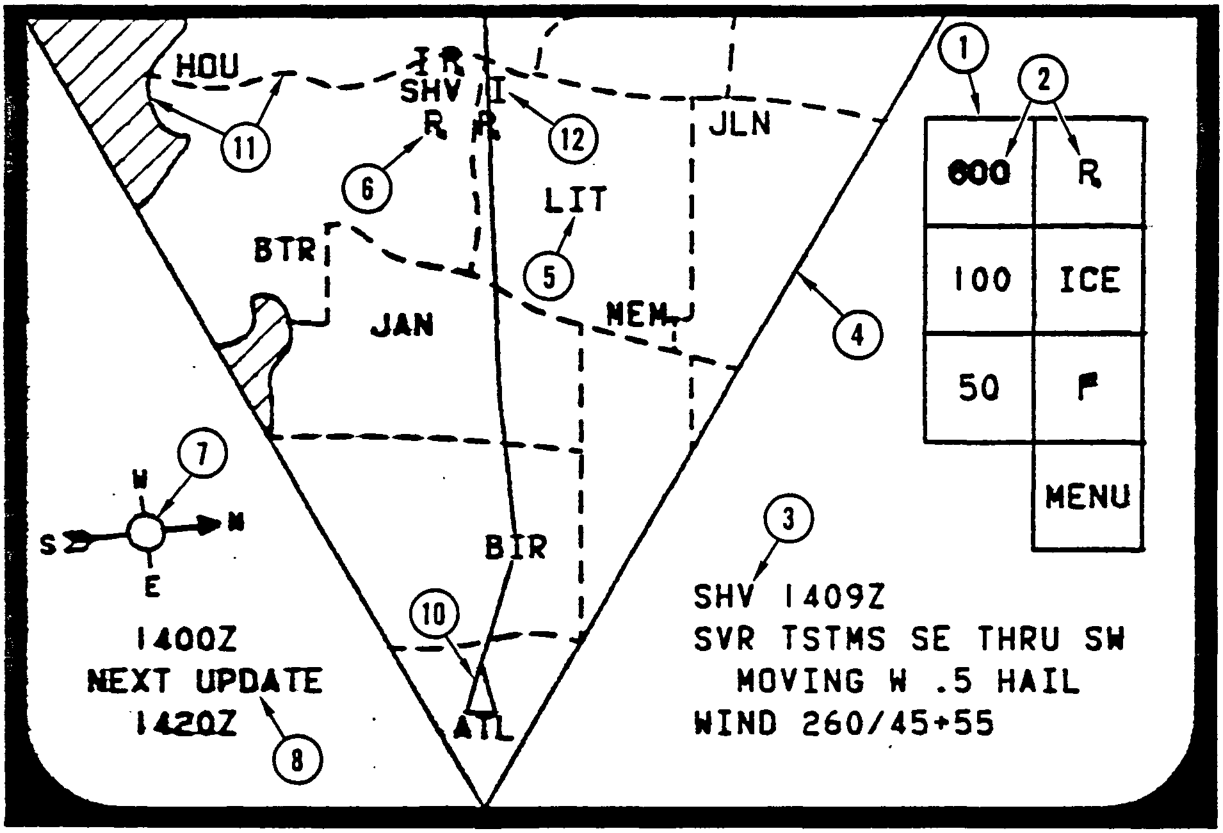
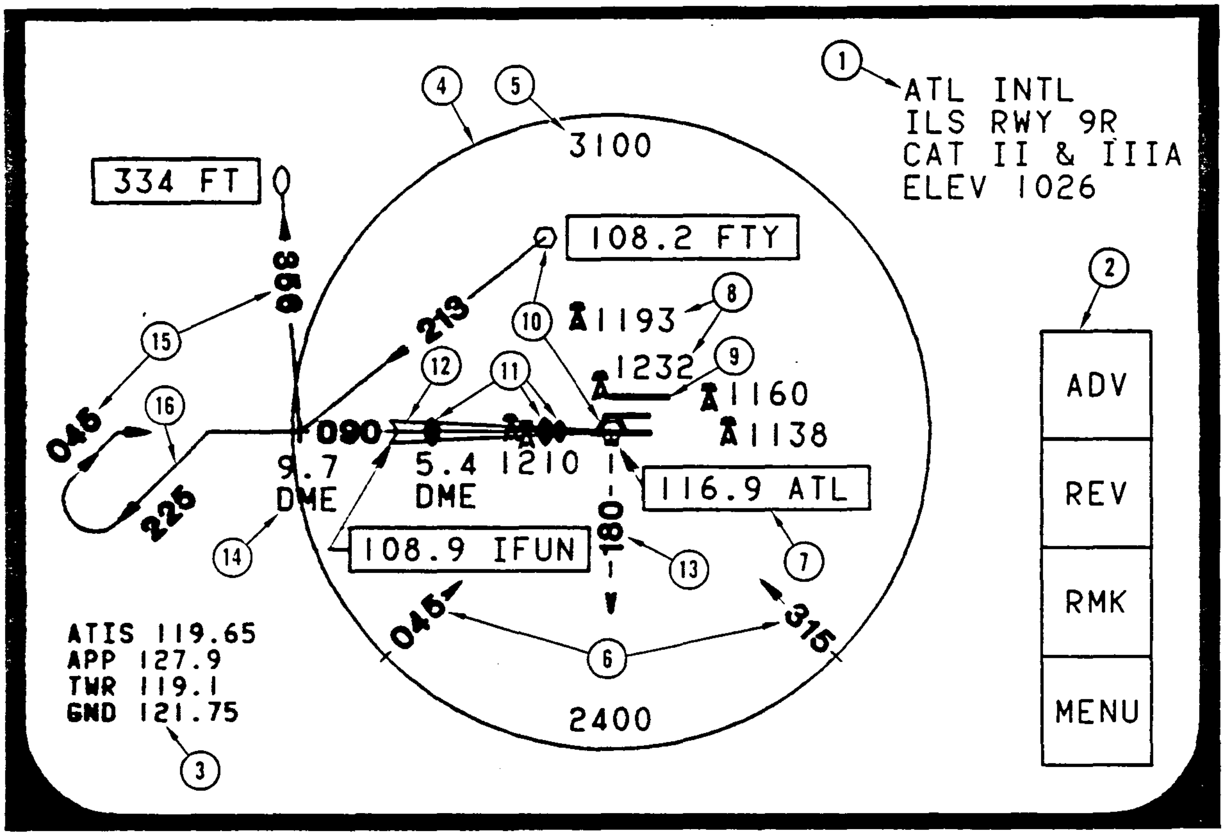


Figure 31. Menu for Lower Portion of Number 2 CRT



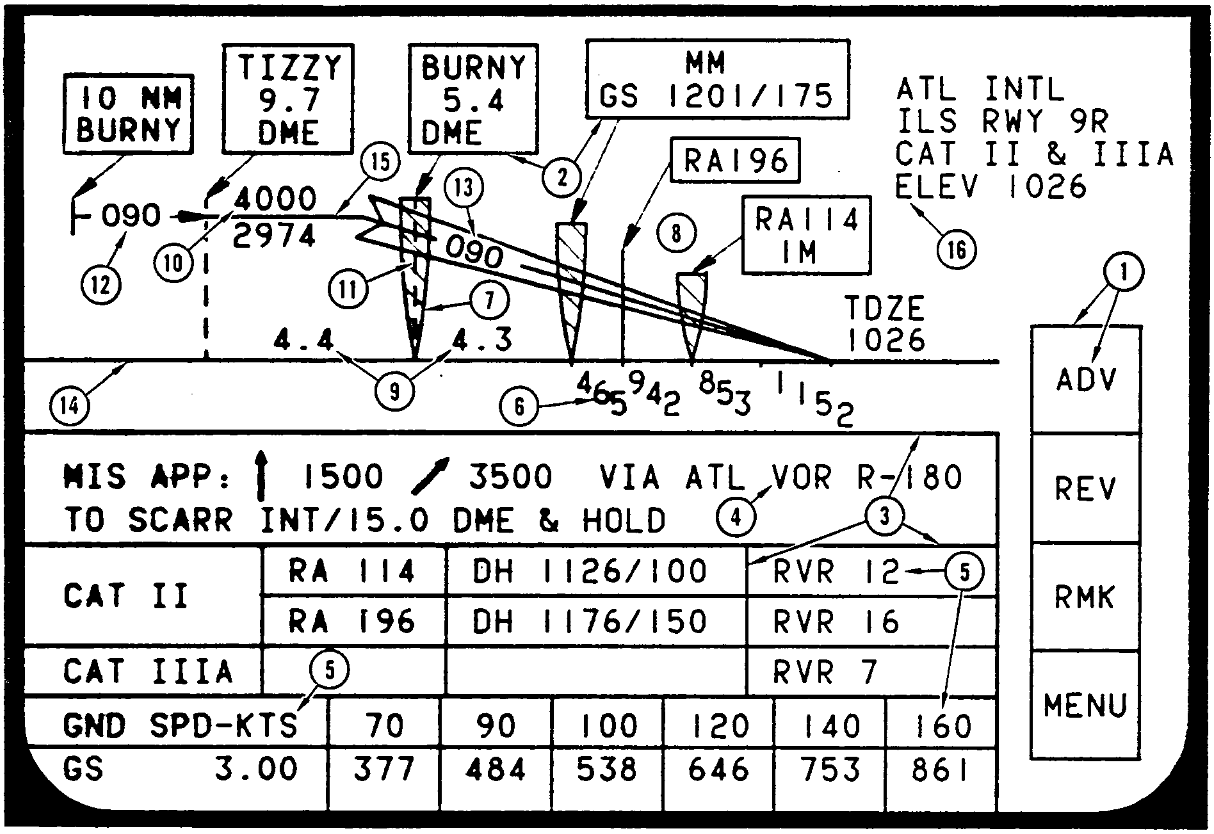
1. TOUCH PANEL OUTLINE - GREEN
2. RANGE AND SYMBOLOGY OVERLAY LABELS - WHITE IF SELECTED (SHOWN AS BOLD FONT,) GREEN OTHERWISE
3. ADVISORY MESSAGE - AMBER
4. MAP BOUNDARY - WHITE
5. REFERENCE CITY LABELS - WHITE
6. THUNDERSTORM SYMBOL - WHITE, LEVEL 1; AMBER, LEVEL 2; RED, LEVEL 3
7. COMPASS SYMBOL - GREEN
8. UPDATE TIME ANNUNCIATION - GREEN
9. COURSE - GREEN
10. AIRCRAFT SYMBOL - WHITE
11. MAP OUTLINES - WHITE
12. ICING SYMBOL - WHITE IF PREDICTED, AMBER IF ENCOUNTERED

Figure 32. Cockpit Display of Weather Information



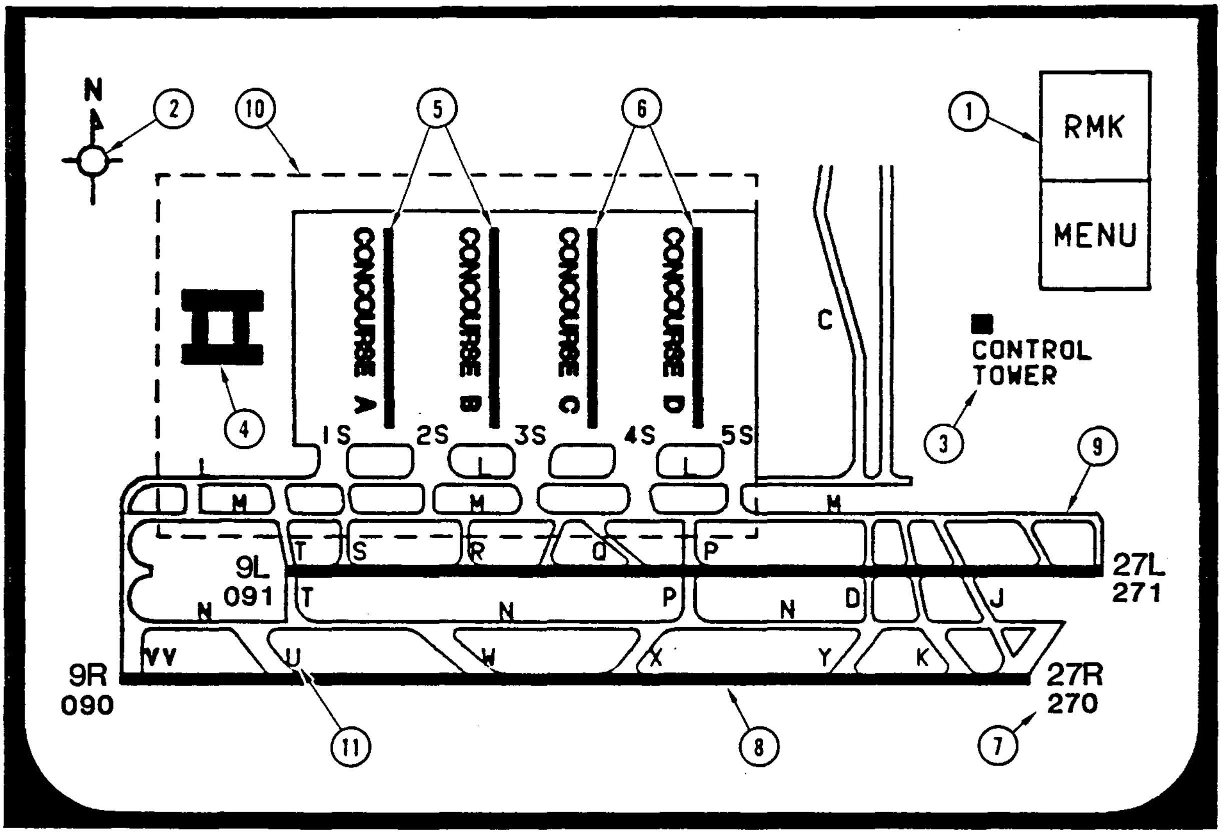
1. INFORMATION BLOCK - GREEN
2. TOUCH PANEL SWITCHES AND LEGENDS - GREEN
3. RADIO INFORMATION BLOCK - GREEN
4. 10 NM BOUNDARY CIRCLE - WHITE
5. ALTITUDE MINIMUMS - GREEN
6. MINIMUM SECTOR ALTITUDE IDENTIFIERS - WHITE
7. NAVAID FACILITY BOXES - BOX, WHITE; ALPHANUMERICS, GREEN
8. OBSTACLES AND HEIGHTS - AMBER
9. RUNWAY SYMBOLS - GREEN
10. NAVAID SYMBOLS - GREEN
11. MARKERS - AMBER
12. LOC SYMBOL - WHITE
13. MISSED APPROACH COURSE - WHITE
14. DME DISTANCES - GREEN
15. HEADINGS - WHITE
16. APPROACH PROCEDURE FLIGHT TRACK - WHITE

Figure 33. Instrument Approach Data (Horizontal Info)



1. TOUCH PANEL SWITCHES AND LEGENDS - GREEN
2. FIX INFORMATION BLOCKS - BOX AND ARROW, WHITE; ALPHANUMERICS, GREEN
3. APPROACH INFORMATION BOX OUTLINES - WHITE
4. MISSED APPROACH INFORMATION - WHITE
5. REMAINING APPROACH INFORMATION - GREEN
6. FIX DISTANCES - GREEN
7. MARKER BEACONS - AMBER
8. DECISION HEIGHT MARKER - WHITE
9. DME DISTANCES - GREEN
10. MINIMUM PROCEDURE TURN ALTITUDE AND HEIGHT ABOVE RUNWAY - GREEN
11. NAMED FIX MARKER - WHITE
12. TRACK - WHITE
13. GLIDESLOPE SYMBOL AND HEADING - WHITE
14. GROUND LINE - WHITE
15. TRACK LINE - WHITE
16. INFORMATION BLOCK - GREEN

Figure 34. Instrument Approach Data (Vertical Info)



1. TOUCH PANEL SWITCHES AND LEGENDS - GREEN
2. COMPASS SYMBOL - GREEN
3. CONTROL TOWER SYMBOL - GREEN
4. TERMINAL SYMBOL - GREEN
5. CONCOURSE SYMBOLS - GREEN
6. CONCOURSE LABELS - WHITE
7. RUNWAY LABELS - WHITE
8. RUNWAY SYMBOLS - GREEN
9. TAXIWAY LABELS - GREEN
10. TERMINAL AREA BOUNDARY - GREEN
11. TAXIWAY LABELS - WHITE

Figure 35. Instrument Approach Data (Taxiway Diagram)

Advisory, Caution and Warning System Display

The top portion of the center or number 3 CRT displays the advisory, caution and warning system (ACAWS). This is a single integrated system through which all alerting information is processed and is assigned to one of three urgency levels. Processing involves determining other-than-normal conditions by logically checking the status of the entire system. For example, low oil pressure, generator off-line, etc., are normal conditions when the engine is not running, and thus would not constitute an alerting situation. Alerts are displayed as they occur and assigned to their respective urgency level. The alert remains in the system until the situation no longer exists or is stored into the system's memory.

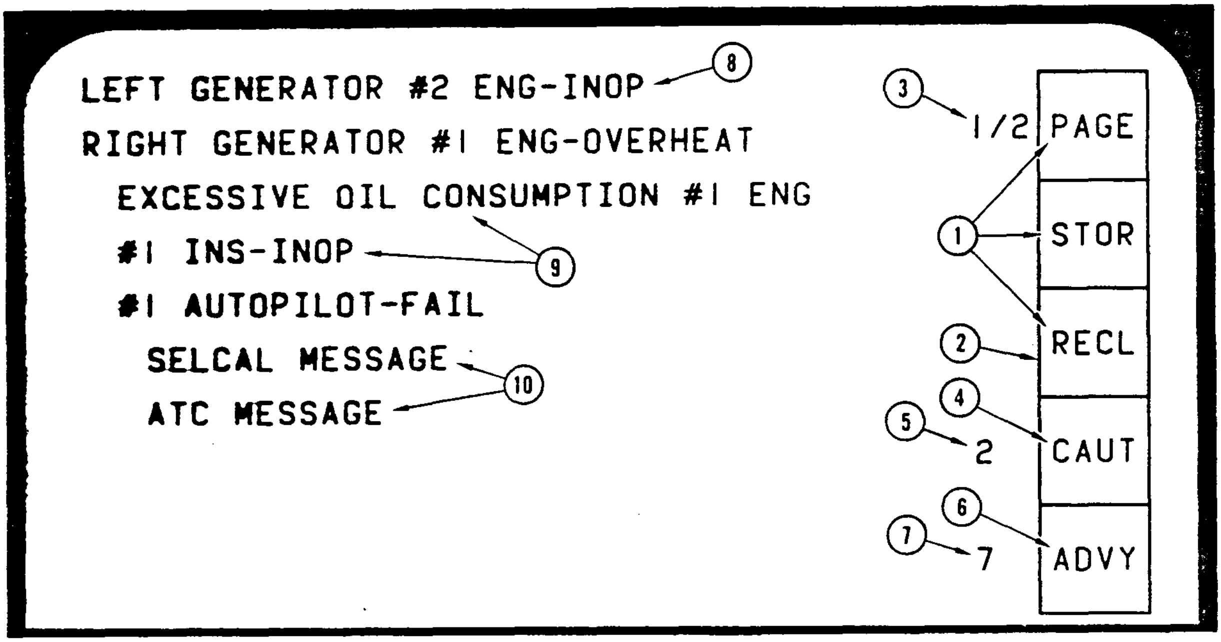
The advisory, caution and warning system has both visual and aural (tone and voice) message outputs. Messages are prioritized (inhibited) by flight phase and equipment failure.

All visual alerting messages, with the exception of those which are time-critical, are displayed on the ACAWS display as shown in Figure 36. It may display a total of nine lines of text. The top two lines in this example are warnings, normally displayed in red; the next three lines are cautions, displayed in amber; and the last two lines are advisories, displayed in white. The number of lines of each vary according to demand.

Time-critical warnings, such as those for collision avoidance, are presented on the pilot's and copilot's flight displays, as shown in Figure 37. The visual message is presented in red and is accompanied by tone and voice, such as the example, "climb right."

Each ACAWS message is accompanied by a tone--chime for alert, steady tone for caution, alternating high-low pitched tone for warning. Warning and caution voice messages are available upon request by depressing a switch on either of the side-stick controllers.

Caution and warning messages are also accompanied by the respective master caution light (Item 5, Figure 15) or master warning light (Item 4, Figure 15), located on the glareshield in front of each pilot. Depressing the master caution or warning light/switch extinguishes the light indication and the associated tone. Requesting a voice annunciation also extinguishes the master light and associated tone.



1. PAGE, STORE AND RECALL LEGENDS - GREEN
2. TOUCH PANEL OUTLINE - GREEN
3. PAGE TALLY ANNUNCIATION - GREEN
4. CAUTION LEGEND - AMBER
5. STORED CAUTION READOUT - AMBER
6. ADVISORY LEGEND - WHITE
7. STORED ADVISORY READOUT - WHITE
8. WARNING MESSAGES - RED
9. CAUTION MESSAGES - AMBER
10. ADVISORY MESSAGES - WHITE

Figure 36. Advisory, Caution and Warning System

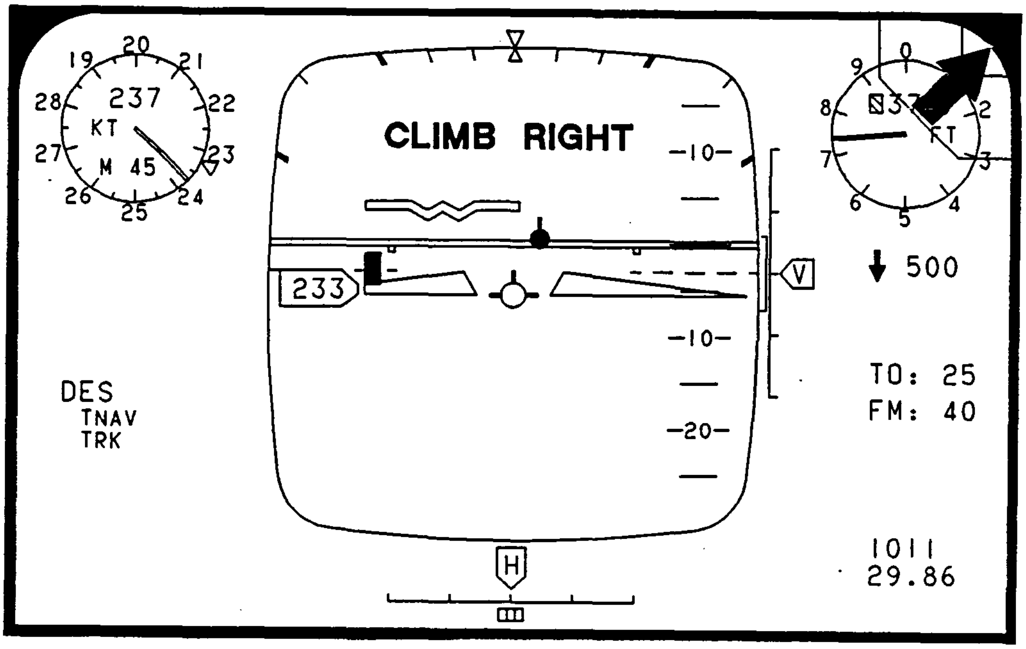


Figure 37. Flight Display with Time-Critical Message

The flight segments used for prioritization of ACAWS messages are listed below. A message output, even though critical, may be inhibited during specific flight phases, such as phase number 5 or 9 below. Less critical messages may be inhibited during other flight phases. Messages are sometimes regraded, caution to warning, advisory to caution, etc., with respect to flight phase.

Messages are also prioritized according to equipment status. For example, in a system such as triple inertial navigation, a single computer failure may result in an advisory message, two computer failures in a caution, and if all computers fail, in a warning.

The flight phases are defined as shown below:

- Phase #1 - 5 minutes after last engine shutdown until engine start and block out
- Phase #2 - Starts at block out through taxi, where velocity is less than 50 knots
- Phase #3 - Takeoff power application to a velocity of 100 knots
- Phase #4 - Velocity of 100 knots to rotation
- Phase #5 - Rotation to 400 ft during takeoff phase
- Phase #6 - 400 ft to 1000 ft during takeoff phase
- Phase #7 - Above 1000 feet
- Phase #8 - 1000 ft to 400 ft during approach phase
- Phase #9 - 400 feet to touchdown during landing phase
- Phase #10 - Touchdown until velocity is 50 knots
- Phase #11 - Velocity less than 50 knots, taxi to block
- Phase #12 - Block to 5 minutes after last engine shutdown

Touch panel switches are used to page through the messages, store them from view, and recall them to view. The operation of the switches is described below.

Page - The page switch calls up information which has overflowed above the nine-line capacity. If an overflow condition has not occurred (i.e., more than one page of alerts), the page key does not operate.

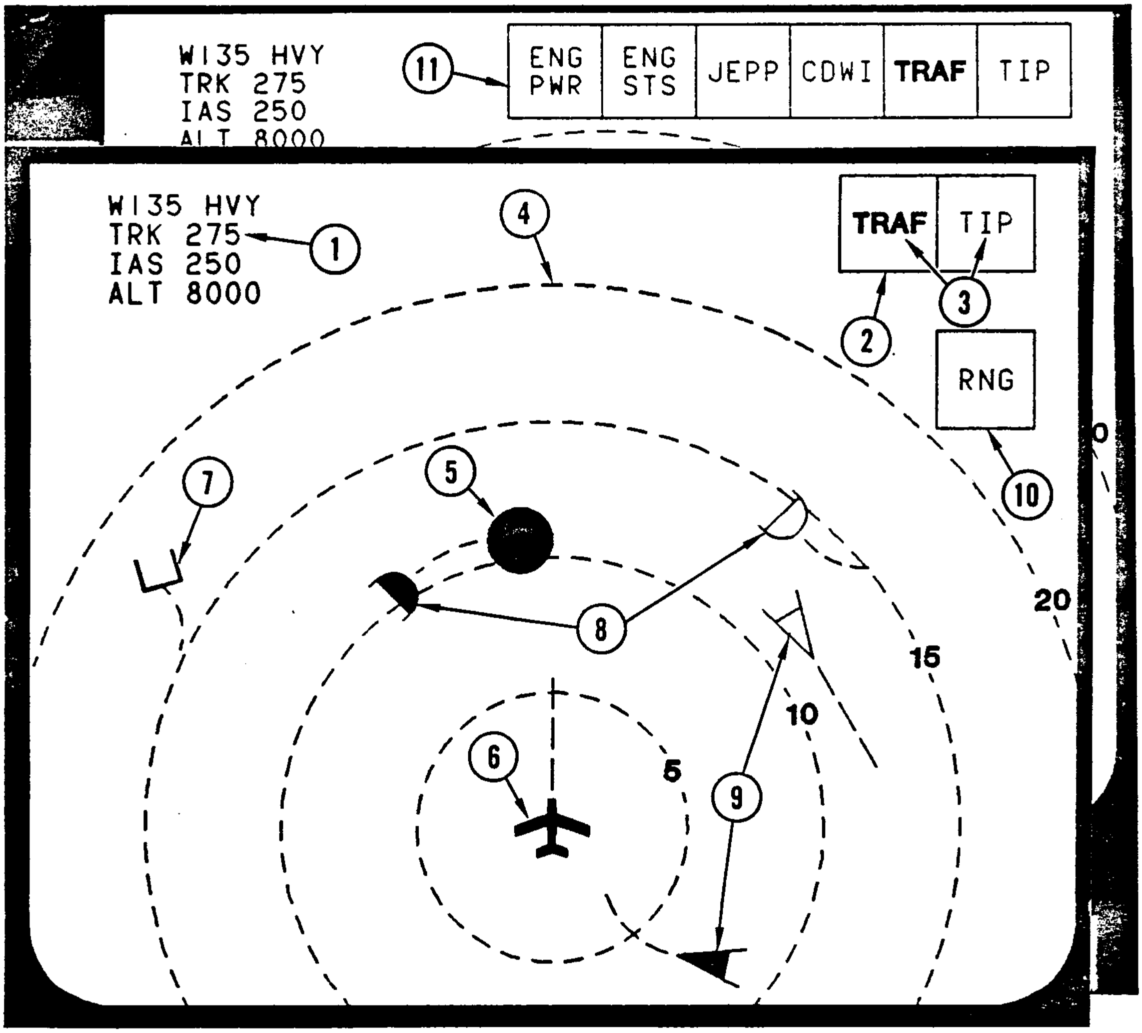
Adjacent to the page key is a number that corresponds to the current page and a number representing the total number of pages, such as 1/2, which would be page 1 of 2.

Store - The store key provides a method of collectively or individually storing cautions or advisories. Warnings cannot be stored. To store a single line the operator touches the line (the alert) and then keys the store switch. To store all cautions or all advisories, the operator keys the appropriate caution or advisory switch, and then selects the store switch. The number adjacent to the caution and advisory switches indicates the number stored.

Recall - The recall switch enables the cautions or advisories to be recalled. To recall cautions, the operator selects the caution switch and then the recall switch. The system operates similarly for advisories.

Cockpit Display of Traffic Information

The lower portion of the number 3 CRT displays the cockpit display of traffic information (CDTI) as shown in Figure 38. The touch switches, shown at the top of that figure, represent the options that become available if one of the other CRTs fail, as discussed earlier and illustrated in Figures 18 and 19.



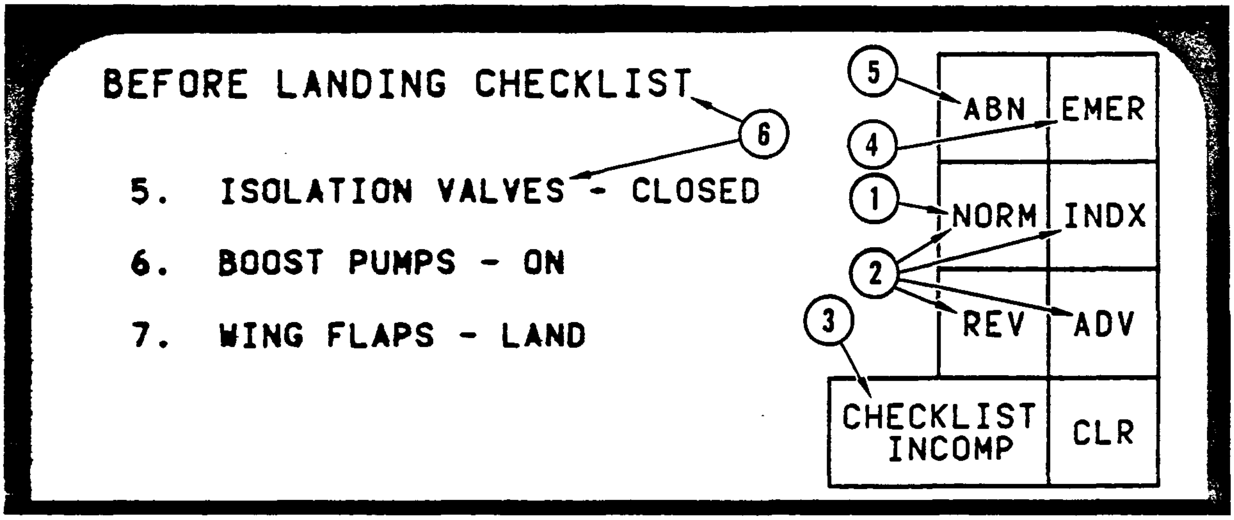
1. SELECTED AIRCRAFT MESSAGE BLOCK - GREEN
2. TOUCH PANEL SWITCHES - GREEN
3. TOUCH PANEL LEGENDS - WHITE, IF SELECTED (SHOWN AS HEAVY FONT); GREEN OTHERWISE
4. RADAR RANGE SCALE - WHITE
5. PROXIMITY WARNING INDICATOR - AMBER, LEVEL 1; RED, LEVEL 2
6. OWN AIRCRAFT SYMBOL AND PREDICTOR - WHITE
7. UNKNOWN ALTITUDE SYMBOL AIRCRAFT AND PREDICTOR - WHITE
8. AIRCRAFT BELOW SYMBOL AND PREDICTOR - UNFILLED AMBER IF 1000-500 FT; FILLED RED IF 500-0 FT
9. AIRCRAFT ABOVE SYMBOL AND PREDICTOR - UNFILLED AMBER IF 1000-500 FT; FILLED RED IF 500-0 FT
10. RANGE TOUCH PANEL SWITCH AND LEGEND - GREEN
11. DEGRADED MODE TOUCH PANEL - SWITCH OUTLINES, GREEN; SWITCH LEGENDS, WHITE IF SELECTED (SHOWN AS BOLD FONT) AND GREEN OTHERWISE

Figure 38. Cockpit Display of Traffic Information

Checklist Display

Checklists are displayed on the top portion of the number 4 CRT, as shown in Figure 39; the system schematics, including touch panel controls, are displayed on the lower portion of the same display. Dedicated touch panel controls for checklist include: abnormal checklist, emergency checklist, normal checklist, index, page advance, page reverse, clear checklist, and checklist incomplete. Initial power application causes the first sequenced checklist to appear. Each item of the checklist is checked off by pressing the line item. When an item is checked off, it is removed from the top of the display and the next items scroll up. When the checklist item appearing at the top of the display requires manipulation or checking of switches, valves, or system parameters which are part of a systems display, the required system schematic automatically appears on the display. For example, during the "before landing" checklist, as one item is checked off the next item appearing at the top of the systems display reads "Isolation Valves - Closed." As this item scrolls to the top of the list, the systems display changes to show the fuel system schematic. The isolation valves are closed by touching the appropriate switches on the schematic. The checklist item is then checked off by touching any place on the "Isolation Valves - Closed" line, causing the next item to scroll to the top, accompanied by a change in the schematic display as appropriate.

If one or more items are skipped in a checklist by pressing other than the top line, the checklist may be continued; however, a note appears beneath the touch panel switches indicating "checklist incomplete." Pressing other than the top line causes that line to move to the top, skipped items to disappear, and the appropriate schematic to appear. The item must then be checked off by pressing the line a second time. Individual checklists are incomplete until all items on the list have been checked off. To recall a skipped item in a checklist, the checklist incomplete message (switch) is touched. This action clears the checklist area and causes the first skipped item in the normal checklist sequence to appear; touching the message again causes the next skipped item to replace the first item, and each successive touch cycles the next skipped item, up to the present position in the checklist. At this point, the first skipped item is again dis-



1. TOUCH PANEL OUTLINE - GREEN
2. NORMAL, INDEX, REVERSE, ADVANCE AND CLEAR LEGENDS - GREEN
3. CHECKLIST INCOMPLETE LEGEND - AMBER WHEN PRESENT
4. EMERGENCY LEGEND - RED
5. ABNORMAL LEGEND - AMBER
6. CHECKLIST TITLE AND ITEMS - GREEN

Figure 39. Checklist Display

played and the sequence repeated as long as the touch panel is activated. If an item is checked off after being called up through the incomplete checklist mode, the system continues as if the item had been checked off in normal sequence. When an item is cleared in this situation, the next uncleared checklist item appears or, if there are no other incomplete checklist items, the next sequenced checklist is displayed.

A clear checklist switch (CLR) is provided on the touch panel display. When touched, it clears all remaining items on the checklist in progress. Although the operations called for by the checklist are not accomplished, the checklist sequence continues as if each item had been completed.

As each checklist is completed, the next sequenced checklist automatically follows. To display a checklist out of sequence the touch panel index (INDX) switch is touched, calling up the index of checklists. If you are operating in one sequence, such as (NORM), and wish to display the index of (ABN) procedures checklists, the ABN switch must first be pressed, followed by the INDX switch. A touch on the line naming the desired checklist causes it to be displayed.

The emergency checklist is separate from the normal checklist and is accessed by touching the EMER switch on the checklist menu. This brings up the emergency checklist index from which the desired checklist may be selected by touching that line item. After the initial access to the emergency checklist, touching INDX will cause the emergency checklist index to be displayed. The system remains within the emergency checklist area until the NORM checklist switch followed by the INDX switch is touched, at which time the normal index will be displayed. The operation of the abnormal checklist is identical with that described above for the emergency checklist, except that the appropriate abnormal switches are operated instead of emergency switches.

The appropriate emergency or abnormal checklist may also be displayed as follows. When a malfunction or emergency occurs which (1) provides an ACAWS message to the pilots, and (2) has a checklist in memory which can be displayed, pressing the appropriate ABN or EMER switch automatically displays the correct checklist. The malfunctioning system schematic is also automatically displayed, if appropriate.

Once the normal checklist is begun, the position in the checklist is retained if the checklist is interrupted for any reason. For example, the third item on the descent checklist has been completed when an engine malfunction necessitates going to the engine shutdown checklist. Pressing the emergency switch followed by the index displays the emergency index. The engine shutdown checklist is then selected by touching the line of the desired checklist. After completion of the emergency checklist, touching the normal checklist switch returns the display to the previous position in the normal checklist. In this specific example, the previous position can also be reached by pressing the checklist incomplete message switch.

The same type of logic is incorporated with the abnormal and emergency checklists. For example, if an emergency checklist is interrupted, return to that position in the checklist is accomplished by simply touching the emergency checklist switch.

The reverse (REV) and advance (ADV) switches are used to scroll the displayed items backward or forward within checklists, within checklist sequences, and within checklist indexes, depending on which has been selected. The display changes three lines at a time except when reaching the end of a checklist or an index. In those cases, one switch hit takes the display to the end of the list, and the next switch hit displays three lines of the following list.

Checklists may also be accessed by voice. This may be accomplished by pressing one of the voice command switches and speaking the name of the desired checklist. The commanded checklist -- normal, abnormal, or emergency -- then appears; and individual items may be checked off as previously described. If a normal checklist is being run and index is activated either by touching the index space on the touch panel or by pressing the voice command switch and commanding index, the normal checklist index appears. Similarly, if index is activated while an abnormal or emergency checklist is in progress, the appropriate index is shown. The same logic prevails under voice control when a checklist is interrupted. That is, when normal checklist is commanded after an interruption has taken place in the normal checklist, the display will return to the point in the checklist where the interruption occurred. The same logic is applicable to the abnormal and emergency checklists.

Aircraft Systems Displays

The lower portion of the number 4 CRT is used to display a wide variety of aircraft functional systems schematics, which are also controlled through touch panel switches. The menu for selecting those systems is shown in Figure 40. The fuel system schematic, which is representative of most others, is shown in Figure 41. Formats of the other systems are included with those systems descriptions.

Display Formats by Flight Phase

Figures 42 through 49 depict one possible solution to the type of information that might be displayed during each flight phase. The information on the flight display is tailored and automatically changes with the flight phase selection on the guidance and control panel. The information on the other displays is changed by the pilot as he wishes.

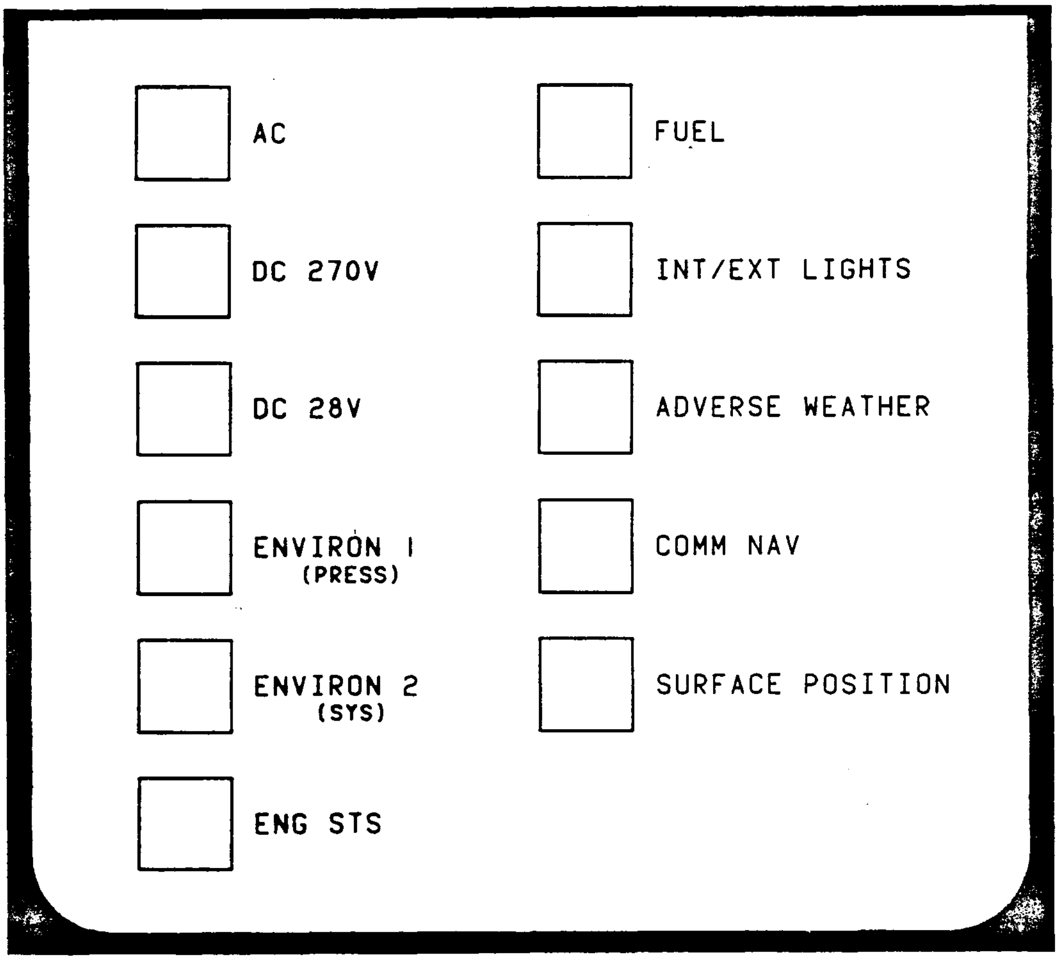
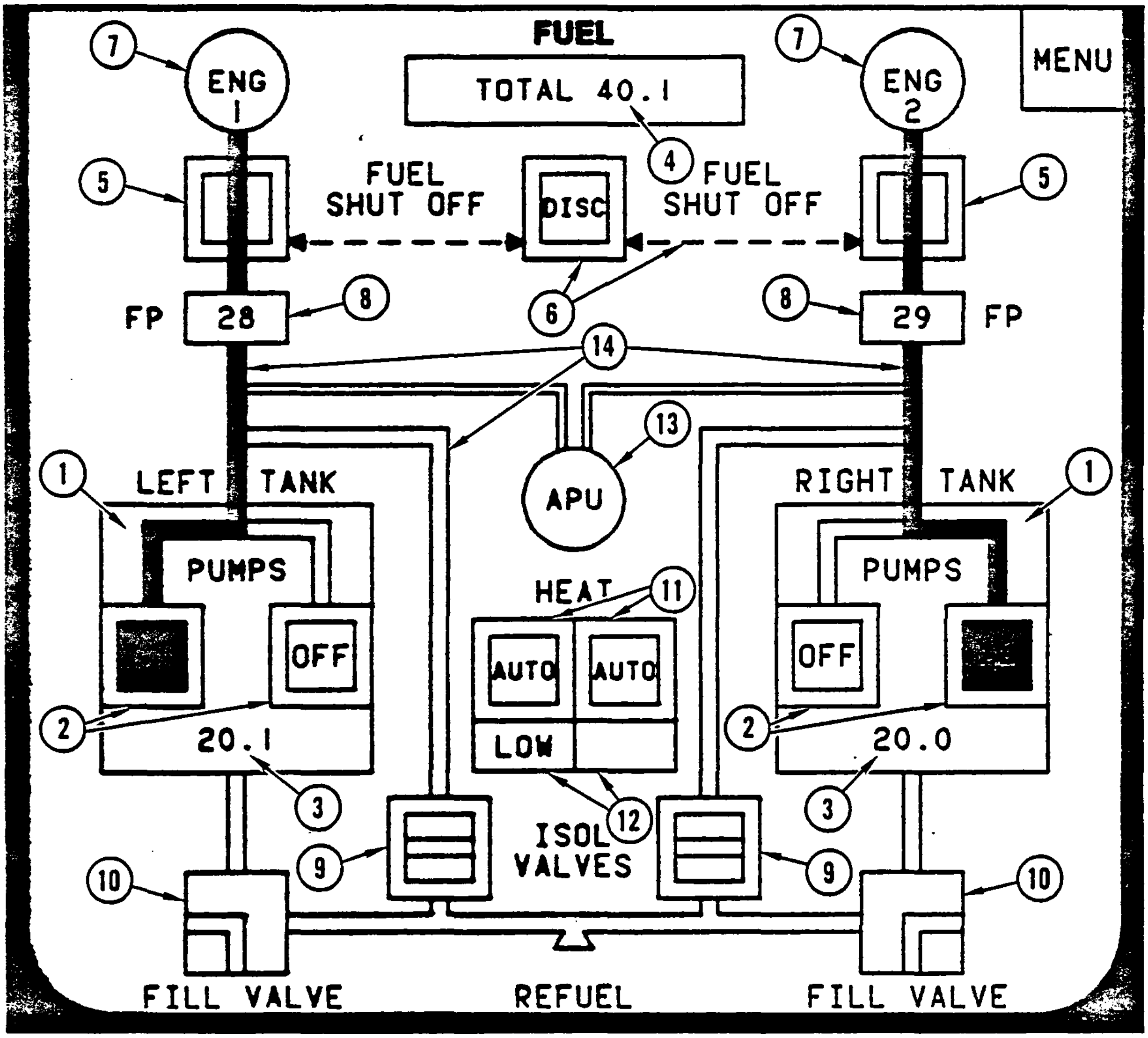


Figure 40. Menu for Selecting Functional Systems



#	SYMBOL	REMARKS
1	FUEL TANK BOX (2)	White, unfilled box. Represents left and right tanks. No change throughout operation.
2	BOOSTER PUMP SWITCHES (4)	Outer square always unfilled white lines. Inner square filled green, when ON; white and unfilled with OFF label, when OFF; inner square filled with red, when failed and ON; unfilled with red X and OFF label, when failed and turned OFF. Switch changes from ON to OFF indication alternately each time it is pressed.
3	FUEL TANK QUANTITY DIGITS (2)	Shows fuel quantity in left and right tank. Digits read from 0.0 to 25.0 and represent thousands of pounds. Color: 0.0 to 2.0 amber, above 2.0 white

Figure 41. Fuel System Display, (Sheet 1 of 3)

#	SYMBOL	REMARKS
4	FUEL QUANTITY TOTALIZER (1)	Shows total of two fuel tank quantity digits. Digits read from 0.0 to 50.0 and represent thousands of pounds. Color of box, word "TOTAL" and digits: 0.0 to 4.0 - amber, above 4.0 white.
5	FUEL SHUTOFF VALVE SWITCHES (2)	Outer and inner squares always unfilled white lines. Green or Amber filled flow line passes through both squares vertically when valve is ON. Unfilled white flow line passes only through inner square horizontally and is not shown on outer square, when OFF. The disconnect switch must be pressed sequentially before the shutoff valve switch in order to turn valve OFF; this is not necessary to turn valve ON.
6	DISCONNECT SWITCH (1) AND ARROWS (2)	Outer and inner squares always unfilled white lines. DISC legend and arrows are white until pressed in sequence, when they turn amber. They will turn back to white when either fuel shutoff valve touch panel switch is pressed, or after a 3-second time period thus either completing or breaking the sequence.
7	AIRCRAFT ENGINES (2)	White, unfilled circle with green ENG 1 or ENG 2 label inside. No change throughout operation.
8	FUEL PRESSURE BOXES AND DIGITS (2)	Digits represent fuel pressure to each engine in PSI. Total range 0 to 99. Color of box and digits: 0 to 30 - amber, above 30 - green.
9	ISOLATION VALVE SWITCHES (2)	Outer and inner squares always unfilled white lines. Amber filled flow line passes through both squares vertically when valve is ON. White unfilled flow line passes only through inner square horizontally and is not shown on outer square, when OFF. Pressing the switch alternately changes it from ON to OFF position.
10	GROUND REFUELING FILL VALVE INDICATORS (2)	White unfilled single square. Unfilled white flow line "corner" indicates position of ground refueling fill valve. Not controllable from touch panel. When simulated in ON position "corner" lines up with flow lines below the fuel tanks.
11	FUEL HEATER SWITCHES (2)	Outer and inner squares always unfilled white lines. Label alternates through three positions changing each time that switch is pressed: MAN (manual), AUTO and OFF. Inner square becomes filled red when heater fails; when failed and turned off red X and OFF both appear on the switch.
12	FUEL TEMPERATURE INDICATORS (2)	White unfilled box. Box is empty to indicate normal fuel temperature. Amber label in box can indicate HIor LOW temperature. This is not a switch, only an indicator.

Figure 41. Fuel System Display, (Sheet 2 of 3)

#	SYMBOL	REMARKS
13	APU (1)	White, unfilled circle with green APU label inside. No change throughout operation.
14	FLOW LINES (ALL)	White unfilled flow line - no fuel or pressure in line. Green unfilled flow lines - normal fuel pressure in lines but no flow. Green filled flow line - fuel flowing in line from normal source, under pressure. Amber filled flow line - fuel flowing in line, but low pressure (gravity feed). Amber unfilled line - no flow and low pressure.

Figure 41. Fuel System Display, (Sheet 3 of 3)

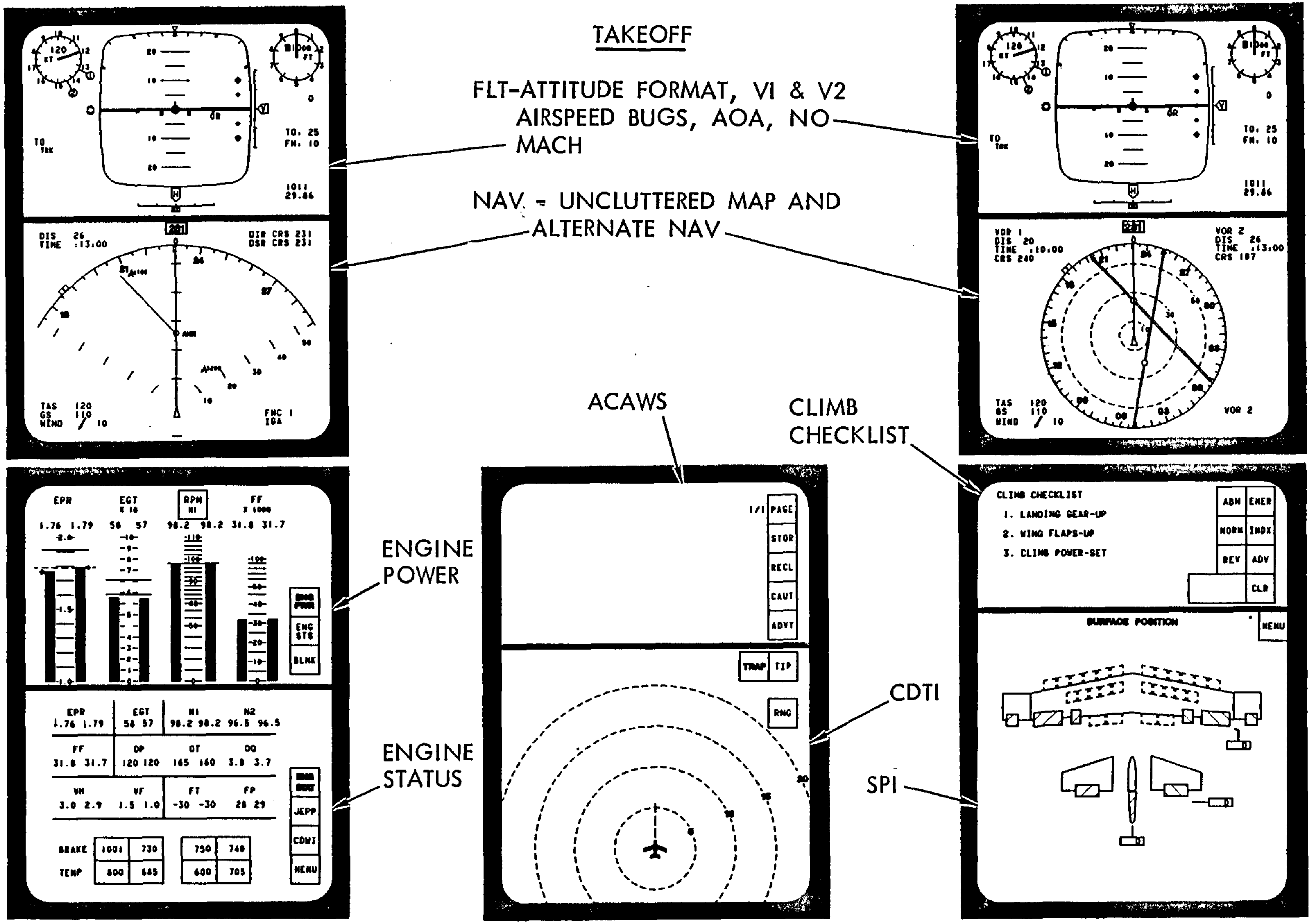


Figure 42. Front Panel Displays - Takeoff Mode

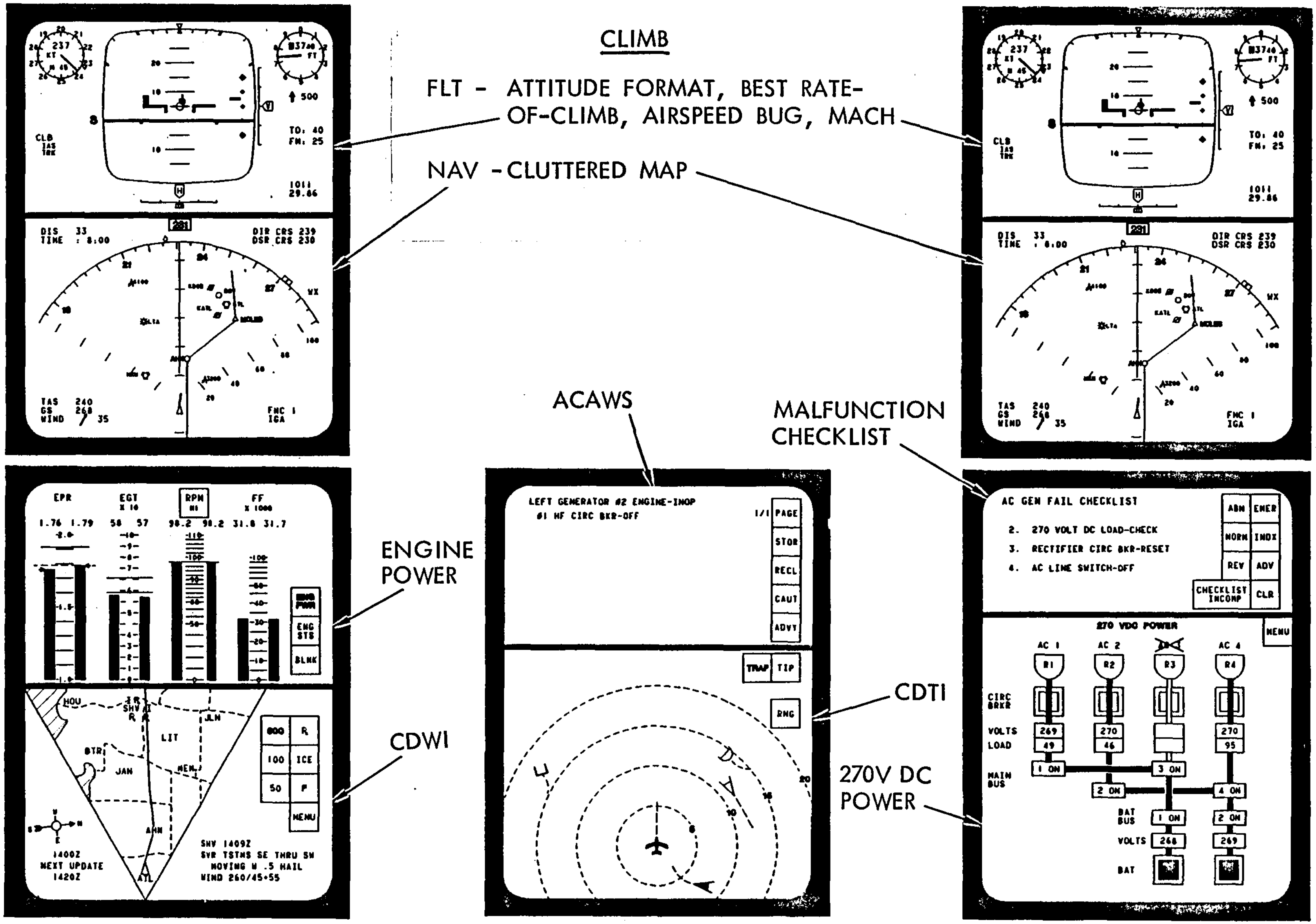


Figure 43. Front Panel Displays - Climb Mode

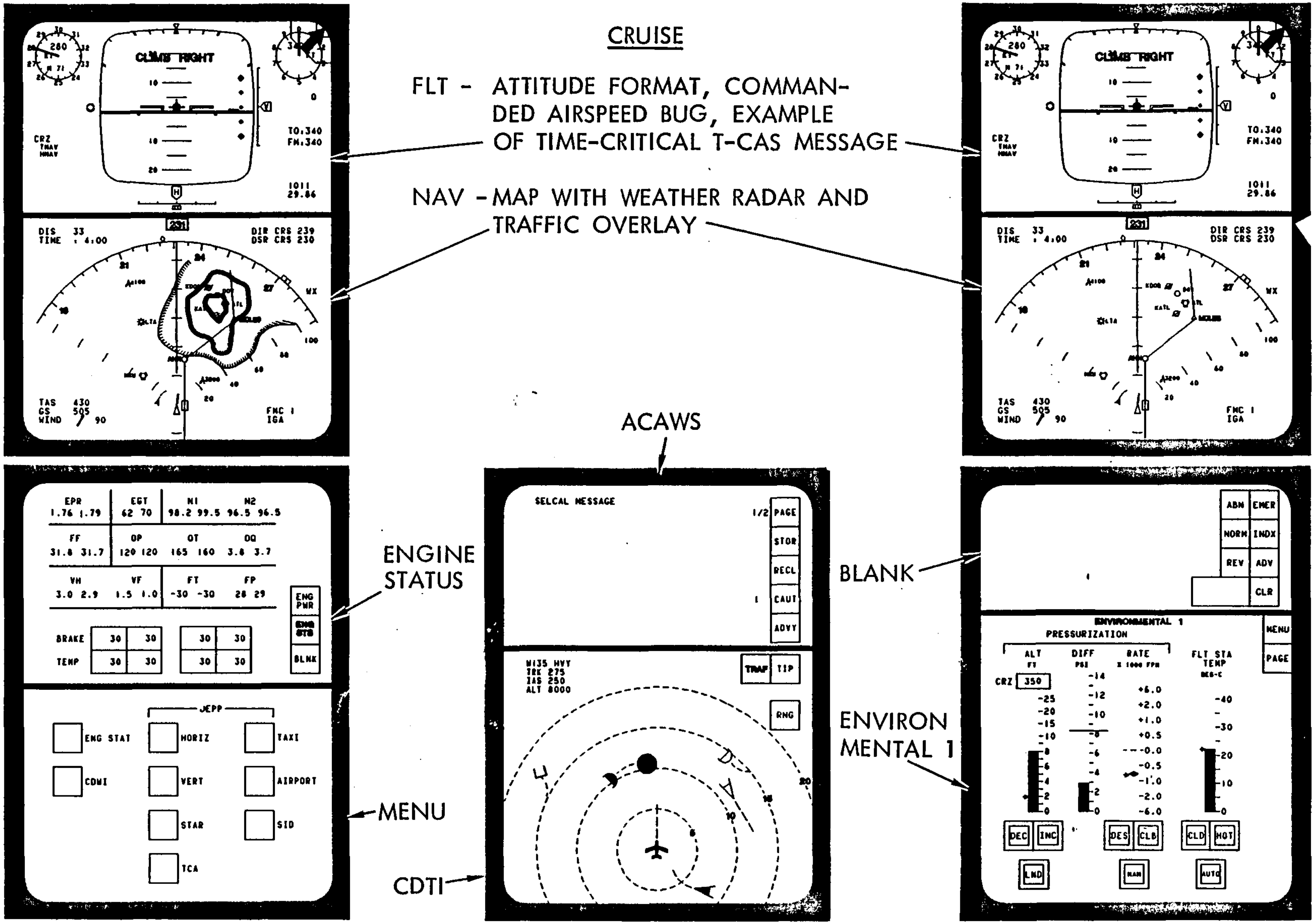


Figure 44. Front Panel Displays - Cruise Mode

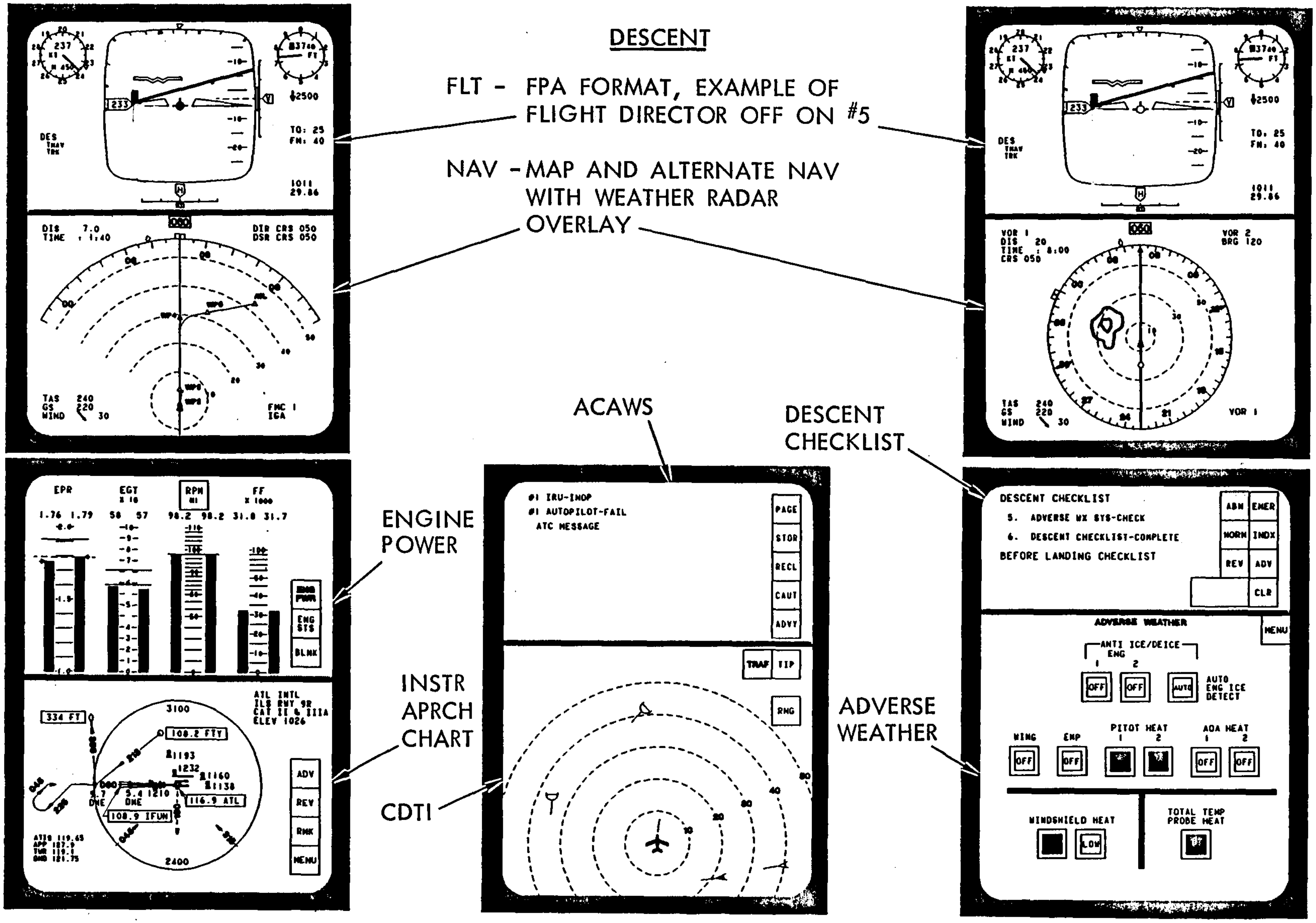


Figure 45. Front Panel Displays - Descent Mode

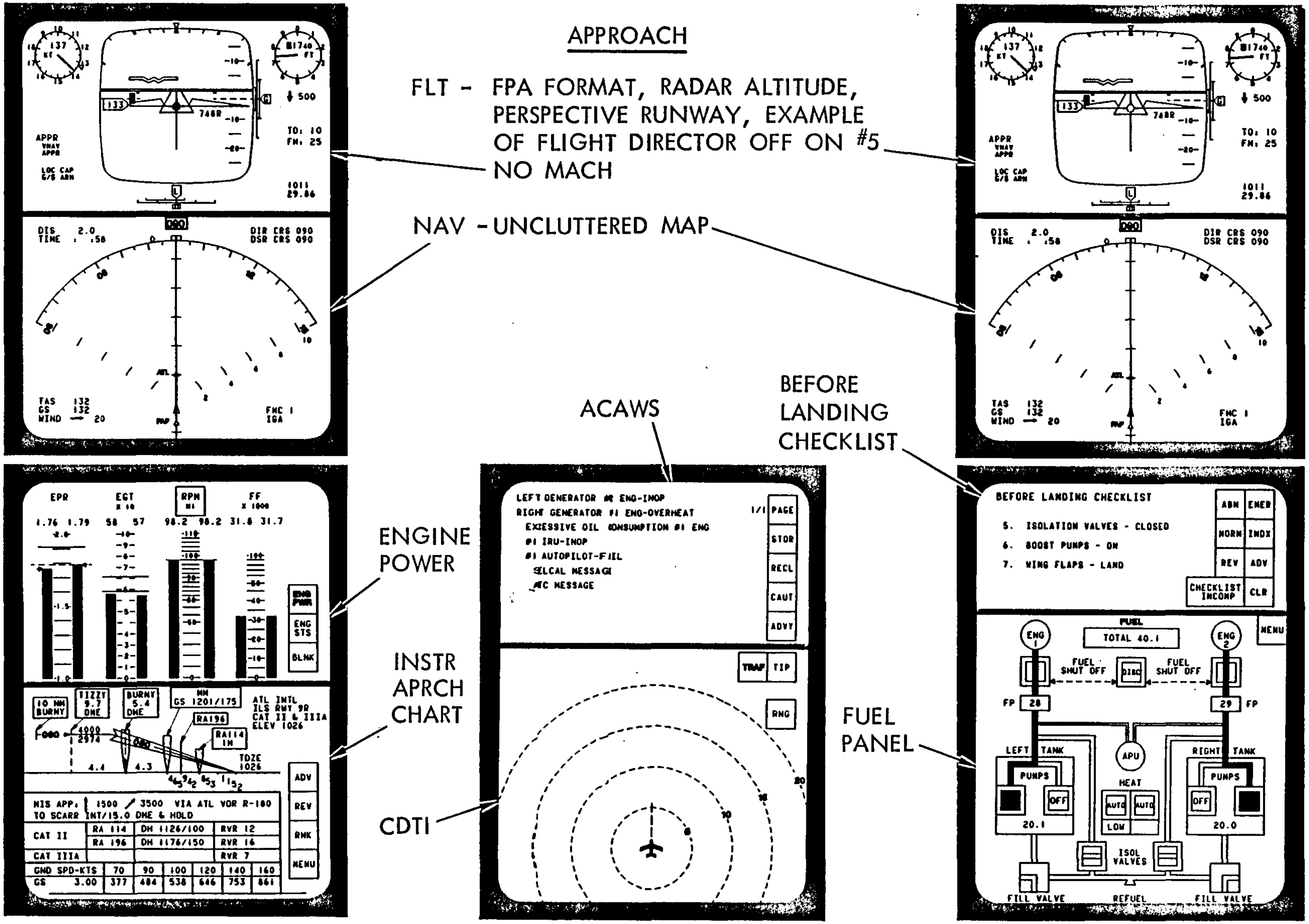


Figure 46. Front Panel Displays - Approach Mode

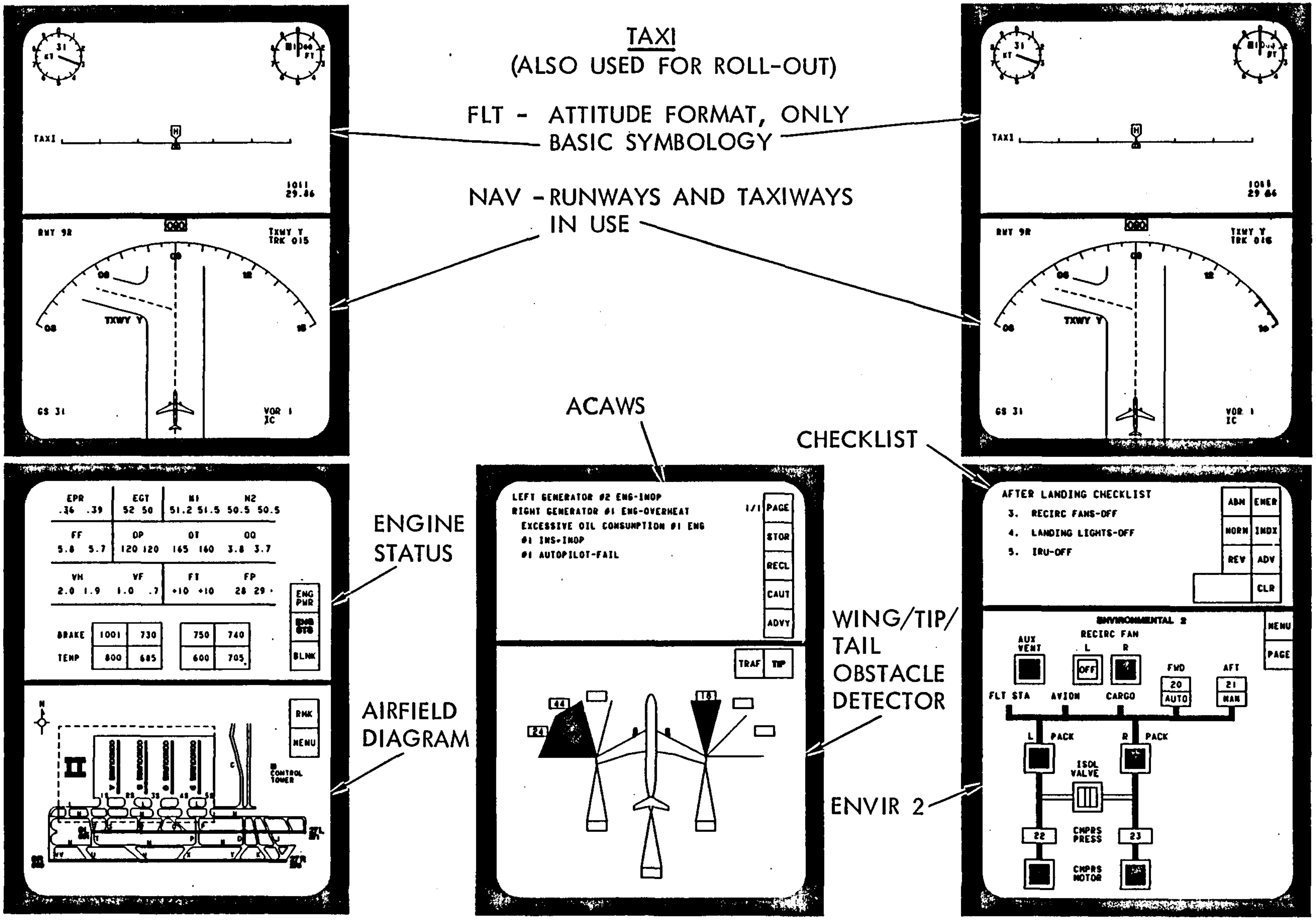


Figure 47. Front Panel Displays - Taxi Mode

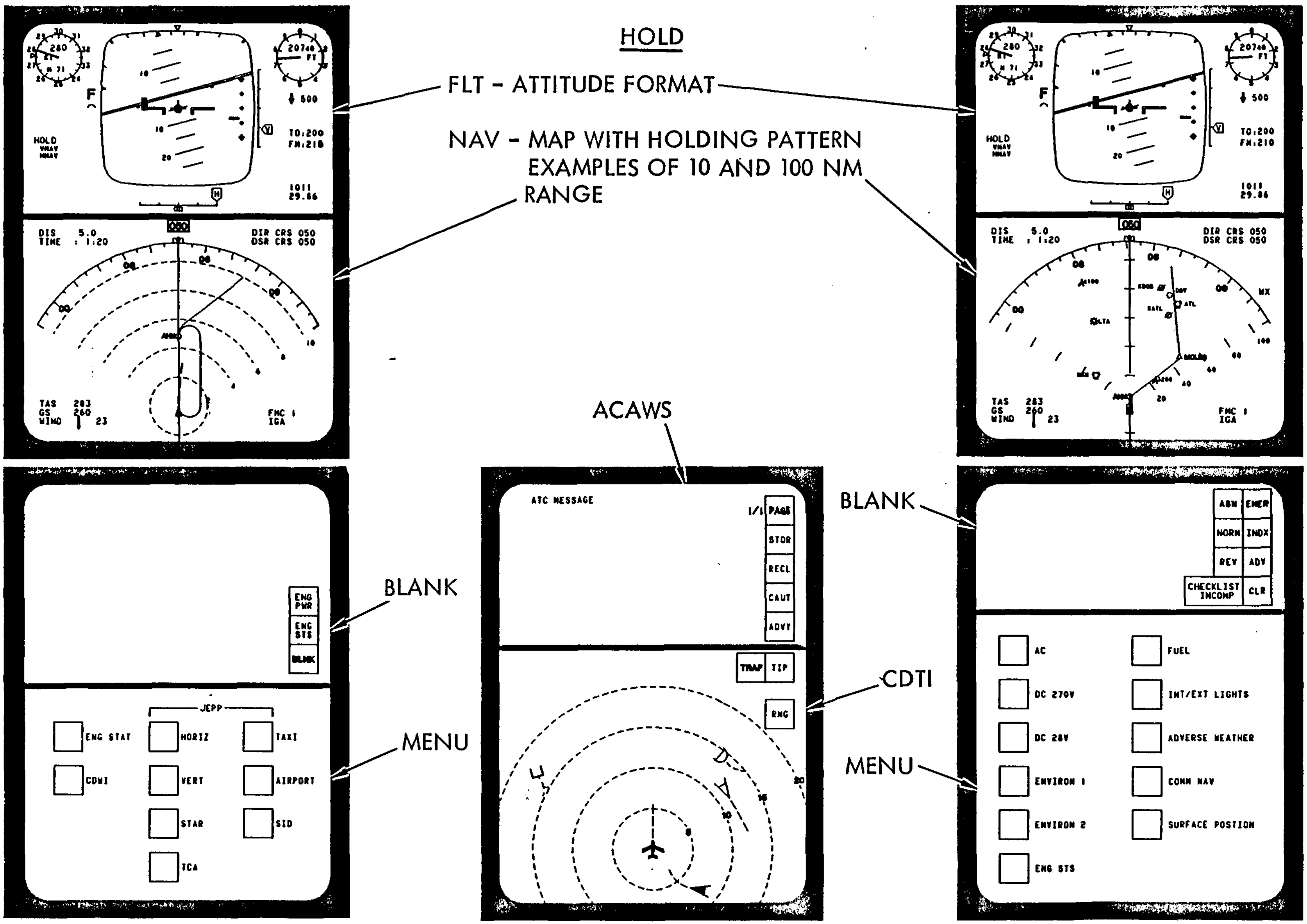


Figure 48. Front Panel Displays - Hold Mode

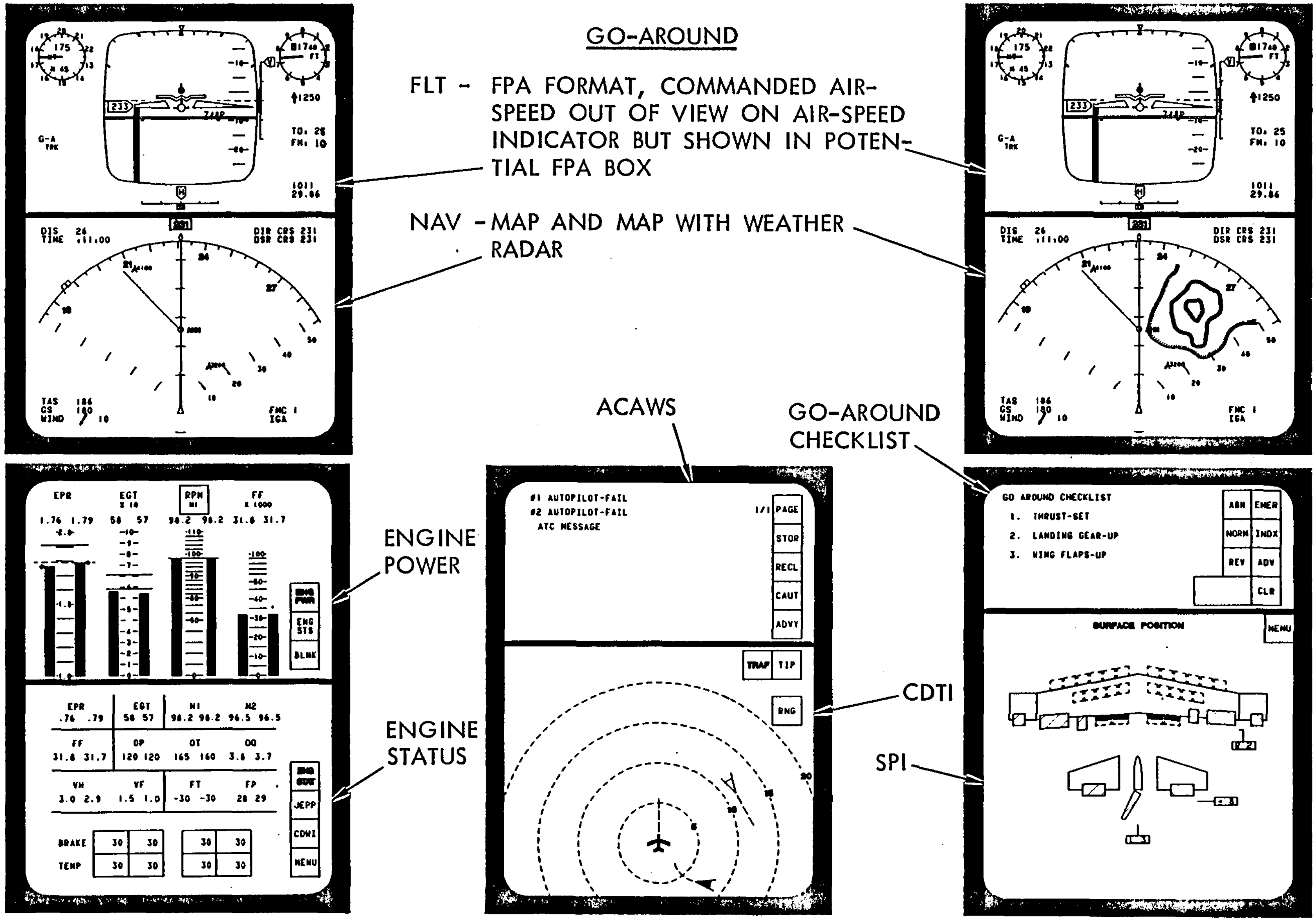


Figure 49. Front Panel Displays - Go-Around Mode

Head-Up Displays

A head-up display (HUD) will be installed at each pilot's position. It is imperative that head-up displays be part of the baseline design for several reasons: (1) there are many areas of research concerning HUD to be addressed in a simulator with full mission capability, such as the ones being constructed; (2) space for the hardware should be designated at the same time that other hardware is being located so that necessary space can be provided; (3) trade-offs can be made on information to be displayed head-up and/or head-down during both normal and abnormal modes of operation; and (4) symbology and formats for the head-up and head-down displays should be developed coincidentally, so that they will be as compatible as possible.

