NASA SP-435

TERMINAL CONFIGURED VEHICLE PROGRAM

TEST FACILITIES GUIDE

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PREFACE

The Terminal Configured Vehicle (TCV) Program of the National Aeronautics and Space Administration is a research activity focused on the development of advanced operating systems technology necessary for conventional transport aircraft to operate routinely in reduced weather minima in a future high-density terminal area.

The broad objectives of the program are to perform research to develop and evaluate new concepts of airborne systems and operational flight procedures in advanced air transportation system environments.

In avionics, significant improvement over current systems in the areas of automatic flight controls and pilot displays is required. Vehicle design may involve changes to improve capabilities for precise speed and flight-path control and for reduced landing and take-off distances. As an aid in realizing the objectives outlined, a typical conventional airplane, a Boeing 737-100 series airplane, was obtained and a second (aft) flight deck and an array of computers and monitors were installed in the passenger cabin. The airplane can be flown both from the forward flight deck with the conventional controls or from the aft flight deck using a fly-by-wire, triply redundant digital computer system. The aft flight deck has advanced electronic displays and pilot selectable automatic navigation, guidance, and control modes. Provisions for monitoring and takeover by the forward flight deck crew ensure in-flight safety.

The necessary capabilities needed for analysis, simulation, and test include the following:

- Sophisticated cockpit and display system simulations with nonlinear aircraft dynamics and motion
- Nonlinear and linearized fast-time landing simulation
- Terminal area simulation that includes other aircraft in order to provide an appropriate environment
- Microwave landing system in which the aircraft can fly curved paths under controlled conditions (and simulation)
- Digital two-way data link between the aircraft and the ground
- Precision tracking
- Noise measurement range
- Laboratory test facility to verify actual hardware systems prior to flight
- An oculometer system to measure the pilot's eye look point

These facilities are located at the NASA Langley Research Center and the NASA Wallops Flight Center.

INTRODUCTION

The Terminal Configured Vehicle (TCV) Program has been established to conduct research and to develop and evaluate aircraft and flight management system technology concepts that will benefit conventional take-off and landing operations in the terminal area.

The objectives and program elements are to:

- Improve terminal area capacity and efficiency through development of:
  - Systems and procedures for ATC evolution
  - Systems and procedures for runway capacity improvement
  - Flight profiles and procedures for fuel conservation
- Improve approach and landing capability in adverse weather using:
  - Human-factor elements for effective flight management
  - Systems and information to minimize wind-shear hazards
- Reduce noise impact through development of flight profiles and configurations

The program is primarily concerned with airborne elements that will be needed for operations in high-density terminal areas equipped with new landing systems and navigational aids under development by DOT-FAA. Emphasis is being placed on the development of operating methods for the highly automated environment anticipated in the future. The research program involves analyses, simulation, and flight experiments. Flight experiments are conducted primarily using a modified Boeing 737 airplane (TCV B-737) (fig. 1)) equipped with highly flexible display and control equipment and an aft flight deck (fig. 2) for research purposes. A series of development and demonstration activities is being conducted to evolve practical systems and to encourage acceptance by flight crews and the airlines.

The purpose of this manual is to describe the capabilities of the experimental systems and the facilities involved in the program.

This publication uses the conventional units common to the U.S. air carrier industry and to the international air traffic control system. A table for conversion of these units to the SI (International System of Units) units is in appendix A. Similarly, the acronyms, some commonly used and some developed for this new system, are defined in appendix B.

Use of trade names or names of manufacturers in this report does not constitute an official endorsement of such products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration.

Figure 1.- NASA TCV B-737 research aircraft.

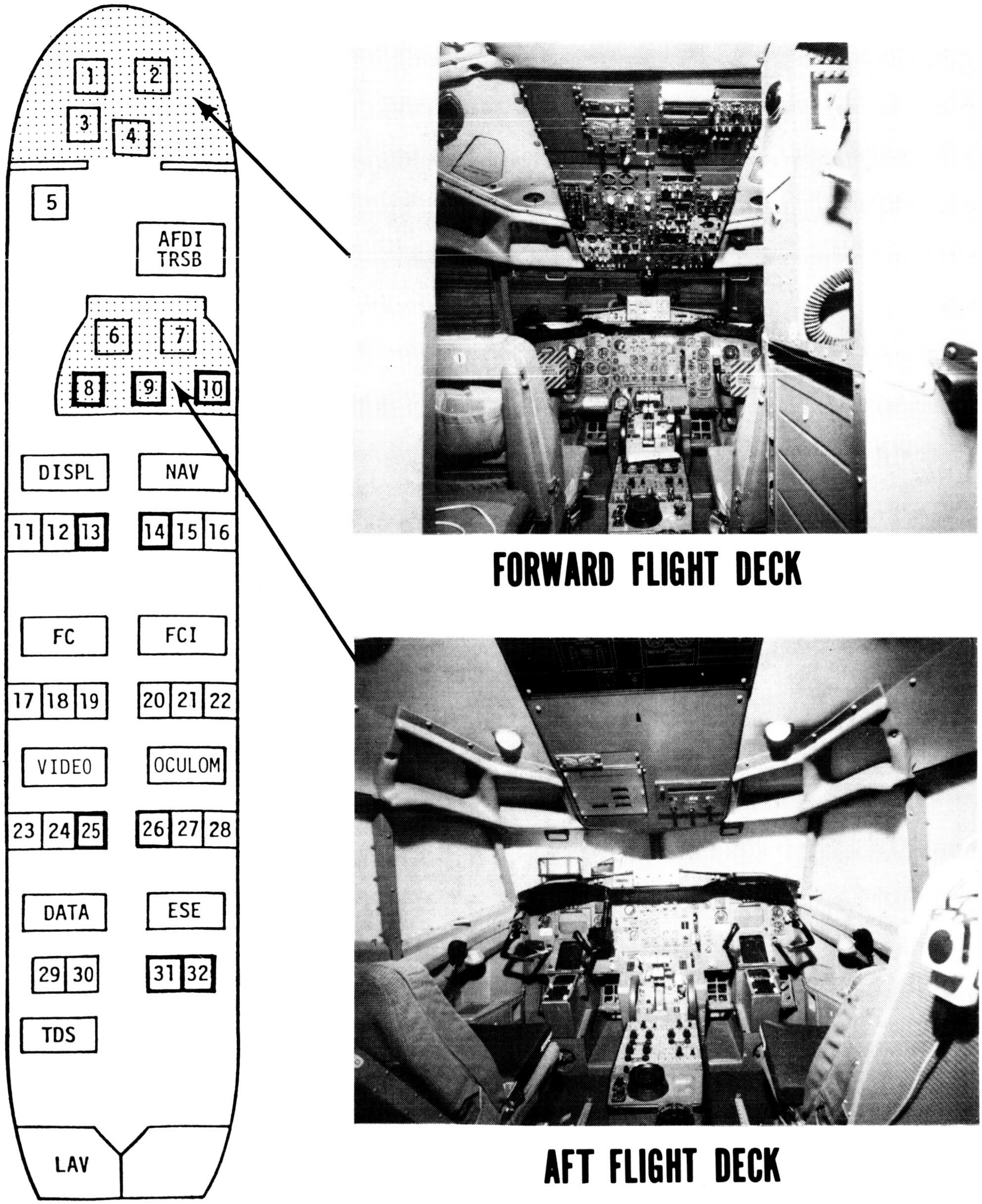


Figure 2.- TCV B-737 internal arrangement

TCV B-737 BASIC AIRPLANE AND OPERATING ENVELOPE

GENERAL ARRANGEMENT

The TCV B-737 was the Boeing Airplane Company's prototype vehicle. Its size and shape are those of the production B-737-100 airplane (fig. 3). Its wing structure is somewhat lighter so the landing gross weight (LGW) is reduced. The airplane normally flies with the array of displays, computers, and data systems indicated in figure 2. The crew and some experimental equipment are varied for each flight. The basic combination of airplane and normal experimental equipment makes up the operating empty weight (OEW). The performance data of table I and the operating limits of table II are based on the normal operation of the experimental airplane. The operating systems of the B-737 which are part of the basic airplane are described on pages 5–13 and are illustrated in figures 4 to 8.

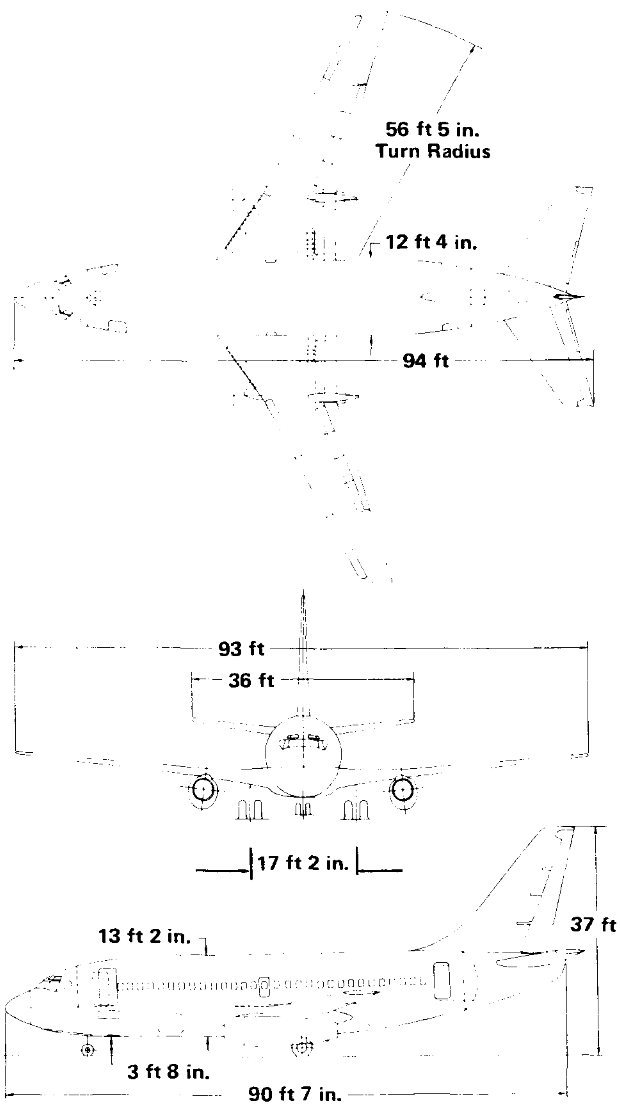


Figure 3.- TCV B-737 external configuration.

SYSTEMS

ELECTRICAL AND ELECTRONICS

The two main ac load buses are energized by two isolated generators driven at constant speed. If a generator fails, selected loads carried by that generator are relayed automatically to the other running generator. Standby power is provided from a battery through a solid-state static inverter to ensure that ac power is always available to essential communication and navigation equipment.

The auxiliary power unit (APU) drives a third generator for ground power and may serve as a third in-flight power source for the experimental systems (fig. 4). It also functions as an alternate system for the basic airplane electrical load.

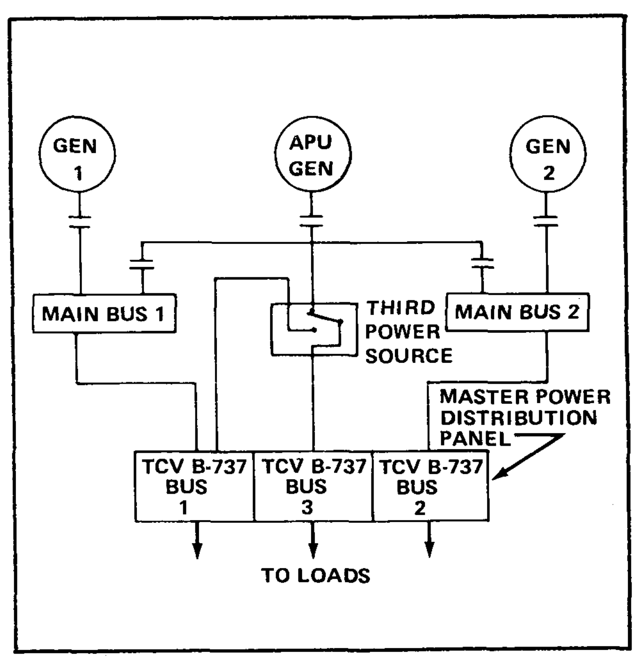
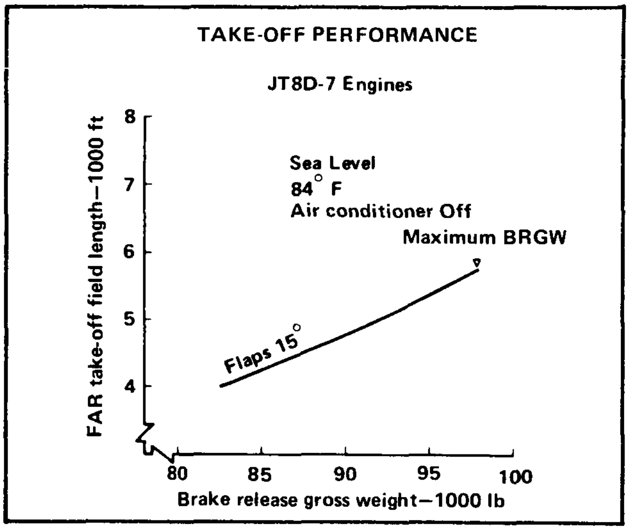


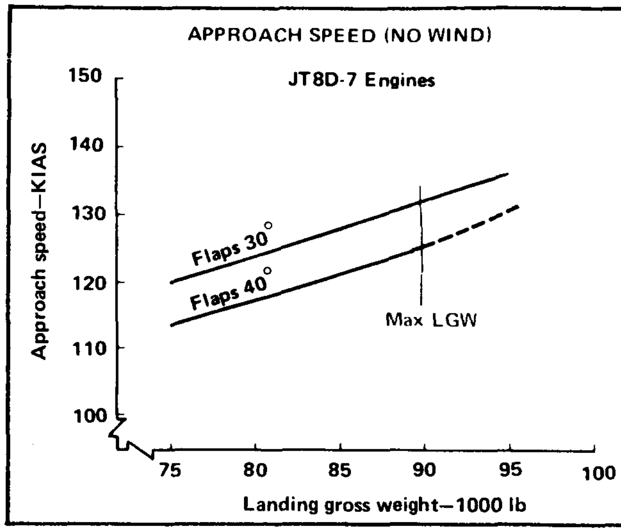
Figure 4.- TCV B-737 power distribution.

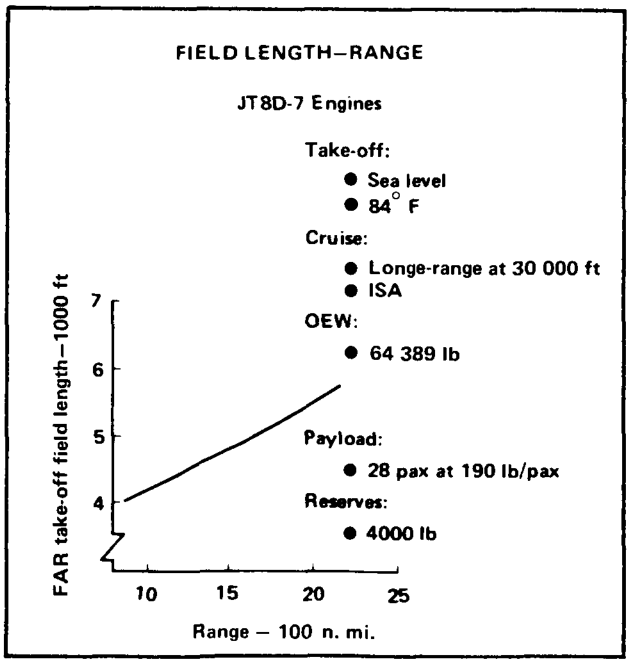
TABLE I.- PERFORMANCE SUMMARY

Maximum landing weight, lb	89 700
Zero fuel weight (typical), lb	66 500
Zero fuel weight (maximum), lb	81 700
Fuel capacity (usable), U.S. gal	4 190
Fuel capacity (JP4), lb	27 235

JT8D-7 CHARACTERISTICS	
Take-off thrust	14 000 lb
Cruise thrust at–	
25 000 ft	4 930 lb
30 000 ft	4 300 lb
Specific fuel consumption, lb/hr/lb, at–	
25 000 ft	0.805
30 000 ft	.798
Bypass ratio	1.10
Weight	3 096 lb







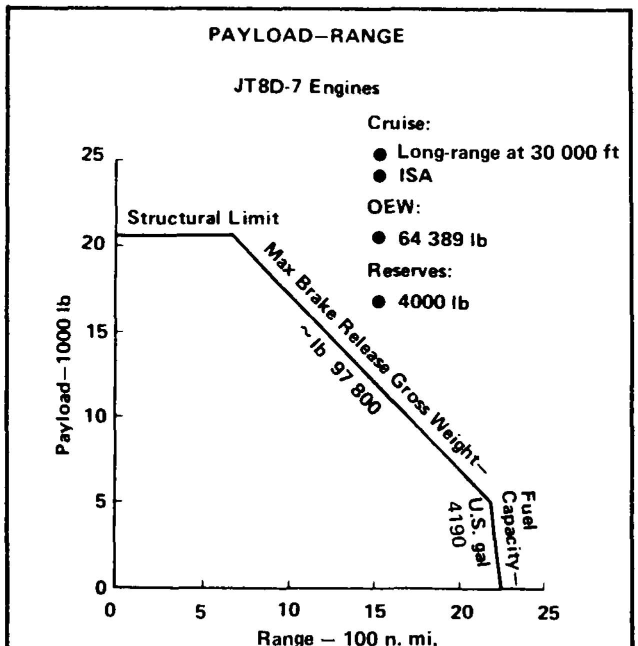


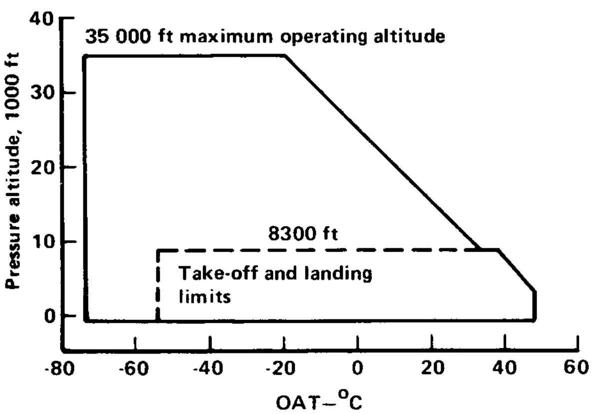
TABLE II.- OPERATIONAL LIMITATIONS

[For specific limitations witn experimental systems operating, see approved manuals]

Operational

During taxi/take-off/landing:
escape slide retention bar installed.
Max. recommended wind for airstair operation: 40 knots

Operational Envelope



Runway slope limits ±2%
Max. take-off/landing tailwind: 15 knots
Max. speeds: observe V_{MO} pointer, gear, and flap placards
Turbulent airspeed: 280 indicated airspeed, knots/0.70M
Mach trim INOP: max. speed 0.74M
TAT/EPR: Do not use on ground with pitot heat ON

Gross Weight and C.G.

Max. taxi weight 97 800 lb (44 361 kg)
May be further restricted by take-off, en route, and landing performance

Max. inflight weight:

Flaps 0°:	97 000 lb (43 998 kg)
Flaps 30°:	95 000 lb (43 091 kg)
Flaps 40°:	89 700 lb (40 687 kg)

Max. landing weight: 89 700 lb (40 687 kg). May be further restricted by field length or climb limits

Max. zero fuel weight: 81 700 lb (37 058 kg)
C.G. limits: Use approved weight and balance system with experimental equipment engaged.

Air Conditioning and Pressurization

Max. differential pressure: 8.65 psi
Operating differential pressure 7.5 ±0.1 psi
Max. cabin differential for take-off/landing: 0.125 psi

APU

Max. EGT: 760° C, max. cont: 710° C
APU bleed + electric load: max. altitude 10 000 ft
APU bleed: max. altitude: 17 000 ft
APU electrical load: max. altitude: 35 000 ft
APU bleed valve closed when
(a) ground air connected and isolation valve open
(b) L.H. engine bleed valve open
(c) isolation and R.H. engine bleed valves open
APU bleed valve may be open during engine start, but avoid engine power above idle
APU generator limit (ground): 125 A
APU generator limit (flight): 111 A

Electrical Power

Max engine driven generator load: 111 A
Max TR load: 65 A (with cooling)
Max TR load: 50 A (no cooling)
TR voltage range 24-30V
Battery voltage range 18-30V
Max CSD oil temperature 157° C
Max CSD oil temperature rise: 20° C

Flight Controls

Max. flap extension altitude: 20 000 ft
Speed-brake usage: minimum recommended altitude: 500 ft
Alternate flap duty cycle: Flight: one cycle, 25 min off.
Yaw damper INOP: Do not engage AFD

NOTE: If the special, 2-inch shorter control column is installed on the First Officer's side (note placard), lack of clearance may interfere with full aft column input and simultaneous wheel input.

Experimental Equipment*

The experimental equipment shall not be operated unless 2 (two) safety pilots are at the forward controls.

**Do not engage experimental systems with either A or B hydraulic systems depressurized.*

Maximum Airspeed Limitations

Flaps Operating and Extended

			AFD Engaged
Position	1	230*	220
	2	230*	220
	5	225*	215
	10	210*	200
	15	195	185
	25	190	180
	30	185	175
	40	170	160

*Do not exceed 210 knots when flaps are extended by alternate (standby) system.

Speeds are indicated airspeed in knots and indicated Mach number.

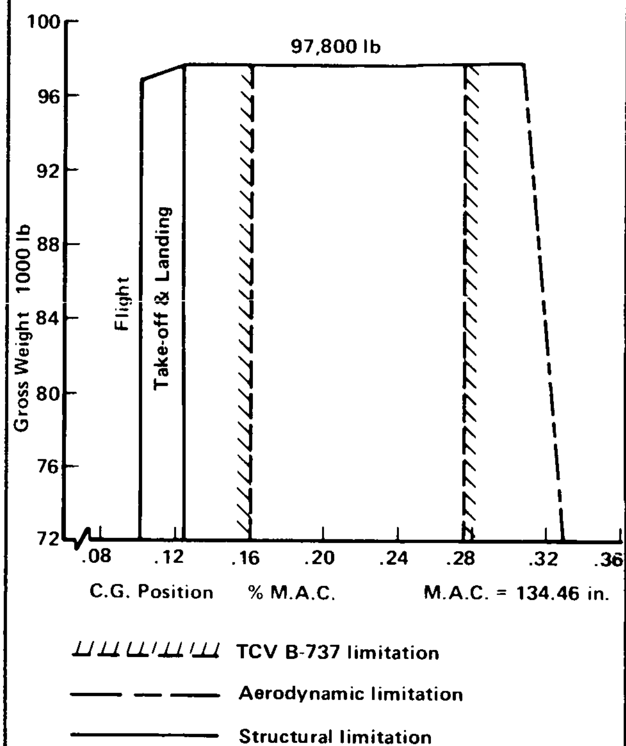
Landing-Gear Operating
Extend 270/0.82 M_1
Retract 235

Landing-Gear Extended
320/0.82 M_1

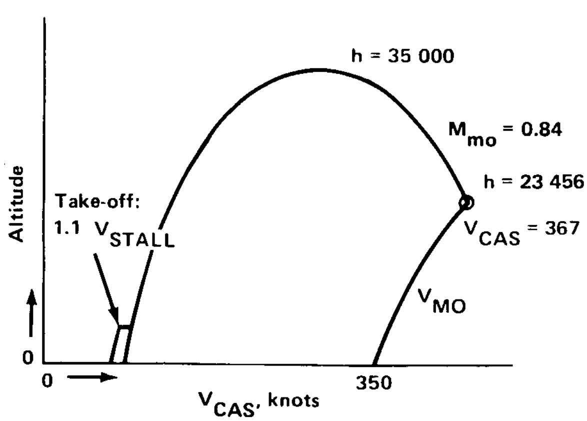
Flight Maneuvering Load Acceleration Limits

Flaps up . . . . +2.5g to -1.0g
Flaps up (experimental systems engaged) . . . . +2.5g to 0.0g
Flaps down . . . . +2.0g to 0.0g

C. G. envelope



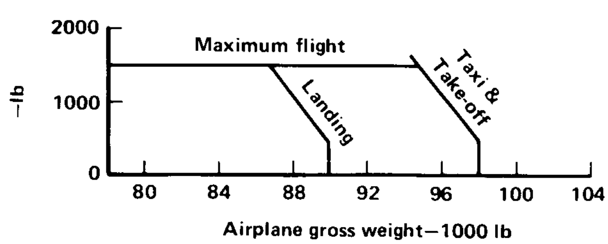
AIRSPEED LIMITS



Fuel

Fuel spec. Pratt & Whitney 522.
Max. temp: 49° C
Min. temp: 3° C above fuel freeze point
Max. fuel quantity: center 8931.0 lb
wing 9262.5 lb each

Allowable Lateral Unbalance



Hydraulic Power

Minimum fuel for cooling of B pumps during ground operations
1675 lb per wing tank

Ice and Rain Protection

Engine TAI must be on for icing conditions during ground operation or take-off
Minimum N1 for operating in icing: 55%
Window heat INOP: max. speed 250 knots, indicated below 10 000 ft

Landing Gear

Do not apply brakes until after touchdown
Towing: depressurize A system
Antiskid: ON for take-off and landing
Autobrakes: OFF for take-off

Lighting

Landing/runway turnoff light duty cycle:
Ground: 5 min on (max.), 5 min off

Navigation Equipment

Weather radar: Do not operate during refueling, near fuel spills or people. Warm up radar in STBY position only.

Pneumatics

Min. duct pressure for engine start: 30 psi
(subtract 0.5 psi/1000 ft above S.L.)

Power Plant

Ignition: On for take-off and landing
Max. N1 RPM: 100.1%, N2 RPM: 100%
Max. EGT: Take-off: 570° C (5 min)
Max. cont: 535° C
Ground Start: 420° C momentary (ambient temperatures above 15° C)
350° C (ambient temperatures below 15° C)
Oil pressure max.: 55 psi
min.: 40 psi
Oil temp: max. cont: 120° C to 157° C for 15 min. Max.: 157° C
Starter duty cycle
Normal start: 30 sec on; 60 sec off
Slow start: 60 sec on; 60 sec off
(2 cycles only, then 5-min cooling)
Motoring (fuel off): 2 min on 5 min cooling
Reverse thrust: for ground use only

Engine Instrument Markings

Maximum limits are marked by red radial line.
Cautionary limits are marked by a yellow arc.
Normal operating range is marked by a green arc.
Minimum limits are marked by a red radial line.

HYDRAULIC SYSTEM

The hydraulic system is divided into three functionally independent 3000 psi systems designated A, B, and standby.

- System A is powered by two engine-driven pumps. It provides hydraulic power for flight controls, ground spoilers, landing-gear extension and retraction, trailing- and leading-edge flaps, slats, nose-gear steering, brakes, and reversers.
- System B is powered by two electric motor-driven pumps to supply power to flight controls and brakes. These pumps may also be used to power system A on the ground only.
- The standby system, powered by a separate electric motor-driven pump, provides backup power to the rudder control system and is also used for alternate extension of the leading-edge flaps and slats and as an alternate power source for the thrust reversers.

Systems A and B provide power for the dual flight-control systems and dual brake systems. Shutoff capability is provided for the A and B powered flight controls to permit isolation of these subsystems for training malfunctions or servicing (fig. 5).

