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The NASA Lewis Integrated Propulsion and Flight Control Simulator

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US ARMY
AVIATION
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THE NASA LEWIS INTEGRATED PROPULSION AND FLIGHT CONTROL SIMULATOR

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ABSTRACT

A new flight simulation facility has been developed at the NASA Lewis Research Center in Cleveland, Ohio. The purpose of this flight simulator is to allow integrated propulsion control and flight control algorithm development and evaluation in real time. As a preliminary check of the simulator facility capabilities and the correct integration of its components, the control design and physics models for a Short Take-Off and Vertical Landing fighter aircraft model have been demonstrated, with their associated system integration and architecture, pilot vehicle interfaces, and display symbology. The initial testing and evaluation results show that this fixed based flight simulator can provide real-time feedback and display of both airframe and propulsion variables for validation of integrated flight and propulsion control systems. Additionally, through the use of this flight simulator, various control design methodologies and cockpit mechanizations can be tested and evaluated in a real time environment.

INTRODUCTION

Historically, the NASA Lewis Research Center has been involved with the design, evaluation, and testing of control designs for advanced engine concepts. Future advanced aircraft configurations, however, will require the integration of the propulsion control system with the flight control system. The Advanced Controls Technology Branch at NASA Lewis is conducting research in this area of integrated flight and propulsion control design, specifically for a Short Take-Off Vertical Landing (STOVL) aircraft. This integrated control design effort requires a means to test and evaluate these integrated control design algorithms. The flight simulator facility developed in this study provides a means to validate integrated design methodologies, to monitor, in real time, engine and airframe parameters during simulation, to evaluate new software partitioning methods, and to test control specification bandwidths and control rates during piloted engineering evaluations.

This integrated propulsion and flight control simulator is an evaluation station for flight and propulsion control research consisting of a cockpit, displays, and visual out-the-window scenery. This paper describes this flight simulation environment; the system communications to integrate the visual system with the host si nulation computer and the control computer; the control design environment; the development for an integrated control task flight simulator cockpit effectors and displays; and simulation testing of the flight simulator using a STOVL aircraft model and integrated control design. Finally, conclusions concerning the suitability of the flight simulator to current research, and recommendations for future enhancements are given.

SIMULATION ENVIRONMENT

The flight simulator facility, as shown in Figure 1, consists of five major components. The Paragon Graphics Visual System generates the Heads Up Display (HUD), the Heads Down Display (HDD), and the out-the-window scenery. The single channel projection system displays the scenery information and the HUD symbology. A mockup fighter cockpit provides pilot effectors for the control of engine and airframe commands. The Applied Dynamics System 100 real time simulation computer executes the real time engine and airframe simulations. Finally, the control computer

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system executes the integrated control design algorithms.

Visual System

The visual system consists of an image generation processor and a PC 80386-20 development station. The image generation processor provides 40 degree by 50 degree color database images with a screen refresh rate of 60 hertz and a scene content of 2000 polygons. Image resolution is 1024 by 1024 pixels. The resolution of the image processor is 32 Bit floating point, and the database can provide up to 16 moving models at any one time. [1]

The development station allows for development of new software models. Additionally, the development station serves as a run time front-end to the visual system. The development station is a 20 MHz, 386-based PC with a 40 Megabyte hard disk, a 5 1/4 inch floppy disk drive, monitor, keyboard, and a chassis with 8 expansion slots. The development station has a DR11W digital parallel interface adapter for communication with the both the control computer and the simulation computer. All the image database management software and image generation libraries for both HUD and HDD development reside on the development station. The development station supports C, FORTRAN, and assembly language programs.

Projection System

The forward projection system consists of a single channel, color projector with a 40 degree in the vertical by 50 degree in the horizontal field of view. The out-the-window scenery and heads up display information are displayed on a free standing, curved, high resolution projector screen.

Cockpit

The mockup fighter cockpit contains a four position, spring loaded, sidestick controller, linear motion sliding throttle, rudder pedals, and a color touch screen monitor to emulate heads down instrumentation. Several discrete switches on the sidestick controller and linear throttle can be used to simulate speedbrake, mode switching, or weapon related functionality.