The design for the head-up display in this simulator is still in the conceptual stage due to design/installation problems associated with transport aircraft. Some factors influencing the hardware selections are the preference of pilots to have the combining glass 12 to 20 inches away from the face, the large field of view (greater than 30°) desired, limited space for mounting image generating equipment, and alignment problems when the combiner is mounted on a separate structure other than the collimating optics module. There exists a direct relationship between the total field of view associated with the HUD and (a) the optics exit aperture size, (b) the distances between the optics, (c) the combining glass, and (d) the eye reference point (ERP). Thus, one cannot arbitrarily select certain values (or limits of these values) for the different parameters without considering the interrelationship of the parameters. For example, the desire to have the combiner on the glareshield at a distance of 12 to 20 inches from the ERP cannot be realized when the space-limited optics exit aperture size and the 30° field of view are satisfied. The following systems description will be valid, however, in terms of signal sources, system components, and type of information to be displayed to the pilot on the HUD.

General Systems Description - Each HUD will receive video-formatted data from the same symbol generator that drives the flight display for that crew position. This will ensure that each pilot receives primary flight data (steering commands, attitude, airspeed, altitude, etc.) from the same set of sensors, whether head-up or head-down.

The HUD system will consist of an image generator/optics unit and a combiner. The image generator will probably be a small monochromatic CRT with a precision ground faceplate. The unit will also contain a high-voltage power supply, x and y deflection amplifiers, yoke assembly, and other associated electronics required to generate the CRT image from the video signals input by the symbol generator. The collimating optics module will project the image from the faceplate of the CRT to the combiner glass, which is positioned to superimpose the image precisely on the real-world scene viewed by the pilot. The combiner may be designed to stow out of view when the HUD is not in use.

HUD Criteria - The following criteria for application in the simulator were determined by reviewing literature on head-up displays currently in use on aircraft.

Integrated Rather Than Retrofit - A frequent complaint among operators and HUD manufacturers is that HUDs are added on after the aircraft has been designed, thus making installation less than optimum. Therefore, they should be part of the baseline design.

Brightness - One of the most frequent complaints concerning HUDs is the lack of adequate brightness control. Most existing brightness controls are linear and do not provide sufficient control at the lower levels of illumination. A range of illumination levels sufficient for the brightest daylight as well as the darkest overcast night is needed.

Field of View - Because this transport has a comparatively slow approach speed, the crab angle with high crosswinds could be as much as 14°. For that reason the instantaneous field of view (IFOV) for the HUD should be at least 30° horizontal. To be useful for steep climbs as well as steep approach angles the HUD should have a 20° vertical IFOV.

Commonality with Other CRTs - Symbol generators already exist for the five CRT displays: therefore, it is highly desirable that the HUDs use as much existing symbology from the flight displays as possible without becoming cluttered. Besides having obvious software advantages, this commonality facilitates the transition from the head-down flight display to the head-up display, or vice versa.

Mounting - A number of possible installation arrangements for the HUD should be investigated—glareshield mounted, overhead mounted, and remotely mounted using fiber optics transmission from some other location.

A desirable distance from the design eye reference point to the combining glass is between 12 and 20 inches. Although a wider field of view is possible by placing the combiner close to the pilot's eye, this tends to restrict the pilot's peripheral vision and could be annoying to him over protracted periods of HUD use. Since it is not known whether the HUD will be used extensively enroute or primarily in the terminal area, a design that permits stowing the combiner when it is not needed is desirable.

Formats - After review of a multitude of technical reports on the subject of HUD symbology and formats, a format which incorporates many of the best design features has been chosen as a starting point. Some of the important criteria are that it (1) maintains commonality with the flight display; (2) is conformal--that is, the symbols should overlay the external picture as closely as possible; and (3) the pilot has capability to selectively call up or declutter various symbols from the format as they are required.

The symbology on the HUD should represent all sensor data that are determined to be necessary for each of the various phases of flight. These data include aircraft pitch, bank angle, heading, angle-of-attack, flight path angle (FPA), reference FPA, barometric altitude, radio altitude, airspeed/ airspeed error, steering commands, MLS/ILS radio navigation data, and possibly other to-be-determined cues.

The baseline design will take advantage of the considerable research on HUD symbology and formats, which has been performed at NASA-Ames. The baseline format, shown in Figure 50, is described in Reference 3, A Head-Up Display for Low Visibility Approach and Landing.

<u>HUD Control Panel</u> - Control of the HUD is through a HUD control panel shown in Figure 51 (Item 37, Figure 15). These controls, one for each HUD, are mounted on the overhead console. The reference FPA on the HUD is the same as on the flight display and is set by the pilot using the VSPD/FPA control knob on the guidance and control panel or, in the case of an MLS approach, the broadcast glideslope for the portion of the approach the aircraft is flying. As previously stated, all data sensors and resulting cues on each HUD are similar to those presented on the associated flight display.

Each control panel contains a power switch and a brightness control for the appropriate display, along with several declutter switches. The information on the HUD is tailored to the flight phase selected on the guidance and control panel; however, these switches are included to provide research capability. Conceptually, information represented by the various switches may be added or deleted from the tailored format, which appears when a specific flight phase is selected. The switches control symbology for pitch ladder (PLAD), flight director (F/D), ILS/MLS, airspeed and altitude (A/S-ALT), heading (HDG), and runway (RWY).

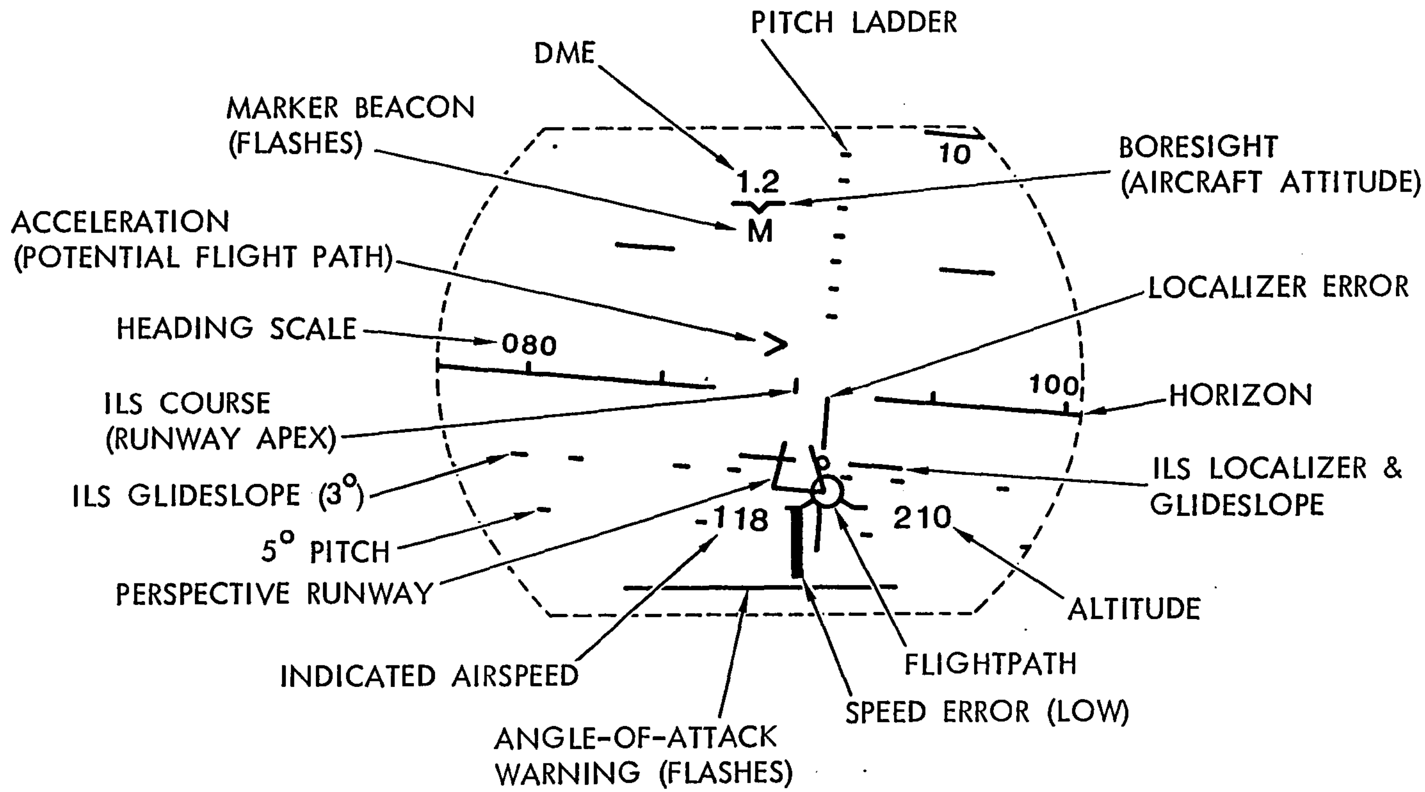


Figure 50. Sample HUD Format

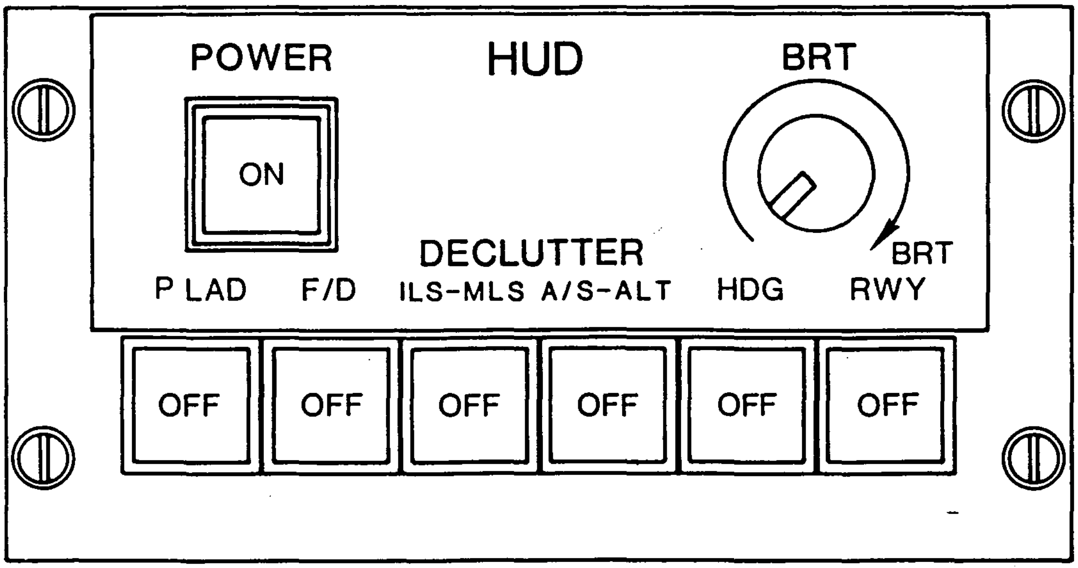


Figure 51. HUD Control Panel

TIME DISPLAY

Greenwich mean time (GMT) is displayed on both the pilot's and co-pilot's time display units. GMT is also transmitted via an ARINC 429 digital data bus from the pilot's display unit to the aircraft mission computers for time synchronization. The pilot's display unit, shown in Figure 52 (Item 2, Figure 15), presents a 24-hour six digit readout: hours, minutes, and seconds, which is set from the front panels.

The clock display also has a stopwatch function to count up or down from 00:00 to 99:59 minutes, 59 seconds, and all intermediate times with an accuracy of $\pm$ one second.

In the flight simulator, when a time is set in the mission computer, the two time displays on the front panel are synchronized to that time, so that all time displays read the same when an initial condition is established.

The label type lighting is controlled by the same dimming control as the switch panels on the bezels of the CRT displays on the main instrument panel. The brightness of the digital displays for each clock is controlled with its own switch located on the consolidated interior lighting panel.

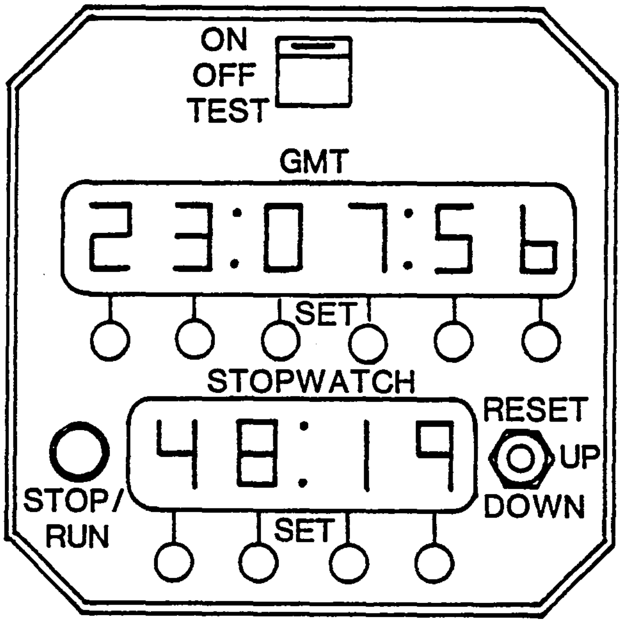


Figure 52. Time Display

FLIGHT CONTROLS

The flight control system consists of conventional flight surfaces (rudder, ailerons, elevators, flaps, slats, and spoilers) employed in normal and unique ways (continuous adjustment of ailerons to reduce wing bending, adjustment of flaps and ailerons to reduce drag, and the use of spoilers coupled with the elevator to maintain glidepath). Additionally, new surfaces (wing tip devices) are employed to alleviate wing twisting forces.

All flight control surfaces are powered by electrical, rather than hydraulic, actuators. Power is applied to individual actuators through electronic power controllers that take the place of conventional circuit breakers. The switches that operate the individual power controllers are incorporated in the control display unit (CDU) touch panel displays and are accessed by selecting the key marked CIR BKRS on either CDU bezel. The pilot may then disconnect or reconnect any specific flight control actuators through this display.

The flight control system is described in three parts: manual flight controls, automatic flight controls, and active flight controls. It is followed by a description of the surface position indicator and the stall warning system.

Manual Control System

Manual flight control is accomplished through the use of side-stick controllers for pitch and roll, and rudder pedals for yaw control. An individual side-stick controller, shown in Figure 53 (Item 19, Figure 15), is provided for each pilot. These controllers--mounted outboard on each pilot's desk--control flight surfaces through redundant electrical paths. To enhance the pilot's perceptual feel of the aircraft controls, an artificial feel system is included in the design. The controllers are mechanically linked so that movement of one will be duplicated by the other. For the advanced concepts flight station simulator, the feel is programmable on the ground but not in flight.

A number of switches are mounted on the side-sticks. They control pitch trim, autopilot disconnect, pitch trim disconnect, voice command, and radio transmission.

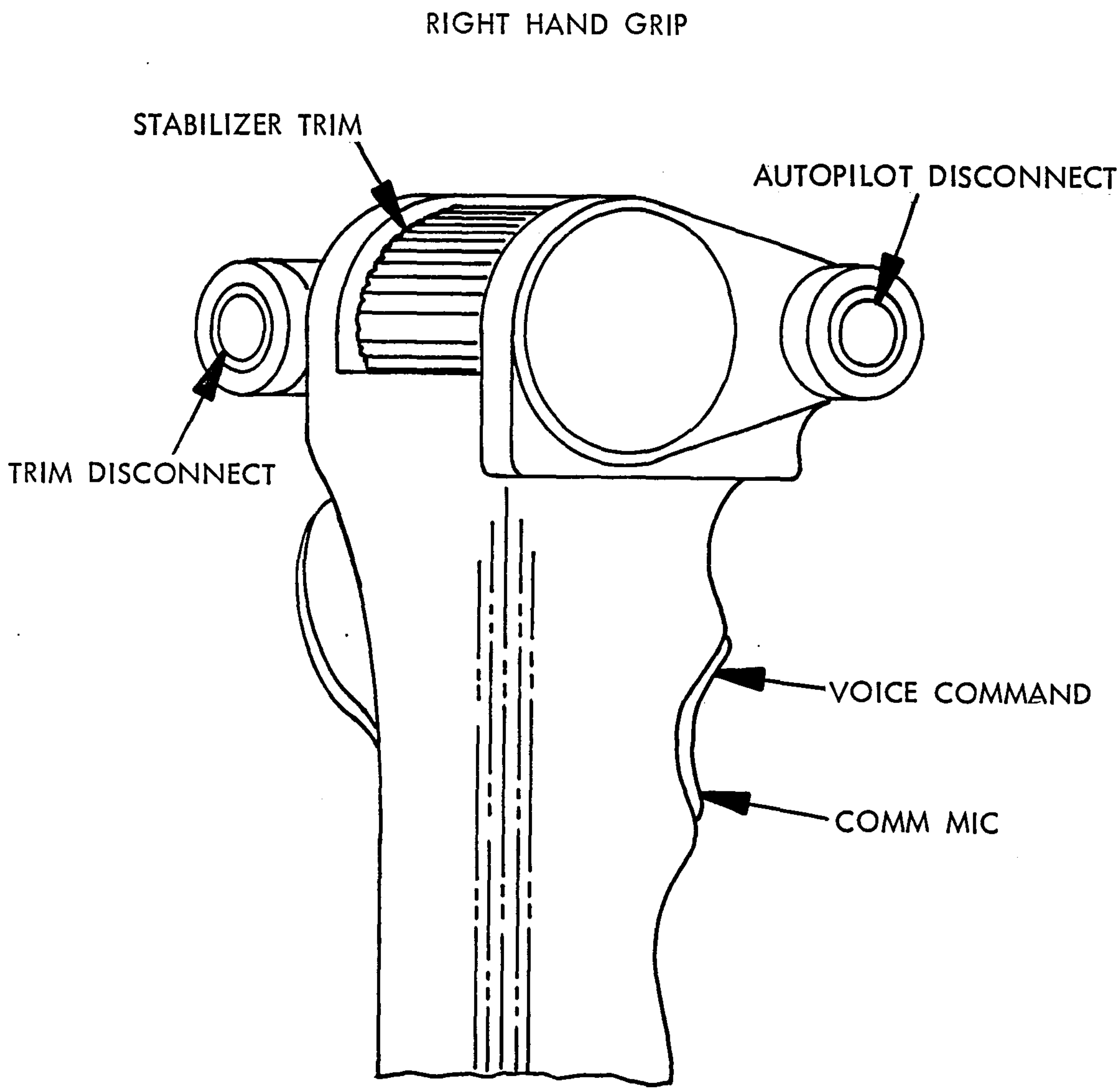


Figure 53. Side-Stick Controller

Conventional rudder pedals with toe brakes are used for yaw control. Rudder pedal movement is transformed into rudder displacement through redundant electrical paths similar to the roll and pitch controls.

Some of the key features of the manual flight control system are:

- Four independent electrical system sources
- Multiple surfaces with redundantly powered electrical actuation systems
- Fail-operational/fail-passive spoiler trim controls
- Fail-passive rudder trim system
- Fail-operational/fail-passive ailerons and pitch trim controls
- Surface and trim position indication
- Separate flap and slat actuation systems
- Use of cascaded or increased maximum spoiler surface deflections from inboard to outboard

The electrical distribution, shown in Figure 54, provides the redundancy necessary to ensure mission completion after one electrical system failure and for maintaining adequate flying qualities after the loss of two electrical systems. Limited control is provided after the loss of three electrical systems.

Roll Control - The manual roll control system, shown in Figure 55, enables the pilots to control the motion of the aircraft about the longitudinal axis using an outboard aileron and three differentially acting outboard spoilers per wing. Roll control is accomplished through asymmetrical deployment of the ailerons and outboard spoilers. As the side-stick controller is moved to the right, the left aileron will go down as the right goes up. This action increases lift on the left wing and simultaneously decreases it on the right. The action of the outboard spoilers aids in the decrease of lift on the right wing, as they are deployed on the side to which the stick is moved. Maximum spoiler deflection varies with velocity.

The side-stick controllers provide for full surface travel when displaced $\pm 20^{\circ}$ with the total system feel forces ranging from 2.5 pounds at breakout to 10

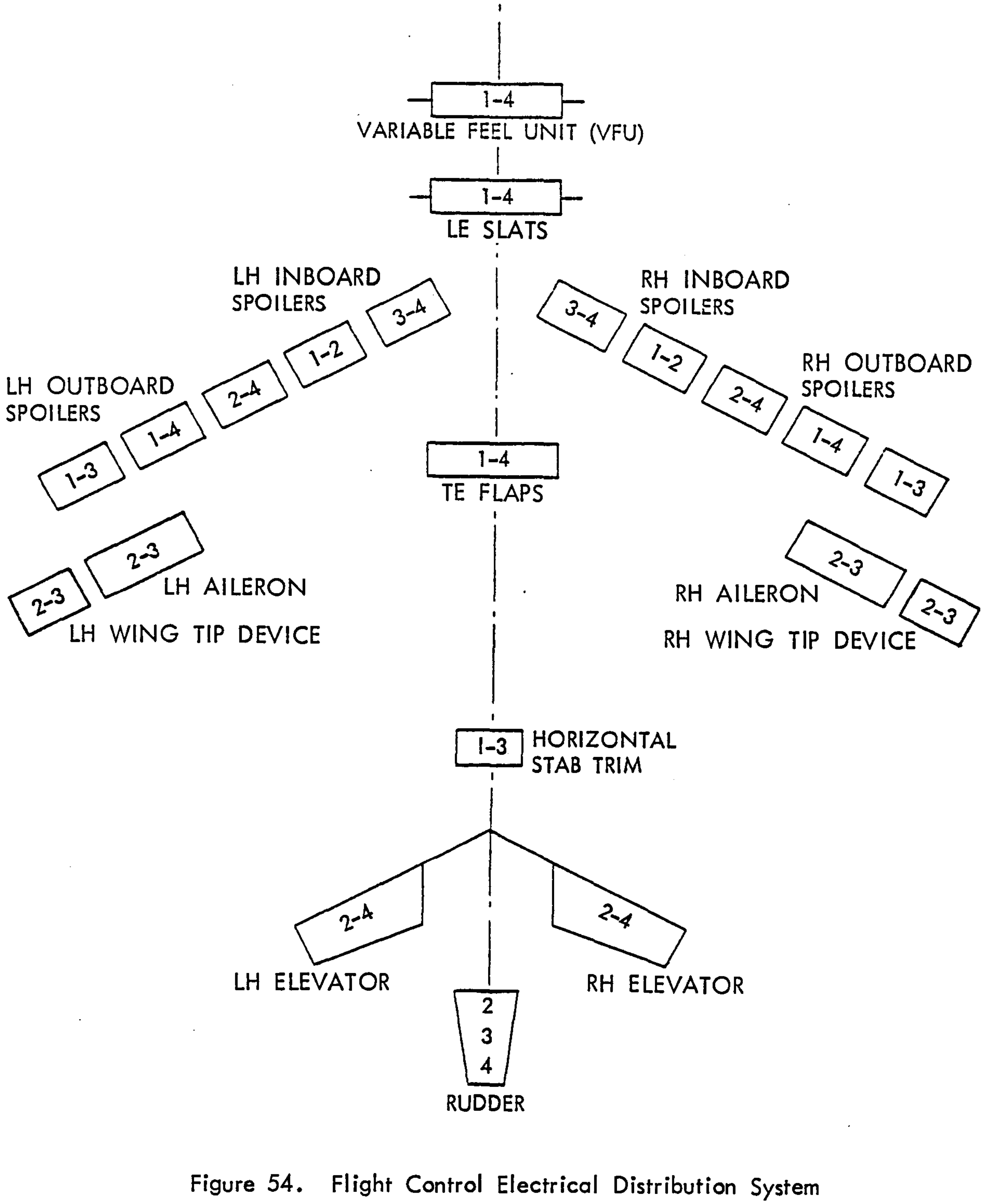


Figure 54. Flight Control Electrical Distribution System

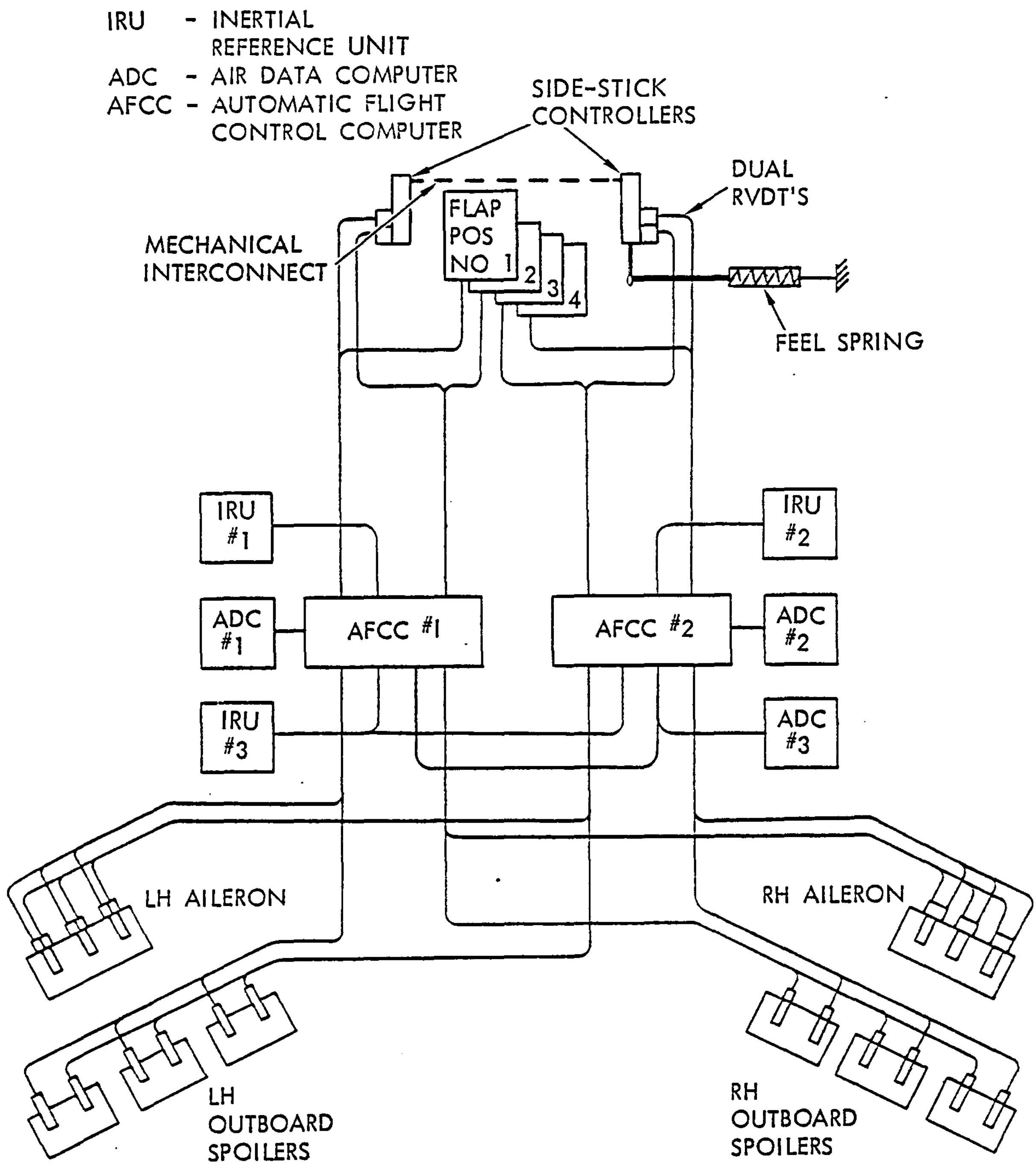


Figure 55. Aileron/Spoiler Roll Control and Actuation System Schematic

pounds at 20° of side-stick controller throw. Artificial feel/centering is required in the roll axis, and this is accomplished with a spring attached to the first officer's side-stick controller to center the controllers and provide feel forces.

Aileron trim is accomplished using the paddle-type switch, shown in Figure 56, mounted on the center console. Should the normal aileron trim fail, an advisory, caution, and warning system (ACAWS) message is displayed. A guarded switch is provided on this same panel (Item 28, Figure 15) to select the alternate aileron trim. Aileron displacements and trim position are displayed pictorially on the surface position indicator (SPI) display discussed later.

The aileron and spoiler surfaces are each activated by dual electro-mechanical actuators powered by the aircraft's four electrical systems. With flaps extended, the spoilers are automatically up-rigged to enhance low speed roll control. An angle of attack/spoiler schedule provides for reducing symmetrical spoiler up-rig to zero with increasing angle of attack to delay aircraft stall. Should the spoiler system fail and the spoilers remain closed, adequate roll control is provided with use of ailerons alone.

In addition to operating differentially for roll control, the outboard spoilers operate symmetrically with the four inboard spoilers as speed brakes, direct lift control devices and ground spoilers. Similarly, the ailerons operate symmetrically through the active lift distribution control system (ALDCS) to modify spanwise loading, thereby reducing wing bending moments. These systems are discussed later.

Pitch Control - The manual pitch control system, shown in Figure 57, enables the pilots to maneuver the aircraft about the lateral axis using mechanically interconnected left- and right-hand hinged elevator surfaces. The surfaces are each actuated by two dual electromechanical actuators.

The elevator servo responds to manual-electrical inputs from the pilots, and to electrical inputs from the automatic flight control system (AFCS) and the active control system. All inputs move the elevator relative to the horizontal stabilizer (i.e., zero elevator is always in parallel with the horizontal stabilizer).

The side-stick controllers are mechanically tied together and are in parallel with pitch autopilot inputs. That is, pitch autopilot inputs reposition the

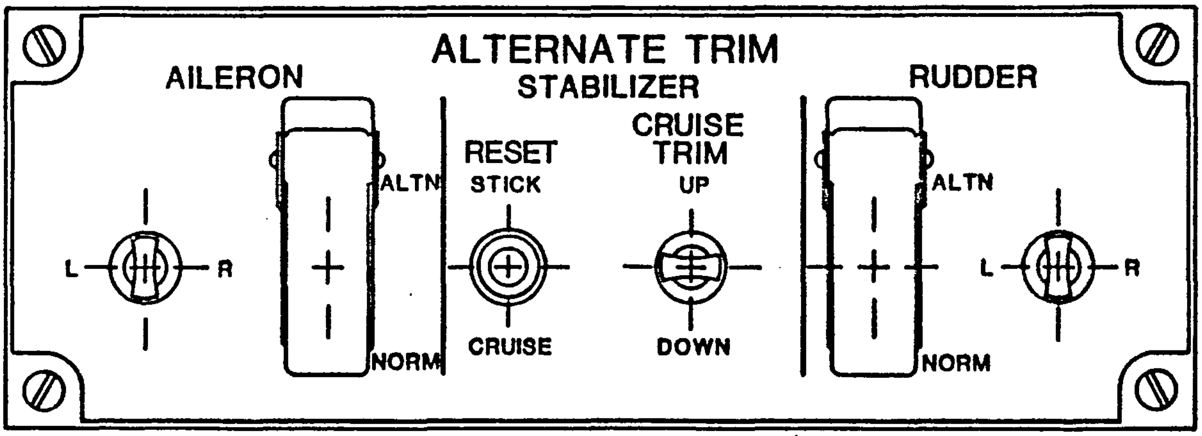


Figure 56. Alternate Trim Control Panel

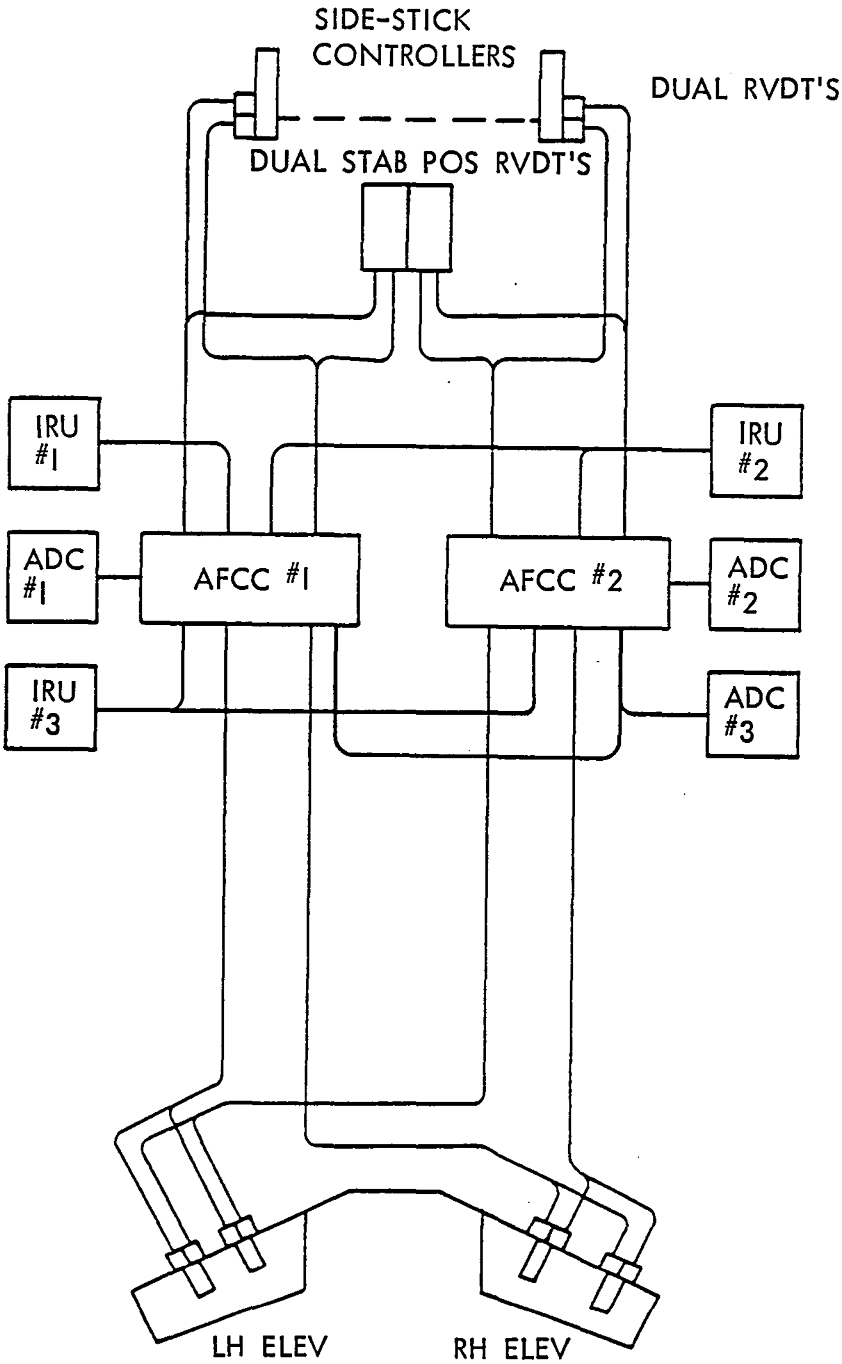


Figure 57. Elevator Control and Actuation System Schematic

controllers. Active control inputs such as stability augmentation are in series and do not move the side-stick controllers.

The pitch primary flight control system is configured to be fail-operative^2/fail-passive. The artificial feel system, shown in Figure 58, is made up of two components. One varies with side-stick controller position and is generated by mechanical springs in the input system. The second component varies with side-stick controller position and dynamic pressure. The variable feel unit (VFU) generates this force. The VFU output forces are unchanged with any single electrical failure or pitot-static failure.

Both elevator surface position and elevator trim position are displayed on the surface position indicator display. Any malfunctions in the control system will appear on the ACAWS display. The crew has access to the appropriate power controllers through the CDUs should they need to remove power to any actuator.

Horizontal Stabilizer Trim Control - Pitch axis trim is accomplished using a moveable horizontal stabilizer pivoted on top of the vertical stabilizer, as shown in Figure 59. The trim actuator is an irreversible screw jack incorporating separate screw and nut drive systems using dual 115 Volt AC 400 cycle continuously running motors and clutched to the gear trains.

There are two ways the pilots can operate the stabilizer actuator. Normal trim is provided with the nut drive using the variable rate trim switch mounted on each side-stick controller. If both pilots try to trim in opposite directions, the control circuit will block both signals and stop operation.

Cruise trim may be accomplished using the paddle-type switch on the alternate trim panel (center console). This switch operates the trim actuator through the electrically powered screw drive system. Automatic pitch trim is accomplished by the automatic flight control computers using this screw drive. This occurs during autopilot operation.

In the event of a trim runaway, a trim disconnect switch on each side-stick controller enables either pilot to shut down all modes of pitch trim. With the pitch trim reset switch, located on the center console, the crew may reselect either the screw drive or the nut drive system. Trim position is annunciated on the surface position indicator display. Additionally, all trim malfunctions are displayed by the ACAWS.

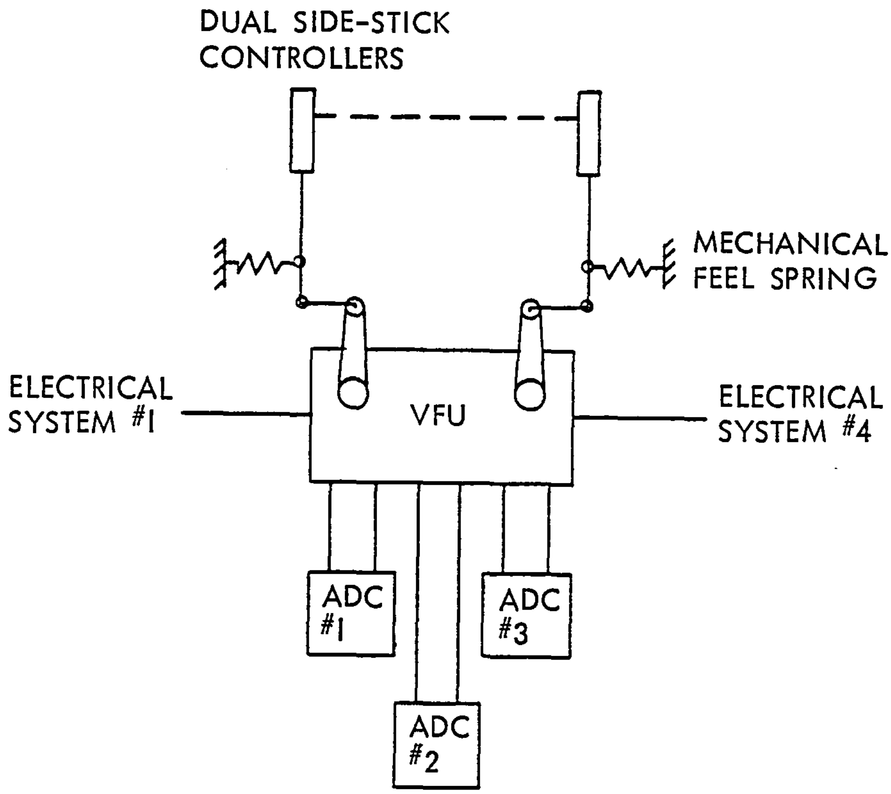


Figure 58. Pitch Variable Feel System - Fixed Spring Plus VFU

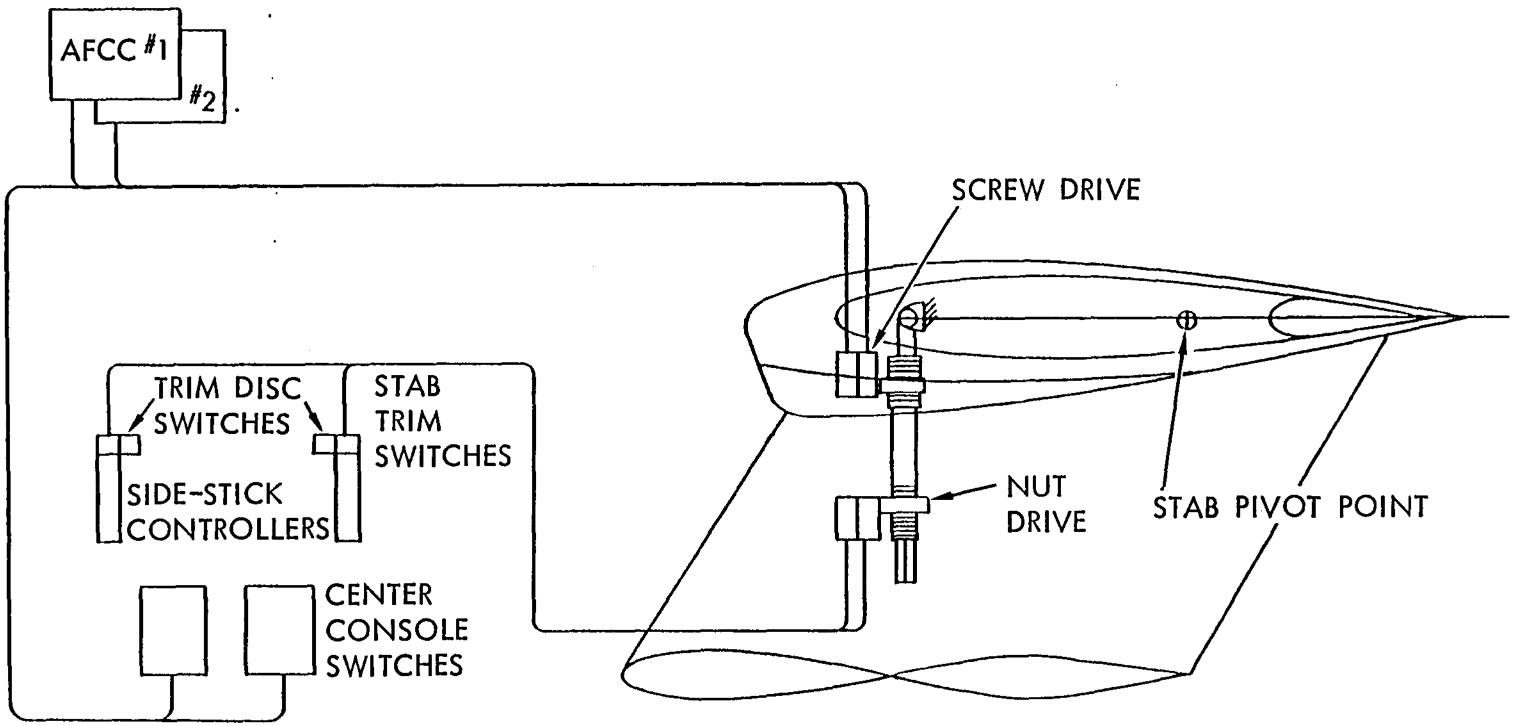


Figure 59. Pitch Trim Control and Actuation System Schematic

Yaw Control - The manual yaw control system enables the pilots to control the motion of the aircraft about the vertical axis using conventional mechanically interconnected captain's and first officer's rudder pedals and a fully powered single rudder control surface. Figure 60 depicts the yaw control system.

The rudder surface is actuated by four dual-motor irreversible servos powered by three of the aircraft's four electrical systems.

Artificial feel/centering is required in the rudder axis. The feel forces vary linearly with pedal travel. The feel spring is part of the first officer pedal controls and also provides the centering forces.

Both normal and alternate rudder trim controls are located on the center console. This is a series trim; therefore, the pedal position will remain unchanged when trim inputs are applied.

Both the rudder position and the rudder trim position are displayed on the surface position indicator.

Ground Spoilers/Speedbrakes - The ground spoiler/speed brake control system controls six outboard and four inboard spoiler surfaces. A schematic of the system is shown in Figure 61. Three modes of symmetrical operation are provided with this system: manual ground spoiler mode, automatic ground spoiler mode, and speed brake mode. Each of the ten spoilers has two dual-motor actuators with the aircraft's four electrical systems distributed among the spoiler servos. The electrical control systems and the servos for the spoilers are fail operative/fail passive.

The spoilers can be activated manually, either in flight or on the ground, or automatically on the ground. A "spoilers mode" switch on the flight control panel controls the spoiler mode. Normal operation is in the automatic mode, with the pushbutton switch legend blank. In this mode, ground spoilers will deploy automatically when the main landing gear wheels spin-up and engine thrust is reversed. This will occur either on landing or aborted takeoff.

The manual mode provides for ground spoiler operation through the throttle switches on landing with flaps retracted, or with flaps extended when the appropriate wheel spin-up speed is achieved and when the throttle levers are retarded to less than the minimum cruise position. Advancing either throttle lever for takeoff with spoilers deployed will cause the spoilers to retract fully.

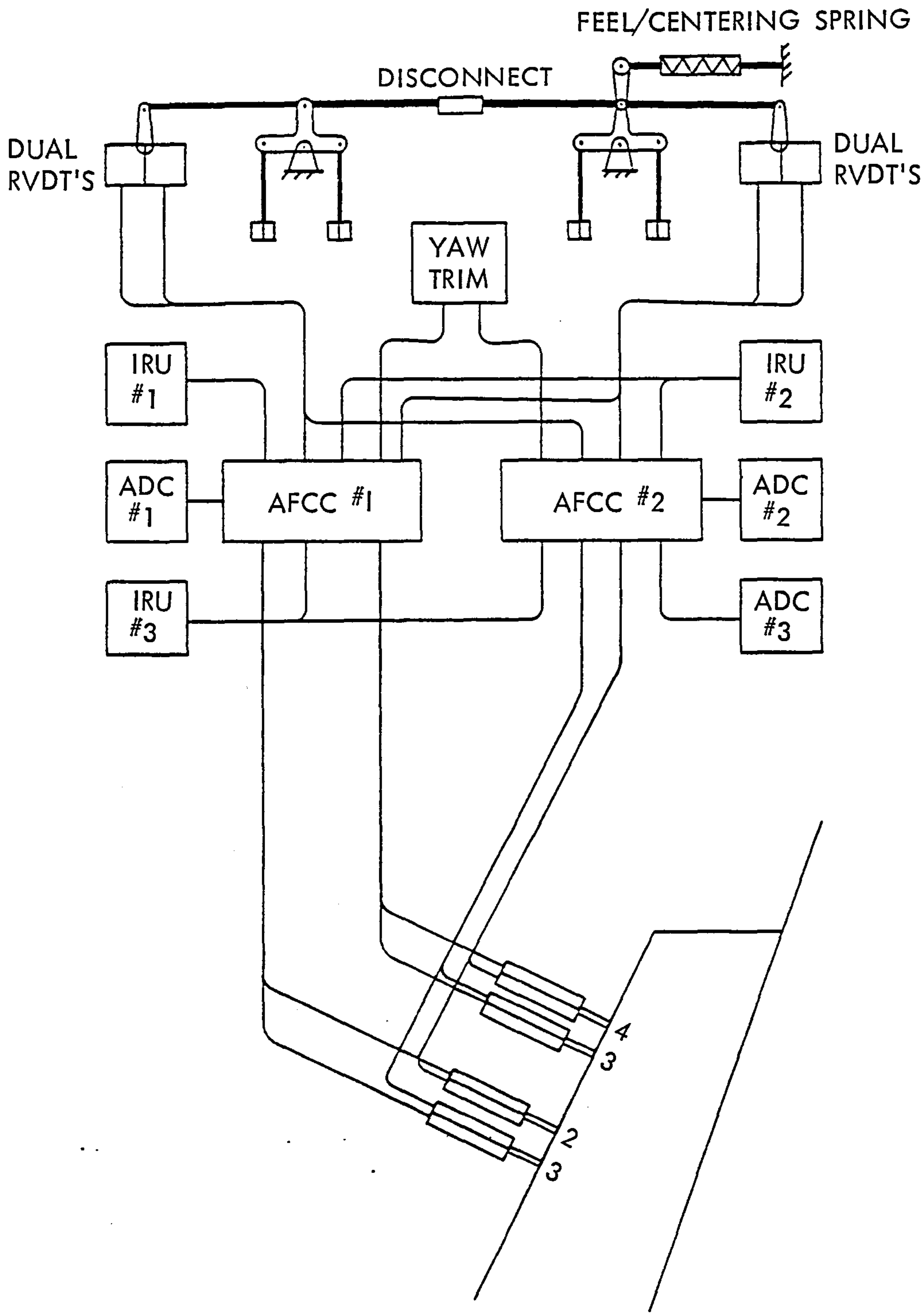


Figure 60. Rudder Control and Actuation System Schematic

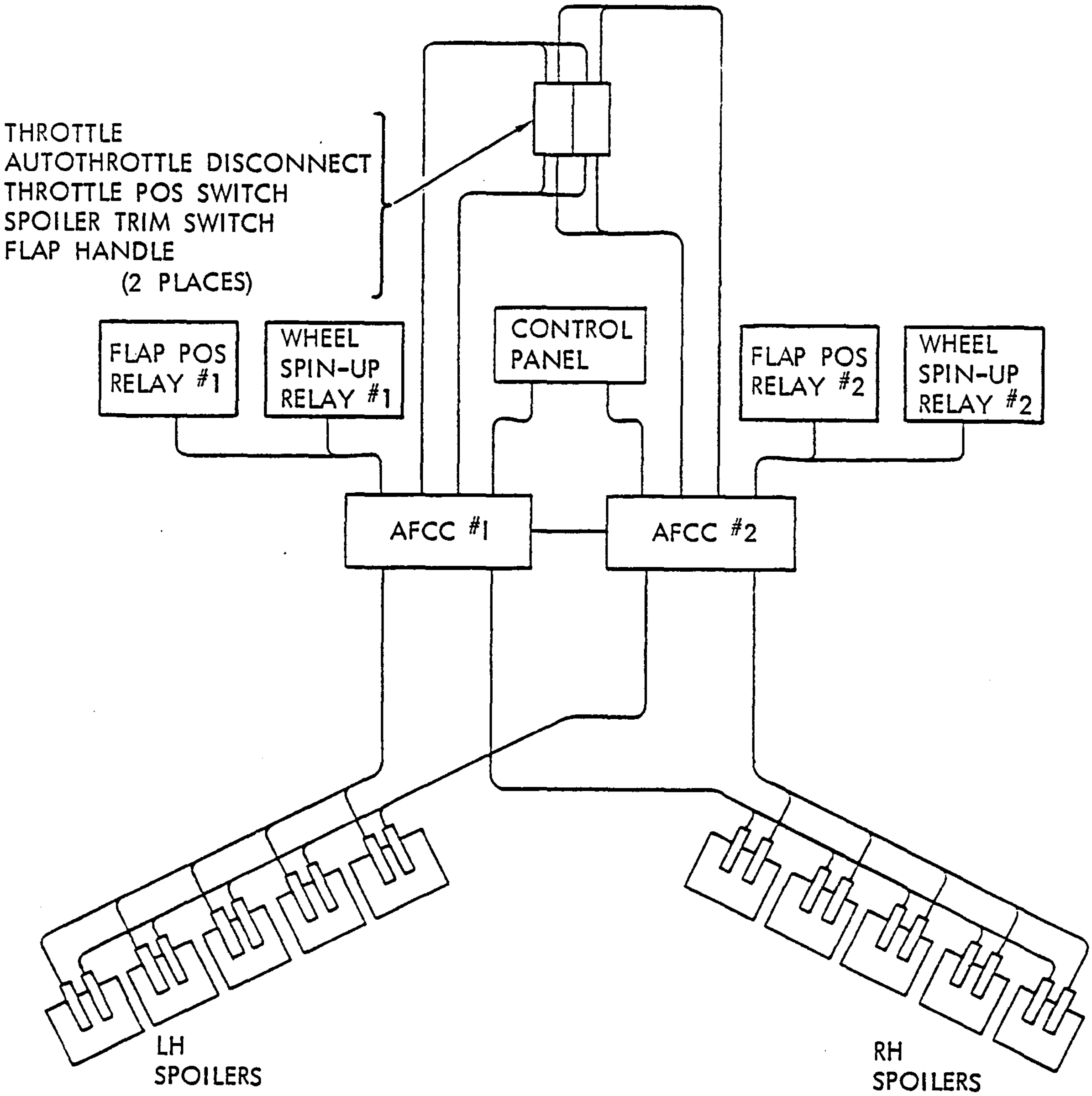


Figure 61. Ground Spoiler/Speed Brake Actuation System Schematic

For manual operation of the ground spoilers, the pilot must first press the spoiler mode switch on the flight controls panel shown in Figure 62 (Item 38, Figure 15). This causes the MANUAL legend to illuminate in the switch and permits either pilot to deploy the ground spoilers (when on the ground) using the throttle-mounted slide switch located on the outboard side of each set of throttles. Each switch has three positions--EXTEND (aft), OFF (center), and RETRACT (forward)--and is spring-loaded to the OFF position. Unlike the speed brakes, ground spoilers may be fully deployed or retracted by momentarily selecting EXTEND or RETRACT with the thumb switch.

Regardless of which spoiler mode is selected, the thumb switches may be used in flight for speed brake operation. To operate the speed brakes either switch must be held in the extend or retract position until the desired amount of spoiler deflection is achieved. When the switch is released, the spoilers will remain in the last position.

An emergency retract (RETR) switch for the spoilers is also located on the flight control panel. This switch may be used at any time to retract the spoilers.

Any malfunction of the spoiler system will be annunciated on the ACAWS display and may be verified on the surface position indicator display. The pilot also has access to the individual spoiler power controllers through the CDU.

Direct Lift Control - The primary purposes of the direct lift control (DLC) function are to provide precise vertical flight path control and to damp aircraft response to atmospheric turbulence during certain flight phases.

The DLC system, shown in Figure 63, is activated when the flaps are extended to the landing position and the spoilers are up-rigged. Spoiler up-rig and series elevator augmentation inputs are appropriately blended to prevent unacceptable aircraft transients during flap extension.

When operating in the DLC mode, the spoilers respond to DLC signals generated by the pilot's elevator side-stick controller inputs. The elevator operates normally, responding to direct manual side-stick controller inputs as well as to the DLC signals via the series inputs from the flight control computer. Aft side-stick controller deflection results in a nose-up pitching moment and an increase in wing lift as the elevator trailing edge deflects up and the

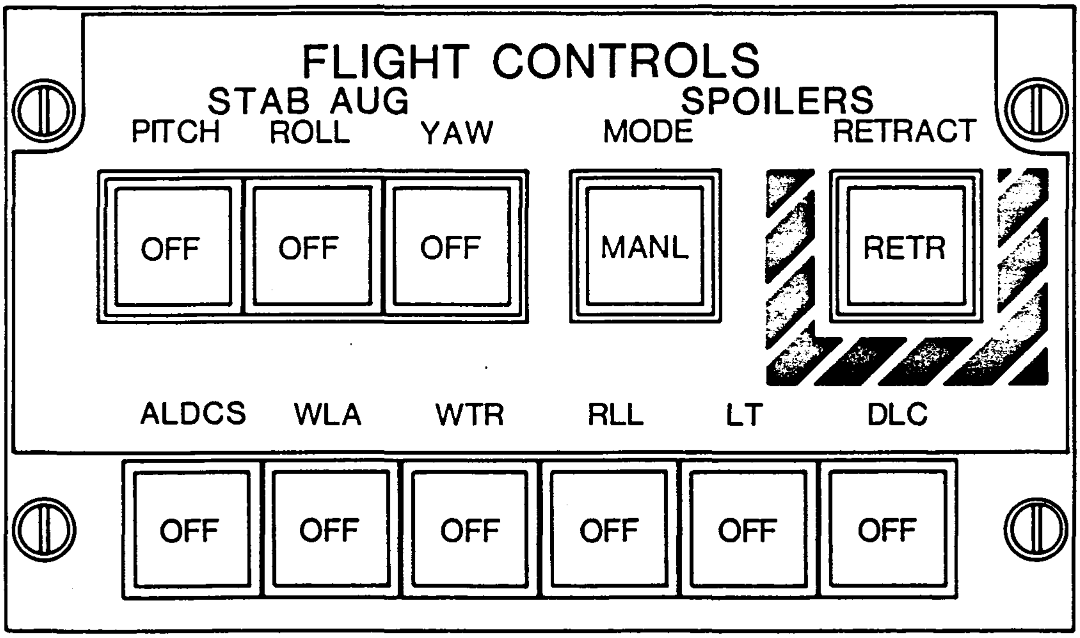


Figure 62. Flight Controls Panel

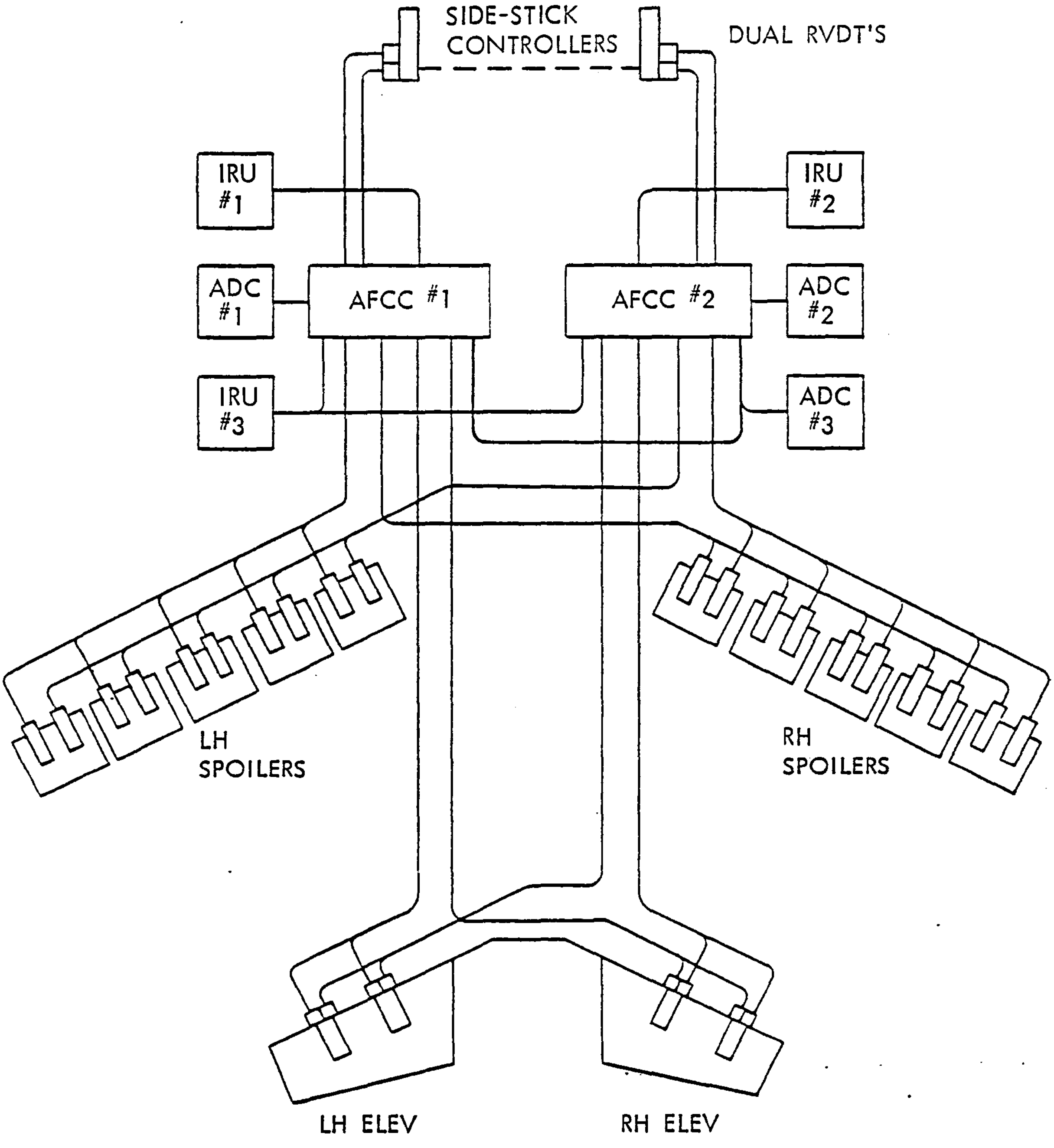


Figure 63. Direct Lift Control System Schematic

spoilers close. Similarly, a nose down pitching moment and a decrease in wing lift occur with forward motion on the side stick-controller. The combined control of the elevators and spoilers provides a quicker aircraft response to control inputs, thereby enabling more precise glidepath tracking during the approach phase. A further benefit from this system is that a near constant deck angle is maintained throughout the approach.

DLC is accomplished by electronically gearing both the outboard and inboard spoilers for symmetric operation about an up-rig position in response to side-stick controller inputs. Following pilot side-stick controller inputs, the spoiler commands are automatically "washed out" to restore the spoilers to their normal up-rig position and prevent saturation of the DLC function during a sustained side-stick controller input. The wash-out is used to restore the spoilers to their up-rigged position so that they will not be saturated should the stick be moved again in the same direction. The variable position limit and up-rig bias function are scheduled (versus angle-of-attack) to remove all spoiler deflection and up-rig by the time stall warning occurs. This reduces the angle-of-attack and protects against stall.

The DLC system is normally on, but a switch is provided on the flight controls panel to disable the DLC system should a malfunction occur. If DLC is turned off, the word OFF will illuminate in the switch. The system has two channels for redundancy, either one of which is sufficient for DLC operation. All DLC system malfunctions and failures are annunciated by ACAWS.

Trailing Edge Flaps/Leading Edge Slats - The high lift devices consist of 10 trailing edge flap panels and 12 leading edge slat panels. The flap panels extend outboard from the fuselage to the ailerons.

Separate systems are provided for the flaps and slats. Fail-safe electrical controls provide proper sequencing during operation. Both actuation systems, shown in Figure 64, employ dual electric motor-driven gear boxes with torque tube drive to ball screw jacks for each panel. The flap/slats system is manually controlled through a single flap control lever, shown in Figure 65 (Item 29, Figure 15), located on the center console pedestal. Flap/slat position indicators, also shown (Item 3, Figure 15), are located on each side of the front console outboard of the CRTs. Dual pointers indicate the position commanded by the flap handle and the actual flap extension. Further, flap and slat position is depicted pictorially on the surface position indicator display.

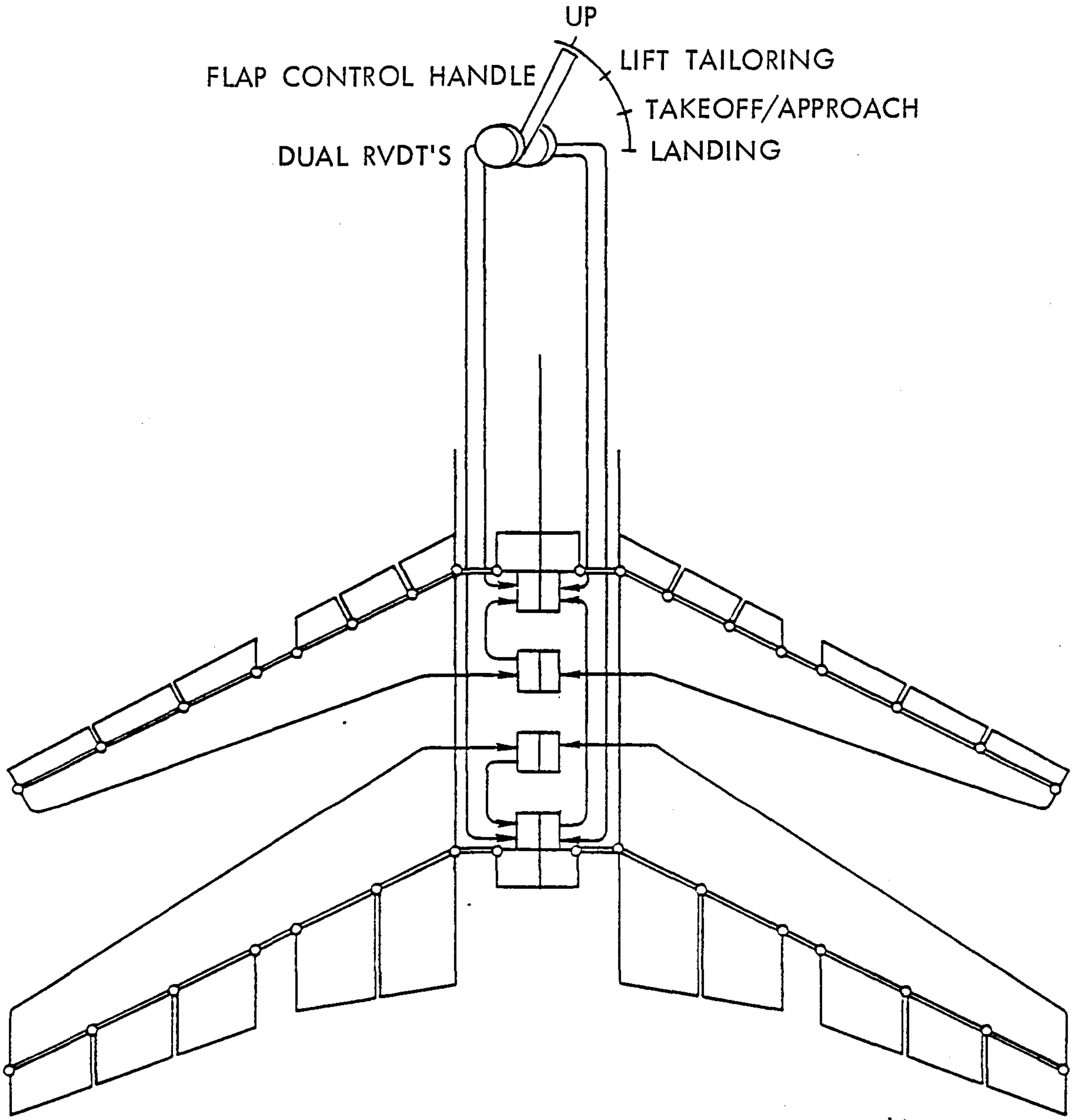
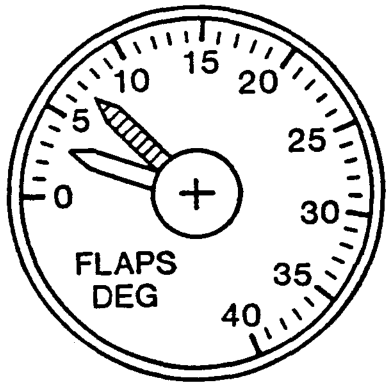


Figure 64. TE Flaps/LE Slats Actuation and Control System Schematic



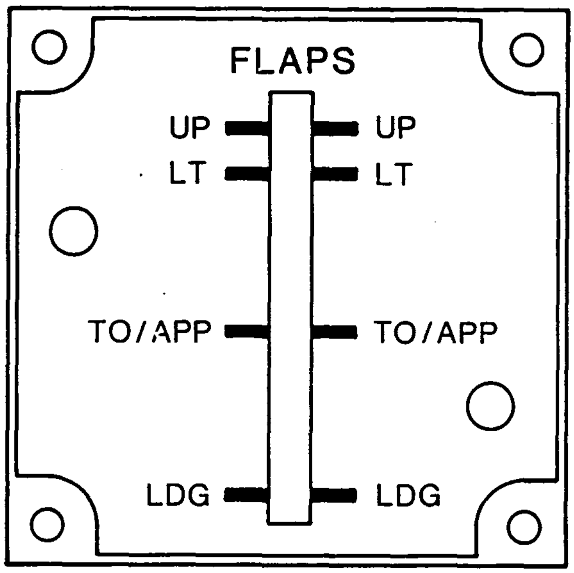


Figure 65. Wing Flaps Position Indicator and Control Panel

Automatic Flight Control System

The automatic flight control system (AFCS), shown in Figure 66, contains two dual-channel flight control computers. The system provides common autopilot/flight director system (AP/FDS) modes of operation, thrust control modes, and altitude alert and stall warning functions. Automatic control is accomplished through the use of parallel servos which move the control stick and throttles in the same manner as the pilot. Flight director commands interface with the electronic flight instrument system for display on the captain's and first officer's flight displays.

The basic AP/FDS modes provided are:

- Roll Attitude/Heading Hold with Control Stick Steering
- Pitch Attitude Hold with Control Stick Steering
- Horizontal Vector Control Stick Steering
- Vertical Vector Control Stick Steering

Selectable outer loop AP/FDS modes available are:

- Track Select
- Altitude Hold and Select
- Indicated Airspeed Hold and Adjust
- Mach Hold and Adjust
- Flight Path Angle
- Approach (VOR, LOC, ILS, MLS)
- Horizontal Navigation (VOR, INS)
- Vertical Navigation (VNAV, Performance Management & TNAV)
- Flare
- Go-Around

The thrust control system (TCS) provides three automatic throttle functions:

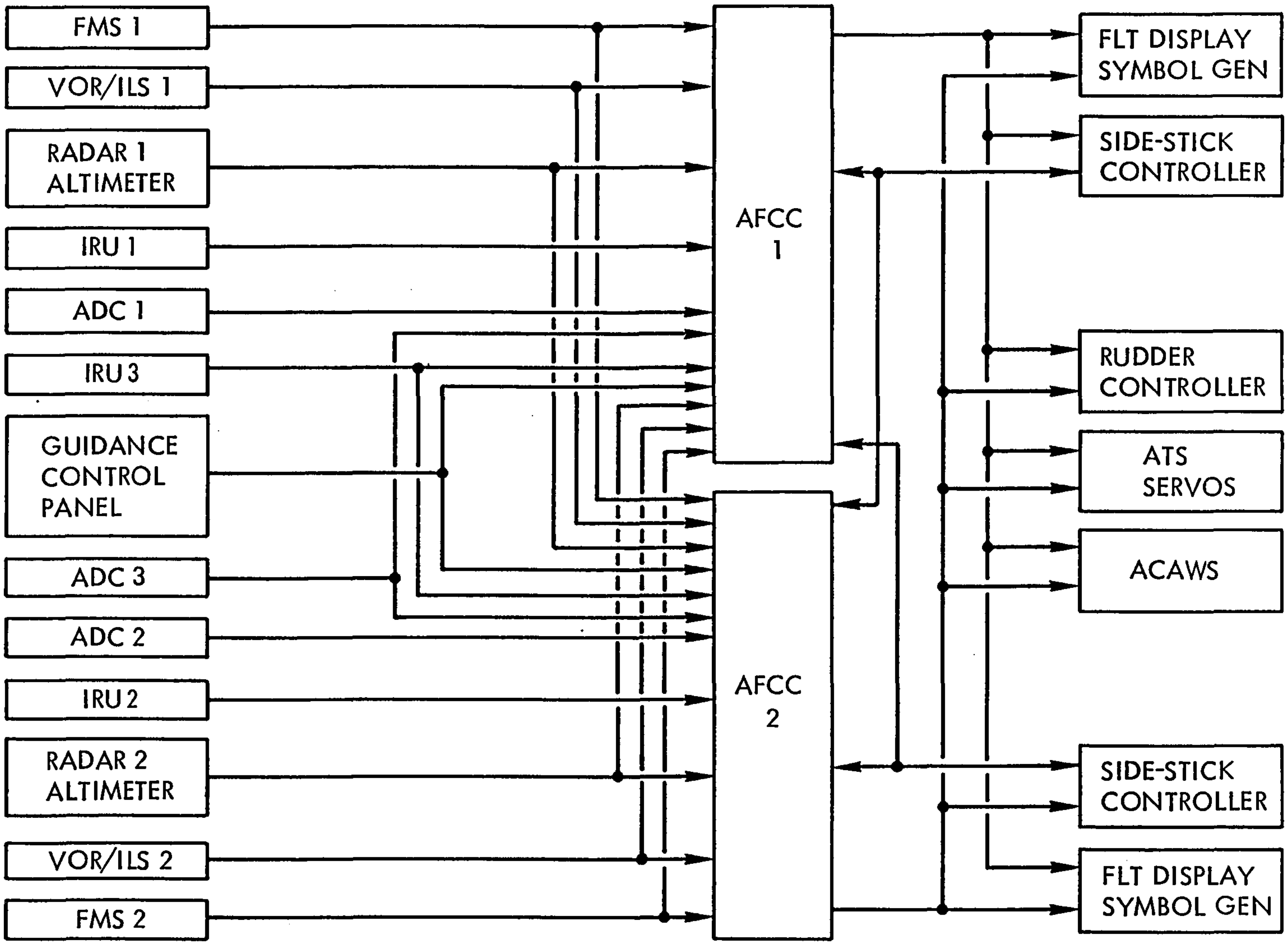


Figure 66. Automatic Flight Control System Block Diagram

- Mach Hold and Adjust
- Indicated Airspeed Hold and Adjust
- Thrust Command (Thrust Rating, Thrust Command, Angle-of-Attack, Minimum Safe Speed)

Autopilot/Flight Director System - Either of the two dual-channel flight control computers can be used to provide autopilot and flight director functions. This configuration assures compatibility between the flight director and autopilot modes. In addition, the availability of two dual-channel computers allows them to meet the requirements for a fail-operational Category IIIb automatic landing system.