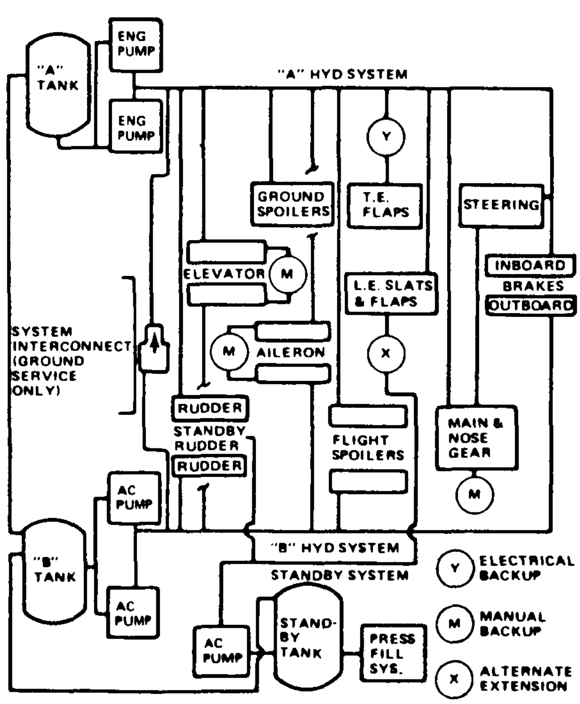


Figure 5.- Hydraulic system.

FLIGHT CONTROLS

The 737 control surfaces are shown in figure 6. All flight controls are hydraulically powered with simple mechanical reversion, except for the rudder which has a third hydraulic power source and separate actuator to back up the primary hydraulic dual-tandem actuator power system.

HIGH-LIFT DEVICES

The leading-edge surfaces consist of three slat sections outboard on each wing and two Krueger flap sections inboard of the engines. These devices are extended by hydraulic cylinders that are controlled by trailing-edge flap extension.

Each trailing-edge flap section consists of three segments: the foreflap, midflap, and aftflap. The flap segments, which nest together in the retracted position, separate as the flaps are extended. Initial flap motion is rearward for a maximum increase in wing area at the lower (take-off) deflections. The segments are mechanically interconnected to open the slots as the flaps are extended for improved aerodynamic efficiency. Extension of the flaps results in an increase of approximately 20 percent in effective wing area (fig. 7).

The trailing-edge flap system consists of one flap section inboard and one section outboard of the engine nacelle on each wing. Each flap section is driven by two ball-bearing drive screws, with all flap screws connected to a dual load-path torque-tube drive. Normal operation is by a single hydraulic motor powered by the engine-driven hydraulic system. Alternate operation of the trailing-edge flaps is by electric motor.

The outboard flap carriages are supported by simple external tracks on the lower wing surface. The inboard flaps are supported by tracks installed within the engine strut fairing and flap body fairing.

LATERAL CONTROL

Lateral control is provided by one aileron and two programmed flight spoiler panels on each wing. The flight spoiler panels also act as speed brakes that may be extended manually by the pilot to modulate deceleration or descent angle. Ground spoiler panels provide additional lift dumping and deceleration after touchdown.

The flight and ground spoiler panels are hydraulically operated by individual actuators and are programmed through a differential mechanism for tailored response. The ailerons are normally powered by two independent hydraulic power packages connected to separate hydraulic systems. Either package is capable of providing control with reduced surface authority. If all hydraulic power is lost, lateral control is maintained by reversion to manual control of the ailerons only.

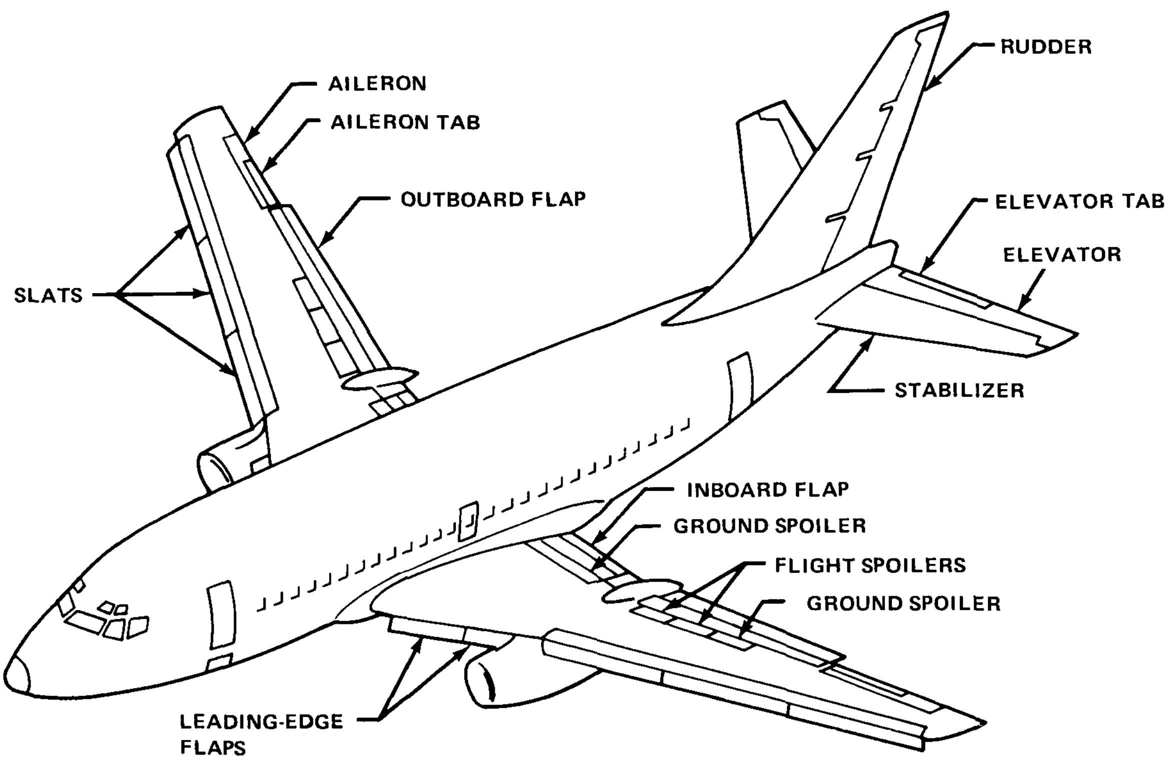


Figure 6.- Control surfaces.

Manual reversion control forces are minimized by aileron balance tabs and simple, hinged balance panels. The balance tabs are mechanically connected to the wing structure by simple rods. No lock-outs or ratio changes are required.

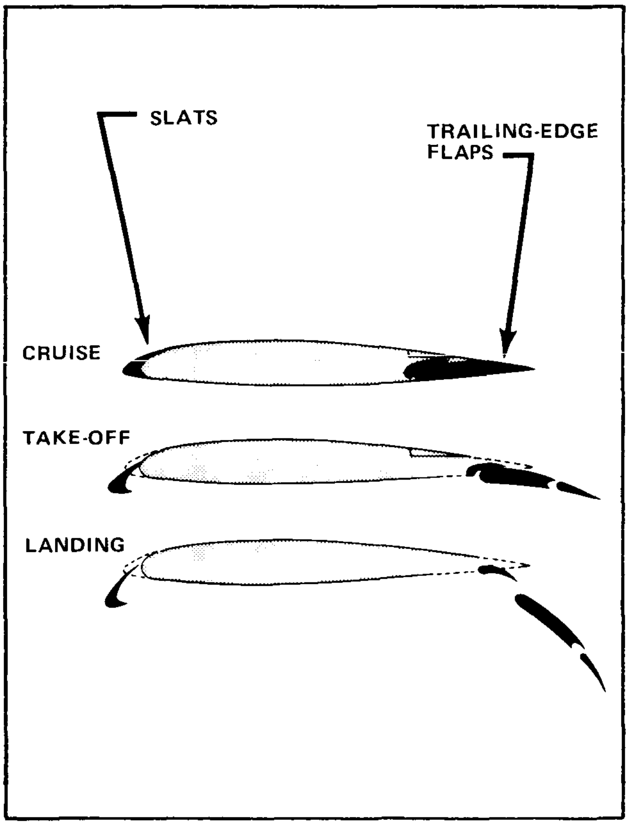


Figure 7.- Wing cross section.

LONGITUDINAL CONTROL

The elevators are powered directly by two independent hydraulic power packages identical to the lateral control power packages, with manual reversion control forces applied directly to the elevators in the event of total hydraulic power loss. One actuator is connected to system A and one to system B. A torque tube that connects the two elevators permits either power package to furnish full control.

Pilot input to the power packages is through a dual cable system and separate actuator-valve control linkages. A completely redundant feel system provides positive pilot feel proportional to airspeed, airplane center of gravity, and gross weight.

The 737 elevators include balance tabs that are hydraulically locked to fair with the elevator surfaces during normal powered operation. With hydraulic power off, the balance tabs are automatically unlocked to reduce manual reversion control forces.

The 737 longitudinal control system includes a warning system designed to provide the pilot with positive indication of an impending stall.

LONGITUDINAL TRIM

Longitudinal trim is accomplished with a movable stabilizer. The stabilizer is powered by an electromechanically driven, dual-load path, single ball screw. Two independent trim motors are used with manual trim backup. One trim motor is a normal speed unit consisting of a unidirectional ac motor and dc magnetic clutches for reversing direction. The second motor is for autopilot trim. The manual trim control wheels, located on each side of the cockpit control pedestal, allow manual trim operation. In addition, an override device in the stabilizer trim jackscrew box permits manual override of both electrical trim systems in case of failure of the electrical trim system.

A stabilizer trim brake coupled to the control column is included in the forward trim mechanism. Movement of the control column in the direction opposite to the direction of trim actuates the brake and prevents further movement of the stabilizer.

RUDDER CONTROL

Directional control of the 737 is provided through a hydraulically powered rudder. A dual-tandem hydraulic actuator is connected directly to the rudder. The actuator, supplied by two separate hydraulic systems, includes complete structural redundancy and is operated through dual-path linkages. Rudder power backup is provided by a standby actuator, powered by a third hydraulic system. Any single power source will ensure effective rudder control.

Rudder feel, proportional to airspeed, is provided at the rudder pedals by a feel and centering mechanism similar to that used in the elevator system. Rudder trim is activated through a single, closed-loop cable system from a crank on the control pedestal. Rudder trim is accomplished by rotating the feel and centering mechanism which, in turn, shifts the null position of the rudder actuator.

AUTOMATIC BRAKE SYSTEM

The automatic brake system applies immediate braking after touchdown by automatically controlling brake pressure to maintain a constant deceleration. This system operates in conjunction with the antiskid system to regulate the deceleration of the airplane to a selected level—minimum, medium, or maximum (fig. 8). The automatic brakes will bring the airplane to a complete stop unless the braking is terminated by the pilots. When stopping on normal runway surfaces, the system will reduce brake pressure as reverse thrust is used so that the total deceleration caused by reverse thrust and braking is equal to the selected deceleration. In this case, the stopping distance using automatic brakes is the same with or without the use of reverse thrust. The automatic ground spoiler will deploy all spoilers to the fully extended position after touchdown. The control panel and annunciators for the autobrake system are shown in figure 8.

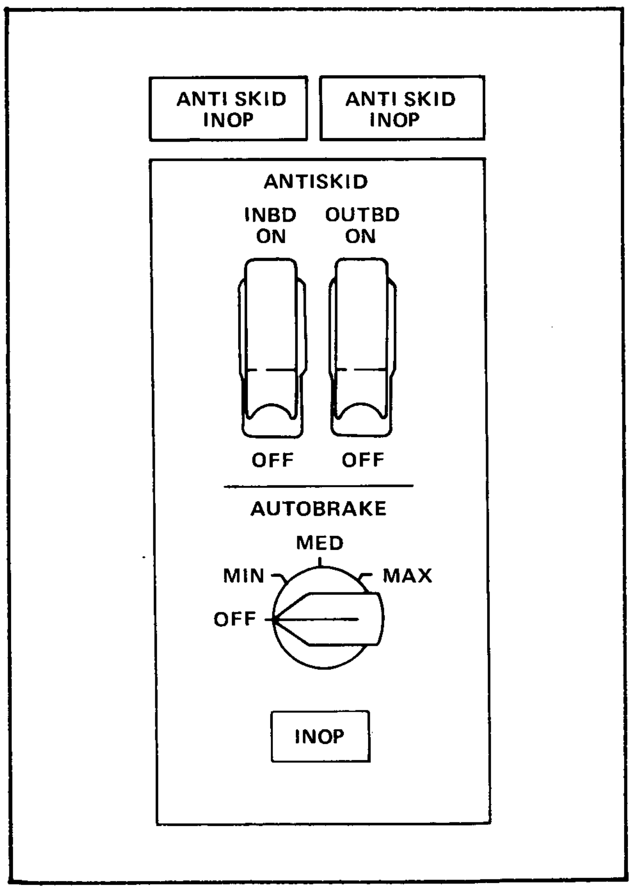


Figure 8.- Autobrake control panel.

TCV B-737 EXPERIMENTAL SYSTEMS

There are five major experimental subsystems installed on and integrated with the basic Boeing 737-100 airplane. These major subsystems are:

- Aft flight deck
- Flight-control computers
- Navigation/guidance system
- Electronic display system
- Data acquisition system

An aft flight deck (AFD) permits evaluation pilots to fly with experimental display and control systems. Essentially, this arrangement allows complete control of the aircraft, except for those functions found on the overhead panel. It is sufficiently complete to permit two-man crew operation studies and has the accessibility for easy modification or replacement of cockpit equipment.

The avionics concept contained in the experimental systems is the combination of appropriate components and functions to reduce complexity but enhance operational capability. Some functions (e.g., autoland) are accomplished through a fail-operational, triply redundant configuration. Other functions, where the current research needs have not required redundancy, are performed in either a single or a dual configuration. The pilot interface with the automatic systems is a vital element, upon which depends the eventual acceptance and utilization of these systems. Electronic displays are the key to this interface. A diagram of the advanced guidance and control system (AGCS) configuration is shown in figure 9.

The navigation/guidance, electronic display, and flight-control subsystems are programmable digital systems that provide the means for evaluating experimental navigation and guidance techniques, flight display formats, flight-control laws, and pilot interfaces in a flight operational environment.

During an experimental flight, in addition to the evaluation pilots in the AFD, engineers monitor performance at each major subsystem pallet and communicate through an interphone system. Limited software modification and experimental-system troubleshooting can also be accomplished. The

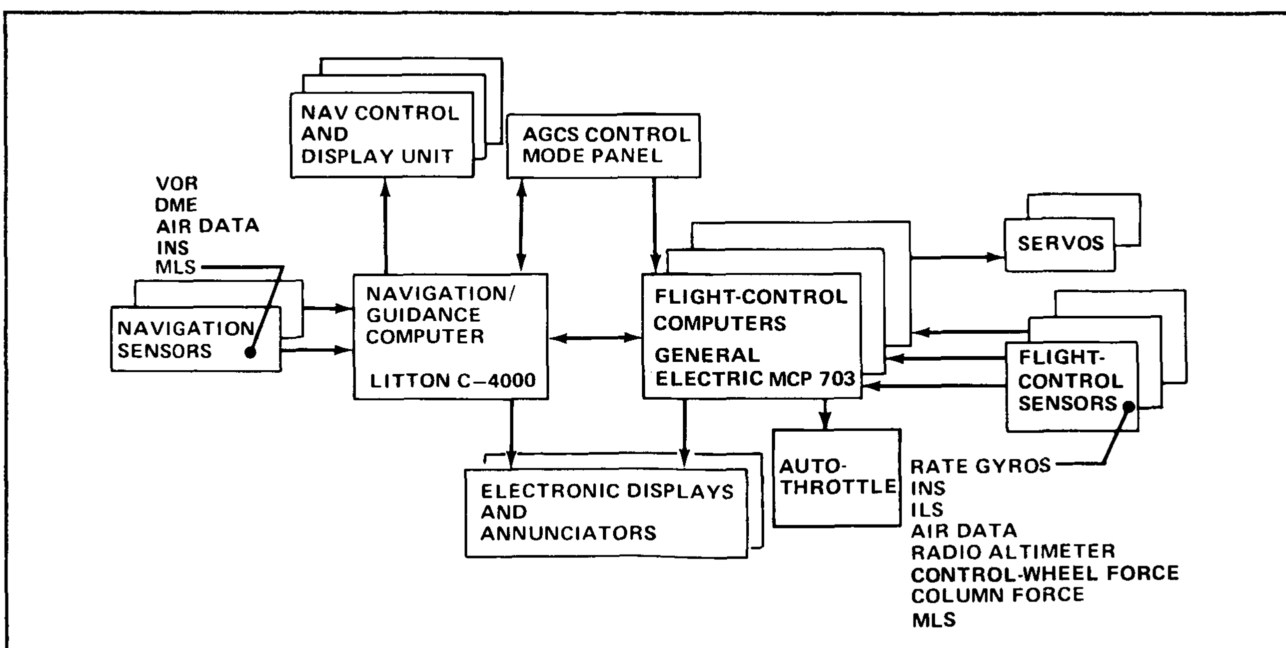


Figure 9.- Advanced guidance and control system.

equipment for each subsystem, though functionally equivalent to a commercial transport installation, is operated in an experimental manner with increased interface output to permit experiment changes.

AFT FLIGHT DECK (AFD)

Installed in the passenger cabin, the AFD (fig. 10) is a second cockpit from which the aircraft can be flown in a fly-by-wire mode. A dust cover behind the AFD instrument panel may be removed for easy access to the control-system mechanism and to the displays. This arrangement reduces maintenance effort and facilitates modification to the control and display equipment.

The basic airplane has been modified to allow fly-by-wire operation of the primary flight controls, flaps, and throttles from the AFD through electrically commanded servos. This is a limited authority system which can be either disconnected or overridden by safety pilots in the forward flight deck (FFD). The fly-by-wire system is summarized in figure 11. AFD requests for landing-gear, speed-brakes, and autobrake operation are annunciated in the FFD. This configuration allows the crew in the AFD to control the aircraft from take-off brake release through landing roll-out. In addition to manually controlling the aircraft, the AFD crew is able to engage automatic control modes. Control authority from the AFD (elevators, ailerons, rudder) has been reduced by about one-half as a safety measure. However, control gains within the normal range of operation have been retained. The AFD is equipped with operating instruments and indicators and functional controls to provide a representative workload for the two-man AFD crew. The panel-mounted pitch and roll controllers (brolly handles) are interconnected rods that slide fore and aft for pitch inputs and rotate for roll inputs. The current configuration of the instrument panel is shown in figure 10.

The AFD interface pallet shown in figure 12 contains the following equipment:

- Auxiliary power supplies for vertical situation display (VSD) and horizontal situation display (HSD)
- Lamp driver electronics
- Instrument buffer electronics
- AFD servo electronics
- Power supplies for electronics

FORWARD FLIGHT DECK (FFD) AND SAFETY PILOT ROLES

The FFD is a standard 737 flight cockpit to which a control and command panel (CCP) has been added. The CCP (fig. 13) is mounted on the glare shield in place of the standard 737 autopilot controller. The panel includes FFD to AFD engage and transfer switches, AFD to FFD command and status

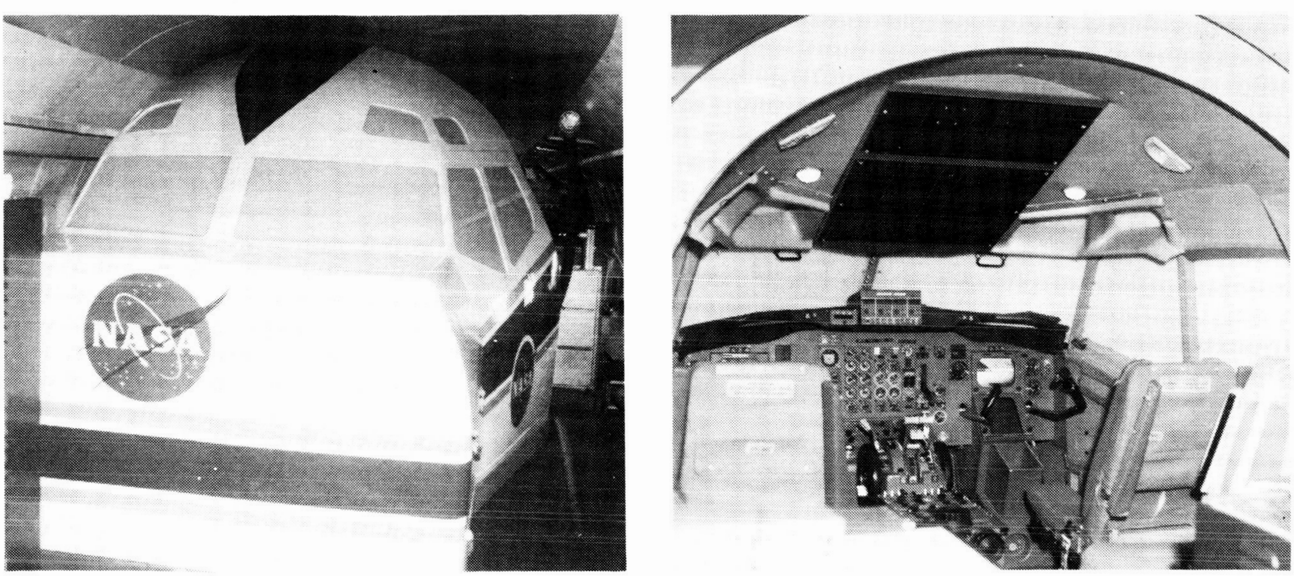


Figure 10.- Aft flight deck.

annunciators, and an emergency disconnect switch. Additional AFD disconnect switches are installed on each FFD control column.

The FFD crew controls the aircraft when AFD experiments are not in progress and is responsible for monitoring and correcting items affecting flight safety when the aircraft is being flown from the AFD. The safety pilot in the FFD performs certain functions upon command annunciation from the AFD, as well as the functions for which control from the AFD is not available.

CONTROL AND COMMAND PANEL (CCP)

ENGAGE/DISCONNECT PADDLE SWITCHES

The safety pilot transfers control of the airplane to the AFD by engaging solenoid-held switches and may return control to the FFD by using the disconnect thumb button on either FFD wheel. An emergency disconnect switch to disable all flight-control servo drives serves as a backup disconnect. Either FFD pilot is able to overpower servos with or without AFD disconnect.

The FFD has attitude control wheel steering (CWS) available. FFD CWS is controlled through the flight-control computer system, a part of the experimental avionics. The FFD pilot may engage this mode using the FFD CWS switch on the control and command panel.

VHF COMM/NAV, ATC TRANSPONDER SWITCHES

The safety pilot uses the separate solenoid-held VHF COMM/NAV and TRANSPONDER switches (located on the CCP) to transfer control of this equipment to the AFD. The FFD and AFD audio select panels are unaffected by the transfer of VHF radio tuning. The AFD or FFD pilots may select audio or transmit from either radio regardless of which flight deck has tuning control.

SERVO CHANNELS SELECT

The safety pilot uses this knob to select either A or B system servos when in either FFD CWS or AFD modes.

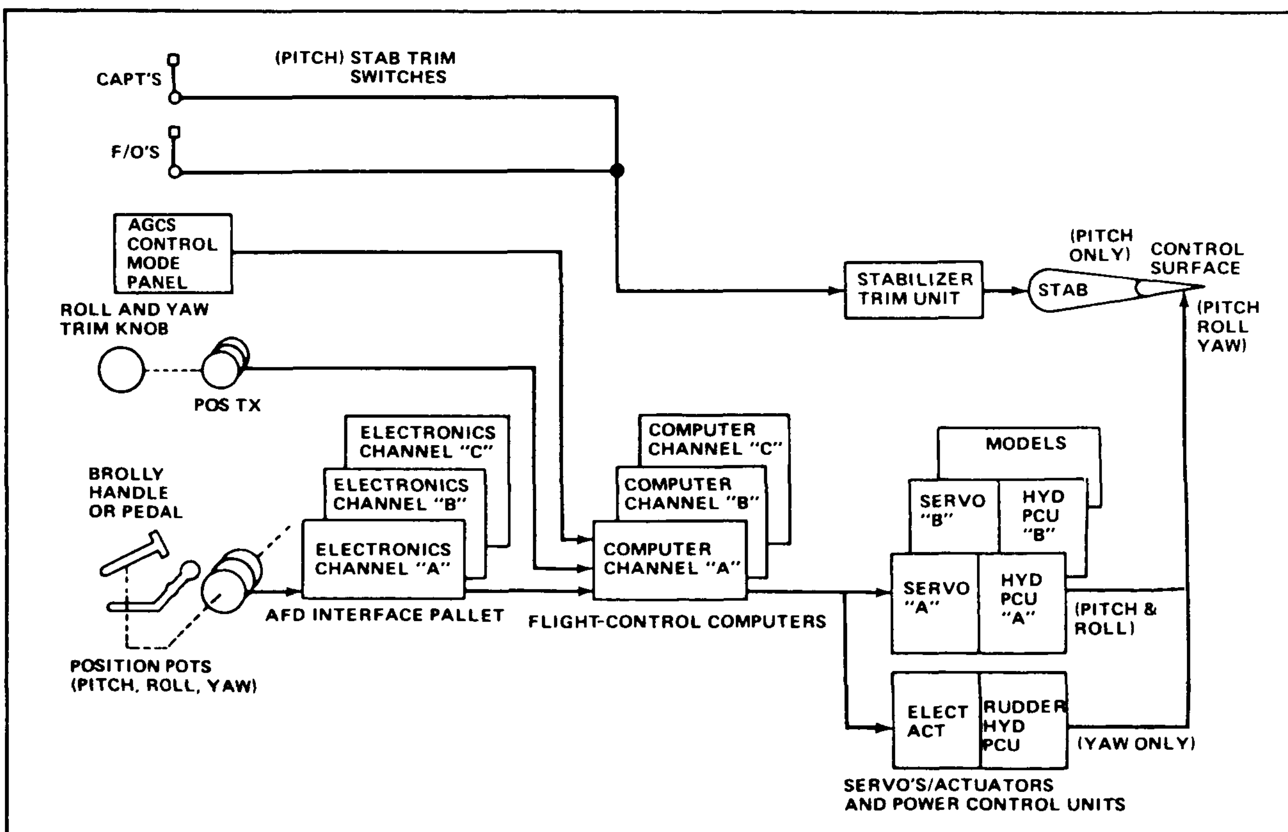


Figure 11.- Fly-by-wire summary.

Figure 12.- AFD interface pallet.

ANNUNCIATOR LIGHTS (AILERON, ELEVATOR, RUDDER, FLAP, THROTTLE)

The amber aileron, elevator, and rudder annunciator lights indicate whenever the respective actuator system authority for the experimental equipment approaches its limit. The flap and throttle amber annunciator lights indicate a discrepancy (beyond a predefined threshold) between the AFD selected flap and throttle positions and the actual values.

SPEED-BRAKES POSITION INDICATOR

This indicator shows the speed-brake handle position selected in the aft flight deck.

ANNUNCIATOR LIGHTS (GEAR, AUTOBRAKES, SPEED BRAKES)

The landing gear and autobrake annunciator lights indicate selected modes from the AFD for landing gear and automatic braking. The speed-brakes annunciator light indicates a discrepancy (beyond a predefined threshold) between AFD selected speed-brakes position and the actual position. The arm-speed-brakes annunciator light indicates the selection of that mode in the AFD.

EPR LIMIT AND FLAP PLACARD ANNUNCIATOR LIGHTS

These annunciators indicate AFD selected thrust and flap position values whenever they are at or beyond predefined limits.

TAKEOVER ANNUNCIATOR LIGHT

The takeover annunciator light indicates a takeover command from the AFD.

FFD CONTROL WHEEL STEERING (CWS)

FFD CWS is selected by lifting the engage paddle on the CCP. This action provides a discrete signal to the control computers to establish control logic for the FFD CWS mode of autopilot operation. Force transducer signals from the FFD control wheel now command elevator and aileron positions through the selected A or B servos. Autotrim is included in the longitudinal control law.

AFD/AUTOPILOT SAFETY DISCONNECTS

The safety pilot is able to disconnect all AFD control with the wheel-mounted AFD disconnect. To provide backup disconnect capability, all engage clutch or hydraulic solenoid valve signals for each flight-control servo flow through separate contacts on the emergency disconnect switch. All remotely controlled servos operate the FFD controls in parallel with limited force authority so that the safety pilot can override the servos with or without AFD disconnect.