Control Computer System

The control computer system consists of Control Interface and Monitoring Unit (CIM) with a control microcomputer, interface hardware, and a hardware and software monitoring system. The CIM unit was fabricated in house to implement and evaluate advanced digital control algorithms with hardware in the loop. It consists of a microcomputer with a real time operating system, the interface hardware for connecting to an engine/airframe simulation or actual engine, and monitoring hardware and software to verify that the control is performing properly. The control computer is intended for use in both simulation and engine test facilities, and is therefore implemented in a portable equipment rack. [2]

The integrated flight and propulsion control algorithms are executed in the control microcomputer of the CIM unit. It consists of a 20 MHz 80386 single board computer, analog and discrete I/O boards, and disk drives with their associated controller boards. The circuit boards are mounted in an industry standard Multibus I microcomputer chassis. The microcomputer runs the iRMX real time operating system. This operating system provides the services needed to construct a real time executive to schedule the execution of the integrated control algorithms, I/O routines, and the data collection software. The executive is coded in PL/M and uses timer generated interrupts to update the control at the desired interval. The integrated control algorithms executing on the microcomputer are coded in FORTRAN.

The purpose of the interface hardware is to route signals throughout the control computer, to connect the control computer to external devices, and to buffer those signals if desired. Cables which interface to both the simulation computer and the cockpit are terminated at the control computer base connectors. A patch panel is available to control the routing of signals throughout the system and to allow quick changes in configuration. The control computer is capable of supporting 64 analog inputs, 32 analog outputs, 24 discrete input signals, and 32 discrete output signals.

The monitoring capabilities of the control computer allow the user to observe analog signals that are sent to and from the system, as well as record variables within the control algorithms during execution. A data acquisition system monitors the control computer I/O and allows the operator to display any desired signal or signals in actual voltages or in engineering units. The Microcontroller Interactive Data System (MINDS) program runs in the spare time on the microcomputer CPU. The MINDS program has both steady-state and transient data gathering capabilities and can access any variable in the control algorithm for display or plotting. These monitoring capabilities allow the user to insure proper control operation and acquire data for later analysis.

Simulation Computer System

The airframe and propulsion models are implemented in the simulation computer which is specifically designed for real time and time critical simulation of continuous, dynamic systems. The simulation system consists of an Applied Dynamics System 100 simulation computer, analog and digital I/O hardware, and a VAXstation II front-end computer. The simulation computer is a 64-bit floating-point multiprocessor which is optimized for numerical integration. The I/O facilities allow communication with the integrated control algorithms running on the control computer, and allow the updated engine and airframe parameters to be transferred to the visual generation system. The models implemented on the simulation computer are coded in ADSIM, a proprietary programming language. Data collection and graphical display utilities are available to allow the user to monitor the simulation. The simulation computer at NASA Lewis is capable of supporting 44 analog input signals, 44 analog output signals, and 32 discrete input and output signals. [3]

SYSTEM COMMUNICATIONS

Design of the flight simulator system configuration, interfaces, and mechanization of the cockpit and displays was performed at NASA Lewis. A system diagram with interface interactions is given in Figure 2. This figure shows that the cockpit control effectors, (i.e. sidestick, throttle, rudder pedals, thumbwheel), produce pilot commands in the form of analog signals. These analog signals are sent directly to the control computer where the control algorithms process the commands. Any discrete commands from the cockpit (switches) are passed over discrete lines directly to the control algorithms on the control computer. Analog control commands generated by the control algorithms on the control computer are sent to the engine and airframe simulations which reside on the simulation computer. Engine and airframe data are passed back to the control algorithms on the control computer via analog signals. Updates in airframe and engine parameters are passed through a digital parallel DR11W interface to update the visual system, heads up display, and heads down display.