The guidance and control panel (GCP), shown in Figure 67 (Item 16, Figure 15), and nav display control panels, shown in Figure 23, provide the control/display interface with the AP/FDS. System number 1 uses inputs from the captain's systems as guidance commands, while system number 2 uses the first officer's. The flight directors are active whenever power is available and a command mode is selected. When no AP/FDS modes are selected, the flight director symbols are removed automatically from the flight displays. The lateral and vertical autopilot modes are selected by the same switches as the flight director. Flight director OFF switches are provided to remove the symbols when desired.

Either autopilot can be engaged (coupled to the pitch and roll autopilot servos) at any time by selection of the number 1 or the number 2 system engagement switch. Initial engagement defaults to the attitude control stick steering (CSS) modes for both vertical and horizontal axes. The selection of any vertical and/or lateral flight guidance mode will cause both flight director formats to display command guidance for the mode selected. These flight director commands can be coupled to the autopilot servos by selecting CMD with one of the autopilot engagement switches. This results in automatic control in the guidance modes selected. Both flight directors display the same vertical guidance commands; however, different nav mode presentations are possible depending on the pilot's and copilot's nav panel selections. A pushbutton switch on both side-stick controllers is provided for the autopilot disconnect command.

Three vertical mode switches on the guidance control panel provide coordinated autopilot pitch axis and thrust control commands for automatic computer

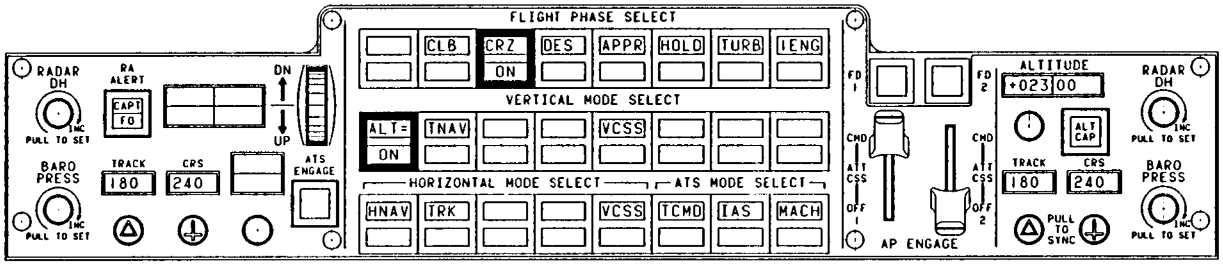


Figure 67. Guidance and Control Panel

controlled flight. The automatic modes are performance management (PM), time path (TNAV), and vertical navigation (VNAV). The remaining semiautomatic mode switches provide commands for nonprogrammed flight, either full time or for temporary diversion from the flight plan.

Thrust Control System - Engagement of the thrust control system (automatic throttles) is accomplished by activating the ATS ENGAGE switch on the GCP panel. Mode selection is available via the IAS, MACH and TCMD switches. When initially engaged (and no mode is selected) the IAS mode is engaged by default, and the TCS adjusts thrust to maintain the IAS at the time of engagement. Speed adjustments may be made by the SPD/MACH adjust knob. Selecting the Mach mode maintains the Mach at the time of engagement. Mach adjustments also may be made by the SPD/MACH adjust knob. The thrust command (TCMD) mode couples engine control with one of three computations available within the flight management computer. When in this mode, the flight management computer is also providing a control signal to the pitch autopilot. When PM, TNAV, or VNAV is selected and the autopilot pitch axis and thrust control systems are engaged in the CMD modes, the commands to each are coordinated to effect programmed vertical navigation control.

In all three functional modes, the TCS will not allow thrust commands which would result in airspeeds below a minimum safe level. The autothrottle servos are located in the throttle quadrant and drive the engine control input system in parallel with the pilot inputs. The autothrottle servos may be overridden manually by a force applied to the throttle lever. During operation, the two servo outputs are compared, the TCS is automatically disconnected, and the pilot is warned if a disagreement is detected. An autothrottle disconnect pushbutton switch is located on each outboard throttle handle.

Active Control System

Additional computerized control systems have been incorporated which result in a more structurally and aerodynamically efficient aircraft. Control switches for these systems are mounted on the active flight control panel located on the overhead console.

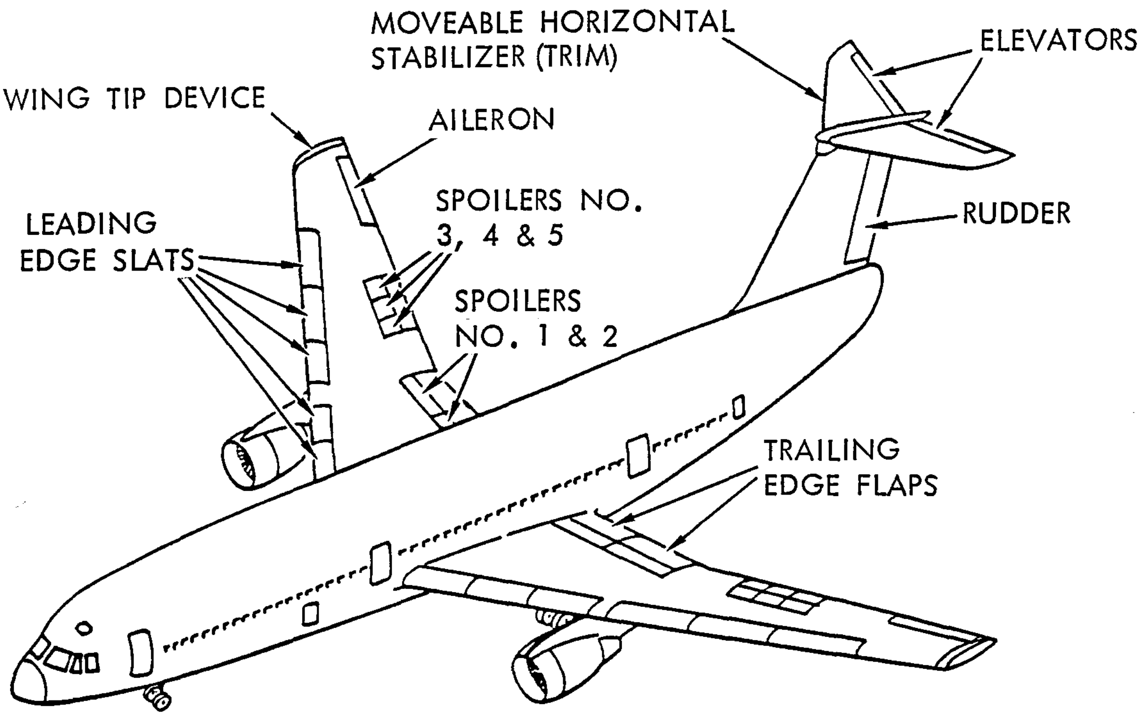
The active control functions are contained in two digital computers, each of which has dual computing channels internally, to provide fail operational/ fail passive capabilities. Figure 68 lists the active control functions available.

Complete preflight testing provisions are included in the active control system hardware and software, and comprehensive monitoring is provided to satisfy both flight safety and maintenance requirements.

Stability Augmentation System - The stability augmentation system (SAS) allows the aircraft to be designed with relaxed static stability, which permits smaller horizontal and vertical tail surfaces. To artificially enhance the stability, flight control inputs from the SAS automatically respond to electrically sensed aircraft attitudes and movements. The reduced empennage size not only results in a significant weight savings but also in decreased drag. Three pushbutton switches, shown previously in Figure 62, control power to the augmentation systems, one each for the pitch, roll, and yaw axes. Pressing any of the switches extinguishes the OFF legend in the switch and powers the selected axis of the stability augmentation system. Pressing the same switch a second time illuminates the OFF legend and removes power from that axis of the system. A failure in any part of the system will cause a message to be displayed on the ACAWS.

Lateral-Directional Stability Augmentation - The lateral-directional augmentation functions to increase dutch roll mode frequency and damping of the unaugmented aircraft; coordinates steady-state turns; and reduces sideslip in turn entry. The system uses strapdown inertial navigation system outputs to provide (1) yaw rate, (2) roll rate and roll attitude feedback signals to rudder, and (3) roll rate and attitude feedback signals to ailerons. A feed-forward element is used in a side-stick controller-to-aileron command loop to decrease the effective roll mode time-constant for low speed (flaps down) configurations.

The system is designed to provide good flying qualities throughout the operational flight envelope. The yaw rate to rudder loop provides adequate dutch roll mode damping. Sideslip feedback increases the dutch roll mode natural frequency. Roll angle feedback to rudder and aileron give convergent



ACS FUNCTION	CONTROL SURFACE
PITCH STABILITY AUGMENTATION (PSAS)	ELEVATOR
ACTIVE LIFT DISTRIBUTION CONTROL (ALDC)	ELEVATOR AILERON
LATERAL STABILITY AUGMENTATION (LSAS)	AILERON
ROLL CONTROL SPOILERS (RCS)	OUTBOARD SPOILERS
DIRECT LIFT CONTROL (DLC)	INBOARD AND OUTBOARD SPOILERS
GROUND SPOILERS (GS)	INBOARD AND OUTBOARD SPOILERS
SPEED BRAKES (SB)	INBOARD AND OUTBOARD SPOILERS
YAW STABILITY AUGMENTATION (YSAS)	RUDDER
RUDDER LIMITER (RL)	RUDDER
WING TORSION RELIEF	WING TIP DEVICE

Figure 68. Active Flight Control Functions

spiral stability and reduce lateral acceleration in steady turning flight. The roll rate feedback to rudder reduces sideslip in turns and coordinates turn entry.

Pitch Stability Augmentation - The design strategy of this aircraft utilizes relaxed longitudinal static stability flying quality criteria, so that the benefits of reduced tail size, aircraft weight, and the associated improved performance characteristics could be incorporated into the program.

Phugoid mode stability is augmented by velocity and longitudinal acceleration feedback signals to the elevator in conjunction with an artificial feel system. Body axis pitch rate and normal acceleration feedback signals to the elevator are used in conjunction with a compressible dynamic pressure scheduled artificial feel system to provide proper short-period dynamic response and steady-state stick force per acceleration (g) characteristics.

Normal acceleration feedback increases the short-period natural frequency for flaps-down aircraft configurations, as it approximates angle-of-attack feedback over the desired frequency range. It also reduces the aircraft flight path response to vertical gusts and has an advantageous effect on stick force per elevator gearing required to obtain adequate stick-force-per-g characteristics.

The normal acceleration signal is obtained from blending normal acceleration from a fuselage-mounted accelerometer with pitch acceleration to obtain an effective accelerometer location near the aircraft center of rotation for elevator inputs, thus more closely approximating angle-of-attack feedback.

Pitch rate feedback is used primarily to obtain proper short-period damping. These two feedbacks also alter the steady-state elevator-per-g characteristics. Longitudinal acceleration is also used for the phugoid mode damping. Low-pass filtering is used to prevent structural coupling with any of the feedback signals.

Active Lift Distribution Control - The active lift distribution control system (ALDCS) is an automatic flight control system function, which provides redistribution of wing spanwise lift through symmetrical deflection of the ailerons. The net aileron control effect is to shift the center of pressure inboard, thus reducing the incremental wing root bending moments. The ALDCS provides the functions of reducing fatigue loads on the wing due to maneuver, gust, and peak-to-peak ground-air-ground load sources. The aileron control channel commands right and left ailerons symmetrically to accomplish gust load and maneuver relief. The feedback sensors utilized for the aileron channel are provided by four vertical accelerometers per wing, located in pairs for fault tolerance such that their summed output provides an effective chordwise location on the elastic axis, eliminating possible adverse coupling with torsional modes.

Indicial lift aerodynamics are used in conjunction with a structural dynamics model to formulate an aeroelastic model including six structural modes. This model is used to derive the feedback compensation required to properly phase the feedback accelerometer signals for control of inner wing bending moments and to attain the requisite stability margins.

A pilot's feed-forward command, acquired from the side-stick position transducer, is summed with the compensated acceleration control signal to provide abrupt maneuver load control. The feed-forward signal is also transmitted to the elevator control system to compensate for pitching moments due to aileron deflections.

The ALDCS signals are gain-scheduled by aircraft dynamic pressure to provide proper stability and load relief curves throughout the operational flight envelope. ALDCS feedback signals do not significantly affect aircraft flying qualities throughout the operational envelope. The aileron series inputs are phased out and the ailerons positioned to a constant up-rig when aircraft speed exceeds or is equal to the maximum horizontal operational speed. ALDCS may be deselected by pressing the ALDCS switch on the flight control panel, which also illuminates the OFF legend.

Rudder Load Limiter (RLL) - An electronic rudder load limiter (RLL) system is provided to limit rudder deflection as aircraft speed increases. By limiting rudder deflection in the higher speed regimes, stresses on the rudder and vertical stabilizer structure are reduced. The system has two redundant operating channels. The system is automatic and requires no pilot control other than deactivation by a switch located on the active flight control panel. Pressing the RLL switch disconnects power from the system and illuminates the OFF legend in the switch. Pressing it a second time turns the power back on. Failures or malfunctions will be displayed on ACAWS.

Rudder limiting is provided by limiting the hinge moment capability of the rudder surface servos. The flight control computers accomplish this by limiting actuator output as a function of dynamic air pressure.

Wing Torsion Relief (WTR) - Wing torsion relief devices on each wing tip are provided to relieve twisting stresses. Wing twisting, imposed by ailerons and other flight load forces, is compensated for by computerized control of the torsion alleviation system. The system is fully automatic with an ON/OFF switch provided on the active flight controls panel. The word OFF is illuminated when the switch is pressed and the system is off. The switch is blank when the system is on. Malfunctions and failures are displayed on the ACAWS. The aircraft may be operated at a reduced load factor without the system.

Wing Load Alleviation (WLA) - A wing load alleviation (WLA) system is included which allows the aircraft to be built with lighter wing structures. During turbulence or other conditions that result in high wing bending stresses, the wing load alleviation system senses the increased load and acts to reduce the stress by deflecting the ailerons upward slightly. Concurrently, pitch attitude is increased to compensate for the reduction in lift. The wing load alleviation system is an automatic system with an ON/OFF switch on the active flight controls panel. The word OFF illuminates when the WLA switch is pressed; in the normal position, the switch is blank. The aircraft can be flown without the system engaged, but at a reduced load factor. System failures or malfunctions will be displayed on the ACAWS.

Lift Tailoring (LT) - To further reduce drag and increase aerodynamic efficiency, a computer-controlled lift tailoring system is incorporated. The system senses aircraft speed and angle-of-attack. Then, using computed data, it optimally positions flaps and ailerons to the minimum drag configuration. When the wing flap control is moved to the LT position, the system operates continuously, sensing, computing, and making small adjustments to the control surfaces.

A switch on the active flight control panel powers the system. The word OFF illuminates when the LT switch is pressed; in the normal ON position, the switch is blank. System malfunctions are displayed on the ACAWS.

Surface Position Display

The surface position indicator (SPI) is a computer-generated CRT display format for use by the pilots in monitoring the aircraft's flight control surfaces. The SPI display is available during all phases of flight on the lower portion of the number 4 CRT which is time shared with aircraft functional systems schematics. It is used primarily on the ground to check for proper control surface movement. With the SPI, the ground observer, who is normally required, is no longer needed.

Figure 69 depicts the SPI with all primary flight control surfaces in their respective neutral positions. All primary surfaces appear on the screen as white hatched boxes except for the rudder which appears as a hatched triangle. For contrast, the basic outline of the wings and tail is shown in green.

Normal operation is indicated in the following manner. While monitoring the SPI, either pilot moves his side-stick controller and rudder pedals. As each control surface moves, position sensors attached to the surfaces detect the movement and send signals back to the flight management computer. The computer then processes this information and moves the corresponding surface on the SPI in parallel with the actual movement. Figure 70 shows the primary control surfaces deflected from neutral.

Should any surface malfunction, the SPI will display its actual position, but its color will change to red. Simultaneously, an ACAWS message will notify the crew of the problem.

The secondary flight control surfaces (slats, flaps, and spoilers) are only visible on the SPI if they are not fully retracted. As these surfaces are extended, movement is depicted on the SPI by solid amber rectangles which appear to grow from the wing, as shown in Figure 70. Any secondary surface which malfunctions will be shown in its actual position, but the color will change to red as the ACAWS alerts the crew. If the wing flaps or slats malfunction in the fully retracted position the words "no flaps" or "no slats," as appropriate, will appear in red as shown in Figure 71.

The trim position of each primary surface is shown on the SPI with a digital readout in a box. Attached to each box is a line which indicates the neutral position of the primary surface. A malfunctioning trim surface will be displayed in its actual position, but the digitial display will change from white to red.

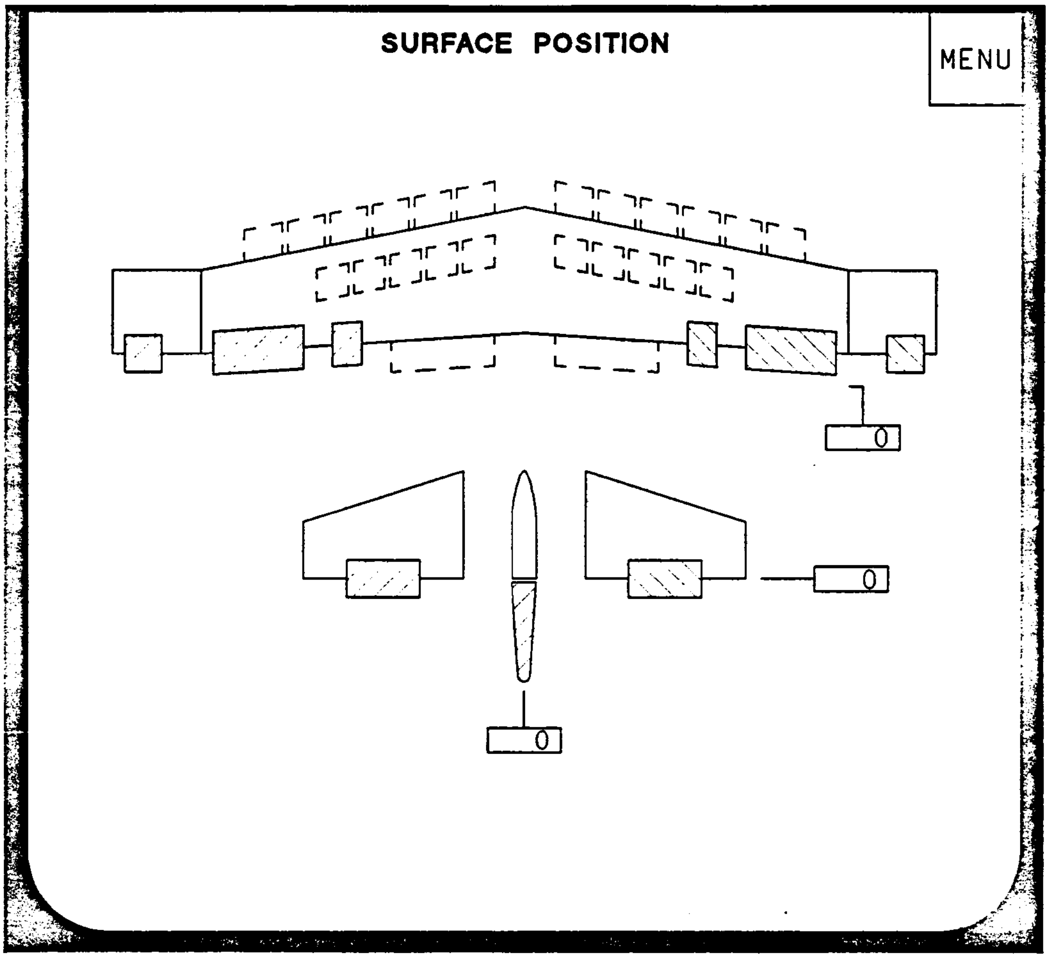


Figure 69. Surface Position Indicator with Primary Surfaces, Neutral and Secondary Surfaces Retracted

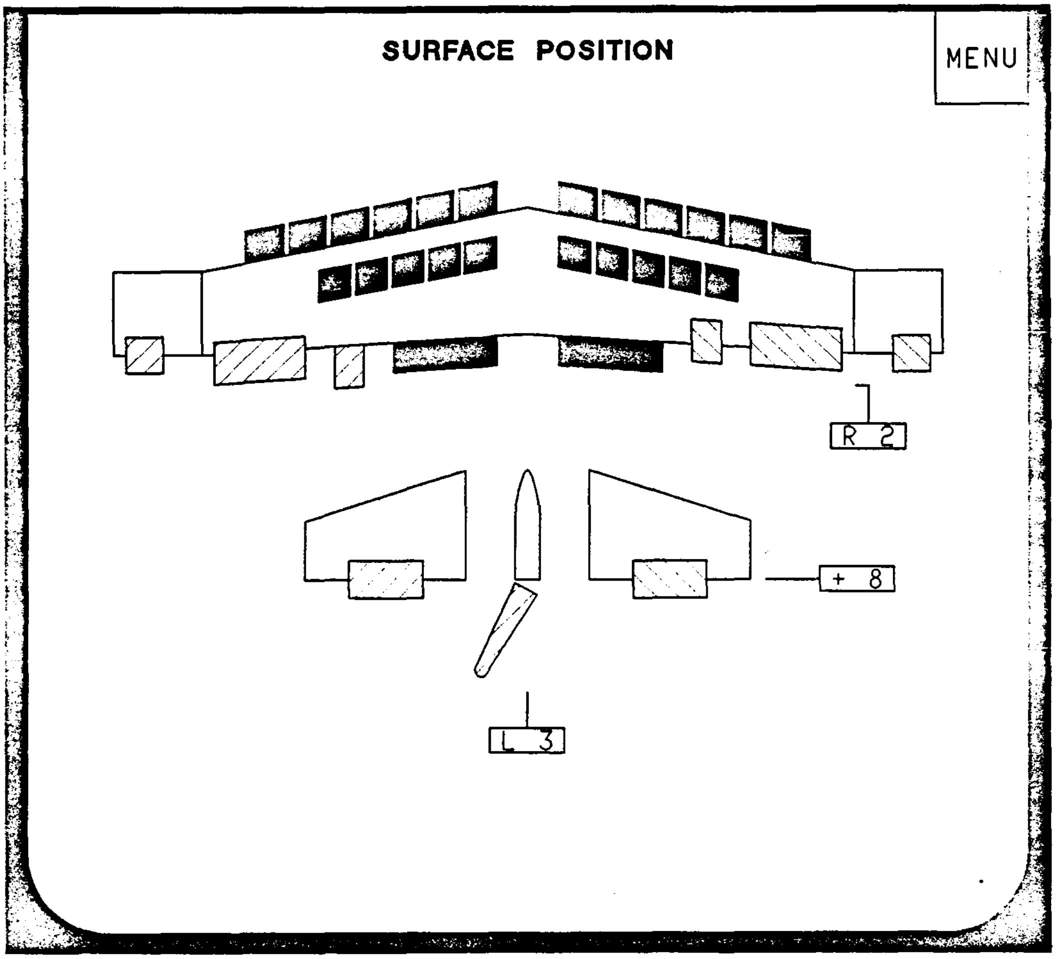


Figure 70. Surface Position Indicator with Secondary Surfaces Extended and Primary Surfaces Deflected from Neutral

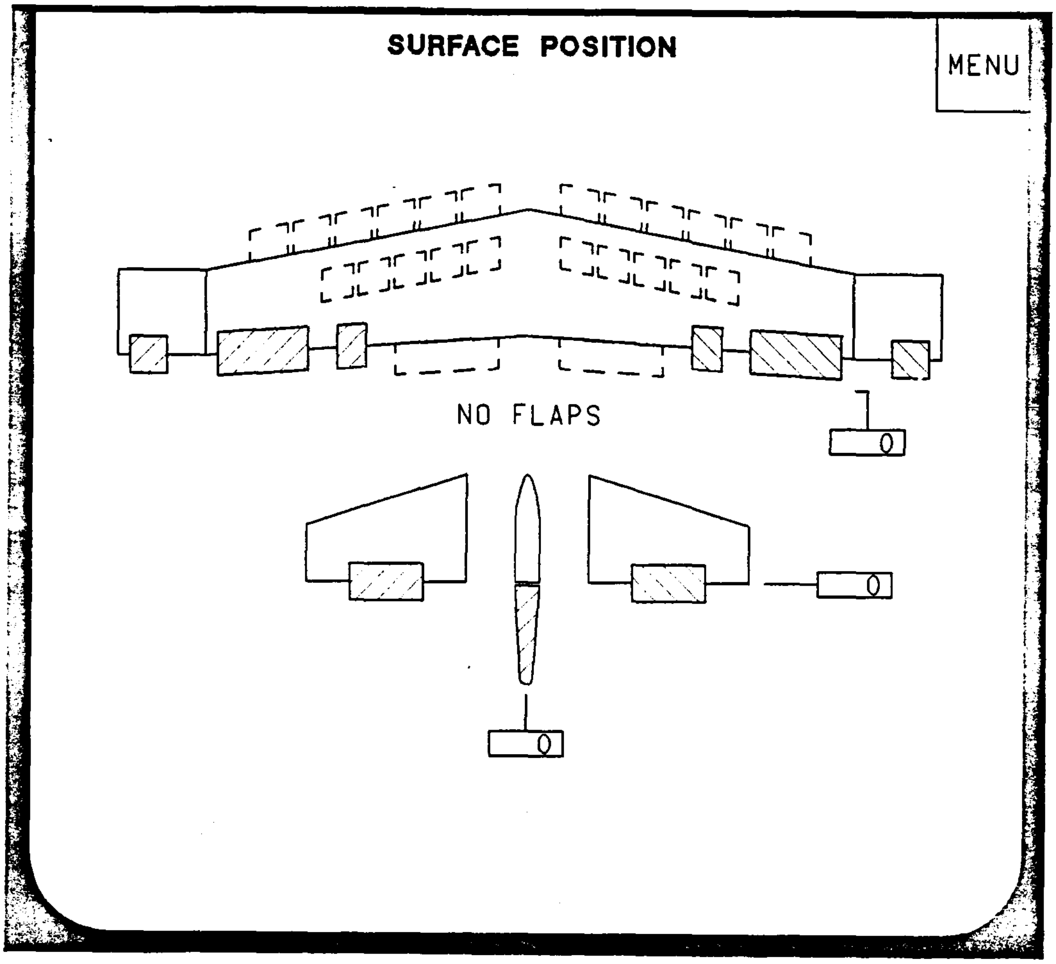


Figure 71. Surface Position Indicator Showing Failures of the Secondary Surfaces in the Retracted Position

Stall Warning System

Each AFCS computer contains a computation channel for the stall warning. Each stall warning channel operates independently to provide signals to the control stick shaker and to the audible stall warning devices. Thus, if either channel fails to operate, stall warning is still provided to both pilots through the other channel. Stall warning angle-of-attack thresholds are a function of Mach number, slat position, and horizontal stabilizer position.

As the aircraft approaches a stall and the angle-of-attack exceeds the value corresponding to a speed of $1.06V_S$, each computer channel activates the warning and interrupts the nose-up elevator trim signals to prevent further nose-up. These conditions persist until the angle-of-attack is reduced below the value scheduled for warning onset. If the angle-of-attack proceeds past warning onset, corresponding to a speed of $1.00V_S$, an audible sound will be emitted from the interphone system and cockpit speakers. To delay premature pilot termination of recovery actions and to reduce the possibility of re-entering the warning regime after recovery, the signal will continue to sound for one second after the angle-of-attack is reduced below that corresponding to a speed of $1.06V_S$.

- The signals at $1.06V_S$ are:

  (1) The master caution light will illuminate.

  (2) The accompanying steady tone will begin.

  (3) The word STALL will appear on the ACAWS display in amber.

  (4) The word STALL will be repeated continuously through the voice alerting system.

- The signals at $1.00V_S$ are:

  (1) The master warning light will illuminate.

  (2) The accompanying variable tone will begin.

  (3) The word STALL will appear on both flight displays in red.

  (4) The word STALL will be repeated continuously through the voice alerting system.

GUIDANCE AND CONTROL PANEL

The guidance and control panel (GCP) is located in the center of the glareshield, as shown previously in Figure 67, and is a component of the automatic flight control system (AFCS). It controls independent dual-redundant fail-operational autopilot/flight director systems (AP/FDS), a monitored autothrottle system, and selection of flight phase modes for the flight management and thrust management systems. The selection of flight phase also tailors the information on both flight displays and provides an input to the ACAWS logic. Flight director (F/D) steering symbols are normally provided whenever any mode is selected on the GCP; however, separate F/D OFF switches for the crew are provided to remove the steering information from individual displays when desired.

Three modes of flight control are available to the crew using information selectable on the GCP: manual with F/D guidance (with or without control stick steering); semi-automatic command using control knobs to set desired performance; and fully automatic command, which receives its signals from the flight management computers. Two modes of control stick steering are provided: attitude control stick steering and vector control stick steering.

Vertical guidance information for both flight displays is selected by the mode select switches on the GCP. However, lateral guidance modes are selected individually by switches on each pilot's navigation mode select panel. To facilitate operating the aircraft from either side, automatic flight control can be coupled to the steering commands as selected on either side by engaging the appropriate autopilot.

Autopilot 1 couples to the steering source selected on the pilot's nav display panel, while autopilot 2 couples to the source selected on the co-pilot's nav display panel. Both autopilots and identical nav aids (ILS or MLS) must be selected for an automatic landing.

The center grouping of switches consists of a 3 x 8 array of switches with programmable legends. The top half of each switch will illuminate if it is an appropriate mode choice. When that mode is selected, the bottom half of the switch will illuminate with ON, ARM, or other appropriate message.

GCP Operational Philosophy

Either pilot may operate the guidance and control panel by following these steps:

(1) Select the flight phase

(2) Select the appropriate vertical, horizontal, and automatic throttle system (ATS) modes

(3) Engage the autopilot and the autothrottle

Steps 1 and 2, above, program the flight director. Once this is done, the pilot need only engage the ATS and the appropriate autopilot. Engagement of the command mode instructs the autopilot to fly what has been programmed into the flight director.

Once the vertical, horizontal, and autothrottle modes have been selected, the flight phase may be changed without having to reselect the vertical, horizontal, and ATS modes.

The flight control system is designed for fully automatic flight from just after takeoff to landing roll-out. A typical automatic flight might use the performance management mode of the flight management computer for takeoff, climb, and cruise to a point where precise time control begins for arrival at a metering fix location. At this point the time navigation (TNAV) mode is selected, which continually computes the ground speed required to arrive at the metering fix point at the time required. After passing the metering fix, point-to-point vertical navigation (VNAV) is normally selected for guidance in the terminal area until ILS or MLS beam capture occurs.

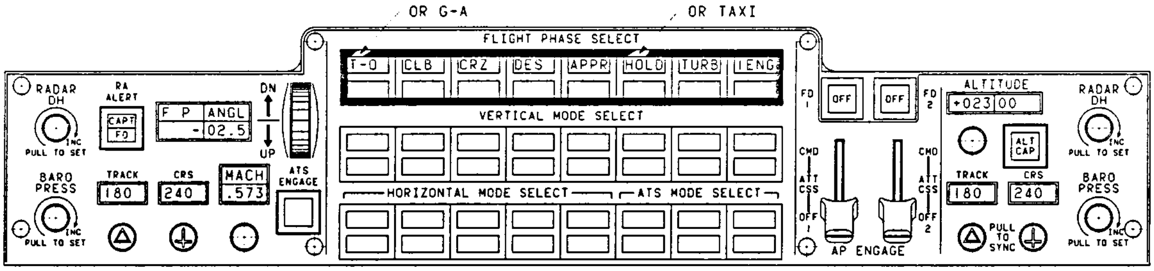
A full complement of semiautomatic autopilot modes is provided to facilitate temporary diversions from the programmed flight plan. Additionally, control stick steering can be selected, which allows the pilot to hand-fly the airplane through the autopilot with flight director commands for guidance. The vector control stick steering mode maintains the flight path angle when force is removed from the stick. This mode is especially compatible with the VNAV mode in the terminal area. The attitude control stick steering mode maintains attitude when force is removed from the stick. This mode is the same as today's control stick (wheel) steering modes.

> Note: The design of the control panel has not been optimized to be a real airplane controller, but has been designed to maximize flexibility for use in a research simulator.

GCP Function Descriptions

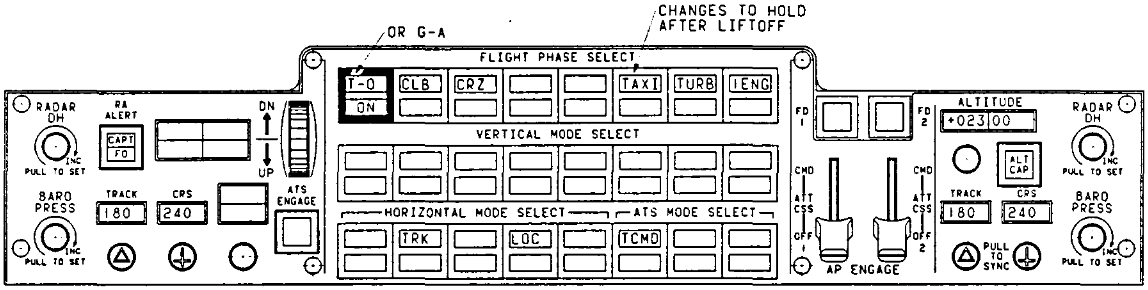
Figure 72 and the associated information describe the function of each switch and operating mode in the guidance and control panel.

Flight Phases



Flight Phase Select Switches - These eight programmable switches determine what information is to be placed on the flight displays and which vertical, horizontal, and autothrottle modes are appropriate choices. During computer-controlled flight, these flight phase switches automatically sequence from takeoff to cruise and provide coordinated pitch and thrust commands. These switches are mutually exclusive with the exception of the HOLD, TURB, and 1 ENG switches, which can work in conjunction with the other phases.

Figure 72. Guidance and Control Panel Operation, (Sheet 1 of 18)

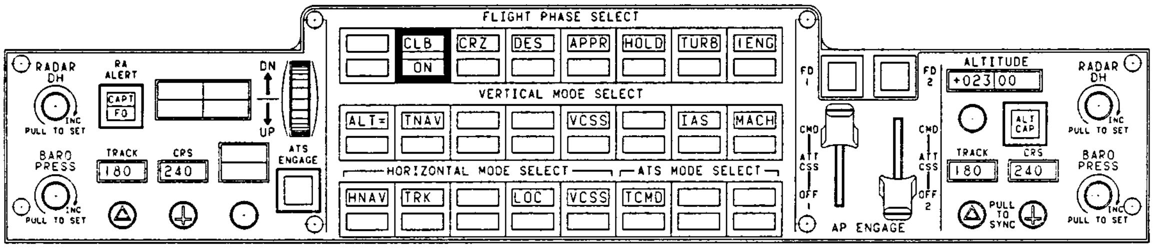


Takeoff/Go-Around (T-O/G-A) - On the ground and immediately after takeoff, the upper window of this switch will display T-O. Once approach is selected, this switch reads G-A. The bottom half of the switch displays ON when the switch is pushed. Only the modes shown above are available. The ON is turned off only when another phase is manually or automatically selected.

Selection of this switch for takeoff tailors the flight displays for takeoff and causes the proper takeoff limit and commanded thrust settings to be displayed on the engine power display. This commanded EPR, whether T-O limit thrust or derated thrust, is determined by what is programmed in the flight management computer. Selection of this switch for go-around always displays the maximum rated EPR as the commanded thrust.

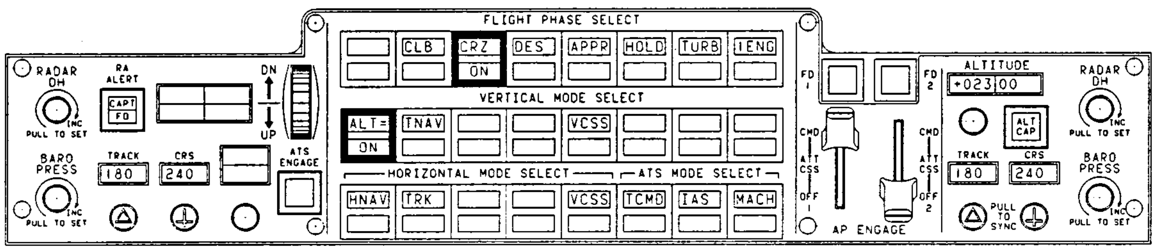
When in the T-O mode and the thrust from one engine is lost, ←OUT or OUT → illuminates automatically in the bottom of the switch marked 1 ENG and the thrust limit EPR is commanded on the good engine. This is the only time that the engine out mode is automatically selected.

Figure 72. Guidance and Control Panel Operation, (Sheet 2 of 18)



Climb (CLB) - This may be activated manually or automatically (as the flaps are retracted). When activated, the flight displays are tailored for climb and the ON appears in the lower half of the switch. Once selected, only the modes shown above are available for selection. When the autopilot is engaged in level flight and the autothrottle is operating in the TCMD mode, pushing this switch initiates a climb and also deactivates the altitude hold switch.

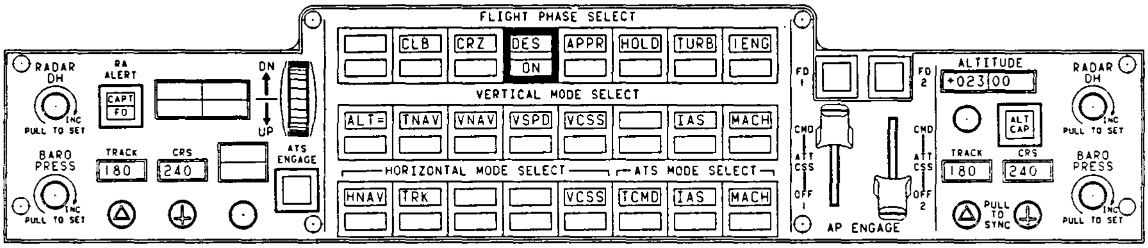
Selection of this switch also causes the climb limit EPR to be commanded. If no other vertical mode has been selected, then the commanded climb speed and EPR setting are automatically displayed.



Cruise (CRZ) - Unlike the other flight phases, the cruise switch is normally not selected manually because it will automatically activate whenever the aircraft captures an altitude. If the pilot is manually flying the aircraft (in either CLB or DES), he must first level the aircraft and then select the cruise switch or altitude hold in order to illuminate this light.

Selection of this switch tailors the flight displays for cruise and causes the cruise limit EPR to be displayed. If performance management is not being used, there is no commanded cruise power setting. When the cruise phase is active, ON appears in the lower half of the switch.

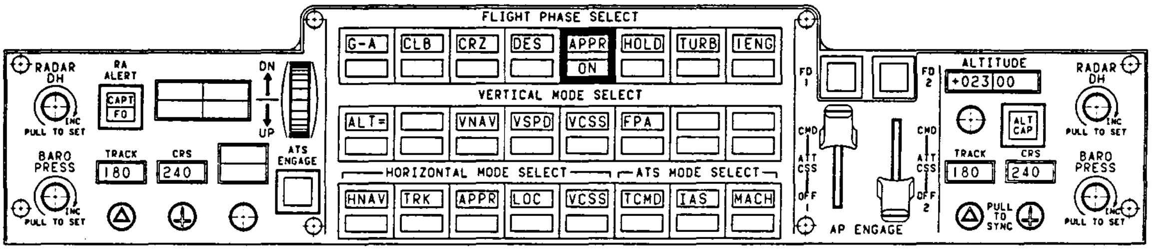
Figure 72. Guidance and Control Panel Operation, (Sheet 3 of 18)



Descent (DES) - This switch may only be manually selected. Doing so causes the aircraft to begin a descent if it is being controlled by the flight management computer. The pilot may also initiate descent by using the vertical speed (VSPD) mode. If the autopilot is fully coupled, the descent continues to a selected altitude, at which time it captures the altitude, activates the altitude hold feature, and switches to cruise. If no altitude is selected for capture, the descent continues until the pilot initiates action.

Selection of this switch tailors the flight displays for descent and causes the descent EPR to be commanded (if in performance management). When the descent phase is active, ON appears in the lower half of the switch. Also, when the descent button is pressed, the altitude hold switch is deactivated.

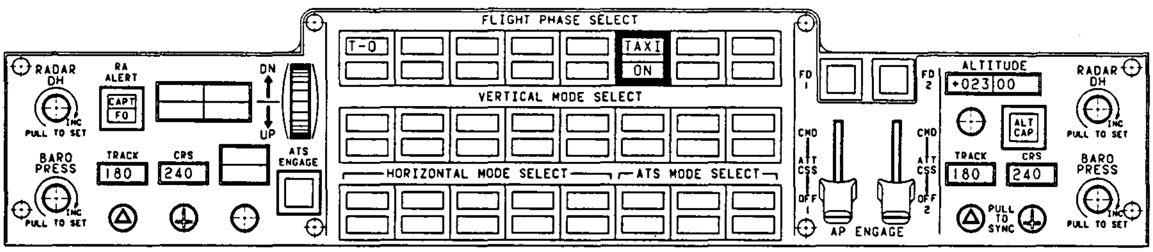
Figure 72. Guidance and Control Panel Operation, (Sheet 4 of 18)



Approach (APPR) - This switch must be manually selected to couple the flight director to the appropriate approach aid (MLS, ILS, or VOR). When the switch is first engaged, ON appears in the lower half of the switch. The horizontal, vertical, and throttle modes shown above are available with this phase.

Selection of this switch tailors the flight displays for approach and causes the go-around switch to be offered as a selection. No EPR setting is commanded, but the climb limit EPR is displayed.

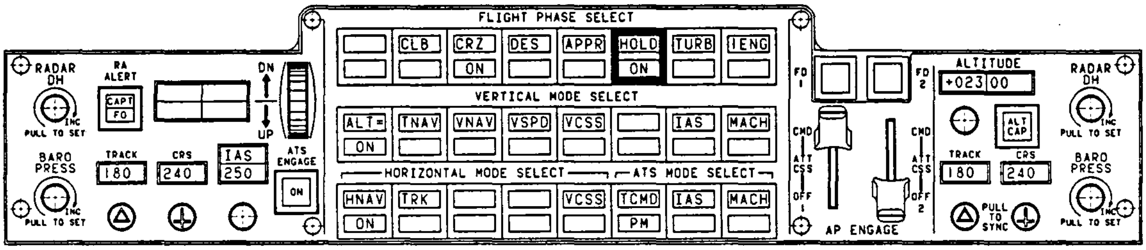
If the approach is being flown semiautomatically the pilot uses the VSPD, FPA, altitude hold, and altitude capture switches to initiate all climbs, descents, and level-offs (not the CLB, CRZ, or DES switches). At any time during the approach the pilot may discontinue the approach by pushing the G-A switch on the GCP or one of the G-A switches near the throttles. While in the approach phase when an altitude is captured, it activates altitude hold, but does not switch to the CRZ phase.



Taxi - This phase will automatically be activated when power is first applied to the aircraft. It may also be manually selected when the aircraft is on the ground. When airborne, this key is relabeled HOLD.

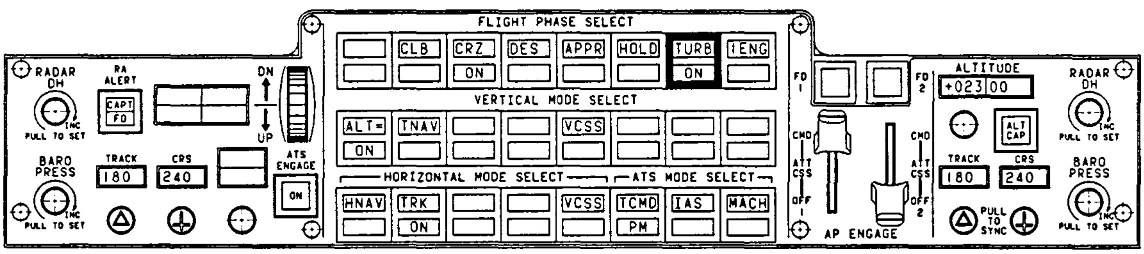
Selection of the TAXI phase tailors the flight and nav displays for blind taxi guidance.

Figure 72. Guidance and Control Panel Operation, (Sheet 5 of 18)



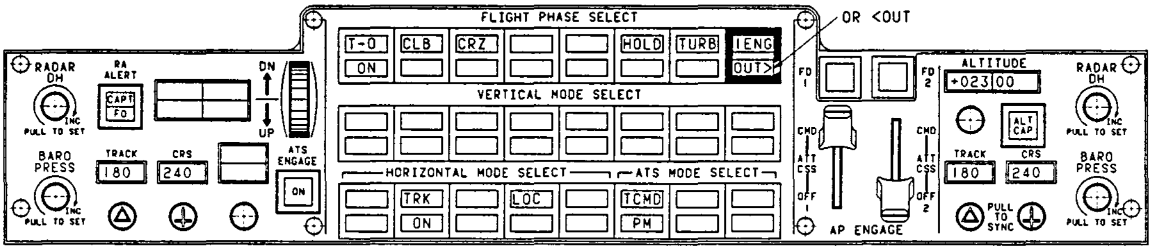
Hold - This switch is manually selected and temporarily transfers control to the appropriate CDU HOLD page. Selection of this switch prior to holding pattern entry causes the autothrottles to reduce the airspeed to that desired for holding. When the holding pattern is intercepted (tangentially, and in the correct direction of orbit), the flight director and autopilot work together to automatically maintain the holding pattern track. Note: If the programmed intercept is not acceptable, the pilot must manually direct the aircraft to intercept the desired holding pattern.

While established in the holding pattern, the aircraft can be directed to climb, cruise, descend, or approach by using the appropriate flight phase and/or semiautomatic vertical mode switches. To discontinue the holding pattern the pilot must deselect the HOLD button. When HOLD is activated the word ON appears in the lower half of the switch.



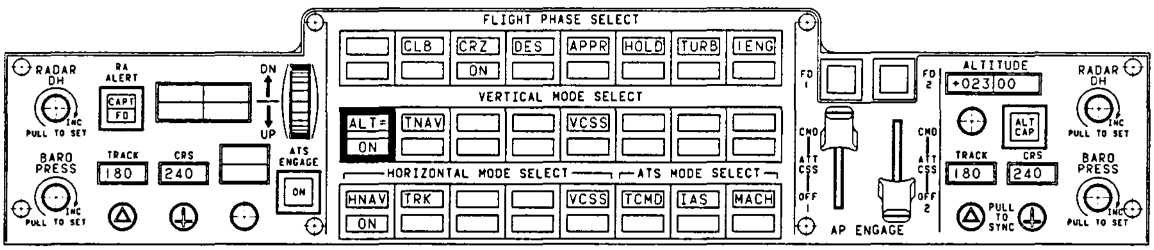
Turbulence (TURB) - Selection of this switch desensitizes the autopilot and autothrottle gains to reduce control surface activity thus providing a smoother ride. Since this switch may be selected during any flight phase, it is ON simultaneously with one of the other flight phases. When selected, an ON appears in the lower half of the switch. To deactivate this mode, the pilot must deselect the TURB switch.

Figure 72. Guidance and Control Panel Operation, (Sheet 6 of 18)



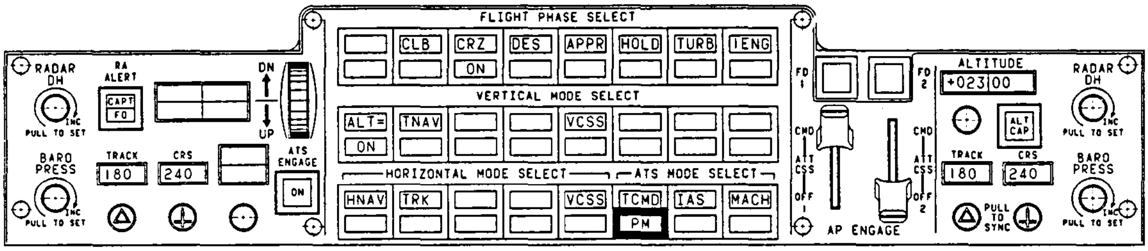
Engine Out (1 ENG) - This switch, like the TURB switch, may be activated in conjunction with any other flight phase switch. When in the T-O phase, this switch is automatically activated upon engine failure. In all other phases the pilot must select this switch. The purpose of this switch is to alter flight director cues and autopilot functions for safe single engine operation and display the maximum continuous limit EPR in all flight phases except T-O. As an example, in the takeoff phase this function furnishes flight director cues necessary to command the best single engine angle of climb and maximum takeoff EPR on the good engine. If the automatic throttles are engaged, these commands are then executed. When the switch is activated, the word OUT appears in the lower half of the switch along with an arrow indicating the bad engine.

Vertical Modes

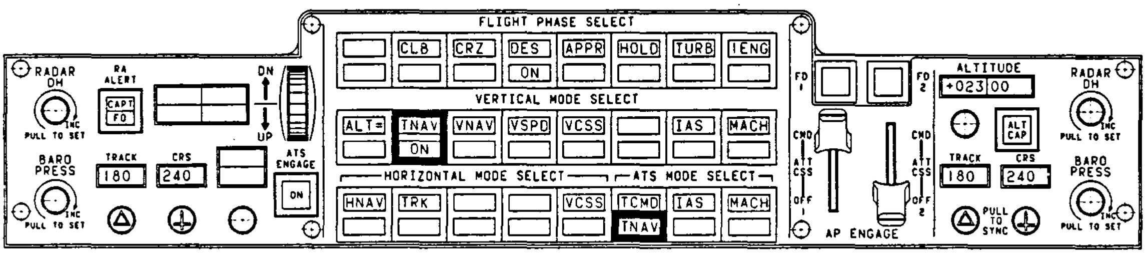


Altitude Hold (ALT =) - This switch causes the aircraft to maintain the present barometric altitude. Normally this switch is activated automatically when a selected altitude has been captured. At the moment of capture, the ALT CAP legend is extinguished and the word ON appears in the lower half of the ALT=switch. At the same time the cruise phase is activated.

Figure 72. Guidance and Control Panel Operation, (Sheet 7 of 18)

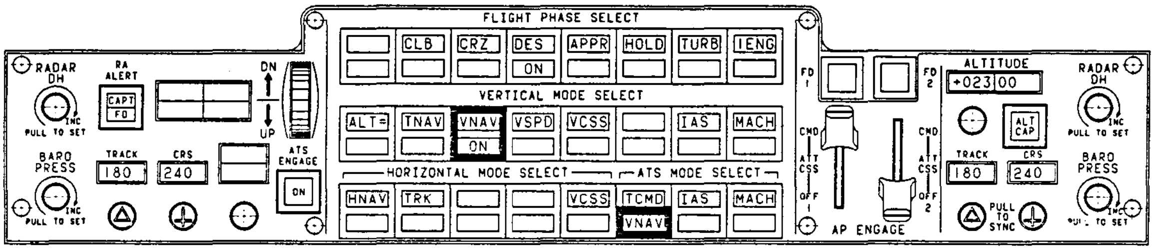


Performance Management (PM) - This is probably the most frequently used mode of the flight management computer. For that reason, if no vertical mode is selected the autopilot automatically defaults to performance management, provided the pilot has selected thrust command (TCMD) with the autothrottle system. This causes PM to illuminate below TCMD, indicating that the autothrottles and pitch axis are working in conjunction with the flight management computer.

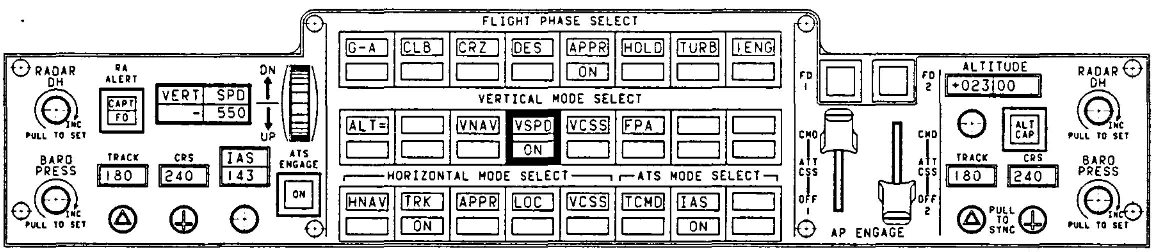


Time Navigation (TNAV) - This is a flight management computer mode used when the aircraft must arrive at a metering fix at a precise time. Working in conjunction with the autopilot and autothrottles, this mode continuously calculates the ETA over the metering fix and controls the speed so as to arrive on time. Selection of this mode places the word ON in the lower half of the TNAV switch and causes a time box to be displayed on the nav display. This time box indicates where the aircraft must be to arrive at the metering fix on time. The pilot must then adjust the speed and flight path of the aircraft to place the aircraft symbol within the time box. Once the aircraft is within the time box, the pilot may select TCMD (thrust command) on the autothrottles to automatically remain within the time box. When TCMD is selected in this case, the word TNAV appears below TCMD indicating that the autothrottles are receiving their signals from the flight management computer's TNAV routine.

Figure 72. Guidance and Control Panel Operation, (Sheet 8 of 18)

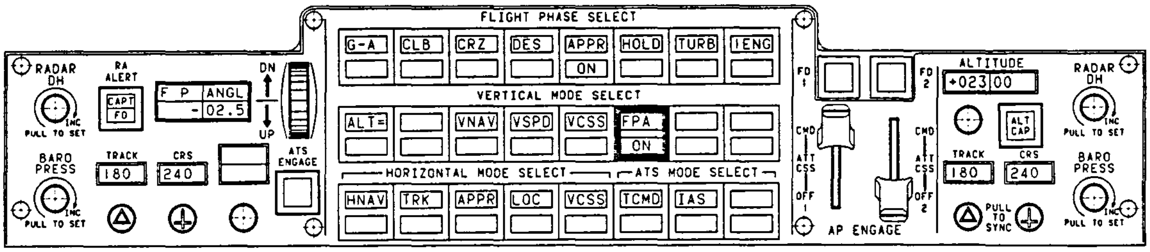


Vertical Navigation (VNAV) - Selecting VNAV couples the autopilot/flight director to the point-to-point vertical path program of the flight management computer. The word ON then appears below VNAV. This option, which is most useful in the terminal area, yields a straight line path between two waypoints and two altitudes. If the aircraft is within the capture threshold, the aircraft captures and tracks the desired vertical path. If the aircraft is outside the capture threshold, it must be maneuvered by the pilot onto an intercept to the desired path. As is the case with most of these modes, any time this mode is selected without autopilot, the flight director displays the proper steering commands so that the pilot may manually fly the proper VNAV course. If the autothrottle system is working in conjunction with VNAV through the thrust command switch, the word VNAV appears below TCMD.

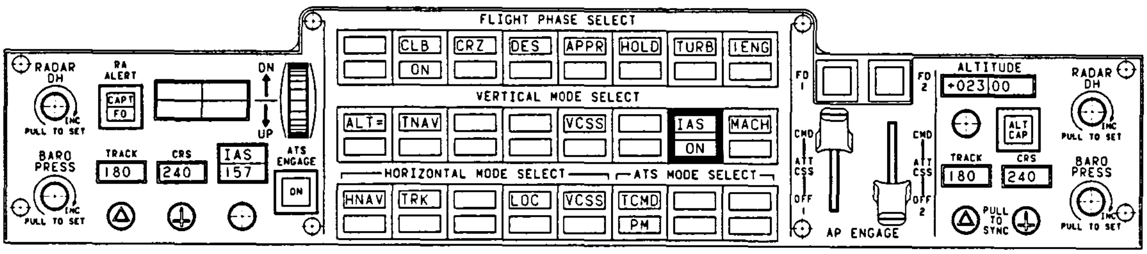


Vertical Speed (VSPD) - When this switch is selected, the display in the VSPD/FPA select window synchronizes to the actual rate of climb or descent, and the AP/FDS attempts to maintain this vertical speed. A conventional thumbwheel is provided to select any other vertical speed. Selection of this mode illuminates the ON in the lower half of the switch.

Figure 72. Guidance and Control Panel Operation, (Sheet 9 of 18)

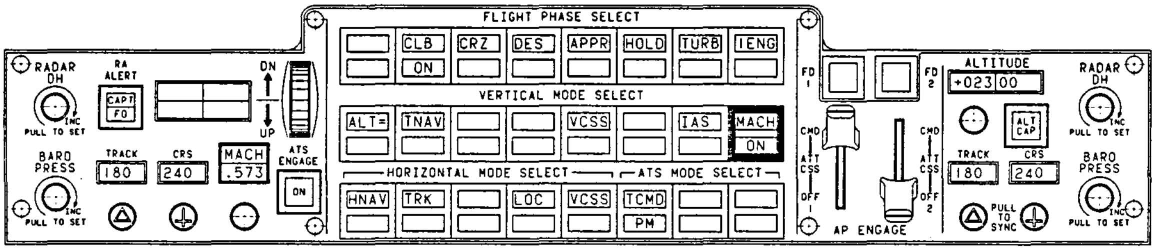


Flight Path Angle (FPA) - Selection of this switch causes the VSPD/FPA display to synchronize to the existing flight path angle (in degrees). The AP/FDS then attempts to maintain this FPA. The thumbwheel allows selection of any desired angle of descent. Selection of this mode illuminates the ON in the lower half of the switch.

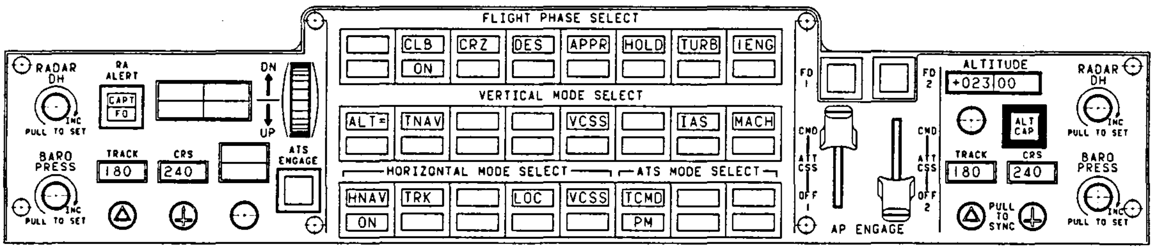


Airspeed Pitch (IAS) - Selection of this switch causes: (1) the digital readout in the SPD/MACH window to synchronize with the existing indicated airspeed and (2) the AP/FDS to maintain this speed by varying the pitch. A knob is provided to change the desired airspeed. The word ON will appear in the lower half of the switch to indicate that this mode is active. This switch is mutually exclusive with the autothrottle IAS or Mach modes. When this switch is selected while the autothrottle IAS mode is active, the autothrottle system is disengaged.

Figure 72. Guidance and Control Panel Operation, (Sheet 10 of 18)



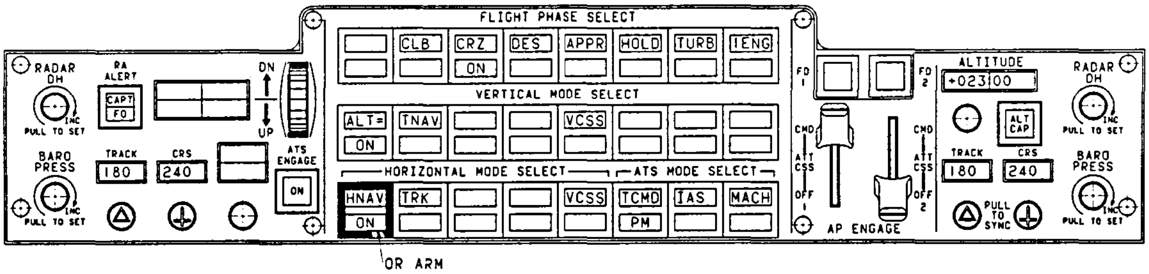
Mach Pitch (MACH) - This mode maintains a constant Mach number with pitch control similar to the IAS (pitch) mode. When selected, this mode will display ON in the lower half of the switch. This switch is mutually exclusive with the autothrottle IAS or Mach modes. Should this switch be selected while the autothrottles are maintaining a constant IAS or Mach, the autothrottle system is disengaged.



Altitude Capture - This feature is used any time the autopilot is to change altitudes. First, the desired altitude is selected in the window. Second, the altitude capture is armed by pushing the ALT CAP switch, which causes it to illuminate. Third, the pilot initiates the climb or descent by pushing the CLB or DES switches. Or, if in the APPR flight phase, he commands an FPA or VSPD. Once the desired altitude is reached, the aircraft levels-off, the ALT CAP light extinguishes, and the CRZ and ALT= switches indicate ON.

Figure 72. Guidance and Control Panel Operation, (Sheet 11 of 18)

Horizontal Modes

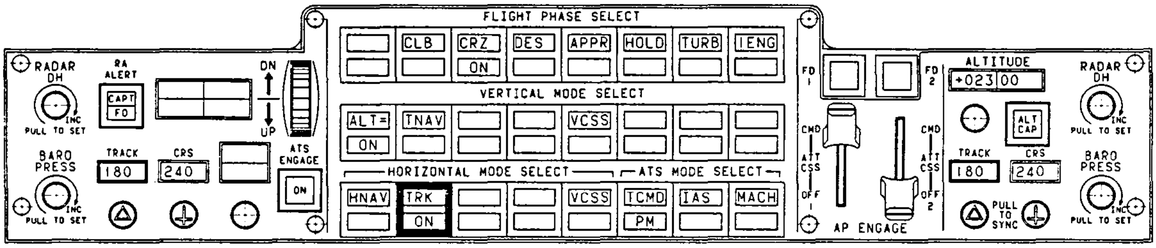


<u>Horizontal Navigation (HNAV)</u> - Selection of this switch couples the AP/FDS to the horizontal path selected by the applicable navigation mode select panel. Normally, the HNAV switch would be used in conjunction with the FMC; however, it may also be used in conjunction with the VOR/ILS mode of the nav mode select panel to navigate along VOR airways.

If the aircraft is within the capture logic threshold, the AP/FDS will capture and track the desired horizontal path and the word ON will appear beneath HNAV. If the aircraft is outside the capture logic threshold, the word ARM appears and AP/FDS flies along the selected track as shown in the TRACK digital readout until the threshold is reached. When the capture logic trips, the AP/FDS then automatically captures and tracks the desired path and the display changes to ON. It also deactivates the TRK mode.

When the AP/FDS is coupled to a VOR, the course select control on the GCP is used to set the desired VOR radial on the digital readout above the control. The two course select controls operate independently unless the SYNC switch is selected. If SYNC is selected, both course readouts may be set simultaneously by one control.

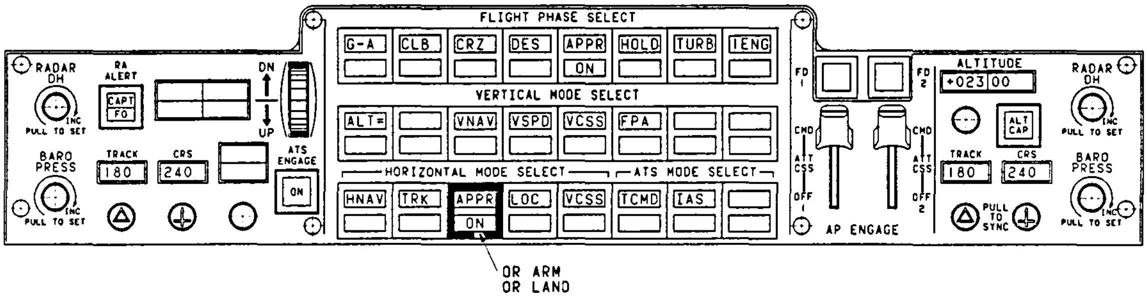
Figure 72. Guidance and Control Panel Operation, (Sheet 12 of 18)



Track Select (TRK) - The track mode is used to command a constant track across the ground. (This function replaces the more conventional heading hold because it corrects for wind.) A track control knob is provided to set the desired track in the digital readout above the control, and the TRK switch is used to select and deselect the mode. If the SYNC switch is selected, both TRACK readouts on each end of the panel may be set simultaneously by one control. If the readouts are set to different tracks before SYNC selection, the number 2 readout is synchronized to the number 1 setting when SYNC is selected, unless the number 2 autopilot is engaged. In this case, the number 1 readout is synchronized to the number 2 setting to prevent an autopilot transient. When the TRK switch is selected, the word ON appears in the lower position of the switch.

The constant track mode can be engaged at any time, whereupon it disengages HNAV. To resume HNAV operation the pilot must again select HNAV. If the aircraft is not within the capture logic threshold, the autopilot remains in the TRK submode, but the TRK ON-light is not illuminated and the word ARM appears on the HNAV switch.

Figure 72. Guidance and Control Panel Operation, (Sheet 13 of 18)

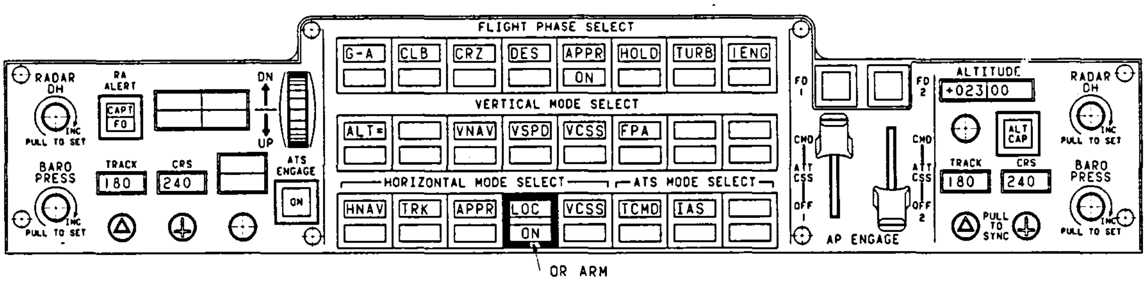


Approach (APPR) - Selection of this switch illuminates the word ARM and arms the autopilot/flight director for ILS or MLS capture. Once the approach aid has been properly tuned, selected, and intercepted, the word ON replaces ARM in the lower part of the switch.

If an automatic landing (Category III) is desired, the pilot must accomplish these additional steps:

- Tune both ILS (or MLS) receivers
- Turn on both radar altimeters
- Engage both autopilots
- Engage the autothrottles

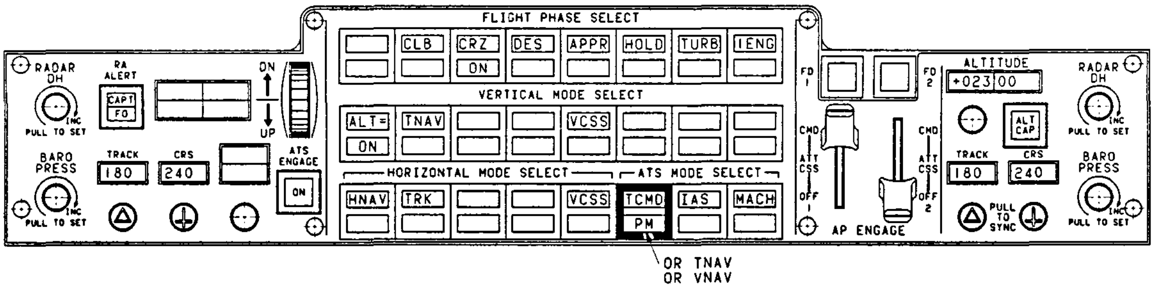
When these actions are completed, the ACAWS annunciates the status of the autoland system, and the word LAND appears in the bottom half of the switch.



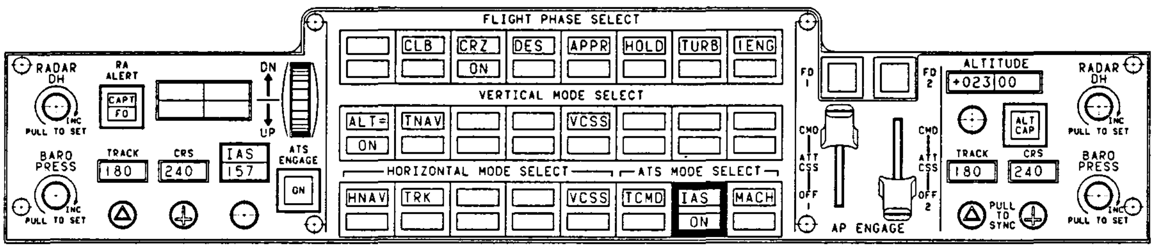
Localizer (LOC) - This mode is exactly like the approach mode except that the glideslope is not tracked. When first selected, the switch displays ARM. Once the localizer is captured, ON replaces ARM.

Figure 72. Guidance and Control Panel Operation, (Sheet 14 of 18)

Autothrottle Modes

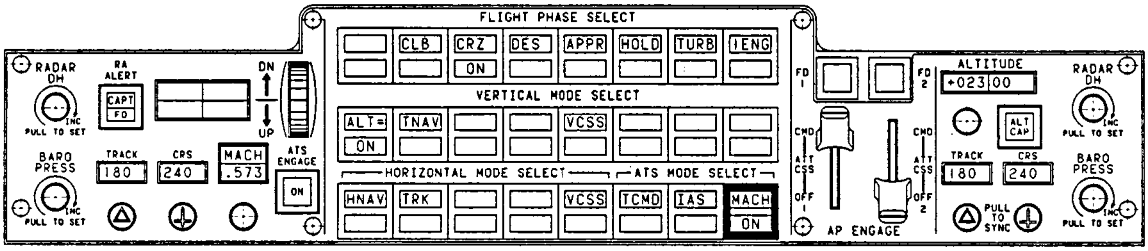


Thrust Command (TCMD) - This switch programs the autothrottle system to take its commands from the flight management computer. When TCMD is selected, the lower half of the switch displays which computer mode (selected from the vertical mode choices) is controlling the throttles. If no vertical mode has been chosen, the TCMD switch always defaults to performance management and displays PM. If time navigation or vertical navigation has been selected, the label reads TNAV or VNAV, as appropriate.

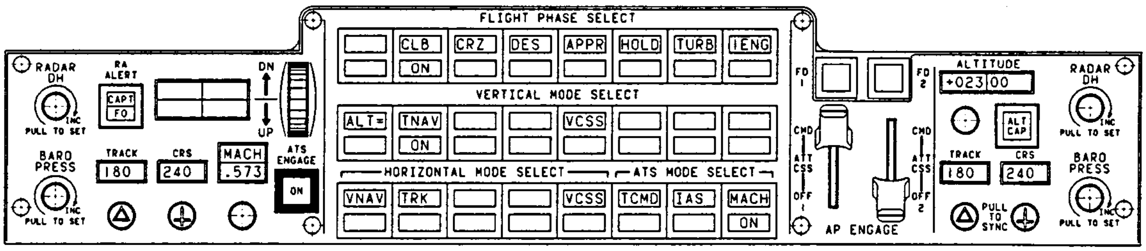


Autothrottle Constant Speed Hold (IAS) - This mode, when selected, displays ON, causes the existing airspeed to be displayed in the SPD/MACH window, and maintains that speed. Once the IAS switch has been selected, a different speed may be commanded by turning the knob beneath the SPD/MACH window. If this mode is selected while either the IAS or Mach pitch mode is active, the selected mode is disengaged and the autopilot reverts to attitude control stick steering.

Figure 72. Guidance and Control Panel Operation, (Sheet 15 of 18)



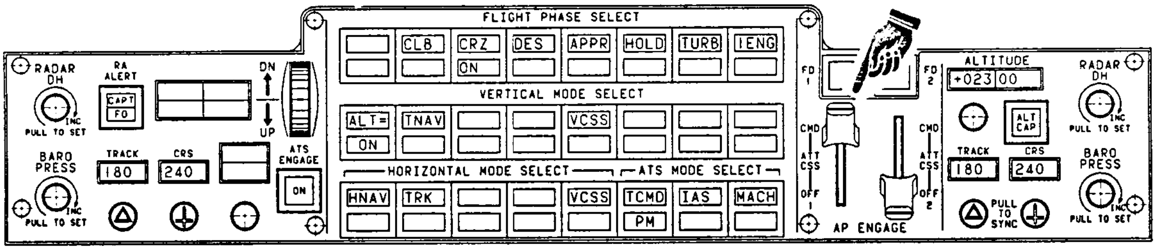
Autothrottle Constant Mach Hold (MACH) - When this mode is selected, the SPD/MACH window synchronizes to the existing Mach number, the word ON appears in the lower half of the switch, and the autothrottle system maintains that Mach number. A different Mach may then be selected by rotating the knob beneath the window. If this mode is selected when either the IAS or Mach pitch mode is active, the selected mode is disengaged and the autopilot reverts to attitude control stick steering.



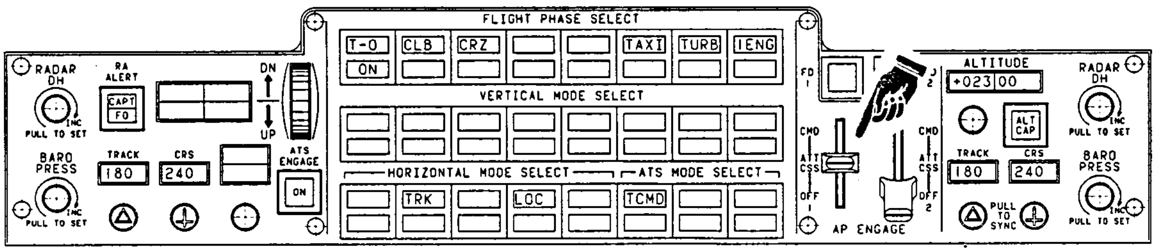
Autothrottle Engagement (ATS ENGAGE) - Once this mode has been selected, the autothrottle system may be engaged by pushing the ATS ENGAGE switch. When this occurs, the word ON illuminates and the autothrottle system begins functioning. The system may be disengaged by pushing the same button or with the ATS disconnect button on the throttles. If an ATS mode has been selected, but the autothrottles have not been engaged, the commanded power setting is displayed as a line on the EPR scale so that the pilot may manually set the throttles.

Figure 72. Guidance and Control Panel Operation, (Sheet 16 of 18)

Autopilot Engagement Modes

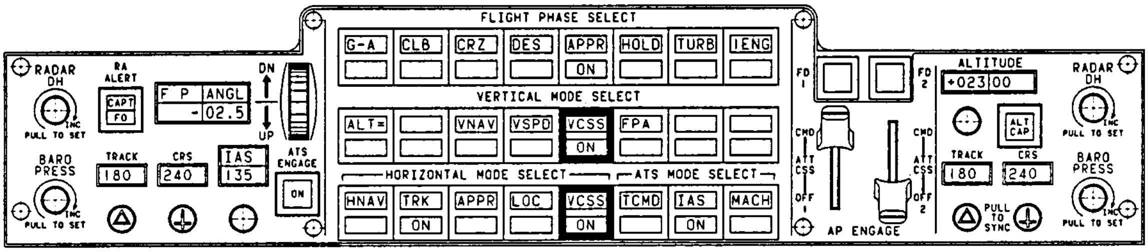


Autopilot Command Mode (CMD) - Once the flight phase and desired vertical and horizontal modes have been programmed, either pilot may couple the autopilot for fully automatic flight by lifting the appropriate bat handle to the CMD position. AP1 gets its information from the captain's side, and AP2 gets its information from the first officer's side. The autopilot may be disengaged in the same manner or by pushing the AP disengage switch on either control stick.



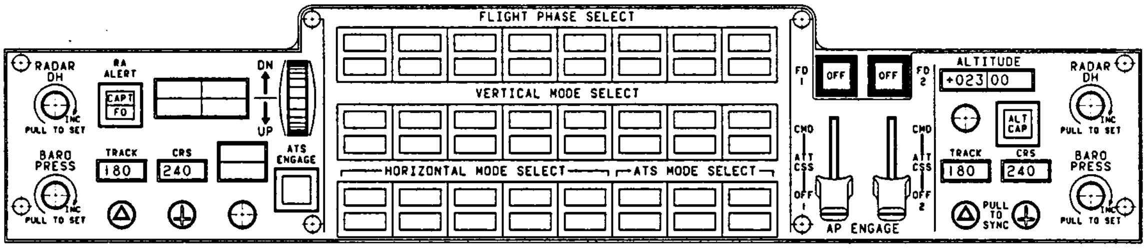
Attitude Control Stick Steering (ATT CSS) - If either autopilot bat handle is lifted to the ATT CSS position, the attitude control stick steering mode is engaged. This option allows the pilot to control the autopilot with his control stick. In the attitude CSS mode, the pitch attitude and aircraft heading at time of mode engagement are maintained as the reference if bank angle is less than 7 degrees. If bank angle is greater than 7 degrees, then the pitch and roll attitude at time of mode engagement becomes the reference. To change the reference, the pilot applies force to the stick to maneuver the aircraft to the desired new reference and then removes the applied force. The established values at the time the forces are removed become the new reference.