The AFD pilots may disconnect the AFD controls and have the FFD safety pilots assume control of the airplane by depressing one of the takeover switches. On activating the takeover switches, the AFD flight-controls switch paddle drops to the disengaged position and thus removes power from the power-control-unit engage solenoid. The amber control light on the AFD status panel illuminates, and the takeover light on the FFD CCP illuminates.

ADVANCED GUIDANCE AND CONTROL SYSTEM (AGCS) CONTROL MODE PANEL

The AGCS modes are accomplished in the navigation/guidance and flight-control computer systems. The modes currently in use are illustrated in the AGCS control mode panel (fig. 14). The modes provide various levels of automation and are configured to relieve the pilot workload.

The AGCS control mode panel is divided into seven sections. The lower left-hand section provides for selection of manual control ATT CWS (ATTitude CWS), VEL CWS (Flight Path or VELocity vector Control mode), or AUTO (AUTOmatic flight-path control). The lower center and right-hand sections provide for selection of the type of automatic path guidance. The four top sections provide for hold, select, and preselect operation of automatic airspeed, altitude, flight-path-angle, and track-angle modes.

The 11 pushbutton switches provide logic inputs to the flight-control computer system and the navigation computer. Logic states in the computers illuminate amber, blue, and green lights in the switches to indicate arm, preselect, or engaged, respectively.

When a particular parameter is not preselected or used as a control reference, the displayed value will be the current value of that parameter. Rotating the associated knob causes the readout to be preselected, incremented or decremented from the present value, and stored as a reference for use in automatic control of the airplane.

The four lower left-hand switches on the panel control the mode status of the flight-control computer system. When VEL CWS is engaged, a control mode is active which provides, through the panel-mounted controllers (PMC's), track-angle and flight-path-angle hold in nonmaneuvering flight. With ATT CWS engaged, this mode provides a pitch- and roll-rate command system through the PMC's, with an attitude-hold capability when the rate inputs by the pilot are zero.

Engaging the AUTO position allows either 2-D, 3-D, or 4-D path following or parameter select levels of automatic guidance to control the airplane. If AUTO is selected, FPA SEL (Flight-Path-Angle SELect) and TKA SEL (TracK-Angle SELect) will be automatically enabled by the AUTO engage. The pilot may input path changes through the FPA SEL and TKA SEL rotary knobs. These knobs will also provide preselect capability when the associated mode is not engaged.

Selecting AUTO and HOR PATH (HORizontal PATH) will activate automatic path following in the horizontal plane (the path currently stored in the navigation/guidance computer). HOR PATH and TKA

Figure 13.- Control and command panel.

SEL cannot be simultaneously engaged. HOR PATH will not engage unless an active flight plan has been stored in the navigation computer.

Selecting ALT ENG (ALTitude ENGage), FPA SEL (Flight-Path-Angle SELect), or VERT PATH (VERTical PATH) while in AUTO will activate altitude hold/capture, FPA hold, or automatic path following in the vertical plane, respectively. ALT ENG, VERT PATH, and FPA SEL are all mutually exclusive modes. ALT ENG will be armed if an altitude reference is selected that makes the initial altitude differential greater than the capture range about the new reference altitude. If an altitude reference change greater than the capture range is selected while in altitude hold, ALT ENG will revert to the armed state and FPA SEL will engage in the flight-path-angle hold mode. The VERT PATH will not engage unless the stored active flight plan in the navigation computer includes definition of the vertical path.

In all the auto modes, if a PMC force higher than the detent value is exerted in any axis, the system will revert to VEL CWS in both axes.

The LAND select button will arm the ILS or MLS capture and track computation for automatic mode engagement subsequent to meeting required logic conditions. Performing an autoland requires that both AUTO and LAND be selected. At least two receivers must be tuned to the ILS in order to obtain the LAND arm state.

When the tracking condition has been established in both pitch and roll, the LAND mode will engage. In this state, no inputs from the navigation computer will be acted upon. The ILS data are inertially smoothed. The maneuver includes localizer and glide-slope capture and tracking, automatic decrab (to a forward slip), automatic flare, and roll-out. The airplane autobrake system may be used in conjunction with the autoland.

The CAS ENG (Calibrated AirSpeed ENGage) mode causes the throttles to be driven to capture the airspeed selected with the CAS ENG knob. An airspeed may be selected prior to or subsequent to depressing the button.

The TIME PATH mode couples the throttle servo system to the 4-D profile stored in the navigation/guidance computer. The TIME PATH mode enables the airplane to automatically capture and track the time profile and may be selected if first

Figure 14.- AGCS control mode panel.

HOR PATH and then VERT PATH is selected. The CAS ENG and TIME PATH modes are mutually exclusive.

FLIGHT-CONTROL COMPUTER SYSTEM

The flight controls use a General Electric MCP 703 general-purpose, triply redundant digital computing system. The computer system receives inputs, performs calculations according to mode control logic and control laws, and issues commands to the control surfaces to direct the airplane in flight.

All mode control logic and control laws are provided by software. The program is originally prepared in assembly language, converted to magnetic tape using a ground-based computer, and loaded into computer memory by means of a tape reader. Changes can be patched into the loaded program during flight by means of the computer monitor and control unit. If desired, additional or alternate control loops could be implemented. In some cases, such additions would require modification of the airplane or the experimental system hardware.

The input/output capability of the FCC is indicated in the following table:

Inputs (per channel)	Outputs (per channel)
28 dc variable 8 ac variable 42 discrete 32 serial digital	15 dc variable 48 discrete 16 serial digital

The system consists of a number of units mounted on the flight-control computer pallet (fig. 15) and a system test panel mounted in the AFD (fig. 16).

The following equipment is installed on the flight-control computer pallet:

- Three computer units
- Three memory units
- Three computer interface units (CIU)
- One servo transmitter and receiver unit (STRU)
- One computer monitor and control unit (includes tape reader)
- One system status and control unit
- One system test repeater
- One sensor failure display

Each computer unit contains a synchronous logic interface unit to receive sensor inputs and transmit output commands and a central processor to perform the required computations. Also included in the computer units are the device controllers needed to interface with the computer monitor and control unit, the system status and control unit, and the system test panel. The memory units are mounted separately on the pallet.

Each CIU processes triplex sensor inputs from all three channels by converting them to the digital format required by the computer unit and also by performing the function of signal selection and failure monitoring. The CIU's also process the computer unit outputs by converting them from internal digital format to the required output formats, namely, analog, digital, and discrete.

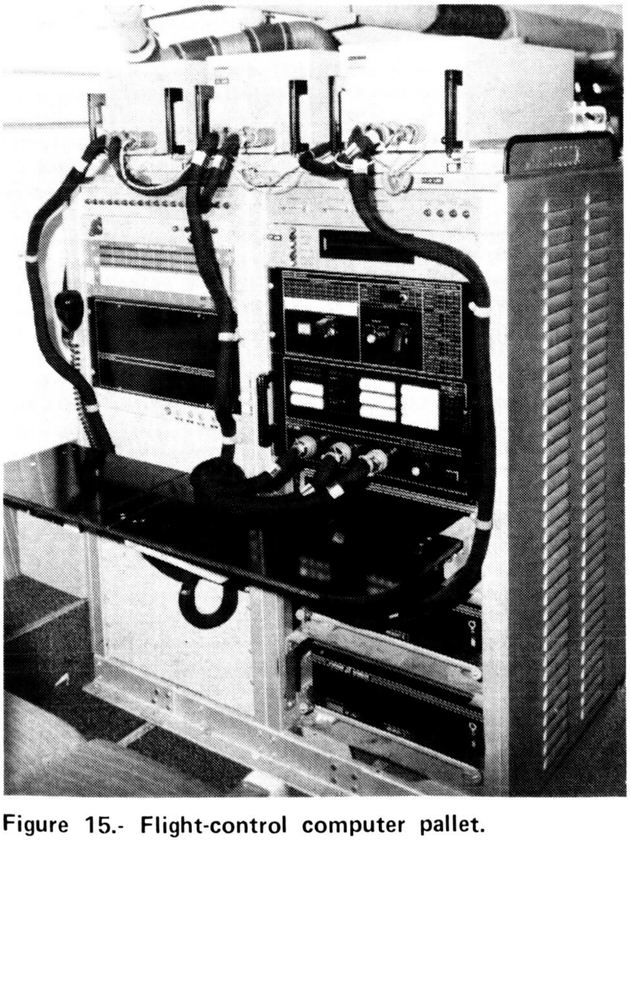


Figure 15.- Flight-control computer pallet.

The servo transmitter and receiver unit performs the same functions as the CIU's except for signal selection and failure monitoring. In this unit, however, the inputs and outputs are associated with the system test function and instrumentation instead of the control of flight, as in the case of the CIU's.

The computer monitor and control unit is used to read out or modify the contents of memory cells or central processor registers, to place the computer in particular operating modes, and to load or change computer programs. The tape reader is located behind the front panel of the computer monitor and control unit.

The system status and control unit tests the computer according to a software-controlled test program. Failures are annunciated by panel displays.

The system test feature of the flight-control computer system is accomplished by means of the system test panel mounted in the AFD and special subroutines in the computer program. A large number of tests may be run with the panel, and the results are displayed as worded messages on a 32-character alphanumeric display. The tests encompass the flight-control system sensors, computers, and servos. In-flight, preflight, and maintenance tests can be performed. In-flight failure data are stored in memory so that later, on the ground, the failures can be identified. The test results are also displayed on the system test repeater located on the flight-control computer pallet.

The flight-control computer is triply redundant and provides fail-operational capability. A block diagram of the system interfaces is shown in figure 17. Most sensors are triply redundant except the radio altimeters and MLS. These instruments are self-monitoring so only two of them are required to provide fail-operational capability. The elevator and aileron control systems each use two electrohydraulic actuators (A or B). Either the A or B actuator may be selected by the pilot. A single electromechanical actuator is used for rudder control and is monitored by an electronic model. All actuators have their displacement authority limited to ensure safety of flight. The 737 production yaw damper is provided to damp Dutch roll.

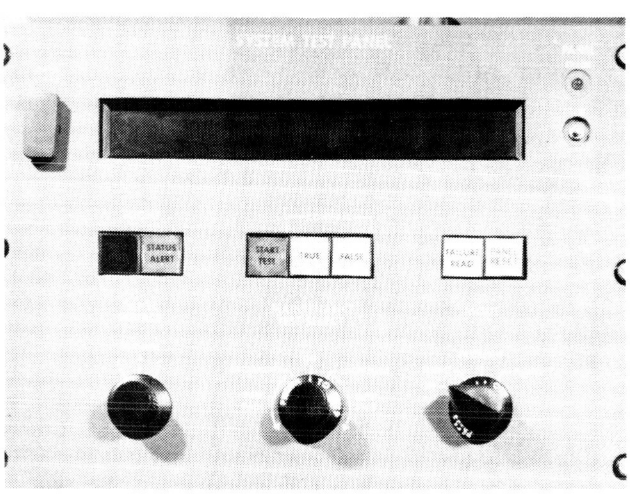


Figure 16.- System test panel.

The AGCS control-mode panel engages modes in both the flight-control and navigation/guidance computer systems. Approach progress displays in both the AFD and FFD annunciate localizer and glide-slope beam capture status.

FLIGHT-CONTROL INTERFACE

The equipment installed on the flight-control interface pallet (fig. 18) allows the test engineer to monitor flight-control signals. This equipment also provides electrical interface between the flight-control computers and other TCV B-737 systems and contains some flight-control sensors.

The following equipment is installed on this pallet:

- Two electronics interface chassis
- Servo amplifier and logic control chassis
- Number 3 VHF NAV RCVR
- Self-test panel
- Annunciator display
- Signal monitor, digital voltmeter, and oscilloscope
- Rate gyros and accelerometers
- Power supply and distribution
- Two digital data formatters

An oscilloscope, a digital voltmeter, and a signal monitor are mounted in this pallet to allow monitoring of the flight-control signals. The

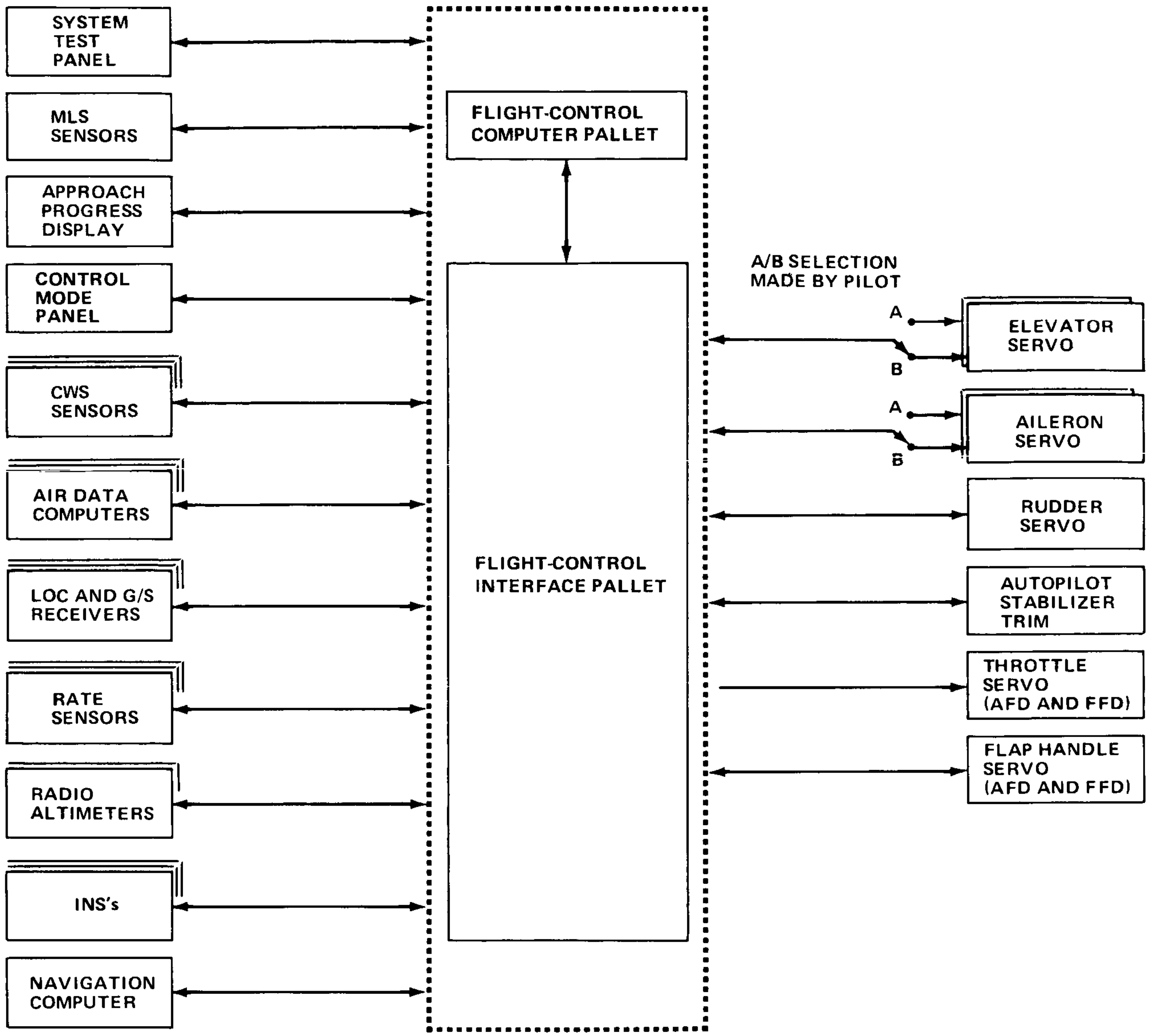


Figure 17.- Flight-control system interface.

annunciator display indicates the mode of automatic control being used. A self-test panel allows remote actuation of the self-test mode on flight-control sensors. The electronic interface chassis provides signal conditioning between the sensors and the flight-control computers while the servo amplifier and logic control chassis drives the flight-control servos and provides engage logic.

NAVIGATION/GUIDANCE SYSTEM

The navigation/guidance system is a single-thread (nonredundant) system of sensors, a navigation computer, control and display units, and peripheral equipment. The navigation computer functions are under software control. Modifications may be made with program patch changes to examine certain variables. Large changes are made by assembly of program tapes using a ground-based computer.

Navigation/guidance system interfaces are shown in figure 19. The pallet containing the navigation computer unit, three INS control display units, and supporting equipment is shown in figure 20.

The navigation computer unit (NCU) is a Litton C-4000 computer that performs navigation and guidance computations. This general-purpose computer features a 32 000 word memory and a 24-bit word size. The NCU's sensor inputs that are used to form navigation estimates include INS velocities from a modified Litton LTN-51 and inputs from a central air data computer, magnetic compass, and radio signals from VOR, DME, and ILS. The NCU is controlled from the AFD by the navigation control display unit (NCDU) and the AGCS CMP. The NCU supplies readout signals to the display unit and properly formatted digital symbology signals to the vertical and horizontal situation displays. Roll, pitch, and speed command signals generated in the NCU are utilized by the flight-control computers and the autothrottle servo. The NCU also automatically tunes two of the airplane's DME receivers to appropriate stations en route.

The primary input device to the navigation and guidance system is the NCDU. The unit consists of a keyboard and a small CRT display on which pages of navigation and guidance information may be displayed. Guidance paths may be built up using the NCDU as an input/output device. During the flight, parameters of interest such as 4-D path guidance errors, navigation data, flight plans, etc., may be displayed on the NCDU (fig. 21).

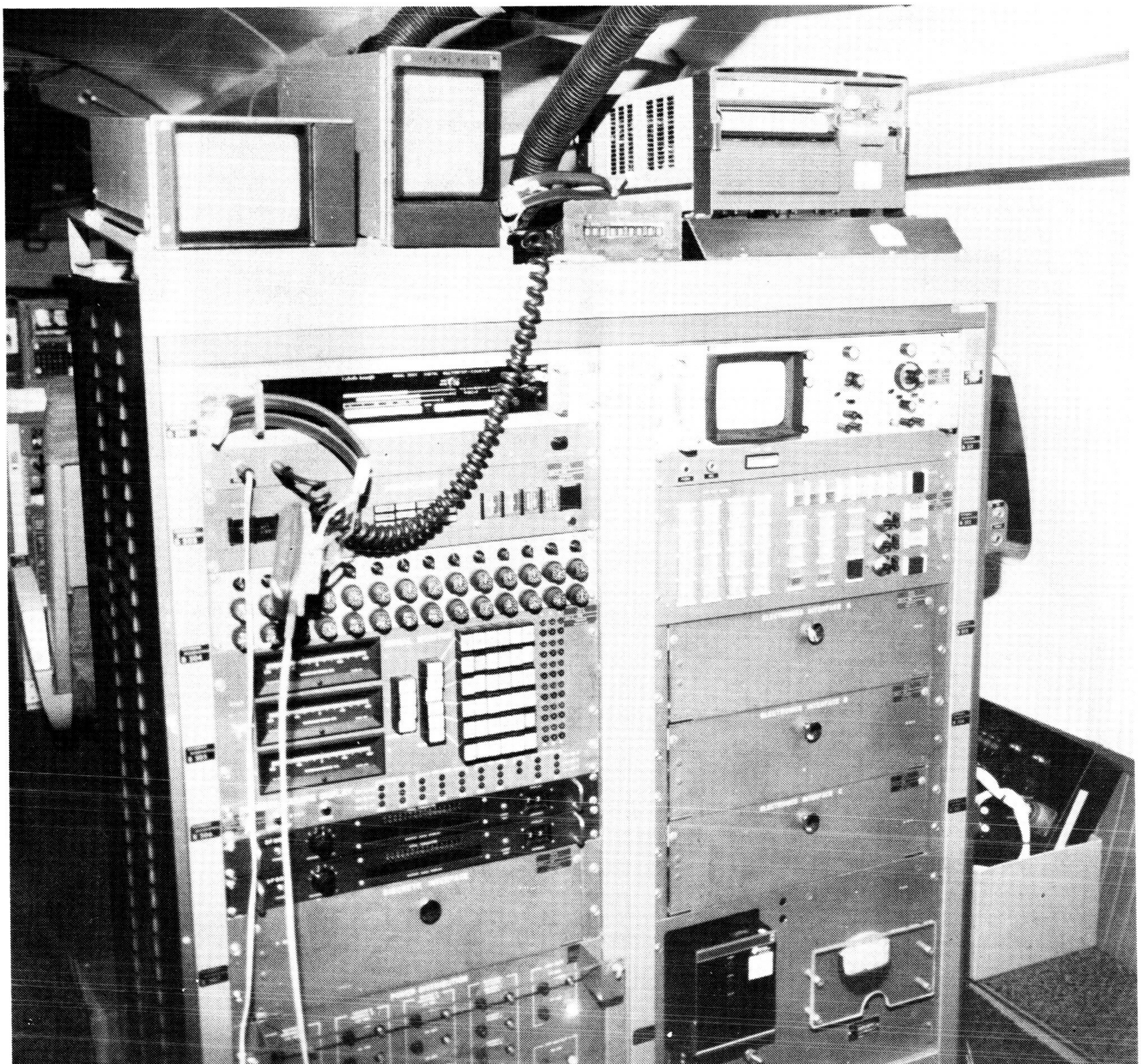


Figure 18.- Flight-control interface pallet.

NAVIGATION

Software in the navigation computer is in a modular format. Main programs are navigation, guidance, and displays (VSD, HSD, and NCDU). The other major software item in the navigation computer is the bulk data storage which contains navigation and geographical information for the area in which the airplane is being flown. This information includes route, airway, SID, and STAR information and airport data pertinent to the area of interest.

The navigation program integrates velocity data from the INS with position error terms derived from radio signal inputs to calculate an estimate of airplane position. Altitude is computed from barometric altitude, corrected for nonstandard pressure effects, and quickened with INS vertical accelerations. This produces an estimate of altitude that is responsive to the airplane's vertical maneuvers but retains the long-term stability of the barometric pressure.

The navigation computer also performs the following tasks:

- Define 2-D, 3-D, and 4-D flight paths
- Automatic station selection and DME tuning

GUIDANCE

Guidance software in the navigation computer consists of the subprograms necessary to:

- Generate guidance errors and the appropriate quantities for display on the HSD and VSD
- Compute steering signals and speed commands for:
  - 2-D, 3-D, and 4-D flight paths for manual and automatic flight
  - Automatic modes such as altitude hold and throttle commands
  - Select/hold modes such as airspeed and flight-path-angle select

Figure 20.- Navigation and guidance pallet.

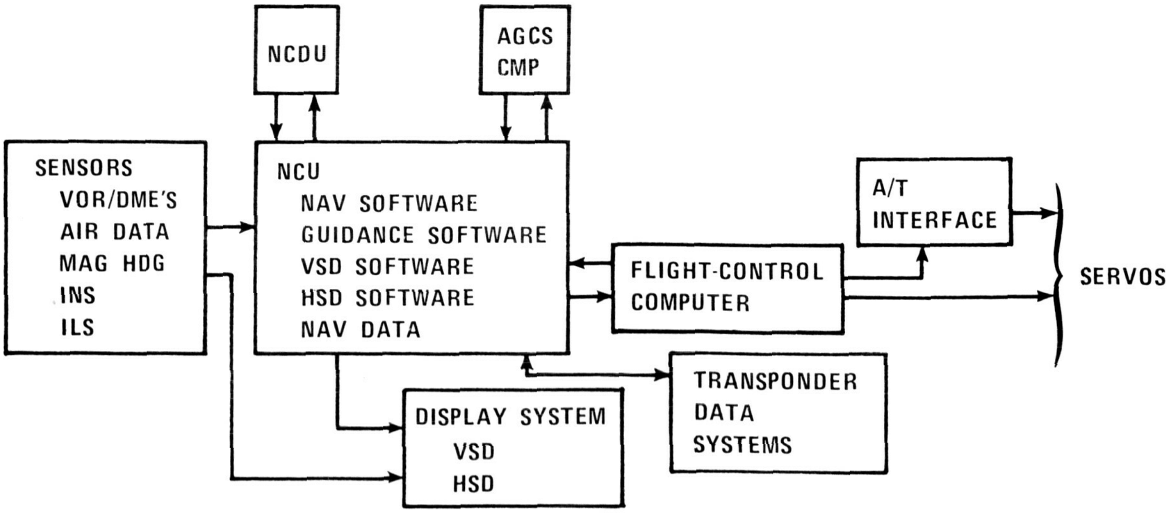


Figure 19.- Navigation and guidance system interfaces.

This software can accept a flight plan in a variety of forms, even while another flight plan is being flown. Much of the information available from the guidance calculations is useful to the pilot and may be displayed on the NCDU, VSD, or HSD at his option.

The basis of the 4-D guidance system is the horizontal path defined by a waypoint string. The waypoints are assigned altitudes and ground speeds. A typical flight plan may consist of up to 30 waypoints which may be input via the NCDU individually or in strings by specifying SID's, STAR's, airways, or routes. It is also possible to manually enter the parameters of waypoints not included in the bulk data storage section of the navigation computer.

For 2-D guidance, the waypoints are defined by name, latitude, and longitude. For SID's and STAR's, the turn radius at each waypoint may be stored in bulk data along with the latitudes and longitudes in the waypoint string. The turn radii for other waypoints are determined from the waypoint assigned altitude and ground speed. The assignment of a waypoint turn radius is desirable because it allows accurate calculation of the length of the path to be flown by the airplane. The "straight" segments between waypoints are arcs of great circles passing through the waypoints beginning and ending each leg.

For 3-D guidance, altitude is added to the definition of each waypoint. The altitude for waypoints within SID's and STAR's is included in the navigation data storage. The altitude at other waypoints is entered via the NCDU. To avoid the necessity of entering the same altitude many times, the altitude or flight level of an early waypoint is "cascaded" down the list to the last en route waypoint before a STAR. The vertical guidance path between waypoints is a constant gradient path based on the altitude change required between the waypoints and the distance between them.

For 4-D guidance, ground speed is added to the definition of each waypoint, and the scheduled arrival time at any one waypoint on the path will then uniquely define the time schedule for the entire path. Speeds may be cascaded through a list of waypoints in the same manner as the altitudes were in a 3-D path. The guidance algorithm provides a linear transition from the speed at each waypoint to the speed assigned to the succeeding waypoint on the path.

DISPLAY COMPUTATIONS

The VSD and HSD software in the navigation computer consists of programs to process and format data for the display system. The VSD computations use data generated by the navigation and guidance programs to control situation and command symbology on the VSD. The HSD program formats airplane position from the navigation program, geographical and desired flight-path data from the guidance program, and computes the path trend vector to control the continuous, real-time map display.

The information and format generated by the electronic display system for the VSD and HSD will be described in a succeeding section.

NAVIGATION CONTROL AND DISPLAY UNIT (NCDU)

The NCDU shown in figure 21 is an airborne cockpit display unit which allows the pilot to monitor and control the navigation computer unit. Data from the navigation computer are displayed by means of 8 rows of 24 alphanumeric characters on a 5-in. CRT. Data entry and mode control are accomplished through a 49-pushbutton keyboard which contains a full set of alphabet keys as well as numeric keys. Data characters are entered into character positions 10 through 24 of line 8 by the keyboard. Depressing the ENT (data ENTry) key then transfers the data into the navigation computer. A solid white line between line 7 and line 8 separates the data entry line from the remainder of the screen.

Mode keys are used to select the display format for the CRT indicator. These formats or "pages" are each used for a different purpose, and the type of communication with the navigation computer is determined by the mode (or format, or page) which has been selected.

The NCDU is currently programmed to perform many functions, some of which are primarily an aid to engineering evaluation and manipulation of the functions in the navigation computer.

Crew interface with the navigation computer is easily accomplished by operating the NCDU. Provisional waypoints and paths selected on the keyboard may be viewed immediately on the HSD map. Only when the pilot is satisfied with the input on the NCDU and pictorial display on the map will he enter the data into the computer.