The DR11W interface consists of a circuit board in each of the computers connected by two 40 conductor flat ribbon cables 50 feet long. Programming of the DR11W consists of manipulating available registers to implement the handshaking needed to transfer data between the computer systems. A C language program on the visual system side, and an ADRIO language program on the simulation computer side are used to control the DR11W interface.[4] Since data are stored on the computers in different 32 bit floating point formats, the data on the simulation computer has to be converted to the visual system format prior to data transfer. After the conversion, the 32 bit floating point data is split into two 16 bit words which are transferred over the interface individually and recombined in the visual system. It requires approximately 1 millisecond to transfer 7 floating point numbers over the DR11W interface.

CONTROL DESIGN ENVIRONMENT

The integrated flight and propulsion control algorithms which are evaluated on the flight simulator are developed in an automated control design environment called MATRIXx, which runs on a VAXstation computer. Within this environment the designer can graphically assemble a block diagram representation of the control system and analyze the representation for correct operation.

Various analysis, design, and optimization tools are available to permit control design and verification. After the control design is complete, a code generation utility is used to generate a FORTRAN version of the discrete time controller from the block diagram representation. This code generation utility is also capable of producing source code in ADA and C programming languages. [5]

The FORTRAN code that is generated from this process is downloaded to the control computer. After compilation the control design is executed for evaluation within the flight simulation facility. If changes to the control are deemed necessary, the above procedure can be repeated.

COCKPIT EFFECTORS AND DISPLAYS

Development of the Pilot Vehicle Interfaces (PVI) for this flight simulator was based upon PVI research by Merrick, Farris, and Vanags at NASA Ames Research Center [6]. For demonstration purposes, a STOVL aircraft model, which is described below, was chosen with its associated HUD symbology, HDD instrumentation, and cockpit effector configuration.

The HUD symbology was generated and updated on the visual system development station. The HUD symbology is projected, in addition to the scenery, on the forward projection screen. The graphics software libraries were provided with the visual system to aid in the creation and implementation of HUD symbology, especially the generation of various fonts and colors. Graphics routines for all the displays were written in the C computer language. The displays and scenery were modified to reflect an integrated engine and airframe control task, typical of a STOVL aircraft. Figure 3 shows an example HUD symbology which was implemented on the flight simulator. The symbology includes a pitch ladder, heading scale, aircraft reference symbol, and flight path symbol. Additionally, engine and aircraft parameters such as altitude, velocity, and nozzle angle also are displayed.

The HDD instrumentation was displayed on a touch sensitive, 19 inch, color monitor, and was generated using the Pepper Graphics NNIOS Development Software. Figure 4 shows an example HDD instrumentation panel that was implemented on the flight simulator. For this STOVL aircraft example, an altimeter, compass, horizontal situation indicator, and airspeed indicator display the airframe parameters in real time. Engine parameters are displayed on fan speed, fuel flow, nozzle angle, and nozzle area gauges. These parameters were chosen for display to aid the control design engineer in evaluating the engine dynamics. Additional engine parameters can be displayed on these simulated gauges. Flight mode information is displayed and altered through the touch sensitive screen. A keypad function allows the user to change the mode information or to select a new scenario or starting point for the simulation.

The switches and effectors in the mock-up fighter cockpit are implemented to reflect the simulation of an integrated flight and propulsion control task. The cockpit effectors were based upon a "rate system" command structure. This rate system was implemented to accommodate the three modes of flight that the example STOVL aircraft can encounter: cruise, transition, and hover. With the rate system commands, the longitudinal stick provides pitch rate/attitude hold; the lateral stick provides roll rate/bank angle hold; the rudder pedals provided sideslip commands; and the linear throttle commands forward velocity. An additional analog effector was added for this simulation – a rotating thumbwheel. The thumbwheel, positioned on the linear throttle, commands flight path angle during the simulation. A diagram of the cockpit effectors and their functionality is found in Figure 5.

SIMULATION TESTING

In order to test and evaluate the hardware and software capabilities of the flight simulation facility, an example control design, aircraft model, and engine model were established. The vehicle model for this simulation test is a six degree of freedom, delta winged E7-D aircraft with a multi-nozzle turbofan engine, which is shown in Figure 6. The airframe is configured with an ejector nozzle, a ventral nozzle, a 2D-CD aft nozzle, and a Reaction Control System (RCS). The RCS allows for control of aircraft attitude during hovering flight. The engine for this aircraft is a mixed flow, vectored-thrust configuration. Further information about the vehicle, the airframe model, and the engine model can be found in reference [7].