Figure 72. Guidance and Control Panel Operation, (Sheet 17 of 18)



Vector Control Stick Steering (VCSS) - Once the CMD mode of either autopilot has been engaged, the vertical and/or the horizontal axes of the autopilot may be placed in the vector control stick steering by pushing the appropriate VCSS switch(s). When the vertical VCSS switch is selected, the flight path angle at time of switch selection becomes the reference value for the pitch axis of the autopilot. When horizontal VCSS is selected, the track angle at time of switch selection becomes the reference for the lateral axis when the bank angle is less than 7 degrees. If the bank angle is greater than 7 degrees, then the existing bank angle becomes the reference. The references can be changed by the same technique described for the attitude CSS mode.

Flight Director



Flight Director (FD) - If either pilot wishes to remove the flight director symbol from his flight display, he may do so by selecting FD OFF. To restore flight director guidance, he must push the FD OFF button again. When the flight director is deselected, the appropriate FD OFF switch illuminates.

Figure 72. Guidance and Control Panel Operation, (Sheet 18 of 18)

FLIGHT MANAGEMENT COMPUTER (FMC)

Many transport aircraft in service today were designed during the 1960s before fully integrated digital systems were feasible. The inertial platform, because of its navigation capability for long overwater flights, was the first completely digital subsystem developed for widespread use on military aircraft. This occurred because the application of digital technology produced faster processing and the capability of using algorithms that were expensive or unobtainable in an analog system.

Displays, autopilots, air data computers and communication systems, however, remained mainly analog, with the result that the digital computer of the inertial system contained the only digital processor within the avionics system. New mission requirements were often designed specifically to operate in the inertial system computer. The expansion and redesign to accommodate these new functions caused considerable impact on the inertial systems' complexity, which has led to program language, hardware, and interface incompatibly between the various aircraft avionics systems now in service.

In contrast, the design trend since the 1970s for commercial aircraft has been to integrate the navigation sensors into a self-contained digital computer, complemented by a control and display unit and comprehensive analog digital interface hardware. This approach yields direct benefits to the operator, and cockpit space requirements are reduced as only one control and display unit is required to control the various inputs of VHF nav, Omega, inertial, and RNAV. The pilot navigates and flight plans, using the same language and techniques regardless of the type of sensor used; and the flexibility of the system permits tailoring the total system to customers' needs.

The avionics on 1990s aircraft will be all digital, with dedicated computers performing the various functions, linked to their respective sensors and to each other via serial and/or parallel bus structures. The flight management computer (FMC) is one of the most important units in the system, providing the pilot with the vital link to the various sensors, displays, and flight management parameters as shown in Figure 73.

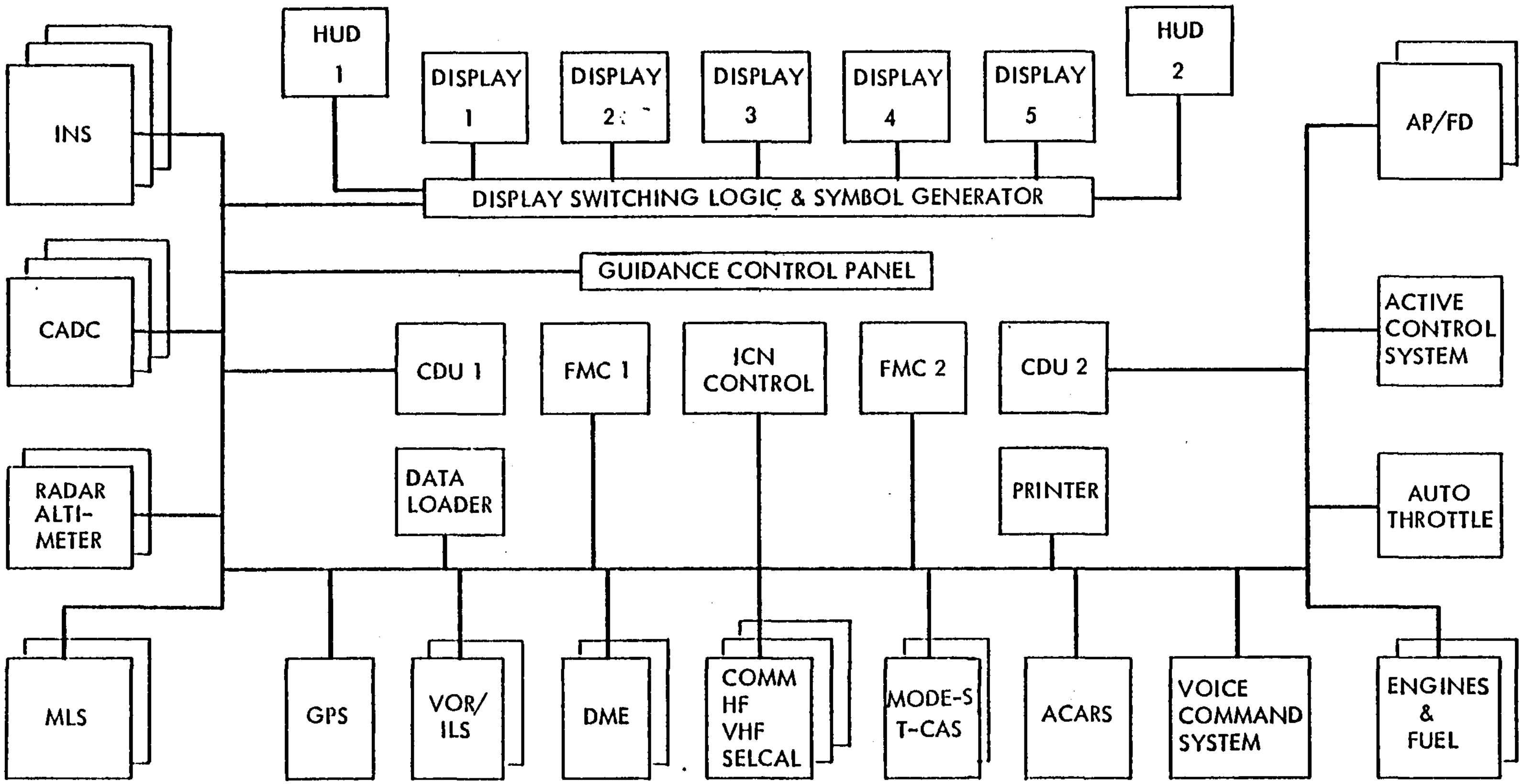


Figure 73. ACFS Management Computer System Block Diagram

Although the actual design of the hardware for the flight management system cannot be definitive at this time, a design concept of the system, including memory sizing for the computer, is an important consideration to the overall goals of the advanced cockpit simulation. The use of large mainframe computers, such as the VAX 11/780, has enormous potential for a flight station research facility; however, since one of the objectives is to develop ideas, algorithms and software that can be used in an aircraft environment (constrained by economics and life-cycle costs of aircraft avionics equipment), then the practical considerations should not be overlooked.

The following flight management system description is based on practical applications for avionics equipment in the mid-80s, but since the system software will be contained in a VAX computer, the proposed memory sizing will not be a constraint for future expansion and research.

System Hardware

The system consists of two identical computers with a common software package, and their respective control and display panels. The computer's architecture accepts a high order language and contains a 128K, 16 bit, nonvolatile memory.

To support automatic entry of flight plan, data base and program into the computers, a data transfer system is used. This is accomplished by either plugging in a data transfer memory device which has previously been programmed, or by plugging in an umbilical cord which directly connects ground computers to aircraft computers. The first of these two options is described below.

Data Transfer System - The data transfer system consists of three units: a transfer module, a module receptacle, and a ground based computer system.

- o **Transfer Module** - The transfer module features a solid-state memory unit in approximately a 3x6x0.75 inch module which allows it to fit into a suit pocket or flight bag. This unit is self-contained and consists of a solid-state bubble 16 bit, 128K memory.

- **Module Receptacle** - The module receptacle resembles a small tape deck in size and appearance. It has low module insertion force, self-wiping connector and spring-loaded, self-aligning feature to prevent contact damage or intermittent data flow due to misalignment of the data module. The unit is situated in the cockpit area within easy reach of the pilot. It has its own power supply and is interfaced with the management computers via a data bus.

- **Ground-Based Computer System** - The ground-based computer system consists of a general-purpose computer system such as the Hewlett Packard 1000 series. The computer interfaces with a display station, line printer, disk drive, and a receptacle for the data transfer module.

This complete system provides flight operations/flight crews with an automated method to flight plan and to transfer data to the data module. The data module is inserted into a receptacle in the aircraft, and all relevant data for the flight are automatically transferred into the computer. The type of information transferred to the aircraft computers includes: flight planning, performance management, fuel and passenger loads for computation of weight and balance and takeoff and landing data, enroute weather, notices to airmen (NOTAMS), emergency airfields, etc.

At the termination of the flight, a transfer module is used to retrieve operational and maintenance data from the computer. This can be analyzed and a hard copy of the information produced in the required format by the ground-based unit.

Compared to systems in use today, this system reduces the amount of bulk memory required in the management computer. Some of today's systems contain a worldwide data base within the computer, stored on an expensive disk system containing millions of bits of information that are not required for the normal day-to-day operation of the aircraft. All maintenance checks and computer program loading can be accomplished by using this system, thus eliminating special carry-on loading devices.

Control/Display Unit - The pilots interface with the flight management computer system through identical control/display units (CDU) located on the desk top at each pilot's station. The CDU, shown in Figure 74, consists of four major components: a DC voltage gas plasma display, a data entry keyboard, a touch panel faceplate for the display, and a group of low-profile membrane switches.

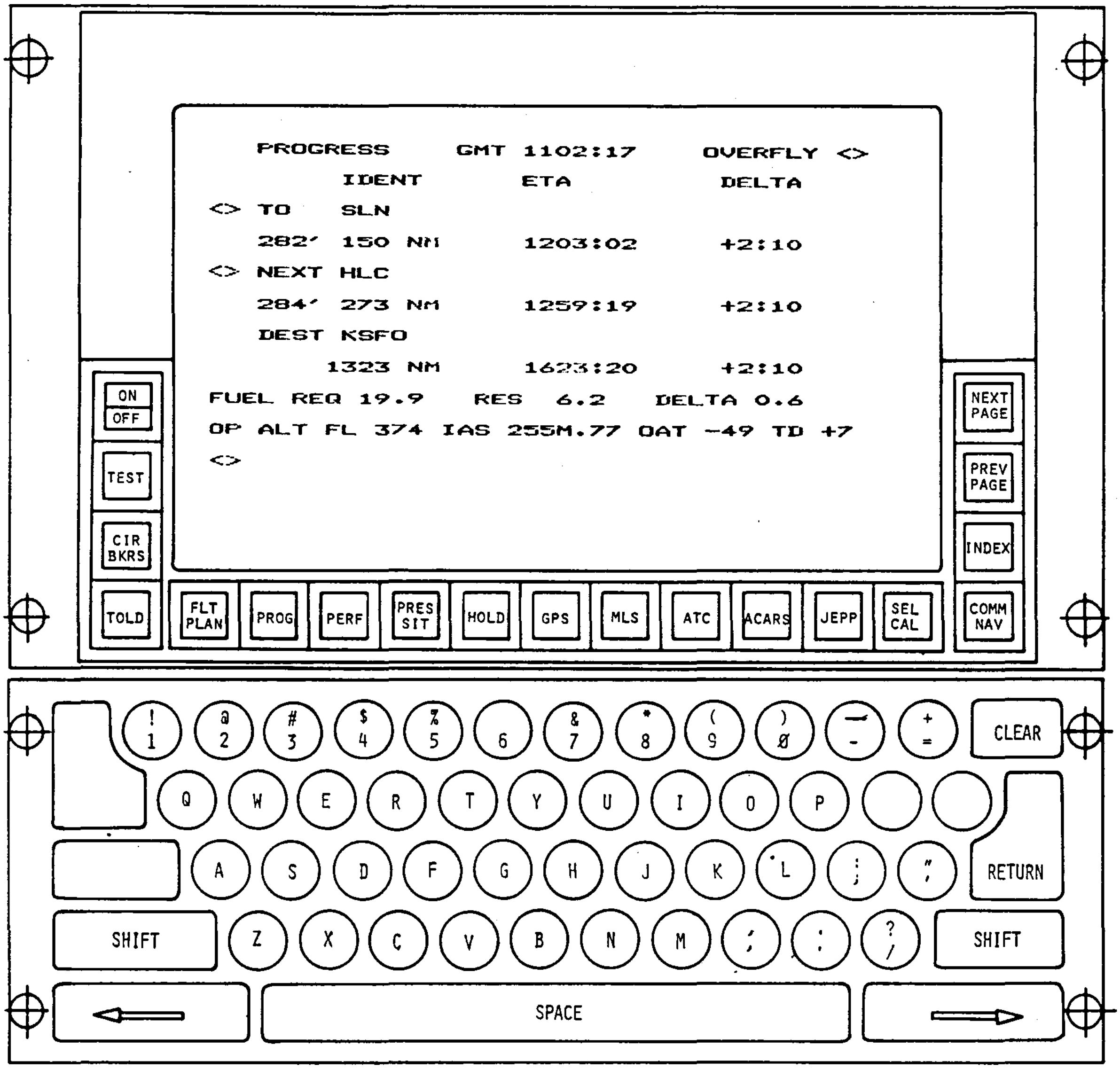


Figure 74. Control/Display Unit (CDU)

- **Display** - The FMC-generated data is presented to the pilots on a green gas plasma flat panel display. The active panel area is approximately 190 mm by 112 mm high, with a capacity of 480 5 x 7 dot matrix characters arranged in a 12 row, 40 characters/row format. Eleven lines are used for data display. The 12th line is used as a scratch pad for verification of data typed or voiced onto the display, before entry to the appropriate line by a touch switch.

- **Keyboard** - The keyboard is a custom-designed unit with the 26 alpha and 10 numeric characters arranged in the standard typewriter key pattern. A set of additional characters (non-alphanumeric) for message composition is included as well. The keyboard provides the means for the pilots to enter and change FMC operating parameters (e.g., flight plan waypoints, takeoff/landing data) and to format messages to be data linked to ground terminals.

- **Touch Panel** - A bezel-mounted touch panel controls the placement on the display of keyboard-entered data. The touch panel consists of infrared (IR) emitters and detectors aligned with each of the 12 rows horizontally and every second column of characters vertically, establishing an X-Y grid with 240 intersections. The placement of a finger close enough to the display surface to interrupt both a horizontal and vertical IR beam identifies to the display processor the location for the keyboard-entered data. Also, the grid coordinate, combined with the data page identifier, defines the data being entered for the FMC.

- **Low-Profile Membrane Switches** - A group of special-purpose membrane switches (to reduce depth) is arranged along the sides and bottom edge of the touch panel faceplate. These switches are used to power up the display, call up specific FMC data, page through multiple-page entries, "freeze" data that is time-dependent, and execute a program or data transmission. These switches are discrete, momentary-action type, requiring a positive, low-pressure force to activate (opposed to the touch panel IR beam "switch"). They interface with the display and the FMC through the display processor.

Software Functions

The operational flight program contains the executive and application software necessary to support the aircraft flight profiles and performs the following functions:

(1) Operating System

(2) Flight Planning

(3) Navigation & Steering

(4) Performance Management

(5) Display Formatting

(6) Navigation and Communications Tuning Support

(7) System Test & Monitoring

(8) Voice Command and Response

Operating System - This is the common software element that resides in the management computer module and provides three basic functions: executive, data base manager, and input/output (I/O) control.

- Executive - The executive provides inter-task command scheduling which controls the execution of tasks based on a predetermined priority scheme.
- Data Base Manager - The data base manager provides the common elements necessary for the common storage of file control within the system.
- I/O Control - The I/O control function provides the capabilities for input/output and for immediate processing of interrupts associated with I/O handling.

Flight Planning - This function is performed primarily on the ground by the crew. It can also be used in flight when necessary to enter data or change the flight plan.

Data Entry - Flight planning is a function that uses the interface between the CDU and the computer to allow the crew to enter data for flight operations. During the design phase, a data base will be implemented to contain the following elements: aircraft flight characteristic parameters, operating checklists, fixed enroute planning data, flight plan, flight requirements.

The flight characteristic parameters are those that enable calculation of performance values for takeoff, landing, and other modes of flight. Fixed enroute planning data include navigation aids, airfields, minimum enroute altitude, and waypoints along the planned route. Checklists will be entered into the data base for retrieval and displayed on the system display to the crew on demand. Flight plans will be stored for review, displayed on the navigation display, and used as a source of data for the steering and alert functions.

Each of these data elements can be loaded with the data transfer module, a ground-based data link, or changed by the crew using the CDU. Crew changes to the data base elements through the CDU will be validated for both format and reasonableness of value.

Navigation and Steering - The navigation function continuously determines the aircraft's position based on data from three inertial platforms configured in a triple mix position mode, supplemented with fix data from DME/VOR, GPS, and in the terminal area by ILS or MLS systems. Specific tasks accomplished by this function are as follows:

(a) Determination of horizontal position

(b) Determination of vertical position

(c) Computation of desired course, track, and wind

(d) Wind prediction including windshear

(e) Great Circle calculations

(f) 4D navigation (time)

Determination of Horizontal Position - The following sensors and routines are used to determine the horizontal position: IRS, DME/DME/VOR, GPS, MLS, manual fixing, clear fixes.

- **Inertial Reference System (IRS)** - A best position is determined from the three inertial platforms. The IRS Z axis direction cosines from the three units (9 total) are used to determine the median set of three direction cosines. These are then used as the best position set. All navigation and steering parameters are calculated from this position.

- **DME/DME/VOR** - This is a means of determining the aircraft's position by computing a radio position. This position is computed using the slant range of two DME stations which have been selected from the FMC data base and automatically tuned. If two DME stations are not available, a DME and a VOR station are selected. The resultant position is then compared to the IRS median position; if the delta between the positions is within limits, update of the IRS median position occurs.

- **Global Positioning System (GPS)** - The basis for the GPS is a space-borne satellite constellation emitting coherent L-band signals whose modulation provides the capability for determining accurate three-dimensional position, velocity, and timing information to the aircraft's installed receiver.

Several development models of aircraft equipment are presently being produced; and the configuration consists of the antenna, preamplifier, receiver, navigation data processor, control/display unit, and power supply. The system can be used as a stand alone navigation system; however, a variety of aiding devices, such as inertial systems, barometric altimeters, or external frequency references can be used to augment the GPS receiver function. It is expected that this particular module within the management computer will undergo many changes during the evaluation process as more user experience becomes available during the next decade.

- **Microwave Landing System** - In the terminal area the MLS receiver decodes the station information and determines the elevation and azimuth angles to the airfield. These data, along with distance information from the integral DME, are used to update the aircraft's position to enable precision horizontal and vertical steering along the desired MLS approach path selected by the pilot from the FMC data base.

  The two-dimensional waypoints, horizontal and vertical parameters that specify a published MLS approach, may be entered automatically through the data loader, manually via the CDU, or transmitted from the ground via data link.

- **Manual Fixing** - Manual update of the aircraft's position is provided by entering the latitude and longitude of a known ground reference via the CDU. The aircraft must be flown over the reference point and the manual fix button pressed at the instant that the pilot judges the aircraft to be over the point. This will update the position to the coordinates entered.

- **Clear Fixes** - This action will clear all fixes, and the system will revert back to the IRS median position.

Determination of Vertical Position - The aircraft's vertical position is determined by using inputs from the vertical velocity channels of the inertial systems and the air data computers. During the enroute portion of the flight, the GPS is used to update this data; during the approach phase, the MLS will be used, if available.

Computation of Desired Course, Track, and Wind - The desired course is derived from the latitude and longitude of the waypoints entered in the flight plan, using Great Circle calculations. The difference between the aircraft's actual ground track and the desired course is used to provide steering commands to the flight director and autopilot. The aircraft's heading, track, and groundspeed are obtained from the inertial systems. These data are used with true airspeed from the ADCs to calculate the current wind speed and direction.

Wind Prediction Including Wind Shear - While measurement of wind in cruise presents no real problem, to construct a realistic model of the winds at lower altitudes, statistical wind data with correlation coefficients relating wind at one level to another is required. Studies performed by NASA and Lockheed-California during the development of 4D guidance algorithms will be used to develop models and algorithms to be incorporated in the flight management module, so that research in this area can continue. When near the ground on departure or approach, increasing or decreasing headwinds, as well as downbursts, may cause a hazardous situation. In these cases, sufficient warning is required so that timely corrective action can be taken. The formulation of algorithms for windshear alerting and control are being developed for the landing phase, using the concept of maintaining the groundspeed expected at touchdown. This groundspeed technique provides a predictive capability procedure, so that if the amount of correction needed exceeds the known performance capability of the aircraft, the pilot is alerted to perform a missed approach prior to penetrating the shear condition.

Mechanization of this concept requires an accurate groundspeed (supplied by the inertial system), a target airspeed at touchdown, surface winds, runway heading, and runway elevation. The computer calculates the touchdown groundspeed which is displayed to the pilot. He can then compare the aircraft's actual speed with the computed touchdown speed and adjust groundspeed to allow sufficient kinetic energy to sustain forthcoming windshear. Various levels of warning, appropriate to the severity of the windshear conditions, are provided to the pilot through the ACAWS system.

Great Circle Calculations - Worldwide navigation capability is accomplished by converting the waypoint latitude and longitude into an earth-centered set of direction cosines from which all distances and desired course lines are calculated. The track-angle change for each waypoint is calculated, and a constant radius of turn is used for smooth transitions between the track changes. Since the navigation system must be capable of providing steering signals over a precise ground-track, "curved path" waypoint transitions are required for 3D and 4D navigation as well as for MLS approaches.

Conventional systems provide the crosstrack distance and track-angle to the new course line. The flight director or autopilot combines these signals and initiates the new course capture. In some cases where there are changes of course of more than 45 degrees, the pilot sets up the capture using the heading mode. Using this conventional system, it is impossible to predict the precise ground-track and distance the aircraft will cover, so this is another variable in estimating time to the waypoints or final destination.

The controlled curved-path method will enable aircraft to make track changes of 180 degrees within ground-track accuracy limited only by the system's knowledge of present position. By the use of GPS and MLS during the final stages of an MLS approach, this position should be known within approximately 50 feet.

4D Navigation (Time) - 2D navigation is defined as a two-dimensional process (latitude and longitude) in the basic horizontal profiles between departure and arrival waypoints.

The third dimension for 3D is vertical. To accomplish fuel-efficient 3D profiles, a performance management system which optimizes and controls the climb, cruise, and descent phases of the flight is added.

The fourth dimension (time), provides the capability of controlling the time enroute to selected metering points and a predicted descent profile to the terminal area. The 4D system, when fully developed and integrated with the ATC system, holds promise of substantial reduction of costly airborne delays.

The computers, navigation algorithms, communications, sensor, and display technologies needed for the research and evaluation of time navigation will be available when the simulation facility is complete.

Performance Management - The primary purpose of the performance management (PM) function is to provide aircraft/engine performance data to the crew and automatic flight control systems, based upon optimal flight profiles and actual/measured aircraft conditions, to minimize fuel usage. Other specific features of the PM computations are as follows:

- The optimum profile (climb, cruise, descent) is computed using forecast data, such as winds, temperature, and altitude, entered as part of the flight plan data.
- Optional profiles are provided to maximize system utility.
- The takeoff and landing data (TOLD) is computed for full or partial thrust takeoff based upon current runway conditions.
- Once in flight, the PM provides updated planning data, time, distance, and fuel to the crew based upon actual/measured conditions.
- The capability is provided to look ahead at any time in the flight to determine best altitude, speed, and thrust based upon forecast or known conditions at other altitudes and other points in the planned mission.
- Engine-out performance data are provided to give the crew immediate performance data during emergency conditions.

The PM function is integrated with the flight planning pages to provide a logical programming sequence for the flight with minimum crew workload. TOLD and vertical plane programming are accomplished concurrently with the navigation planning in the flight plan pages. Optional trajectories for each flight segment are provided on separate pages in the performance section to allow the crew to select flight segment submodes (such as maximum rate climb or best angle climb in lieu of minimum fuel) when special performance capability is desired.

During flight, speed and thrust targets for the appropriate flight segment are displayed on the flight instruments and routed to the automatic flight controls. Flight segment control is provided for the takeoff, climb, cruise, descent, and land flight phases by crew selection of the applicable flight display switch. The guidance and control switches are essentially an extension of the special function keys of the management computer CDU keyboard. Automatic flight path control is accomplished by selecting the PM switch when the autopilot and autothrottles are engaged.

The following tables contain the information available to the crew from the PM function from preflight to touchdown:

(1) Preflight

- o Flight Plan
  - Retrieve nav aids and map features
  - Calculate course, distance, time enroute, magnetic variation, enroute fuel, and wind
- o TOLD (Same as for takeoff mode)

(2) Takeoff

- o Aircraft gross weight
- o Aircraft takeoff center of gravity
- o Stabilizer trim setting
- o Takeoff roll distance
- o Critical field length
- o Critical engine failure speed
- o Takeoff engine pressure ratio (EPR)
- o Rotation speed
- o Maximum brake application speed
- o Go/No-Go distance
- o Maximum exhaust gas temperature (EGT)

(3) Climb

- o Minimum climb-out speed
- o Minimum flap retraction speed

- o Climb thrust EPR
- o Maximum EGT

(4) Cruise

- o Maximum range speed
- o Maximum range altitude
- o Maximum endurance speed
- o Maximum endurance altitude
- o Maximum endurance speed for a given altitude
- o Maximum endurance range for a given altitude
- o Estimated fuel remaining over destination
- o Estimated fuel remaining over alternate

(5) Descent/Approach/Missed Approach

- o Minimum fuel consumption descent
- o Speed for minimum fuel consumption descent
- o Climb-out speed
- o Climb-out EPR

(6) Landing/Missed Approach

- o Landing gross weight
- o Landing center of gravity (CG)
- o Approach speed for a given flap position
- o Threshold speed for a given flap position
- o Landing roll
- o Reverse power setting
- o Maximum braking speed
- o Touch and go takeoff EPR
- o Flap retraction speeds
- o Rotation speed

Display Formatting- The pilots interface with the flight management computer via the CDU, as described previously. Additional data on the page formats that have been developed for the FMC are provided below on the appropriate pages of CDU figures.

Two additional displays which are directly linked to the FMC are the flight and navigation displays. The flight displays provide the pilots with the attitude and flight parameters required to fly the aircraft and to maintain a specified route or flight profile. The FMC (when engaged) provides the display with the navigational parameters. This is relatively simple, since most of the data must be computed in the navigation module as part of the overall navigation task.

The map format on the navigation display presents a more complex formatting and data retrieval concept which, when coupled with the CDU formatting and control, is one of the most demanding tasks within the FMC.

Navigation and Communications Tuning Support - The communication support function provides autotuning for VOR/DME navigation aids and an alternate tuning method for all communication radios.

Navigational Aids - When the automatic tuning mode is selected, the navigation aids function retrieves selected station tuning information from the active flight plan data base and transmits this information to the selected navigation aid. This function is a part of the integrated communication/navigation (ICN) panel, which under normal operation is the master controller for all communication and short-range navigation systems.

Alternate Tuning Control - As opposed to the ICN panel, an alternate tuning capability is provided to allow all communication functions to be activated from the FMC CDUs. The CDU communication control pages are formatted to duplicate all functions provided by the ICN panel.

Air Traffic Control (ATC) System - Because the ATC systems (including Mode-S transponder, T-CAS, CDTI, CDWI, ETIS and ACARS) are described in a later section, the specific functions of each system are not presented here. The interface between the FMC and the ATC systems provides communication facilities for receiving and transmitting messages via the FMC CDUs, and the keyboards to the various ground data link control devices.

System Test and Monitoring - This function is separated into three main categories:

(1) CDU pages and touch panel routines to provide monitoring and activation of the electrical power controllers

(2) Display of malfunctions detected by the advisory, caution and warning system

(3) Preflight test functions and recording of selected parameters

These functions will be developed later in the design phase, after more detailed design of the systems has occurred.

Voice Command and Response - The FMC interfaces with the voice command and response systems by providing parameters for voice output alerts when specific values have been selected. The values are discussed in the section dealing with each system. The systems are: barometric altitude, radar altitude, airspeed, T-CAS commands, windshear, ground proximity, and unsafe landing gear. Other voice outputs, selectable by the pilots, include readout of Mode-S transponder, ACARS, and ACAWS messages and TOLD information, and the echo of voiced entries.

Voice input or control functions are: call-up of formats on front panel displays, comm/nav tuning and frequency entry, operating rain removal systems and landing lights, call-up of CDU pages, and entering navigation waypoints.

CDU Page Formats - Figure 75 provides examples of the formats for the various CDU pages along with an abbreviated explanation of the information contained on each page.

INDEX TO THE ACFS CDU PAGE FORMATS

1 DESCRIPTION OF CDU DISPLAY
2 SAMPLE OF PAGE FORMAT
3 FLIGHT DATA CURRENCY
4 PREFLIGHT
5 IRS CONTROL AND STATUS
6 ----------------------------------
7 WEIGHT AND BALANCE
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18 ----------------------------------
19 ----------------------------------
20 PREFLIGHT PLANNING 1
21 PREFLIGHT PLANNING 2
22 FUEL PLANNING
23 NON-STANDARD FUEL
24 FLIGHT PLAN 1/4
25 FLIGHT PLAN 2/4
26 FLIGHT PLAN 3/4
27 FLIGHT PLAN 4/4
28 FLIGHT PLAN FUEL
29 PROGRESS
30 PRESENT SITUATION
31 INS POSITION COMPARE
32 INS FIX DATA COMPARE
33 HOLD
34 ATC MESSAGE
35 WAYPOINT DATA
36 MLS APPROACH SELECTION
37 ACARS MESSAGE FROM
38 ACARS MESSAGE TO
39 CIRCUIT BREAKERS 9/35
40 CIRCUIT BREAKERS 15/35
41 JEPP
42 COMM/NAV
43 HF SELCAL
44 TEST
45 ----------------------------------
46 ----------------------------------
47 ----------------------------------
48 ----------------------------------
49 ----------------------------------
50 PM INDEX
51 PM INDEX - CLIMB MODES
52 PM INDEX - CRUISE MODES
53 PM INDEX - DESCENT MODES
54 PM CLIMB - ECONOMY
55 PM CLIMB - CONSTANT SPEED
56 PM CLIMB - BEST ANGLE
57 PM CLIMB - MAX RATE
58 PM CLIMB - ENGINE OUT
59 PM CRUISE - ECONOMY
60 PM CRUISE - CONSTANT SPEED
61 PM CRUISE - MAX ENDURANCE
62 PM CRUISE - ENG OUT MAX RANGE
63 PM CRUISE - ENG OUT MAX ENDR
64 PM DESCENT - ECONOMY
65 PM DESCENT - CONSTANT SPEED
66 VERTICAL NAV - CLB/CRS/DES/APPR
67 ----------------------------------
68 PM ABBREV TRIP PLAN
69 PM WIND TRADE
70 PM FLIGHT LEVEL
71 VERT NAV CLB/CRS/DES/APPR
72 VERTICAL NAV - HOLD
73 TIME NAV - INDEX
74 TIME NAV - HOLD
75 ----------------------------------
76 ----------------------------------
77 ----------------------------------
78 ----------------------------------
79 ----------------------------------
80 TOLD INDEX
81 TOLD - TAKEOFF PLANNING 1/1
82 TOLD - TAKEOFF PLANNING 2/2
83 TOLD - TAKEOFF 1/1
84 TOLD - LANDING PLANNING 1/1
85 TOLD - LANDING 1/1
86 TOLD - LANDING ENG OUT 1/1
87 ----------------------------------
88 ----------------------------------
89 ----------------------------------
90 ----------------------------------

Figure 75. CDU Page Formats, (Sheet 1 of 63)

```
                                  CDU 1
----------------------------------------
THIS CDU PANEL IS A UNIQUE INTERACTIVE
PERIPHERAL INTERGRATING THE TECHNOLOGIES
OF ALPHANUMERIC DC PLASMA DISPLAY WITH
TOUCH PANEL SWITCHES.
A TOTAL OF 12 LINES OF 40 CHARACTERS
EACH CAN BE DISPLAYED. 11 LINES ARE USED
FOR DATA DISPLAY,THE 12TH LINE IS USED
FOR VERIFICATION OF DATA ENTERED VIA THE
KEYBOARD BEFORE ENTRY TO THE APPROPRIATE
LINE BY A TOUCH SWITCH INDICATED BY A
SYMBOL <> .
----------------------------------------
```

```
                                  CDU 2
----------------------------------------
1---------------------------------------
2---------------------------------------
3---------------------------------------
4---------------------------------------
5---------------------------------------
6---------------------------------------
7---------------------------------------
8---------------------------------------
9---------------------------------------
10--------------------------------------
11--------------------------------------
----------------------------------------
```

Figure 75. CDU Page Formats, (Sheet 2 of 63)

```
------------------------------------------------------------
           FLIGHT DATA CURRENCY

OPERATIONAL SOFTWARE                OS634 3-16-87
NAVIGATION DATA BASE                ND234 1-21-90
A/C PERFORMANCE DATA                PD234 1-21-90
CHECKLIST                           CL612 5-20-89
------------------------------------------------------------
WEIGHT & BALANCE G/W 219364              CLEAR <>
TOLD ATL RWY 09 TEMP +10                 CLEAR <>
INS POS 33 37'44"N  84 26'06"W           CLEAR <>
ROUTE 72 KATL-KSFO                       CLEAR <>


------------------------------------------------------------
```

3. <u>FLIGHT DATA CURRENCY.</u> THIS PAGE PROVIDES A LISTING OF SOFTWARE FILES IN THE COMPUTER. THE PILOTS REVIEW THE DATES OF EACH FILE FOR CURRENCY. THIS PAGE IS AUTOMATICALLY DISPLAYED WHEN POWER IS FIRST APPLIED TO THE CDU, OR IT MAY BE SELECTED FROM THE <u>INDEX</u> PAGE.

   LINES 8-11 - PRESSING THE <> ON THE APPROPRIATE LINE CLEARS THE WEIGHT & BALANCE, TOLD PLANNING, INS POSITION, AND FLIGHT PLAN.

Figure 75. CDU Page Formats, (Sheet 3 of 63)

CDU 4

PREFLIGHT

ROUTE 72 KATL–KSFO 12–15–90 1530 GMT

MODIFIED BY CREW 12–15–90 1715 GMT

IDENT	GATE #	ROUTE
<> KATL	23A <>	72 <>

LAT	LONG
<> 33 37′44"N	84 26′06"W <>

HEADING SELECT MAG/TRUE

<> MAG

---

4. PREFLIGHT. THIS PAGE IS USED TO DETERMINE CURRENCY OF FLIGHT PLAN IN THE COMPUTER AND TO PREPARE THE IRS FOR FLIGHT BY PUTTING IN THE PRESENT POSITION DATA, EITHER THRU THE SCRATCH PAD OR VOICE INPUT SYSTEM, AND CHECKING THE STATUS OF THE UNIT.

   LINE 2 - INDICATES THE CURRENT FLIGHT PLAN IN THE COMPUTER THAT WAS LOADED BY THE DATA LOADER. THE DATE AND TIME OF THE GENERATED PLAN IS ALSO SHOWN.

   LINE 3 - IF THE FLIGHT PLAN HAS BEEN MODIFIED THROUGH THE KEYBOARD BY THE CREW, A MESSAGE WILL BE DISPLAYED WITH THE TIME AND DATE.

   LINE 6 - ENTER PRESENT POSITION AS THE AIRFIELD IDENTIFIER AND PARKING SPOT NUMBER, IF APPROPRIATE. ENTER ROUTE IDENTIFIER, IF APPROPRIATE.

   LINE 8 - LAT/LONG. AUTOMATICALLY READS OUT IF LINE 6 HAS BEEN COMPLETED. IF NOT, ENTER LAT/LONG. AT THIS TIME, THIS POSITION WILL AGREE WITH PRESENT POSITION ON IRS POSITION COMPARE PAGE (CDU PAGE 31), WHEREAS LATER PRESENT POSITION WILL READ THE TRIPLE MIX POSITION.

   LINE 11 - PERMITS PILOT TO SELECT MAGNETIC OR TRUE FOR ALL MISSION COMPUTER/IRS HEADINGS. IT AUTOMATICALLY COMES ON TO THE MAGNETIC POSITION AND TRUE ONLY NEEDS TO BE SELECTED IF DESIRED. THIS PAGE CAN BE DISPLAYED BY PRESSING THE NEXT PAGE KEY FROM THE FLIGHT DATA CURRENCY PAGE OR SELECTED FROM THE INDEX PAGE.

Figure 75. CDU Page Formats, (Sheet 4 of 63)

```
                                              CDU 5
------------------------------------------------------
          IRS CONTROL AND STATUS                1/2

 IRS#1               IRS#2                 IRS#3

<> OFF                 OFF <>                  OFF <>
<> ALIGN             ALIGN <>                ALIGN <>
  -00:45             10:15                   11:01
<> NAV                 NAV <>                  NAV <>
BAT 00:00          BAT 00:00              BAT 00:00

<> DISCONNECT IRS

------------------------------------------------------
```

5. IRS CONTROL & STATUS. THIS PAGE IS USED TO CONTROL THE MODE AND ANNUNCIATE THE STATUS OF THE THREE INERTIAL REFERENCE SYSTEMS. THE PRESENT STATUS OF EACH SYSTEM (OFF, ALIGN OR NAV) IS HIGHLIGHTED.

LINES 5, 6, & 11 - A SYSTEM IS TURNED ON BY TOUCHING THE DIAMOND NEXT TO ALIGN OR NAV. TO TURN A SYSTEM OFF, THE DISCONNECT IRS SWITCH MUST BE ACTIVATED BEFORE TOUCHING THE OFF SWITCH. ONCE THE DISCONNECT IRS SWITCH IS TOUCHED, IT REMAINS ARMED FOR THREE SECONDS OR UNTIL ANY TOUCH SWITCH ON THE PAGE IS TOUCHED. EITHER OF THESE CONDITIONS WILL DISARM THE DISCONNECT SWITCH.

LINES 2 & 4 - IF A VALID PRESENT POSITION IS NOT AVAILABLE AND ANY SYSTEM HAS BEEN IN ALIGN FOR 90 SECONDS, THE MESSAGE "ENTER PRESENT POSITION" APPEARS ON LINE 2, IMMEDIATELY BELOW THE PAGE TITLE. IF A SYSTEM HAS NO COMPUTED DATA FOR ANY REASON, THE MESSAGE "FAIL" APPEARS ON LINE 4, IMMEDIATELY BELOW THE IDENTIFIER OF THE AFFECTED SYSTEM.

LINE 7 - THE TIME IN MINUTES AND SECONDS THAT EACH SYSTEM HAS BEEN IN ALIGN IS DISPLAYED UNDER THE ALIGN LEGEND.

LINE 8 - TO ENTER THE NAVIGATION MODE (TYPICALLY FROM ALIGN MODE) THE DIAMOND ADJACENT TO NAV IS TOUCHED. THE SYSTEM AUTOMATICALLY SWITCHES FROM ALIGN TO NAV WHEN THE AIRCRAFT PARKING BRAKE IS RELEASED.

LINE 9 - IF A SYSTEM IS OPERATING ON ITS INTERNAL BATTERY, THE LEGEND "BAT" IS HIGHLIGHTED AND THE TIME IN BATTERY OPERATION IS DISPLAYED IN MINUTES AND SECONDS.

Figure 75. CDU Page Formats, (Sheet 5 of 63)

CDU 7

WEIGHT AND BALANCE

LEFT	FUEL LBS	RIGHT
19000	TOTAL	19000
	38000	

<> OPERATING WEIGHT 121664 LBS

<> PAYLOAD WEIGHT 60000

TAKEOFF FUEL WEIGHT 37700

TAKEOFF GROSS WEIGHT 219364

M A C 25 % LIMIT 21-40%

---

7. WEIGHT AND BALANCE. THIS PAGE PROVIDES A SENSED READOUT OF FUEL QUANTITY AND DISTRIBUTION. THE INFORMATION IS USED FOR AUTOMATIC CALCULATION OF CENTER OF GRAVITY. THE FUEL QUANTITY PROVIDES CURRENT INFORMATION THROUGHOUT THE FLIGHT SO IT MAY BE USED AS A BACKUP FUEL QUANTITY INDICATING SYSTEM.

   LINES 6-7 - PROVIDE A DISPLAY OF AIRCRAFT WEIGHT AND PAYLOAD WEIGHT. BOTH CAN BE UPDATED BY THE CREW BEFORE TAKEOFF.

   LINE 8 - FUEL WEIGHT ALLOWANCE IS MADE FOR FUEL USED ON RAMP AND TAXI.

   LINES 9-11 - TAKEOFF GROSS WEIGHT CALCULATED FROM DATA ON THIS PAGE TOGETHER WITH PERCENT M.A.C.

Figure 75. CDU Page Formats, (Sheet 6 of 63)

CDU 20

PREFLT PLANNING KATL–KSFO MOD(*) 1/2

IDENT	MODE	ALT	IAS/M	WIND	TEMP	D
<>KATL	STEP		M.77	300/10	+1	<>
<>CHA	"		"	300/15	+3	<>
<>BNA	"		"	310/49	"	<>
<>FAM	"		"	310/100	+4	*<>
<>BUM	"		"	290/165	+7	<>
<>SLN	"		"	280/160	"	<>
<>HLC*	"		"	270/145	"	*<>
<>GLD	"		"	280/140	+6	<>
<>IOC	"		"	260/148	+5	*<>

20, 21. PREFLIGHT PLANNING 1/2 THROUGH 2/2. THESE PAGES ARE USED TO ENTER FLIGHT PLANNING INFORMATION MANUALLY OR TO DISPLAY THE INFORMATION IF IT HAS BEEN ENTERED THROUGH THE AUTOMATIC DATA LOADING SYSTEM.

LINE 2 - DISPLAYS TITLES OF COLUMNS OF INFORMATION CONTAINED ON LINES 3 THROUGH 9, 11, IDENTIFICATION OF WAYPOINTS, PERFORMANCE MODE (IF CONSTANT ALTITUDE, ALTITUDE APPEARS) INDICATED AIRSPEED OR MACH, WIND DIRECTION AND VELOCITY AND TEMPERATURE DEVIATION FROM STANDARD.

LINES 3 THROUGH 9, 11 - FLIGHT PLANNING INFORMATION IS ENTERED VIA THE AUTOMATIC DATA LOADER OR MANUALLY AS APPROPRIATE. WAYPOINTS MAY BE ENTERED AS 2, 3, 4, OR 5 LETTER IDENTIFIERS OF POINTS HELD IN MEMORY. IF THE FLIGHT PLANNING DATA HAS BEEN ENTERED BY THE AUTOMATIC LOADING SYSTEM AND IS MODIFIED BY THE PILOTS, I.E., ANOTHER WAYPOINT OR WIND DATA, AN * SYMBOL WILL BE DISPLAYED TO INDICATE THAT A CHANGE HAS BEEN MADE, ALSO A MOD (*) SYMBOL WILL BE DISPLAYED IN THE TITLE LINE.

Figure 75. CDU Page Formats, (Sheet 7 of 63)

CDU 21

```
PREFLT PLANNING KATL-KSFO               2/2
 IDENT   MODE  ALT     IAS/M  WIND      TEMP D
<>OAL    STEP          M.77   250/100  +3   <>
<>MOD      "             "    230/78    0   <>
<>KSFO     "             "    240/100  +2   <>
<>KLAX                 M.7    350/900   "   <>
<>------------------ END-------------------<>
<>                                         <>
<>                                         <>
<>                                         <>
<>                                         <>
```

Figure 75. CDU Page Formats, (Sheet 8 of 63)

```
FUEL PLANNING
DESTINATION                  WF
KSFO                       -126
ALTERNATE                    WF
KLAX                        -56

FUEL ETE REQUIRED    31200 LBS
RESERVE  REQUIRED     6200
FUEL DELTA             300
ENDURANCE             7+56
<> PRESS FOR NON-STANDARD FUEL
```

---

22. FUEL PLANNING. INFORMATION ON THIS PAGE IS AUTOMATICALLY CALCULATED FROM FLIGHT PLAN AND PERFORMANCE INFORMATION PREVIOUSLY ENTERED. IT IS DISPLAYED TO SHOW FUEL QUANTITY REQUIREMENTS.

LINE 1 - TITLE LINE.

LINE 3 - DESTINATION AIRFIELD AND EXPECTED WIND FACTOR FOR THE FLIGHT.

LINE 5 - ALTERNATE AIRFIELD AND EXPECTED WIND FACTOR FROM DESTINATION TO ALTERNATE.

LINES 7-8 - THE TOTAL FUEL, IN POUNDS, TO DESTINATION VIA FLIGHT PLAN, AND SELECTED PERFORMANCE MODES ARE CALCULATED AND DISPLAYED, AS WELL AS THE AMOUNT OF FUEL REQUIRED TO MEET STANDARD RESERVE REQUIREMENTS OF 10% OF ENROUTE PLUS 45 MINUTES HOLDING PLUS 15 MINUTES FOR APPROACH AND LANDING FUEL TO THE DESIGNATED ALTERNATE.

LINES 9-10 - THE DIFFERENCE (DELTA) BETWEEN TOTAL FUEL REQUIRED INCLUDING STANDARD RESERVE, ETE REQ + RES REQ, AND TOTAL FUEL ONBOARD IS DISPLAYED AS WELL AS THE FUEL ENDURANCE, IN HOURS AND MINUTES, TO DRY TANKS IF THE AIRCRAFT IS OPERATED VIA FLIGHT PLAN AND PLANNED PERFORMANCE MODES.

LINE 11 - IF OTHER THAN STANDARD ENROUTE FUEL AND FUEL RESERVES ARE REQUIRED, PRESSING THIS LINE KEY DISPLAYS THE NON-STANDARD FUEL PAGE.

THIS PAGE IS DISPLAYED BY PRESSING THE NEXT PAGE KEY FROM THE PREFLT PLANNING PAGE OR FROM THE INDEX PAGE.

Figure 75. CDU Page Formats, (Sheet 9 of 63)

NON STANDARD FUEL

MISSED APPROACH AT DESTINATION

<> LBS

ADDITIONAL LANDINGS

<> # OF LANDINGS LBS

FUEL ETE REQUIRED

RESERVE REQUIRED

FUEL DELTA

ENDURANCE

TOTAL NON STANDARD FUEL LBS

---

23. NON STANDARD FUEL. THIS PAGE FORMAT IS DISPLAYED IF THE DIAMOND ON LINE KEY 11 (PRESS FOR NON-STANDARD FUEL) ON THE PREVIOUS FUEL PLANNING PAGE IS SELECTED. ADDITIONAL FUEL REQUIREMENTS, OVER AND ABOVE STANDARD, ARE ENTERED ON LINES 3 AND 5, AS APPROPRIATE.

    LINE 3 - PRESSING THIS LINE KEY WILL INCREASE REQUIRED FUEL BY THE AMOUNT NECESSARY TO MAKE A MISSED APPROACH AND AN ADDITIONAL INSTRUMENT APPROACH. THE PREDETERMINED AMOUNT OF FUEL WILL BE AUTOMATICALLY DISPLAYED.

    LINE 5 - THE NUMBER OF ADDITIONAL (PRACTICE) LANDINGS THAT ARE PLANNED IS ENTERED. THE PREDETERMINED AMOUNT OF FUEL REQUIRED FOR THAT NUMBER OF LANDINGS IS AUTOMATICALLY DISPLAYED AND ADDED TO THE REQUIRED FUEL.

    LINE 7-8 - THE TOTAL FUEL REQUIRED, IN POUNDS TO DESTINATION VIA FLIGHT PLAN AND SELECTED PERFORMANCE MODES IS CALCULATED AND DISPLAYED, AS WELL AS THE AMOUNT OF FUEL REQUIRED TO MEET ALL STANDARD AND NON STANDARD RESERVE REQUIREMENTS.

    LINE 9-10 - THE DIFFERENCE (DELTA) BETWEEN TOTAL FUEL REQUIRED INCLUDING NON STANDARD RESERVE REQUIREMENTS ETE REQ + RES REQ AND THE TOTAL FUEL ON BOARD IS DISPLAYED AS WELL AS THE TOTAL FUEL ENDURANCE, IN HOURS AND MINUTES, TO DRY TANKS IF THE AIRCRAFT IS OPERATED VIA FLIGHT PLAN AND PERFORMANCE MODES.

    LINE 11 - THE TOTAL NON-STANDARD FUEL REQUIRED (SUM OF LINES 3 AND 5) IS DISPLAYED ON THIS LINE AND BECOMES PART OF THE TOTAL PLANNED FUEL DISPLAYED ON THE FLIGHT PLAN FUEL PAGE.

Figure 75. CDU Page Formats, (Sheet 10 of 63)

FLIGHT PLAN	KATL-KSFO R72					1/4
IDENT	MODE	CRS/DIST	ETE	TT		
	ALT	TAS/MACH			FUEL	TFB
KATL						
CHA	STEP	336/86	+21	+21		
	FL310	300M.5			1.9	1.9
L-OFF	FL350		+03	+24		
					0.3	2.2
BNA	STEP	313/102	+20	+44		
	FL350	453M.77			2.0	4.2

24-27. FLIGHT PLAN: THESE PAGES DISPLAY A SYNOPSIS OF FLIGHT PLAN INFORMATION TO THE CREW. DATA ARE CONSOLIDATED FROM PREVIOUS ENTRIES AND NO DATA ARE ENTERED ON THESE PAGES.

LINE 2/3 - TITLES OF COLUMNS OF INFORMATION ON REMAINING LINES OF THE FLIGHT PLAN ARE DISPLAYED.

LINE 4 - DISPLAYS DEPARTURE AIRFIELD IDENTIFIER.

LINE 5 THROUGH END OF PLAN - INFORMATION ON TOP PORTION OF THE LINE CONSISTS OF THE WAYPOINT (IDENTIFIED AS 2, 3, 4 OR 5 LETTERS, DESIRED COURSE, DISTANCE BETWEEN WAYPOINTS, TIME BETWEEN WAYPOINTS, AND TOTAL (CUMULATIVE) FLIGHT TIME FROM DEPARTURE. INFORMATION ON THE BOTTOM PORTION OF THE LINE CONSISTS OF ALTITUDE/FLIGHT LEVEL, TRUE AIRSPEED AND MACH, PLANNED FUEL TO BE USED BETWEEN WAYPOINTS, AND TOTAL (CUMULATIVE) PLANNED FUEL FROM DEPARTURE. THE DESTINATION, PREVIOUSLY IDENTIFIED ON THE PREFLIGHT PLANNING PAGE IS RECOGNIZED AS THE END OF THE FLIGHT PLAN UNLESS AN ALTERNATE AIRFIELD HAS BEEN IDENTIFIED ON THE SAME PAGE. IN EVENT OF THE LATTER, THE FLIGHT PLAN INFORMATION TO THE ALTERNATE IS DISPLAYED.

LAST LINE - PRESSING THIS KEY (FLIGHT PLAN REVIEW) PROVIDES A MEANS FOR THE PILOTS TO REVIEW THE FLIGHT PLAN IN A MAP FORMAT ON THE PILOT'S OR CO-PILOT'S NAV DISPLAY. THE FLIGHT PLAN WILL BE CONTINUOUSLY SLEWED AS LONG AS THE KEY IS DEPRESSED. THE MAP ON THE NAV DISPLAY WILL AUTOMATICALLY RETURN TO THE PRESENT POSITION WHEN A DIFFERENT CDU PAGE IS SELECTED. THE SLEW FEATURE IS INHIBITED IN FLIGHT FOR THE NAV SYSTEM BEING USED FOR AIRCRAFT NAV GUIDANCE.

Figure 75. CDU Page Formats, (Sheet 11 of 63)

CDU 25

```
-----------------------------------------------
FLIGHT PLAN KATL-KSFO R72               2/4
IDENT  MODE   CRS/DIST ETE   TT
       ALT    TAS/MACH               FUEL  TFB
FAM    STEP   299/194   +43 1+27
       FL350  450M.77                4.1   8.3
BUM    STEP   280/205   +41 2+08
       FL350  448M.77                3.0  11.3
SLN    STEP   279/152   +32 2+40
       FL350  448M.77                2.4  13.7
HLC    STEP   273/123   +25 3+05
       FL350  447M.77                1.9  15.6
-----------------------------------------------
```

CDU 26

```
-----------------------------------------------
FLIGHT PLAN KATL-KSFO R72               3/4
IDENT  MODE   CRS/DIST ETE   TT
       ALT    TAS/MACH               FUEL  TFB
GLD    STEP   267/69    +14 3+19
       FL390  447M.77                1.1  16.7
IOC    STEP   261/123   +24 3+43
       FL390  445M.77                1.8  18.5
OAL    STEP   254/634  2+08 5+51
       FL390  444M.77                9.9  28.4
DESCENT                 +18 6+09
                                     1.4  29.8
-----------------------------------------------
```

Figure 75. CDU Page Formats, (Sheet 12 of 63)

```
FLIGHT PLAN KATL-KSFO R72                      4/4
IDENT  MODE   CRS/DIST ETE   TT
       ALT    TAS/MACH                  FUEL  TFB
MOD    STEP   246/153  +08  6+17
       FL390  443M.77                   0.6  30.4
KSFO   STEP   254/68   +11  6+28
       FL390  443M.77                   0.8  31.2
KLAX   MXRNG  120/294  +36  7+04
       FL310  300M.7                    2.7  33.9

<> FLIGHT PLAN REVIEW
```

Figure 75. CDU Page Formats, (Sheet 13 of 63)

FLIGHT PLAN FUEL KATL-KSFO R72

IDENT	ETE	TT	FUEL	TFB
KSFO		6+28		31.2
KLAX	+36	7+04	2.7	33.9
HOLD	+45	7+49	3.0	36.9
APP & LANDING		FUEL	0.5	37.4
IDENTIFIED EXTRA		FUEL	0.0	37.4

---

28. FLIGHT PLAN FUEL. THIS PAGE PROVIDES A SYNOPSIS OF ALL FUEL QUANTITY PLANNING INFORMATION.

LINE 2 - DISPLAYS TITLES OF COLUMNS OF INFORMATION ON LINES BELOW, I.E., IDENTIFICATION OF LOCATION OR REASON FOR DETERMINING FUEL REQUIREMENT, ESTIMATED TIME ENROUTE/ELAPSED AS APPROPRIATE (ETE), FUEL USED ON THIS SEGMENT (FUEL), TOTAL TIME (CUMULATIVE) (TT), AND TOTAL FUEL BURNED (CUMULATIVE) (TFB).

LINE 3 - DISPLAYS IDENTIFICATION OF DESTINATION AIRFIELD AND TT AND TFB TO DESTINATION.

LINE 4 - DISPLAYS IDENTIFICATION OF ALTERNATE AIRFIELD AS WELL AS TIME AND FUEL INFORMATION FOR THE ALTERNATE.

LINE 5 - DISPLAYS INFORMATION ON STANDARD HOLDING (TYPICALLY 45 MINUTES).

LINE 6-7 - DISPLAYS INFORMATION ON APPROACH AND LANDING FUEL AND ANY EXTRA FUEL THAT HAS BEEN IDENTIFIED. LAST FIGURE SHOWS TOTAL FUEL REQUIRED AT DEPARTURE AIRFIELD TO MEET ALL REQUIREMENTS.

THIS PAGE CAN BE DISPLAYED BY PRESSING THE NEXT PAGE KEY FROM THE FLIGHT PLAN PAGE OR FROM THE INDEX PAGE.

Figure 75. CDU Page Formats, (Sheet 14 of 63)

```
   PROGRESS      GMT  1102:17        OVERFLY <>
          IDENT          ETA            DELTA
<> TO     SLN
   282°   150  NM      1203:02          +2:10
<> NEXT   HLC
   284°   273  NM      1259:19          +2:10
   DEST   KSFO
         1323  NM      1623:20          +2:10
FUEL  REQ  19.9   RES   6.2   DELTA  0.6
OP  ALT  FL  374  IAS  255M.77  OAT  -49  TD  +7
<>
```

29. PROGRESS. THIS PAGE DISPLAYS INFORMATION WHICH THE PILOT WILL FIND MOST USEFUL TO MONITOR HIS INFLIGHT PROGRESS. THE PAGE IS ALSO EXTREMELY FUNCTIONAL TO PERFORM SPECIAL FUNCTIONS SUCH AS DIRECT TO, OVERFLYING WAYPOINTS, AND DISPLAYING POSITIVE INFORMATION FROM ANY WAYPOINT IN MEMORY.

LINE 3 - DISPLAYS THE TO WAYPOINT IN THE FLIGHT PLAN, THE COURSE, DISTANCE AND ESTIMATED TIME OF ARRIVAL (ETA) AT THAT WAYPOINT, AND THE TIME DEVIATION, IN MINUTES, OF THE ETA FROM THE ORIGINAL FLIGHT PLAN. THIS INFORMATION REMAINS CURRENT AS THE FLIGHT PROGRESSES. IF IT IS DESIRED TO PROCEED FROM PRESENT POSITION DIRECT TO, A LOCATION OTHER THAN THE TO WAYPOINT, THE DIRECT TO POINT IS TYPED ON THE SCRATCH PAD AS AN ALPHA IDENTIFIER, LAT/LONG OR BEARING/ DISTANCE AND ENTERED IN THE TOP (TO) LINE. THE NEW COURSE, DISTANCE AND ETA (BASED UPON CURRENT WINDS) ARE CALCULATED AND DISPLAYED. THE TIME DEVIATION IS NOT SHOWN. AIRCRAFT STEERING WILL IMMEDIATELY REFLECT THE CHANGE OF COURSE. THE OVERFLY KEY INHIBITS THE AUTOMATIC UPDATE OF THE NAVIGATION SYSTEM. THIS PERMITS THE AIRCRAFT TO TRACK OUTBOUND FROM THE TO WAYPOINT RATHER THAN AUTOMATICALLY UPDATING THE TRACK INBOUND TO THE NEXT WAYPOINT. DESELECTING THE OVERFLY KEY PERMITS THE AUTOMATIC UPDATE.

LINE 5 - DISPLAYS THE NEXT WAYPOINT (NEXT SEQUENTIALLY FOLLOWS TO) IN THE FLIGHT PLAN, THE COURSE DISTANCE AND ETA AT THAT WAYPOINT, AND THE PRESENT TIME DEVIATION FROM PLANNED FLIGHT PLAN. THIS WAYPOINT MAY BE CHANGED BY TYPING A NEW IDENTIFIER ON THE SCRATCH PAD AND ENTERING IT WITH THE LINE KEY. THE NEW COURSE AND DISTANCE WILL BE CALCULATED AND DISPLAYED BUT THE ETA AND TIME DELTA BLOCK WILL NOT BE SHOWN, INDICATING THAT THE PILOT MUST INSERT THE INFORMATION IN THE PROPER SEQUENCE ON THE PREFLIGHT PLANNING PAGE ALONG WITH WIND AND TEMPERATURE DEVIATION FOR CORRECT CALCULATIONS AND DISPLAY.

Figure 75. CDU Page Formats, (Sheet 15 of 63)

29. PROGRESS (CONTINUED)

LINE 7 - THE IDENTIFICATION OF THE FLIGHT PLAN DESTINATION, DISTANCE REMAINING AND ETA TO DESTINATION, AND THE PRESENT TIME DEVIATION FROM PLANNED FLIGHT PLAN ARE DISPLAYED. CHANGES TO THIS LINE CANNOT BE ENTERED.

LINE 9 - CURRENT INFORMATION ON FUEL QUANTITY REQUIRED TO REACH DESTINATION, THE FUEL DELTA BETWEEN FLIGHT PLANNED FUEL AND FUEL BURNED TO THIS TIME, THE FUEL RESERVE REQUIRED.

LINE 10 - THE OPTIMUM CRUISING ALTITUDE FOR THE PRESENT AIRCRAFT WEIGHT, AS WELL AS THE CALCULATED INDICATED AIRSPEED, MACH, TOTAL OUTSIDE AIR TEMPERATURE, AND TEMPERATURE DEVIATION FROM STANDARD ARE DISPLAYED.

LINE 11 - THIS LINE MAY BE USED TO OBTAIN DATA/CALCULATIONS FROM THE MISSION COMPUTER. THE DESIRED INFORMATION IS IDENTIFIED ON THE SCRATCH PAD AND IS DISPLAYED ON THIS LINE. FOR EXAMPLE, A 2, 3, 4 OR 5 LETTER IDENTIFIER OF A WAYPOINT IN MEMORY OR LAT/LONG OR BEARING DISTANCE OF A POINT IS TYPED ON THE SCRATCH PAD AND THE LINE KEY ADJACENT LINE 11 IS PRESSED. THE IDENTIFIER, COURSE, DISTANCE AND TIME ENROUTE (BASED UPON PRESENT TRUE AIRSPEED AND WINDS) FROM PRESENT POSITION DIRECT TO THAT LOCATION ARE DISPLAYED.

THIS PAGE CAN BE DISPLAYED BY PRESSING THE PROG SPECIAL FUNCTION KEY OR THE NEXT PAGE KEY FROM FLIGHT PLAN FUEL PAGE.

Figure 75. CDU Page Formats, (Sheet 16 of 63)

PRESENT SITUATION		GMT 1102:15
LAT		LONG
38 17′ 12″N		94 32′ 36″W
WIND	DRIFT	COURSE
292/146	1° L	281
G/S	TAS	TK ERROR
299	448	1° R
AVG WF		XTK ERROR
-100		0.5 L NM
OAT	TEMP D	A/C GROSS WT
-49	+ 7	208364 LBS

30. PRESENT SITUATION. THIS PAGE DISPLAYS A SYNOPSIS OF THE PRESENT SITUATION OF THE AIRCRAFT.

LINE 3 - PRESENT POSITION IS DISPLAYED IN LATITUDE/LONGITUDE.

LINE 5 - PRESENT WIND DIRECTION AND VELOCITY, DRIFT, AND COURSE ARE DISPLAYED.

LINE 7 - PRESENT AIRCRAFT G/S, TAS, AND TRACK ANGLE ERROR ARE DISPLAYED.

LINE 9 - AVERAGE WIND FACTOR FROM DEPARTURE TO PRESENT POSITION AND THE CROSSTRACK ERROR ARE SHOWN.

LINE 11 - PRESENT OAT, TEMP D AND AIRCRAFT GROSS WEIGHT ARE DISPLAYED.

THIS PAGE IS DISPLAYED BY PRESSING THE PRES SIT SPECIAL FUNCTION KEY OR THE NEXT PAGE KEY FROM THE PROGRESS PAGE.

Figure 75. CDU Page Formats, (Sheet 17 of 63)

IRS POSITION COMPARE

PRESENT POSITION 38 18'06"N 94 37'42"W

IRS #	RE	BRG	XTRACK	ATRACK
1	0.8	87	0.2 R	0.8 B
2	3.1	177	3.0 L	0.6 B
3	0.9	331	0.7 R	0.5 A

GROUND TRACK 279	NAV TIME 2+44
<> MODE TRIPLE MIX	FIX TIME 0+00
<> RNAV FIX	GPS FIX <>
<> MANUAL FIX	CLEAR FIXES <>

31. IRS POSITION COMPARE. THIS PAGE IS USED TO DISPLAY THE IRS PRESENT POSITION AND TO COMPARE THE RADIAL ERROR (RE), CROSS TRACK ERROR (XTRACK) AND ALONG TRACK ERROR (ATRACK) BETWEEN EACH IRS AND THE TRIPLE MIX POSITION. ADDITIONALLY, THE PAGE PROVIDES A MEANS OF PERFORMING SEVERAL FUNCTIONS, DESCRIBED BELOW.

    LINE 2 - DISPLAYS IRS PRESENT POSITION IN LAT/LONG. THIS IS THE TRIPLE MIX POSITION OR THE MEAN OF THE CLOSEST LAT/LONG POSITIONS FROM THE THREE IRS UNITS.

    LINE 4 - DISPLAYS THE RE, XTRACK, AND ATRACK DIFFERENCE BETWEEN THE TRIPLE MIX POSITION AND IRS 1 POSITION.

    LINES 5 & 6 - DISPLAYS THE SAME INFORMATION AS LINE 4 FOR IRS 2 AND 3.

    LINE 9 - PERMITS SELECTION OF PURE IRS MODE OR TRIPLE MIX MODE BY ALTERNATE PUSHES OF THE LEFT-HAND LINE KEY. IT ALSO DISPLAYS THE AMOUNT OF TIME SINCE THE IRS HAS BEEN PLACED INTO THE NAV MODE AND THE AMOUNT OF TIME SINCE THE LAST FIX WAS ACCOMPLISHED.

    LINE 10 - PERMITS SELECTION OF THE RNAV OR GPS MODE OF OPERATION. THE RNAV MODE ALLOWS THE IRS TO AUTOMATICALLY AND CONTINUOUSLY UPDATE FROM SHORT RANGE NAV AIDS. THE GPS MODE PROVIDES AUTOMATIC UPDATING FROM THE NAV STAR GLOBAL POSITIONING SYSTEM. IF THE RNAV FIX OR GPS FIX SWITCH IS TOUCHED, THE APPROPRIATE RNAV OR GPS POSITION INFORMATION WILL APPEAR ON CDU PAGE 32, LINE 8. THE PILOT MAY THEN ACCEPT OR REJECT THE FIX TO UPDATE THE IRS. THE LEGEND IS HIGHLIGHTED WHEN INSUFFICIENT INFORMATION IS AVAILABLE FOR FIXING, AS SHOWN BY RNAV IN THE EXAMPLE.

    LINE 11 - PERMITS SELECTION OF THE MANUAL FIX MODE OF OPERATION. THIS SELECTION CHANGES THE FORMAT TO THAT SHOWN ON THE CDU, PAGE 32, WHERE MANUAL FIXING IS ACCOMPLISHED. ADDITIONALLY, THIS LINE PERMITS THE PILOT TO CLEAR ALL FIXES THAT HAVE PREVIOUSLY BEEN ENTERED.

Figure 75. CDU Page Formats, (Sheet 18 of 63)

CDU 32

```
IRS FIX DATA COMPARE
PRESENT POSITION 38 18'06"N   94 37'42"W
IRS #     RE     BRG     XTRACK       ATRACK
    1     0.8     87     0.2 R        0.8 B
    2     3.1    177     3.0 L        0.6 B
    3     0.9    331     0.7 R        0.5 A
FIX DELTA FROM PRESENT POSITION
GPS       0.2    270     0.0          0.2 A
ENTER MANUAL FIX COORDINATES
<>
<> ACCEPT FIX                   REJECT FIX <>
```

32. IRS FIX DATA COMPARE. THE LOWER PORTION OF CDU PAGE 32 ILLUSTRATES THE FORMAT WHICH APPEARS WHEN THE GPS FIX KEY ON THE PREVIOUS PAGE (CDU PAGE 31) HAS BEEN PRESSED. IT PERMITS ACCOMPLISHMENT OF A GPS FIX FOR INERTIAL SYSTEM UPDATE. SIMILAR INFORMATION APPEARS IF RNAV FIX OR MANUAL FIX IS PRESSED.

LINES 1 TO 6 - SAME AS PREVIOUS PAGE (CDU PAGE 31).

LINE 8 - DISPLAYS THE DIFFERENCE IN RE, BRG, XTRACK AND ATRACK BETWEEN THE PRESENT POSITION OF THE FIX IDENTIFIED BY THE GPS AND THAT CALCULATED BY THE INERTIAL SYSTEM. SIMILAR COMPARISONS ARE MADE BY PRESSING THE RNAV FIX OR MANUAL FIX SWITCHES. THIS PERMITS THE PILOTS TO REVIEW THE INFORMATION FOR POSSIBLE ERROR/CORRECTNESS BEFORE DECIDING TO ACCEPT THE FIX OR REJECT IT.

LINE 9 - THE INSTRUCTION TO ENTER MANUAL FIX COORDINATES ONLY APPEARS IF THE MANUAL FIX KEY ON PAGE 31 HAS BEEN PRESSED.

LINE 10 - THE LATITUDE AND LONGITUDE OF A KNOWN LOCATION THAT IS TO BE USED FOR FIXING IS ENTERED ON THIS LINE FROM THE SCRATCH PAD OR THRU THE VOICE SYSTEM, WHEN A MANUAL FIX IS BEING ACCOMPLISHED.

LINE 11 - PRESSING THE ACCEPT FIX KEY ENTERS A FIX INTO THE MISSION COMPUTER AND BEGINS AN UPDATE OF THE NAV SYSTEM. PRESSING THE REJECT FIX KEY ERASES THE FIX INFORMATION SO THAT IT CANNOT BE ENTERED INTO THE COMPUTER.

THIS PAGE IS DISPLAYED BY PRESSING THE NEXT PAGE KEY FROM THE PRESENT SITUATION PAGE OR FROM THE INDEX PAGE.

Figure 75. CDU Page Formats, (Sheet 19 of 63)

CDU 33

```
                         HOLD
  INBOUND COURSE                          1.40 EPR
<>                                    IAS     250 <>
  TURN R-L
<> R                                  MACH .---   <>
  MILES
<> 5
 AT WAYPOINT                          FLIGHT LEVEL
                                           ----- <>
<>
 AT PRESENT POSITION
<>                                         SELECT <>
```

33. HOLD. THIS PAGE IS USED TO DEFINE HOLDING PATTERN PARAMETERS AND HOLDING POINT LOCATIONS. HOLDING PATTERNS ARE DEPICTED ON THE NAV DISPLAY MAP FORMAT AT THE APPROPRIATE HOLDING WAYPOINT.

LINE 3 - ENTER INBOUND HOLDING COURSE FOR THE HOLDING PATTERN. THE IAS FOR THE PERFORMANCE MODE WHICH HAS BEEN SELECTED IS SHOWN. THAT IAS CAN BE CHANGED WITH THIS LINE KEY.

LINE 5 - ENTER THE DIRECTION OF TURNS FOR THE HOLDING PATTERN. THE DIRECTION IS NORMALLY DEFAULTED TO R (RIGHT) FOR A STANDARD HOLDING PATTERN AND NEED ONLY BE CHANGED IF NECESSARY. HOLDING MACH CAN BE ENTERED, IF APPROPRIATE.

LINE 7 - ENTER THE LENGTH OF INBOUND HOLDING PATTERN LEG DESIRED. THIS DISTANCE IS NORMALLY DEFAULTED TO 5 MILES FOR A STANDARD HOLDING PATTERN AND NEED ONLY BE CHANGED IF NECESSARY.

LINE 9 - ENTER THE IDENTIFICATION OF THE HOLDING LOCATION. THIS CAN BE A WAYPOINT IN MEMORY, OR A WAYPOINT MAY BE DEFINED AS A LAT/LONG OR BEARING DISTANCE. THE FLIGHT LEVEL FOR HOLDING CAN BE ENTERED, IF APPROPRIATE.

LINE 11 - PRESS THE LEFT HAND LINE KEY IF HOLDING AT PRESENT POSITION IS DESIRED. PRESS THE SELECT LINE KEY IF HOLDING WITH THE CHOSEN PERFORMANCE MANAGEMENT MODE IS DESIRED.

THIS PAGE IS DISPLAYED BY PRESSING THE HOLD SPECIAL FUNCTION KEY OR THE NEXT PAGE KEY FROM THE STANDARD ROUTES PAGE.

Figure 75. CDU Page Formats, (Sheet 20 of 63)

ATC MESSAGE 2/3

AIR TRAFFIC ADVISORY. OCT 21 1319Z
CONFLICTING TRAFFIC OVER HLC. B747
FL350 J28 OKC TO DEN. EXPECT CLIMB
TO FL390 50 EAST HLC.

<> CLEAR <> PRINT RCVD <>

---

34. ATC MESSAGE. WHEN A MESSAGE IS DATA-LINKED TO THE AIRCRAFT VIA TRANSPONDER MODE S, AN ADVISORY WILL BE DISPLAYED ON ACAWS. THE MESSAGE MAY BE SEEN BY SELECTING THE ATC MESSAGE PAGE. THE MESSAGE CAN BE ACKNOWLEDGED TO THE SENDER BY PRESSING THE RCVD SWITCH, PRINTED IN HARD COPY ON THE FLIGHT STATION PRINTER BY PRESSING THE PRINT SWITCH, OR CLEARED FROM THE SCREEN BY PRESSING THE CLEAR SWITCH. WHEN TECHNOLOGY IS AVAILABLE, THE MESSAGE MAY ALSO BE VOICED TO THE PILOTS, UPON SELECTION, THROUGH THE VOICE OUTPUT SYSTEM.

Figure 75. CDU Page Formats, (Sheet 21 of 63)

WAYPOINT DATA

<> BUM BUTLER MEM MO

VORTAC

LAT LONG

38 16'20"N 94 29'17"W

CHAN 106

FREQ 115.9

BEARING/RANGE FROM PRESENT POSITION

300/548

<> RETURN

35. WAYPOINT DATA. THIS PAGE DISPLAYS INFORMATION ON ANY WAYPOINT OR AIRFIELD IN MEMORY OR PILOT DEFINED WAYPOINT. THE PAGE IS DISPLAYED TO THE PILOT BY PRESSING AN ADJACENT LINE KEY TO A WAYPOINT ON THE PREFLIGHT PLANNING PAGE (CDU PAGE 20), OR PROGRESS PAGE (CDU PAGE 29). ONCE THE PAGE HAS BEEN CALLED UP, A DIFFERENT WAYPOINT AND ITS ASSOCIATED INFORMATION MAY BE CALLED UP TYPING THE NEW IDENTIFIER IN THE SCRATCH PAD AND PRESSING THE TOP LINE KEY.

LINE 2 - DISPLAYS IDENTIFIER, NAME AND TYPE OF WAYPOINT

LINE 5 - DISPLAYS COORDINATES OF WAYPOINT IN LAT/LONG, IF THE WAYPOINT HAS BEEN IDENTIFIED IN OTHER VALUES (SUCH AS BEARING/DISTANCE), THOSE VALUES WILL ALSO BE DISPLAYED.

LINES 6-7 - DISPLAYS TACAN CHANNEL, VOR AND/OR ADF FREQUENCIES AS APPROPRIATE.

LINE 8 - DISPLAYS AIRFIELD INFORMATION, IF APPROPRIATE.

LINE 9 - DISPLAYS BEARING AND RANGE FROM THE AIRCRAFT'S PRESENT POSITION TO THE IDENTIFIED WAYPOINT.

LINE 10 - PRESSING THIS ADJACENT LINE KEY (RETURN) RECALLS THE PAGE THAT WAS BEING DISPLAYED IMMEDIATELY BEFORE THE WAYPOINT DATA PAGE.

Figure 75. CDU Page Formats, (Sheet 22 of 63)

MLS APPROACH SELECTION

<> AUTO ATL MLS 42 MANUAL <>

<> TO POSITION 38 18'06" N 135 37'42" W

<> RWY AZIMUTH 291 ALTITUDE 468 <>

<> MLS FIX 2 FROM TOUCHDOWN.

FROM TOUCHDOWN-----OR-----LAT/LONG

<> AZIMUTH 264 LAT 38 23'14" N <>

<> ELEVATION 6.1 LONG 123 45'18" W <>

<> DME 2.3 NM ALTITUDE 1500 FT <>

<> RADIUS OF TURN 7500 FT

<> REVIEW APPROACH

36. MLS APPROACH SELECTION. THIS PAGE IS USED TO TELL THE MLS COMPUTER EXACTLY WHICH APPROACH PATH WILL BE FLOWN. THIS SAME INFORMATION IS USED BY THE GPS COMPUTER WHEN IT FUNCTIONS AS AN INDEPENDENT LANDING MONITOR.

LINE 2 - THE MAJORITY OF THE TIME MLS APPROACHES WILL BE STORED WITH THE JEPPESEN INFORMATION. TO SELECT ONE OF THESE APPROACHES, THE CREW MERELY TYPES THE APPROACH IDENTIFIER (E.G., ATL MLS 42) AND TOUCHES THE "AUTO" SWITCH. IF THE DESIRED APPROACH IS NOT STORED IT MAY BE ENTERED MANUALLY BY TOUCHING "MANUAL" AND THEN COMPLETING LINES 3 THROUGH 10.