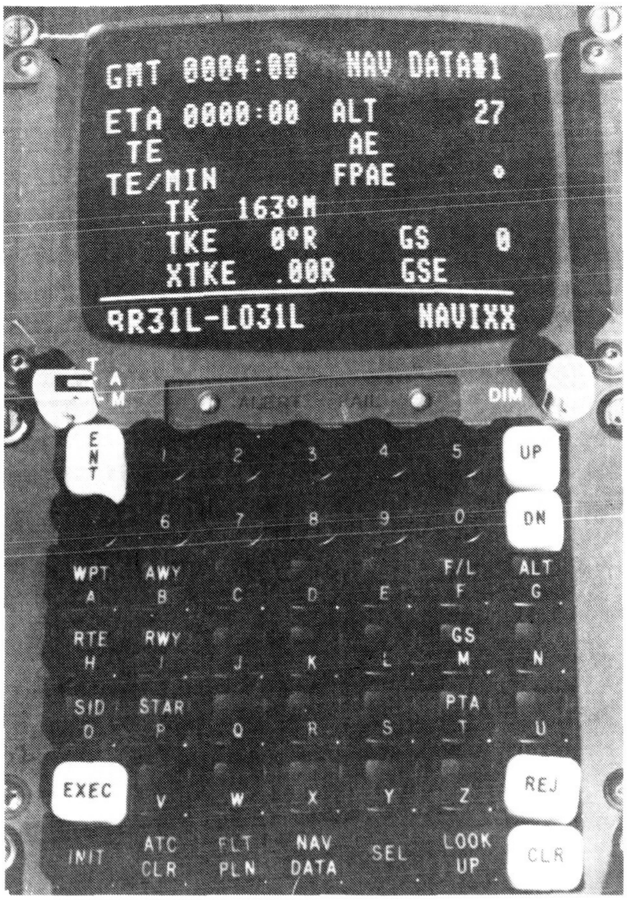


Figure 21.- Navigation control and display unit.

ELECTRONIC DISPLAY SYSTEM

The electronic display system developed by General Electric provides two displays for each pilot, a VSD and a HSD.

The formats and symbols on these displays are controlled by software programs, in the display processor, and in the navigation computer. This allows easy modification of the displays for pilot evaluation.

The following electronic display hardware is installed in the AFD:

- Two VSD's
- Two HSD's
- One VSD control panel
- Two HSD control panels

The following hardware is mounted on the display pallet installed in the passenger cabin (fig. 22):

- HSG (hybrid symbol generator)
- PCU (program control unit)
- Display system control unit
- Display monitors for VSD and HSD
- Power supplies for HSG and PCU

The system control unit is used to load and modify the software in the program control unit. Display monitors show the VSD and HSD display information recorded by the video recorders.

ELECTRONIC DISPLAY SOFTWARE

The program control unit is a programmable unit containing a 16-bit digital computer, a symbol generator controller, and an 8 000-word 24-bit memory. It performs the final display computations and controls the hybrid symbol generator. Programming capability includes limited programmable raster modulation and programmable stroke writing for the VSD. Only programmable stroke writing is utilized for the HSD. The display system symbol set is in software.

VERTICAL SITUATION DISPLAY (VSD)

At present, an EADI format is presented on the VSD and is the pilot's primary display of pitch and roll attitude for instrument flight. Additional symbology for velocity vector, flight-path acceleration, vertical guidance, speed error, and thrust command is integrated into the display format. A symbol indicating raw ILS data appears in the display format during final approach, and radio altitude is also displayed in digital form. Command bars are included for flight director modes. A forward-looking TV image can be presented on the VSD at pilot option in registration with the artificial symbology (fig. 23). The VSD symbology is illustrated in figures 24 and 25. A flare command is given by flashing the flight-path symbols at flare altitude.

The VSD mode control panel is shown in figure 26. The bottom row of switch lights is used for selecting the various display options. The switches will illuminate green when an option is selected ON and white to indicate OFF.

TV

When the TV option is selected on the VSD mode control panel, the TV picture seen by the forward-looking TV camera is displayed in registration with the VSD symbology. Since the flight-path-angle and flight-path-acceleration symbols are referenced to the pitch attitude display, they too are in registration with the television picture. On an approach, for example, the instantaneous projected touchdown point is shown on the televised image within the gap in the flight-path-angle symbol.

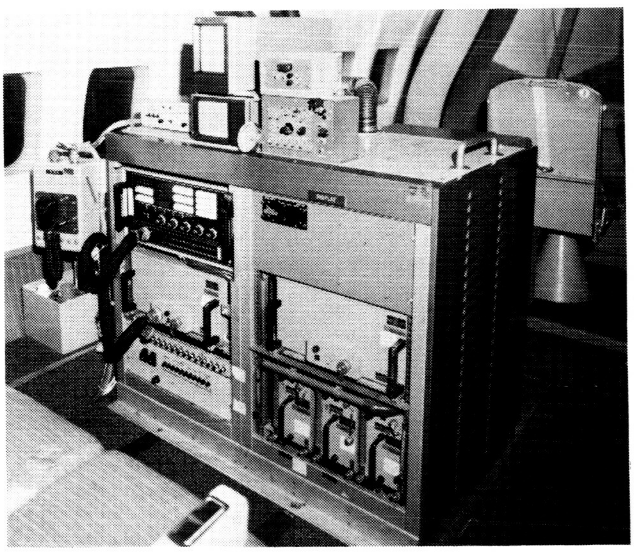


Figure 22.- Display pallet.

RUN WAY

An artificial runway symbol showing the true perspective of the runway based on navigation position estimates is presented on the screen. The runway symbol can be driven by either ILS or MLS signals.

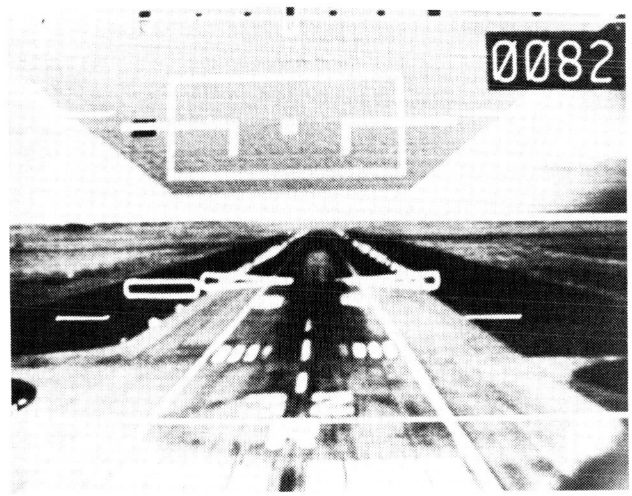


Figure 23.- Forward-looking television on VSD.

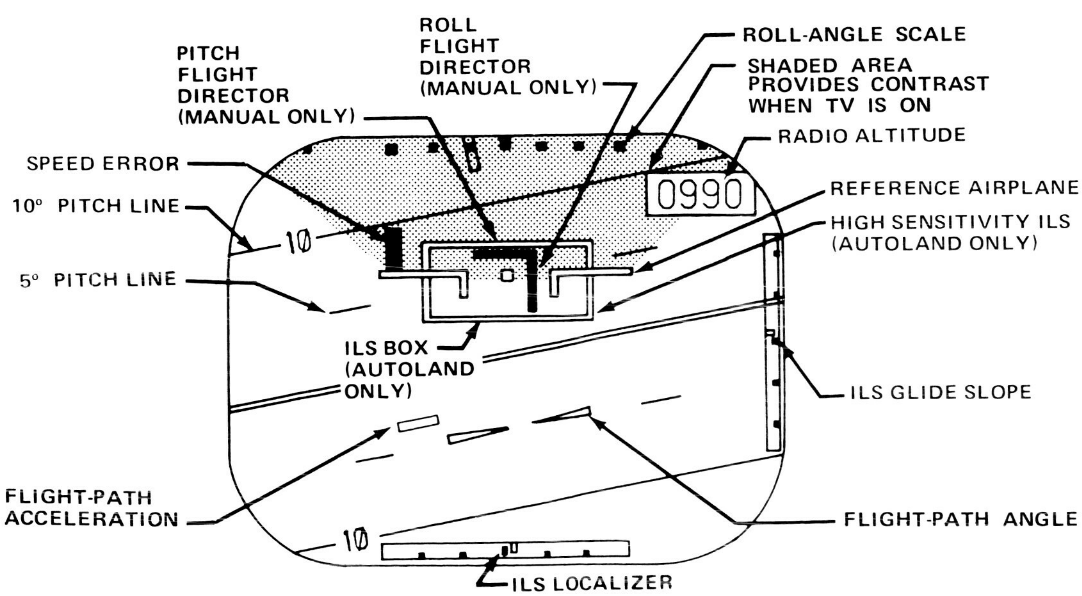


Figure 24.- Land symbology.

ILS

Whenever the ILS option is selected on the VSD mode control panel, one of two symbols will be displayed.

The ILS box is displayed on ILS or MLS autoland approaches. It is displaced laterally with localizer

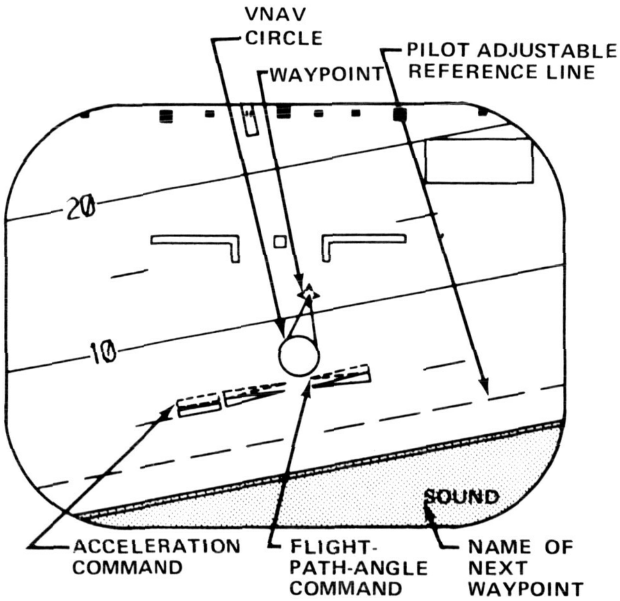


Figure 25.- RNAV symbology options.

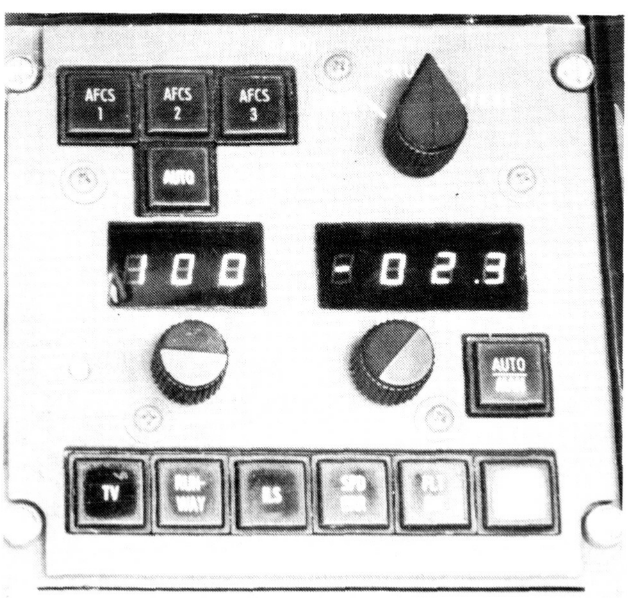


Figure 26.- VSD mode control panel.

deviation and vertically with glide slope. The size and shape of the box is representative of the CAT II ILS (± 25 μA LOC, ± 37 μA G/S) window. Whenever the center dot of the reference airplane symbol is within the box, the airplane is within that CAT II window.

Other ILS symbols are displayed when on an ILS or MLS approach but not on autoland. These symbols show localizer and glide-slope deviation on a fixed scale at the right side and bottom of the VSD. These symbols will only be displayed if the ILS option is selected and both the localizer and glide-slope signals are valid.

**SPD
ERR**

On an approach, the speed error is the difference between present airspeed and the value selected by the CAS ENG dial on the AGCS control mode panel.

**FLT
DIR**

The double cue command bars may be selected via the FLT DIR button. The command bars are driven by path commands from the navigation computer.

**V
NAV**

The area navigation waypoint symbol (four-pointed star) may be selected via the VNAV button to provide situation data both laterally and vertically with respect to the next waypoint. The identity of the waypoint is indicated by the name displayed in the lower right corner of the VSD. The waypoint symbol moves with respect to the attitude lines so that its vertical and horizontal displacement from the airplane symbol shows the relative elevation and bearing angles, respectively, from the aircraft to the waypoint.

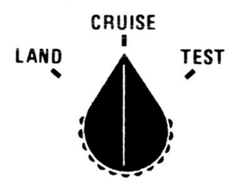
AUTO
MAN

The AUTO/MAN switch controls the mode of the pitch reference line. In MAN mode, the reference line can be positioned by the knob located immediately to the left of the AUTO/MAN switch. The pilot can use the reference line as an aid during flight-path-angle or pitch maneuvers. In AUTO mode, the pitch reference line is positioned by the navigation computer. In either case, the value of pitch reference will be displayed digitally in the window just above the switch.

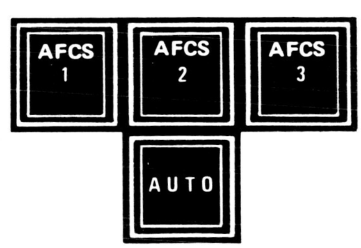
The DH adjust knob is provided to input a minimum decision height into the system. The value of DH is displayed digitally in the window immediately above the knob. When the radio altitude reaches the DH value, the center dot of the reference airplane symbol will begin to flash.

R/A TEST

The R/A test button, when depressed, puts a self-test signal into the radio altimeter. Proper operation of the radio altimeter and the VSD is indicated by 100 feet displayed on the VSD.



The LAND/CRUISE/TEST switch is provided for VSD mode selection. Although any of the optional symbols can be selected ON or OFF at any time, switching to LAND mode will automatically select TV, ILS, runway, and SPD ERR options. The TEST mode will cause a predetermined test pattern to be displayed on the VSD.



The AUTO and AFCS 1, 2, and 3 switch lights are not presently used.

HORIZONTAL SITUATION DISPLAY (HSD)

The HSD (or EHSI) is now used only as a pictorial navigation display which provides the pilot with an accurate display of airplane position relative to the guidance path, flight-plan waypoints, and geographic points of interest such as airfields, mountains, and VORTAC's. Other air traffic may also be represented in planned experiments. The desired horizontal flight path is displayed by a solid line connecting the waypoints. The curved trend vector is a dashed line

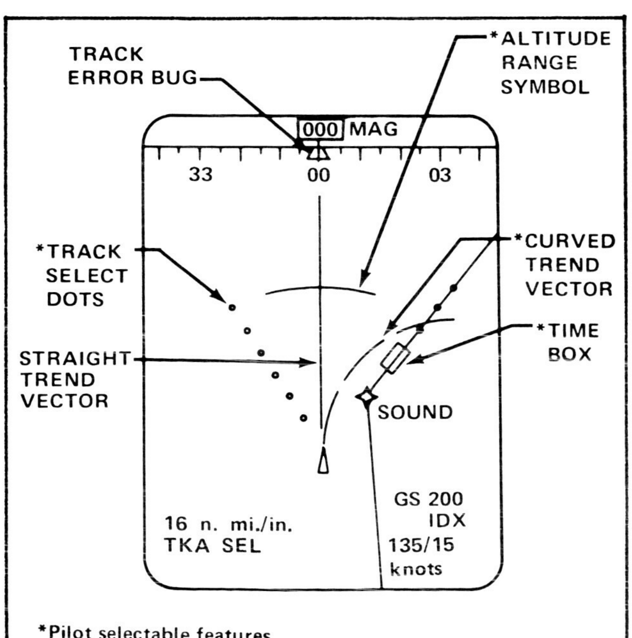


Figure 27.- HSD symbology.

emanating from the triangular aircraft symbol. A box indicates the desired along-path position during 4-D operations. Magnetic track is indicated at the top of the HSD (fig. 27). At the bottom of the display are the indicated map scale (16 n. mi./in.), automatic control mode (TKA SEL), ground speed (GS 200) in knots, navigation sensors being used (IDX (inertial with a single DME)), and calculated winds (135/15 knots, wind of 15 knots from 135° magnetic). The operating modes of the two HSD's (pilot and first officer) are independent (i.e., one may be operated in the north-up mode while the other is in track-up); they may also be operated with different scales or with different options.

The HSD mode control panel is shown in figure 28.

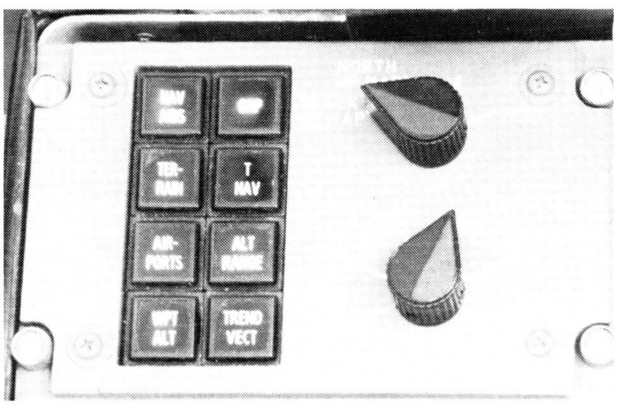
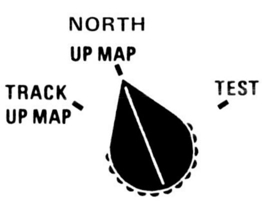
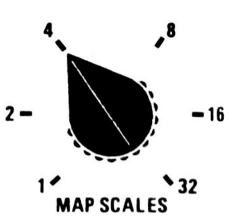


Figure 28.- HSD mode control panel.



The HSD has two basic modes of operation, north-up and track-up, selectable on the HSD mode control panel. Selection of the test mode allows the pilot to confirm proper operation of all display generating functions.



Six different scale factors are provided for the HSD map. These scales are 1, 2, 4, 8, 16, and 32 n. mi./in. and are independently selectable on the two HSD mode control panels. The selected scale is displayed on the lower left-hand corner of the map.

Nondirectional Beacon, VOR, or TACAN stations may be selected ON and OFF with the NAVAIDS option switch.

Prominent terrain features in the area may be selected ON or OFF with the TERRAIN option switch. These features include the elevation above sea level of obstacles, obstructions, or hazards in the area covered by stored bulk data.

Airport symbols are selectable ON and OFF with the AIRPORTS option switch. These symbols show the location of airports, the orientation of the primary instrument runway, and the airport four-letter identifier.

When the WPT ALT option is selected ON and a 3-D or 4-D path has been entered, the identifier tag for the waypoint will include the desired altitude and, if assigned, the desired ground speed for that point.

Geographical reference points (GRP) are used for flight planning and route selection and encompass all air traffic control points and facilities not covered by the NAVAIDS switch. These symbols may be selected ON or OFF by the GRP option switch.

A time box representing the desired location of the airplane along the flight path in accordance with the programmed 4-D path is available. Three small circles will also be located along the route line ahead of the time box. These circles indicate the time-box future position at 30, 60, and 90 sec. The time box and circles will be displayed whenever a time path has been entered through the NCDU and the TNAV option switch is selected ON.

The altitude/range symbol consists of an arc some distance from the airplane symbol which represents where the airplane would reach a reference altitude, selected via the AGCS control mode panel, if the current flight-path angle is maintained. The altitude/range symbology is displayed when:

- An altitude reference has been entered
- The HSD map is in track-up mode
- The ALT RANGE option switch light is selected ON

The straight trend vector represents the instantaneous track angle of the airplane. The straight trend vector will always be displayed regardless of which mode, scale factor, or options are selected. However, a curved trend vector, consisting of three curved dashes whose end points represent the predicted, future airplane position at 30-, 60-, and 90-sec intervals, can be displayed. On the 1-n. mi./in. map scale, the trend vector is reduced to a single dash representing the airplane position over a 30-sec span. The curved trend vector may be selected ON and OFF with the TREND VECT option switch light. The curvature of the curved trend vector is a function of the current ground speed and turn rate.

ELECTRONIC DISPLAY SYSTEM INTERFACES

Display system interfaces are shown in figure 29. The electronic display system receives information from the navigation computer. The displays are driven by the hybrid symbol generator under the control of the program control unit. Some sensor signals are interfaced directly to the program control unit. The hybrid symbol generator receives video information from the forward-looking TV camera (FLTV).

DATA ACQUISITION SYSTEM (DAS)

DAS (fig. 30), an airborne system operating in real time, acquires and records signals representing variables pertinent to a given test condition. The heart of the DAS is the piloted aircraft data system (PADS), a system designed and built by Langley Research Center (fig. 31). PADS combines onboard data acquisition and recording with an L-band telemetry downlink to either fixed or mobile ground data systems which provide real-time and/or safety-of-flight monitoring. Under most circumstances, the air-to-ground link distance for reliable telemetry reception is 15 n. mi. when the ground station uses omnidirectional antennas, or 50 n. mi. when the ground station uses directional antennas.

For the TCV application, PADS is configured to accept and digitize 104 analog signals at a 40 samples per second rate (0 to 5 Hz frequency response). These digitized signals are formatted into a serial pulse code modulation (PCM) data stream that is recorded on a wideband magnetic tape recorder and is also sent to the telemetry transmitters. The parameters to be recorded originate in the navigation and guidance pallet, the flight-control interface pallet, and in several dedicated instrumentation transducers located throughout the airplane. Since there are normally more than 104 data signals available, a patch panel is provided on the DAS pallet so that the desired parameters for a given test may be selected.

To assist in the evaluation and analysis of the digital flight-control system, two autopilot data formatters are mounted on the flight-control computer pallet. These formatters receive digital inputs from the CIU's and reformat them into a serial PCM data signal. The autopilot formatters, as currently used, handle a total of 156, 16-bit variables, 32 sensor failure codes, and 64 discretes. The output data bus (ARINC 561 format) from the navigation computer is also routed to the DAS pallet. Since the content of this data bus is software controlled, any 31 of the many navigation variables may be selected for a given test. The autopilot formatter and the ARINC 561 data channels are recorded on the same magnetic tape recorder as the PADS PCM but are not available on the L-band telemetry link.

Display information available in the TCV B-737 is recorded as follows: an image converter on the video recorder pallet reproduces the VSD and HSD formats into conventional video signals. These images are recorded at the video recorder pallet (fig. 32). An onboard system of three oscillographs, located across the aisle from the PADS pallet, provides near real-time records of selected data during research flights.

All recorded data signals are retrieved from the magnetic tape by a ground-based NASA data reduction facility. This facility has the capability to:

- Produce oscillograph-type time histories
- Reformat digital data for computer compatibility
- Produce digital listings of time histories
- Produce cross plots of variables
- Perform computations on digitized data

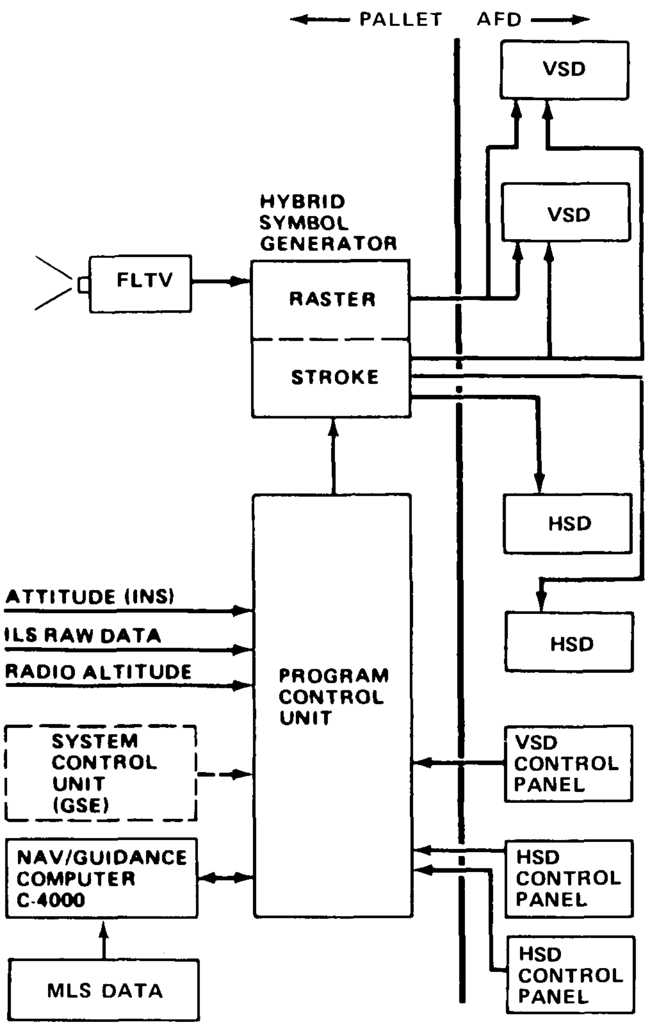


Figure 29.- Display system interfaces.

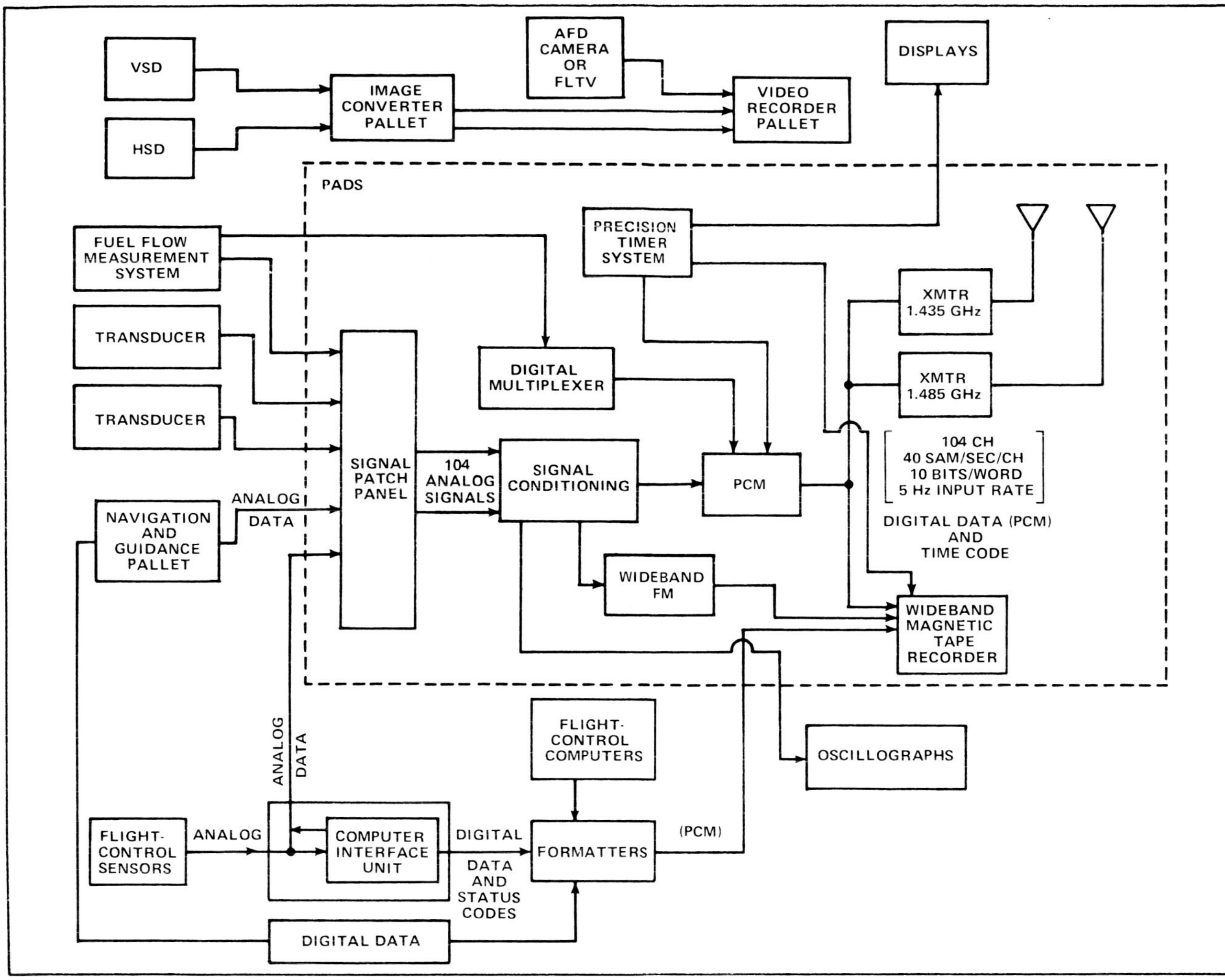


Figure 30.- Data acquisition system (DAS).

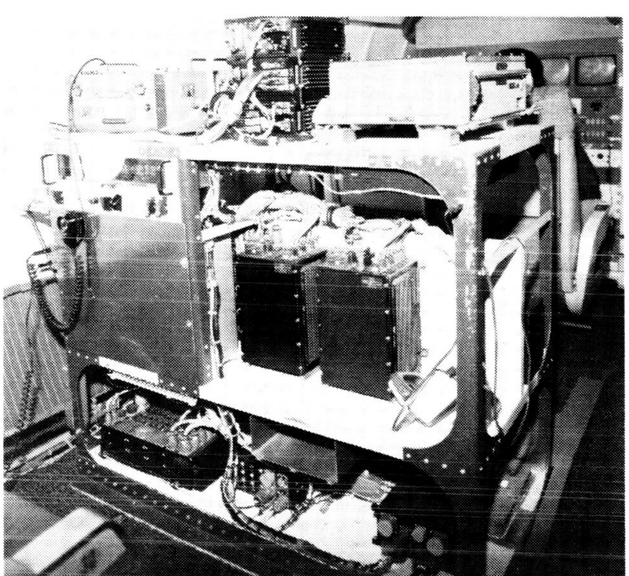


Figure 31.- Piloted aircraft data system (PADS).

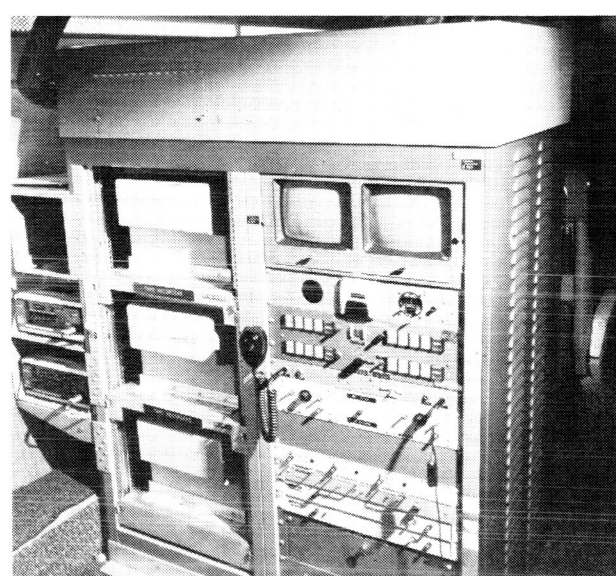


Figure 32.- Video recorder pallet.

CONFIGURATION DOCUMENTATION

The overall TCV B-737 configuration scheme is outlined in figure 33. The flight configuration record is the primary element for defining the experimental system's configuration for each flight test. It includes a definition of the hardware changes and software changes accomplished to a specific flight number/test number.

The hardware changes are controlled by the release of an experimental systems work request (ESWR) which fully describes the work to be accomplished and identifies the engineering record changes (drawings, diagrams, schematics, etc.) that must first be red-lined, then the vellums updated. Signature space is also provided for ESWR approval, functional test completed, and work completed. A master file of the original ESWR's is maintained. The ESWR serves to reflect the status of a hardware change and is used as a reference in revising the appropriate documentation. After release of the documentation describing a configuration, approximately every 6 months, the baseline drawing is referenced, and the last ESWR change number documented is shown for each system (i.e., display, NAV/GUID, etc.).

The software changes are controlled by a software change request (SCR) which identifies the function affected, the reason for the change, and the change. Approval signatures are shown for verification of the change and the patch verification to the basic tape. Software change request originals are maintained in a master file for reference and for creating a new tape/listing that incorporates all the approved patches. Both the basic tape and patches to the basic tape are shown on the flight configuration record for identifying the software configuration of each system.

From the above information (plus flight folder data) for all experimental flight activity, a specific TCV B-737 experimental system configuration is referenced that will define a subsystem level configuration down to a level that shows a wire with its signal content.

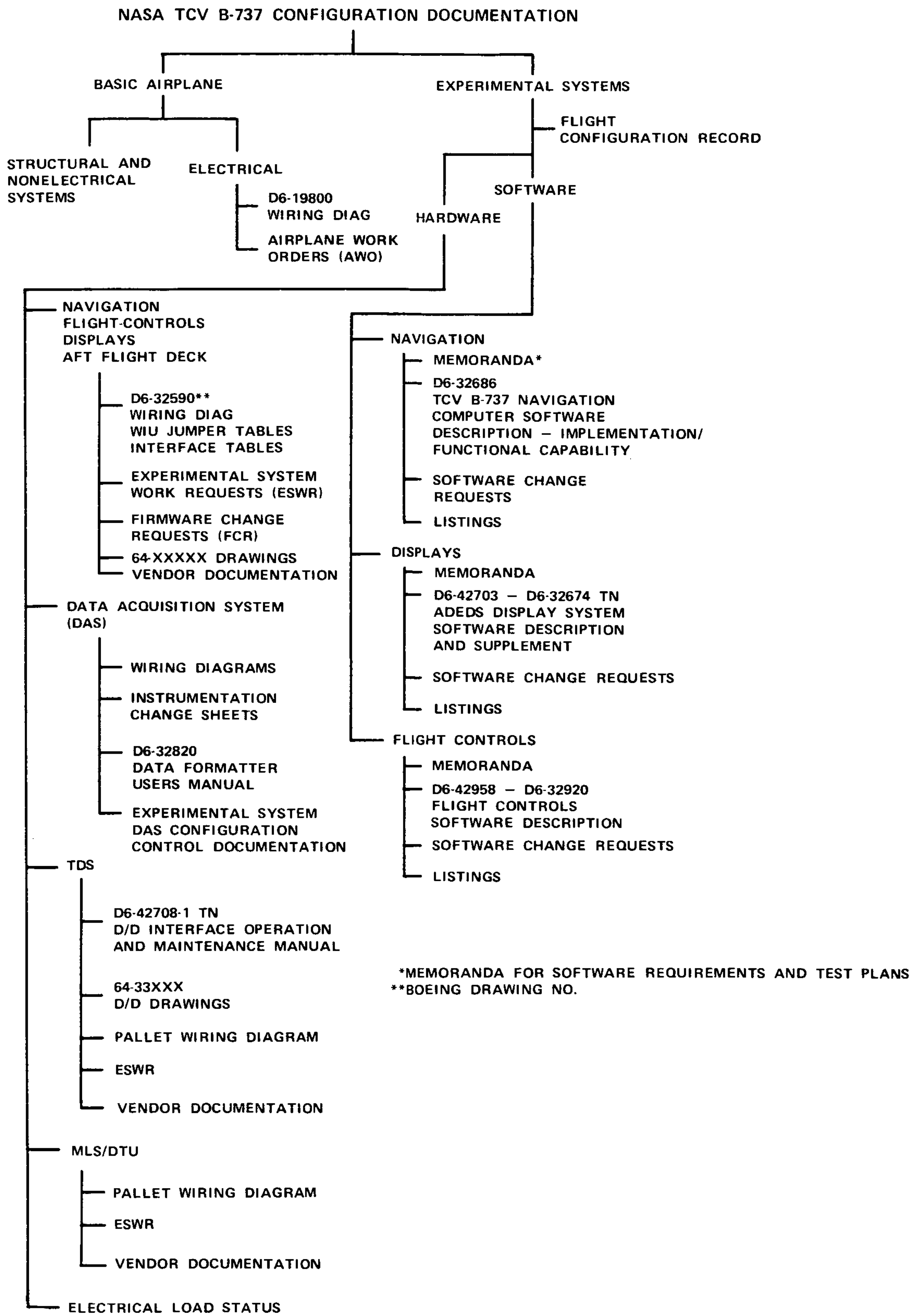


Figure 33.- NASA TCV configuration documentation tree.

GROUND-BASED EXPERIMENTAL FACILITIES

TERMINAL AREA AIR TRAFFIC MODEL

The Terminal Area Air Traffic Model (TAATM) permits analyzing and combining current and advanced air-traffic management system configurations, including ground and airborne instrumentation and new and modified aircraft characteristics. The simulation model is used to determine the sensitivities of terminal area traffic flow, safety, and congestion to aircraft performance characteristics, avionics systems, and ATC elements.

The facility will also be used to provide a realistic multiple-aircraft environment for the evaluation of pilot displays, terminal optimized vehicle configurations, collision-hazard warning-system techniques, and advanced landing guidance systems operating in present-day and proposed future ATC systems.

The terminal area air traffic model is a flexible simulation of the airborne, ground control, and communication aspects of the terminal area environment which is, with input data changes, adaptable to existing terminal areas and which can be and is being expanded to incorporate advanced concepts of instrumentation and control. The airborne aspects modeled include aircraft dynamics, performance capabilities of 20 different classes of aircraft, traffic samples depending on desired operations per hour and probabilities of aircraft types and route loadings, aircraft load factors, intended flight plans, flight-path errors, and meteorological effects. The ground control aspects include control procedures (both current ATC procedures and advanced control techniques), control options (i.e., speed control, alternate paths, altitude change, holding patterns), separation standards, navigational aids, terminal area geometrics, air-route structuring, runway handling constraints, and surveillance errors. The communication aspects reflect only controller to pilot communication and include message content, delays associated with the actual delivery of a message, delays associated with controller work load, and priority delivery of messages.

The TAATM, which can be run in both a real-time or a fast-time mode, outputs overall performance measures for trade-off evaluation of various navigational or control techniques as they relate to the terminal environment as a whole. In addition, the real-time mode offers a visual and audio environment for a realistic real-time simulation of traffic in the terminal area and is capable of providing automatic guidance information for real aircraft. TAATM is composed of three independent units, including a traffic generation program, the terminal area simulation, and postanalysis routines.

TRAFFIC GENERATION

The traffic generation program is responsible for supplying traffic samples to be input to the terminal area simulator. These samples describe the initial conditions for arrival aircraft on a prescribed perimeter about the runway or for departing aircraft on the runway apron. Inputs to this program include limitations and deviations on initial speeds and altitudes for different performance classes of aircraft and on headings and lateral positions for the entry points on desired routes. Depending on the desired operations per hour and probabilities of aircraft types and route loadings, the program outputs offer times, initial positions, headings, and velocities of aircraft which comprise the traffic sample. Realistic traffic samples can be generated based on known probabilities of aircraft in a particular terminal area, or special-purpose samples can be generated by varying the input parameters. Such a special-purpose sample might consist of all similar type aircraft or a modified distribution of aircraft on the terminal area routes.

TERMINAL AREA SIMULATION

The terminal area simulation was designed to be adaptable to both existing and advanced concepts of instrumentation and control. The needed versatility and flexibility were accomplished through the identification of the various functions performed within the terminal area into three groups: airborne functions, communications, and ground control. These three groups correspond to the three bracketed sections of the flow chart in figure 34: TRACK (update of aircraft position data considering aircraft dynamics, performance capabilities of different classes of aircraft, and use of particular navigation aids), COMMUNICATIONS (communication of ground control with aircraft, considering channel loads and priority of messages to be sent), and CONTROL (ground control procedures used to control the flow of aircraft and to resolve potential conflicts between aircraft). Unit organization of the functions within these three groups permits the use of or exclusion of any subset of functions as is required by a particular data set.

When the simulator is initialized, all traffic is assumed to be on the runway or outside the perimeter of the terminal area of interest, waiting in the master traffic sample to enter the terminal area. Examining a 4-sec incremental clock (corresponding to a 4-sec radar scan rate), the control section of the simulator determines if the offer time associated with an aircraft in the master traffic sample has been reached. If this time has been reached, initial control procedures are performed for the aircraft, and it is either entered into the "active" traffic of the terminal or held in an enroute delay queue outside the terminal area perimeter.

Movement of the aircraft within the terminal area is based on predefined intended flight plans which can be modified for a particular aircraft by the control section of the program in order to facilitate the traffic flow. Modifications to a flight plan must, however, be communicated to the pilot through the communications section of the program. The intended flight plans and any optional flight paths are described by the data in terms of the navigational aids to be used to fly each portion of the path ("flight modes" such as a VOR radial, a DME radius, a vector, an ADF beacon, an ILS system, an MLS system, or RNAV) and in terms of the navigational aids used as the objective at the end of each portion of the path ("flight mode objectives" such as VOR radial intersection, a DME radius, a new altitude, RNAV turn anticipation, etc.). The position of each aircraft in "active" traffic is updated every 4 sec based on the navigational algorithms which describe each navigational aid being used by the aircraft and on the aircraft dynamic model. Each updated position reflects the impact of current winds and navigational errors. In addition to the actual calculated position, a radar tracking position is calculated which reflects surveillance errors.

The control routines in the program are called on as necessary during the simulation, depending on the criteria for determining when to utilize control. Each possible route has associated with it a set of control procedures to be performed for each aircraft at various points or regions on the route. In addition to the predefined control points or regions, immediate control procedures for a particular aircraft can be requested when a potential conflict exists which must be resolved by a second aircraft.

The control section of the simulator consists of control modules which are called upon as needed according to the status of the aircraft in the terminal area and according to the desired degree of control defined by the input data. Current ATC procedures define control sectors where a controller is responsible for handing aircraft in his/her sector to another controller with adequate separation. This control philosophy permits limited look-ahead capability into future sectors and concentrates on separating aircraft within a sector, with little knowledge of the impact on the entire terminal area. This philosophy is handled in the simulator by establishing an ETA point within a sector just prior to a handoff point to a new controller. The control algorithms then simply maintain separation between aircraft in the sector up to this point. An optimum control philosophy might be one in which each aircraft is assigned an ETA at the runway considering separation requirements. Control is then responsible for maintaining the schedule of aircraft or reassigning schedules when necessary. The simulator handles this logic with an initial scheduling module as each aircraft is entered into "active" traffic and dynamic speed control and path control modules as an aircraft proceeds on its path to the runway. When a schedule can no longer be maintained due to flight errors, a rescheduling module is called.

The control section of the program is capable of simulating both the controller decisions and the computer-aided decisions which might be offered to a controller to assist in the resolution of the traffic flow problem. In either case, the results of the decision are transmitted from a controller to a pilot via a voice communications channel. Simulation of the communication aspects of terminal area environment is accomplished through the use of two message arrays per channel, one ordered on the earliest time of delivery (future messages) and one ordered on the latest time of delivery (current messages). As a control decision is made, a time envelope is associated with each message containing the results of the decision. This time envelope corresponds to the earliest and latest times a controller can deliver the message to a pilot such that the control decision remains valid. Initially, all messages are ordered on earliest time of delivery and placed into a future message array. As the time associated with a message in this array comes up, the message is moved into a current message array and ordered on latest time of arrival. These two arrays enable a priority delivery of messages. Message delivery delays are simulated by assigning an elapsed time for the delivery of each message and by permitting only one message at a time to be delivered by a controller. At present, the simulator handles up to 10 message channels.

POSTRUN ANALYSES

In the batch or fast-time mode of operation, data from the terminal area simulation are output on a data tape containing scan-by-scan information, which is in turn used as input to postprocessing analysis programs. These postprocessing programs include statistical analysis programs and a position plotting program. The accumulation of data for postprocessing analysis is usually accomplished by running the simulation for a simulated 2-hr time period after the simulation stabilizes to a steady-state operational condition.

A summary of the types of output data available from the simulation programs is shown below.

Statistical Analyses – histograms, sample means, and standard deviations of the following parameters:

- Time between entries in take-off queue and departures
- Actual time between departures
- Imposed delay in take-off queue and departures
- Time between successive departures from terminal area
- Actual flight time in terminal area for departures
- Total time in terminal area for departures
- Time between entries in enroute queue for arrivals
- Actual time between arrivals
- Imposed delay in enroute queue for arrivals
- Time between successive touchdowns for arrivals
- Actual flight time in terminal area for arrivals
- Total time in terminal area for arrivals
- Range to closest aircraft for the five closest aircraft
- Interarrival time error

Plots of aircraft positions and density plots

REAL-TIME GRAPHICS DISPLAYS

Operating in the real-time simulation mode, the air traffic flow is monitored on a simulation console display (CRT). Information displayed includes nominal route structures, controller message information, and data for each aircraft such as a symbol for its position and a tag containing flight identification, speed, altitude, and hold status. The display, updated every 4 sec, may be oriented with respect to arbitrary geographic coordinates and scaled as chosen by the observer. The origin of coordinates may also be referenced to a chosen aircraft to produce a moving aircraft centered display.

INTEGRATION OF TAATM WITH OTHER FACILITIES

Two types of system simulations have been run using TAATM to generate scenarios. The first used the TCV B-737 cockpit simulator to conduct human pilot-in-the-loop experiments. Figure 35 shows a block diagram of this integration. The second consists of a TAATM/Wallops tie which is used to provide a realistic ATC environment to the TCV B-737 aircraft for conducting flight experiments. The TAATM simulation is structured such that both the simulator cockpit and a real aircraft, or several simulator cockpits, could be simultaneously used in order to conduct pilot-in-the-loop interactive studies.

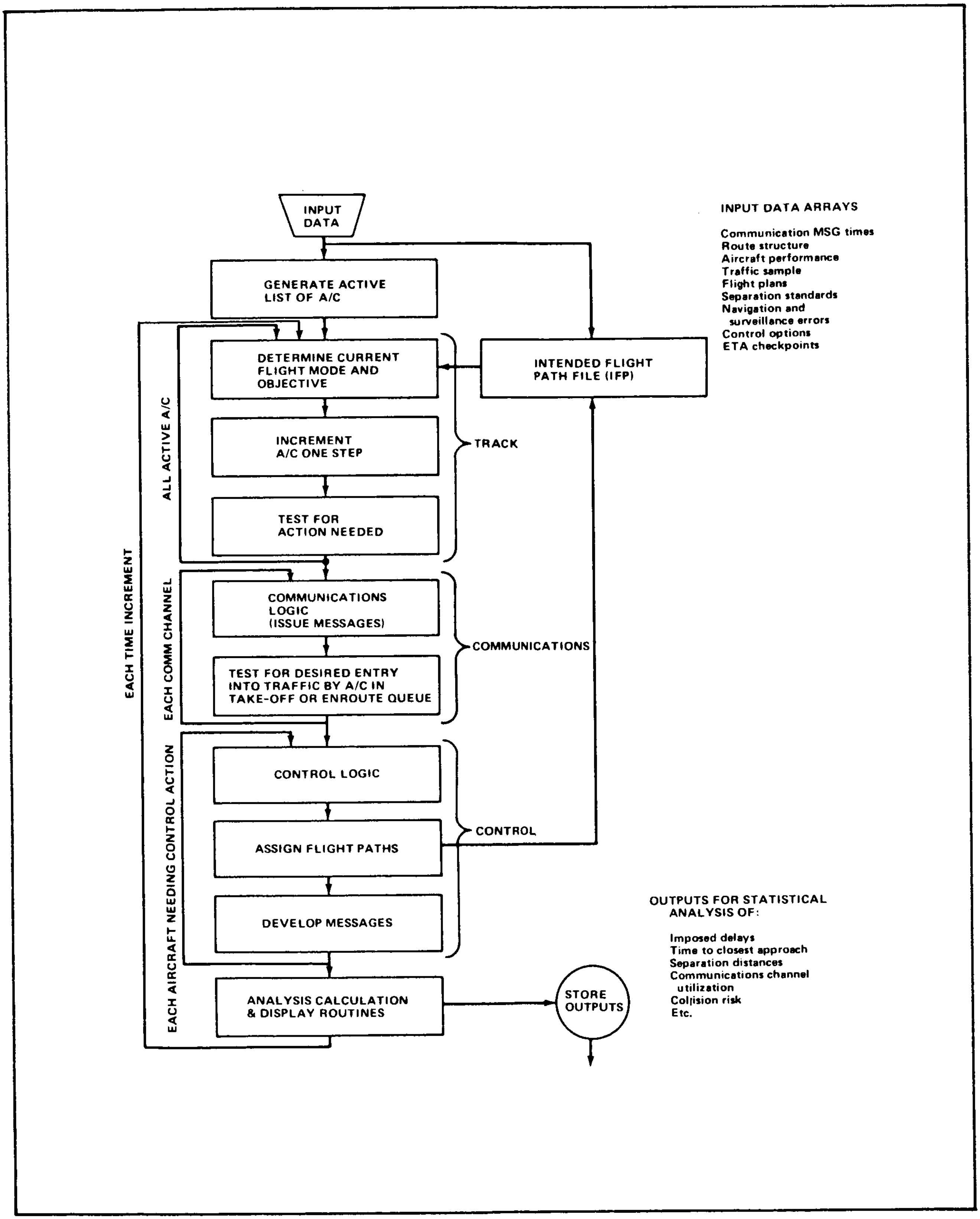


Figure 34.- Overall organization of terminal area simulation program.

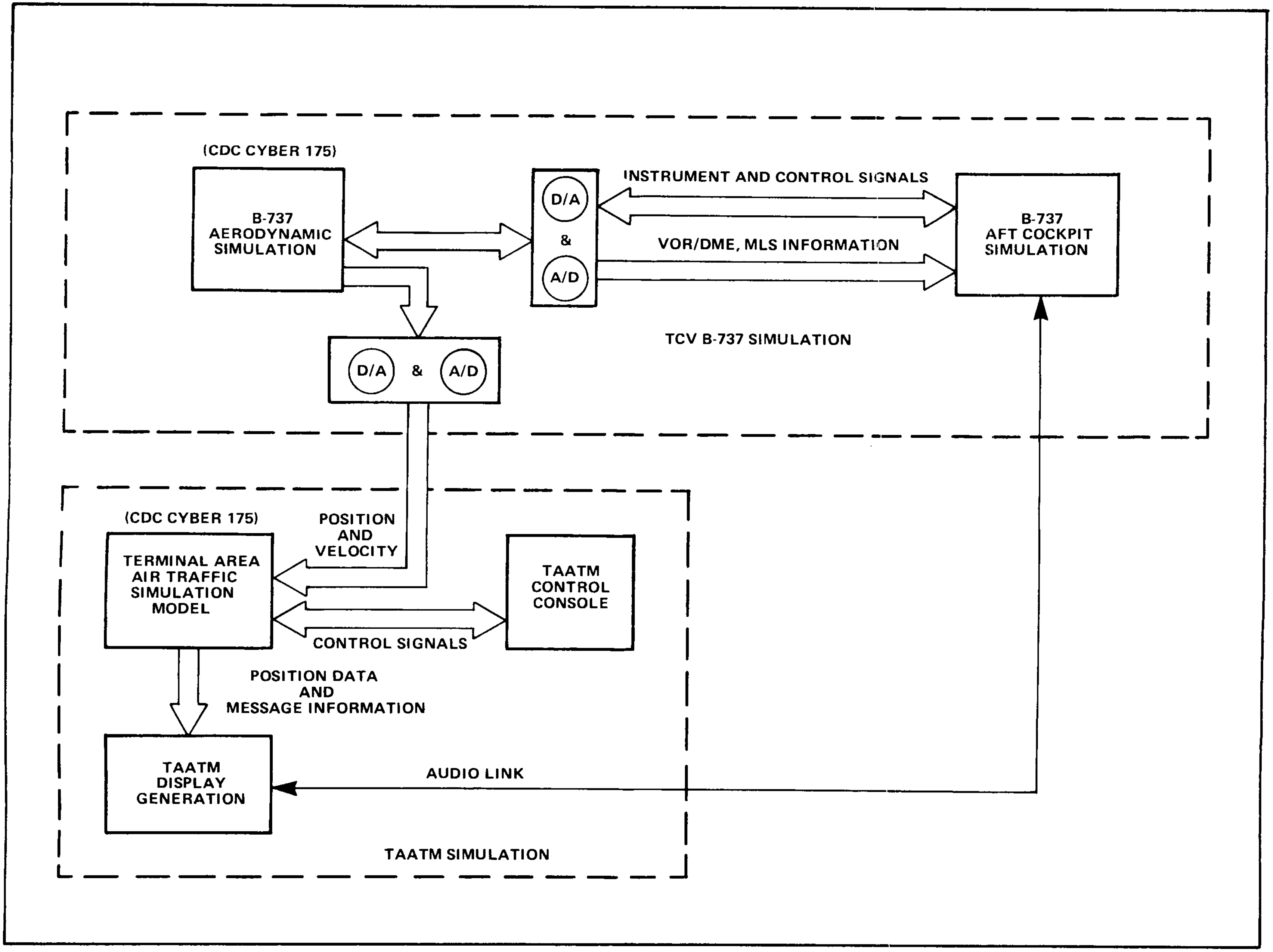


Figure 35.- Block diagram of integration of terminal area simulation with cockpit simulator.

VISUAL MOTION SIMULATOR

The six-degrees-of-freedom motion simulator consists of a *two-pilot-station cockpit mounted on a* servo-controlled, hydraulically powered platform. This simulator is employed to study methods and effects of limited motion in aircraft simulation and is used in support of TCV applications where some degree of motion is essential to valid simulation.

The cockpit is a general-purpose, modular design, two-man transport type and contains appropriate instrument panels, primary and secondary flight controls, visual display, and audio cues. Instrument panel mounting frames are provided at left and right forward panels for pilot/first officer primary flight instruments and a center instrument panel between pilot and first officer for engine instruments. Flight controls consist of hydraulically loaded wheel, column, and rudder pedals to provide the pilot with realistic control feel, two- and four-throttle quadrants, and control-surface trim controls. The visual display consists of a set of optical lenses that view a standard television monitor and provide the pilot with a television representation of an out-the-window view from the Redifon System. Audio cues are provided to simulate engine sounds, aerodynamic noise, landing-gear noise, on-the-ground noise, and warning signals.

The platform for mounting the cockpit is driven by six hydraulically powered servo-mechanisms arranged in three bipod pairs (fig. 36). A central control station will allow visual surveillance of the motion base area. All normal control of the system can be exercised from this station. Communications will be available between the central computer, the control station, and the cockpit. Separate communication is available between the control station, platform maintenance area, and the hydraulic power area. Emergency power is provided for the communications system.