LINES 3 & 4 - THESE LINES DESCRIBE THE TOUCHDOWN POINT ON THE RUNWAY FOR USE IN MANUALLY ENTERING THE MLS APPROACH.

LINE 5 - THIS LINE SELECTS THE PARTICULAR MLS FIX TO BE DEFINED. IN THIS CASE THE SECOND FIX FROM THE TOUCHDOWN POINT HAS BEEN SELECTED. NOTE: THESE FIXES ARE NUMBERED BACKWARDS FROM THE TOUCHDOWN POINT. ONCE THE ENTIRE APPROACH HAS BEEN DESCRIBED, THESE POINTS ARE AUTOMATICALLY ASSIGNED WAYPOINT NUMBERS AND ARE ADDED TO THE EXISTING FLIGHT PLAN.

Figure 75. CDU Page Formats, (Sheet 23 of 63)

36. <u>MLS APPROACH SELECTION</u> (CONTINUED)

LINES 6 THRU 9 - THE PILOT MAY DEFINE EACH FIX AS EITHER LAT/LONG/ ALT OR AS AN AZIMUTH/ELEVATION/DME FROM THE TOUCHDOWN POINT. WHEN ONE SET OF COORDINATES HAS BEEN ENTERED THE COMPUTER WILL AUTOMATICALLY COMPLETE THE OTHER SET.

LINE 10 - AFTER THE SELECTED FIX, IF A TURN IS REQUIRED, THE PILOT MAY SPECIFY A RADIUS OF TURN FOUND ON THE APPROACH CHART.

LINE 11 - AS A MEANS OF CHECKING THE APPROACH (EITHER AUTO OR MANUAL) THE CREW CAN TOUCH THIS SWITCH AND THE ENTIRE MLS APPROACH PLAN VIEW WILL BE DISPLAYED ON WHICHEVER NAV DISPLAY IS NOT CURRENTLY COUPLED TO THE AUTOPILOT. THIS DISPLAY WILL REMAIN AS LONG AS THE SWITCH IS HELD.

Figure 75. CDU Page Formats, (Sheet 24 of 63)

ACARS MESSAGE 1/1

FROM:ATL00DL. OCT 21 1423Z

EXPECT EQUIPMENT CHANGE IN DENVER.

PARK AT GATE 23.

FLT 618 WILL CONTINUE TO LAX USING SHIP

NO.243 AT GATE 25.

<> CLEAR <> PRINT RCVD <>

---

37. ACARS MESSAGE. WHEN A MESSAGE IS DATA-LINKED TO THE AIRCRAFT VIA THE AIRINC COMMUNICATIONS ADDRESSING AND REPORTING SYSTEM, AN ADVISORY WILL BE DISPLAYED ON ACAWS. THE MESSAGE MAY BE SEEN BY SELECTING THE ACARS MESSAGE PAGE. THE MESSAGE CAN BE ACKNOWLEDGED TO THE SENDER BY PRESSING THE RCVD SWITCH, PRINTED IN HARD COPY ON THE FLIGHT STATION PRINTER BY PRESSING THE PRINT SWITCH, OR CLEARED FROM THE SCREEN BY PRESSING THE CLEAR SWITCH. THE MESSAGE MAY ALSO BE VOICED TO THE PILOT, THROUGH THE VOICE OUTPUT SYSTEM, UPON HIS SELECTION.

Figure 75. CDU Page Formats, (Sheet 25 of 63)

CDU 38

ACARS MESSAGE 1/1

TO: ATLARTCC. OCT 3 0934Z <>

REQUEST FL290 AFTER BRAVO <>

<>

<>

<>

<>

<>

<>

<>

<> CLEAR <> PRINT SEND <>

38. ACARS MESSAGE. THIS PAGE IS SELECTED WHEN THE CREW WISHES TO TRANSMIT A MESSAGE VIA THE AIRINC COMMUNICATIONS ADDRESSING AND REPORTING SYSTEM. WHEN TYPING THE MESSAGE, THE WORDS "TO" AND THE ADDRESSEE MUST BE TRANSFERRED FROM THE SCRATCH PAD TO LINE 2 BY TOUCHING THE SWITCH ON THAT LINE. AT THAT TIME THE DATE TIME GROUP AND THE SEND SWITCH AUTOMATICALLY APPEAR.

WHEN TYPING THE BODY OF THE MESSAGE, THE SYSTEM AUTOMATICALLY EDITS THE TEXT TO BREAK IT BEFORE THE WORD WHICH WOULD CAUSE THE LINE TO BE TOO LONG FOR THE SPACE PROVIDED. THE TEXT IS AUTOMATICALLY TRANSFERRED FROM THE SCRATCH PAD TO LINES 3 THRU 10 IN SEQUENCE AS THE TEXT IS TYPED. THAT IS, THEY DO NOT HAVE TO BE TRANSFERRED WITH THE LINE SWITCHES.

A CHANGE TO ANY LINE CAN BE MADE BY RETYPING THE INFORMATION INTO THE SCRATCH PAD AND TOUCHING THE SWITCH ON THE LINE TO BE CHANGED. THE INFORMATION ON THAT LINE IS REPLACED WITH THAT FROM THE SCRATCH PAD.

THE MESSAGE CAN BE TRANSMITTED TO THE ADDRESSEE BY PRESSING THE SEND SWITCH, PRINTED OUT IN HARD COPY ON THE AIRCRAFT PRINTER BY PRESSING THE PRINT SWITCH OR CLEARED FROM THE SCREEN BY PRESSING THE CLEAR SWITCH.

THE TEXT MAY ALSO BE ENTERED BY A VOICE INPUT SYSTEM.

Figure 75. CDU Page Formats, (Sheet 26 of 63)

	CIRCUIT BREAKERS		9/35
<>	VHF 1	XPONDER 1	<>
<>	VHF 2	XPONDER 2	><
<>	HF 1	MODE C	<>
<>	HF 2	MODE S	<>
<>	VOR 1	SELCAL	<>
<>	VOR 2	RADAR ALT 1	<>
<>	ILS 1	RADAR ALT 2	<>
<>	ILS 2	PUB ADD	<>
<>	MLS 1	CBN INPH 1	<>
<>	MLS 2	CBN INPH 2	<>

39. & 40. CIRCUIT BREAKERS. MOST OF THE CIRCUIT BREAKERS (POWER CONTROLLERS) ON THE AIRCRAFT ARE REMOTELY CONTROLLED FROM THIS SERIES OF PAGES (ESTIMATE 35 PAGES OF WHICH THESE ARE ONLY EXAMPLES). WHEN THE CIRCUIT BREAKER PAGE IS FIRST SELECTED, AN ALPHABETIZED LISTING OF ALL THOSE THAT ARE TRIPPED (OFF) APPEARS. FOLLOWING THE ALPHABETIZED LISTING OF TRIPPED BREAKERS, ALL BREAKERS, INCLUDING THOSE THAT ARE TRIPPED, ARE ARRANGED VIA FUNCTIONAL SYSTEM. THIS LISTING MAY BE VIEWED BY USING THE NEXT PAGE AND PREVIOUS PAGE KEYS. TRIPPED BREAKERS ARE HIGHLIGHTED AND THE DIAMOND SYMBOL CHANGED TO AN X SYMBOL. THEY MAY BE CONTROLLED (TURNED ON OR OFF) BY PRESSING THE SWITCH ADJACENT TO THE LEGEND.

Figure 75. CDU Page Formats, (Sheet 27 of 63)

CIRCUIT BREAKERS 15/35

L-SLATS-R		L-SPOILERS-R	
<> 1	<> 8	<> 1	7 <>
<> 2	<> 9	<> 2	8 <>
X 3	<> 10	<> 3	9 <>
<> 4	<> 11	<> 4	10 <>
<> 5	<> 12	<> 5	11 <>
<> 6	<> 13	<> 6	12 <>
<> 7	<> 14		

<> L ---- WING TIP DEVICE ---- R X

Figure 75. CDU Page Formats, (Sheet 28 of 63)

JEPP

	AIRFIELD/RWY	DEPART	
<>	ATL/08	ATL 8(VECTOR)	<>
	STAR	ARRIVAL	
<>	LA GRANGE 3	ILS CAT 2	<>
<>	MACEY 3	ILS CAT 3A	<>
<>	ROME 1	MLS	<>
<>	SINCA 3	NDB	<>
		A/D RMKS	<>

41. JEPP. THIS PAGE PERMITS THE PILOTS TO IDENTIFY AN AIRFIELD OR AREA OF OPERATION AND TO DISPLAY INFORMATION CONCERNING IT EITHER ON THE CDU OR ON THE #2 DISPLAY ON THE FRONT INSTRUMENT PANEL.

LINE 3 - ENTER THE IDENTIFIER OF THE AIRFIELD AND THE RUNWAY OF INTENDED APPROACH OR DEPARTURE.

LINES 4 THRU 11 - LEGENDS FOR INFORMATION CONCERNING THAT AIRFIELD AND RUNWAY (STAR, SID, ARRIVAL, ETC.) AUTOMATICALLY APPEAR ON THESE LINES WHEN LINE 3 IS COMPLETED. DETAILED INFORMATION, AS APPROPRIATE, CAN THEN BE CALLED UP BY PRESSING THE SWITCH ADJACENT TO THE LEGEND.

NOTE: AFTER LINE 3 HAS BEEN COMPLETED, PRESSING THE JEPP SWITCH ON THE TOUCH PANEL OVERLAY TO THE #2 DISPLAY ON THE FRONT INSTRUMENT PANEL CALLS UP JEPPESEN INFORMATION. THE PLAN VIEW OF THE APPROACH IS DISPLAYED FIRST, FOLLOWED BY THE VERTICAL PROFILE, THE AIRFIELD DIAGRAM, AND AIRDROME REMARKS. THERE IS FURTHER DESCRIPTION IN THE SECTION ON FRONT PANEL DISPLAYS.

Figure 75. CDU Page Formats, (Sheet 29 of 63)

```
                                        CDU 42
------------------------------------------------
                  COMM/NAV

   ACTIVE            XFER            STANDBY
<> 119.00            V 1 <>          149.975 <>
<> 121.50            V 2 <>          127.925 <>
<> 2000              H 1 <>          29999   <>
<> 6727              H 2 <>          6738    <>
-------------------- NAV -----------------------
<> 108.00   NAV 1          NAV 2     117.95  <>
<> 583      MLS 1          MLS 2     651     <>
<> 6735     XPONDER

------------------------------------------------
```

42. <u>COMM/NAV.</u> THIS PAGE IS USED TO CONTROL AND DISPLAY ALL COMMUNICATION AND NAVIGATION FREQUENCIES AND THE TRANSPONDER CODES. IT IS A REPLICA OF THE SWITCHES AND DISPLAYS CONTAINED ON THE INTEGRATED COMM/NAV (ICN) PANEL (DISCUSSED IN A SECTION BY THAT TITLE) AND OPERATES IN EXACTLY THE SAME WAY. WHEN THE DIGITS ARE TYPED, THEY APPEAR ON THE SCRATCH PAD OF BOTH CDUs, IF THE COMM/NAV PAGE IS SELECTED ON BOTH. THE DIGITS FROM THE SCRATCH PAD CAN THEN BE ENTERED FROM EITHER CDU BY PRESSING THE APPROPRIATE <u>ACTIVE</u> OR <u>STANDBY</u> SWITCH. WHEN THEY ARE ENTERED THEY DISAPPEAR FROM THE <u>SCRATCH</u> PAD. BETWEEN THE CDU AND THE ICN THE LAST FREQUENCY, CHANNEL, OR CODE ENTERED INTO ANY SPECIFIC UNIT REPLACES THE PREVIOUS ONE.

Figure 75. CDU Page Formats, (Sheet 30 of 63)

HF SELCAL

------ HF 1 ------		------ HF 2 ------	
<> SCAN	<> FIX	<> SCAN	FIX <>
<>1	2476	<>5	12223
<>2	3795	<>6	14327
<>3	4735	<>7	16285
<>4	9087	<>8	23194

43. HF SELCAL. THIS PAGE PERMITS THE PILOTS TO SELECT THE HF SELECTIVE CALL MODE AND TO INSERT UP TO EIGHT FREQUENCIES TO BE SCANNED WHEN THE SCAN MODE IS SELECTED. WHEN THE FIX MODE IS SELECTED SELCAL OPERATES ON THE FREQUENCY TO WHICH THE RECEIVER IS TUNED.

LINE 4 - THE SCAN OR FIX MODE FOR EITHER HF 1 or HF 2 MAY BE SELECTED BY PRESSING THE APPROPRIATE SWITCH. ALL FOUR SWITCHES ARE MUTUALLY EXCLUSIVE SO THAT ONLY ONE CAN BE SELECTED AT A TIME.

LINES 6 THRU 9 - HF FREQUENCIES TO BE SCANNED CAN BE INSERTED OPPOSITE SWITCHES 1 THRU 8.

Figure 75. CDU Page Formats, (Sheet 31 of 63)

TEST

<>	1 MASTER	INDICATOR LIGHTS	<>
<>	2 MASTER	FMC 1	<>
<>	3 MASTER	FMC 2	<>
<>	DISPLAYS	CADC 1	<>
<>	FUEL SYSTEM	CADC 2	<>
<>	VOICE RECORDER	CDU 1	<>
<>	RADAR	GPWS	<>
<>	DABS	ACARS	<>
<>	ACAWS	VOICE SYSTEM	<>

44. TEST. MOST SYSTEMS WILL BE SELF MONITORING AND SELF TESTING. A MESSAGE ON ACAWS WILL ANNUNCIATE ANY MALFUNCTION OR FAILURE. THIS PAGE PROVIDES THE CAPABILITY TO INITIATE SYSTEMS TESTS, SHOULD THAT BE DESIRED. IT IS ONLY AN EXAMPLE TO SHOW HOW TESTING WILL WORK CONCEPTUALLY. THERE WILL BE A NUMBER OF MASTER TEST SWITCHES, WHICH CAN ONLY BE ACTIVATED ON THE GROUND, AND WILL SEQUENTIALLY TEST A SERIES OF UNITS SHOWING THE STATUS ON ONE OF THE FRONT INSTRUMENT PANEL DISPLAYS.

IN ADDITION TO THE MASTER SWITCHES A TBD NUMBER OF SYSTEMS MAY BE TESTED INDIVIDUALLY ON THE GROUND OR IN THE AIR. DURING THESE TESTS THE STATUS WILL NORMALLY BE DISPLAYED EITHER ON THE UNIT BEING TESTED OR ON THE CDU DISPLAY.

Figure 75. CDU Page Formats, (Sheet 32 of 63)

CDU 50

PM – INDEX

<> CLIMB	ABBREV TRIP PLAN <>
<> CRUISE	WIND TRADE <>
<> DESCENT	FLIGHT LEVEL <>
<> CRUISE	
<> HOLD	
<> TIME NAV	
<> TOLD	SET COST INDEX FACTOR
	X.X <>

---

50. INDEX-PERF 1/1. THIS PAGE IS THE MASTER INDEX PAGE FOR THE PERFORMANCE MANAGEMENT FUNCTION. IT IS CALLED UP BY SELECTING THE PERF SPECIAL FUNCTION KEY AND DOUBLE ACTUATION OF THE INDEX KEY.

    LINES 2 THROUGH 8 LEFT HAND AND 2 THROUGH 4 RIGHT HAND LINE SWITCHES ARE FOR SELECTING APPLICABLE PERFORMANCE MODE INDEX.

    THE LOWER RIGHT LINE SELECT KEY IS USED TO SET THE APPROPRIATE MIN FUEL/COST INDEX FACTOR, WHICH IS USED TO COMPUTE THE EPR/SPEED SCHEDULES WHEN AN ECONOMY MODE IS SELECTED.

Figure 75. CDU Page Formats, (Sheet 33 of 63)

```
PM INDEX - CLIMB MODES

<> ECONOMY CLIMB                    ACTIVE

<> CONSTANT SPEED

<> BEST ANGLE

<> MAX RATE

<> ENGINE OUT
```

51. INDEX-PERF CLIMB MODES. LINES 3 THROUGH 11 - LINE SWITCHES TO SELECT A SPECIFIC CLIMB MODE PERFORMANCE PAGE. THE MODE PROGRAMMED TO BE AFFECTED WHEN THE CLB FLIGHT MODE ON THE AFCS PANEL IS SELECTED, IDENTIFIED, AND DISPLAYED AS THE ACTIVE PERFORMANCE MODE. THIS PAGE IS CALLED UP BY SELECTING THE CLIMB KEY ON THE PM-INDEX PAGE (CDU PAGE 50) OR BY PRESSING THE PAGE ADVANCE KEY WHILE IN THE CLIMB FLIGHT SEGMENT.

Figure 75. CDU Page Formats, (Sheet 34 of 63)

```
------------------------------------------------
    PM INDEX - CRUISE MODES

<> ECONOMY CRUISE                          ACTIVE

<> CONSTANT SPEED

<> CRUISE CLIMB

<> MAX ENDURANCE

<> MAX RNG/ALT--ENG OUT------MAX ENDUR <>
------------------------------------------------
```

52. INDEX-PERFORMANCE CRUISE MODES. LINES 3 THROUGH 11 - LINE SWITCHES TO SELECT A SPECIFIC CRUISE MODE PERFORMANCE PAGE. THE MODE PROGRAMMED TO BE AFFECTED WHEN THE CRZ FLIGHT MODE ON THE AFCS PANEL IS SELECTED IS IDENTIFIED AND DISPLAYED AS THE ACTIVE PERFORMANCE MODE.

    THIS PAGE IS CALLED UP BY SELECTING THE CRUISE KEY ON THE PM-INDEX PAGE (CDU PAGE 50), OR BY PRESSING THE PAGE ADVANCE KEY WHILE IN THE CRUISE FLIGHT SEGMENT.

Figure 75. CDU Page Formats, (Sheet 35 of 63)

PM INDEX – DESCENT MODES

<> ECONOMY DESCENT

<> CONSTANT SPEED

---

53. <u>INDEX-PERFORMANCE DESCENT MODES.</u> LINES 2 and 3 - LINE SWITCHES TO SELECT A SPECIFIC DESCENT MODE PERFORMANCE PAGE. THE MODE PROGRAMMED TO BE AFFECTED WHEN THE DES FLIGHT MODE ON THE AFCS PANEL IS SELECTED IS IDENTIFIED AS THE ACTIVE PERFORMANCE MODE.

THIS PAGE IS CALLED UP BY SELECTING THE <u>DESCENT</u> KEY ON THE <u>PM-INDEX</u> PAGE (CDU PAGE 50).

Figure 75. CDU Page Formats, (Sheet 36 of 63)

```
                                                        CDU 54
--------------------------------------------------------------
    PM CLIMB - ECONOMY
1.68 EPR               ACTIVE              IAS     270
                                           MACH    .---
CLIMB TO
<> FL290

RNG/TIME TO LEVEL OFF            35NM/0+06

END OF CLIMB SPEED               MACH .720 <>

                                              SELECT <>

--------------------------------------------------------------
```

54. PM CLIMB-ECONOMY. INFORMATION RELATED TO THE ECONOMY CLIMB MODE. THIS PAGE IS CALLED UP BY SELECTING THE ECONOMY CLIMB KEY ON THE PM INDEX - CLIMB MODES PAGE, OR AUTOMATICALLY DISPLAYED IF IT IS THE ACTIVE PAGE UPON SELECTION OF CLB AND PERF.

LINES 2 AND 3 - COMPUTED THRUST AND SPEED COMMANDS FOR CLIMB PATH THAT RESULTS IN MINIMUM FUEL BURN BASED UPON THE PRE-PROGRAMMED INDEX FACTOR. THESE COMMANDS ARE USED BY THE AUTOTHROTTLE AND AUTOPILOT WHEN THEY ARE ENGAGED AND THE THR CMD AND PRF MGT SWITCHES ON THE AFCS PANEL ARE SELECTED. MACH WILL BE DISPLAYED AT THE IAS/MACH CROSSOVER ALTITUDE.

LINES 3 AND 4 - CREW ENTERS CLIMB-TO ALTITUDE OR IT IS AUTOMATICALLY DISPLAYED FROM PREVIOUS INFORMATION. THE CLIMB-TO ALTITUDE MAY BE CHANGED ON THIS PAGE OR ON THE PROGRESS PAGE AND DIST/TIME TO NEW ALTITUDE WILL BE UPDATED.

LINE 5 - COMPUTED RANGE AND TIME TO INTERCEPT THE CRUISE ALTITUDE.

LINE 6 - THE COMPUTED END OF CLIMB SPEED WILL BE DISPLAYED, OR A COMMAND SPEED MAY BE MANUALLY ENTERED. A MANUAL ENTRY WILL AUTOMATICALLY SET UP THE CONSTANT SPEED CRUISE MODE WHEN THE CRUISE ALTITUDE IS REACHED.

LINE 7 - THIS LINE SWITCH WILL ACTIVATE THIS MODE IF ANOTHER CLIMB MODE IS PRESENTLY THE ACTIVE MODE.

Figure 75. CDU Page Formats, (Sheet 37 of 63)

```
    PM CLIMB - CONSTANT SPEED
1.68 EPR                          IAS    250 <>
                                  MACH  .--- <>
CLIMB TO
<> FL290

RNG/TIME TO LEVEL OFF      35NM/0+06

END OF CLIMB SPEED         MACH .720 <>

                                  SELECT <>
```

55. PM CLIMB-CONSTANT SPEED. INFORMATION RELATED TO THE CONSTANT SPEED CLIMB MODE.

LINES 2 AND 3 - CREW ENTERS VALUES FOR THE DESIRED IAS/MACH CLIMB SPEED SCHEDULE. THE REST OF THE DATA IS SIMILAR TO CDU PAGE 54.

Figure 75. CDU Page Formats, (Sheet 38 of 63)

PM CLIMB – BEST ANGLE

1.68 EPR IAS 250

MACH .---

CLIMB TO

<> FL290

RNG/TIME TO LEVEL OFF 35NM/0+06

END OF CLIMB SPEED MACH .720 <>

SELECT <>

56. PM CLIMB-BEST ANGLE. INFORMATION RELATED TO THE BEST ANGLE CLIMB MODE.

    LINES 2 THROUGH 8 - COMPUTED THRUST AND SPEED COMMANDS THAT RESULT IN MAXIMUM GAIN OF ALTITUDE IN MINIMUM HORIZONTAL DISTANCE. THE REST OF THE DATA IS SIMILAR TO CDU PAGE 54.

Figure 75. CDU Page Formats, (Sheet 39 of 63)

```
                                        CDU 57
----------------------------------------------
   PM CLIMB - MAX RATE
1.68 EPR                          IAS    285
                                  MACH  .---
CLIMB TO
<> FL290

RNG/TIME TO LEVEL OFF          35NM/0+06

END OF CLIMB SPEED             MACH .720 <>

                                     SELECT <>


----------------------------------------------
```

57. <u>PM CLIMB-MAXIMUM RATE.</u> INFORMATION RELATED TO THE MAXIMUM RATE OF CLIMB MODE.

LINES 2 THROUGH 8 - COMPUTED THRUST AND SPEED COMMANDS THAT RESULT IN MAXIMUM GAIN OF ALTITUDE IN MINIMUM TIME. THE REST OF THE DATA IS SIMILAR TO CDU PAGE 54.

Figure 75. CDU Page Formats, (Sheet 40 of 63)

PM CLIMB - ENGINE OUT

1.68 EPR IAS 220

BEST ALTITUDE FL252

SELECT <>

58. PM CLIMB-ENGINE OUT. INFORMATION RELATED TO ENGINE OUT MODE.

LINES 2 AND 3 - COMPUTED THRUST, AIR SPEED AND BEST ALTITUDE FOR SINGLE ENGINE OPERATION.

Figure 75. CDU Page Formats, (Sheet 41 of 63)

CDU 59

PM CLIMB — CRUISE ECONOMY

1.68 EPR IAS

MACH .770

RNG/TIME TO STEP CLIMB 896NM/2+10

RNG/TIME TO BEGIN DESCENT 1412NM/3+35

NEXT FLT LEVEL FUEL OVER DEST

<> FL330 31.9

SELECT <>

---

59. <u>PM CLIMB-CRUISE ECONOMY.</u> INFORMATION RELATED TO THE ECONOMY CRUISE MODE.

LINES 2 AND 3 - TARGET THRUST (EPR) AND CONSTANTLY VARYING SPEED WHICH RESULTS IN A RANGE OPTIMIZED SCHEDULE FOR CONSTANT ALTITUDE (STEP CLIMB) CRUISE, BASED UPON THE COST INDEX FACTOR.

LINES 4 THROUGH 7 - COMPUTED DATA BASED ON PREVIOUS INFORMATION. HOWEVER, THE NEXT CRUISE FLIGHT LEVEL CAN BE REPROGRAMMED BY ENTERING THE DESIRED FLT LEVEL VIA THE LINE KEY.

Figure 75. CDU Page Formats, (Sheet 42 of 63)

```
   PM CRUISE - CONSTANT SPEED
-.-- EPR                                  IAS    ---  <>
                                          MACH   .--- <>
RNG/TIME TO STEP CLIMB              ---NM/-+--

RNG/TIME TO BEGIN DESCENT          ----NM/-+--

NEXT FLT LEVEL                     FUEL OVER DEST
<> FL330                                     31.9

                                          SELECT <>
```

60. PM CRUISE-CONSTANT SPEED. INFORMATION RELATED TO THE CONSTANT SPEED CRUISE.

LINES 2 THROUGH 8 - CREW ENTERS DESIRED VALUE OF CRUISE MACH OR IAS. THE OTHER DATA IS SIMILAR TO CDU PAGE 59.

Figure 75. CDU Page Formats, (Sheet 43 of 63)

CDU 61

```
   PM CRUISE - MAX ENDURANCE
-.-- EPR                         IAS    ---  <>
                                 MACH  .702  <>
TIME TO RESERVE + ALTN                 3+23

TIME TO EMPTY TANKS                    4+48

BEST FLIGHT LEVEL/SPEED            FL220/240

BEST SPEED CURRENT FLT LEVEL   MACH .63
                                  SELECT <>
```

61. PM CRUISE-MAXIMUM ENDURANCE. INFORMATION RELATED TO THE MAXIMUM ENDURANCE CRUISE MODE (SOMETIMES USED FOR HOLDING).

    LINES 2 AND 3 - SPEED AND THRUST SCHEDULE WHICH RESULTS IN MINIMUM FUEL FLOW.

    LINES 4 AND 5 - TIME TO RESERVE + ALTERNATE AND TO EMPTY TANKS BASED ON SELECTED HOLDING SPEED.

    LINES 6 AND 7 - CALCULATED DATA FOR OPTIMUM PERFORMANCE.

Figure 75. CDU Page Formats, (Sheet 44 of 63)

PM CRUISE – ENG OUT MAX RANGE

–.–– EPR MACH .–––

OPT FLIGHT LEVEL –––––

RNG/TIME REMAINING ––––NM/–+––

SELECT <>

ENG OUT MAX ALTITUDE

–.–– EPR MACH .–––

MAX FLIGHT LEVEL –––––

RNG/TIME REMAINING ––––NM/–+––

SELECT <>

---

62. PM CRUISE-ENGINE OUT MAX RANGE. INFORMATION RELATED TO ENGINE OUT MAXIMUM RANGE OR MAXIMUM ALTITUDE MODES.

LINES 2 THROUGH 5 - INFORMATION TO ACHIEVE MAXIMUM RANGE WITH ONLY ONE ENGINE OPERATING. MODE IS ACTIVATED BY ENGAGE SWITCH ON LINE 5 OR AUTOMATICALLY IF ENG OUT FLIGHT DISPLAY SWITCH IS SELECTED IN CRUISE AND THE CURRENT ALTITUDE IS BELOW THE MAX FL/ALTITUDE.

LINES 7 THROUGH 9 - INFORMATION TO MAINTAIN MAXIMUM ALTITUDE CRUISE WITH ONLY ONE ENGINE OPERATING. MODE IS ACTIVATED BY ENGAGE SWITCH ON LINE 10 OR AUTOMATICALLY IF ENG OUT FLIGHT DISPLAY SWITCH IS SELECTED IN CRUISE AND THE CURRENT ALTITUDE IS ABOVE THE MAX FL/ALTITUDE.

Figure 75. CDU Page Formats, (Sheet 45 of 63)

PM CRUISE - ENG OUT MAX ENDURANCE

-.-- EPR IAS ---

MACH .---

TIME TO EMPTY TANKS -+--

BEST FLIGHT LEVEL -----

SELECT <>

63. PM CRUISE-ENG OUT MAX ENDURANCE. INFORMATION RELATED TO SINGLE ENGINE OUT MAXIMUM ENDURANCE MODE.

LINES 2 THROUGH 5 - DATA ENTRY AND CALCULATED INFORMATION SIMILAR TO CDU PAGE 62.

Figure 75. CDU Page Formats, (Sheet 46 of 63)

```
   PM DESCENT - ECONOMY
1.02 EPR        ACTIVE          IAS    ---
                                MACH  .700
DESCEND TO FLIGHT LEVEL
<> FL100

RNG/TIME TO LEVEL OFF           70NM/0+12

BOTTOM OF DESCENT SPEED         IAS   250   <>

                                   SELECT <>
```

64. PM DESCENT-ECONOMY. INFORMATION RELATED TO THE ENROUTE DESCENT MODE.

LINES 2 AND 3 - THRUST AND SPEED COMMANDS FOR AN ECONOMY FUEL DESCENT PROFILE.

LINES 4 AND 5 - CREW ENTERS BOTTOM-OF-DESCENT ALTITUDE.

LINE 6 - COMPUTED INFORMATION TO BOTTOM-OF-DESCENT POINT.

LINE 7 - CREW ENTERS DESIRED BOTTOM OF DESCENT SPEED.

Figure 75. CDU Page Formats, (Sheet 47 of 63)

```
                                                  CDU 65
------------------------------------------------------------
   PM DESCENT - CONSTANT SPEED
1.02 EPR                                  IAS    ---  <>
                                          MACH  .---  <>
DESCEND TO FLIGHT LEVEL
<> FL100

RNG/TIME TO LEVEL OFF                     70NM/0+12

BOTTOM OF DESCENT SPEED                   IAS    250  <>

                                              SELECT  <>

------------------------------------------------------------
```

65. <u>DESCENT-CONSTANT SPEED.</u> INFORMATION RELATED TO THE CONSTANT SPEED DESCENT MODE.

LINES 2 THROUGH 7 - CREW ENTERS VALUES FOR THE DESIRED MACH/IAS DESCENT SCHEDULE. OTHER DATA IS SIMILAR TO CDU PAGE 64.

Figure 75. CDU Page Formats, (Sheet 48 of 63)

CDU 66

```
----------------------------------------------------------
   VERTICAL NAV - CLB/CRS/DES/APPR
1.68 EPR                              IAS     270 <>
                                      MACH   .--- <>
FROM IDENT/FLT LEVEL TO IDENT/FLT LEVEL
<>                   <>

<> PT-TO-PT MODE     <> PT OFFSET MODE
     ACTIVE
SPEED AT IDENT  IAS --- <>  MACH .--- <>
RNG/TIME TO IDENT  ----NM/-+--
                                         SELECT <>

----------------------------------------------------------
```

66. VERTICAL NAV-CLB/CRS/DES/APPR. INFORMATION RELATED TO VERTICAL NAVIGATION DURING THE CLIMB, CRUISE, DESCENT AND APPROACH MODES IS ENTERED AND/OR SELECTED ON THIS PAGE.

Figure 75. CDU Page Formats, (Sheet 49 of 63)

PM – ABBREV TRIP PLAN	1/1
DEST IDENT	+/– TEMP DEV
<> KSTL	--- <>
TRIP DISTANCE	AVG WIND
<> 963	270/50 <>
ETA AT DEST 2+12	
FUEL AT DEST 31300	
OPT FLT LEVEL 33900	

68. ABBREVIATED TRIP PLANNING. QUICK REFERENCE INFORMATION COMPUTED FROM AIRCRAFT'S CURRENT POSITION TO DESTINATION.

    LINES 2 THROUGH 5 - CREW ENTERS TRIP PLAN DATA. IF A DESTINATION IDENTIFIER IS ENTERED, TRIP DISTANCE WILL AUTOMATICALLY BE DISPLAYED.

    LINES 6 THROUGH 8 - INFORMATION COMPUTED BASED UPON LINES 3 AND 5 DATA. THE COMPUTATION ASSUMES AN ECONOMY CLIMB, CRUISE, AND DESCENT PROFILE WITH STANDARD RESERVES AT THE DESTINATION.

Figure 75. CDU Page Formats, (Sheet 50 of 63)

```
PM - WIND TRADE                        1/1

PROPOSED FLT LEVEL
<> -----

WIND FACTOR FOR SAME MILEAGE ---
```

69. WIND TRADE. LINES 2 THROUGH 4 - CREW ENTERS PROPOSED FLIGHT LEVEL. THE EQUIVALENT WIND AT THE PROPOSED ALTITUDE TO ACHIEVE SAME FUEL BURN TO DESTINATION IS DISPLAYED ON LINE 2.

THE COMPUTATION IS BASED UPON A COMPUTED AVERAGE WIND FACTOR USING THE PROGRAMMED WINDS AND VERTICAL PROFILE OF THE REMAINING FLIGHT PLAN.

Figure 75. CDU Page Formats, (Sheet 51 of 63)

```
  PM - FLIGHT LEVEL                        1/1

OPT     FLT LEVEL FL382

MAX     FLT LEVEL FL397

CURRENT FLT LEVEL FL360
```

70. FLIGHT LEVEL. LINES 2 THROUGH 4 - AIRCRAFT PERFORMANCE INFORMATION BASED ON CURRENT GROSS WEIGHT AND AIR TEMPERATURE.

Figure 75. CDU Page Formats, (Sheet 52 of 63)

CDU 71

```
---------------------------------------------------------------
   VERTICAL NAV - CLB/CRS/DES/APPR               1/1
1.68 EPR                                IAS    270 <>
                                        MACH   .--- <>
FROM IDENT/FLT LEVEL  TO IDENT/FLT LEVEL
<>                    <>

<> PT-TO-PT MODE      <> PT OFFSET MODE
     ACTIVE
SPEED AT IDENT   IAS --- <>   MACH .--- <>
RNG/TIME TO IDENT   -----NM/-+--
                                        SELECT <>

---------------------------------------------------------------
```

71. VNAV CLB/CRS/DES/APPR. INFORMATION RELATED TO THE VERNAV MODE. THIS PAGE IS CALLED UP WHEN THE VNAV VERTICAL MODE SWITCH AND EITHER THE CLB, CRS, DES, OR APPR FLIGHT PHASE SWITCH IS SELECTED, AND THE PERF KEY ON THE CDU IS SELECTED.

LINES 2 AND 3 - THRUST AND SPEED DATA. THE SPEED IS DEFAULTED TO THE FLIGHT PLAN VALUE, BUT MAY BE CHANGED VIA THE LINE KEY.

LINES 4 AND 5. REQUIRED ALTITUDES FOR THE PAST AND NEXT WAY-POINTS ARE DISPLAYED/SET HERE.

LINES 6 & 7 - THE POINT-TO-POINT VERTICAL NAVIGATION MODE IS THE DEFAULT MODE, BUT THE POINT OFFSET MODE MAY BE SELECTED. THE POINT OFFSET MODE GIVES AN INTERCEPT OF THE NEXT WAYPOINT ALTITUDE AT A PREDETERMINED DISTANCE PRIOR TO THE WAYPOINT.

LINE 8 - THE SPEED REQUIRED AT THE NEXT WAYPOINT. IF IT IS DIFFERENT FROM THE CURRENT SPEED, A PROGRAMMED SPEED CHANGE WILL BE ACCOMPLISHED BEGINNING AT A PREDETERMINED POINT BEFORE THE WAYPOINT.

LINE 9 - COMPUTED RANGE AND TIME TO THE NEXT WAYPOINT.

Figure 75. CDU Page Formats, (Sheet 53 of 63)

CDU 72

```
  VERTICAL NAV - HOLD                       1/1
  INBOUND COURSE                       1.40 EPR
<>                                  IAS    250 <>
  TURN R-L
<> R                                MACH .---  <>
  MILES
<> 5
 AT WAYPOINT                        FLIGHT LEVEL
<>                                       ----- <>
 AT PRESENT POSITION
<>                                      SELECT <>
```

72. VNAV HOLD. INFORMATION RELATED TO THE HOLDING PATTERN MODE WHEN THE VNAV SWITCH IS SELECTED ON THE GCP. THIS PAGE IS CALLED UP WHEN THE FLIGHT PHASE HOLD SWITCH IS SELECTED ON THE GCP AND THE PERF KEY ON THE CDU.

THE DATA IS SIMILAR TO CDU PAGE 67.

Figure 75. CDU Page Formats, (Sheet 54 of 63)

TIME NAV - INDEX

<> CLIMB

<> CRUISE

<> DESCENT

<> HOLD

73. TIME NAV-INDEX. INFORMATION RELATED TO THE CLIMB/CRUISE/DESCENT/HOLD MODES WHEN THE TNAV SWITCH IS SELECTED ON THE GCP. THIS PAGE IS CALLED UP WHEN EITHER OF THESE FLIGHT PHASE SWITCHES AND THE PERF KEY ON THE CDU ARE ALSO SELECTED.

Figure 75. CDU Page Formats, (Sheet 55 of 63)

```
  TIME NAV HOLD
  INBOUND COURSE                        1.40 EPR
<>                                   IAS    250 <>
  TURN R-L
<> R                                 MACH .---  <>
  MILES
<> 5
 AT WAYPOINT                         FLIGHT LEVEL
<>                                        ----- <>
 AT PRESENT POSITION
<>                                        SELECT <>
```

74. TIME NAV HOLD. INFORMATION RELATED TO THE HOLDING PATTERN MODE WHEN THE TNAV SWITCH IS SELECTED ON THE GCP. THIS PAGE IS CALLED UP WHEN THE FLIGHT PHASE HOLD SWITCH ON THE GCP AND THE PERF KEY ON THE CDU ARE ALSO SELECTED.

THE DATA IS SIMILAR TO CDU PAGE 67.

Figure 75. CDU Page Formats, (Sheet 56 of 63)

TOLD - INDEX

<- TAKEOFF PLANNING

<- LANDING PLANNING

<- TOLD - TAKEOFF/EMER RETURN

<- TOLD - LANDING

<- TOLD - ENG OUT LANDING

80. INDEX-TOLD. THIS PAGE IS THE MASTER INDEX PAGE FOR THE TAKEOFF AND LANDING DATA (TOLD) FUNCTION.

LINES 2 THROUGH 6 - THE LINE SWITCHES ARE USED TO SELECT A SPECIFIC TOLD PAGE. THIS PAGE IS CALLED UP THROUGH THE INDEX PAGE.

Figure 75. CDU Page Formats, (Sheet 57 of 63)

TOLD – TAKEOFF PLANNING		1/2
TAKEOFF GROSS WEIGHT ------		
RWY	RWY AVAIL	RWY SLOPE
<> ---	<> ----	0 <>
RWY ELE	RWY RCR	RWY RSC
<>	<> 23	0 <>
OBST HEIGHT	OBS DIST	CLIMB GRAD
<> 0	<> 0	2 <>

81. TAKEOFF PLANNING 1/2. THIS PAGE IS USED IN THE CALCULATION OF TAKEOFF AND EMERGENCY LANDING PERFORMANCE DATA (TOLD) FOR THE SPECIFIC AIRCRAFT AND AIRFIELD.

LINE 2 - TAKEOFF GROSS WEIGHT IS AUTOMATICALLY DISPLAYED FROM PREVIOUS INFORMATION ON THE WEIGHT AND BALANCE PAGE (CDU PAGE 6).

LINES 3 THROUGH 8 - ENTER APPROPRIATE INFORMATION ON DEPARTURE AIRFIELD. VALUES SHOWN IN THE EXAMPLE ARE AUTOMATICALLY DISPLAYED AND NEED ONLY BE CHANGED AS NECESSARY.

Figure 75. CDU Page Formats, (Sheet 58 of 63)

CDU 82

```
----------------------------------------------------
  TOLD - TAKEOFF PLANNING                      2/2

<> RWY OAT ----             PRESS ALT ---- <>

<> WIND DIR/VEL/GUST ---/---/--

-------------TAKEOFF THRUST-------------------------

<> RATED THRUST             REDUCED THRUST <>

              EXCEEDS LIMIT

----------------------------------------------------
```

82. <u>TAKEOFF PLANNING 2/2.</u> THIS PAGE IS USED IN THE CALCULATION OF TAKEOFF AND EMERGENCY LANDING PERFORMANCE DATA (TOLD).

LINES 1 THROUGH 3 - ENTER APPROPRIATE INFORMATION ON DEPARTURE AIRFIELD.

LINE 4 - SELECT TAKEOFF RATED THRUST (TRT) OR REDUCED EPR THRUST AS APPROPRIATE. THE SELECTED CALCULATED EPR FOR TAKEOFF IS DISPLAYED HERE AND ON THE DIGITAL EPR DISPLAY ON THE ENGINE INSTRUMENT PANEL. IF AIRCRAFT PERFORMANCE IS EXCEEDED, THE MESSAGE IS AUTOMATICALLY DISPLAYED.

Figure 75. CDU Page Formats, (Sheet 59 of 63)

```
 TOLD - TAKEOFF                                 1/1
EPR-TO 2.32      EPR-NRT 2.42      V-GO   125
TRIM SET 2 NU    FLAP SET 45 DEG
RWY OAT +20C     CK EGT 838C       V-ROT  125

ACCEL CK SPD/TIME 110/32           V-R    144
GRD RUN 6150 FT    CFL 7820 FT
                   H-MFR 1900      V-MFR  160
-----------EMERGENCY RETURN------------------
LAND DIST 4520 FT                  V-APR  126
<> TAKEOFF PLAN                    V-G/A  139
```

83. TOLD-TAKEOFF. TAKEOFF PERFORMANCE DATA IS AUTOMATICALLY CALCULATED AND DISPLAYED ON THIS PAGE. LANDING DATA FOR AN EMERGENCY RETURN TO THE DEPARTURE FIELD IS AUTOMATICALLY CALCULATED AND DISPLAYED ON THIS PAGE.

Figure 75. CDU Page Formats, (Sheet 60 of 63)

```
  TOLD - LANDING PLANNING
EST LND GROSS WT ------
RWY                 RWY AVAIL            RWY SLOPE
<> ---              <> ----                   0 <>
RWY ELEV            RWY RCR                RWY RSC
<> ---              <> 23                     0 <>
RWY OAT             FLAPS                 PRES ALT
<> ---              <> ---                 ---- <>
RWY WIND DIR/VEL/GUST                    V-APR INCR
<> ---/---/--                               +15 <>
NORMAL LANDING <>          <> ENGOUT LANDING
```

84. <u>LAND PLANNING.</u> THIS PAGE IS USED IN THE CALCULATION OF APPROACH AND LANDING DATA FOR THE SPECIFIC AIRCRAFT AND DESTINATION AIRFIELD.

LINE 1 - LANDING GROSS WEIGHT ESTIMATE IS COMPUTED AND AUTOMATICALLY DISPLAYED.

LINE 2 - ENTER APPROPRIATE INFORMATION ON DESTINATION AIRFIELD. V-APR INCR IS THE INCREMENT OF AIRSPEED TO BE ADDED TO 1.3 V_S SPEED FOR THE APPROACH IN EVENT OF WIND GUSTS, ETC. THE SPEED BUGS ON THE AIRSPEED SCALE ON THE FLIGHT DISPLAY WILL REFLECT THE APPROACH SPEED AND THRESHOLD SPEED.

LINE 11 - SELECT APPROPRIATE TYPE OF LANDING FOR TOLD CARD INFORMATION DESIRED.

Figure 75. CDU Page Formats, (Sheet 61 of 63)

TOLD - LANDING 1/1

EPR-G/A 2.32 V-APR+INCR 127

LANDING DIST 3220 FT

TOUCH AND GO

EPR-G/A 2.32 TRIM SET 2 N/M V-ROT 125

<> LAND PLAN

---

85. TOLD-LAND 1/1. LANDING PERFORMANCE DATA IS AUTOMATICALLY CALCULATED AND DISPLAYED ON THIS PAGE. THIS PAGE IS CALLED UP BY PRESSING THE TOLD SPECIAL FUNCTION KEY WHEN DES OR APPR LAND FLIGHT MODE HAS BEEN SELECTED ON THE GCP, FROM THE LAND PLANNING INDEX PAGE (CDU PAGE 84) OR THE NEXT PAGE KEY FROM CDU PAGE 84.

Figure 75. CDU Page Formats, (Sheet 62 of 63)

```
TOLD - LANDING ENGINE OUT                    1/1

EPR-G/A 2.32                   V-APR+INCR 135

LANDING DIST 4520 FT




<> LAND PLAN
```

86. <u>TOLD-LAND ENGINE OUT.</u> SAME AS ITEM 85, EXCEPT FOR SINGLE ENGINE OPERATION.

Figure 75. CDU Page Formats, (Sheet 63 of 63)

PRINTER

The printer, installed in the aft portion of the center console (Item 34, Figure 15), provides a means for recording data as desired by the pilots. It will be a rugged commercial printer adapted for use in the flight station.

Criteria

The printer is built to best commercial standards and packaged as a single unit. It interfaces with the processing equipment via an RS-232 data link. Data are received, decoded, and output as alphanumeric messages on the printing medium. The printer provides real-time hard copy recording.

- Size - The overall dimensions of the unit do not exceed 10 inches wide, 6 inches high, or 12 inches deep.
- Weight - The weight of the unit does not exceed 15 pounds.
- Cooling - The unit does not require forced air cooling and operates in a temperature environment of 0° to $50^{\circ}C$.
- Built-In-Test - The unit has the capability, upon command, of printing the complete alpha, numeric, and symbol repertoire.
- Recording Process - The printing is through a dot-line thermal process.
- Printing Rate - The printer has the capability to continuously print messages at a rate of at least one line per second.
- Line Width - Each line of print has provisions for at least 40 characters.
- Character Size - The printed characters are at least 0.1 inch high, a nominal six lines per inch.
- Character Set - Full alphanumeric with special characters as defined by American Standard Code II provided.
- Printing Medium - The printing medium is paper. No special processing is required to develop the printed message.

- <u>Printing Medium Capacity</u> - A printing medium capacity for recording up to 10,000 lines is provided.

- <u>Input/Output</u> - Data transfer is in accordance with RS-232 guidelines.

- <u>Input Data Rates</u> - The printer accepts data rates of up to 9600 BAUD.

- <u>Operation of the Printer</u> - Messages to be printed are provided to the printer by one of the pilots typing and inserting outgoing messages into the FMC, or they are received through data link via Mode-S transponder and the ARINC communications addressing and reporting system (ACARS). The messages are displayed initially on the captain's or first officer's CDU. A printed hard copy of the displayed message is made when the PRINT touch panel switch is pressed on the appropriate ATC message or ACARS page. The unit will have a front panel paper slew switch for advancing the paper.

  Examples of incoming and outgoing messages are shown later in the description of the ACARS system. Examples of other types of information that may be printed include ATC clearances, weather advisories, traffic advisories, or company instructions.

- <u>Electrical Power</u> - The unit operates with a power source of 115 VAC (nominal), 50 to 430 Hz.

- <u>Power Control</u> - Power for the unit normally comes on with aircraft power. It may be turned OFF/ON with remote controlled circuit breakers that are controlled through the flight management CDU.

AIR TRAFFIC CONTROL SYSTEMS

The FAA's National Airspace System Plan, Reference 1, describes planned air traffic control system improvements to accommodate increased traffic and to enhance safety. The plan includes modernization of the en route computers, streamlining the national airspace system architecture, automating the en route ATC, providing automated integrated traffic flow management service, automating the flight service stations, modernization of the weather detection, observation, data collection and dissemination systems, establishment of airborne collision avoidance systems, improvement of voice and data-linked communication systems, and streamlining and modernizing the navigation systems. Several of the planned changes will directly affect the design of the 1995 aircraft and the tasks required of the aircrew. The major impact may be the result of phasing-in new systems before the present ones are phased out, the situation depicted previously in Figure 2.

While some of the systems are still in the planning or development stages, their aircraft-aircrew interfaces have been conceptualized for the purpose of providing a baseline design for the research simulation facilities. As the actual systems become better defined and developed, the baseline can be updated. Descriptions of some of the conceptual baseline systems are contained in the following paragraphs.

Mode-S Transponder

The FAA, in Reference 4, describes the Mode-S transponder system as an improved ATC Radar Beacon System which has been developed to add a new discrete addressing capability and an integral data link to the current Mode-A (identification) and Mode-C (altitude reporting) of the Air Traffic Control Radar Beacon System. Mode-S will provide improvements in air traffic control secondary surveillance radar (SSR).

Its data link will provide direct pilot access to automated data bases through control/display units in the flight station in much the same way that the ARINC communications addressing and reporting system (ACARS) is providing limited service today. Data link services are targeted at reducing controller and pilot workload and enhancing safety. For example, services may include:

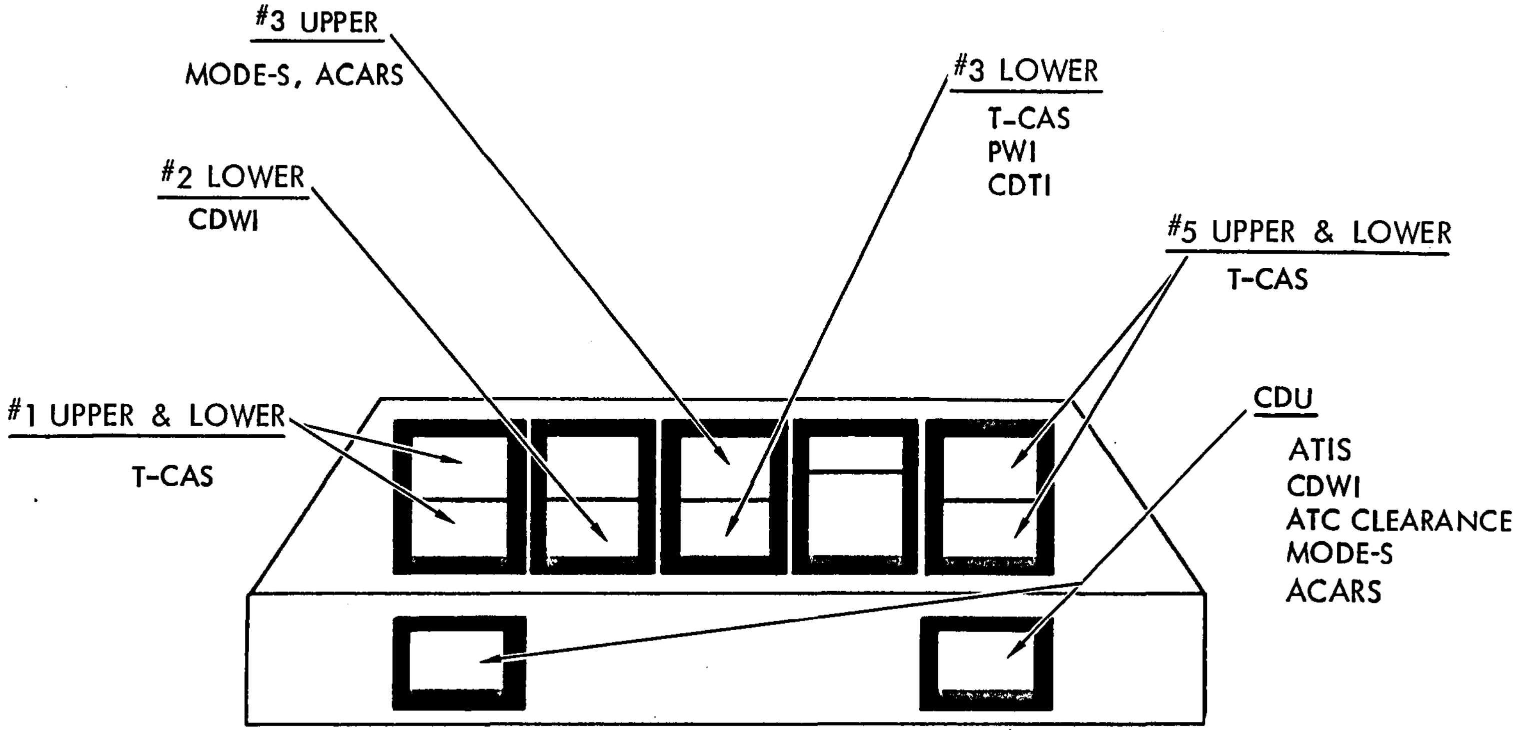
1) En route handoff service to automatically alert aircraft of assigned altitude, new communications frequency and the next waypoint.

2) Weather products, altitude assignment confirmation, minimum safe altitude warning, and clearance delivery.

3) Airborne based collision avoidance systems.

For the baseline design of the research facility, simulated data-linked information will be displayed on the front panel displays and the CDUs as shown in Figure 76. In the case of ATC messages an advisory will appear on the ACAWS format on the upper portion of the number 3 display, as shown in Figure 77. This will indicate the presence of a message from air traffic control on the CDU. For example, the message could be a change of clearance or a change of communications frequency. Terminal area information could conceivably be data-linked and displayed through the same process.

A conceptual system, which will be included in the baseline design, could serve to enhance the present automatic terminal information service (ATIS), which for more than a decade has provided pilots continuous reporting of pertinent airfield data (e.g., runway in use, surface winds and temperature, visibility, ceiling, altimeter setting, nav aid status, and advisories). While ACARS is currently providing some of this information via data-link, Mode-S will make it possible to expand these services. The major disadvantages of ATIS are: (1) the message is broadcast over a discrete radio frequency, requiring the tuning of a comm radio to monitor the message; (2) it is a "continuous loop" recording, requiring the pilots to listen through two or three full cycles in order to verify (and sometimes copy) pertinent data; and (3) updating the recording requires an individual to verify the validity of each segment of data, then re-record the whole message on a new tape. During a rapidly changing weather environment, such as the passage of a cold front, the ATIS report can be so grossly in error as to create additional cockpit-to-air traffic controller exchanges on the radio as the crew attempts to determine existing weather conditions.



ACARS	AIRINC COMMUNICATIONS ADDRESSING AND REPORTING SYSTEM
ATC	AIR TRAFFIC CONTROL
CDTI	COCKPIT DISPLAY OF TRAFFIC INFORMATION
CDWI	COCKPIT DISPLAY OF WEATHER INFORMATION
ATIS	AUTOMATIC TERMINAL INFORMATION SERVICE
MODE-S	TRANSPONDER WITH DATA LINK
PWI	PROXIMITY WARNING INFORMATION
T-CAS	TRAFFIC-ALERT AND COLLISION AVOIDANCE SYSTEM

Figure 76. Display Location for ATC Systems

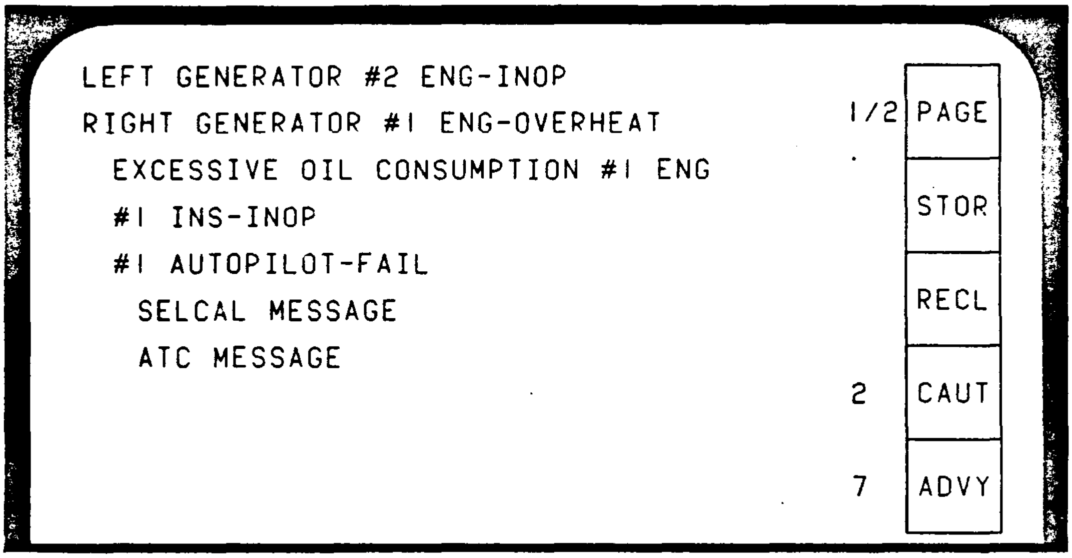


Figure 77. ACAWS Display Showing ATC Message Available on the CDU

With Mode-S data link, this information is uplinked to the aircraft on request and displayed visually to the crew on a display page of the CDU or on printer hardcopy. The various segments of the reports are continuously and independently updated by the various sensors/agencies, resulting in the immediate availability of actual surface conditions to the aircrew with minimal workload on the part of the ground personnel. Additionally, the pilot can specify the items of interest he wants monitored for change (e.g., during an approach—surface winds, runway visual range (RVR), and altimeter setting) and disregard the ATIS unless alerted to a change. Display highlighting will be used to show the revised data. The result is less distraction for the crew, reduced oral communication with the ground controllers, and automatic annunciation when a specified parameter changes in value.

Cockpit Display of Weather Information

For purposes of this baseline design it is conceived that weather data is transmitted to and from the aircraft via the Mode-S transponder data link using a system called the cockpit display of weather information (CDWI).

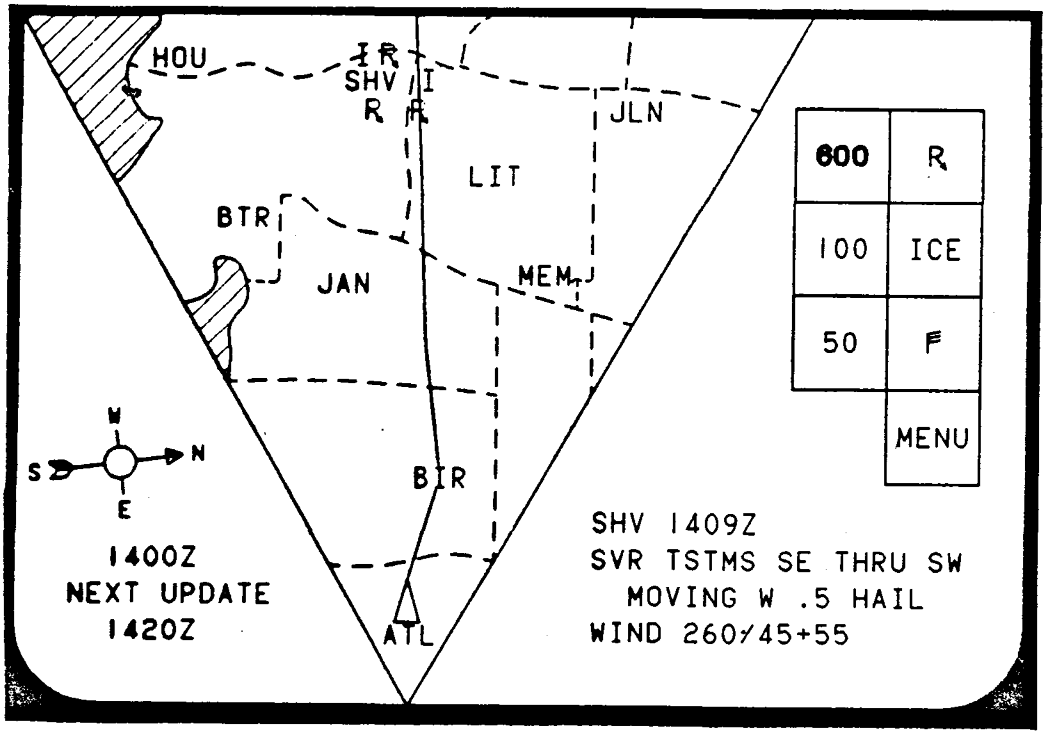
All Mode-S equipped aircraft automatically transmit information to the ground data base. The exact type and quantity of this information is yet to be determined, but it will probably include wind speed and direction, outside air temperature, moisture, and turbulence. This information, along with that from ground-based sensing and detecting systems, makes up the total data base. Weather data, the amount and type still undetermined, is then automatically uplinked from the data base to the aircraft, using a Mode-S system with expanded capability compared with the present ACARS. Additionally, weather data may be requested by the pilots, (e.g., surface observations, terminal forecasts, and pilot reports (PIREPS)) using the CDU to type in the location identifier and other pertinent data. This request is then downlinked in reply to a standard Mode-S interrogation. The requested data are then uplinked for presentation on the CDU display as an alphanumeric message. The basic weather data, however, are displayed in a map format. As a result of this capability to receive and monitor a variety of weather data in a map and/or alphanumeric format throughout the flight, a significant amount of verbal communication with the ground is eliminated. This, in turn, reduces the workload of the pilots while enhancing the presentation of the weather data.

CDWI is designed to provide the aircrew with long-range weather information and is not to be confused with the airborne weather avoidance radar system which overlays the navigation display. Graphic CDWI data are displayed on the number 2 display when selected by the pilot and are used to: (1) update the forecast en route weather; (2) provide more detailed information than is available from the airborne radar, such as wind, icing, or height and movement of thunderstorms; (3) enable the crew to decide at an optimum time the need to amend routing due to large masses of severe weather; and (4) serve as a (degraded) backup in the event the airborne radar system malfunctions.

CDWI data are uplinked from the ground using Mode-S extended-length message (ELM) protocol. The format permits the grouping of up to 16 message segments (80 bits of data/segment) into a single entity. If required, a message continuation can be used to string together consecutive ELMs. When the received ELMs are identified as CDWI data, their contents are transferred to the flight management computers for coordinate transformation. Once the required conversion from geographic coordinates to aircraft-referenced rho-theta coordinates is completed, the data are sent to the symbol generators to be formatted for the front panel display or control/display unit as appropriate.

The CDWI map format, on the lower portion of the number 2 display, is accessed by touching the CDWI switch on the menu page. CDWI presented in this location includes graphic and abbreviated alphanumeric formats as illustrated in Figures 78 through 83.

The alphanumeric information presented in the CDWI format includes the times of the last update and next projected update of weather information, weather advisories, and destination weather. If an advisory message is issued, it is displayed along with a graphic portion of the format, when the CDWI format is selected, as shown in Figure 78. If no advisory is present, the destination weather is presented. The advisory is replaced by the destination weather when one of the three map overlays--thunderstorms, R ; ice, ICE; or wind, —is selected.



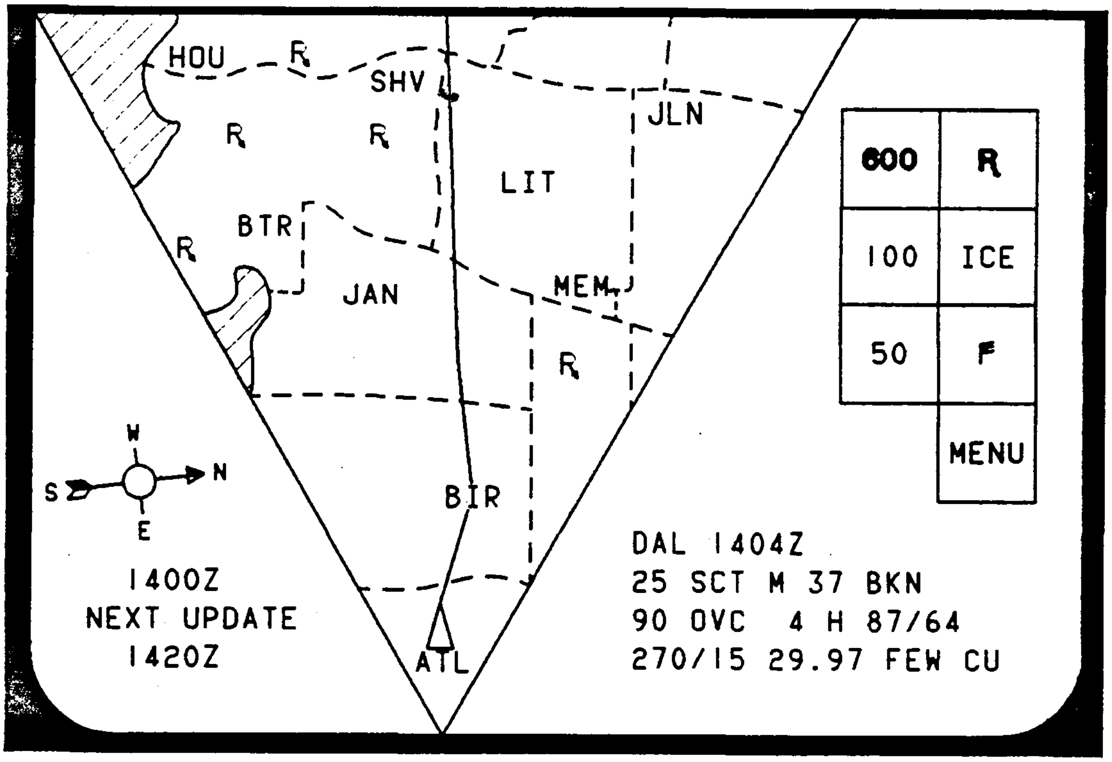
NOTE:

A RANGE OF 600 NM ALONG THE FLIGHT PLANNED ROUTE HAS BEEN SELECTED. THE POSITION OF THE OWNSHIP IS NOT CONTINUALLY CORRECT IN REFERENCE TO THE MAP, SINCE THE INFORMATION IS ONLY UPDATED AT SPECIFIC TIME INTERVALS. SYMBOLS THAT MAKE UP THE ADVISORY ARE SHOWN AS WELL AS STATE BOUNDARIES.

Figure 78. CDWI on 600 NM Range with Advisory Information

The graphic CDWI format is a map display that is updated every TBD minutes. The map shows 600-, 100- or 50-mile forward-look along the flight path. The map is centered on the flight plan route which depicts major land boundaries and selected navigation aids for reference. Map overlays are available for thunderstorms, icing, and winds with only one overlay available at a time. The information for these three weather parameters is depicted for altitudes ± 2000 feet from the selected flight plan altitude. Touching the touch panel area labeled ☈ calls up the thunderstorm overlay as shown in Figure 79. The ☈ symbol is used to identify storms in the 600-mile range mode; filled polygons, shown in Figure 82, are used in the 100- and 50-mile ranges for better format resolution. Severity of the thunderstorm areas is indicated through conventional color coding. The ☈ symbol indicates the most severe level in the weather cell.

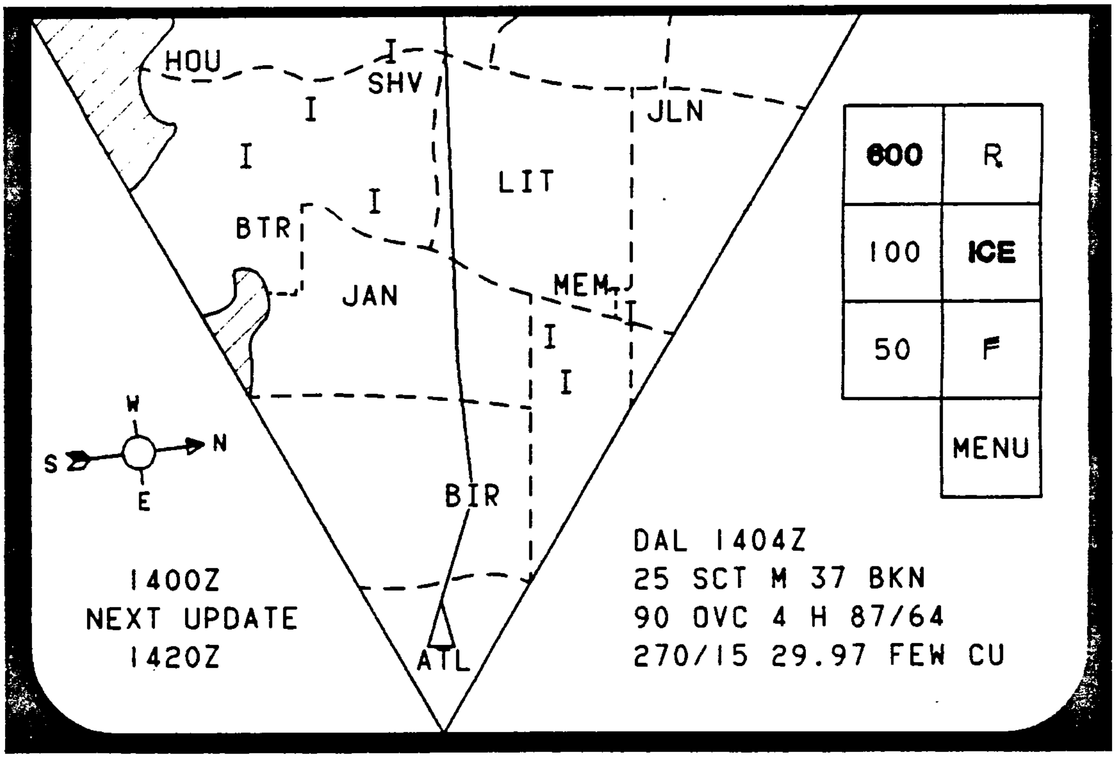
Touching the touch panel area labeled ICE calls up the icing overlay as shown in Figure 80. Predicted and encountered icing conditions are distinguished by color coding. An I symbol is used to identify icing in the 600-mile range mode, while conventional symbology is used in the 100- and 50-mile range modes, as shown in Figure 83. Touching the touch panel area labeled ⊧ calls up the wind overlay as shown in Figure 81. This overlay uses conventional symbology to indicate direction and velocity. The touch panel legend for the overlay that is displayed is highlighted.



NOTE:

THUNDERSTORMS AND 600 NM RANGE HAVE BEEN SELECTED. LATEST REPORTED WEATHER AT DESTINATION (DAL) SHOWN.

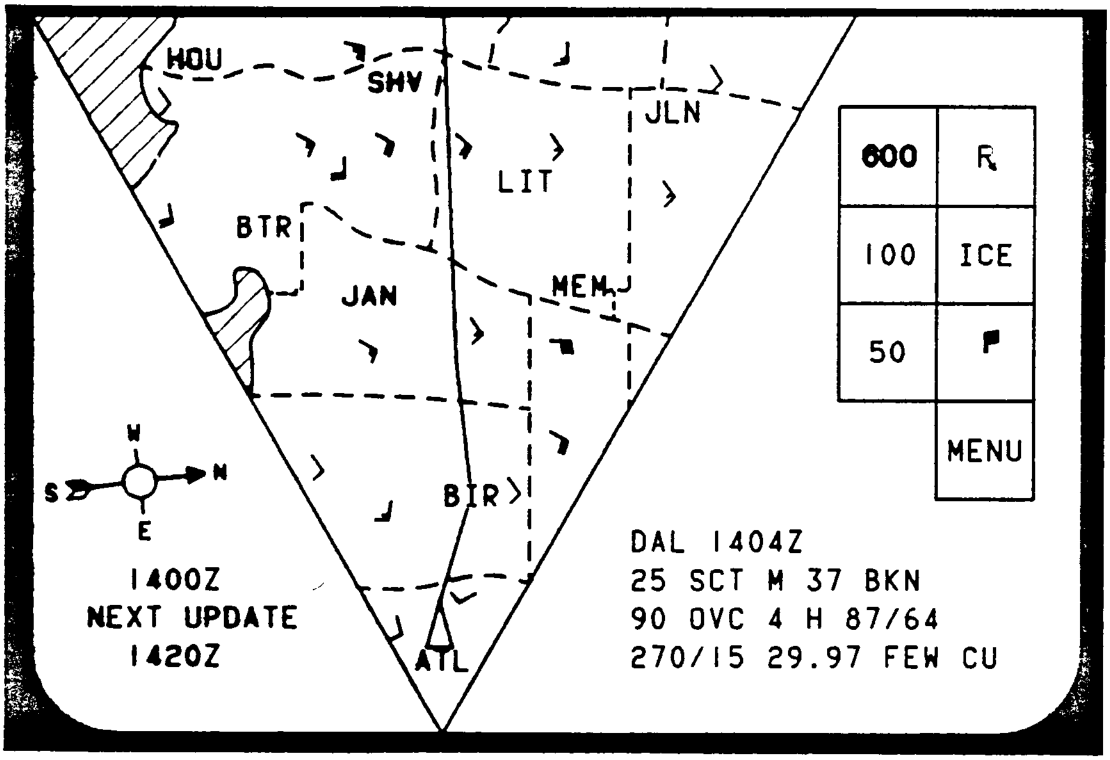
Figure 79. CDWI Showing Thunderstorms



NOTE:

ICING AND 600 NM RANGE HAVE BEEN SELECTED. ICING CONDITIONS ARE SHOWN AT AIRCRAFT ALTITUDE ±2000 FEET.

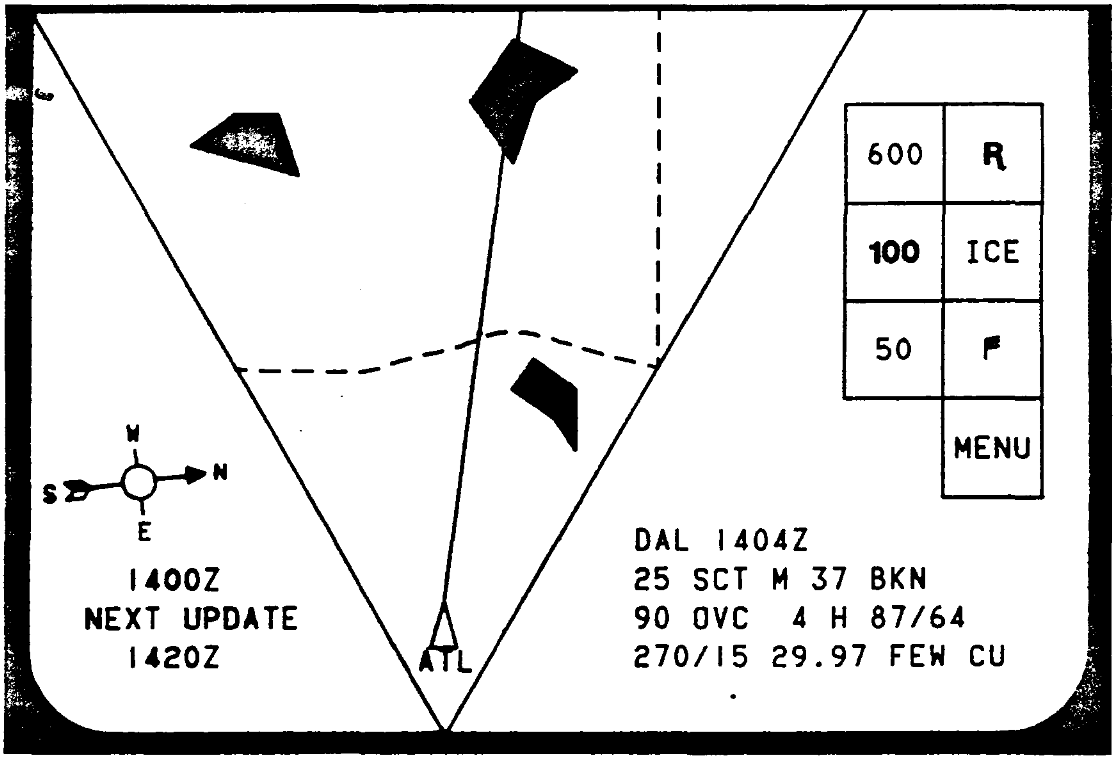
Figure 80. CDWI Showing Icing Conditions



NOTE:

WIND AND 600 NM RANGE HAVE BEEN SELECTED. WIND DIRECTION AND VELOCITY ARE SHOWN FOR AIRCRAFT ALTITUDE ± 2000 FEET.