The system interfaces with the central computer system to provide real-time computing capabilities. Design features inhibit computer control of the motion system until all systems are in readiness. The motion envelope is given in the following table:

Degree of freedom	Pitch	Roll	Yaw
Rotation, deg	+30,-20	±22	±32
–Velocity, deg/sec	±15	±15	±15
–Acceleration, deg/sec	±50	±50	±50
	Long.	**Lateral**	**Vertical**
Displacement, in.	±48	±48	39 up, 30 down
–Velocity, in./sec	±24	±24	±24
–Acceleration, g	±0.6	±0.6	±0.8

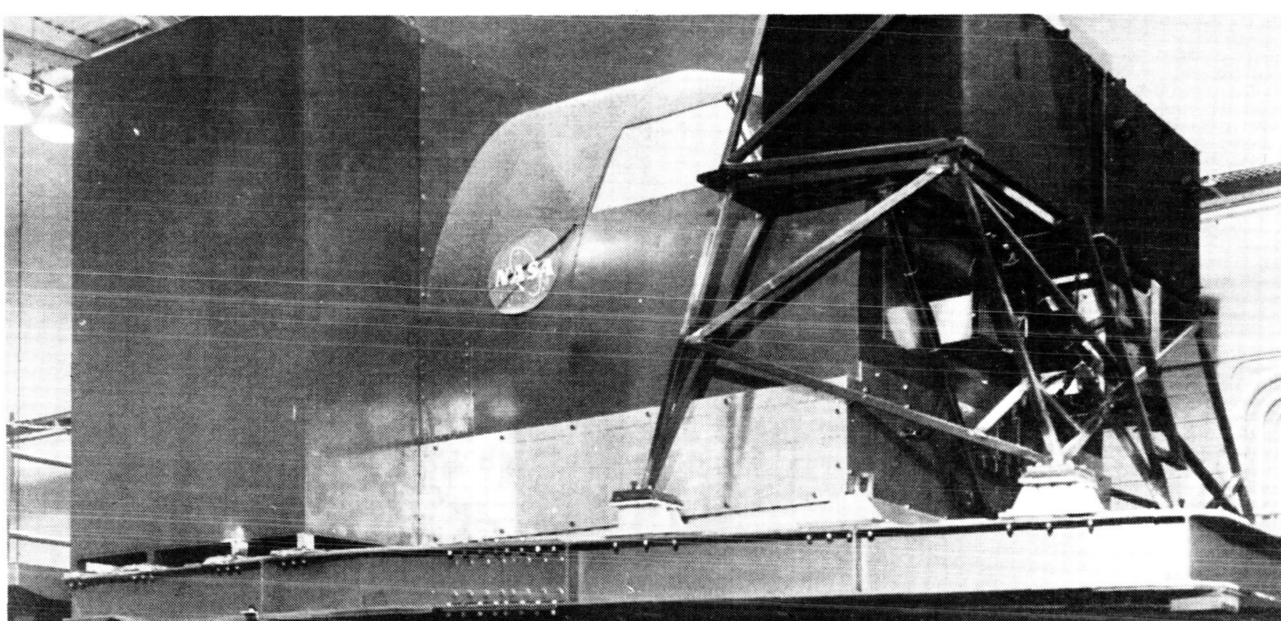


Figure 36.- Visual motion simulator.

FIXED-BASE SIMULATOR

A simulator supporting the TCV Program and duplicating the TCV B-737 AFD is also available. The simulator can be used to:

- Develop and evaluate preliminary concepts of advanced flight procedures including crew roles, controls, displays, and ATC interaction
- Provide pilot familiarization with advanced piloting techniques
- Provide a mechanism through which interested parties can see and evaluate program technical activities

The facility consists of the TCV B-737 AFD simulator shown in figure 37, a real-time simulation subsystem (CDC CYBER 175 and program control station), and a graphics computer built by ADAGE. As outlined in figure 38, the facility provides the experimenter a close simulation of the TCV B-737 AFD. The simulator is equipped with actual flight instrumentation including basic cockpit instruments, AGCS, NCDU, VSD, HSD, and an equivalent brolly handle force feel system.

The computer program includes the basic 737 nonlinear real-time simulation with the additions of landing-gear dynamics, gust/wind models, nonlinear actuator models, and ILS and MLS sensor models. Automatic flight-control and navigation-control functions have also been simulated and include control wheel steering, autoland with decrab and roll-out capability, and outer loop guidance and control (2-D, 3-D, 4-D). Bulk data storage (SID's, STAR's), display computations, and NCDU computations on the CDC CYBER 175, combined with the display generation capability of the ADAGE graphics terminal, present to the simulator pilot the same displays as used on the aircraft with equivalent man-machine interaction capabilities. The terminal area simulation has been tied to the fixed-base simulator for system studies (fig. 35).

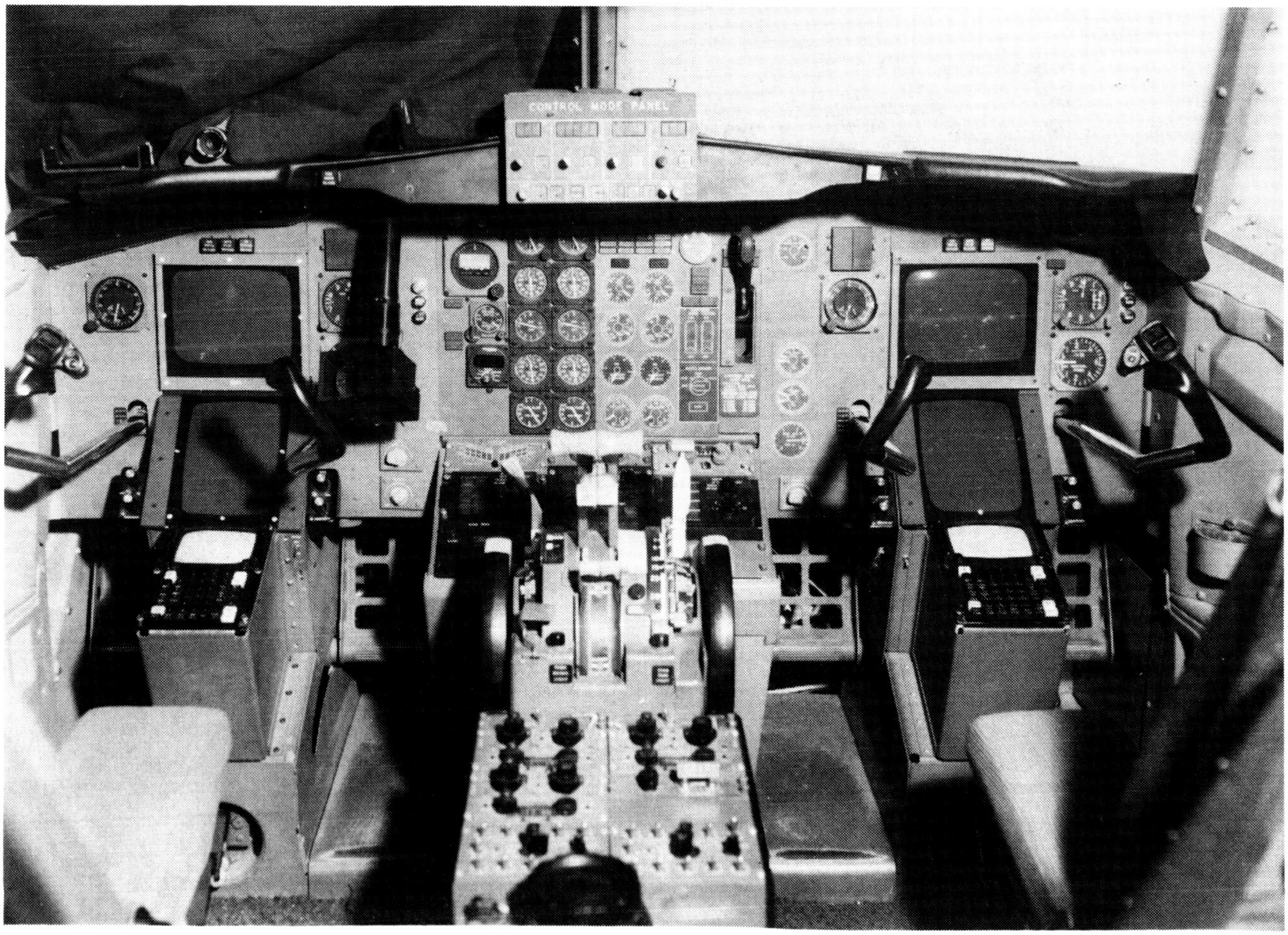


Figure 37.- Fixed-base simulator.

CREW TRAINING PROGRAM

A training program for airline captains and first officers is under development to provide a large pool of crews trained in advanced systems who can participate in TCV AFD research studies. This program will be multimedia in nature, that is, pilot manuals, slide-tape presentations, computer-based education (PLATO) courses, and in-simulator training.

A major part of the program is the PLATO computer-based education system. The system handles instruction, testing, scoring, prescribes study activities such as videotapes and slide-tape presentations, displays student progress, and provides data for evaluating the effectiveness of the instructional material. At the terminal, students use the keyboard or touch the screen to work through instructional materials. The system provides the student with "simulations" of how various research displays work and interpretations of the displayed information. Students may repeat key exercises as often as desired, or "freeze" a situation at a certain point for instant review of performance.

Training programs are planned for the HSD, VSD, AGCS, and the NCDU. The research AFD cockpit simulation is used for the final phase of the training.

AUTOMATIC NAVIGATION, GUIDANCE, AND CONTROL SIMULATIONS

Three digital FORTRAN simulations (BANKTRN, ALERT, and FILCOMP) are in use to evaluate and analyze the performance of navigation, guidance, and control systems. The elements of the simulations are shown in figure 39. The initial conditions, sensor noises, wind disturbances, and desired path parameters are specified through name-list inputs. The programs are normally executed through the CRT interactive terminals but can be run with the use of card decks. The programs are stored in update libraries, and thus it is easy to evaluate modifications to the systems. These programs are similar in many respects. The similarities and differences are compared in table III.

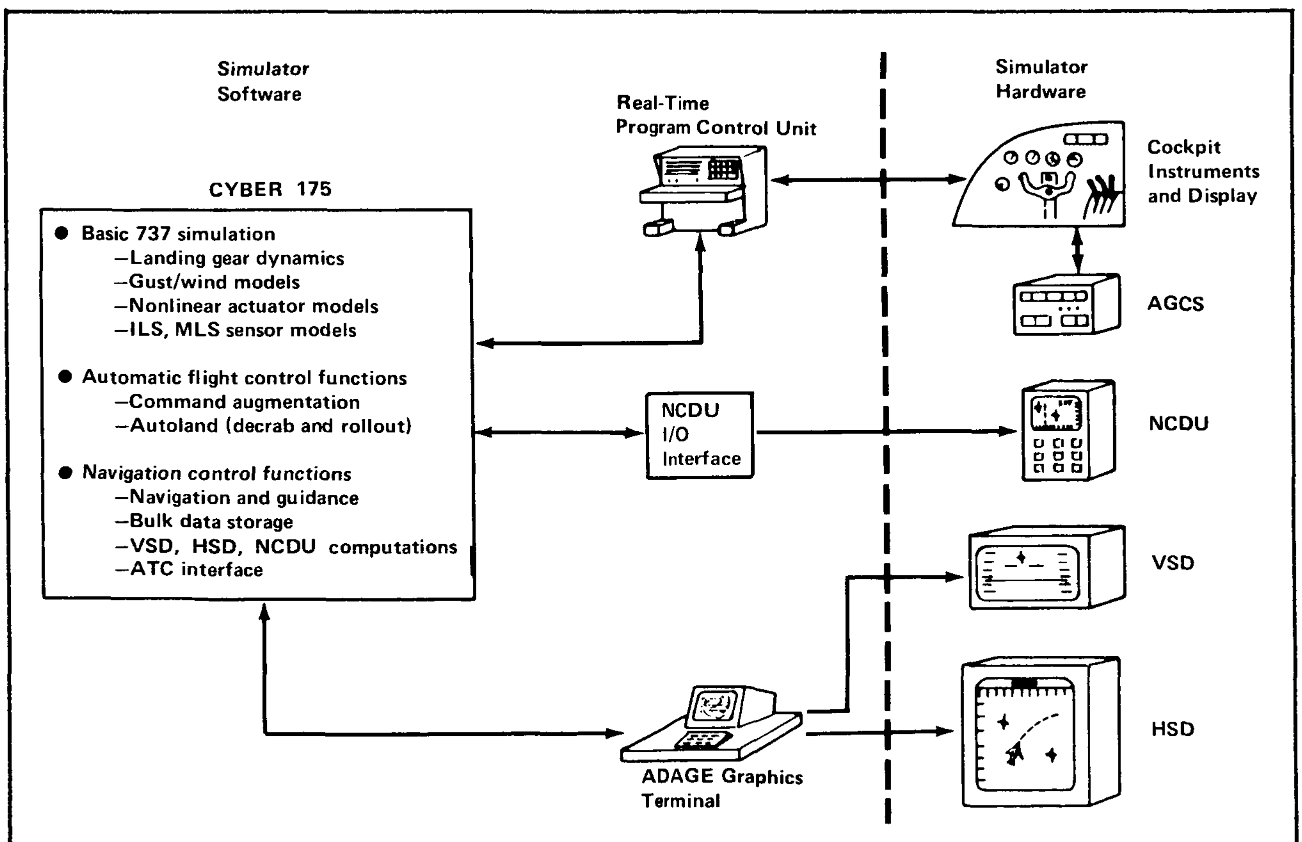


Figure 38.- Fixed-base simulator system facility.

BANKTRN

The BANKTRN simulation provides a tool to evaluate the MLS navigation and automatic control modes of the TCV B-737 experimental systems. The guidance and control modes included are 3-D RNAV (vertical path and horizontal path), airspeed hold, autoland, roll-out, and turnoff. The MLS navigation that has been implemented consists of second-order digital prefilters to smooth the MLS signals and third-order complementary filters. This program contains the systems used in flight demonstrations with the TCV B-737 of the time-reference scanning beam (TRSB) MLS.

ALERT

The ALERT simulation is generally the same as BANKTRN except for navigation. The ALERT simulation contains a Kalman filter with time-varying gains for navigation.

FILCOMP

The FILCOMP simulation was developed to evaluate transition into MLS from VORTAC navigation and to evaluate the Kalman filter versus the discrete third-order complementary filter for flight to touchdown.

FILCOMP has two basic differences from the BANKTRN and ALERT simulations. First, the program provides for RNAV path definition through waypoint specification in a name-list input. Second, the inertial coordinate frame is Earth centered and the dynamics are for a rotating circular Earth.

WIND DISTURBANCES FOR SIMULATIONS

Wind modeling includes steady shear and gust winds. Wind shear is approximated by linear wind variations and is treated as a perturbation from the steady-state wind.

Wind components of gusts are generated according to the Dryden spectra. They enter the equations of motion as perturbations to the airspeed components and angular rate perturbations.

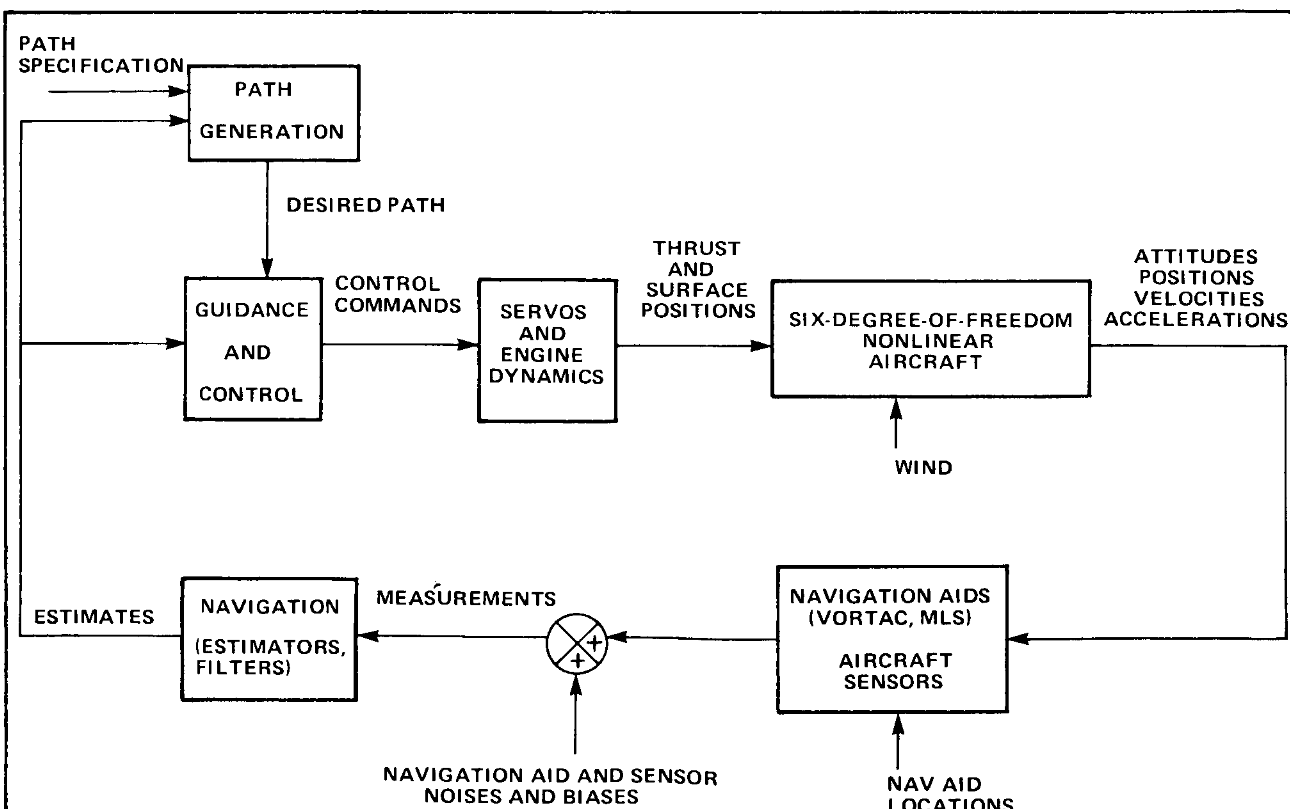


Figure 39.- Block diagram of navigation, guidance, and control FORTRAN simulations.

TABLE III.- COMPARISON OF BASIC ELEMENTS OF SIMULATIONS

Program	Aircraft EOM	Guidance and control modes	Navigation filters	Navigation aids	RNAV path specification
BANKTRN	Six-degree-of-freedom nonlinear, flat Earth runway inertial coordinate frame	3-D RNAV, autoland (including decrab and flare), roll-out, turn-off, autothrottle (airspeed hold)	Prefilters, third-order complementary filters	MLS, magnetic cable sensors, radar altimeter	Limited to straight line and circular turn onto final
ALERT	Six-degree-of-freedom nonlinear, flat Earth runway inertial coordinate frame	3-D RNAV, autoland (including decrab and flare), roll-out, turn-off, autothrottle (airspeed hold)	Kalman filter with time-varying gains	MLS, magnetic cable sensors, radar altimeter	Limited to straight line and circular turn onto final
FILCOMP	Six-degree-of-freedom nonlinear, rotating circular Earth, Earth centered inertial coordinate frame	3-D RNAV, autoland (including decrab and flare), autothrottle	Discrete third-order complementary filter and Kalman time-varying filter	MLS, VORTAC radar altimeter, barometric altimeter	Path specified by waypoints (dimensioning set for 10 waypoints)

SENSOR ERRORS FOR SIMULATIONS

The MLS errors are modeled as a bias plus first-order exponentially correlated noise.

The attitude, attitude rates, radar altimeter, VORTAC, barometric altimeter, and specific-force measurement errors are modeled as a bias plus white noise. Misalignment of the accelerometer package, as well as scale-factor errors on the accelerometers, is also modeled.

Airspeed error is modeled as a multiplicative noise.

All of the sensor errors can be varied by means of input data.

EXPERIMENTAL AVIONICS SYSTEM INTEGRATION LABORATORY

The experimental avionics systems integration laboratory (EASILY) is a special-purpose test facility utilized for the development and integration of the advanced TCV experimental flight avionics hardware and software systems (fig. 40). The EASILY was established in 1976 prior to the MLS demonstration flights, recognizing that the sophisticated TCV avionics required a higher level of integrated tests than had been previously provided. EASILY tests, which are in essence a ground-based extension of flight tests, integrate actual flight hardware and software with a mathematical simulation of the TCV aircraft in real time. Prototype flight profiles through touchdown and turnoff are debugged and verified, thereby authenticating the hardware integrity and hardware/software compatibility of the flight systems.

A resident Digital Equipment Corporation PDP11/55 digital computer is used to model the TCV aircraft. The six-degree-of-freedom simulation iterates its mathematical solution every 40 msec to 12-place accuracy. The computer's digital output channels provide simulated air data, inertial and body referenced attitudes and rates, flight-path accelerations, and terminal guidance parameters to dedicated signal conditioning equipment (SCE). The SCE reformats the computer digital signals to make them compatible with the experimental flight systems.

Real-time analysis of the aircraft system performance during the simulated flights is provided by six multichannel strip-chart recorders and two cathode ray tube (CRT) repeater displays of the aircraft's ground track and flight attitude. The CRT's are laboratory counterparts of the pilots' flight displays and are used by the laboratory engineers during simulation runs in a manner analogous to the research pilots' use of the flight displays. The strip-chart recorders provide 78 data channels for quick-look analysis. Real-time CRT display of 20 variables in predetermined engineering units augments the permanent strip-chart records. Two nine-track digital tape recorders are used to record system variables for off-line analysis.

A remotely located Langley Research Center central computer complex (Analysis and Computation Division) provides an equivalent digital simulation capability to augment PDP11/55 systems. Duplicate analog sensor and command signals are transmitted between the sites over buried telephone lines. A master control switch in EASILY selects either the remote or PDP11/55 simulation. The EASILY equipment dedicated to the backup mode is controlled through the master control switch.

VERIFICATION AND VALIDATION LABORATORY

A software verification and validation (V & V) laboratory has also been provided, in which a General Electric MCP 703 computer is used. The configuration of this laboratory is shown in figure 41. An aircraft simulation of the TCV B-737 is programmed on the CYBER 175 digital computer. An interface box is connected between the General Electric control computer and the CYBER 175. This allows the proper digital-to-digital (D/D) conversions, as well as providing the mechanism for the closed-loop simulation. As a means of interfacing directly with and loading the control computer, a typewriter and cassette tape capability has been provided.

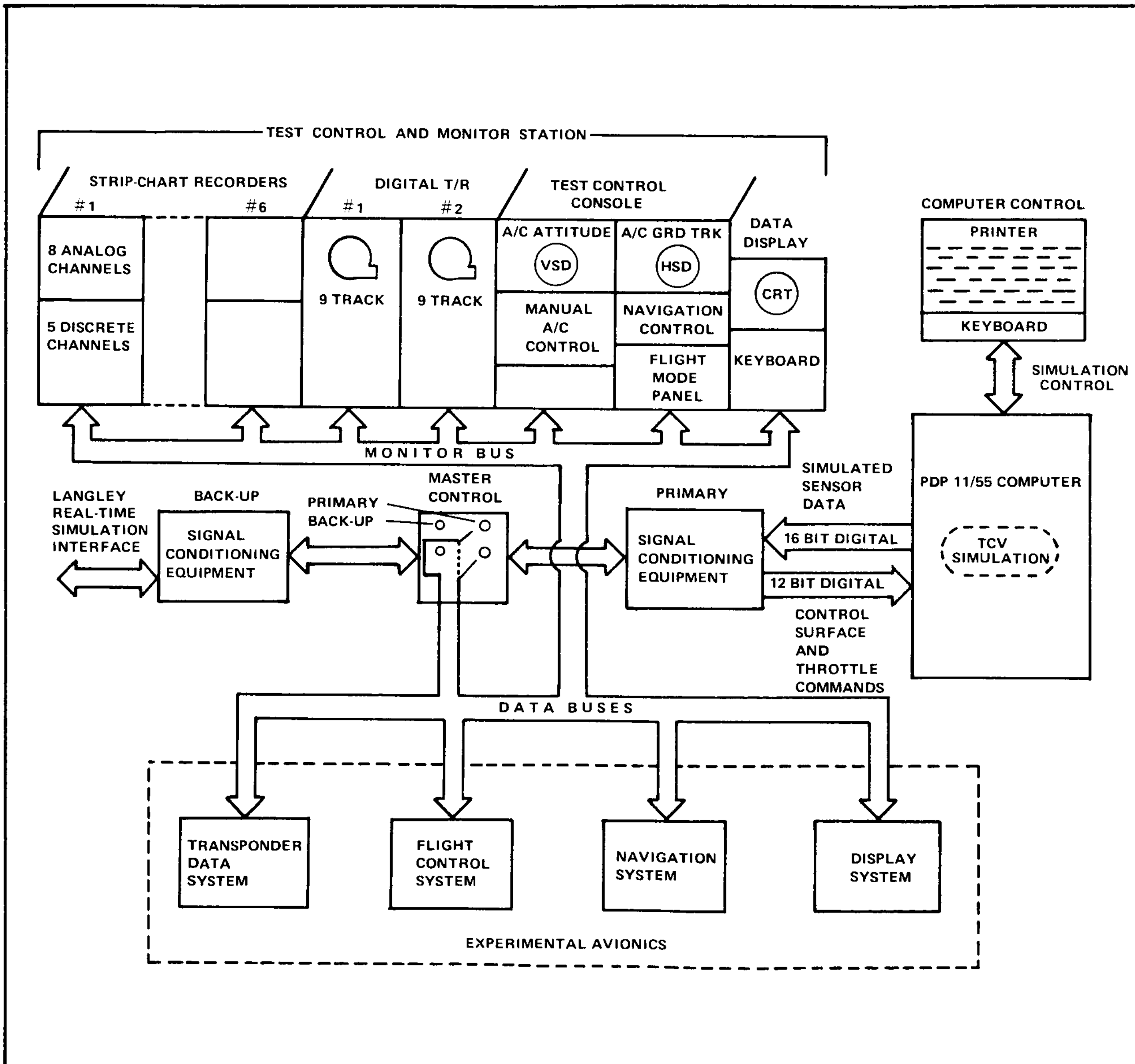


Figure 40.- Block diagram of experimental avionics systems integration laboratory (EASILY).

Other verification and validation tools that are available include interpretive computer simulations (ICS) for both the General Electric control computer and the Litton C-4000. An ICS interprets machine-level code, simulates input/output functions, is controlled by code being interpreted, and contains diagnostic aids (overflow detection, timing, trace, etc.). This support software tool can be run with or without an aircraft simulation.

The ICS's and the General Electric control computer in the V & V laboratory enable new software to be checked and assured ready for flight without impact to the available TCV B-737 flight time. These tools all provide an advanced state-of-the-art mechanism both for use in the development and for visibility in the software aboard the TCV B-737.

In addition to these tools, a Langley Research Center program for multiuser-oriented software technology (MUST) is providing the following specific support software tools:

- Software configuration control management.
- PLAP: Documentation maintenance is provided in machine-readable form for easy modification and update. Enhancements include automatic paging and any-width printing.
- Meta assemblers: Assemblers may be generated for any computer an experimenter may wish to use.

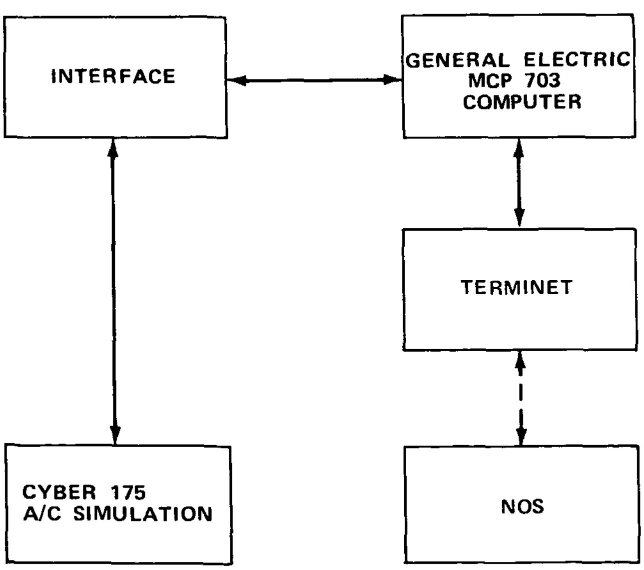


Figure 41.- Verification and validation laboratory activities.

- Assembler: This data formatter display symbol assembler supports both the Litton C-4000 and the General Electric control computer.
- Automatic flowcharter: This flowcharter utilizes HAL/S and PASCAL programs.
- Flight-controls library: This software tool is resident in the General Electric control computer assembly code.

RADIO FREQUENCY ANECHOIC FACILITY

The radio frequency anechoic test chamber (fig. 42) provides simulated free-space conditions in which antenna designs and locations may be optimized using scale-model aircraft. Complete spherical radiation characteristics of antennas can be measured automatically using digital techniques and magnetic tapes for data storage. The measured data stored on tape can then be processed by using available computer programs to provide antenna directivity, polar plots of the radiation patterns, and contour plots of the radiation density.

OCULOMETER

The oculometer is a nonintrusive system for measuring the pilot's eye look point. It has two primary subsystems: the electro-optical head and the signal processing unit. The electro-optical system generates a collimated beam of infrared-sensitive light which is directed through a beam-splitting mirror toward the subject's eye. The only thing seen by the pilot is a dull red light. Reflections from the eye are directed by the beam splitter to an infrared-sensitive TV camera. The high infrared reflectivity of the human retina leads to a backlighting of the pupil so that the camera sees the pupil as a bright, circular area. It also sees a small bright spot due to reflection at the corneal surface. The relative positions of the center of the pupil and the corneal reflections depend on the angle of rotation of the eyeball with respect to the infrared beam. The signal processing unit uses the TV signal to compute this angle of rotation and the coordinates of the look point on, for instance, an instrument panel. Figure 43 presents a pilot's eye track superimposed on an instrument panel.

The range in which the look point can be determined is ±30 deg horizontal and -10 to 30 deg

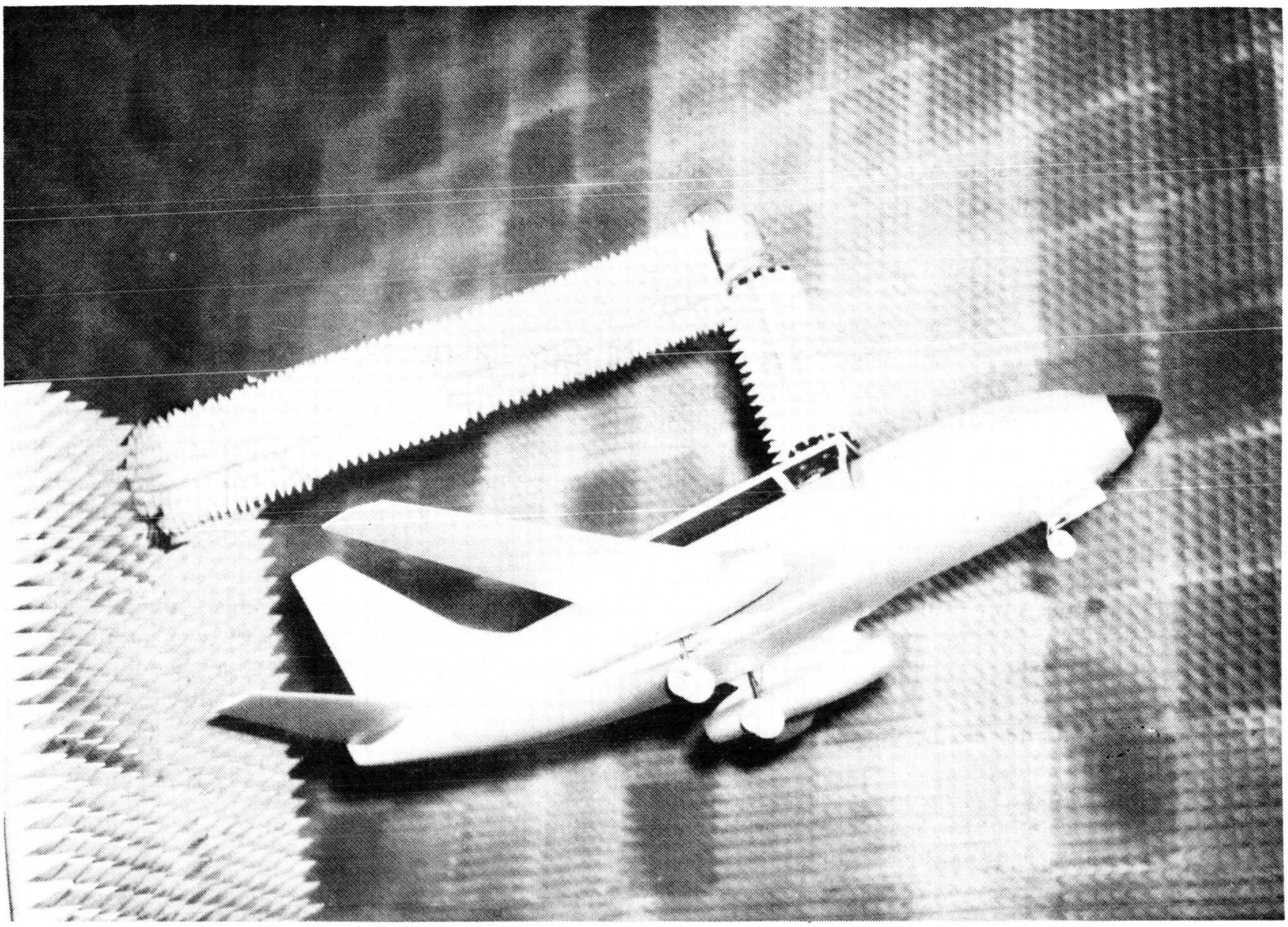


Figure 42.- Radio frequency anechoic facility.

vertical with respect to the infrared beam. A set of moving mirrors and a focus system are used to track the location of the subject's eye, thereby providing capability to track the subject's eye (or head) motion as it moves about anywhere within a cubic foot volume. Figure 44 shows the system installed in the simulator for studies of the pilot's use of the information on both the vertical and horizontal situation displays during curved approaches with adjacent traffic displayed. The electro-optical head is positioned so that both displays are within the viewing envelope. The system can also be installed in the airplane for verification of simulation studies.

The oculometer output overlaid on a TV picture of the scene of interest can provide, in real time, the pilot look point for use by observers. In addition, the system outputs are easily recorded for further analysis. Thus, eye look point information can be time-correlated with aircraft state conditions, control inputs, crew interactions, etc., for flight management studies on new flight systems and displays proposed in the TCV program.

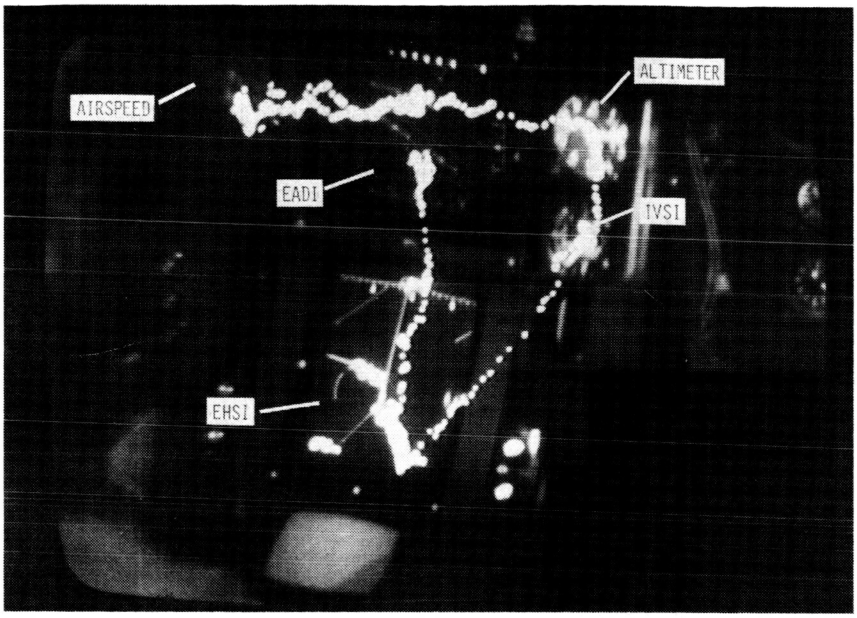


Figure 43.- Pilot's eye track superimposed on instrument panel.

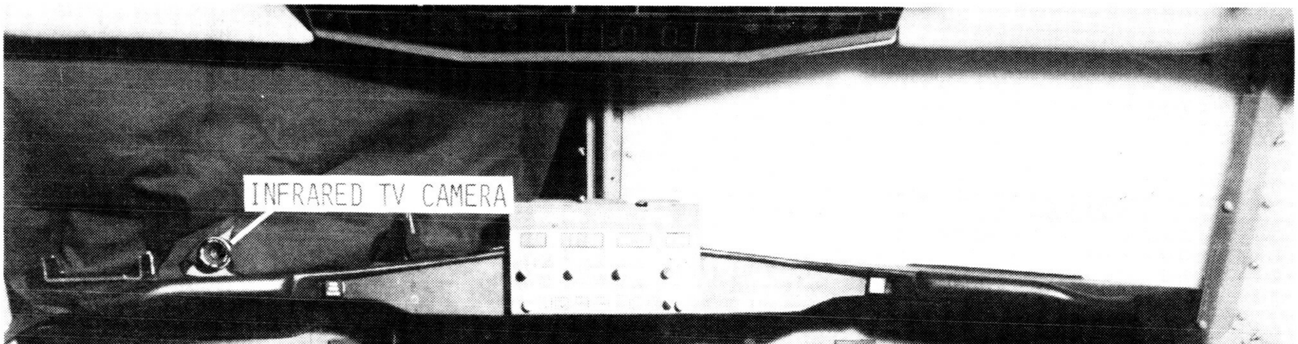


Figure 44.- Oculometer system installation in the TCV simulator.

WALLOPS FLIGHT CENTER

WALLOPS FLIGHT CENTER AIRPORT

The NASA Wallops Flight Center (WFC) operates an airport primarily to support aeronautical research and development in those areas dealing with flight characteristics and performance and related aircraft systems. The airport has all essential equipment found at both civilian and military airports. In addition, the airport has experimental facilities, including a grooved runway, a wind data system, a project control center, a telemetry and tracking system complex, and a flight display facility.

The telemetry and tracking system complex, with its integrated flight display facility, is called the aeronautical research radar complex (ARRC). The ARRC is shown in figure 45 near the intersection of runways 17/35 and 10/28. The air traffic operations tower with its project control center is also shown in figure 45. A large parking lot is located adjacent to the ARRC building which is capable of supporting up to eight instrument vans with individual 208/110 VAC power outlets. The flight display research system (FDRS) trailer uses one of the slots.

Additional tracking-system support can be provided with mobile units such as the MPS-19 (S-band) and Ka-band radars.

The project control center (PCC) can provide radar and telemetry readouts, air-to-ground communications, various television displays, and meteorological data.

The three concrete and asphalt runways have the following dimensions:

Runway	Dimension
10/28	8000 ft by 200 ft
04/22	8750 ft by 150 ft
17/35	4820 ft by 150 ft

The center 3850 ft of runway 04/22 contains grooved sections plus other sections with different

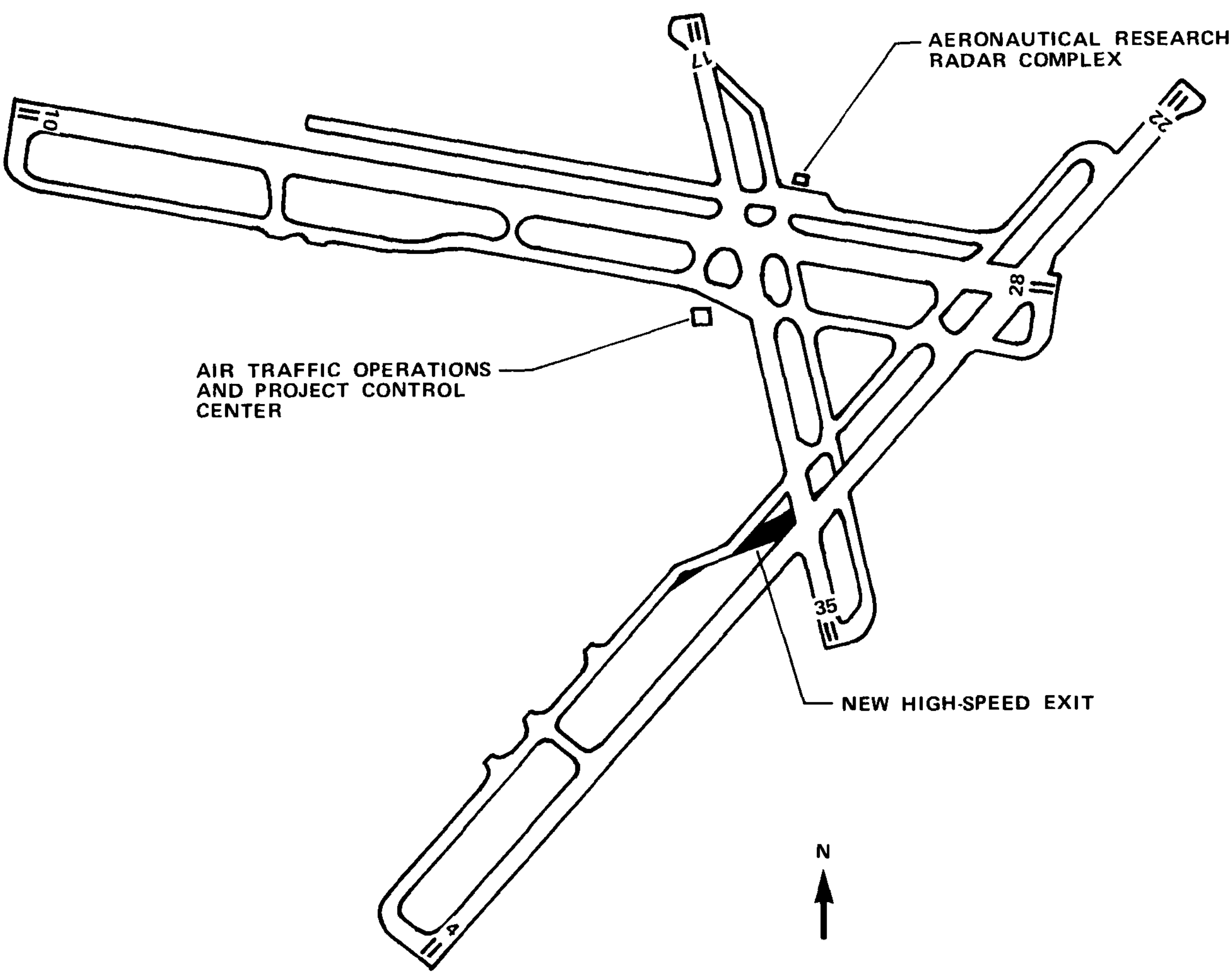


Figure 45.- Wallops Flight Center (WFC) runway layout.

finishes and compositions. The test area is smooth and flat, and the remainder of the runway is crowned with the standard 1-percent slope.

Runway 28 has a camera pit at the 1000-ft marker. A television or film camera can be used there, aligned with a 3-degree glide slope, to provide aircraft path- and attitude-deviation information throughout the final approach up to the flare maneuver.

A high-speed runway exit for research studies is being constructed off runway 22 and is scheduled to be operational by spring 1980.

PROJECT CONTROL CENTER

A project control center (PCC) is located on the third floor of the air traffic operations tower. The PCC has large observation windows that permit a clear view of all three runways to an experimenter and a WFC flight coordinator stationed there. (See fig. 46.) The PCC is used to monitor and control experiments using the airport. Real-time displays and recordings available in the PCC include the following items (fig. 47 illustrates the flow of information):

- Plotboards showing the flight track derived from the radar/laser systems
- Television display of the scene derived from the FPS-16 radar boresight camera
- Plan position indicator display derived from the ASR-7 weather radar
- ILS data indicators (localizer and glide slope) derived from the FPS-16 or Ka-band radars
- Meteorological data displays and recordings derived from a mobile wind data system and sensors mounted on top of the operations tower
- Time-of-day display and recording
- Television display of the pictures being transmitted from the FDRS to the aircraft

Figure 46.- Wallops air traffic operations tower with project control center.

- Television display from the runway projects (camera pit in runway 28)
- Radar/laser derived printouts and recordings

Communications available in the PCC include the following:

- Air to ground
- Intercom to all major facilities at WFC
- Radio communications to mobile support units
- WFC standard paging system
- Regular telephone system

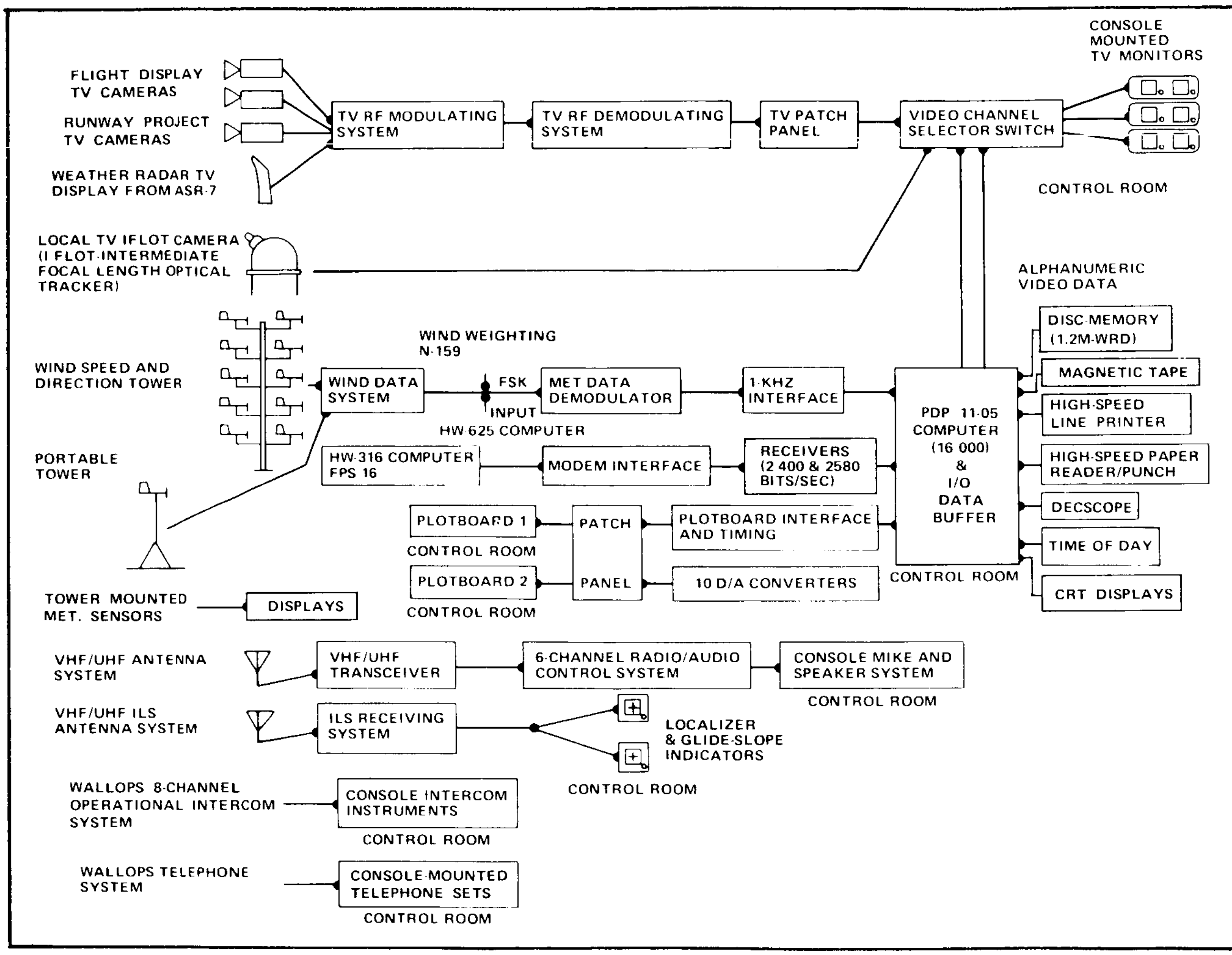


Figure 47.- Project control center system.

WALLOPS AERONAUTICAL RESEARCH RADAR COMPLEX/AIRCRAFT/LANGLEY INTERFACE

The interaction of all subsystems that make up the ARRC facility and how they interface with the research aircraft and Langley is shown in figure 48. The FPS-16 C-band radar is the primary tracking system at ranges in excess of 6 to 10 miles. The laser normally provides slant range data within the 6- to 10-mile range, and angle information is derived from the FPS-16 mount sensors. Some experimenters in the future may desire the use of the Ka-band radar for final approach experiments because it has a very narrow beam width, making it less susceptible to multipath than the FPS-16 in the skin-track mode. The mobile radars that can be reactivated are the GSN-5 and MPS-19 (S-band) radars. The Langley/WFC line is a two-way datalink that operates by Langley initiating a message and then Wallops' computers responding.

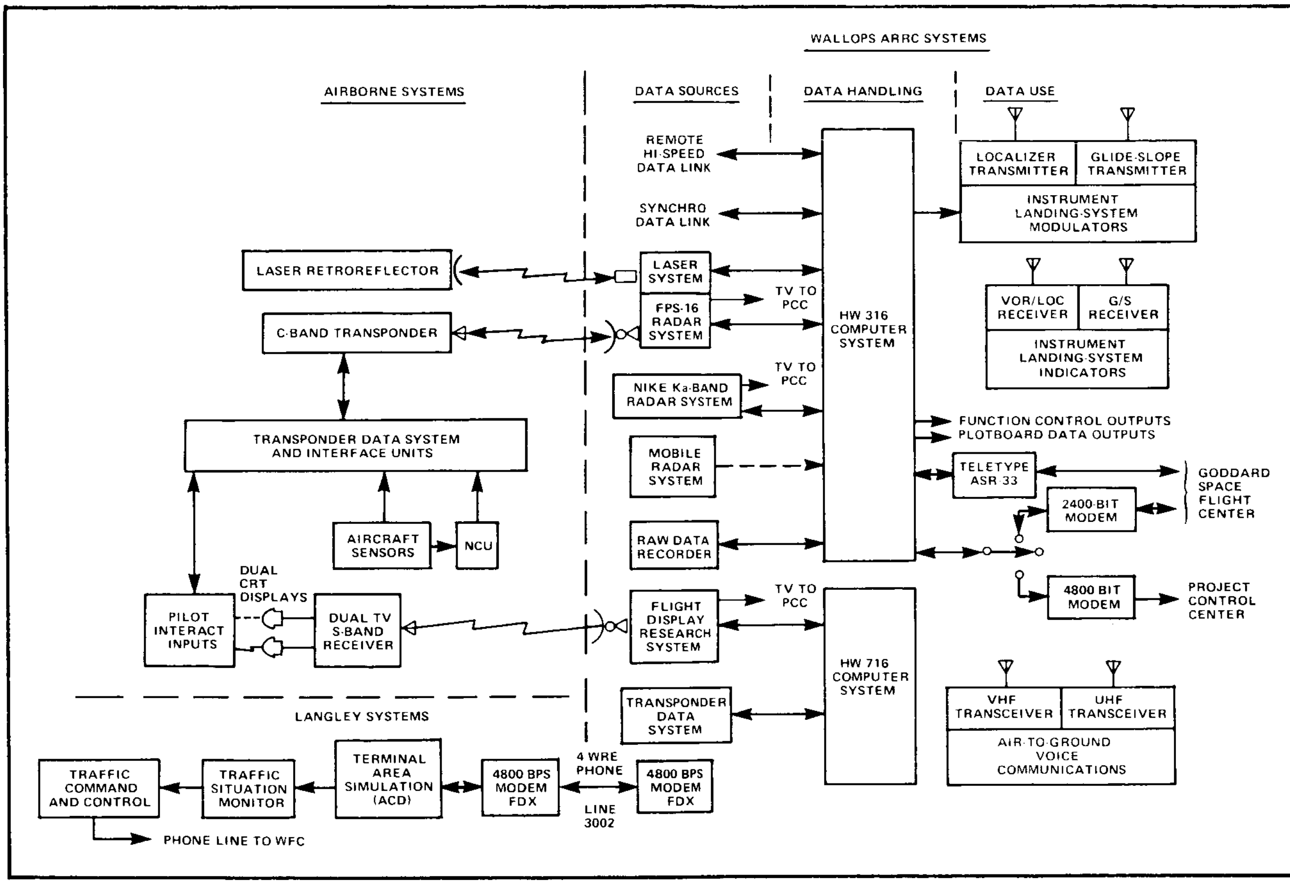


Figure 48.- Aeronautical research radar complex (ARRC)/aircraft/Langley interface.

FLIGHT DISPLAY RESEARCH SYSTEM

The flight display research system (FDRS) uses a ground-based interactive graphics terminal in conjunction with televised displays as shown in figure 49. The equipment is contained in a mobile equipment van adjacent to the FPS-16 building, A-41. Experimental flight displays are generated by using a programmable interactive graphics display terminal. The displays are driven by position and velocity data derived from the tracking radar, by inertial and air-mass-referenced data derived from the research aircraft (the data are telemetered via the transponder data system), and by TAATM simulation data via the LRC/WFC tie line. The generated displays are converted into a television format and transmitted via an S-band television link to the aircraft where they are displayed on high-resolution television monitors. The ground S-band antenna is mounted with the radar antenna on the FPS-16 pedestal.

The FDRS utilizes an ADAGE interactive graphics display system which provides the capability for the researcher to create a wide variety of complex cockpit displays using high-level FORTRAN language. It also provides basic compatibility with software developed for the ADAGE graphics computer of the TCV fixed-base simulator.

The interactive graphics display controls television imaging devices (such as static and dynamic background image files) and creates graphic images which are scan converted. A hybrid interface and patching subsystem integrates analog and discrete signals and direct high-speed data paths for digital signals. Once the images are in a television format, they can be processed and mixed using studio television equipment to enhance the basic display generation capability of the graphics display system, thereby achieving an advanced color/monochrome, stroke/rastergraphic display capability.

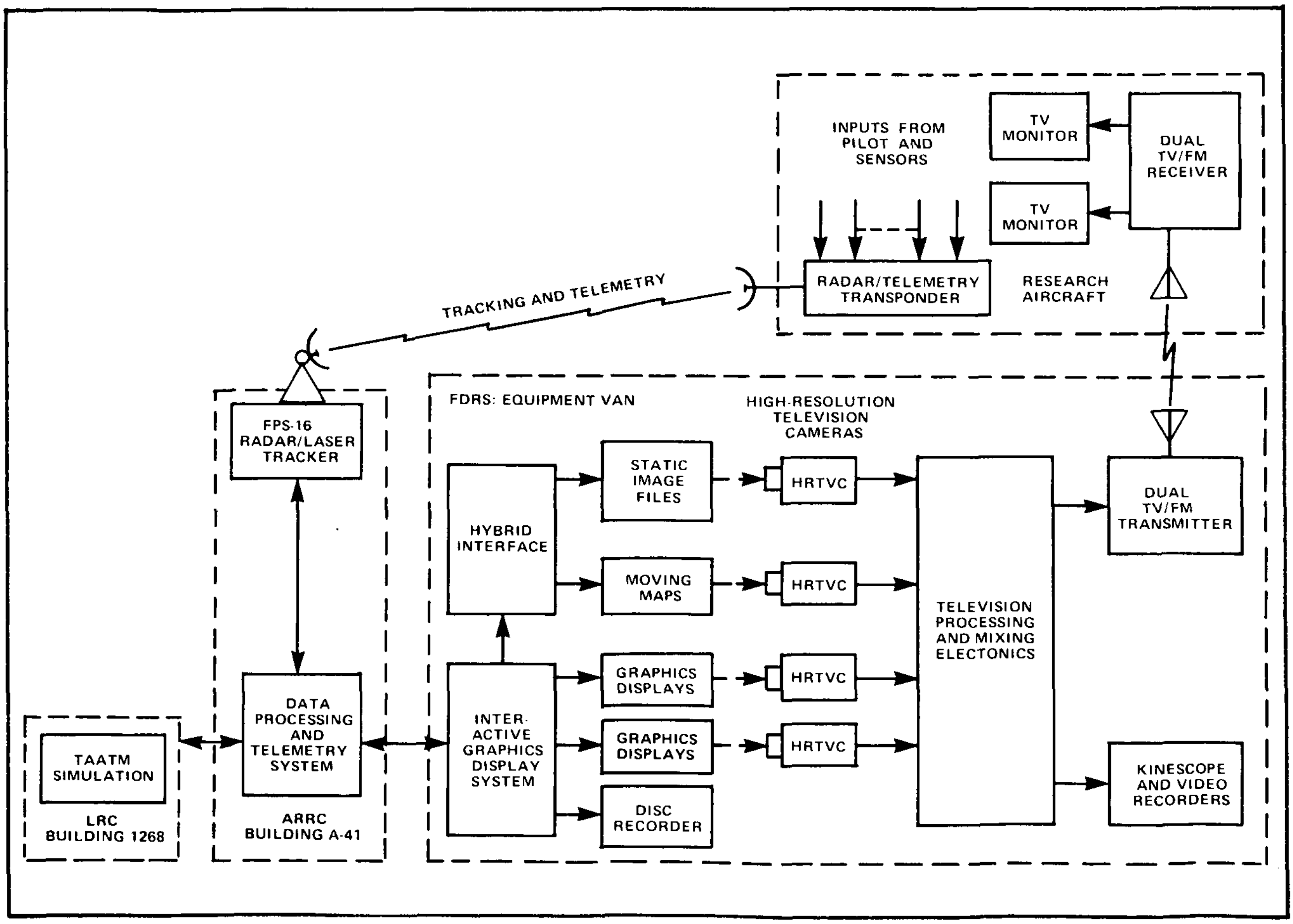


Figure 49.- Flight display research system (FDRS).