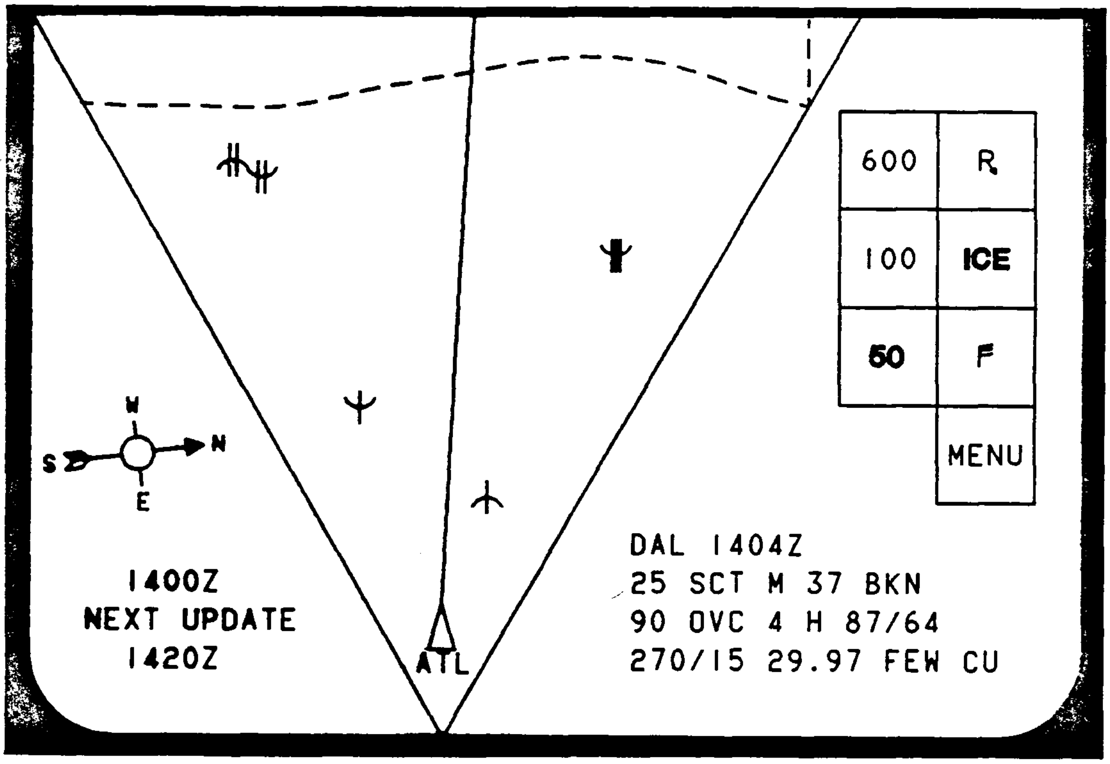
Figure 81. CDWI Showing Winds



NOTE:

THUNDERSTORMS AND 100 NM RANGE HAVE BEEN SELECTED. WHEN 100 NM OR 50 NM RANGE IS SELECTED, THE GENERAL LOCATION AND SHAPE OF THE STORMS ARE SHOWN WITH CRUDE GEOMETRIC SYMBOLOGY.

Figure 82. CDWI Showing Thunderstorms on the 100 NM Range



NOTE:

ICING AND 50 NM RANGE HAVE BEEN SELECTED. STANDARD ICING SYMBOLS WHICH DESCRIBE SEVERITY ARE DISPLAYED FOR AIRCRAFT ALTITUDE ± 2000 FT.

Figure 83. CDWI Showing Icing on the 50 NM Range

T-CAS

The quotations from the FAA administrator that are presented below provide an excellent discussion of the desired capabilities of the traffic-alert and collision avoidance system (T-CAS). However, it should be noted that the T-CAS system is still under development and contains many uncertainties. Some very real problems have yet to be resolved for the system to operate precisely as described. Changes and compromises may become necessary as the program matures.

The FAA Administrator describes the traffic-alert and collision avoidance systems, T-CAS I and T-CAS-II, in Reference 5 as "an independent airborne backup to the ground-based ATC system to provide yet another measure of safety."

He goes on to say that:

> "T-CAS will operate throughout the airspace without dependence on ground equipment in the current and future ATC system. It has at its heart the new Mode-S transponder and its integral data-link, and it uses the Mode-S message format for T-CAS-to-T-CAS communications to insure compatibility with the internationally standardized SSR.
>
> "Various levels of collision protection will be available from T-CAS equipments. The least expensive T-CAS-I option, intended for installation in small general-aviation aircraft, will indicate to the pilot that an intruding aircraft is in the near vicinity. In addition, T-CAS-I equipment can display the position and maneuver intent of T-CAS-II aircraft of concern.
>
> "The more sophisticated T-CAS-II unit will not only be able to provide an alert that an aircraft is nearby, but will also indicate the relative position of the intruder by displaying a traffic advisory and coordinated resolution advisory on a cockpit display. The more expensive T-CAS-II will provide the maximum protection in all airspace.
>
> "T-CAS-II is a full-capability system intended for installation in air transports and sophisticated general-aviation aircraft. The minimum T-CAS-II can provide-
>
> -Climb/descend resolution advisories in high-density airspace.
>
> -Proximity warning of nearby aircraft, including the bearing of the intruding aircraft.
>
> -Crosslink traffic and maneuver advisories to T-CAS-I equipped aircraft to allow safe maneuvering between T-CAS-I and T-CAS-II-equipped aircraft.

-Assurance that signals transmitted by T-CAS-II avionics do not degrade the ability of the ground-based ATC radars to sense traffic. "In addition, development work on an enhanced T-CAS-II will assess the technical and economic feasibility of possible improvements. A more powerful system would be able, in addition to the minimum capabilities, to provide precise angle measurements and horizontal-maneuver advisories.

"T-CAS-I provides a limited set of traffic advisory services and includes an integral Mode-S transponder that improves ground surveillance and permits a small general-aviation aircraft to be seen by a nearby T-CAS-II aircraft.

"T-CAS-I can also receive and display the Mode-S advisories crosslinked by T-CAS-II-equipped aircraft. Finally, T-CAS-I can sense the presence of nearby aircraft by passively listening to their transponders' replies."

Cockpit Display of Traffic Information (CDTI)

In this preliminary design, traffic-alert and collision avoidance system (T-CAS) information is provided to the pilot on the cockpit display of traffic information. Since the actual system has not been developed, many changes can be expected before the design is completed. The following description is a conception from which to begin further research.

The CDTI format is presented on the lower portion of the center display. The CDTI format integrates T-CAS and proximity warning information into a single format as shown in Figure 84. The display consists of coded symbology representing: own-ship, other aircraft, other aircraft's relative altitude and position, critical altitude, and projected points of conflict. The own-ship symbol is centered in the lower third of the screen and is shaped distinctly different from the other aircraft symbols. The remaining ship symbols are shaped to represent their relative altitude to the own-ship or the lack of an altitude transponder. "D"-shaped symbols represent other aircraft below own-ship altitude, "A"-shaped symbols represent aircraft above the own-ship, and "U"-shaped symbols represent aircraft without altitude transponders. The "D" and "A" symbols are color coded when the altitude separation is $\pm$1000 feet (amber) and $\pm$500 feet (red). "U"-shaped symbols are always white. All the aircraft have predictor information based on transponder encoded vector information. The system is capable of showing probable point of minimum separations based on predictor information. The system displays a filled proximate advisory circle (amber), a filled threat advisory circle (red), or a filled resolution advisory circle (red) based on that information. The red resolution

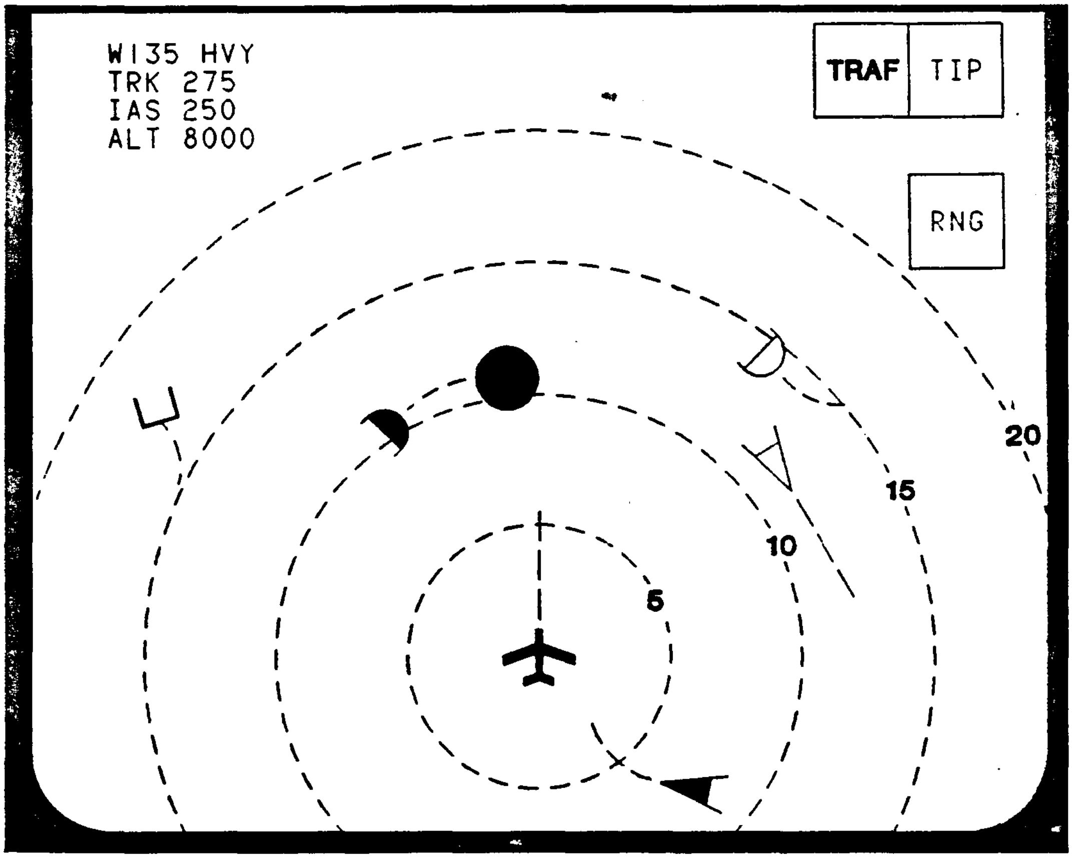


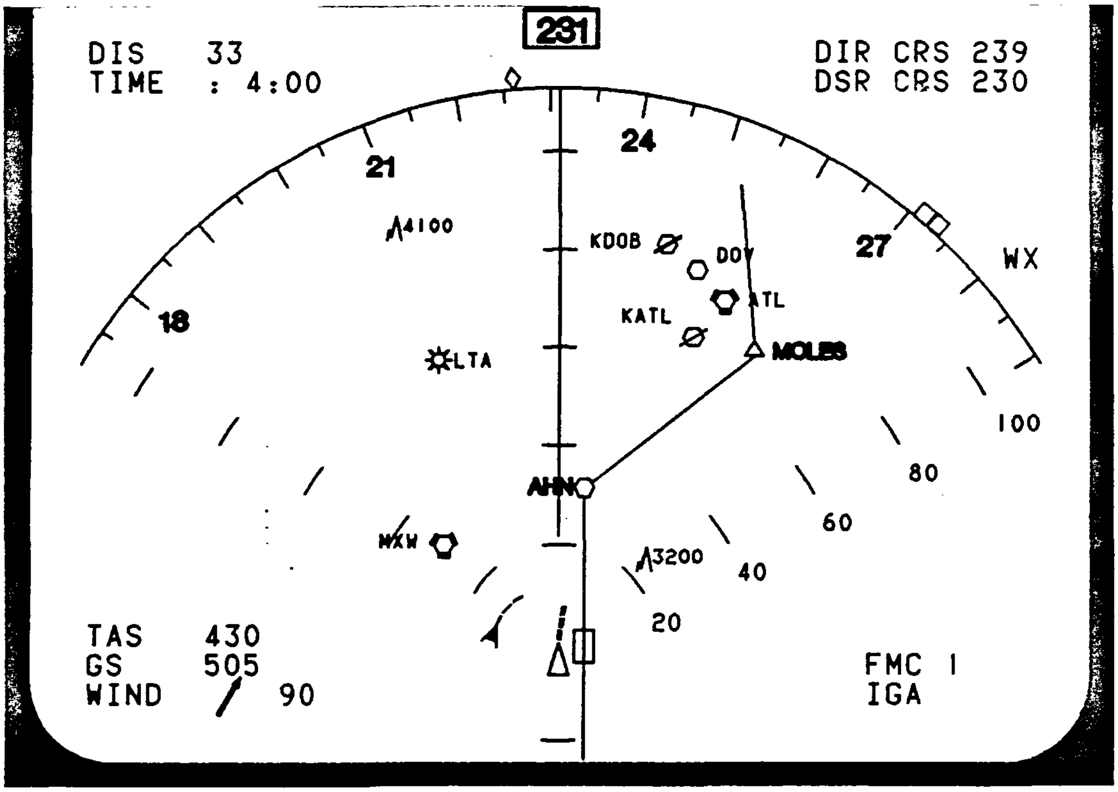
Figure 84. CDTI and Proximity Display

advisory circle is accompained by a time critical message on the primary flight display, a case that is discussed later. Two display ranges, 20 and 50 miles, are provided. The alternate range is selected by touching the touch panel labeled RNG. A data box of infomation on any selected target may be viewed by touching that specific aircraft symbol. The data box appears in the upper left corner of the display for a seven second period after selection and includes aircraft identification, track, indicated airspeed, and altitude.

The symbology for some conflicting traffic can be overlayed on the captain's and/or first officer's navigation display, as shown in Figure 85, by selecting the traffic (TRFC) switch on the appropriate nav display control panel. The type and amount of CDTI to be displayed is yet to be determined.

In addition to the CDTI format, time-critical T-CAS messages are superimposed on the primary flight display format, as illustrated in Figure 86, and are automatically "voiced" to the pilots. This preliminary set of time-critical messages consists of the negative and positive resolution advisories and the vertical speed limit (VSL) and vertical speed minimum (VSM) advisories shown in Table 3.

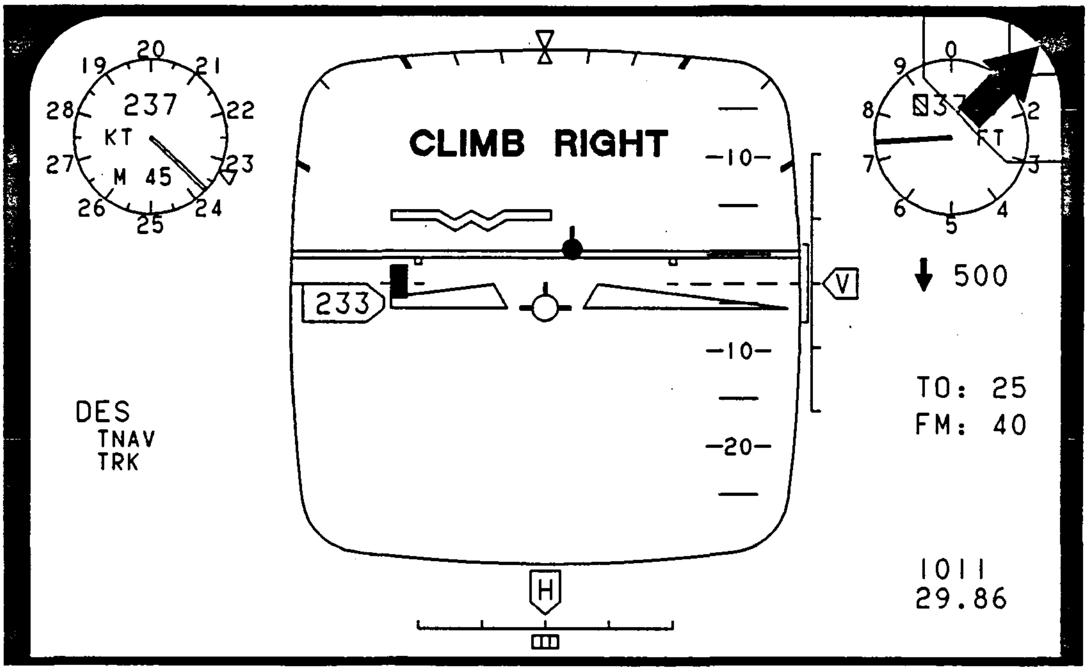
Combinations of commands, such as "climb right," are also permissible. Positive action commands are displayed using both an alphanumeric message and a symbolic command, as shown in Figure 86. The alphanumeric message always appears in the upper center portion of the flight display, while the location of the symbolic command is determined by the command, as illustrated in Figure 87. Positive action commands are displayed in red. Negative action, VSL and VSM commands consist of only an alphanumeric message and are displayed in yellow.



NOTE:

SPECIFIC TYPES OF CONFLICTING TRAFFIC (E.G., SYMBOL TO LEFT OF OWNSHIP) CAN BE OVERLAYED ONTO THE NAV DISPLAY BY SELECTING TRAFFIC (TRFC) ON THE NAV DISPLAY CONTROL PANEL.

Figure 85. Traffic Symbology on Nav Display



NOTE:

TIME-CRITICAL ALPHA MESSAGE (E.G., CLIMB RIGHT) ALWAYS APPEARS IN THE SAME AREA. DIRECTIONAL ARROWS APPEAR IN THE AREA OF THE DISPLAY CORRESPONDING TO THE COMMANDED CORRECTION. SYMBOLOGY DISAPPEARS WHEN CORRECTIVE ACTION IS INITIATED.

Figure 86. Flight Display with T-CAS Message

TABLE 3

TRAFFIC RESOLUTION ADVISORIES

<u>Negative Resolution Advisories</u>

Don't Turn Right

Don't Turn Left

Don't Climb

Don't Descend

<u>Vertical Speed Limit (VSL) Advisories</u>

Climb Max 500 FPM

Climb Max 1000 FPM

Climb Max 2000 FPM

Descend Max 500 FPM

Descend Max 1000 FPM

Descend Max 2000 FPM

<u>Positive Resolution Advisories</u>

Turn Right

Turn Left

Climb (No VSL)

Descend (No VSL)

<u>Vertical Speed Minimum (VSM) Advisories</u>

Climb Min 500 FPM

Climb Min 1000 FPM

Climb Min 2000 FPM

Descend Max 500 FPM

Descend Min 1000 FPM

Descend Min 2000 FPM

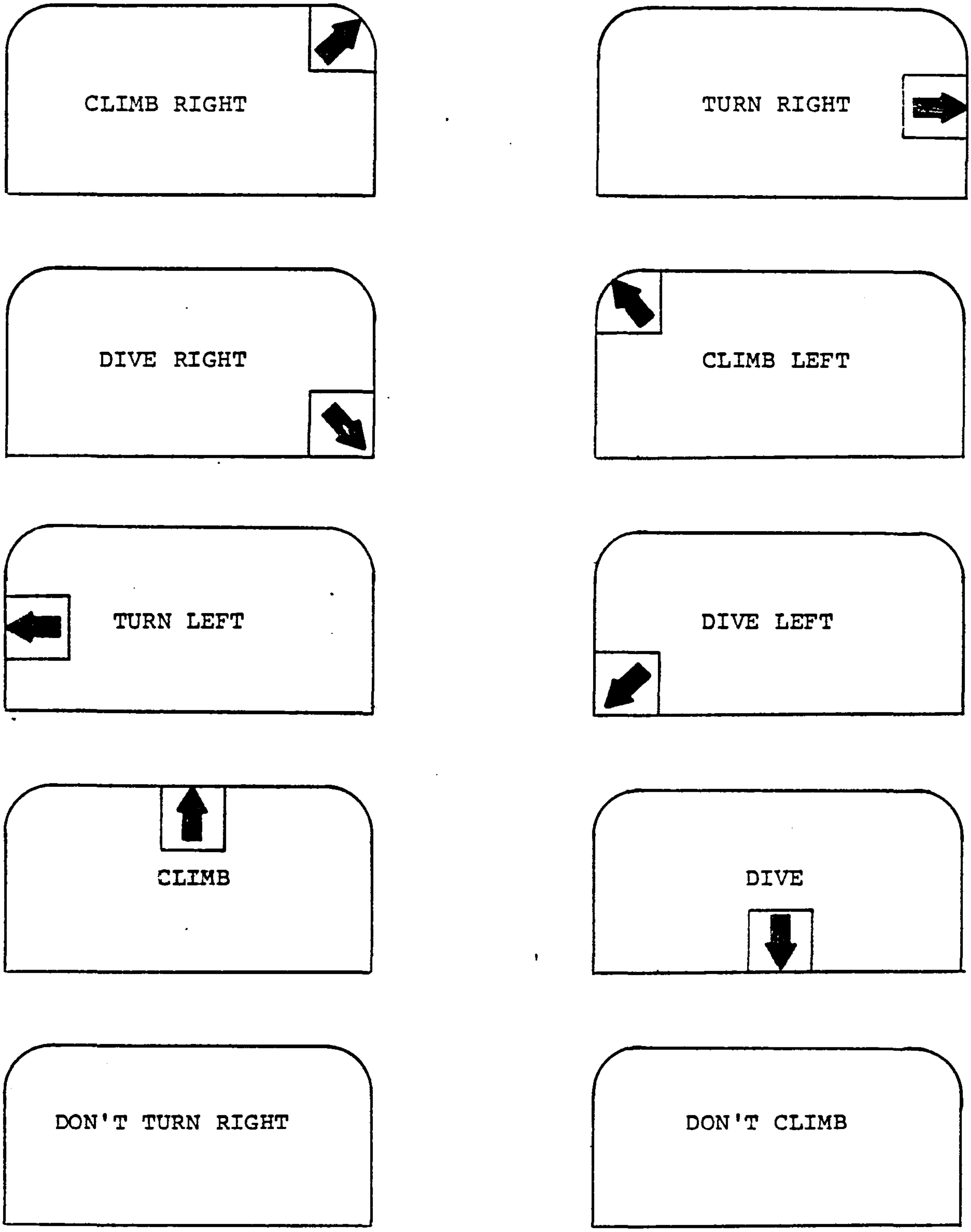


Figure 87. Examples of T-CAS Messages

DIGITAL AIR DATA SYSTEM

The digital air data system consists of: four pitot-static ports; plumbing which cross connects left and right side heads into dual systems; three air data computers (ADC); dual temperature sensors; and four (dual, left and right) angle-of-attack sensors.

One pitot-static system will feed ADC number 2, the other will feed ADC number 1, and its valving will connect to ADC number 3. One set of angle-of-attack sensors will be connected to number 1 ADC and one set to number 2.

ADC number 1 is powered from the number 1 forward AC bus, and ADC number 2 from the number 2 forward AC bus. Number 3 ADC is powered from the number 3 forward AC bus.

The number 1 ADC furnishes data to the captain's flight and nav displays; the number 2 ADC furnishes data to the first officer's flight and nav displays. The number 3 ADC is used as a redundant system to either of the other two and may be switched to drive either or both sets of displays by using the switches shown earlier in Figure 20.

The air data computers use pitot and static pressure and total temperature to compute outside air temperature, altitude rate, calibrated airspeed, true airspeed, and Mach. These calculations and the outputs to all other systems conform to ARINC 706. True angle-of-attack is also calculated and output on the air data buses in ARINC 429 format.

The other interfaces are as follows:

(1) Outputs from all three ADCs are furnished to both channels of the flight control system.

(2) Outputs from number 1 and number 2 ADCs are fed to both flight management computers (FMC) and Mode-S transponder.

(3) Each of the ADCs feed the respective inertial reference system (IRS) (i.e., number 1 to number 1, etc.).

(4) The output of the number 3 ADC is automatically switched to replace a failed system (i.e., number 1 FMC and captain's displays, or number 2 and first officer's displays as appropriate). Manual controls are also provided on the bezel of number 1 and number 5 CRT displays. Manual controls do not override an automatically switched condition.

RADAR ALTIMETER SYSTEM

Dual radar altimeters are provided to obtain terrain clearance at clearance altitudes between -20 feet and 2500 feet. Each system consists of a receiver/transmitter unit and a pair of identical antennas, one used for transmitting and one used for receiving. The beam widths of the antenna are sufficient to allow 60° roll angles and $\pm 40^{\circ}$ pitch angles without causing the system to unlock. A serial digital output is provided to the display systems, the ground proximity warning system (GPWS), the autoland system, and the navigation system. This output contains the altitude to the nearest one-tenth foot, an out-of-range indication bit, decision height and decision height discrete, and a fail bit. A decision height input (analog) is accepted and determines the height at which an automatic trip occurs, indicating that the aircraft is below the set decision height.

Operation

The system transmits pulses from a downward pointing antenna and measures the time until a return pulse from the nearest object is received. The time is measured to the leading edge of the return. The cable and receiver delays are subtracted, and the resulting time is converted to range in tenths of feet. If the pulse received indicates more than 2500 feet altitude, an out-of-range bit is sent along with an altitude value of 2500. If no pulse is received, a fail bit is transmitted with a zero altitude code. During test an altitude of 20 feet should be transmitted with the test bit set.

The altimeter can be adjusted for system delay so that zero altitude corresponds to the altitude at touchdown. The unit will read TBD altitude when the aircraft is parked and fully loaded.

An analog decision height knob varies the decision height from zero to 500 feet. When the aircraft descends below the set height, the decision height discrete is set. If the aircraft then goes above this height by 10 feet, the bit is reset to zero.

Controls and Displays

The radar altitude alerting system is controlled through set knobs located on both ends of the guidance and control panel, as shown in Figure 88. Both controls have rotary knobs through which the desired decision height is set. The digital readout of the set altitude is displayed on the appropriate pilot's flight display when the knob is pulled out. Pushing the knob in causes the digital readout to disappear. The captain's or first officer's system is selected to provide audio alerting through a two position (CAPT/FO) switch on the captain's side. At 100 feet above decision height during a descent, the visual DH symbol begins to flash on and off and a voice alert announces "One Hundred Above." From decision height to DH minus 30 feet, the visual DH symbol remains steady, at which time it disappears from view. Voice alerts announce one hundred feet above decision height, decision height, and the height above touchdown in 50 foot increments below that.

ALTITUDE ALERT

The altitude alert system serves as a reminder to the crew to reduce the likelihood of cruise altitude deviations and to warn of the proximity to the runway during landing approach. The system consists of two parts: barometric altitude alert and the radar altitude alert.

Barometric Altitude Alert

This system compares the actual altitude obtained from the pilot's barometric altimeter with the reference altitude set in the altitude window of the guidance and control panel. Figure 88 shows the location of this window on the GCP. When the aircraft converges to within ± 250 feet of the reference altitude, a voice message will say, "altitude." Once within 250 feet of the reference, the system will alert the crew with "check altitude" if the altitude deviates more than 250 feet from the reference.

Radar Altitude Alert

This system compares the altitude obtained from the radar altimeter with the decision height which has been set into that radar altimeter. The radar altitude alert system works in conjunction with either the captain's or first officer's radar altimeter, depending on the position of the radar alert switch located on the GCP, shown in Figure 88. The radar altimeter set knob is used to set the alert altitude for the radar altimeter. The alert altitude is displayed on the flight displays and can be reset when either the captain's or the first officer's push-pull-rotary switch is pulled out. The display disappears when the switch is pushed in. The selected altitude alert (alert/decision height) is automatically displayed on both flight displays when that altitude is reached.

Voice alerts announce 100 feet above the decision height, decision height, and the height above touchdown at 50-foot intervals until touchdown. For example, if the decision height is set at 200 feet above ground level, the voice alert would announce: "ONE HUNDRED ABOVE," "DECISION HEIGHT," "ONE HUNDRED FIFTY FEET," "ONE HUNDRED FEET," and "FIFTY FEET."

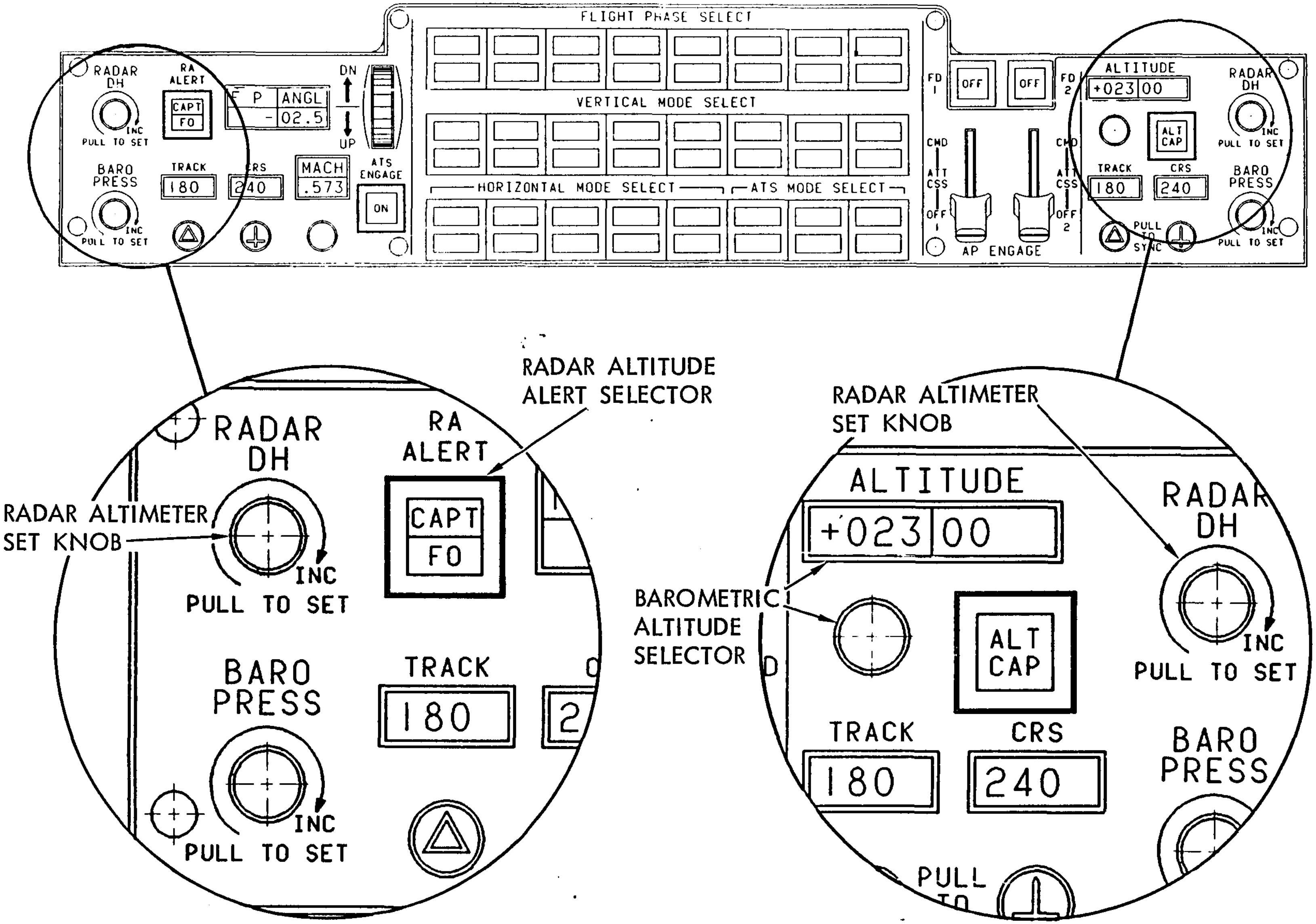


Figure 88. Altitude Alerting System Controls

Barometric Pressure Set Control

The barometric pressure altimeter settings for the captain's and first officer's flight displays are controlled through separate push-pull-turn knobs shown in Figure 88. When the knob is pulled to the "out" position, barometric pressure is displayed on the appropriate flight display in inches of mercury and millibars; the setting may be changed by rotating the knob. Pushing the knob to the "in" position causes the display of pressure setting to disappear and declutches the knob so that the setting cannot be changed. While this control is not part of the altitude alert system, it is discussed here because of the compatibility of the figures involved.

GROUND PROXIMITY WARNING SYSTEM

Although the ground proximity warning system (GPWS) is part of the ACAWS, it is discussed separately because of its sensors and specific capability to detect and annunciate terrain avoidance information. A voice message alerts and identifies the specific flight-path-to-terrain problem. Additionally, a time-critical message is presented on the captain's and first officer's flight displays whenever "pull-up" action is required. The format for this message is similar to that used for T-CAS with a red arrow pointing up and the words "pull-up."

The GPWS computer contains the latest state-of-the-art digital hardware, self test capability, and fault retention capability to enhance the maintainability of the system. The computer generates isolated digital signals indicating the message to be heard and displayed. These are sent to the central voice message system and to the flight displays. A forward-looking radar sensor uses monopulse techniques to detect terrain along the flight path and provides the computer with the range and range rate to the threatening terrain.

Seven different warning modes are programmed into the GPWS computer. These seven modes produce 10 different voice warning messages. These modes and their associated voice warnings are listed below.

o <u>Mode 1</u> - Excessive barometric descent	(A)	"Sink Rate - Pull-Up"
o <u>Mode 2</u> - Terrain closure rate	(A)	"Terrain - Pull-Up"
o <u>Mode 3</u> - Descent after takeoff	(A) (B)	"Don't Sink - Flaps" "Don't Sink - Gear"
o <u>Mode 4</u> - Unsafe terrain clearance	(A) (B)	"Too Low - Gear" "Too Low - Flaps"
o <u>Mode 5</u> - Descent below glideslope	(A) (B)	"Glideslope" (High Volume) "Glideslope" (Low Volume)
o <u>Mode 6</u> - Descent below decision heights	(A)	"Minimums"
o <u>Mode 7</u> - Terrain in flight path	(A)	"Terrain Ahead - Pull-Up"

The conditions which set off each of the warnings or cautions listed above are set by the Radio Technical Commission for Aeronautics document DO-161A, Reference 6. As an optional feature, the range, bearing, and height of the threatening terrain can be furnished for an obstacle display. With the advent of "look-ahead" capability, some of the warning modes may be unnecessary and may be eliminated in the future. Additionally, warning limits will be adjusted to reduce nuisance warnings.

Note: Since the baseline simulator does not have a terrain simulation, the forward-looking capability will not be exercised initially. Programmed points, such as the air route minimum safe altitude points, could be used to simulate terrain. Additionally, obstacles currently shown on terminal area charts could be used to trigger this warning.

Operation of the GPWS

The ground proximity warning system is controlled by remotely controlled circuit breakers, a test switch in the CDU, and an inhibit switch.

GPWS Inhibit Switch - This switch, located on the overhead console on the engine start panel, is used to inhibit all modes during situations where the system is activated during intended operations. When this switch is depressed, a GPWS INHIBIT message appears on the ACAWS display as an advisory message.

GPWS Test Switch - A ground test switch is provided for the GPWS on a test page. in the CDU. Pressing the test switch initiates a dynamic check of each mode and verifies normal internal system operation. Successful self-test is indicated when the advisory "GPWS TEST - OK" and the "PULL-UP" indication has been displayed.

Airborne self-test may be accomplished above 1,000 feet radio altitude with the gear and flaps up. The airborne self-test is a status check of applicable validities, voice circuitry, and full time internal monitoring. The sequence of operations is the same as for the ground self-test.

System Indicators - In addition to the messages displayed in the top center of the flight display, two additional GPWS messages will appear on ACAWS. The GPWS INHIBIT advisory was discussed previously. A GPWS FAULT indication is displayed as a caution message, indicating that the GPWS has failed and is inoperative.

INTEGRATED COMMUNICATIONS/NAVIGATION SYSTEM

The integrated communications/navigation (ICN) system provides the means for tuning and frequency readout of all aircraft radios. This greatly reduces the required console space and consolidates all controls into one location where they can be easily operated by either pilot. The system consists of a frequency entry panel, a frequency display panel, a transmit and monitor control panel for each pilot, and auxiliary controls that are operated through a touch panel overlay on the functional systems (#4) CRT. The units provide tuning data to two each of the following: (1) VHF comm radios; (2) HF comm radios; (3) VOR receivers; (4) DME receivers; (5) MLS receivers; (6) ILS receivers; and (7) the transponders. System redundancy is provided through the captain's and first officer's flight management computer control/display units (CDUs). Operation by that method is described in the section on CDU operation.

Frequency Entry Panel

The frequency entry panel, shown in Figure 89 (Item 26, Figure 15), is located on the desk top between the throttles. Its operation is described below.

When a communications/navigation frequency, preset navigation channel, or transponder code is typed on the keyboard, the digits are displayed on a pre-entry readout window. The display is left-justified, thus the first character typed appears on the left end of the window. When the frequency/channel is entered into the system by pressing the ACTIVE or STANDBY select key on the frequency display panel, the digits disappear from the pre-entry display and appear in the selected frequency display window. Additionally, one frequency can be preset in each of the four communications radios for later recall. This is accomplished by typing the frequency as described above, then pressing the appropriate preset frequency key (F1 or F2 for VHF, F3 or F4 for HF). This will cause the pre-entry readout window to go blank and the frequency to be stored. After the frequency is stored, it can be recalled by pressing the appropriate preset frequency key again. This displays the stored frequency in the pre-entry readout window, where

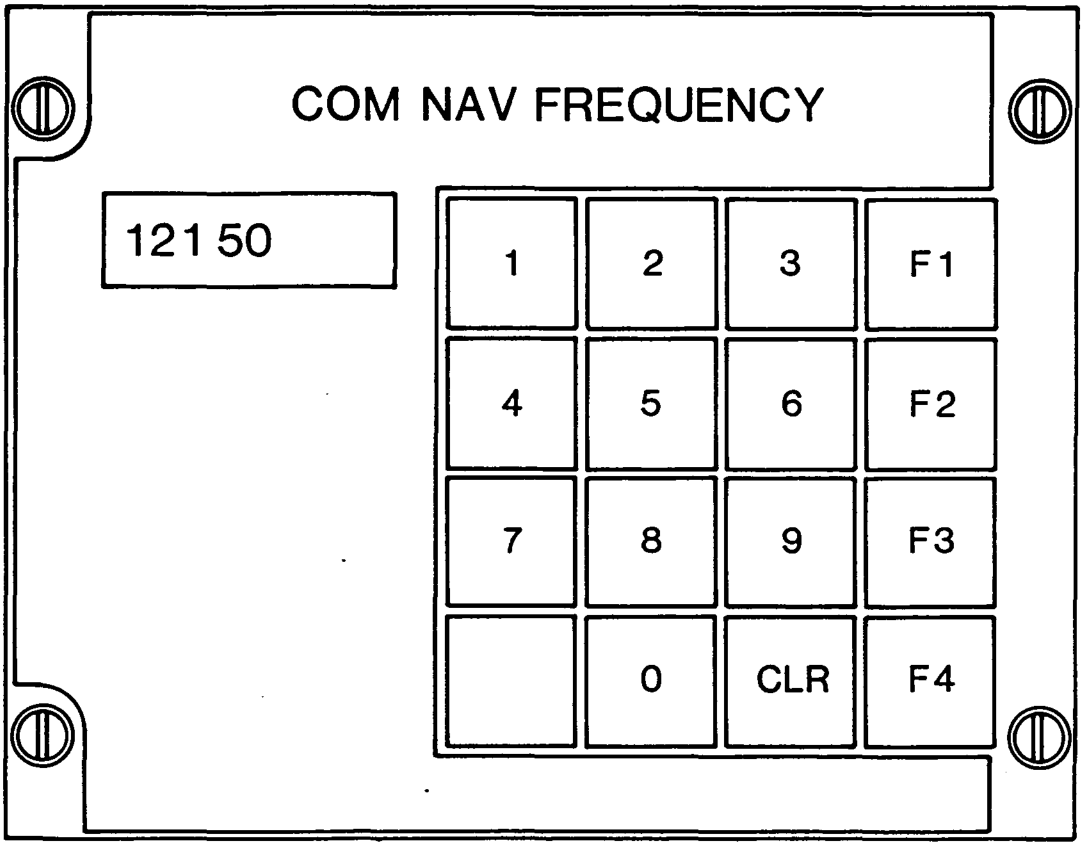


Figure 89. Comm/Nav Frequency Entry Panel

it can be transferred to either the ACTIVE or STANDBY position on the frequency display panel.

When the comm/nav page is selected on the CDU, frequencies typed on the scratchpad can be entered into the active or standby position through the touch panel control over the CDU display. When this occurs, the frequency disappears from the scratchpad and appears in the selected position on both the CDU display and the frequency display panel.

The intercom transmit selectors and mic buttons are monitored by the system so that a radio cannot be retuned (active frequency) while in the transmit mode condition. Tuning occurs immediately upon release of the mic switch. Since frequencies can be entered from either of the flight management CDUs or the frequency entry panel, a priority system for entry has been established. The last one entered in any particular radio has priority, and this replaces a previously entered frequency.

A keyboard, consisting of 10 numerical keys, a clear key, and 4 preset frequency entry keys, is used to type frequencies and channels for tuning purposes.

Frequency Display Panel

The frequency for all tuned communication and short-range navigation radios are displayed on the frequency display panel shown in Figure 90 (Item 25, Figure 15).

The display panel contains two 6-digit (plus one decimal for VHF) frequency windows for each VHF and each HF communications radio (one active and one standby); one 6-digit (plus VHF decimal) frequency window for each VHF nav receiver; one 3-digit channel window for each MLS receiver; and a 4-digit code display window for the transponder. Line select keys are provided alongside each display window for frequency entry. Depressing a line select key enters the pre-entry readout number in the associated frequency/channel/mode display window, and in the case of active frequencies, the radio is tuned to that frequency. A frequency transfer key, located between the active and standby windows, is provided for each communications radio. This key interchanges the active and standby frequencies.

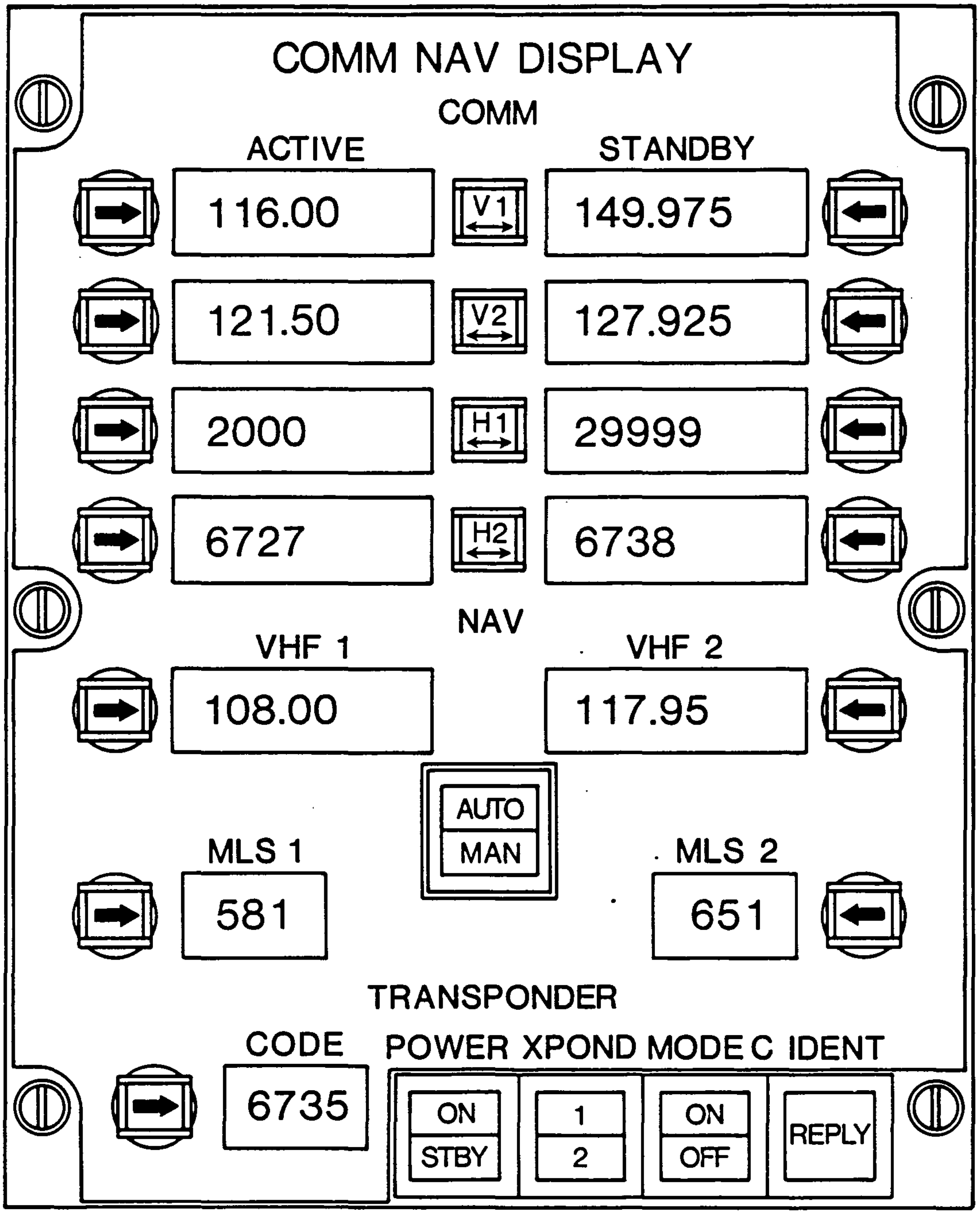


Figure 90. Comm/Nav Frequency Display Panel

An automatic or manual (AUTO/MAN) selection is provided for the VOR/DME radio navigation system. This allows manual frequency/channel tuning by the pilots through the keyboard or automatic tuning by the flight management computer. In either case, the tuned frequencies are displayed in the appropriate windows.

All transponder controls and displays are contained within this panel. The transponder code display window and line entry key operate similarly to the communication and navigation functions. Additionally, lighted push-button switches are provided to: (1) select either the number 1 or number 2 transponder unit; (2) select transponder power to ON or STANDBY; (3) turn Mode-C ON or OFF; and (4) to transmit the aircraft identification code (IDENT) or display the ground radar's interrogation signal (REPLY).

Note: The IDENT pushbutton activates the transponder identification function only if the transponder is not under lock-out control of a Mode-S transponder ground station. The identification function is used only by ATCRBS systems and not by Mode-S systems, since the Mode-S reply normally contains the aircraft identity by registry number.

Tuning

Two cross-linked computers are used for redundancy. The computers accept keyboard entries and display them in the scratchpad. When a line select key is pressed, the pre-entry readout is tested to determine if a valid frequency/channel/mode has been entered for the radio selected. If the frequency is valid, the signal is sent to the proper radio for tuning, provided the radio is not selected for transmit and the mic button is not depressed. If the selection is invalid, it will not transfer and the displays remain unchanged. When the radio is tuned, the signal from the radio is returned to the display and to the computer. The computer checks for proper frequency and, if the frequencies do not match, sends a fail signal to the ACAWS. When a standby frequency is entered, it is stored in memory until a new active is selected, either through the line select switch or the transfer switch. Whenever this occurs, the old active over-writes the current standby frequency.

When the power has been turned off to any receiver through the remote circuit breakers (which are controlled through the flight management computer CDU), the active and standby frequency displays are blank. If the power to the receiver is ON, and a malfunction has occurred, a series of dashes (----) appears on both the active and standby frequency displays. A series of dashes (----) is also displayed in the standby window if a frequency has not been entered into that display.

Tuning the Communication Radios - Radio frequencies are typed on the keyboard and displayed in the pre-entry readout window as described above. After they appear in this display, they may be entered into either the active or standby display window on the comm/nav frequency display panel by pressing the line select key opposite the appropriate window. For instance, if 13595 is typed and appears in the pre-entry readout window, it can be entered into either the active or standby side by pressing the key adjacent to that position. It can be transferred between active and standby by pressing the transfer switch located between the two frequency windows. Each time the transfer switch is depressed the frequency which was active is transferred to standby, and the standby frequency is simultaneously transferred to the active side. The receiver/transmitter (R/T) unit is also retuned. When a frequency is entered directly into the active side, the previous active frequency automatically transfers to the standby window and the previous standby frequency is eliminated. When tuning a VHF frequency ending in the 25 or 75 KHz range (e.g., 135.925 or 135.975), the last digit (5) becomes understood and, therefore, does not have to be typed. The 5 is displayed, however, and the R/T unit tuned to that frequency when 135.92 or 135.97 is in the active side.

Tuning the Navigation Radios - VOR/ILS and MLS radios are tuned in the same manner as the communication radios through the keyboard and the pre-entry display. Frequencies are transferred to the appropriate radio by pressing the select key adjacent to the navigation frequency display window on the frequency display panel. VOR radios may be automatically tuned by the mission computer when the auto position of the AUTO/MAN switch, located between the VHF nav frequency windows, has been selected. Auto-tuned frequencies/channels appear in the frequency/channel display windows, as do those that are manually tuned. The AUTO or MAN legend illuminates when activated to indicate the appropriate tuning status.

The computer stores the proper glideslope frequency and DME channel paired with each VHF nav frequency and tunes these frequencies along with the VHF nav receiver. The DME channel associated with each MLS channel is also stored and is tuned whenever an MLS channel is selected.

Note: Up to six frequencies are sent to each DME in auto and two in manual. The DME scans these frequencies and determines the distance from each. As stated earlier, however, the scan function will not be part of the baseline simulation.

Auxiliary Comm/Nav Control (Touch Panel)

The auxiliary control, accomplished through a touch panel overlay on the number 4 CRT display shown in Figure 91, furnishes control for a number of communications and navigation functions.

Two VHF squelch selectors set the VHF squelch to an automatically determined level (ON) or disable it completely to allow broken or weak signals to be heard (OFF).

The HF squelch controls, consisting of increase or decrease switches for each radio, furnish squelch level control for the HF receivers or turn the squelch completely off. During HF selective call (SELCAL) operation, these controls are rendered ineffective, and squelch is controlled automatically by the SELCAL unit. When selective call is selected, the SELCAL indicator illuminates, and an ACAWS advisory is displayed whenever a properly addressed message is received on HF. Depressing the CALL switch activates a go-ahead reply and sets the squelch to normal level. In SELCAL operation, squelch is set to maximum so that no message is output on the audio line to intercom.

Upper sideband (USB) or lower side band (LSB) on the HF radios may be selected through alternate selections on selector switches for each HF radio. The HF scan or fix functions are used during HF selective call operation and are discussed in the section on that subject.

High or low range on the marker beacon receiver is also selected on this panel.

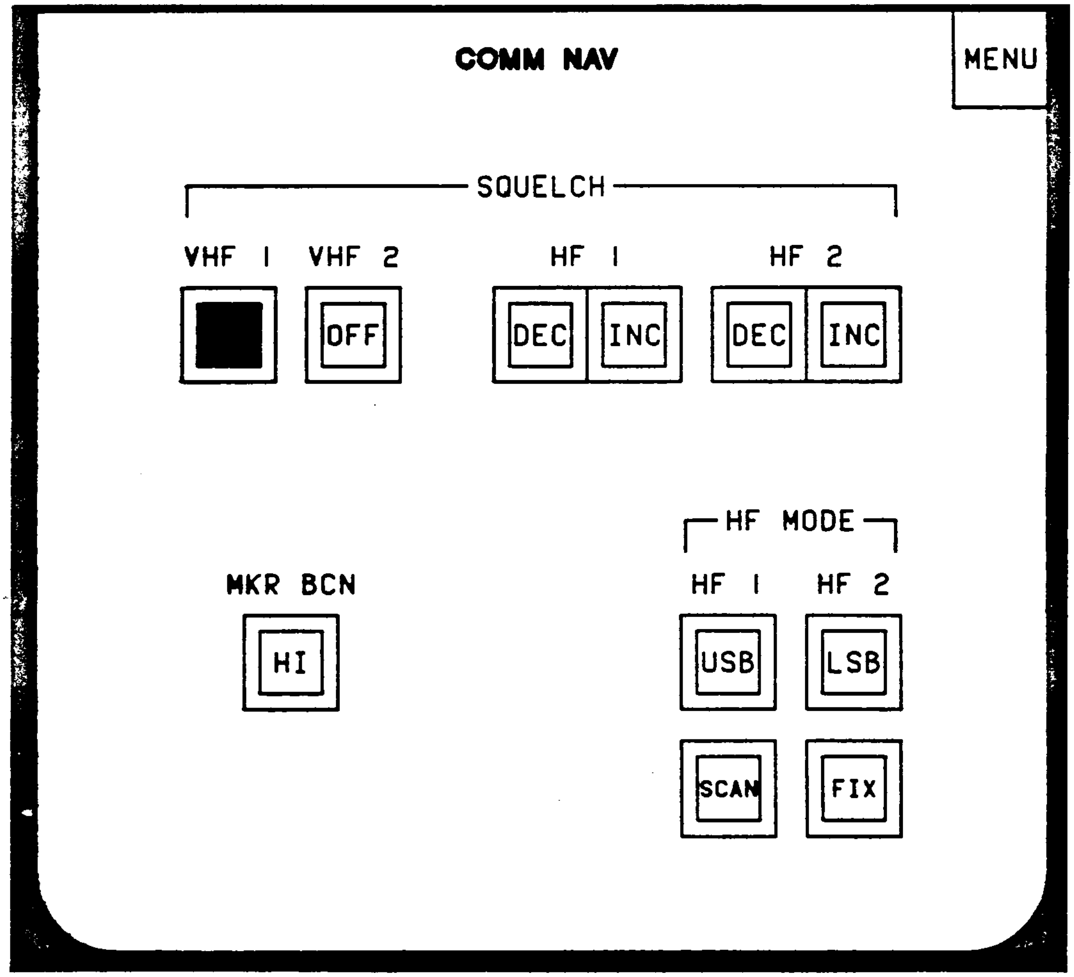


Figure 91. Comm/Nav Auxiliary Controls

Transmit/Monitor Panel

The transmit/monitor control panels, shown in Figure 92 (Item 23, Figure 15), provide each pilot with the capability to selectively and simultaneously monitor any or all comm and nav receivers, simultaneously or individually control the reception volume on each radio, and selectively transmit on any one transmitter when the microphone switch is activated.

> Note: Microphone switches are provided on each control stick for boom mics and on hand-held microphones. Additionally, foot-operated mic switches for boom mics are located near the feet of each pilot. The pilots may receive the audio signals through individual headsets or speakers located in the headrests of each pilot's seat. Speakers may be turned ON or OFF through a switch on the headrest.

"Pull to monitor," "push to turn off," and "turn to control volume" switches are provided for each comm and nav radio. The pilot can monitor the functions individually or in any combination by pulling out the appropriate switches. The volume can be adjusted individually by turning the switch. The master volume control is used to adjust all monitored radios simultaneously.

Lighted pushbutton switches are used to select any transmitter (i.e., VHF 1 or 2, HF 1 or 2, intercom or public address). Since they are mutually exclusive, only one may be selected at a time. Pressing a switch causes the switch light to illuminate, any other selected switch to be disconnected, and its switch light to go out. The associated monitor switch does not need to be pulled to the ON position in order to monitor a radio with the transmitter selector switch pushed. This automatically provides monitor capability for that radio.

A rotary selector switch for intercom provides the capability to communicate with the ground maintenance crew or any station in the cabin individually or simultaneously (ALL). A pushbutton cabin attendant call switch activates a chime in the cabin at whatever station is selected on the rotary knob.

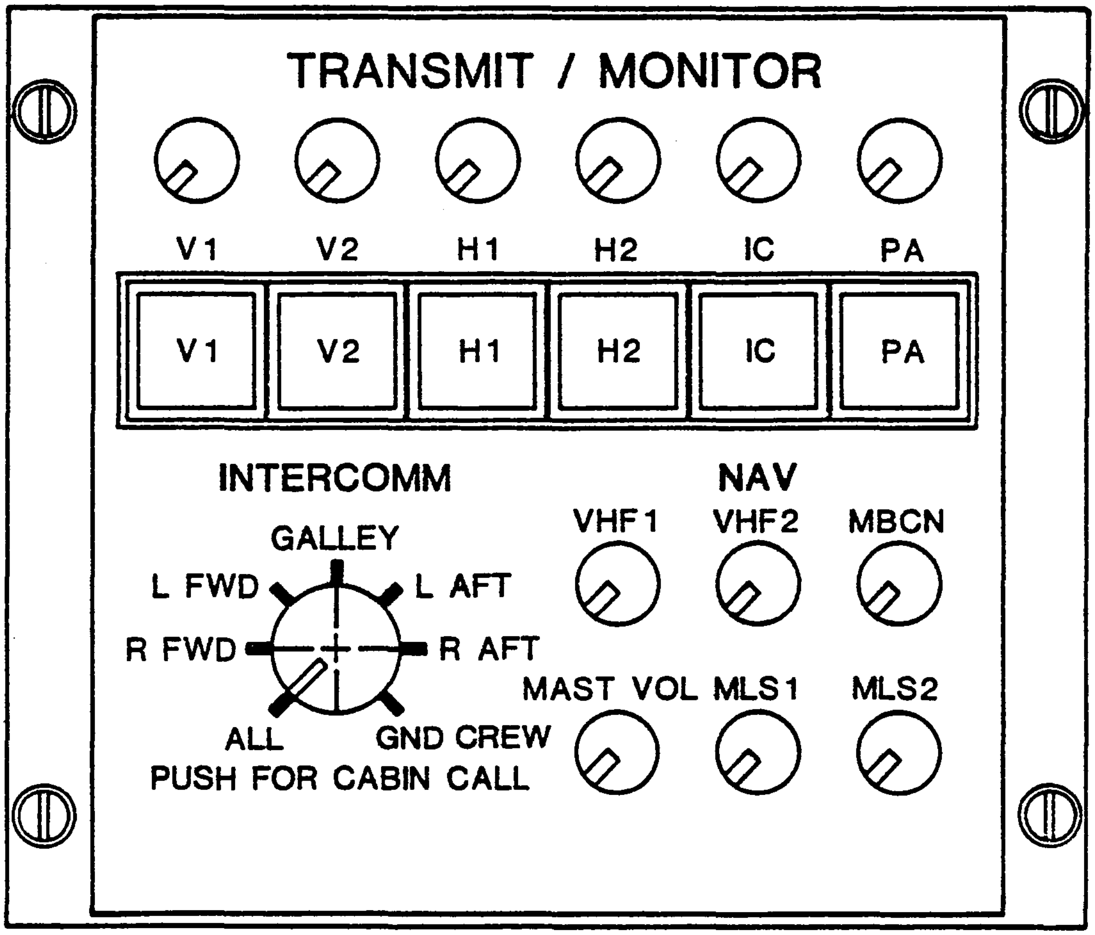


Figure 92. Comm/Nav Transmit/Monitor Control Panel

Radio Power Control

The power for all communications and navigation radios and transponders are controlled through the remote circuit breakers. Although the radios are typically powered up and down with aircraft power, they may be controlled individually through the circuit breaker page in the flight management CDU.

VHF COMMUNICATIONS RADIO SYSTEM

The VHF communication system consists of dual VHF blade antennas and dual VHF transceivers which are independently powered from different buses. Frequency control is through a centralized tuning control and the control/display units.

The antennas are standard VHF blades and are located one on top and one on the bottom of the aircraft. Antennas are not switched between units.

The VHF transceiver meets ARINC characteristic 716 in its entirety. Pertinent portions of the system performance are as follows:

(1) The unit is digitally tuned by the control through either one of two ARINC 429 input ports. The labels, frequencies, and other data are as specified in ARINC 429 and ARINC 716. An ARINC 429 input from the ACARS will also tune the transceiver as determined by the condition of the voice/data discrete from the ACARS.

(2) The number 2 transceiver receives inputs from either the intercom or ACARS processor for transmission and sends received signals to the ACARS processor and intercom system. The intercom receives VHF audio only in the voice mode.

(3) The number 2 transceiver receives only voice from the intercom along with the transmit discrete.

(4) The number 1 transceiver receives only voice from the intercom along with the transmit discrete.

(5) All signal levels are as specified in ARINC 716.

(6) ON/OFF control of both VHF transceivers is via remotely controlled circuit breakers in the control/display units.

(7) A squelch on/off control is provided on the comm/nav display with touch panel overlay on the number 4 CRT.

HIGH FREQUENCY COMMUNICATIONS & SELECTIVE CALLING (SELCAL) SYSTEM

The high frequency (HF) subsystem consists of dual, digitally tuned transceivers, dual digital antenna couplers, a single slot antenna located at the base of the vertical fin, and a SELCAL unit. The HF subsystem interfaces with the integrated comm/nav tuning system and the flight management system CDUs. The subsystem is adaptive and can be preset to tune sequentially over eight different frequencies, testing for a signal at each one. If a signal is received, it is tested by SELCAL for address; and, if intended for the aircraft, the set will lock on that frequency, transmit a go-ahead signal to the ground, and signal a "call" signal to the pilot. Conversely, in scan mode, the transmitter will transmit the intended call sign of the ground station over up to eight frequencies. When the ground station responds with a go-ahead, an "HF contact" signal is relayed to the aircraft signifying that the voice transmission may begin. The system may also be manually tuned to a single frequency and may be used without SELCAL. When SELCAL is used, only those transmissions preceded by the aircraft radio call sign will be distributed.

The number 2 HF radio may also be dedicated to ACARS operation. In this instance, operation is as described under the ACARS system description; ACARS messages are never distributed through the interphone system. This radio cannot be used for both ACARS and SELCAL simultaneously.

Note: The scan mode will not be part of the baseline simulation.

HF Transceiver

The HF transceiver operates over the band from 2 to 30 megahertz, in 100 Hz steps (280,000 channels). Tuning is provided, however, only in 1000 Hz steps. The tuning cycle of the transceiver includes the antenna coupler tuning time and takes approximately 10 seconds when a frequency is initially tuned. Up to eight frequencies are remembered, however, and these eight can be retuned by the coupler in 100 milliseconds. Initial tuning requires transmitter "keying" which occurs automatically. A tone sounds when the frequency is properly tuned. Subsequent tuning does not require transmission of a signal.

The transceiver output is 400 watts peak output power on upper or lower side band, which is adequate for worldwide coverage.

SELCAL Unit

The SELCAL unit reads a tone/pulse code which is transmitted indicating the radio call sign of the aircraft for which the message is intended. When the aircraft responds, the conversation can be initiated.

Interface with the Integrated Comm/Nav System

The integrated comm/nav system is used to tune the HF transceivers in the fixed (manual) mode as described in the section on the ICN. Additionally, the system interfaces with the number 4 display touch panel controls to select the scan (search) or fix (manual) mode of operation. When scan is selected, the search pattern is a one-fourth second dwell on each frequency (2-second cycle) which looks for a call tone on each frequency. If a tone is detected, the receiver dwells on the frequency until the call sign is decoded. If it corresponds to the aircraft call sign (determined by wiring), the ICN remains on that frequency; if not, it resumes search.

In scan (adaptive) mode, the computer accepts up to eight frequencies, sequentially tunes each frequency, looks for a valid SELCAL signal on each, and stops scanning whenever a properly coded signal is received. When the proper signal is received, the receiver squelch is then reset just above ambient noise level waiting for the message. While scanning a SELCAL frequency, the active display on the integrated comm/nav panel shows a distinctive symbol. When the receiver is tuned to a frequency, the frequency is displayed. After a suitable pause (10 seconds) when a signal is no longer received, search will be resumed. Transmission occurs on the last frequency on which a valid reception was made within the past minute.

Interface with Flight Management CDU

The scan mode frequencies for adaptive HF are tuned and displayed on the flight management CDU. The format for this information is described in the CDU section.

A selective call switch (CALL) is located on the ACARS and SELCAL panel. When the aircraft is paged on either HF or VHF, the CALL light comes on, a "SELCAL message" signal appears on the ACAWS display, and the corresponding advisory tone can be heard through the headset. Pressing the CALL switch turns the light out, rearming it for another call.

ARINC COMMUNICATIONS, ADDRESSING AND REPORTING SYSTEM (ACARS)

The ACARS is a digital data link and voice communications system which uses the existing VHF and HF airborne communications systems to enhance air-ground operational control communications. It consists of one or more input-output devices, a printer, a processor and the VHF and HF transceivers and their associated antennas.

The ACARS system provides selection of voice or data (digital) mode; VHF or HF transmission of messages; automatic generation and transmission of certain fixed format messages; manual transmission of any selected message; indication of receipt of a message; indication of messages awaiting transmittal; and indication of actual transmission occurring. Although ACARS is normally thought of as a "company" communications system, it is tied in to the air traffic control system and flight services system for weather, flight plan filing, etc.

ACARS Protocol

The protocol for the system requires that no data link information be transmitted while voice communications are taking place. It is necessary, therefore, for the processor to contain message storage and transmit command memory so that a message is transmitted in the first clear interval when no traffic is on the frequency (channel) being used. Data necessary to use the system include frequency and call signs of the addressee, channel(s) to be monitored in a given area, and status of traffic on the channel including an acknowledgement of receipt of message. The system is capable of operating in a demand (AUTO) mode where messages are transmitted as required whenever the system senses a clear channel (and a message is awaiting transmission), or in a polled (ASK) mode where transmissions are made only in response to ground request. In the polled mode, a notification that a message is waiting for transmission is made to the ground station whenever the aircraft is queried, even if the "poll" is a request for specific information. Any time a message is transmitted via ACARS the receiving terminal acknowledges or denies receipt of the message. This prevents garbling or causing a message to be missed without the knowledge of the sender. Any unacknowledged messages are retransmitted. If no reply is received, the message is tried up to five more times. A complete description of the protocol is contained in ARINC 724.

Downlink Information

The ACARS transmits aircraft registry and flight number, status, departure and arrival information, ETA reports, on/off schedule reports, engine health data, fuel and destination reports, etc., in a fixed format which is described in ARINC 724. "Free talk" text message formats are also described. Receipt of downlink requests will be acknowledged by the operator on the ground.

Uplink Information

Information such as weather, requests for flight plan changes, questions and requests for data, etc., and answers to queries are uplinked from the ground to the aircraft. Receipt of an uplink is acknowledged by the operator in the aircraft. Description of the message format is contained in ARINC 724. Many of the ground requests for data, such as position reports, are handled automatically by the FMC and ACARS. Questions or messages requiring pilot response are flagged by an ACAWS message.

"Free talk" messages are uplinked to the aircraft to fill the need for conversational type messages which do not fit a fixed format.

Note: The simulation of this system, as is the case with most air-ground interfaces, can be very complex or extremely simple depending upon the amount of realism desired. As a minimum, the automated standard messages will be available for call up on the flight management CDU. Response will also be available for display when the pilot requests a flight plan change, even if this response merely "rubber stamps" the request. Additionally, a two way manual message capability will be available. For instance, weather data will be canned or dynamic.

Controls/Displays

The ACARS requires an alphanumeric input and display which is provided by the CDUs. Selection of ACARS mode on the CDU provides this capability. An ACARS message advisory is provided on ACAWS to alert the pilot when information is available on the CDU.

Selection of either the VHF or HF radio for ACARS operation, selection of voice or data operation for that radio, and selection of the demand (AUTO) or polled (ASK) protocol is made with three switches on the ACARS and SELCAL panel shown in Figure 93.

The ACARS message format is a simple and straightforward approach for transmitting and receiving ACARS messages via the CDU. When a message is received, the first indication to the crew is an advisory on ACAWS stating "ACARS Message." One pilot must then select ACARS on his CDU, and the message will appear as in Figure 94. Should the message be longer than 10 lines, the crew can scroll it forward or backward using the next page and previous page switches on the CDU bezel. To clear the entire message the crew must select CLEAR. A switch marked RCVD is provided to acknowledge receipt of the message, and the PRINT switch causes the entire message to be printed on the hardcopy printer.

Figure 95 is an example of an outbound conversational message to be sent via ACARS to Atlanta Center. The crew selects ACARS, CLEAR, and then enters TO ATLARTCC in the first line. Once the TO has been entered, the date time group appears at the top, the diamond symbols appear down the right side, and the legends, including a SEND switch, appear at the bottom. When typing the body of the message, the system automatically edits the text to break it before the word which would cause the line to be too long for the space provided. The text is automatically transferred from the scratchpad to the display, line by line, as the text is typed. That is, it does not have to be transferred with the line switches. The diamonds permit individual line entry or editing. As with the inbound messages, there are keys provided for printing and clearing the message. Once the message is entered to the satisfaction of the crew, it may then be transmitted by pushing the SEND switch.

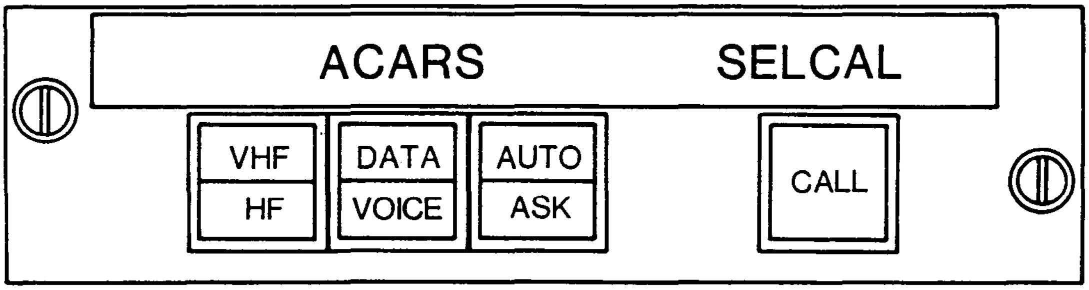


Figure 93. ACARS and SELCAL Panel

```
                                              CDU 37
----------------------------------------------------------
                ACARS MESSAGE                  1/1
FROM:ATLOODL.          OCT 21   1423Z
EXPECT EQUIPMENT CHANGE IN DENVER.
PARK AT GATE 23.
FLT 618 WILL CONTINUE TO LAX USING SHIP
NO.243 AT GATE 25.



<> CLEAR        <> PRINT                  RCVD <>

----------------------------------------------------------
```

37. ACARS MESSAGE. WHEN A MESSAGE IS DATA-LINKED TO THE AIRCRAFT VIA THE AIRINC COMMUNICATIONS ADDRESSING AND REPORTING SYSTEM, AN ADVISORY WILL BE DISPLAYED ON ACAWS. THE MESSAGE MAY BE SEEN BY SELECTING THE ACARS MESSAGE PAGE. THE MESSAGE CAN BE ACKNOWLEDGED TO THE SENDER BY PRESSING THE RCVD SWITCH, PRINTED IN HARD COPY ON THE FLIGHT STATION PRINTER BY PRESSING THE PRINT SWITCH, OR CLEARED FROM THE SCREEN BY PRESSING THE CLEAR SWITCH. THE MESSAGE MAY ALSO BE VOICED TO THE PILOT, THROUGH THE VOICE OUTPUT SYSTEM, UPON HIS SELECTION.

Figure 94. ACARS Incoming Message

```
                                              CDU 38
------------------------------------------------------
                 ACARS MESSAGE                 1/1
TO: ATLARTCC.          OCT 3  0934Z              <>
REQUEST FL290 AFTER BRAVO                        <>
                                                 <>
                                                 <>
                                                 <>
                                                 <>
                                                 <>
                                                 <>
                                                 <>
<> CLEAR       <> PRINT                  SEND    <>
------------------------------------------------------
```

38. ACARS MESSAGE. THIS PAGE IS SELECTED WHEN THE CREW WISHES TO TRANSMIT A MESSAGE VIA THE AIRINC COMMUNICATIONS ADDRESSING AND REPORTING SYSTEM. WHEN TYPING THE MESSAGE, THE WORDS "TO" AND THE ADDRESSEE MUST BE TRANSFERRED FROM THE SCRATCH PAD TO LINE 2 BY TOUCHING THE SWITCH ON THAT LINE. AT THAT TIME THE DATE TIME GROUP AND THE SEND SWITCH AUTOMATICALLY APPEAR.

WHEN TYPING THE BODY OF THE MESSAGE, THE SYSTEM AUTOMATICALLY EDITS THE TEXT TO BREAK IT BEFORE THE WORD WHICH WOULD CAUSE THE LINE TO BE TOO LONG FOR THE SPACE PROVIDED. THE TEXT IS AUTOMATICALLY TRANSFERRED FROM THE SCRATCH PAD TO LINES 3 THRU 10 IN SEQUENCE AS THE TEXT IS TYPED. THAT IS, THEY DO NOT HAVE TO BE TRANSFERRED WITH THE LINE SWITCHES.

A CHANGE TO ANY LINE CAN BE MADE BY RETYPING THE INFORMATION INTO THE SCRATCH PAD AND TOUCHING THE SWITCH ON THE LINE TO BE CHANGED. THE INFORMATION ON THAT LINE IS REPLACED WITH THAT FROM THE SCRATCH PAD.

THE MESSAGE CAN BE TRANSMITTED TO THE ADDRESSEE BY PRESSING THE SEND SWITCH, PRINTED OUT IN HARD COPY ON THE AIRCRAFT PRINTER BY PRESSING THE PRINT SWITCH OR CLEARED FROM THE SCREEN BY PRESSING THE CLEAR SWITCH.

THE TEXT MAY ALSO BE ENTERED BY A VOICE INPUT SYSTEM.

Figure 95. ACARS Outbound Message

ACARS Interfaces

The FMC inputs data to the ACARS for the navigation and air data information required for the fixed format report messages. Discrete inputs from the landing gear, engine switches, and wheel sensors provide the necessary information for departure/arrival/takeoff/taxi type reports which are automatically sent when the event is sensed.

VHF NAVIGATION SYSTEM

The VHF navigation system consists of dual VOR receivers connected through a power divider to a common omnidirectional antenna.

Number 1 receiver power is supplied from avionics bus number 1 and number 2 from avionics bus number 2. The receivers are tuned through the integrated comm/nav control or the control display units. The operation and interfaces of the VOR receiver are as described in ARINC 711. The VOR provides omnibearing, station identification, the frequency tuned, and marker beacon information (see marker beacon system description) on the ARINC 429 data bus output. This information is supplied to the flight management computer and the number 1 and number 5 CRT displays. No course resolver function or deviation calculations are provided by the VOR receiver. The course resolver function and deviation calculation are performed by the display system.

Automatic tuning of the VOR/DME system is provided by the flight management computer when the pilot selects that feature. Either flight management computer can tune both VORs and both DMEs.

DISTANCE MEASURING EQUIPMENT SYSTEM

The distance measuring equipment (DME) system is comprised of dual interrogator-responder units, DME1 and DME2. Dual-L band antennas are used for each system, one on the top and one on the bottom of the fuselage. The DME unit has frequency diversity capability and automatically selects the proper antenna. Each unit provides both precision DME (P-DME) for approach and navigation DME (N-DME) for cruise.

The units meet the requirements of ARINC 709 for N-DME and ARINC TBD for P-DME and are described therein. Accuracies for the P-DME are as follows:

Terminal area entry	±600 ft
Glideslope capture	±600 ft
100 ft decision height	±100 ft
50 ft altitude	TBD ft
Touchdown	TBD ft
VTOL landing	± 20 ft

Tuning and selection of the DME is accomplished through the integrated comm/nav unit or control/display units by tuning and selecting of either microwave landing system (MLS) for P-DME or VOR/ILS for N-DME. Automatic tuning of the VOR/DME frequency is provided by the flight management computer when the pilot selects that feature. The DME can accept up to six frequencies from the comm/nav page on the control/display unit. It scans these frequencies and continually tracks the distance to each station. When the system receives an override from the MLS, denoting that it is within 20 miles of the MLS, the system then tracks the associated precision DME continuously. DME information is provided to the flight management computer and number 1 and number 5 CRT displays.

Note: The capability to enter six frequencies and the scanning function will not be implemented on the baseline simulation.

MICROWAVE LANDING SYSTEM

The microwave landing system (MLS) consists of: (1) dual MLS receiver-processors; (2) dual DME units; (3) a C-band antenna and dual L-band antennas; (4) course, glideslope(s) and approach altitude selection (using the FMS control/display unit) and processing in the dual FMC's program to convert the MLS angle and range signals to flight path deviations; and (5) distance to the touchdown zone, flare guidance and steering commands. All output signals will be sent to the flight displays and flight director/autopilot computers via low speed ARINC 429 data buses.

MLS Receiver-Processor

The MLS receiver is a 200 channel receiver operating from 5031.0 MHz to 5090.7 MHz. Channel spacing is 0.3 MHz with the channels numbered 500 to 700. The MLS signal is a time-division, multiplex channel containing azimuth approach angle, elevation angle, flare elevation angle, high rate azimuth approach angle, back azimuth angle, and basic data in a differential phase shift keying format. The above data are transmitted at the following scan rates from the ground antennas as they scan "to" and "fro".