LASER/FPS-16 RADAR

The laser is co-located with the FPS-16 radar antenna on a common mount. The radar and laser are capable of simultaneously tracking the same target. Each system will develop its own range information. The angle data are derived from sensors on the mount. Each system can develop angle error signals to control rotation of the mount. The radar operator can switch mount rotation control to either system or he can allow the system to automatically switch control, with the laser signal being the master whenever the laser signal is of sufficient amplitude. Range data from both systems as well as angle data are recorded. The aircraft is normally equipped with a transponder/antenna and laser reflector to establish a central tracking point for the radar and laser, respectively. The transponder also provides longer range capability for the radar and allows a telemetry signal capability to be incorporated with the standard radar track ability. The laser provides greater range measurement accuracy (0.6 ft) at the close-in ranges and provides accurate tracking at lower elevation angles than the radar. Figure 50 graphically illustrates how the laser and FPS-16 complement each other. Some of the important performance characteristics of the laser and radar are listed in table IV.

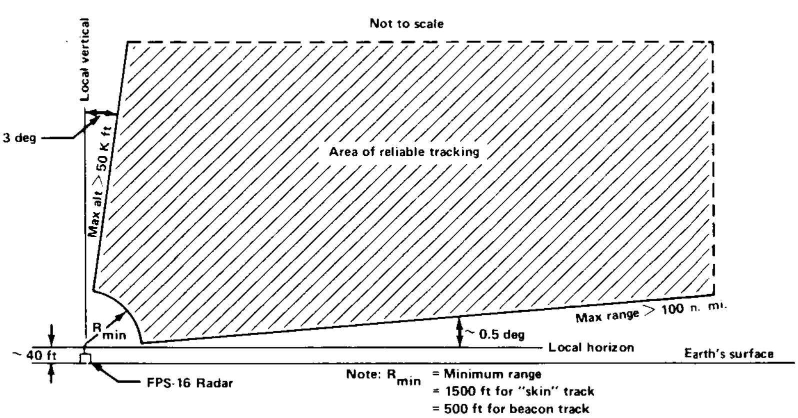


Figure 50.- Coverage of FPS-16 radar and laser tracker.

TABLE IV. - PERFORMANCE CHARACTERISTICS OF WALLOPS LASER TRACKER AND FPS-16 RADAR

[System azimuth and elevation angle error through the mount: 0.1 mil, 1 σ, random
Mount azimuth rotation: Continuous; 800 mil/sec maximum
Mount elevation rotation: -10° to $+90^{\circ}$, 450 mil/sec, maximum]

Characteristic	Laser	FPS-16 radar
Pulse repetition rate	---	160, 640, 1024 pps
Pulse width	---	0.25, 0.5, and 1.0 μsec
Measurement interval	350 to 60 000 ft	500 ft to 32 000 n. mi. (beacon track)
Range resolution	0.5 ft	2 yd/bit
Velocity tracking capability	10 000 ft/sec (maximum)	60 000 ft/sec
Acceleration tracking capability	2 500 ft/sec/sec (maximum)	60 000 ft/sec
Slew rate	10 000 ft/sec (maximum)	720 000 ft/sec (maximum)
Beam width	2 mrad (approximately)	0.71°
Measurement accuracy	0.6-ft rms for ranges of 350 ft to 10 000 ft 0.003 percent of range rms for ranges from 10 000 to 60 000 ft	15 ft, random error (maximum)

TRANSPONDER DATA SYSTEM

The transponder data system (TDS) is a two-way, air-to-ground telemetry link superimposed on the C-band radar signals. The FPS-16 radar is the common ground-based transmitter/receiver terminal, and the transponder is the common aircraft transmitter/receiver unit as illustrated in figure 51.

The TDS ground equipment adds three pulses prior to each transmitted radar pulse. Each added pulse is positioned in time with respect to the range pulse to form a pulse position modulation (PPM) code. The transponder receives the signals and passes the signal to the TDS airborne system where the signal is decoded and processed. The range pulse (fourth pulse in the train of four pulses) is delayed 5 μsec and then retransmitted to the ground. Three pulses are added to the downlink range pulse, again to form a PPM telemetry code. The FPS-16 radar receives these signals, processes the first pulse as a normal range pulse, and passes the video train to the TDS ground units for decoding and processing.

Figure 52 presents a summary of some of the important TDS characteristics that are not shown in figure 51. A discrete channel essentially provides an on-off function or status. A proportional channel contains quantitative data such as position, heading, and altitude. The encoders, airborne and ground, can accept either analog or digital inputs. Due to the unique coding technique used for discrete channel information, four discrete channels must be grouped together per PRF, but only one proportional channel can be transmitted per PRF. Error detection codes are included in each frame of data. The operators can select the security mode desired for the TDS processing equipment.

- **Maximum security** – data will not be accepted if any error occurs within a frame
- **Normal security** –

  Accept: accept all data words regardless of error

  Reject: reject data words containing errors

  (discrete and proportional channels have separate normal modes)
- **Minimum security** – accept all data words regardless of errors

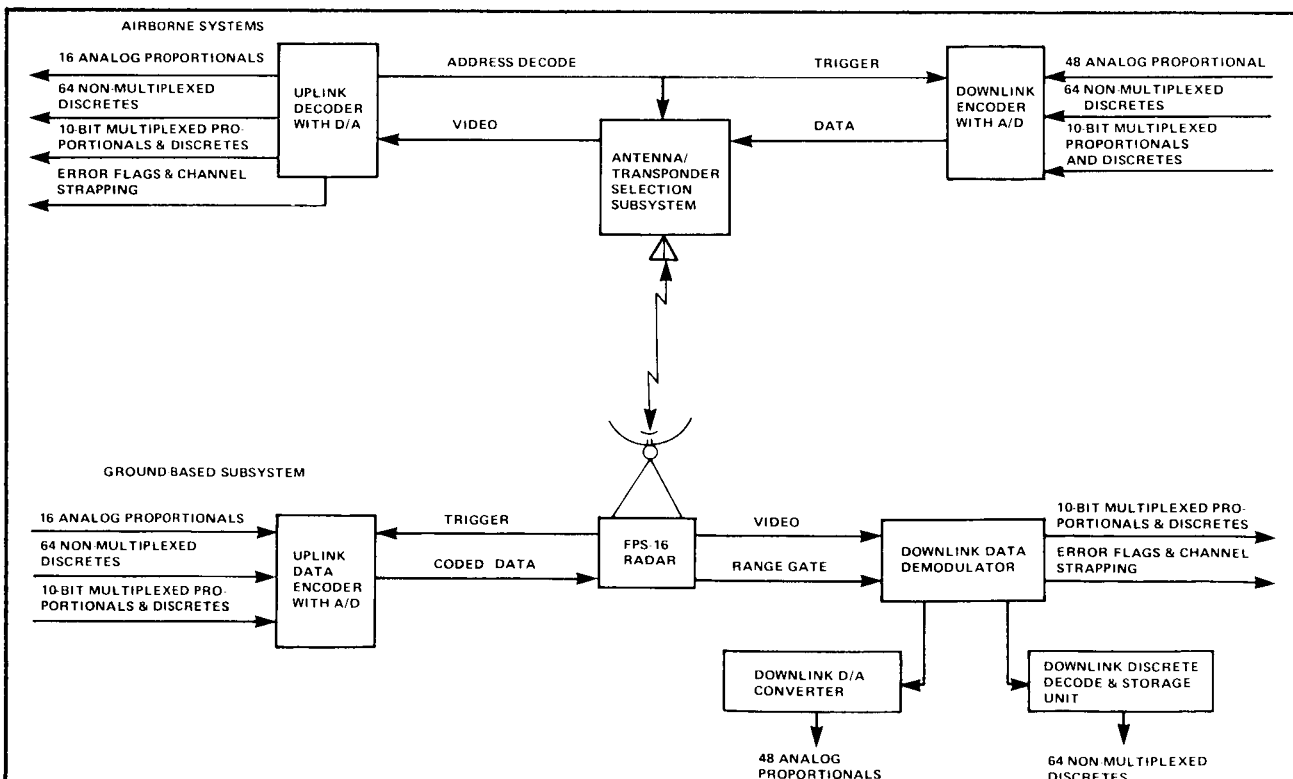


Figure 51.- Transponder data system (TDS).

Transponder Data System
Characteristics Summary

Modulation technique:	Digital PPM coding interspersed between radar/ transponder range pulses	
Telemetry link data rates:	1.9 kilobit at 160 PRF 7.7 kilobit at 640 PRF 12.3 kilobit at 1024 PRF	
Type of data transmitted:	Proportional or discrete channels	
	Analog I/0	Digital I/0
Accuracy:	0.5% of full scale	0.3% of full scale
Resolution:	0.1% of full scale	0.1% of full scale

Special features:

a) Proportional channel strapping for increased sampling rate (2 to 8 channels/strapped channel)
b) Proportional channel pairing for increased accuracy (16 to 20 bits)
c) Higher update rates for selected discretes

Figure 52.- Transponder data system characteristics summary.

MICROWAVE LANDING SYSTEM (MLS) SIMULATION

A model of the microwave landing system has been developed to aid in studying efficient ways of utilizing the system. The MLS simulation is implemented and used at Wallops. The aircraft is tracked by radar and laser. Tracking data are computer processed, and position and/or track error data transmitted to the aircraft. Noise or error characteristics may be generated within the ground computer, and the resulting aircraft performance observed. Aircraft control laws and data-processing techniques can then be developed to minimize disturbances.

Data are transmitted to and from the airplane via coded radar pulses on the transponder data system (TDS). Figure 53 illustrates the coordinate transformation from the radar-laser system to that required in the MLS simulation. The resulting simulated MLS angle and range data are then transmitted to the aircraft using the transponder data system.

The MLS simulation can be used with any Wallops runway, and the MLS antenna locations varied. The coverage may be varied ±90° in azimuth and 0° to 90° in elevation. Different update rates (5, 10, 20 Hz) and DME ranges may also be selected (15, 30 n. mi.).

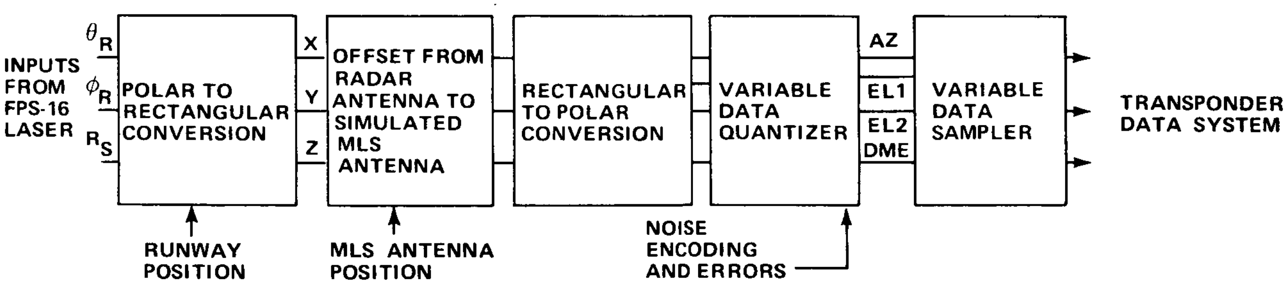


Figure 53.- Microwave landing system simulation.

TRSB MLS INSTALLATION AT WALLOPS

A TRSB MLS is being installed on runway 22 at Wallops and is scheduled to be operational by spring 1980. This MLS is preproduction hardware of the Bendix Basic Wide System which has the following coverage characteristics:

Azimuth:	$\pm 60^\circ$
Elevation:	1.52° to 20°
Range:	0 to 20 n. mi.

The MLS antennas will be located as shown in figure 54.

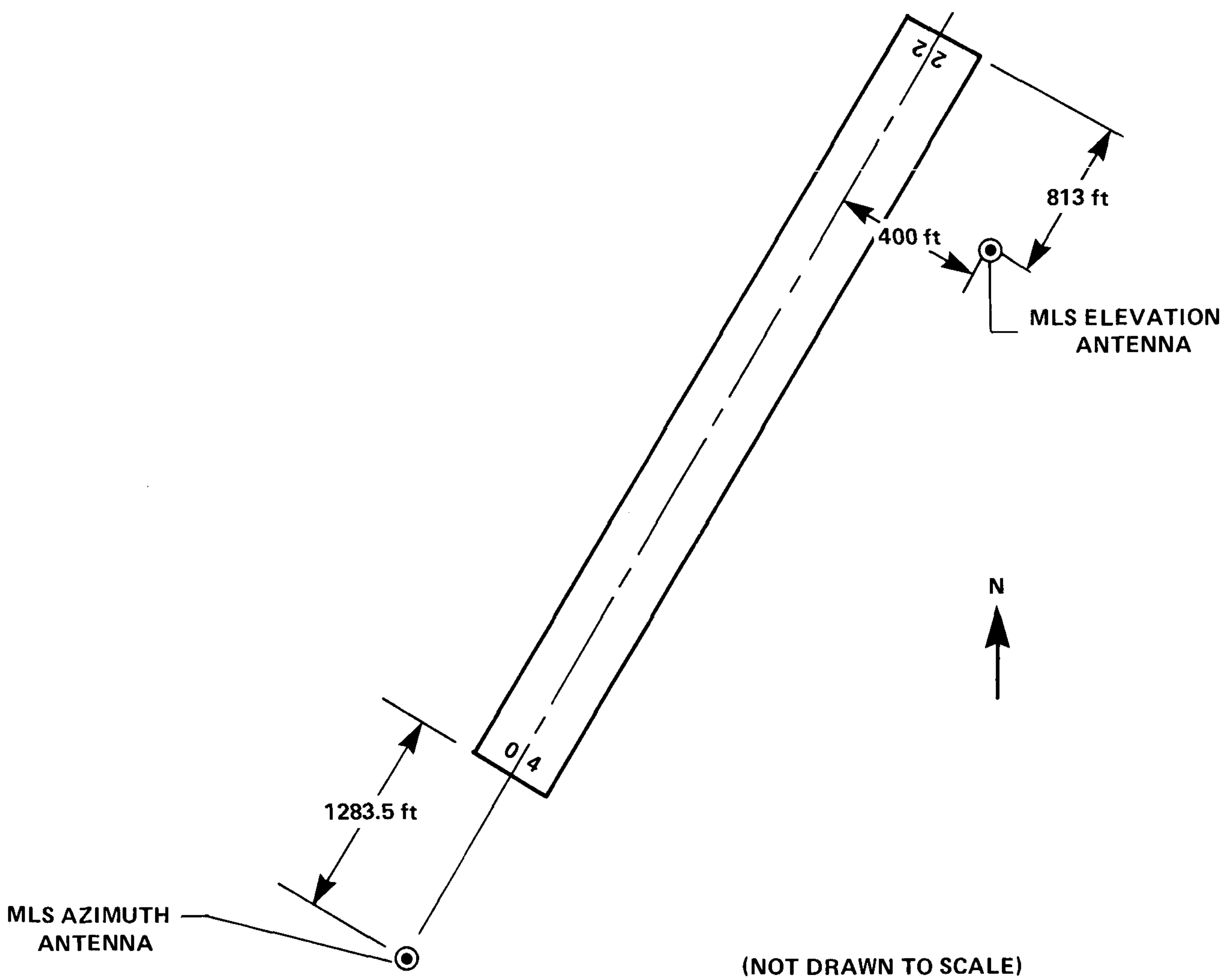


Figure 54.- TRSB MLS installation at Wallops Flight Center.

NOISE RANGE

The photographs in figure 55 depict the essential facilities which provide the NASA capability to conduct flyover noise research. They focus upon the major components of the flyover acoustic range at Wallops Flight Center. Though the range is at Wallops where the flight operations are routinely conducted, the range is staffed and operated by Langley Research Center.

Flyover noise measurements are a necessary and invaluable tool, not only for actual evaluation of noise-reduction techniques through flight hardware changes and flight operations procedures, but also for study of the propagation effects of a moving, complex noise source through a variable atmosphere. A detailed analysis of this latter problem is basic to the validation of airport community noise-prediction computations.

Accurate and repeatable flyover noise measurements require high-quality acoustic instrumentation, detailed measurements of the low-level atmospheric structure, accurate tracking of airplane position and velocity over the acoustic range, low ambient noise, and controlled airspace so that ground-recorded signals are clear of interference from either intruding aircraft or ground traffic. All of these systems must be tied to a common time base, and all must be closely coordinated during the flyover.

Figure 55.- Flyover noise research.

LANGLEY-WALLOPS OPERATIONS

Facilities at Langley and Wallops are interconnected through a data link as shown schematically in figure 56. This data link permits the terminal area ATC simulation at Langley and at NAFEC (National Aviation Facilities Experimental Center) to drive the flight display research system in the generation of experimental traffic situation displays. The aircraft under test can therefore be flown under controlled conditions in a representative air traffic environment. The system will be used to study total aircraft/ATC system performance and interactions.

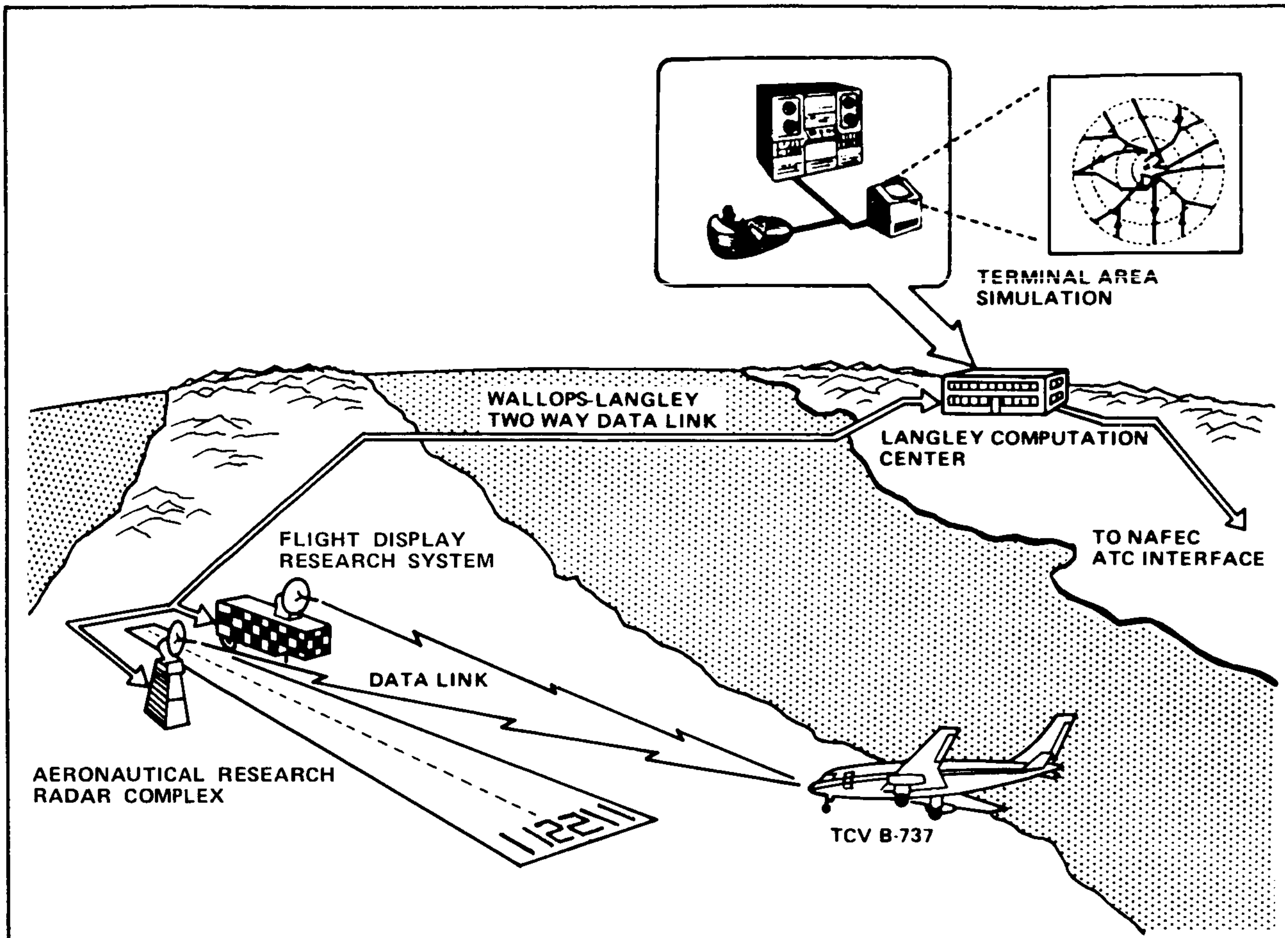


Figure 56.- Wallops-Langley aircraft flight research facility.

APPENDIX A - CONVERSION TABLE

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

To convert from	to	multiply by
temperature ^{o}F	temperature ^{o}C	$T_{oC} = (T_{oF} - 32)/1.8$
foot	centimeter	3.048×10^{1}
feet per second	centimeter per second	3.048×10^{1}
feet per second squared	centimeter per second squared	3.048×10^{1}
gallon	liter	3.785
inch	centimeter	2.54
inch per second	centimeter per second	2.54
knot	kilometer per hour	1.85
nautical mile	kilometer	1.85
nautical mile per inch	kilometer per centimeter	7.3×10^{-1}
pound	kilogram	4.535×10^{-1}
pound per square inch	gram per centimeter squared	7.031×10^{1}

APPENDIX B - ACRONYMS

ACRONYMS

The following is a list of all acronyms and symbols used in this document.

AC	alternating current
A/C	aircraft
ACD	Analysis and Computation Division
ACT	actuator
A/D	analog to digital
ADEDS	advanced electronic display system
ADF	automatic direction finder
AFCS	automatic flight control system
AFD	aft flight deck
AFDI	aft flight deck interface
AGCS	advanced guidance and control system
ALT	altitude
ALT ENG	altitude engage
APU	auxiliary power unit
ARINC	Aeronautical Radio, Inc.
ARRC	aeronautical research radar complex
A/T	autothrottle
ATC	air traffic control
ATT	attitude
AUTO	automatic
AWO	airplane work orders
az	MLS azimuth signal
BPS	bits per second
BRGW	brake release gross weight
CAPT'S	captain's
CAS ENG	calibrated airspeed engage
CAT	category
CCP	control and command panel
CDC	Control Data Corporation
C.G.	center of gravity
CH	channel
CIU	computer interface units
CMP	control mode panel
COMM/NAV	communication navigation
CRT	cathode ray tube
CSD	constant-speed drive unit
CWS	control wheel steering
DC	direct current
D/A	digital to analog
DAS	data acquisition system
D/D	digital to digital
DH	decision height
DME	distance measuring equipment
DOT	Department of Transportation
DTU	data translation unit
EADI	electronic attitude director indicator
EASILY	experimental avionics systems integration laboratory
EGT	exhaust gas temperature
EHSI	electronic horizontal situation indicator
EL1	MLS elevation signal
EL2	MLS flare antenna signal
ENT	entry
EOM	equation of motion
EPR	engine pressure ratio
ESE	experimental systems equipment
ESWR	experimental system work request
ETA	estimated time of arrival
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FC	flight control
FCC	flight-control computer
FCI	flight-control interface
FCR	firmware change request
FDRS	flight display research system
FDX	full duplex two-way operation
FFD	forward flight deck
FLT DIR	flight director (also F/D)

FLTV	forward looking television
FM	frequency modulation
F/O's	first officer's
FORTRAN	FORmula TRANslator (computer language)
FPA SEL	flight-path-angle select
FSK	frequency shift keying modulation
GEN	generator
GRP	geographical reference points
GS	ground speed
G/S	glide slope
GSE	ground support equipment
h	altitude
HOR PATH	horizontal path
HRTVC	high-resolution television cameras
HSD	horizontal situation display
HSG	hybrid symbol generator
HW	Honeywell
HYD	hydraulic
ICS	interpretive computer simulations
IFLOT	intermediate focal length optical tracker
IFP	intended flight path
ILS	instrument landing system
INBD	inboard
INOP	inoperative
INS	inertial navigation system
I/O	input/output
ISA	international standard atmosphere
IVSI	instantaneous vertical situation indicator
L.E.	leading edge
LGW	landing gross weight
L.H.	left hand
LOC	localizer
LRC	NASA Langley Research Center
M	Mach number
M.A.C.	mean aerodynamic chord
MAG HDG	magnetic heading
MAN	manual
max.	maximum
MET	meteorological
min.	minimum
MLS	microwave landing system
M_{mo}	maximum operating Mach number
MODEM	modulator demodulator
MSG	message
MUST	multiuser-oriented software technology
M_1	indicated Mach number
NAFEC	National Aviation Facilities Experimental Center
NCU	navigation computer unit
NAVAIDS	navigation aids
NCDU	navigation control and display unit
NOS	network operating system for NASA Langley CDC Computer Complex
OAT	outside air temperature
OEW	operating empty weight
OUTBD	outboard
pax	passenger
PADS	piloted aircraft data systems
PCC	project control center
PCM	pulse code modulation
PCU	program control unit, also power control unit
PLATO	programmed learning by automated teaching objectives
PMC	panel-mounted controller
POS TX	position transducer
POTS	potentiometers
PPM	pulse position modulation
PPS	pulses per second
PRF	pulse repetition frequency
rms	root mean square
R/A	radio altimeter
RCVR	receiver
RF	radio frequency

R.H.	right hand
R_{min}	minimum range
RNAV	area navigation
R_S	range from radar site
SAM	sample
SCE	signal conditioning equipment
SCR	software change request
SID	standard instrument departure
S.L.	sea level
SPD ERR	speed error
STAB	stabilizer
STAR	standard terminal arrival route
STBY	standby
STRU	servo transmitter and receiver unit
TAATM	terminal area air traffic model
TACAN	tactical air navigation
TAI	thermal anti-icing system
TAT	total air temperature
TCV	Terminal Configured Vehicle
TDS	transponder data system
T.E.	trailing edge
TNAV	time navigation (4-D)
TKA SEL	track-angle select
TR	transformer/rectifier
T/R	tape recorder
TRSB	time-reference scanning beam
TV	television
UHF	ultrahigh frequency
V	volt
V & V	verification and validation
V_{CAS}	calibrated airspeed
VEL	velocity
VERT PATH	vertical path
VHF	very high frequency
V_{MO}	maximum operating velocity
VNAV	vertical navigation
VOR	VHF omnidirectional range
VSD	vertical situation display
V_{STALL}	stall speed
VORTAC	co-located VOR and TACAN
WFC	NASA Wallops Flight Center
WWCS	whole word computer system
WPT	waypoint
X,Y,Z	ground reference cartesian coordinates
XMTR	transmitter
θ	azimuth from simulated MLS antenna
θ_R	azimuth from radar site
ϕ	elevation from simulated MLS antenna
ϕ_R	elevation from radar site

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