Function	Rate
Approach azimuth	13 per sec
High rate approach azimuth	39 per sec
Back azimuth	6.5 per sec
Approach elevation	39 per sec
Flare elevation	39 per sec
Basic data	See table 4

The receiver detects the "to" and "fro" signals from the azimuth ground station and elevation ground station(s) along with calibration, timing, and scaling data. It then determines the azimuth and elevation angles to the station in planar and conical coordinates as applicable. The azimuth angle is 0° parallel to the runway centerline and positive in the clockwise direction to $+62^{\circ}$. It is negative in the counterclockwise direction to -62°.

The elevation angle (conical) is zero at horizontal and positive in the upward direction to +30 degrees. It is negative in the downward direction to -1.5°. The elevation station origin may be offset side-to-side from the runway centerline and in height relative to threshold height. It is located parallel to the threshold.

The azimuth antenna is located beyond the runway end and may or may not be on the centerline of the runway. No distance is prescribed from the azimuth station to the runway threshold (measured parallel to the centerline). The MLS datum point is not always located at runway threshold.

TABLE 4

MLS TRANSMITTED DATA

The basic data word transmitted to the aircraft contains the following information:

(1) Location of the azimuth antenna relative to the landing threshold.

(2) Location of the elevation antenna relative to the MLS datum point.

(3) Location of the MLS datum point relative to the landing threshold.

(4) Location of the DME relative to the MLS datum point. The MLS datum is always on the runway centerline.

(5) Back azimuth station location relative to the back azimuth datum point.

(6) Identification of the MLS channel, the DME channel, normal glidepath and minimum glidepath, equipment performance level and status, and failure warning.

(7) Coverage limits of the azimuth, back azimuth, and elevation stations.

Each MLS azimuth and elevation station transmission also contains station identification and time reference. When outside the coverage limits, the station transmits an out-of-coverage signal and a "fly to" signal to assist in capturing the proportional angle region.

The MLS processor receives the angle information on both the to and from scans and determines the actual angle to the ground antenna to an accuracy of TBD degrees. The accuracy is about 0.05 degree at close range (5 nm) and 0.2 degree at long range (20 nm).

The output of the processor is transmitted on two digital serial buses using ARINC 429 format. It includes the angle measurements and the basic data, including time reference, and station identifications and status. Further definition of the MLS system particulars is contained in ICAO, Annex 10, Volume I, Part I - Standards and Recommended Practices for MLS, Reference 7.

Precision DME

The normal L-band N-DME, which is the current standard, is being changed to provide a precision DME function for use with the MLS. The notation for this function is P-DME (or alternatively M-DME which covers N-DME and P-DME). The sole difference in the two systems (as far as external effects) is the accuracy, with P-DME being much more accurate.

The DME channels will be paired with the MLS channels such that selecting an MLS channel will also select a particular DME channel. The DME interrogator-responder meets the requirements of ARINC 709 in the cruise (N-DME) mode and will meet the requirements of ARINC TBD in the approach mode (P-DME). The interface will be in accordance with ARINC 709.

MLS Computation in the Flight Management Computer

The MLS receiver decodes the station information and determines the elevation and azimuth angles to the ground station. These data are then transferred to the flight management computer along with precision distance information from the DME. The flight management computer uses this information along with selected approach information to calculate path deviation and steering (command) information. The calculated information is then sent to the display system for display and to the flight director and autopilot for use in automatic or manual control computations.

MLS Crew Systems

The three-dimensional waypoints and horizontal and vertical paths that go to make up a published MLS approach may be placed into the flight management computer automatically through the data loader or manually by the pilot using the CDU. The procedure for manual entry is included with the description of the CDU. Once the desired approach path is in the computer, the pilot needs only to tune the appropriate MLS nav aid channel on the integrated comm/nav unit and select the MLS mode on the appropriate nav display panel. This provides the aircraft with the guidance signals to fly the MLS approach and the pilots with the necessary formats on the flight and nav displays.

INSTRUMENT LANDING SYSTEM (ILS)

The ILS consists of two ILS receivers, a tail-mounted omnidirectional localizer antenna, and a nose-mounted ILS antenna. These antenna are switched as a function of localizer capture (deviation below 2^{o}). The number 1 ILS receiver obtains power from the number 1 bus, and the number 2 receiver obtains power from the number 2 bus.

The ILS receiver conforms to ARINC characteristic 710. The outputs of the system are connected to the flight control and flight director systems as well as the display system. Appropriate mode selection on the guidance and control panel and navigation display panel provides deviation and command information and sets up the approach or autoland modes. The ILS receivers are fully monitored to conform to Category III requirements.

MARKER BEACON

The marker beacon receiver is a fixed-tuned 75 MHz receiver with a bottom-mounted antenna. This receiver is within the VOR receiver and obtains power from the same source. The output consists of a digital data word and an audio line which outputs one of three tones when the aircraft flies over a marker. These interfaces are described in ARINC 711.

The visual indications are provided on the number 1 and number 5 CRT displays, and the aural tones may be monitored through the intercom system by selection on the transmit/monitor panel. The high or low intensity selection is made through touch panel control on the number 4 CRT display.

GLOBAL POSITIONING SYSTEM

The global positioning system (GPS) consists of a hemispherical-coverage receiving antenna and pre-amplifier and a receiver/processor unit. This configuration allows the unit to operate as an independent, stand-alone navigation system.

The antenna and pre-amplifier receive the signal from all satellites available in an area and amplify the received signal sufficiently enough that it may be carried by coaxial cable without degrading the signal-to-noise ratio.

The receiver takes the received signals, detects them and passes the information to the processor. The time of arrival of each signal is also furnished to the processor using the highly accurate atomic clock contained in the receiver. Doppler shift of the received signals is also furnished to the processor to aid in tracking the signals.

At least three satellite signals must be present to provide horizontal position (latitude and longitude). Four must be available to obtain altitude in addition to horizontal data.

The processor decodes and identifies each signal, compares the time of transmission to time of reception, and "tracks" the distance and rate of change of distance to each available satellite. A calibration signal is also evaluated to correct these distances in the highly accurate independent landing monitor (ILM) mode, discussed later. The processor computes the latitude, longitude, altitude, ground speed, ground track and altitude rate. These signals are then transmitted to the flight management computer on an ARINC 429 data bus. The GPS receives aircraft present position and velocity from the FMC to assist it in acquiring and tracking the satellite signals. It also receives approach path information from the FMC in the ILM mode. The flight management computer control/display unit is used to input present position, approach path and waypoints. Information available for display includes: computed position, ground track, ground speed, time, altitude, vertical speed, desired course, distance to waypoint or touchdown, selected glideslope angle, flight path angle, runway heading, type of approach, deviation (lateral and vertical) from the desired approach, and other selected information about the number of satellites available and being tracked, and the estimated position accuracy. System status is also available for display.

When the system is initially turned on, it will acquire coarse synchronization in TBD seconds without inertial information, or in TBD seconds with inertial data. Fine synchronization occurs TBD minutes after course acquisition with inertial data and TBD minutes without it.

Independent Landing Monitor Using GPS

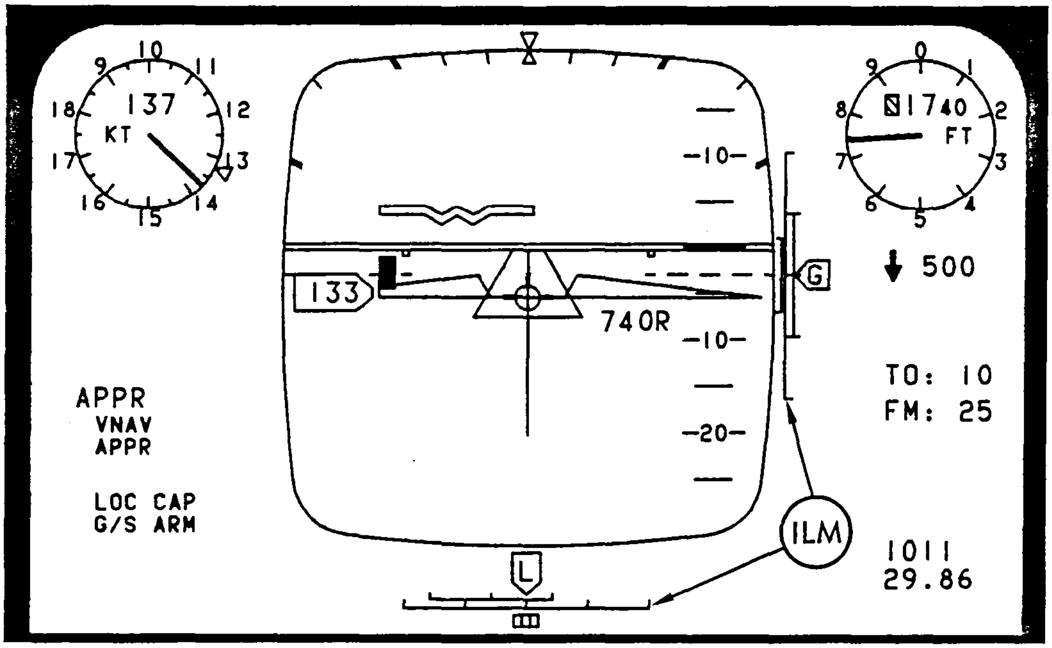
Although it has not been determined that the Department of Defense will permit civil aircraft to operate on GPS without degrading the signal for accuracy, this conceptual baseline system employs GPS to provide an independent landing monitor. The ILM function for Category III automatic landings is performed by the global positioning system receiver-processor operating in a special high-accuracy mode. The satellite signals are received along with a special calibration signal which provides an accuracy of 2 to 3 meters. The receiving antenna has a hemispherical pattern and is located on top of the aircraft. The processor takes the received signals, a highly accurate time signal, and satellite ephemeris, and computes aircraft position in latitude and longitude as described earlier. The course description is automatically obtained from the flight management computer.

The processor takes aircraft position and desired position (as computed from the desired course) and converts the difference to deviation from the flight path (vertical and horizontal) and distance to the touchdown point. These parameters are then transmitted to the displays in the same coordinates as used in the MLS or ILS system. The coordinate frame to be used and the ILM function are set up whenever both the captain and the first officer select ILS or MLS and the autoland function on the guidance and control panel.

An approach may be made using only GPS signals by selecting GPS on the navigation display panel and approach mode on the guidance and control panel. In this case, since only a single GPS system is provided, Category I minimums apply. The accuracy is not degraded in this mode, but "failure effects" criteria prevent use of any single thread system for a Category II or III approach.

__ILM Display__ - ILM information appears on the flight displays, as shown in Figure 96, only during ILS or MLS autoland approaches.

Brackets on each of the horizontal and vertical deviation scales indicate path deviations as determined from the ILM. Since this information appears along with ILS/MLS deviations, the two may be easily compared. If a discrepancy exists the pilot can take appropriate action.



NOTE:

INDEPENDENT LANDING MONITOR BRACKETS ARE DISPLAYED WHEN IN THE APPROACH MODE, WITH TWO SEPARATE AND INDEPENDENT SOURCES OF NAVIGATION, SUCH AS ILS AND MLS OR GPS.

Figure 96. Flight Display Showing ILM Symbols

INTERTIAL REFERENCE SYSTEM HEADING AND ATTITUDE REFERENCE AND NAVIGATION DATA

The intertial reference system (IRS) is comprised of three inertial reference units (IRU), one triple mode selection panel, and three batteries. Control of the systems is through the IRS control and status page of the control/display unit. Off, align, and navigate modes may be selected. Indications of systems failures are displayed on the ACAWS.

The mode selectors operate as follows. When the system is OFF, the unit is inactive. From OFF it can be turned to the align or nav mode. If the align mode is selected, the system course aligns and prompts the FMC to send present position data. The FMC sends this data, if available, and then the system continues to the fine align mode. After approximately 90 seconds, the system completes the alignment and signals "Nav Ready" to the FMC. If the selector remains in align, the system continues to refine its alignment until the aircraft parking brake is released, at which time it will automatically switch to nav mode. If the parking brake is released less than 90 seconds after turn on, a system warning is issued to all using systems and the ACAWS. When the unit is switched to nav mode, it begins navigation computations in addition to calculating the aircraft attitude, rates, and accelerations.

The unit meets all the accuracy and interface requirements of ARINC 704 and FAA Advisory Circular 25-4, dated February 18, 1966, Reference 8.

The accuracies required are as follows:

(1) A one nautical mile per hour (CEP) error growth during any one hour of operation

(2) A 2 nautical mile per hour error rate (95% probability) for flights up to 10 hours

(3) A 20 nautical mile crosstrack error and 25 nautical mile along track error on a sigma basis after 10 hours of flight

The IRUs are powered from three separate sources so that a single power failure will have minimal effect. Each IRU can also be powered from its own battery for a period of not less than 30 minutes in the event of loss of power. Circuitry exists to cause the systems to shut down when power is shut off on the ground. In event of failure of the number 1 or number 2 IRU, the number 3 unit is automatically switched to replace it. This selection can also be performed manually through the attitude (ATT) switches on the bezel of the number 1 and number 5 CRT displays.

Heading and Attitude Reference

The IRS produces digital aircraft oriented rates (roll, yaw, pitch) and accelerations (lateral, normal, and longitudinal). The computer integrates these (using initial platform position) to produce true heading, pitch and roll, and along track, crosstrack and vertical velocities. All these parameters are transmitted in digital format (ARINC 429) to the automatic flight control system, the display system, and navigation system. The characteristics of these signals are specified in ARINC 704.

In the event of computer failure, the body rates, aircraft accelerations, and aircraft axis velocities are still available. Since there is no stable platform, attitudes and heading will not be available; therefore, no separate attitude mode is provided.

Magnetic heading is derived by the FMS using the IRS heading and a magnetic variation table stored in memory. Variation is stored in increments of two degrees latitude and two degrees longitude. Linear interpolation will be used to calculate variation at the actual present position. The output will be computed to the nearest tenth of a degree.

Navigation Data

The IRS supplies present position, X and Y velocities, altitude rate, and aircraft altitude to the FMC. It also supplies velocity, heading and present position to the global positioning system for initialization and to assist in tracking the satellite signals.

PROPULSION SYSTEM

The aircraft is powered by two advanced high bypass turbofan engines which contain full-authority electronic engine control both for manual operation and for interface with the performance management system to obtain performance parameters from the flight management computer for automatic operations. Thrust is adjusted by the pilots through manual throttles or by the performance management system through autothrottles. Engine power and status are displayed to the pilots on the number 2 or number 4 front panel CRTs. Two 150 KVA starter/generators mounted on each engine are used to start the engines with either an aircraft auxiliary power unit or external power.

Manual Throttles

Two sets of throttle levers, shown in Figure 97, are provided to manually control engine thrust. Both throttle levers for each engine are interconnected and move in unison. The throttle system is a fly-by-wire/light system controlling an electronic engine control (EEC) for each engine. Moving the throttles forward increases fuel flow, RPM, and thrust, and affects the other engine parameters as appropriate. During manual control of the throttles, when performance management has not been selected, the EEC senses ambient conditions and throttle position, computes the corresponding EPR for those conditions, and electronically controls engine fuel flow to provide the computed thrust. When the performance management system is used to calculate performance parameters for either manual or autothrottle control, the values are provided by the flight management computer.

The throttles may be moved manually through a range from maximum reverse, through idle, to a rated overboost position, as shown in Figure 98. There is a mechanical stop at each end of the scale and a mechanical gate between forward and reverse idle. Additionally, there are mechanical detents at the reverse idle and the takeoff thrust positions. Takeoff and go-around thrust settings are normally calculated for both reduced thrust and limiting thrust maneuvers. When reduced thrust provides an adequate

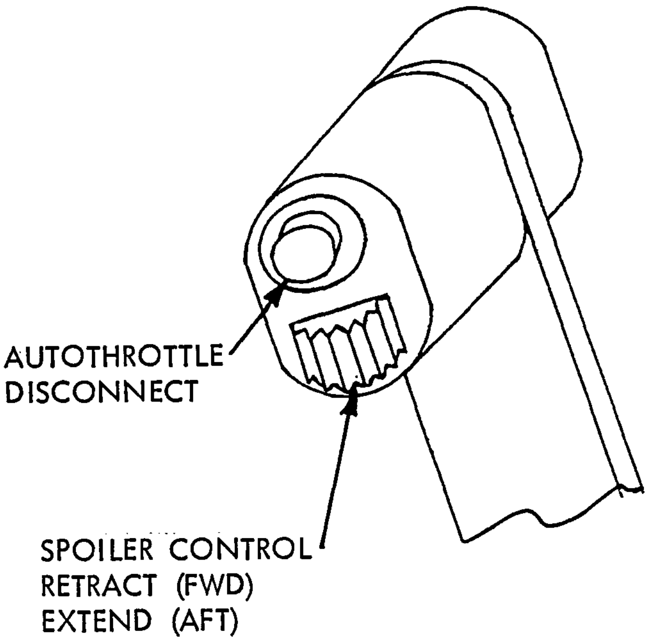


Figure 97. Throttle Lever with Switches

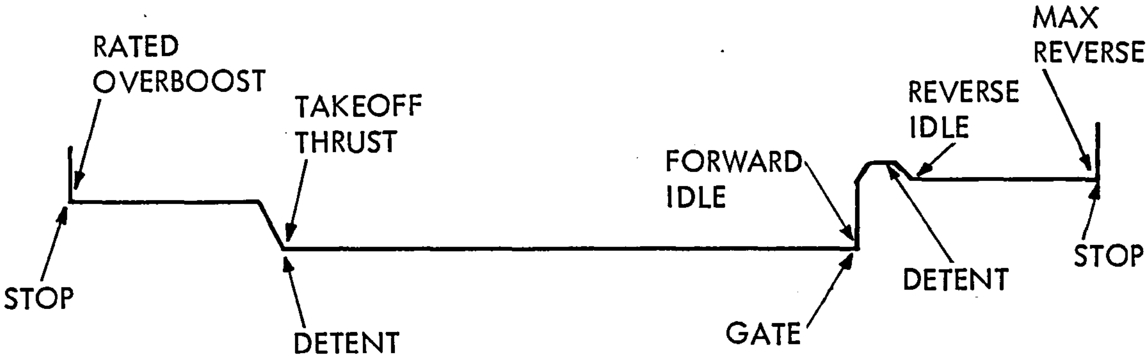


Figure 98. Throttle Range and Positions

margin of safety, it becomes the preferred setting in order to extend engine life. Either limiting thrust or reduced thrust for takeoff is selected through the mission management CDU. The appropriate takeoff thrust setting for the engines for any given atmospheric condition is always provided when the throttles are advanced to the takeoff thrust detent. This value (EPR, RPM, etc.) changes as conditions change. Additional power, above limiting thrust, can be obtained by the pilot manually pushing the throttle beyond the forward detent. Any operation in this area can cause damage to the engine, depending upon the amount of overboost and length of time, and should only be used in an emergency. The maximum overboost available provides approximately 10 percent above limiting thrust.

The engines use a "fan-only" reverser designed for ground use only. The thrust reverser has a feature to prevent a thrust increase above idle in the event a thrust reverser fails to deploy. Additionally, power is automatically reduced to near idle if the reverser inadvertently deploys or retracts. When the levers are lifted through the gates and moved aft, the thrust reversers are deployed and reverse thrust is applied. Reverse thrust increases as the throttles are moved aft beyond the gate. Thrust reverser position is indicated through the ACAWS system, with advisory, caution, or warning messages to indicate appropriate positions or out of sync conditions in relation to flight conditions.

Throttle friction is adjusted to approximately 10 pounds and has no pilot control. Each throttle handle contains an autothrottle disconnect pushbutton switch and a spoiler extend-retract switch on the outboard end, as shown in Figure 97.

Autothrottles

Any one of the following autothrottle modes can be selected on the guidance and control panel shown in Figure 99: thrust command mode (TCMD) with performance management (PM); time navigation (TNAV), or vertical navigation (VNAV); indicated airspeed hold mode (IAS); or Mach hold mode (MACH). If IAS or Mach hold modes are selected, the desired value for that mode can be selected and displayed by turning the commanded speed/Mach

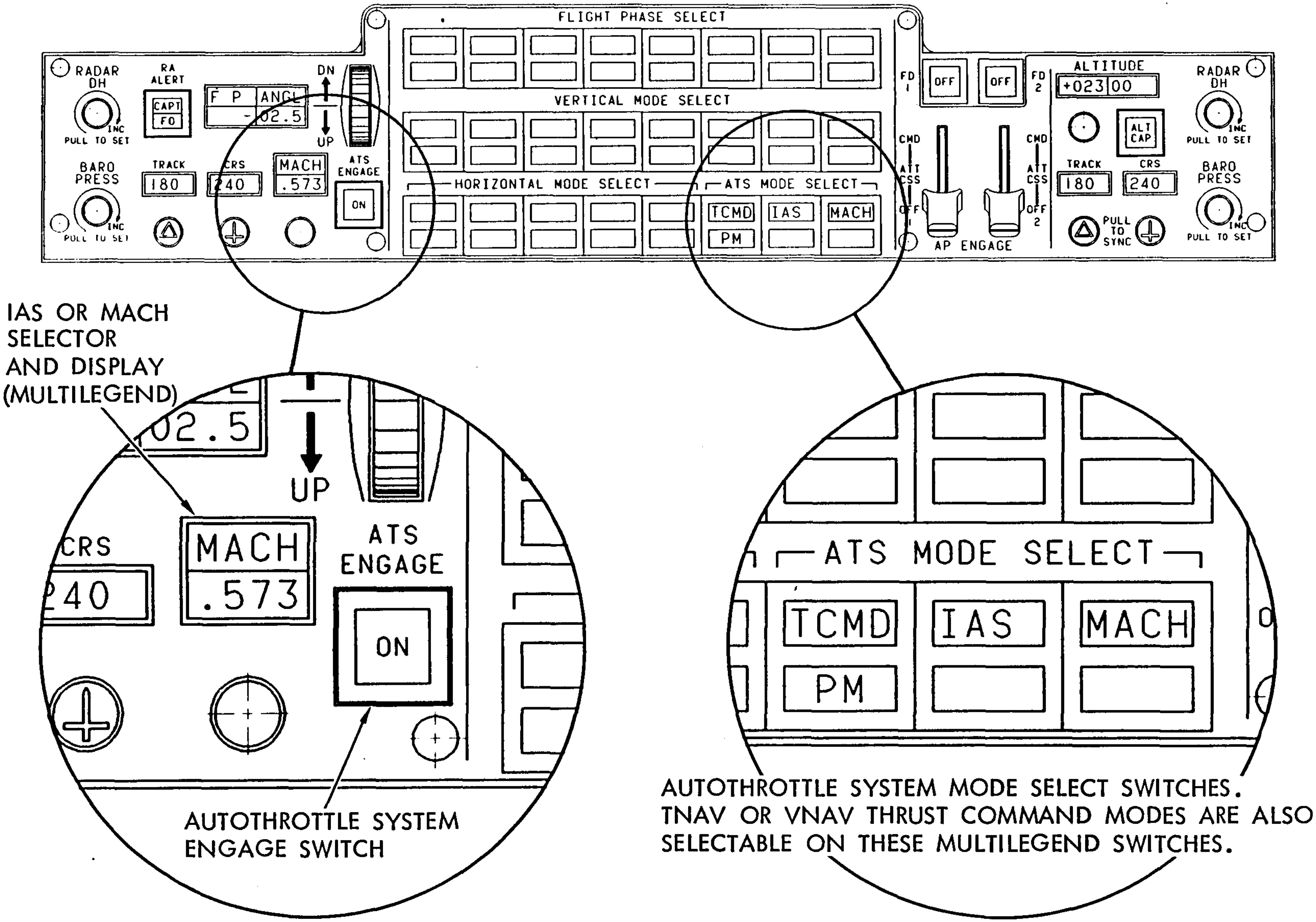


Figure 99. Guidance and Control Panel with Autothrottle System Controls and Displays

knob. The autothrottle system is engaged by pressing the ATS ENGAGE switch. Thrust required to either hold the commanded airspeed/Mach or to fly the selected performance management profile is maintained by the autothrottle system. The throttle levers move with any change of power to provide positive feedback of throttle position to the pilots. The total range of operation for the autothrottle system is from forward idle to takeoff thrust. The autothrottle system can be overridden at any time by the pilots applying pressure to the throttle levers. This causes the ATS switch to disengage.

Engine Power and Engine Status Displays

Engine power and health status are displayed on the number 2 or number 4 front panel CRT, as shown in Figure 100. The engine power display shows EPR, EGT, RPM, and fuel flow in a bar graph format. Digital values representing the top of the bars are also shown. Small arrowhead indices on the EPR scale move at the same rate as the throttles and indicate throttle position. The actual EPR, indicated by the bar graph, moves at the same rate as the engine power. The command EPR, provided by the energy management system, is indicated by a dashed white line that crosses both EPR bars. The limiting EPR is indicated in the same manner by a solid red line. Cautionary limits on any engine parameters are indicated by changing two-thirds of the bar graph and the appropriate digital readout to an amber color. Out-of-tolerance conditions are shown similarly with red color. The limits are also designated with an amber/red line across the bars. The RPM bar graphs can display either N1 or N2 through selection of the touch panel switch around the RPM label. N2 is typically only observed during starting operations.

The engine status format, shown in the lower portion of the CRT in Figure 100, can also be shown in the upper portion by selecting ENG STS on the touch panel or on the number 4 CRT display. In addition to the parameters shown on the bar graphs, oil pressure, oil temperature, oil quantity, vibration at two stages, fuel temperature, fuel pressure, and brake temperature by wheel are displayed digitally. Out-of-tolerance conditions cause the digits to change to amber or red as appropriate. If

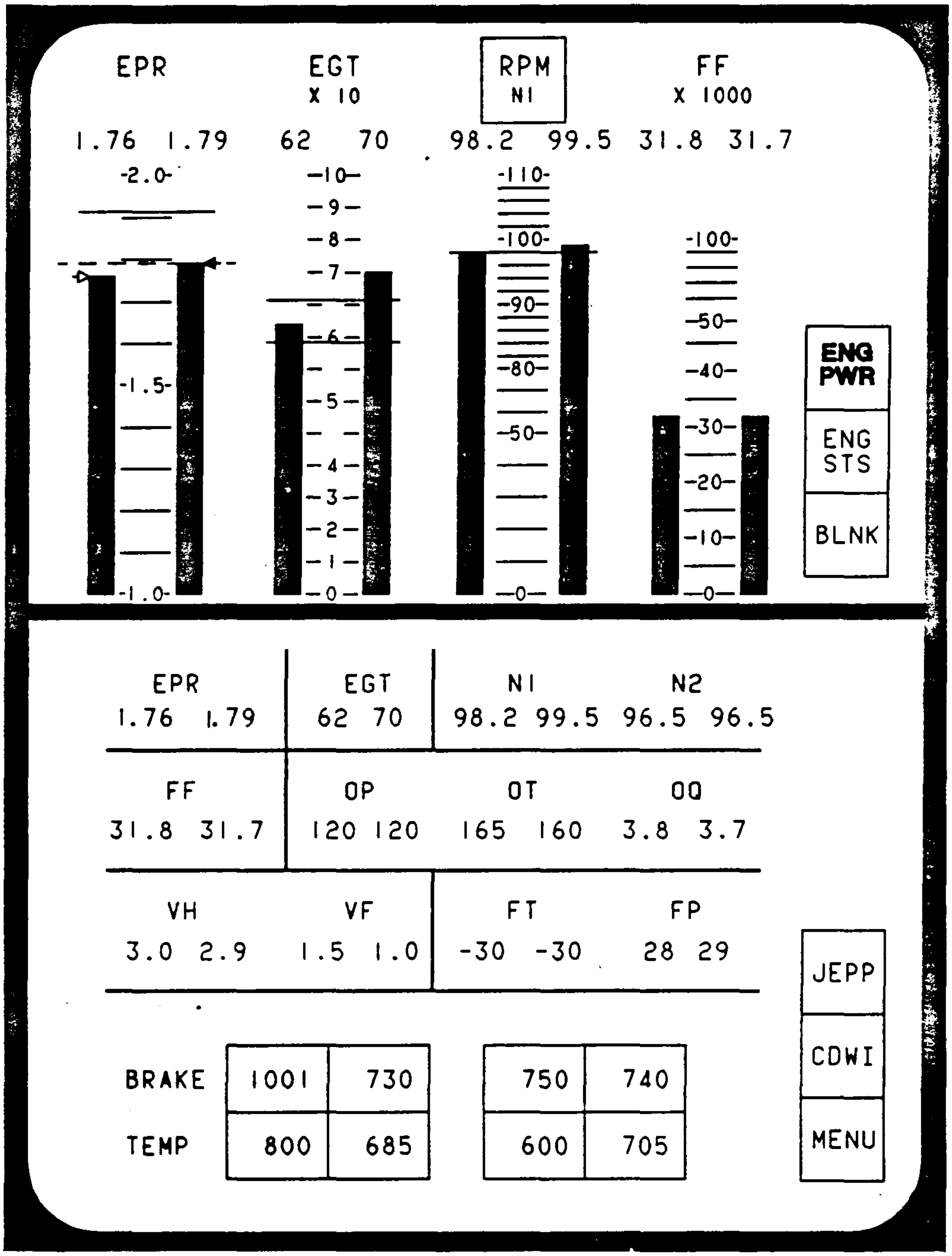


Figure 100. Engine Power and Engine Status Display

the top portion of the display has been blanked (BLNK), the entire engine status display is automatically recalled to that location in the event that one of the parameters goes into a yellow or red range of operation. A master caution or warning and ACAWS message also accompanies any out-of-tolerance condition.

Engine Start Panel

The engine start panel, located in the overhead console, contains the start and stop switches for engine control. It is shown in Figure 101 (Item 39, Figure 15).

Start Switches - The starting sequence is automatically controlled by the electronic engine computer when the start switch is pressed. The computer monitors N2 to determine the appropriate time to turn on the fuel and ignition. The start switches illuminate when pressed and remain illuminated until the engine comes up to speed or the stop switch is pressed.

Stop Switches - The stop switch removes fuel and ignition and disconnects the start switch circuit. The engines may be motored without fuel and ignition by pressing the stop and start switches simultaneously.

Main Engine Start Sequence - Before starting, the throttles are set at idle. When the START switch is pressed, the start logic provides a signal to the starter/generator contactor relays and the start switch illuminates. The start logic provides a signal to the electronic engine control, which energizes both ignition systems and supplies fuel to attain the appropriate engine speed. The engine starts and accelerates to idle speed without further action by the pilot. At about 60 percent N2, the logic system de-energizes the starter/generator relays and ignition system. Inflight starting with starter assist is basically the same procedures as for ground starting.

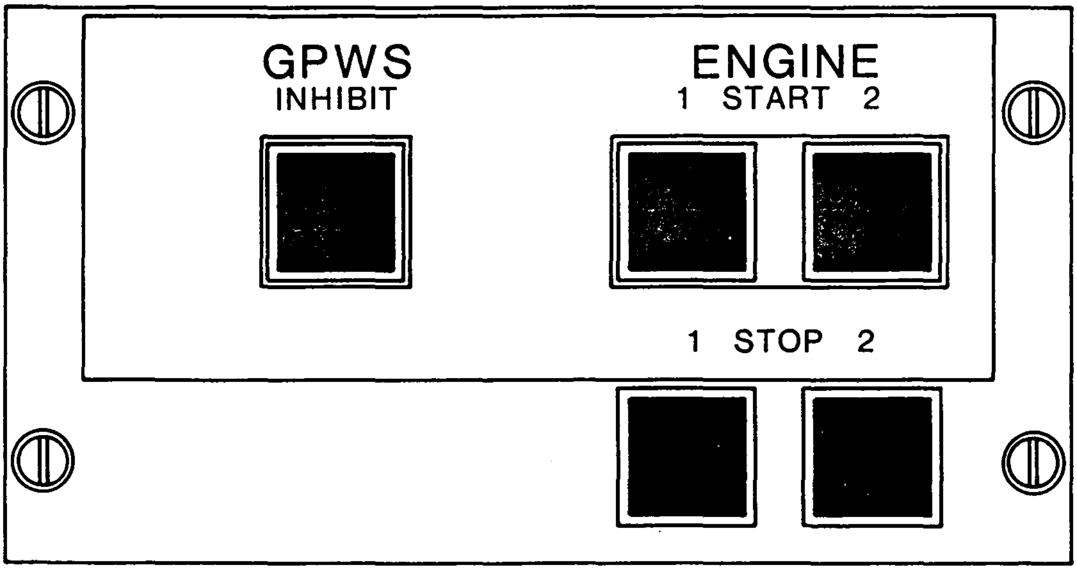


Figure 101. Engine Start Panel

ELECTRICAL POWER SYSTEMS--AC, DC, APU, AND EXTERNAL

The aircraft is equipped with primary engine-driven alternating current (AC) starter-generator systems, multivoltage direct current (DC) and battery systems, auxiliary power unit (APU) AC generator systems, and an external power plug, plus necessary controls and displays. The main bus distribution diagram is shown in Figure 102.

AC Power System

Primary electrical power is supplied by four 150 kilovolt-ampere (KVA) starter/generators. Each engine drives two generators through individual variable-speed constant-frequency converters which maintain constant voltage and frequency regardless of engine speed. The converters provide 400 Hz, 3-phase, 115/200V AC power to four main AC buses and a tie bus. Starting and emergency power is provided by two APU-driven generators which are the same as the engine-driven generators. APU description and operation are discussed later in this section. Engine starting is accomplished by applying power to one of the starter/generators on each engine. Starting power may be supplied by external power or APU. Once the engine stabilizes on speed, generators are automatically connected to the respective main AC buses, and then the bus tie contactor automatically disconnects the main AC bus from the tie bus. After all main generators are operating, the APU is disconnected from the tie bus and the main generators may then be operated in parallel by connecting them to the tie bus.

Control and monitoring of the AC electrical system is performed from a touch panel display, shown in Figure 103, on the system display CRT.

The AC power system format may be displayed by touching the MENU area of the system display CRT, then selecting AC power system by touching AC power system on the MENU list. The following controls and indicators are located on the AC power system display.

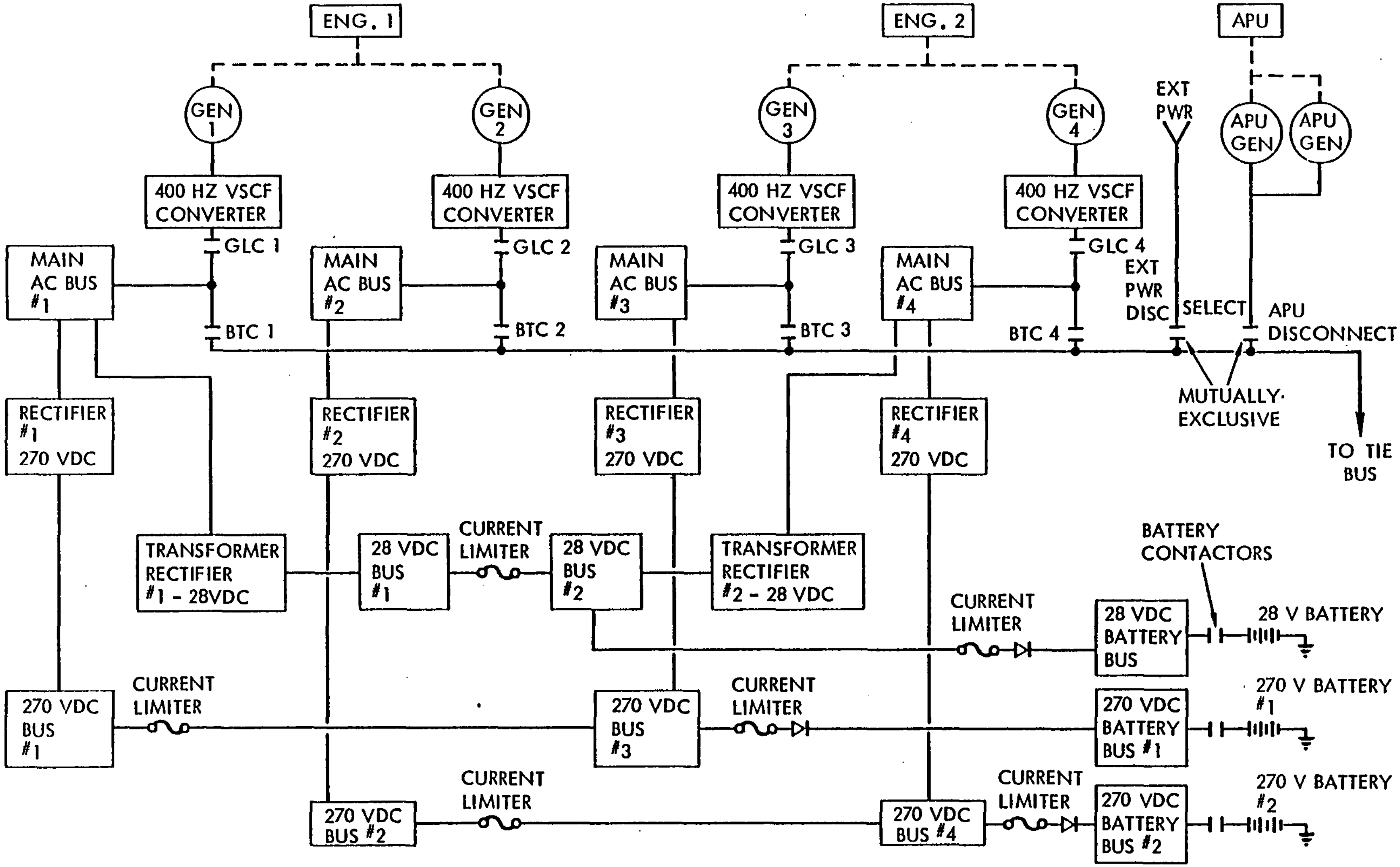


Figure 102. Main Bus Distribution

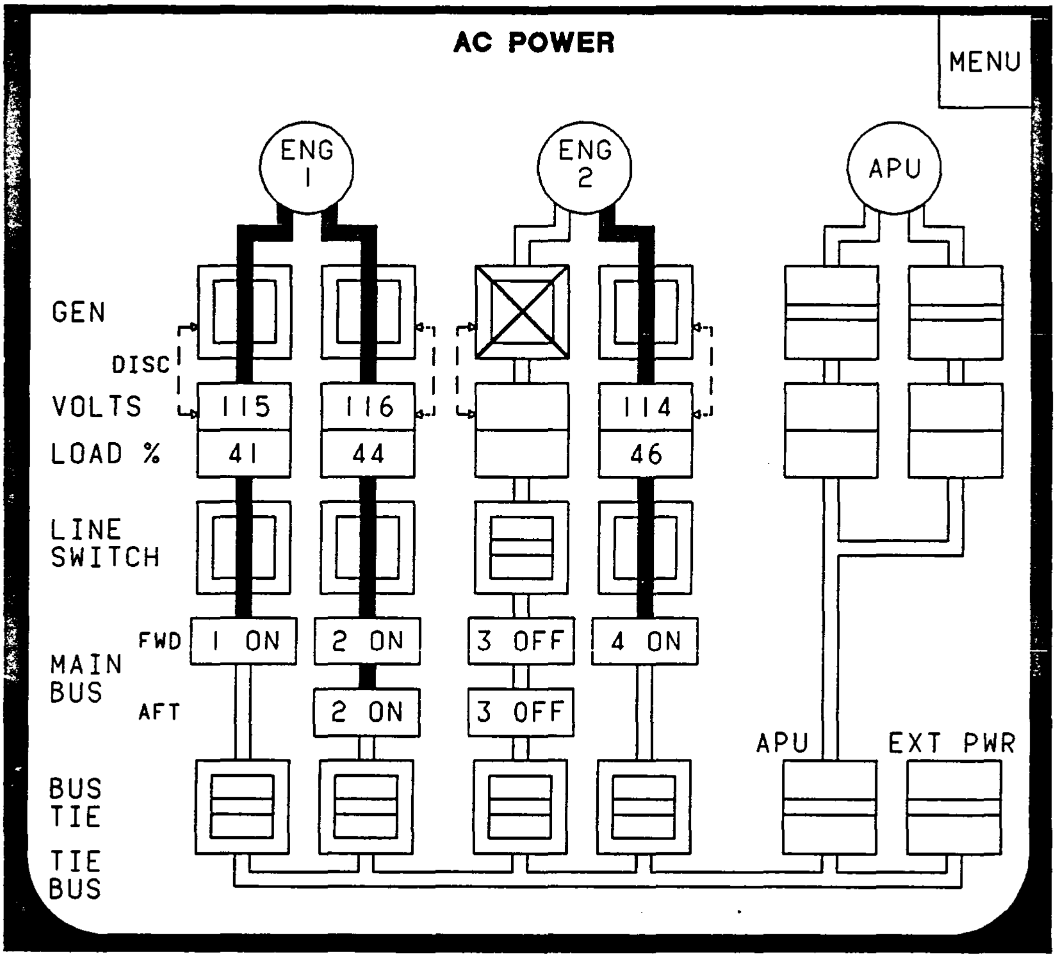


Figure 103. AC Electrical System

Engine/APU Indicators - Each of the generator driving sources--engine 1, 2, or APU--is represented at the top of the display by a circle enclosing ENG 1, ENG 2, or APU.

Generator Disconnect - Generator disconnect switches are provided for each of the main generators. Touching the VOLTS/LOAD indicator followed sequentially by the GEN DISC switch disconnects the generators from the engine, removes the connecting lines, and displays a red X in the switch area. The disconnect is mechanical and cannot be reconnected in flight.

Voltage and Load Indicators - Individual voltages and loads are displayed in digital form. Voltage readout is displayed in a boxed area in each branch above the load area. Loads are displayed in percentages of the rated generator load. If the generator in a given branch is not providing power, the load indicator in that branch is blank. The voltage is displayed whenever the generator is functional, even if the controller is OFF.

Line Switches - The line switches connect each generator to its respective main bus. A horizontal line across the switch is displayed when the line switch is OFF (open). When the line switch is ON (closed), a vertical line is displayed in the center of the switch. If the line switch is ON, it may be turned OFF by touching the appropriate switch. Touching the switch again will turn it ON. The switch legend changes to reflect the line switch position. The line switches will automatically close (turn ON) when the generator comes up to power and remain ON for normal operation. At the same time, the bus tie contactors go OFF.

Main AC Bus Status Indicators - A bus status indicator labeled MAIN BUS is provided for each AC main bus, four in the forward part of the aircraft (FWD) and two in the rear (AFT). An ON legend is displayed when power is applied to the bus; OFF is displayed when the bus is unpowered.

Bus Tie Switches - A bus tie switch is provided for each of the main AC buses and external power. A single switch is provided for both APU generators. Each of the switches connects its respective bus or power source, in the case of the APU and external power, to the tie bus. When the bus tie switch is open (OFF), a horizontal line across the switch is displayed. To close the bus tie, the switch area is touched. This closes the bus tie, removes the horizontal line, and replaces it with a vertical line in the switch indicating that the bus tie is closed (ON). The bus tie switch is OFF (open) during normal operation with all four generators operating. The tie bus is not powered for normal flight.

APU and External Power - The schematic of the APU and external power system is shown along with the rest of the AC power system for completeness, but the controls for these systems are on a dedicated panel. The APU and external power cannot both be on at the same time.

DC Power Systems

DC power is supplied from transformer/rectifier units fed from the AC power systems. There are four 270V DC systems with two batteries, as shown in Figure 104, and two 28V DC systems with one battery, as shown in Figure 105. Control and monitoring of the systems are performed from CRT touch panel system displays.

The 28 volt or 270 volt DC power system display is selected by touching the menu area of the system display CRT and then touching the appropriate power system on the menu list.

The following controls and indicators are located on the DC power systems displays shown in Figures 104 and 105.

Transformer/Rectifier Indicators - Each of the transformer/rectifiers or rectifiers is represented by a half circle labeled TR 1, 2, or R 1, 2, 3, 4. If a rectifier or transformer/rectifier fails, a red X appears in the circle, a horizontal line appears in the circuit breaker switch, and the voltage and load readings disappear from the voltage/loadmeter indicator. The red X in the example in Figure 104 indicates that the number 3 AC system, which supplies the number 3 rectifier, has failed.

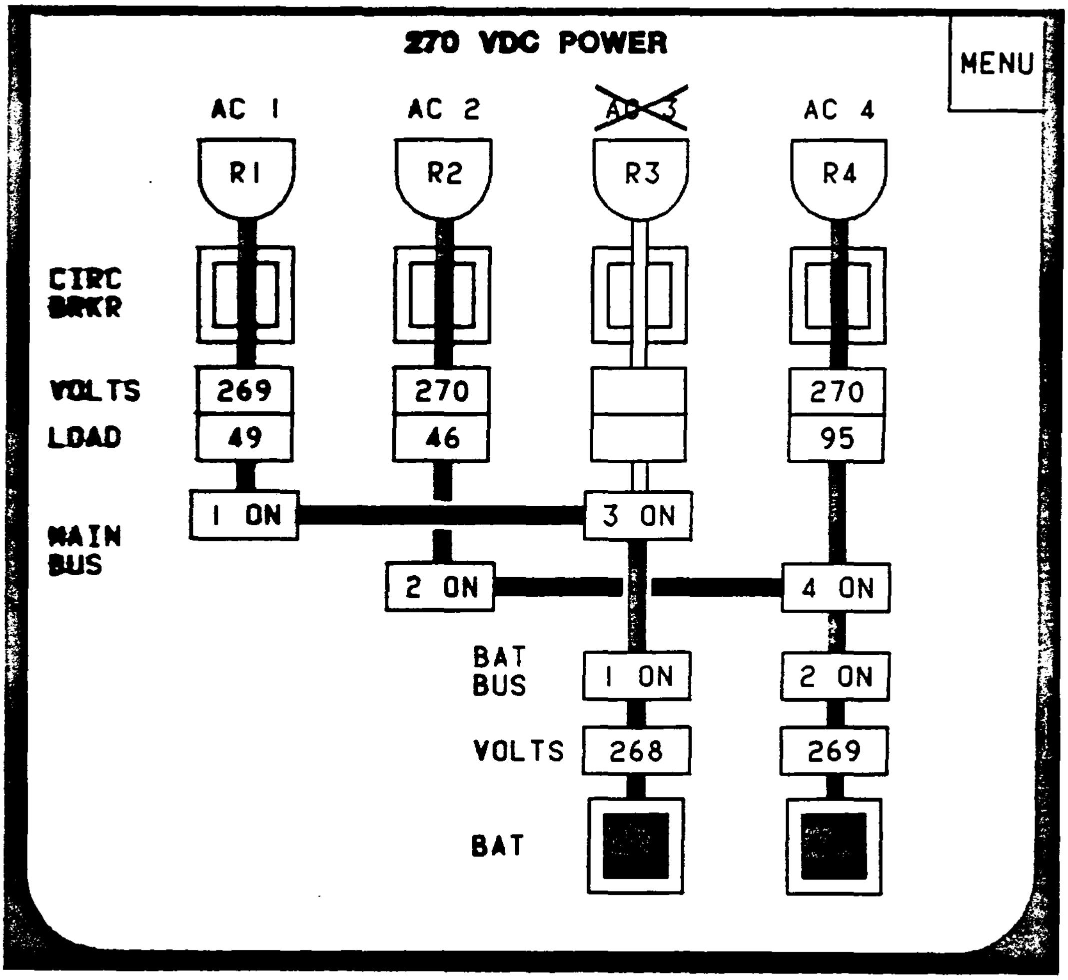


Figure 104. 270 Volt DC System

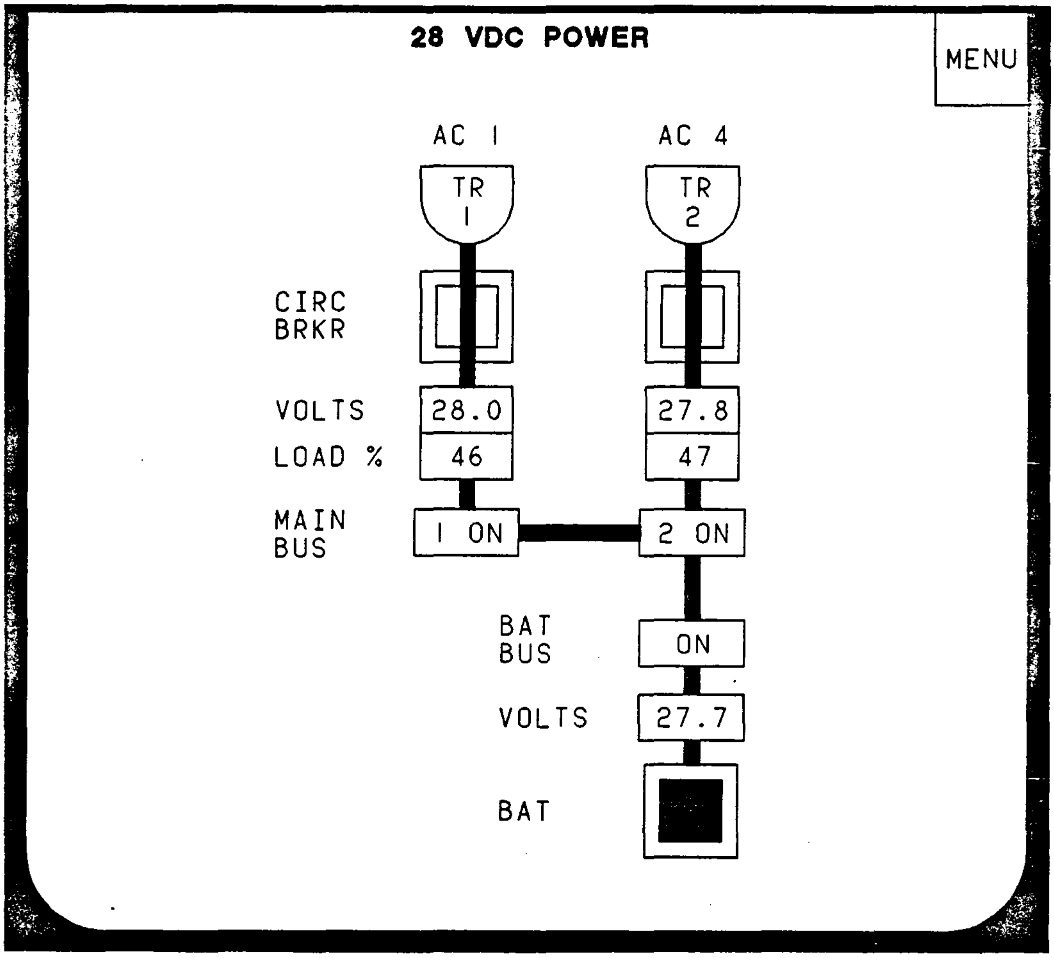


Figure 105. 28 Volt DC System

Control and Disconnect - The circuit is controlled by a circuit breaker. A circuit may be disconnected by pressing a circuit breaker switch which causes a horizontal line to appear across the switch and the values for the voltage and load to disappear. A vertical line passes through the circuit breaker switch when the circuit is ON.

Voltage and Load Indicators - Voltage and load indicators are displayed in digital form when they are present on the bus. Load is displayed in percent. Voltage is displayed whenever it is available; when voltage is not available, that portion of the display is blank.

Batteries and Disconnect - Batteries are shown as two boxes in each system. A battery may be disconnected by pressing the battery switch. The voltage indicator displays a voltage when connected, but it is blank when disconnected. The state of battery condition is shown by color change of the battery switch (Green--Good, Amber--Marginal, Red--Out-of-Limits).

The indicator displays OFF when it has been turned OFF; it displays a red X and the word OFF when it has failed and been turned OFF.

Auxiliary Power Unit (APU) and External Power

The APU provides electrical power in the form of two 150 KVA oil-cooled generators. This power is used for aircraft maintenance and ground checkout, cabin and avionics cooling on the ground, and main engine starting. During flight, the APU replaces failed main engine generator power through the tie bus and bus tie contactors. Starting and monitoring the APU are automatic on the ground. There is also an in-flight manual override capability. APU-start power is supplied by the 28V DC battery system. The APU/external power control panel, shown in Figure 106 (Item 43, Figure 15), is located in the overhead console.

Start/Run Switch - The start switch is connected directly to the APU battery. Pressing the start switch initiates the automatic start/run sequence and illuminates the START legend on the upper portion of the switch. After the APU is on speed, the RUN legend on the lower portion of the switch is illuminated and the START legend is extinguished.

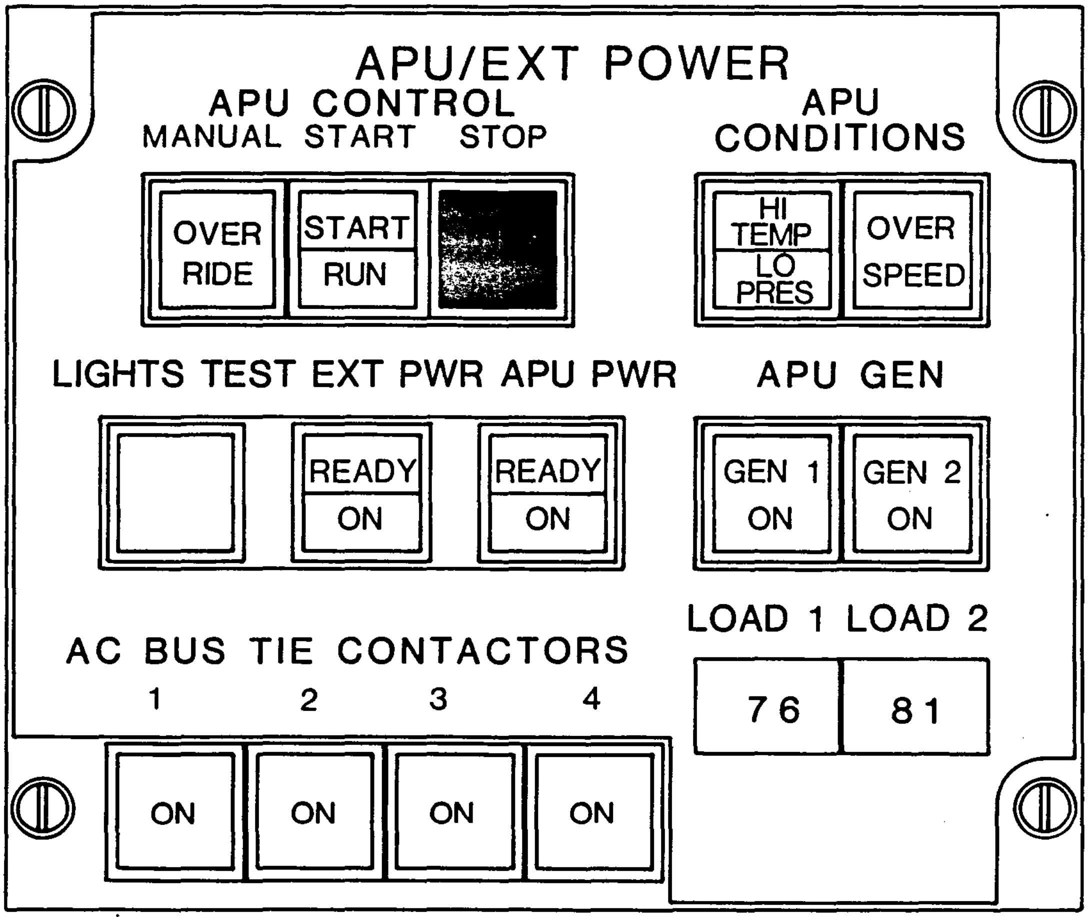


Figure 106. APU/External Power Control Panel

Manual Override Switch - In flight, pressing the manual override switch negates the automatic shutdown feature; the APU continues to run until the stop switch is pressed.

APU Condition Indicators - Indication is provided to alert the crew to out-of-tolerance APU operating parameters that activate the automatic shutdown sequence. The parameters are HI TEMP (EGT), LO PRES (OIL), and OVER SPEED (HIGH RPM).

Stop Switch - Pressing the stop switch signals the APU electronic control unit to initiate the shutdown sequence. The RUN indication is extinguished as the APU is shut down. The light in the stop switch illuminates, when pressed, until the APU has stopped running.

APU Generator Switches - When the APU run light has illuminated, either APU generator can be selected by pressing the generator ON switch. After a generator is providing power to the bus (through the APU power switch), the second APU generator is activated automatically when the load on the first approaches maximum. Two indicators illuminate the legends GEN 1 ON and GEN 2 ON when the generators are providing power.

APU Power Switch/Ready Indicator - The legend READY illuminates when the generator is providing power; pressing the switch illuminates the ON legend and connects the generator to the tie bus.

APU Load Indicator - Two indicators, one for each APU generator, display the percentage of power load that is being supplied by each of the generators. They provide indications only when the APU power is ON.

Bus Tie Contactor Switches - Four AC bus tie contactors automatically connect the tie bus to the main AC buses when either external AC or APU power is connected to the tie bus. When the main buses are powered by the tie bus, the bus tie contactor switches each illuminate ON. Individual contactors may be disconnected by pressing these switches.

External Power Selector Switch/Ready Indicator - The legend READY illuminates when external power is connected to the aircraft; pressing the switch illuminates the ON legend and connects the power to the tie bus. The bus tie contactor switches then automatically provide power to the four AC buses.

The APU/external power system is displayed schematically on the AC electrical system display to provide a total picture of system status.

Lights Test Switch - When the lights test switch is pressed, all switch lights and indicators on the APU/external power panel are illuminated. The switch is connected directly to the battery bus for power.

FUEL SYSTEM

The fuel system is designed to maximize operational flexibility while minimizing the fuel management and monitoring efforts of the flight crew. Only one fuel tank per wing with dual, independent, fuel pumps provides simple, reliable fuel management and requires minimum crew attention. Automatic features for refueling provide proper fuel loading for correct aircraft balancing. The fuel system includes a subsystem for adding heat to the fuel tank that will be necessary for the future high freeze point temperature fuels projected for the 1990s.

The fuel is carried in integral wing tanks with a capacity of 21,250 pounds per side or 42,500 pounds total usable. Both individual tank and total fuel quantity are displayed on the fuel system schematic display, shown in Figure 107. Individual tank quantities are also shown on a dedicated display on the right side of the main instrument panel, as shown in Figure 108. Each tank has three compartments consisting of inboard and outboard auxiliaries and a main compartment, as shown in Figure 109. The main compartment has a pump sump subcompartment on the inboard end. The auxiliary compartments have flapper-type check valves installed on the bottom of the compartment boundaries to allow fuel to flow only into the main portion of the tank. Fuel in the outboard section of the main compartment can flow into the sump. Small holes in the top of the compartment boundary allow vent relief and excess fuel to spill back into these compartments.

The fuel usage sequence allows the aircraft center-of-gravity to remain nearly constant as fuel is burned. During flight, the fuel is transferred simultaneously from both auxiliary compartments into the main compartment pump sump by jet pumps powered by the tank boost pumps. Fuel for the engine is pumped from the sump compartment with any excess flow spilling back into the auxiliary compartments.

The auxiliary compartments are sized to carry only enough fuel for normal warmup, taxi, takeoff, and climb to cruise altitude. Thus, the auxiliary fuel is used before its temperature can drop to its projected freeze point temperature, eliminating the need to heat the auxiliary fuel compartments.

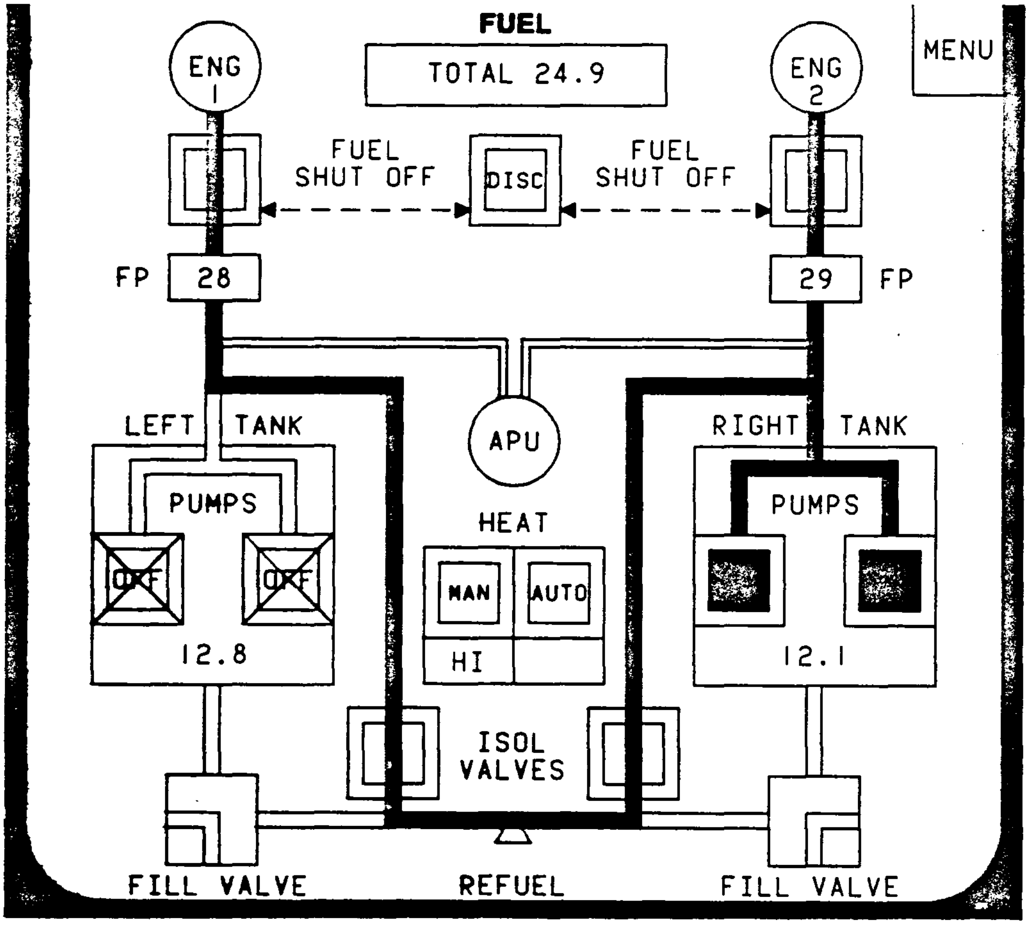


Figure 107. Fuel System Schematic Display and Touch Panel Control

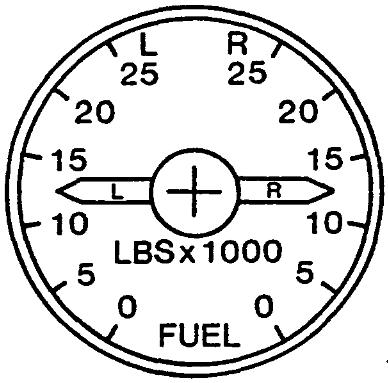


Figure 108. Fuel Quantity Indicator

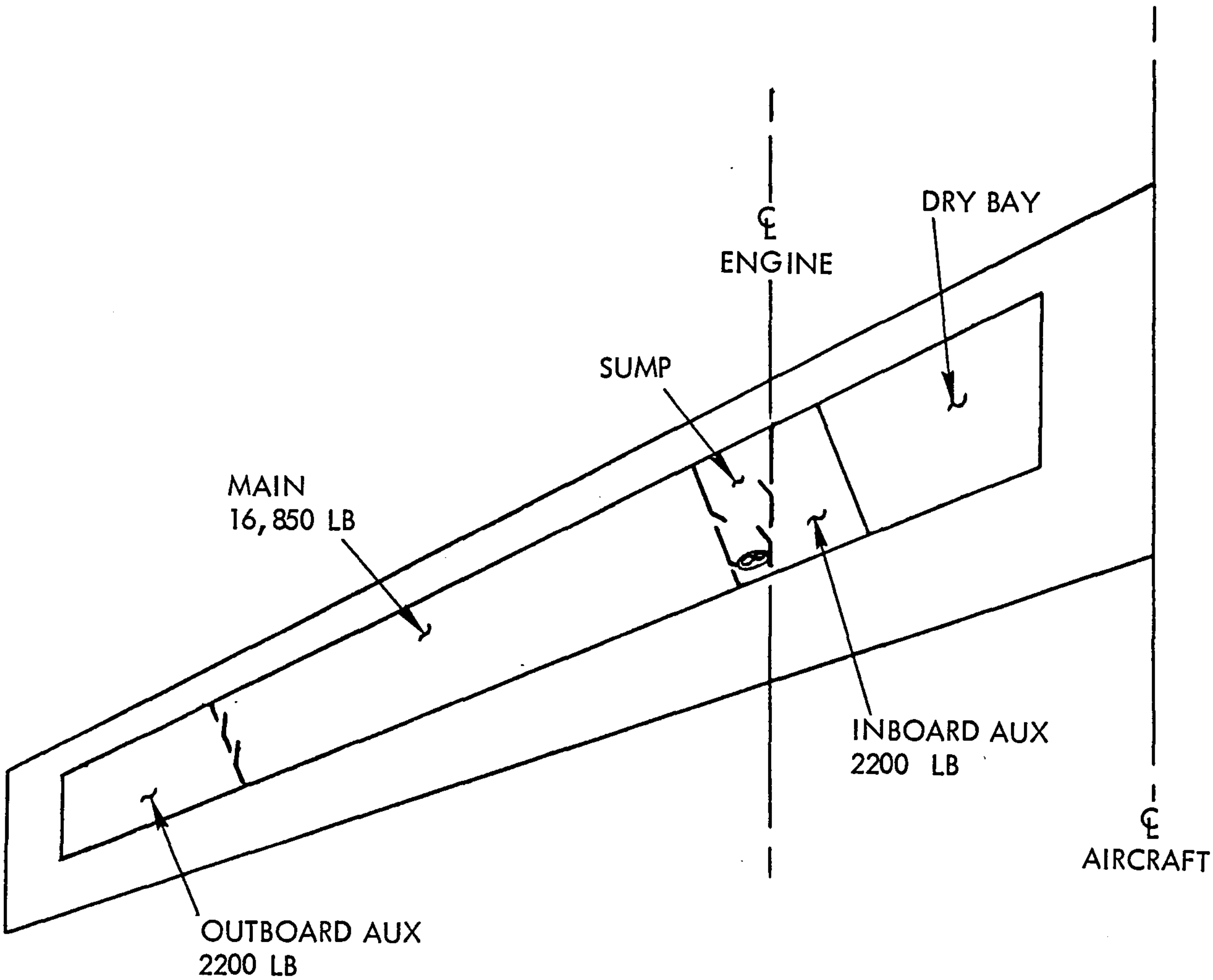


Figure 109. Fuel Tanks - Left Wing

The fuel is normally supplied to each engine directly from its own tank. However, a tank can also supply fuel to the opposite engine by opening the isolation valves. The tank boost pump consists of two independently wired and operated electrical pumping elements installed in a common housing. Each pumping element is sized to supply maximum rated fuel flow to the engine plus provide sufficient motive flow for the jet pumps in the auxiliary compartments and the outboard sections of the main compartment. Thus, the crew turns on one pump in each tank at the start of a flight and turns it off after completion. Should a pump fail, the crew simply turns on the other pump in that tank to complete the flight. Since the fuel gravity feeds, the engines can operate without pumps under normal conditions. Continuous use of one pump is recommended, however, to preclude inadvertent surging or fuel starvation.

The fill valves can be operated such that any desired quantity of fuel can be loaded. Fuel into a tank can be stopped or started at any time by solenoid action or by float shutoff at the full level. The fill valve is installed in the outboard auxiliary compartment of each tank. Fuel flows into the main compartment through the flapper valves and into the other auxiliary compartment through the fueling interconnect line. A check valve prevents reverse flow in this line.

The fuel heating system provides heat from an electrical heater to the fuel in the sump of the main compartment. Power from the airplane power bus is directed to the fuel heater any time the fuel temperature in the main compartment approaches the fuel freeze point. Oil is then heated and routed into a heat exchanger installed in the pump sump. Cold fuel picked up from the low spots in the main compartment by the jet pumps is dumped over the exchanger. The heater is controlled automatically or manually through touch panel switches on the fuel system schematic.

When the flight operable APU is started in flight after an engine is shut down, fuel is supplied to it from the tank and boost pump of the disabled engine. The APU can also be pressure-fueled by the DC-powered pump used for ground operation.

Control and Display

The fuel system control/display is on the lower portion of the number 4 CRT, shown in Figure 107; a touch panel overlay provides the switching function. The display is a schematic presentation of the major components of the fuel system with digital readouts for the two fuel tank quantities and total fuel quantity, as well as fuel pressure to each engine. Under normal operating conditions, the system requires only limited action by the pilots. Fuel flow is indicated by lighted fuel lines. Controls, indicators, and switch functions are as follows:

Tank Fill Valve Indicators - One fill valve is located in the refueling manifold for each tank and is opened for filling the tanks. Control is on the ground refuel panel located near the single point refuel connection; the valve position, however, is shown on this display. Upon reaching a preset fuel quantity, the valve automatically closes.

Boost Pump Switches - Each tank contains dual independent fuel boost pumps, outboard and inboard, each controlled by a separate switch. Pressing a boost pump switch applies power to that pump. The center area of the switch turns amber indicating low pressure, then as the pump applies pressure to the discharge port, the switch color turns green. If the color remains amber or turns red during operation (in conjunction with an ACAWS "Fuel Pressure Low" message), pressing the switch removes power from that pump and presents an OFF legend with a red X through it indicating the pump has failed. The other pump should then be selected.

Isolation Valve Switches - In the event both fuel boost pumps for one tank become inoperative, pressing the isolation valve switches opens the normally closed isolation valves. This allows the other tank to supply fuel to both engines. The open valve is indicated by a filled flow line through the switch.

Fuel Heat Switches - Automatic fuel heat is supplied as required with a manual override capability. The fuel heat switches are cyclic through the AUTO ON, AUTO OFF, MANUAL ON, MANUAL OFF positions. They are typically operated in the AUTO ON mode and are defaulted to that position. An ACAWS message will alert the pilot in the event of high or low fuel temperature. This out-of-tolerance temperature indication also appears in amber directly below the heat control switch. The switch nomenclature sequence is as follows:

FUEL HEAT

(1)	AUTO		Auto on, temp normal
(2)	AUTO	HIGH	Auto on, temp high
(3)	OFF	HIGH	All heat off, temp high
(4)	OFF		All heat off, temp normal
(5)	OFF	LOW	All heat off, temp low
(6)	MAN	LOW	Manual heat, temp low
(7)	MAN		Manual heat, temp normal
(8)	AUTO		Auto on, temp normal

APU Fuel - Indication of APU fuel use is shown by filling the lines to the APU symbol on the system schematic display.

Fuel Shutoff Valve Switches - Fuel to the engine can be shut off by pressing the disconnect switch (DISC) followed by the appropriate fuel shutoff valve switch. This sequenced switching acts as a safety measure. The fuel shutoff is depicted in the normally open position by a flow line through the valve, or closed by a filled flow line turned across the switch. Pulling an engine FIRE-PULL handle (manual control on the overhead console) also shuts off fuel to the engine. It is depicted in the same manner as described above.

ENVIRONMENTAL SYSTEM

The environmental system is made up of the cabin pressure supply system and the environmental control system (ECS).

Cabin Pressure Supply System

The cabin pressure supply system provides pressurized air for cabin pressurization. The system consists of two independent centrifugal compressors powered by two standard AC-induction drive motors along with appropriate controls and displays.

The compressor incorporates inlet guide vanes and a dump valve for compressor load control. The compressor controller receives a flow demand signal from the temperature controller, which is used to adjust the inlet guide vanes to achieve the desired environmental control system (ECS) air mass flow. This is necessary because the ECS flow requirements are normally greater than the pressurization requirements. When ECS requirements are less than pressurization requirements, the pressurization requirements take priority.

The dump valve is used in conjunction with the inlet guide vanes to unload the compressor in the event of overheat or surge conditions. In an overheat condition, the controller automatically unloads the compressor by adjusting the inlet guide valves and directs all flow overboard. This allows the drive motor to be run under a reduced load and the motor cooling fluid to circulate at a higher rate (due to the RPM increase when unloaded) with a reduced cooling load input to the cooling fluid itself. Manual control for this automatic feature is also provided. This method of unloading the compressor drive motor avoids unnecessary stops and restarts of this motor that could pose substantial start-current loads on the electric power systems.

If one compressor unloads, the other compressor is locked into maximum flow condition and can be shut off only by a critical overheat of the unit. The overheat circuit detects initial overheat at 200°F and starts the automatic cooling procedure. If overheat progresses, the drive motor is shut down at 350°F.

Each drive motor has two separate internal windings to be compatible with the variable frequency, variable voltage power generation system. The compressor controller senses the supply current frequency and switches power input to the appropriate motor windings to achieve the desired motor RPM range, independent of engine power setting.

Active cooling for the motors is provided by a coolanol (or oil loop to a fluid to air) heat exchanger.

Environmental Control System

The environmental control system consists of two advanced air cycle machines (packs) arranged in a regenerative configuration with high-pressure water separators. These two packs will interface directly with the cabin pressure supply systems, and all fresh air to the cabin will pass through them. Cabin pressure supply system air enters each of the two parallel air conditioning packs through a flow control valve, which also functions as a pack shutoff valve, and enters the primary heat exchanger where it is cooled by ram air. After passing through the primary heat exchanger, the air enters the compressor section of the packs where it is compressed to a higher pressure and temperature. The air is cooled again by ram air in the secondary heat exchanger and, after passing through the high-pressure water separator equipment, enters the turbine section of the pack. In expanding through the cooling turbine, the air generates power to drive the compressor and cooling air fan impellers. The energy removed from the turbine airflow causes a substantial temperature reduction, permitting a turbine discharge temperature well below the ram temperature.

Conditioned air from the two packs is delivered through check valves to a manifold where it mixes with recirculated cabin air for delivery to the flight station, avionics zone, cargo compartment, and two passenger zones.

Cabin recirculation air is supplied to the manifold by electric fans through check valves that prevent reverse flow when the fans are not operating. The purpose of the recirculation is to maintain the desired level of cabin ventilation while minimizing the use of cabin pressure supply system air.

Control of the cabin pressure supply system and environmental control system is accomplished through touch panel switches on the environmental 2 systems schematic shown in Figures 110 and 111. During normal operation, each compressor motor provides flow through its designated pack to the manifold. Distribution from the manifold is made to five zones in the aircraft on a designed flow schedule. The system provides adequate supply for most normal operations even in the event that one compressor and/or one pack fails, as shown in Figure 111, although it may be necessary to avoid operation at high altitudes.

Compressor motors are turned ON or OFF by alternately pressing the CMPRS MOTOR switches at the bottom of the display. The compressor pressure (CMPRS PRESS) from each compressor is shown digitally above the motors. The left and right packs are turned ON and OFF by alternately pressing the pack switches.

The isolation valve, normally closed, may be opened to bypass a failed pack.

The auxiliary vent switch (AUX VENT) opens a vent valve and depressurizes the aircraft. This procedure is normally used only to rid the aircraft of smoke or pungent fumes.

The recirculating fan switches (RECIRC FAN) are normally in the ON position so that the fans can automatically be cycled to recirculate pressurized air without going back through the compressors.

The temperature control mode (automatic or manual) and the temperature in degrees centigrade in the forward and aft cabin are displayed above the pressurization manifold line. These are only monitors, since the controls are located in the cabin.

Pressing the PAGE switch alternately displays environmental 1 and environmental 2 formats.

Pressurization and Temperature Control

Aircraft pressurization is maintained by controlling the outflow air through an electrically-driven valve. The pressurization control system has automatic or manual control and normally maintains a cabin pressure up to an 8.3 psi differential.

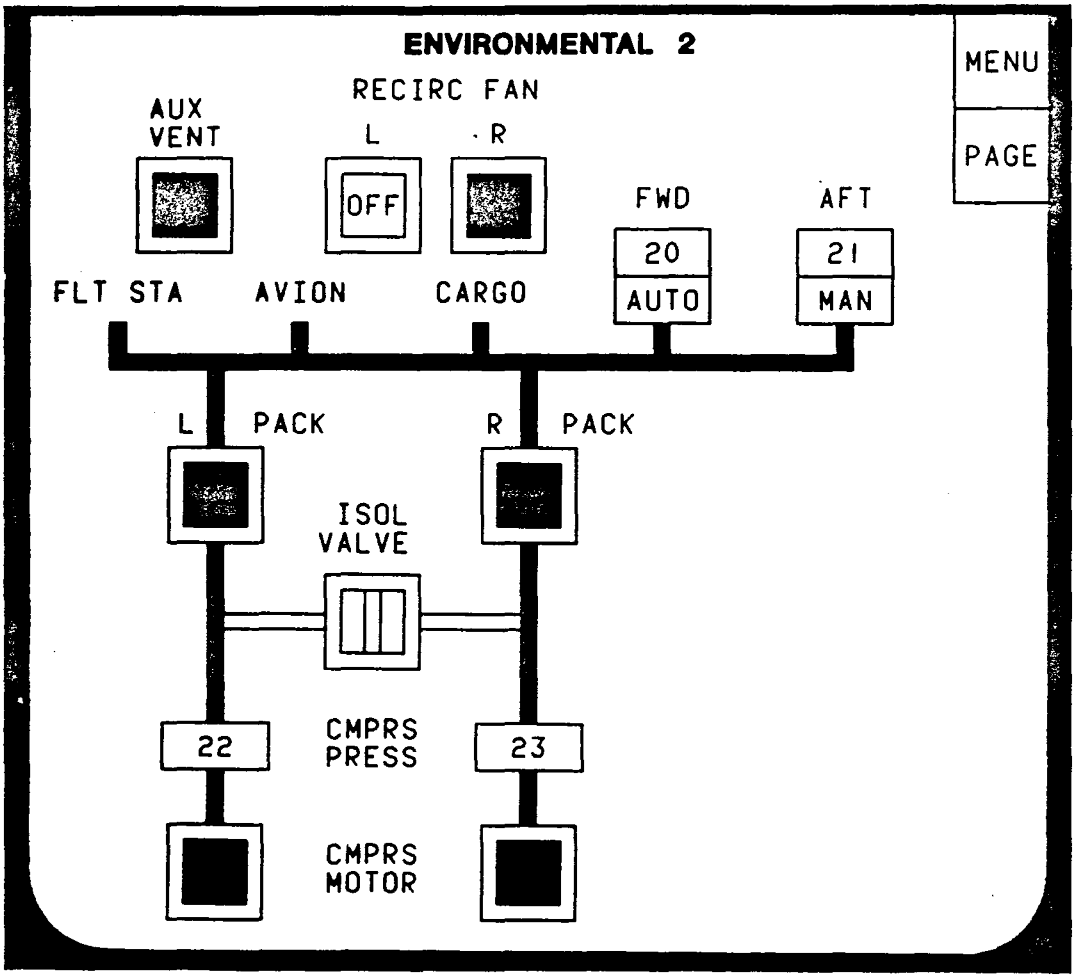


Figure 110. Environmental 2 Format

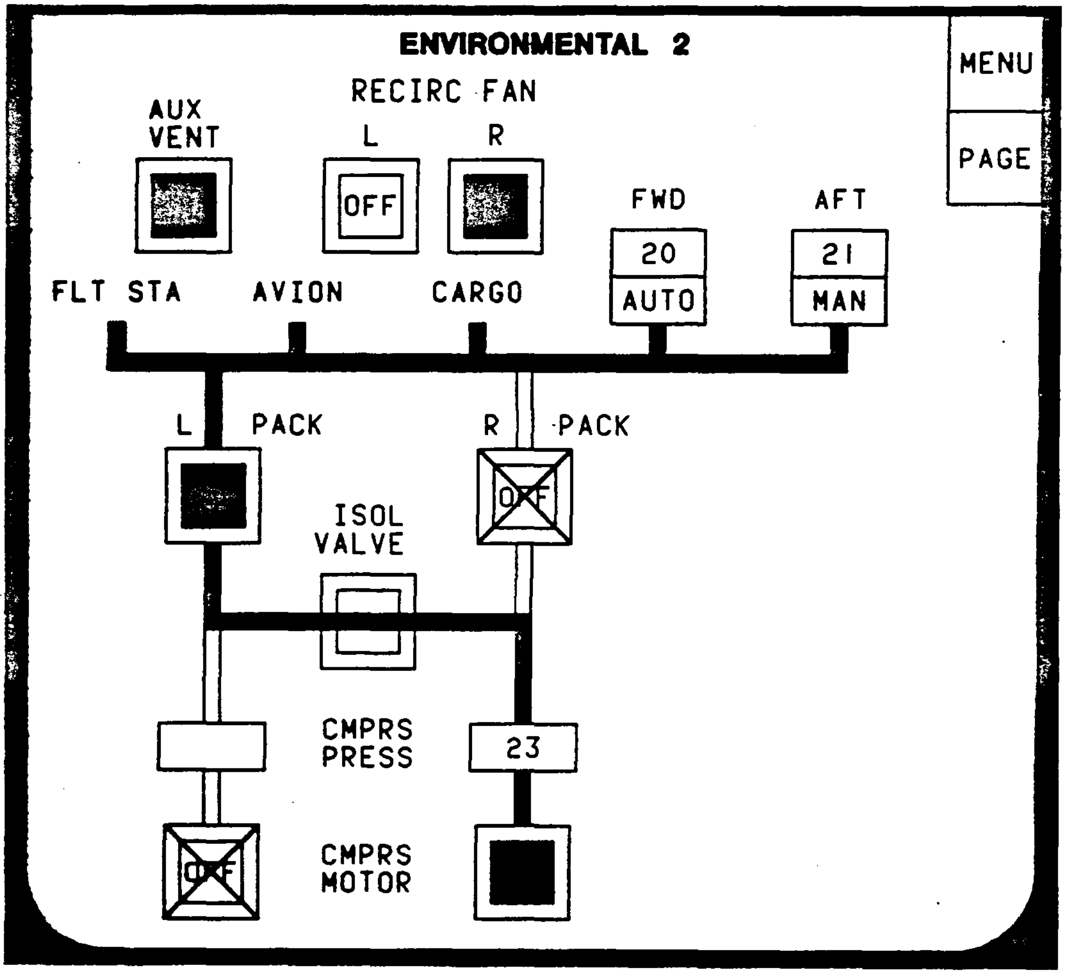


Figure 111. Environmental 2 Format with Failed Compressor and Pack

The automatic mode automatically maintains cabin pressure to a preprogrammed schedule. In this mode, the pilot selects cruise and landing altitudes, and all cabin pressurization functions are performed by one of two automatic digital controllers. One of these controllers performs the pressurization functions, while the other controller monitors the selected controller to detect faults. If a fault is detected, control automatically switches to the monitoring controller and an ACAWS message is displayed. If both automatic systems fail, an ACAWS message is displayed and the pilot must switch to the manual control mode for cabin pressure control.

In the manual mode, the position of the outflow valve is adjusted by using the manual climb or descent switches to obtain the desired rate of change of cabin pressure. Aircraft pressurization and flight station temperature are controlled by touch-sensitive switches on the environmental 1 functional systems format, shown in Figure 112 and 113.

The touch switch at the lower left of the format is alternately selectable between cruise (CRZ) and land (LND). When CRZ has been selected, the decrease (DEC) and increase (INC) switches are used to set the digital cruise altitude readout above the altitude scale. The digits slew slowly, showing each 1000 feet between 0 and 50,000 as either switch is held down. Only three digits are shown indicating thousands of feet or the flight level. When LND has been selected the decrease and increase switches are used to set the "arrow" index on the cabin altitude scale (ALT) to the elevation of the landing runway. These two values are typically set prior to takeoff and only require adjustment in the event of change of cruising altitude or destination. The actual cabin altitude is read at the top of the bar graph against the altitude scale.

The differential pressure in pounds per square inch between the cabin and the ambient atmosphere is read out at the top of the bar graph against the differential (DIFF) scale. Maximum allowable differential is shown under the red line as 8.3.

The rate of change of cabin pressure changes automatically at a preprogrammed rate based upon the required change of cabin altitude and differential pressure. The system is designed to maintain as little change as possible and at the lowest rate. This means that the cabin altitude is always kept as low as possible during cruise. Therefore, when the aircraft

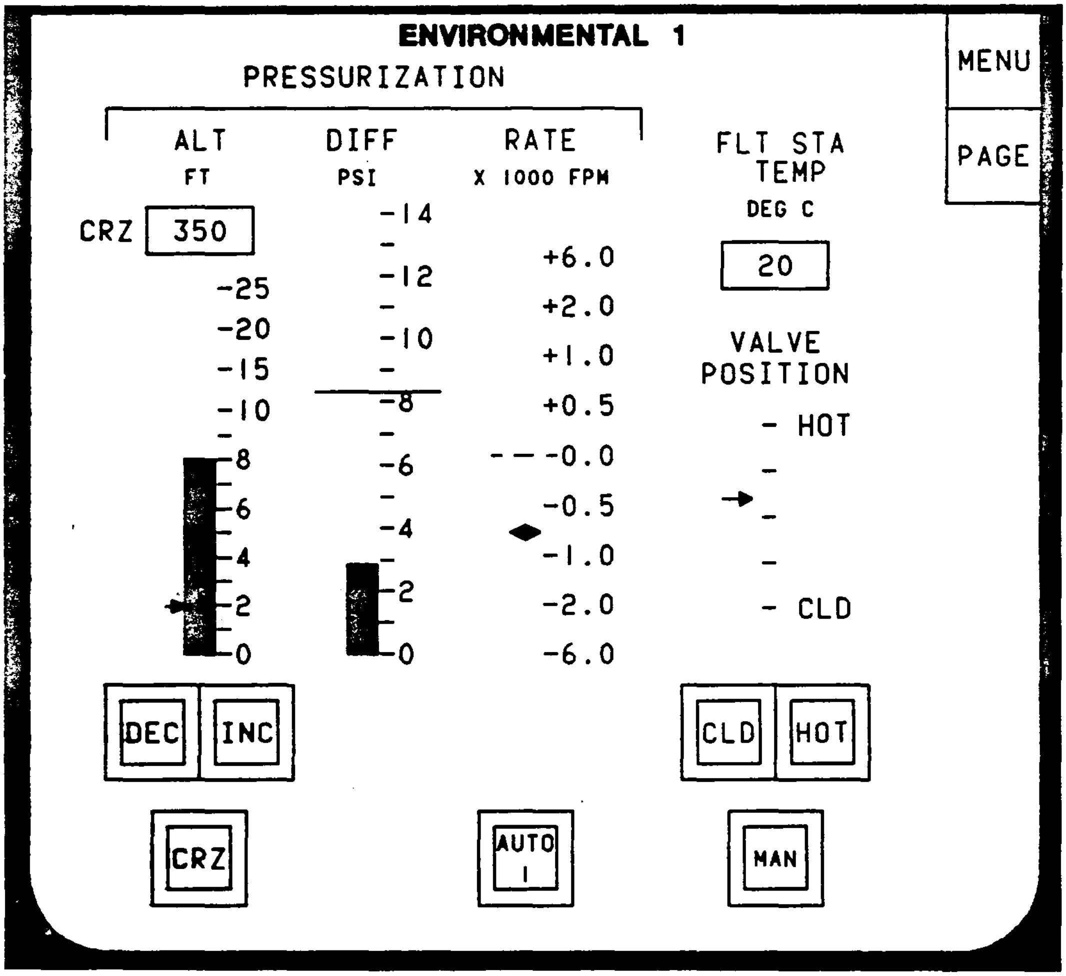


Figure 112. Environmental 1 Format with Pressurization Rate in Auto and Temperature Control in Manual

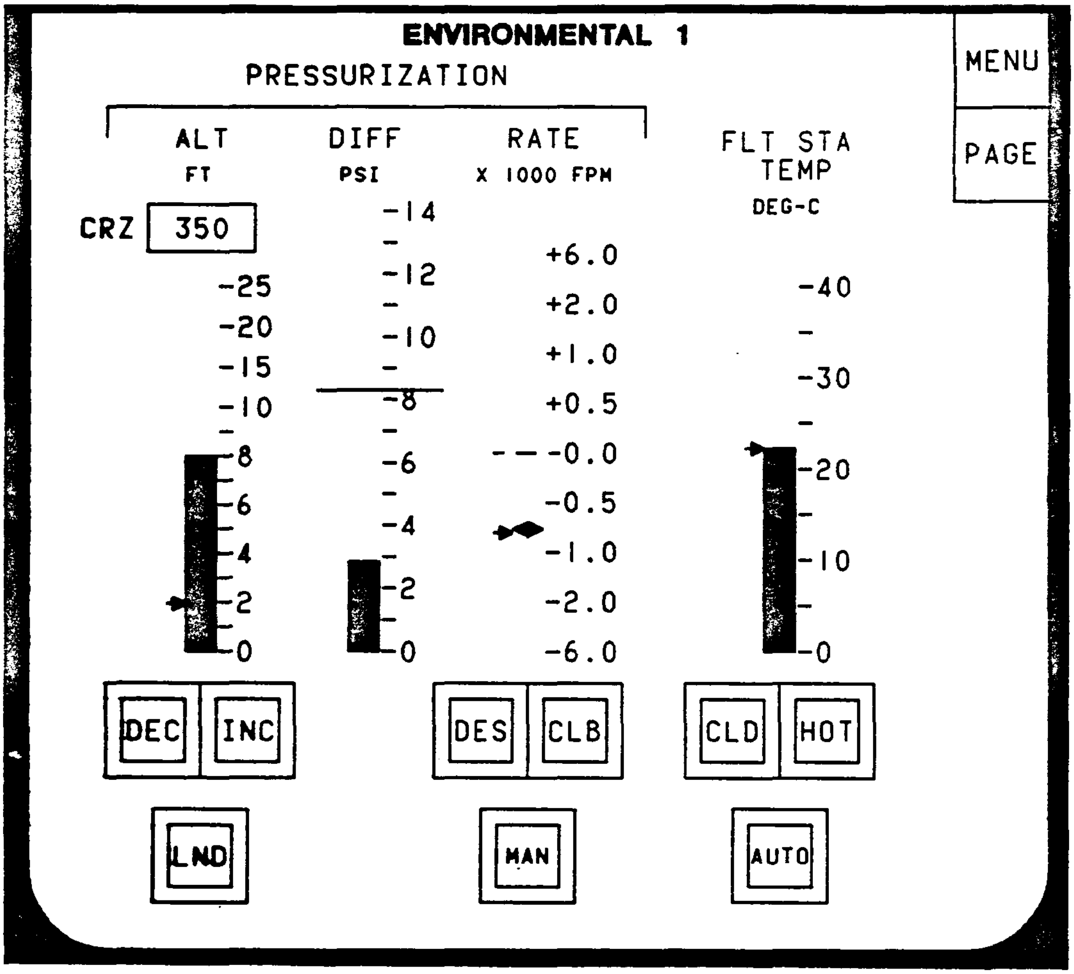


Figure 113. Environmental 1 Format with Pressurization Rate in Manual and Temperature Control in Auto

is climbing and the system is operating in automatic, the system is scheduled to increase the cabin altitude as slowly as possible toward a cabin altitude which provides a maximum pressure differential at cruise altitude. When descending, the rate of change is equally slow from cabin cruise altitude to landing field elevation. The actual rate of change of cabin altitude is shown by a diamond index marker against the rate scale.

In the event that both automatic systems fail, the pilot can select manual (MAN) control on the touch switch beneath the rate scale. When MAN is selected, descent (DES) and climb (CLB) touch switches also appear as shown in Figure 113. Holding either of these switches moves an "arrow" index on the rate scale to the commanded position.

Flight station temperature can be controlled automatically, as shown in Figure 113, or manually, as shown in Figure 112. When the system is automatic (AUTO), the cold (CLD) and HOT switches are used to position the "arrow" index against the temperature scale to the commanded temperature. The system automatically maintains that temperature, which is shown as a bar graph. When MAN control has been selected, the flight station temperature appears as a digital readout, and the CLD and HOT switches are used to change the position of the heat valve to a colder or hotter setting. Once set, the valve remains stationary, but the temperature may vary.

ADVERSE WEATHER SYSTEMS

Adverse weather systems include those necessary for engine anti-icing, wing and empennage anti-icing, sensor heating, windshield heating, continuous ignition, and rain removal. All controls for these systems except the last two are available on the touch panel overlay to the number 4 CRT labeled ADVERSE WEATHER. The format for this display is shown in Figure 114. The controls for continuous ignition and rain removal are on a dedicated panel labeled LIGHTS/ADV WX, located on the overhead console and shown in Figure 115 (Item 35, Figure 15).

Engine Anti-Ice

Engine anti-icing is controlled by a separate ON/OFF touch switch for each engine on the adverse weather systems display. Next to these switches is the switch which activates the automatic or manual ice detection system. Normally, this switch is in automatic; however, the manual or OFF position can be selected. Should icing conditions be detected with the system in auto or manual, an ACAWS advisory which says "engine icing conditions" is displayed.

When in auto, the system automatically activates the individual engine switches. When icing is no longer detected, these switches automatically turn off. In the manual position, detection is provided but automatic heat is not. The detection system may also be manually turned off. In that case, there is no ice detection and the heat switches must be manually turned on or off.

Several ACAWS messages are associated with the system. If the engine switches are not turned ON (automatically or manually) within one minute of detecting icing, the ACAWS advisory is upgraded to this caution: "engine icing." If overheating occurs in either engine inlet, the following ACAWS caution appears: "#1 (or 2) engine anti-ice-overheat." If either side fails to heat, the caution, "#1 (or 2) engine anti-ice-inop," will appear. A failure is also indicated by a red X across the malfunctioning unit's touch panel switch.

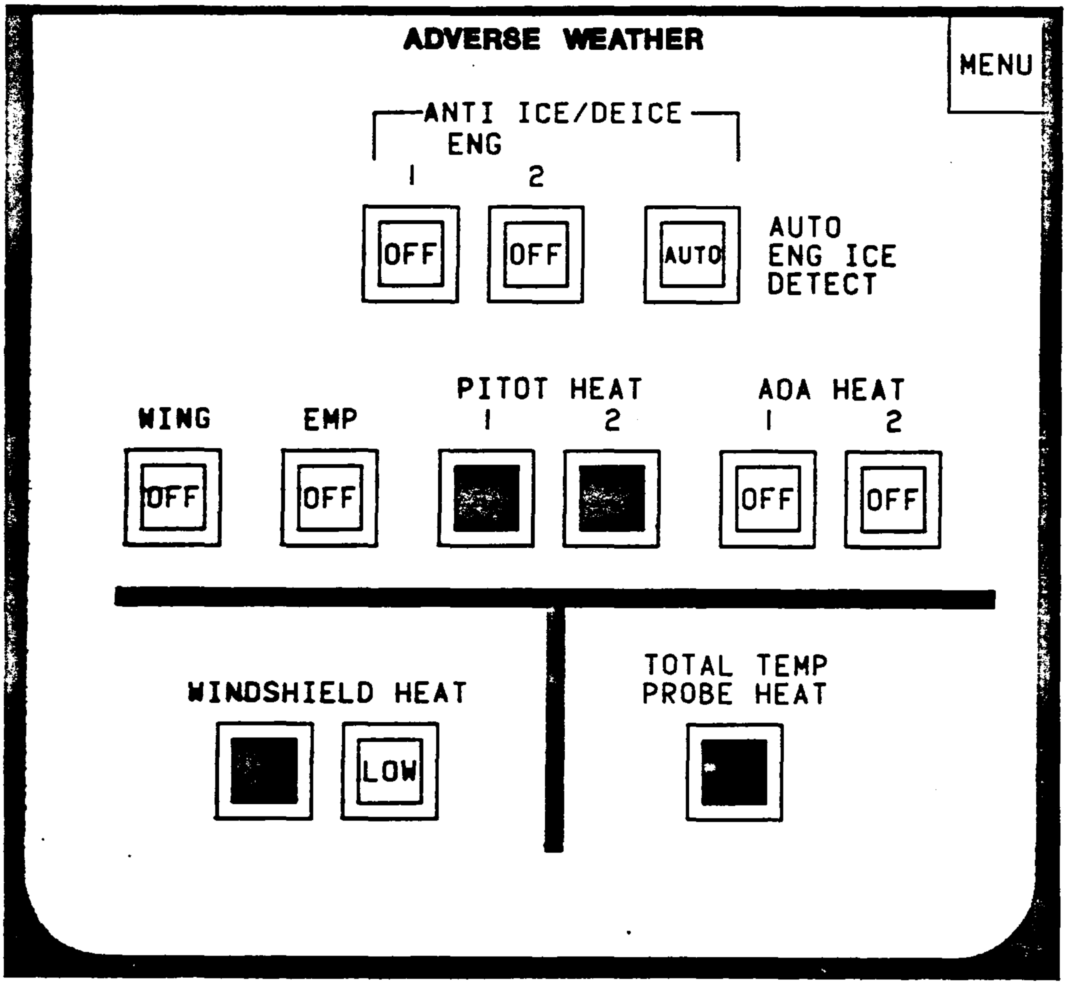


Figure 114. Adverse Weather CRT Format and Touch Panel

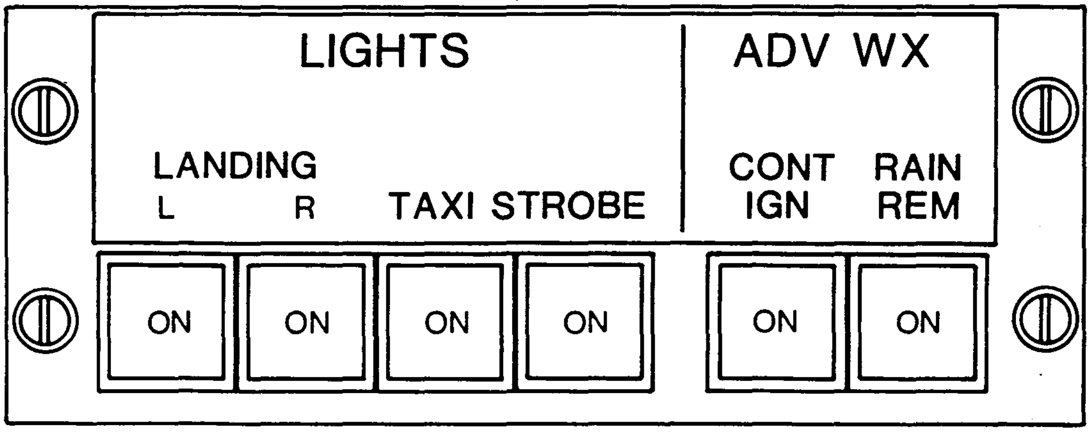


Figure 115. Lights and Adverse Weather Panel

Wing and Empennage Anti-Icing

Wing and empennage anti-icing is controlled manually by separate ON-OFF switches. The following ACAWS cautions are associated with these two systems:

- o WING ANTI-ICING - OVERHEAT
- o WING ANTI-ICING - INOP
- o EMP ANTI-ICING - OVERHEAT
- o EMP ANTI-ICING - INOP

A red X also appears on the touch panel indicating which system has malfunctioned.

Sensor Heat

Switches are also provided on the touch panel for control of heat to the pitot heads, angle-of-attack (AOA) sensors, and the total temperature probe. A failure of any of these displays a caution on ACAWS and a red X over the switch. Those cautions are listed below.

- o #1 (or 2) PITOT HEAT - INOP
- o #1 (or 2) AOA HEAT - INOP
- o TOTAL TEMP HEAT - INOP

Windshield Heat

Conventional windshield heat is provided electrically to remove ice, fog, and frost. Two switches for this system are provided on the touch panel display. One switch turns the system ON or OFF, and the other switch selects (and annunciates) either LOW or HI. When the system is initially turned on, the ON/OFF switch is solid green, and the low/high switch indicates the LOW position. If a greater rate of heating is desired, the low/high switch may be pushed, at which time the label reads HI.

A failure of this system causes a red X to be displayed over the ON/OFF switch. Accompanying this is an ACAWS caution. Possible ACAWS messages might be:

- o WINDSHIELD HEAT - INOP
- o WINDSHIELD HEAT - OVERHEAT

Rain Removal

Rain or snow is removed from the windshields by a steady blast of air. The switch which controls this system is located on the overhead console, near the landing gear control handle, on a panel labeled LIGHTS/ADV WX. Pressing this switch applies power to an electric blower and illuminates the word ON on the switch. A failure of the system causes the following caution on the ACAWS: "rain removal-inop."

Continuous Ignition

Located adjacent to the rain removal switch is a switch labeled continuous ignition (CONT IGN). Pressing this switch illuminates the ON legend and supplies continuous power to the engine ignitors to minimize the likelihood of flameout due to rain or ice ingestion. If the system fails "cont ignition-inop" appears as a caution on the ACAWS display.

WEATHER RADAR

The weather avoidance radar has the following characteristics:

- o Solid state design
- o Digital processing
- o Microcomputer logic
- o Digital display using color CRT with TV raster scan
- o Low power output (approximately 120 watts)
- o Operation at X-band frequency (9.375 GHz)
- o Flat plate antenna design
- o ARINC 708 design compatibility
- o Dual antenna and dual R/T units
- o Self test and automatic monitoring
- o Doppler processing for turbulence detection
- o One control unit

The dual antenna is a single flat plate antenna with dual inputs for the two R/T units, dual power regulators and dual motor drive circuits. The radar antenna scans in front of the aircraft, $\pm 90^{\circ}$ about the aircraft track, which necessitates input of a drift offset to the scan servo loop. This antenna scan pattern does not provide for weather video from behind the aircraft.

The crew systems connected with the radar consist of a control panel located on the center console, the nav displays on which the symbology is displayed, and the nav display control panel on the desk top.

Radar Control

The radar panel, shown in Figure 116 (Item 31, Figure 15), is located on the center console and contains most of the controls for operating the

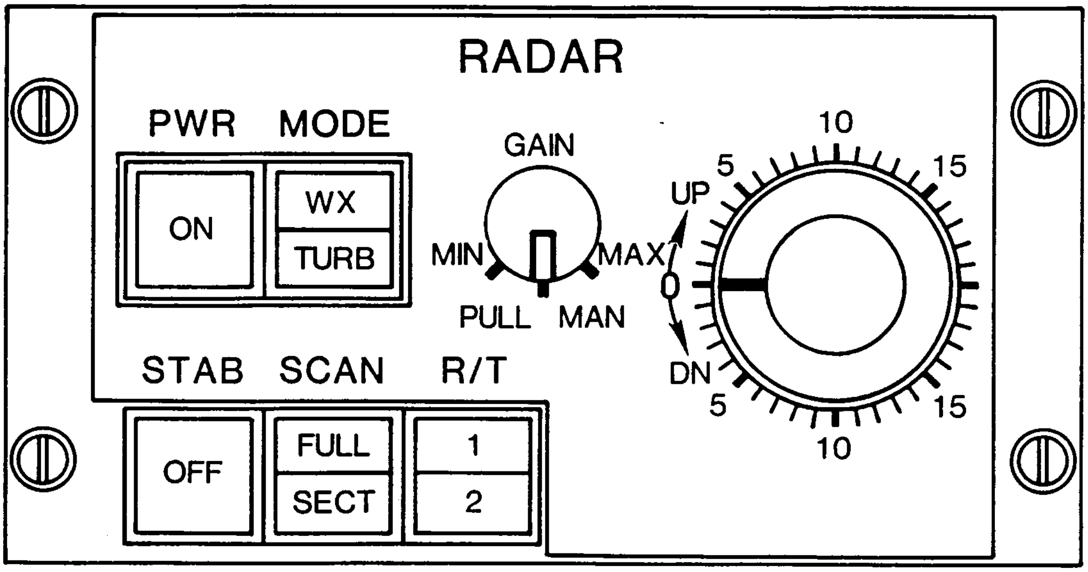


Figure 116. Radar Control Panel

unit. Power is applied or taken from the unit through the power (PWR) ON/OFF switch. The split-legend mode selector switch is used to select weather (WX) or turbulence (TURB) mode. Antenna stabilization is turned on or off with the stabilization switch (STAB). The scan pattern for the radar can be selected to either the FULL position to scan $\pm 90^{\circ}$ from aircraft track, or the sector (SECT) position to scan $\pm 45^{\circ}$ from the aircraft track. Either the number 1 or number 2 receiver/transmitter unit may be selected with the R/T switch. The radar receiver gain can be operated in the automatic mode (knob pushed in) or manual mode (knob pulled out). The gain can be manually adjusted toward minimum or maximum, as desired, by turning the GAIN knob. With the rotary antenna tilt knob (ANT TILT), the antenna can be tilted $\pm 15^{\circ}$ from the aircraft's longitudinal axis so that the pilot can scan along the vertical flight path, as well as above or below it.

Radar Display and Display Controls

The nav display control panels, shown previously in Figure 23, are located on the desk top outboard of each set of throttles. One panel controls the captain's nav display; the other, the first officer's. The functions of the switches on these panels were described earlier along with the navigation displays. The range switches and radar display symbology switch are also pertinent to this description, however.

Weather or turbulence symbology can be displayed on either, neither, or both the captain's and first officer's navigation displays by selecting the radar (RDR) switch ON or OFF. Only the mode (WX or TURB) selected on the radar control panel can be displayed, and that mode is identified on the right center of the picture as shown previously in Figure 24. The various levels of intensity of the weather or turbulence are indicated by the color of the contours -- white for light, amber for moderate, red for severe. The centers of the contours are not filled so as to reduce clutter and to permit symbology to be seen "beneath" the contoured area.

The distance that the radar imagery can be seen is selectable and independent for either pilot. The nautical mile range and range marks for each display are selectable to 2.5/.5, 5/1, 10/2, 50/10, 100/20, or 200/40. The display range switches on each panel are mutually exclusive.

LANDING GEAR SYSTEM CONTROLS

The landing gear system includes normal extension, retraction, and position indication; emergency release and extension; nose wheel steering control; braking; and a parking brake. All systems function electrically except for nose wheel steering which requires an electrically driven hydraulic system.

Extension-Retraction

The gear control panel, shown in Figure 117 (Item 36, Figure 15), is located in the overhead console. It contains a two-position (UP-DOWN) lever which controls the normal operation of the landing gear. Normal operating time is 15 seconds. An emergency release handle and an emergency extend switch are provided as backups to the normal extension system. The release handle, located in the aft end of the center console, activates a cable release of the uplock solenoids. The emergency extend switch provides an alternate electrical means of extending the gear. Emergency extension may take up to 95 seconds.

Gear Position Indicators - Three split-legend gear position indicators, shown in Figure 118, illuminate green in the lower half of the switch when the gear is down and locked. The upper portion of the indicator illuminates red when the gear position is not in agreement with the handle position and when either throttle is retarded to 5 percent above flight idle and the gear is not down and locked. A timer is included to signal the ACAWS system should the disagreement continue for more than 30 seconds. The indicators are not illuminated when the gear is up and locked. The indicators are located on the overhead panel adjacent to the gear control panel (Item 40, Figure 15).

Warning System - Cautions and warnings associated with the gear not down prior to landing or with gear malfunctions are all integrated into the ACAWS. The key aircraft parameters which make up the warning logic are throttle position, radar altitude, barometric altitude, and flap position.

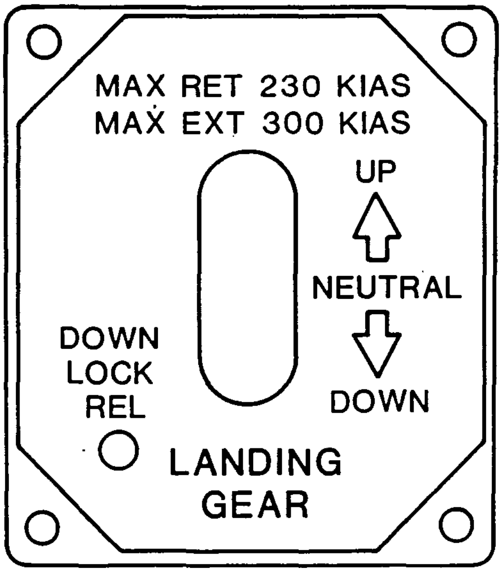


Figure 117. Landing Gear Control Panel

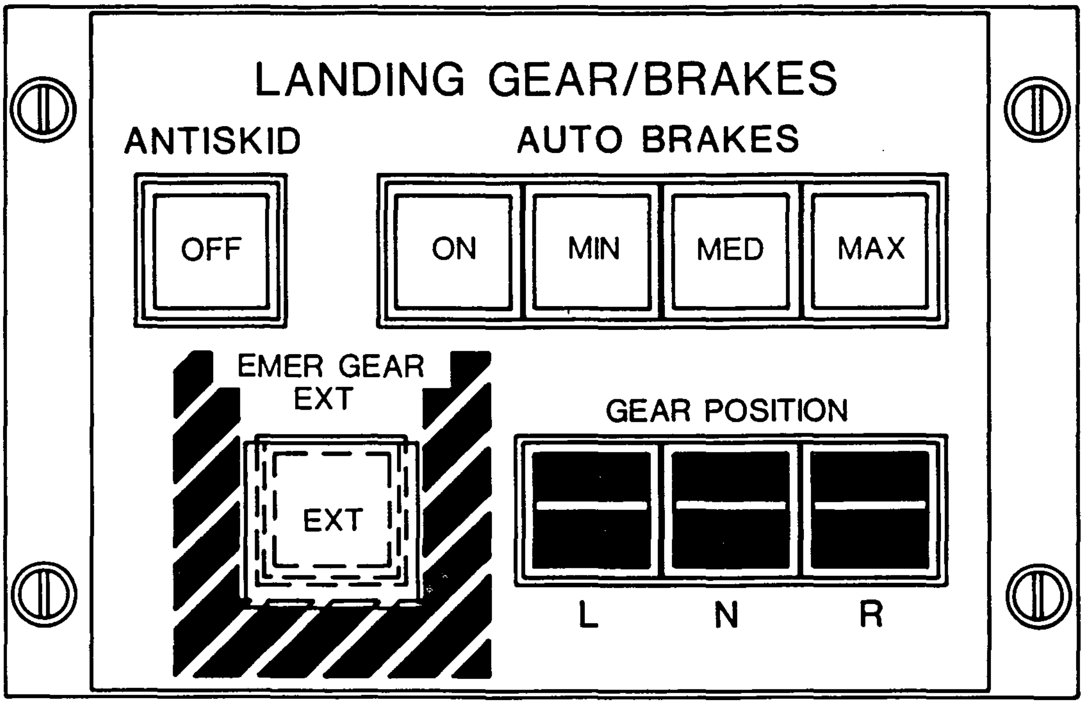


Figure 118. Landing Gear/Brake Control Panel

Nose Wheel Steering

Nose wheel steering is accomplished by rudder pedal or steering wheel control of a self-contained hydraulic system. The steering authority of the rudder pedals is limited to $\pm 15^{\circ}$ steering angle. The full $\pm 60^{\circ}$ steering is available by using either steering wheel. These wheels, shown in Figure 119, (Item 48, Figure 15), are located on each side of the desk top adjacent to each control stick. An ACAWS message will indicate low hydraulic pressure (steering power failure). After failure of the nose wheel steering system, limited steering is possible with differential braking.

Brake System

The totally-electric braking system consists of conventional toe brakes on the rudder pedals, an automatic braking system, an anti-skid system, and a parking brake.

The anti-skid system is controlled by a two-position anti-skid switch located on the LDG GEAR/BRAKES control panel. Pressing the switch disconnects the system and the OFF legend is illuminated. Pressing the switch a second time arms the anti-skid and extinguishes the legend.

The brake system has both normal and alternate actuators with automatic transfer from normal to alternate.

Automatic Braking - For automatic braking, the pilot must select either minimum (MIN), medium (MED), or maximum (MAX) deceleration.

In the landing mode, the following conditions are required to arm the automatic braking system:

- Aircraft airborne
- Landing gear lever in DOWN position
- Anti-skid ON and self-tested
- Normal brake system selected
- Accelerometer connected and operational
- MIN, MED, or MAX selected by the pilot

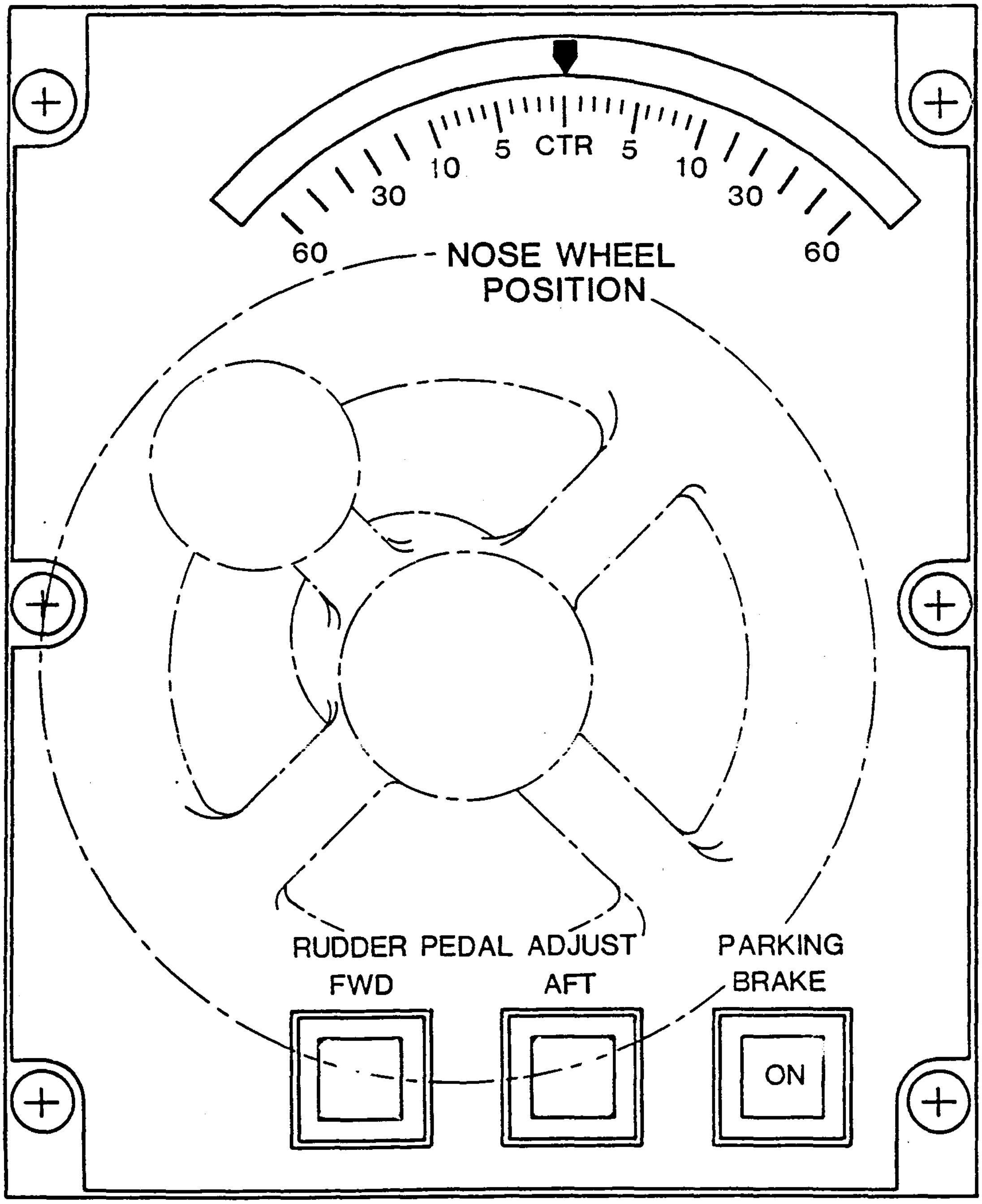


Figure 119. Nosewheel Steering and Parking Brake Control Panel

When the system is properly armed, an advisory alerts the pilot. Brake application is initiated when all of the following conditions are met:

- At least one rear wheel on each main landing gear is on the ground and exceeding 80 knots.
- Throttles retarded to flight idle or less.
- Nose wheel on the ground.

When these conditions are met, a three-second time delay takes place before brake application. Braking is applied in the MIN, MED, and MAX landing modes until the selected deceleration rate is achieved. Deceleration levels for MIN, MED, and MAX are 4 ft/sec/sec, 6 ft/sec/sec, and maximum available deceleration, respectively. The automatic braking system disarms automatically if any of the following conditions occur:

- A fault is detected
- Anti-skid system is turned off
- Alternate brake power source is selected
- Landing gear lever is moved up
- Automatic braking is turned off
- Either pilot uses the toe brakes
- Throttles are advanced

Normal operation of the toe brakes or throttles while taxiing does not disarm the system, nor does operation of the parking brake. During the takeoff, the system immediately applies braking in the event of an aborted takeoff. The pilot must arm the system before beginning the takeoff roll. To do so, these conditions must exist:

- Anti-skid ON
- Normal brake system in use
- MAX braking selected

Arming is completed when the pilot selects MAX. The armed condition is indicated by an advisory on ACAWS.

If the pilot aborts the takeoff after exceeding a ground speed of 80 knots, automatic braking is initiated the moment ground spoilers are deployed or reverse thrust is selected; full brake system power is applied at this time. Below 80 knots, automatic braking does not occur. This avoids unnecessarily severe braking when runway distance remaining does not warrant maximum performance stopping.

Parking Brake - When pressed, the parking brake switch, shown in Figure 119, adjacent to each nose wheel steering control wheel, illuminates the legend PARKED on the switch, illuminates a PARKING BRAKE SET advisory on ACAWS, and actuates the parking brake solenoid. Pressing the switch again releases the brakes, extinguishes the legend, and clears the ACAWS advisory.

LIGHTING

The aircraft lighting system consists of exterior and interior lighting. Most exterior lighting and some of the interior lighting will not be simulated. However, the switches and indicators are included on panels and CRTs to maintain realism of the flight station.

Exterior

Part of the exterior lighting controls are on a dedicated EXT LTG panel as depicted previously in Figure 115. This panel is located on the overhead panel near the landing gear control handle.

Landing Lights - The landing lights, left and right, are located in the wing or on the main landing gear so that extend-retract switches are not required. Two push-ON/push-OFF switchlights are provided for control and indication. These switches function in the simulator.

Taxi Lights - The taxi lights are located on either side of the nose gear and are turned ON and OFF by a single switchlight on the EXT LTG panel. This switch is functional in the simulator.

Strobe Lights - There is one switch for ON-OFF located on the EXT LGT panel.

The remaining exterior lighting controls are located on a CRT touch panel on the number 4 CRT display shown in Figure 120. In the flight simulator they perform no function except to indicate switch selection.

Navigation Lights - The navigation lights are controlled and monitored on the CRT display shown in Figure 120. Two switches are provided for ON-OFF and steady-flash selections.

Anticollision - One touch panel switch for ON-OFF indication is provided.

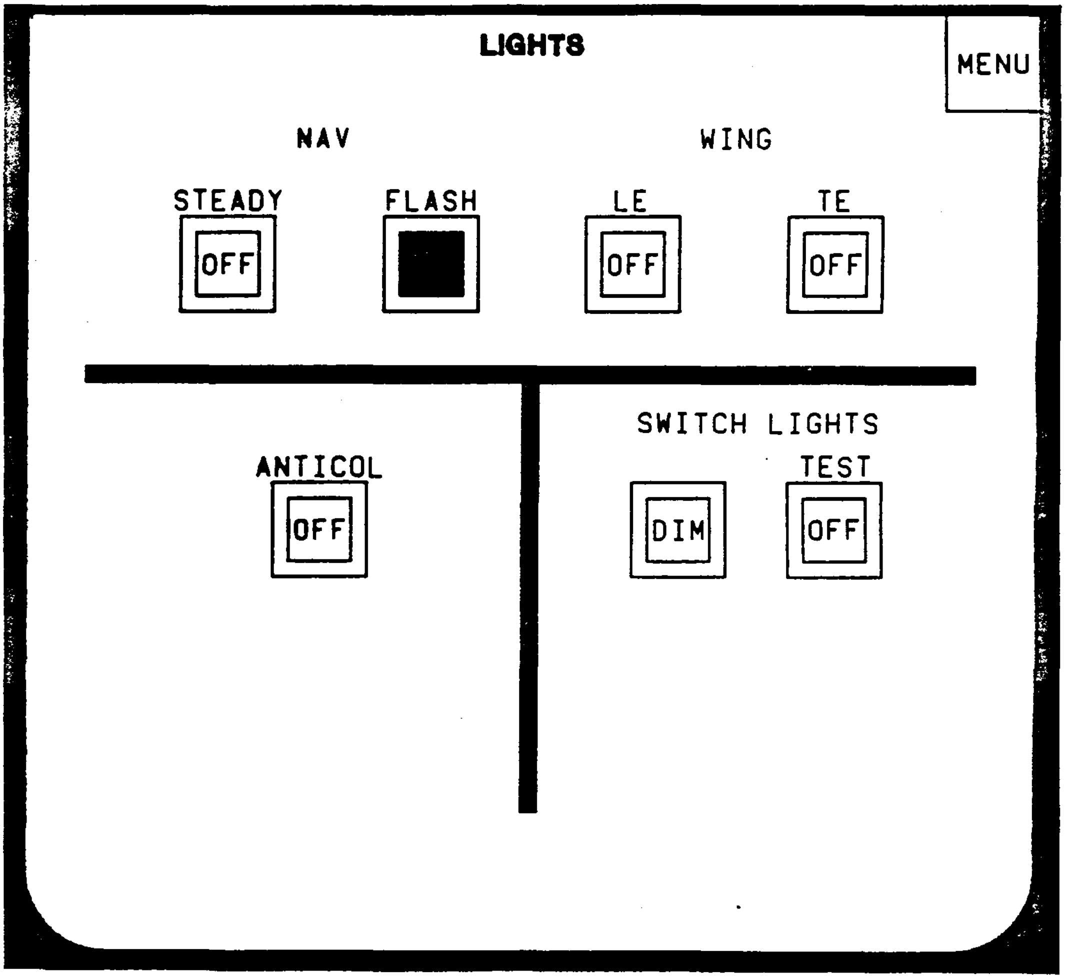


Figure 120. CRT Touch Panel Light Controls

Wing Inspection - Switches are provided on a CRT touch panel to indicate ON-OFF for leading edge (LE) and trailing edge (TE) inspection.

Switch Light Bright/Dim Control - A switch is provided on the touch panel to select a bright or dim level of illumination on all switch lights. This switch functions in the simulator.

Switch Light Test Control - A switch is provided on the touch panel to test the bulbs in all switches in the cockpit. When pressed all bulbs illuminate to the brightness selected on the BRIGHT/DIM switch and remain ON for approximately seven seconds before extinguishing. This switch is functional in the simulator.

Interior

Most of the simulator interior lighting functions are the same as on the aircraft. Integral instrument lighting, for the most part, is not required. Most of the panel lighting is electroluminescent (EL) and is controlled from the dedicated panel on the overhead console, as shown in Figure 121 and described as follows.

CRT Displays - Each of the five front panel CRTs is controlled through continuous OFF-BRT switches.

Main Instrument Panel - Two switches are provided to control lights on the main instrument panel. The PNL switch provides continuous OFF-BRT control of the EL panels around the CRT bezels and the master CRT brightness. The INSTRU switch controls the integral lighting in the fuel quantity indicator, flap position indicator, clock, and inclinometer.

Desk - Three separate switches provide control to the desk top. The PNL switch provides continuous OFF-BRT control of all EL panels. The DSPY switch controls the intensity of the alphanumeric displays, and the KBD switch controls the lighted keyboards.

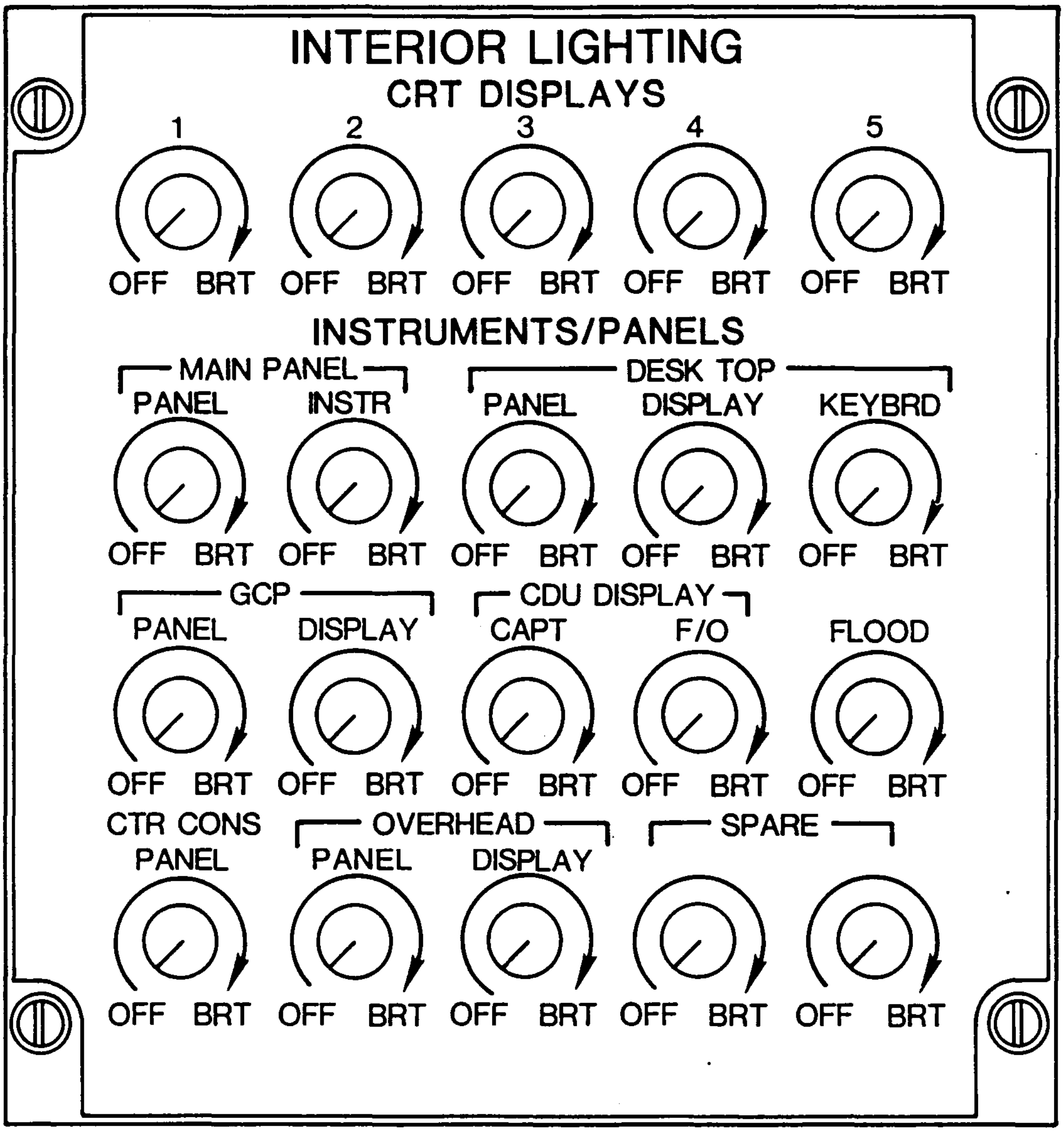


Figure 121. Interior Lighting Control Panel

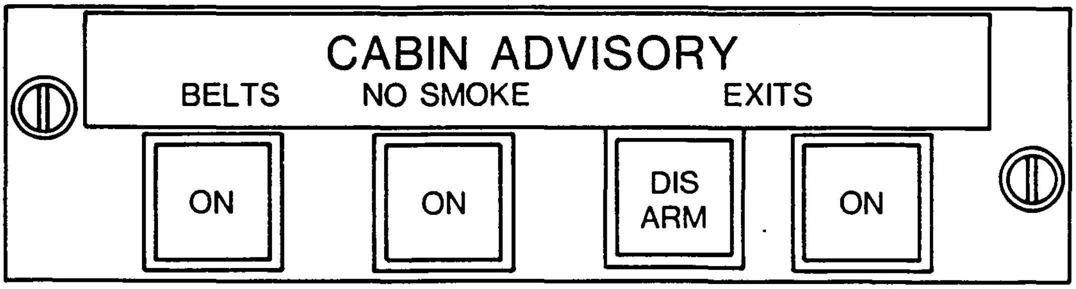


Figure 122. Cabin Advisory Lights Panel

Center Console - The CTR CON switch provides continuous OFF-BRT control of all EL panels on the center console.

Overhead Console - Two switches are provided to control the lights on the overhead console. The PNL switch provides continuous OFF-BRT control of the EL panels. The DSPY switch controls the intensity of the alphanumeric displays on the loadmeters and oxygen quantity indicator.

Control Display Unit - The intensity of each CDU display is controlled separately with the CAPT and F/O switches.

Guidance and Control Panel - Two switches are provided to control the lights on the guidance and control panel. The PNL switch provides continuous OFF-BRT control of the EL panels. The DSPY switch controls the intensity of the alphanumeric displays.

Flood - The FLOOD switch controls the flood lights which also function as thunderstorm lights.

Cabin Advisory - Separate switch lights are provided for control of the "fasten seat belt" and "no smoking" advisory signs, as shown in Figure 122. These switches are located on the overhead panel near the landing gear control handle. Switches for the emergency exit lights are also on that panel. One of these switches turns them ON or OFF; and the other switch arms the lights for automatic activation in case of crash landing, ditching, or power failure.

Utility - Two detachable, swivel mounted, dimmable utility/map lights are mounted so that they illuminate the laps of the captain and first officer. Self-contained OFF-BRT pots are provided for continuous control.

FIRE PROTECTION SYSTEM

The fire protection system contains a detection and warning system for each engine and for the auxiliary power unit. Two bottles of extinguishing agent are provided for engine protection and two additional bottles for APU protection. Both engine bottles can be discharged to either engine, if required. The fire control panel is shown in Figure 123 (Item 46, Figure 15).

Fire Detection and Indication

A fire detection signal for engine 1, engine 2, or the APU illuminates the red master warning indicators on the glare shield and the appropriate fire control light (i.e., the light in the number 1 or number 2 engine pull handle or the APU fire light switch). Additionally, it provides an ACAWS and voice message indicating "Fire #1 ENGINE" (#2 ENGINE or APU). As with an emergency warning, the appropriate emergency checklist may be called-up on the checklist display, if desired, by selecting the appropriate emergency or abnormal checklist switch.

Fire Extinguishing

Pulling a lighted engine fire pull handle or pressing the APU fire switch shuts off all fluids to that equipment, routes the extinguishing agent, and arms the extinguisher bottles. For engine fire, rotating the pulled handle counterclockwise 60° from center releases the agent from bottle number 1 and illuminates the BTL OUT indicator. Rotating the pulled handle 60° clockwise from the center releases the contents of bottle number 2, and subsequently that BTL OUT light illuminates. For an APU fire, pressing either push-to-discharge switch releases the agent, and the APU BTL 1 or 2 OUT legend illuminates in the bottle used. The other bottle can then be discharged, if required, and the BTL OUT legend lighted.

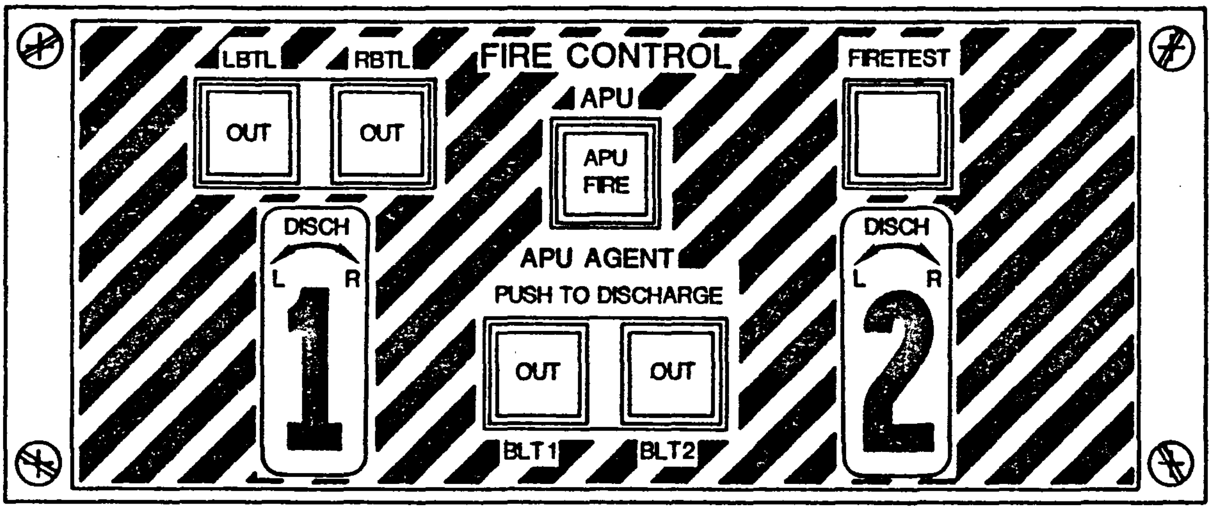


Figure 123. Fire Control Panel

Fire Detection System Test

The fire detection system and all associated lights are tested for continuity and light bulb condition by pressing the fire test switch. When pressed, if the system is operating properly, the system is tested and all switch lights and the lights in the fire handles illuminate for a period of a few seconds. Any discrepancy (e.g., fire detection loop to #1 engine is open) to system continuity causes an appropriate ACAWS message and illuminates the master warning light.

OXYGEN SYSTEM

An on-board oxygen generating system is installed. The system is composed of an air separation module utilizing bleed air, a compressor, heat exchanger, storage bottles, main regulator, diluter regulator, passenger drop-out masks, crew oxygen masks, and an oxygen control panel. The system is totally automatic for normal operation. In event of decompression, the generation system turns ON and passenger and crew masks deploy automatically.

If manual control is desired, as might be the case with smoke or fumes in the aircraft, the crew can manually start the system and deploy the masks in either the flight station or cabin or both by pressing the appropriate switch(es) on the oxygen/emergency panel shown in Figure 124. The oxygen quantity, measured in pounds-per-square-inch, is displayed on a digital readout.

EMERGENCY LOCATOR TRANSMITTER

The emergency locator transmitter (ELT) provides the necessary controls and audible output simulating actual aircraft ELT operation. The oscillator provides the audible signal to simulate the activation of an ELT. The output from the oscillator is a frequency sweeping downward from 1600 to 300 Hz at a repetition rate of between 2 and 4 Hz. The oscillator is connected to the intercom system and can be monitored aurally by tuning the VHF radio to the emergency frequency (normally 121.5) and selecting VHF monitor. The oscillator is activated (commanded ON) by the ELT transmit switch, by the experimenter's panel, or the processor system.

The ELT system is powered up to the automatic position when power is applied to the aircraft. The normal switch position is AUTO, which is an unlighted position. In this position the experimenter, simulating frangible switch activation, can command the oscillator ON. The processor system simulating excessive "Gs" can also command the system ON. Turning the power OFF with the remote controlled circuit breaker in the flight management CDU inhibits/resets the oscillator. The pilot can activate the oscillator by pressing the ELT transmit switch, which also illuminates the legend XMT.

EMERGENCY DEPRESSURIZATION SWITCH

In the event that the pilot needs to rapidly depressurize the aircraft, he can raise the guard and press the emergency depressurization switch shown in Figure 124. This causes the outflow valves to open, the cockpit and cabin to rapidly depressurize to atmospheric pressure, the compressors to unload, and the DEPRES light in the switch to illuminate. The outflow valves cannot be reset by the pilot, so the DEPRES light remains ON until extinguished by ground personnel.

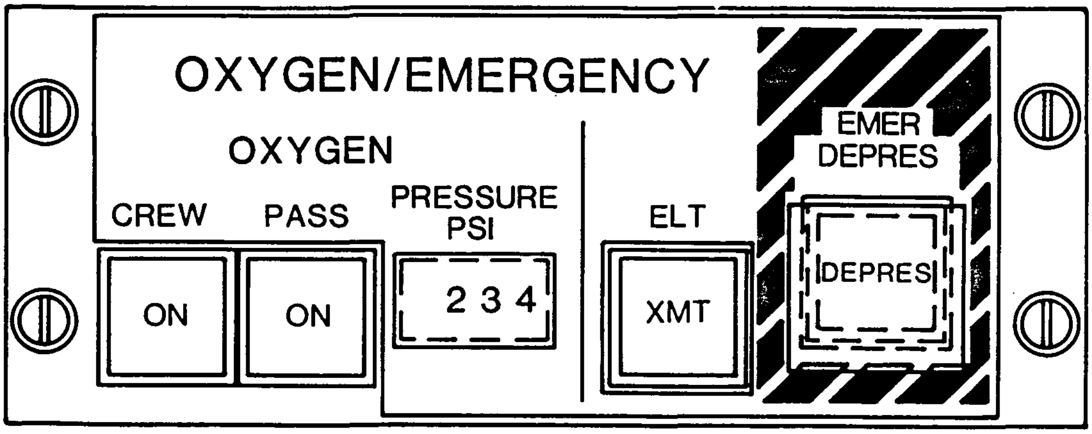


Figure 124. Oxygen and Emergency Panel

CRASH DATA RECORDER SYSTEM

The crash data recorder (CDR) system consists of the digital flight data recorder (DFDR) and the cockpit voice recorder (CVR). The DFDR records aircraft and flight data; the CVR records crew conversation and flight deck audio. Both recorders are normally ON any time power is applied to the aircraft.

No intervention by the crew is required for the DFDR. Automatic internal monitoring assures that the unit is operational. Should a failure of the unit occur, it is announced by the ACAWS.

The CVR requires crew intervention to ensure an operational system. A test switch is provided on the CDU TEST page which, when pressed, outputs a controlled audio signal to the recorder then causes a playback and comparison of the recorded to the input signal. Additionally, an erase function can be activated by a switch on the cockpit voice recorder panel as shown in Figure 125 (Item 45, Figure 15).

Note: The CDR system will not be implemented in the baseline simulator.

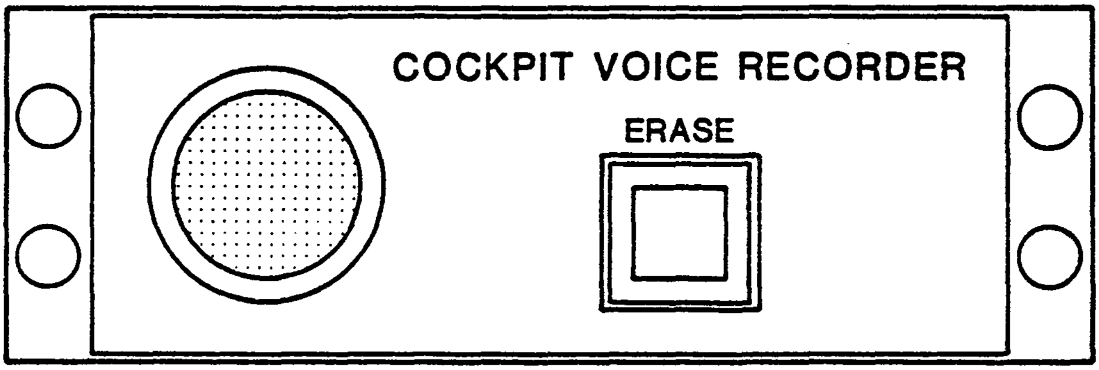


Figure 125. Cockpit Voice Recorder Panel

CONCLUSIONS AND RECOMMENDATIONS

The aviation community is preparing to cope with large increases in air traffic and operating costs projected during the next decade, while continuing to maintain safe operating procedures and methods. To do this the Federal Aviation Administration is updating and improving air traffic control systems, while airframe manufacturers and aircraft operators are developing methods to reduce aircraft weight, fly fuel efficient profiles, and optimize crew complements. New technologies are being exploited and efficient crew systems are being designed. In order to evaluate these systems in a near-real-world environment, full mission flight simulators are being constructed.

During the effort described in this report, 1990s technologies were projected, and a preliminary set of aircraft systems were defined for operation in the projected 1990's air traffic control system and technology environment. All crew systems were defined, including controls and displays and operational descriptions for each system. A full scale flight station mockup was configured, and pilots' checklists were prepared. Experienced airline pilots currently flying commercial transport aircraft, NASA test pilots, and Lockheed flight operations pilots then evaluated the crew systems and flight station design by "flying" various high workload segments of a transport aircraft mission scenario. Comments, critiques, and data from the test subjects, taken during the evaluation and later on questionnaires, were used to refine the design. This design is now being incorporated into full mission research flight simulators as the baseline design from which to begin further research.

The simulation facilities will provide the capability to examine a multitude of research issues facing the aviation community. Examples of recommended areas to be explored include the applicability and use of large electronic displays, touch panel controls, voice command, head-up displays, and fly-by-wire/light flight and thrust controllers. Aircraft and aircrew interfaces with new air traffic control systems can be tested, and crew complements and operating techniques can be optimized. The research performed on these and other pertinent issues will provide timely answers for future designers, manufacturers, and operators. It is essential that relevant segments of government and industry team together to accomplish this needed research.

APPENDIX A

The test subjects evaluated the flight station and crew systems by flying a series of very structured "slice-in-time" mission scenarios in the mockup. They each completed the following questionnaire after completion of the flying sessions. Summarized responses are included. On questions which required the use of a rating scale, the Mean and Standard Deviations are shown. Pertinent comments were incorporated into the design, as appropriate.

POST-MOCKUP QUESTIONNAIRE

1. Were all controls reachable?

___ 1 All controls were reachable without effort
___ 2 A few controls required a slight effort to reach
___ 3 Most controls required a slight effort to reach
___ 4 A few controls required considerable effort to reach
___ 5 Most controls require considerable effort to reach

Comments:

MEAN 1.4
STANDARD DEVIATION .516

Please use the following scale to rate questions 2 through 6.

1 Excellent, the controls and displays are arranged in an optimal manner
2 Good
3 Fair
4 Poor
5 Bad, the arrangement is totally unacceptable

2. Please rate the control/display arrangement on the overhead console. _____

Comments:

MEAN 1.9

STANDARD DEVIATION .567

3. Please rate the control/display arrangement on the main instrument panel. _____

Comments:

MEAN 1.9

STANDARD DEVIATION .422

4. Deleted

5. Please rate the control/display arrangement on the desk console for the two-throttle configuration. _____

Comments:

MEAN 1.3

STANDARD DEVIATION .483

6. Please rate the control/display arrangement on the center console.

_____

Comments:

MEAN 1.3
STANDARD DEVIATION .483

7. Do you feel that there are any functions which should have dedicated switches that do not in the current configuration? _____ yes _____ no

If yes, what are they?

YES 2
NO 7

8. Do you feel that there are any dedicated switches that could be placed on a touch panel or in the CDU? _____ yes _____ no

If yes, what are they?

YES 7
NO 1

Please use the following scale to rate the intepretability of the various display formats.

<u>Format Interpretability</u>

1 Excellent, all information is well organized and easy to interpret
2 Good, most information is organized and easy to interpret
3 Fair, the interpretability is acceptable
4 Poor, some information is difficult to interpret
5 Bad, the information in the format is impossible to interpret

9a. Please rate the information interpretability on the flight display format. _____

Comments:

MEAN 1.4
STANDARD DEVIATION .516

9b. Is all required information for this format present? ____ yes ____ no

Comments:

YES 8
NO 2

9c. Does the color coding aid in the location of information in the format? _____ yes _____ no

Comments:

YES 10
NO 0

10a. Please rate the interpretability of the map format, navigation display. _____

Comments:

MEAN 1.3
STANDARD DEVIATION .483

10b. Is all required information for this format present? ____ yes ____ no

Comments:

YES 9

NO 1

10c. Does the color coding aid in the location of information in the format? _____ yes _____ no

Comments:

YES 10

NO 0

11a. Please rate the interpretability of the alternate navigation display formats. _____

Comments:

MEAN 1.33

STANDARD DEVIATION .5

11b. Is all required information for these formats present? ___ yes ___ no

Comments:

YES 9

NO 0

11c. Does the color coding aid in the location of information in the format? _____ yes _____ no

Comments:

YES 8

NO 1

12a. Please rate the interpretability of the engine instrument format. ____

Comments:

MEAN 1.3

STANDARD DEVIATION .483

12b. Is all required information for this format present? ____ yes ____ no

Comments:

YES 9

NO 1

12c. Does the color coding aid in the location of information in the format? ____ yes ____ no

Comments:

YES 10

NO 0

13a. Please rate the interpretability of the system status formats.

____ yes ____ no

Comments:

MEAN 1.35

STANDARD DEVIATION .579

13b. Is all required information for this format present? ____ yes ____ no

Comments:

YES 9

NO 0

13c. Does the color coding aid in the location of information in the format? _____ yes _____ no

Comments:

YES 10

NO 0

14a. Please rate the interpretatability of the two instrument approach chart formats. _____

Comments:

MEAN 1.6

STANDARD DEVIATION .699

14b. Is all required information for these formats present? ___ yes ___ no

Comments:

YES 9
NO 1

14c. Does the color coding aid in the location of information in the formats? _____ yes _____ no

Comments:

YES 8
NO 1

15a. Please rate the interpretability of the surface position indicator format.

Comments:

MEAN 1.5
STANDARD DEVIATION .756

15b. Is all required information for this format present? ____ yes ____ no

Comments:

YES 10
NO 0

15c. Does the color coding aid in the location of information in the format? _____ yes _____ no

Comments:

YES 8
NO 2

16a. Please rate the intepretability of the CDWI (cockpit display of weather information) format. _____

Comments:

MEAN 1.2
STANDARD DEVIATION .422

16b. Is all required information for this format present? ____ yes ____ no

Comments:

YES 9
NO 1

16c. Does the color coding aid in the location of information in the format? _____ yes _____ no

Comments:

YES 10
NO 0

17a. Please rate the interpretability of the ACAWS (advisory, caution and warning system) format. _____

Comments:

MEAN 1.3

STANDARD DEVIATION .483

17b. Is all required information for this format present? ____ yes ____ no

Comments:

YES 10

NO 0

17c. Does the color coding aid in the location of information in the format? _____ yes _____ no

Comments:

YES 10

NO 0

18a. Please rate the interpretability of the CDTI (cockpit display of traffic information) format. _____

Comments:

MEAN 1.55

STANDARD DEVIATION .726

18b. Is all required information for this format present? ____ yes ____ no

Comments:

YES 6

NO 1

18c. Does the color coding aid in the location of information in the format? _____ yes _____ no

Comments:

YES 9

NO 0

19a. Please rate the interpretability of the various functional systems formats. _____

Comments:

MEAN 1.2

STANDARD DEVIATION .422

19b. Is all required information for these formats present? ___ yes ___ no

Comments:

YES 9

NO 0

19c. Does the color coding aid in the location of information in the formats? _____ yes _____ no

Comments:

YES 10

NO 0

20. Please give a general overall rating of the interpretability of all the formats. _____.

Comments:

MEAN 1.3

STANDARD DEVIATION .422

21. Is there any additional information that you feel should be presented on the front CRT displays? _____ yes _____ no

If yes, what is it?

YES 6

NO 3

22. Please rate the overall color coding scheme.

- ___ 1 Excellent, very helpful
- ___ 2 Good
- ___ 3 No effect, neither helps nor detracts
- ___ 4 Poor
- ___ 5 Bad, degrades the formats

Comments:

MEAN 1.3

STANDARD DEVIATION .483

23. Do you like having the checklists on a CRT? _____ yes _____ no

Comments:

YES 9

NO 1

24. Did you like the way in which the checklists were mechanized?

___ yes ___ no

Comments:

YES 9

NO 1

25. Is the terminal keyboard on the CDU (control/display unit) an acceptable way for the pilot to interact with the mission computers?

___ yes ___ no

Comments:

YES 10

NO 0

26. Please evaluate the adequacy of the information presented on the CDU.

___ too much ___ adequate ___ too little

TM 0

A 10

TL 0

If you feel that too much or not enough information is presented on the CDU, please elaborate below.

Comments:

27. Please rate the integrated communication/navigation system design.

- ___ 1 Excellent, easy to operate
- ___ 2 Good
- ___ 3 Fair
- ___ 4 Poor
- ___ 5 Very bad, confusing, hard to operate

Comments:

MEAN 1.5

STANDARD DEVIATION 1.269

28. Please rate the operation and display of the guidance control panel.

- ___ 1 Excellent, easy to understand and use
- ___ 2 Good
- ___ 3 Fair
- ___ 4 Poor
- ___ 5 Bad, confusing, difficult to use

Comments:

MEAN 1.6

STANDARD DEVIATION .699

29. Please rate the acceptability of a side-arm controller in transport aircraft as compared to a control wheel.

Left-Hand Controller	Right-Hand Controller
___ 1 Excellent	___ 1 Excellent
___ 2 Good	___ 2 Good
___ 3 Fair	___ 3 Fair
___ 4 Poor	___ 4 Poor
___ 5 Bad	___ 5 Bad

Comments:

Left-Hand Controller	Right-Hand Controller
MEAN 1.6	MEAN 1.33
STANDARD DEVIATION .843	STANDARD DEVIATION .707

30. Please rate the useability of the side-arm controller.

Left-Hand Controller	Right-Hand Controller
___ 1 Excellent, very easy to use	___ 1 Excellent, very easy to use
___ 2 Good	___ 2 Good
___ 3 Fair	___ 3 Fair
___ 4 Poor	___ 4 Poor
___ 5 Bad, very difficult to use	___ 5 Bad, very difficult to use

Comments:

Left-Hand Controller	Right-Hand Controller
MEAN 1.66	MEAN 1.625
STANDARD DEVIATION .707	STANDARD DEVIATION .744

31. Please rate the amount/type of use of voice command and response systems in this design.

- ___ 1 Excellent, right amount, right systems
- ___ 2 Good
- ___ 3 Fair
- ___ 4 Poor
- ___ 5 Bad, far too much or too little, wrong systems

Comments:

MEAN 1.857

STANDARD DEVIATION .899

32. Please rate the need for a HUD (head-up display) in the flight station for use on approaches to landings.

- ___ 1 Required
- ___ 2 Probably should be required
- ___ 3 Nice to have
- ___ 4 Might be useful once in a while
- ___ 5 Not needed and distracting

Comments:

MEAN 1.888

STANDARD DEVIATION 1.36

33. Please rate the HUD format.

___ 1 Excellent, not confusing, easy to interpret

___ 2 Good, some clutter, but still relatively easy to interpret

___ 3 Fair, moderately attached and confusing, but still helpful

___ 4 Poor, very cluttered, marginally useful

___ 5 Bad, difficult to interpret, would be of no help

Comments:

MEAN 1.875

STANDARD DEVIATION .641

34. On the scale below, please rate your average workload on the primary aircraft that you are currently flying.

Left Seat	Right Seat
___ 1 Low	___ 1 Low
___ 2 Moderately low	___ 2 Moderately Low
___ 3 Moderate	___ 3 Moderate
___ 4 Moderately high	___ 4 Moderately high
___ 5 High	___ 5 High

Comments:

Left Seat	Right Seat
MEAN 3.0	MEAN 2.2
STANDARD DEVIATION .577	STANDARD DEVIATION 1.095

35. On the scale below, please estimate what you feel your average workload would be in the flight station configuration you have been flying today.

Left Seat			Right Seat		
___	1	Low	___	1	Low
___	2	Moderately low	___	2	Moderately low
___	3	Moderate	___	3	Moderate
___	4	Moderately high	___	4	Moderately high
___	5	High	___	5	High

Comments:

Left Seat	Right Seat
MEAN 2.937	MEAN 2.916
STANDARD DEVIATION .5629	STANDARD DEVIATION .664

<u>Note</u>: The higher workload rating reflected in the answers to question 35 over 34, for the right-seat pilot, can probably be attributed to two factors: (1) the majority of the test subjects were currently flying as members of 3-person flight deck crews, and (2) more of the tasks, presently performed by the flight engineer, were allocated to the first officer than to the captain.

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16. Abstract

Aircraft functional systems and crew systems were defined for a 1995 transport aircraft through a process of mission analysis, preliminary design, and evaluation in a soft mockup. This resulted in a revolutionary Pilot's Desk Flight Station design featuring an all-electric aircraft, fly-by-wire/light flight and thrust control systems, large electronic color head-down displays, head-up displays, touch panel controls for aircraft functional systems, voice command and response systems, and air traffic control systems projected for the 1990s.

The conceptual aircraft, for which crew systems were designed, is a generic twin-engine wide-body, low-wing transport, capable of worldwide operation. The flight control system consists of conventional surfaces (some employed in unique ways) and new surfaces not used on current transports.

The design will be incorporated into flight simulation facilities at NASA-Langley, NASA-Ames, and the Lockheed-Georgia Company. When interfaced with advanced air traffic control system models, the facilities will provide full-mission capability for researching issues affecting transport aircraft flight stations and crews of the 1990s.

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