Figure 7 shows the discrete linear control design that is executed on the control computer. The pilot inputs from the cockpit effectors are sent to the control computer. These signals are scaled by the input effector gradients. The signals are also filtered by the linear ideal response models. These ideal response models convert the pilot selections of acceleration, pitch rate, flight path angle, roll rate, and sideslip, into desired velocities, accelerations, and body angles or rates for the controller. The ideal response models are based upon desired handling quality characteristics of the E7-D aircraft, response dynamics of the airframe and engine, modal coupling and decoupling, and flight kinematics for turning flight consistency. [8]

The output from the ideal response models is the desired perturbation of the airframe outputs. This desired amount of change is adjusted by the measured outputs from the simulated aircraft dynamic models. This desired amount minus measured amount is input to the discrete linear control, K(z). For this example, the integrated flight and propulsion controller is a reduced order H-infinity design, [8] which is a linear, 21st order system. The output from the control is then added to the nominal plant actuator values and sent to the airframe and engine physics models located on the simulation computer.

Figure 8 shows the calculations performed by the simulation computer of the linear E7-D airframe and engine perturbation models. The system inputs from the control computer minus the nominal physics model inputs are fed into the linear plant, G(z). The basic integrated engine and airframe models are a 14th order system with 12 inputs and 10 outputs. The output from the engine and airframe plant is the measured amount of change from the dynamic models. This output is added to the nominal plant outputs and fed back to the control computer and to the coordinate transforms. Coordinate transformations are performed to provide body reference system airframe and engine parameters to the visual system for visual scenery and display updates.

During integration and testing of the facility, it was desirable to obtain a measurement of the computational capability of the simulator, therefore, several benchmarks were performed. Since the simulation facility consists of several different computer systems connected by various communication links, one important benchmark was to insure correct timing between the distributed portions of the simulation running on these separate computer systems.

Figure 9 shows a timing diagram for the cockpit, the control computer, the simulation computer, and the visual generation system along with the handshaking that occurs between the systems. The control computer runs asynchronously from the other computer systems. The integrated control algorithms execute every 40 milliseconds using timer generated interrupts. The first event to occur within the control computer upon an interrupt is the I/O with the cockpit and the simulation computer. The controls microcomputer then executes the integrated airframe and propulsion control algorithm. The MINDS data acquisition system runs in the spare time. The simulation computer updates the airframe and propulsion models every 20 milliseconds. Upon each update it performs the analog I/O with the controls computer and then executes the airframe and engine models. Every 40 milliseconds the simulation computer sends updated visual information digitally to the visual generation system over the DR11W interface. The visual generation system update is thus synchronized with the simulation computer. After reading the inputs, the visual system will update the cockpit HDD, the HUD, and the scenery. It then waits for new data to be provided from the simulation computer.

CONCLUSIONS

The integrated propulsion and flight simulator has successfully been designed, built, and demonstrated as a real time, pilot-in-the-loop, evaluation station for integrated engine and airframe control laws. Benchmark tests for timing and integration show that the flight simulation system performed in real time, without degradation of the visual displays, for a sample STOVL aircraft application. For its designated use as an engineering evaluation simulator, the flight simulator system performs well for real time display of flight control parameters and engine control parameters. The simulation system at NASA Lewis, as further confirmation of its real time capabilities, will undergo engineering evaluations of the system configuration to evaluate interface structures and control mode structures. Additionally, the simulator will be used to evaluate nonlinear, integrated control designs.

A planned improvement to the flight simulator facility is a real time digital communications network between facility components. Networking hardware and software will expand the capability to monitor simulation and control parameters of all hardware in the simulation in real time. This expansion will also allow for easy reconfiguration of the system components for use with actual engine hardware in the loop. Finally, through the modular system design of the flight simulator, component upgrades and modifications can be made to accommodate future research, or expand to motion based simulation.

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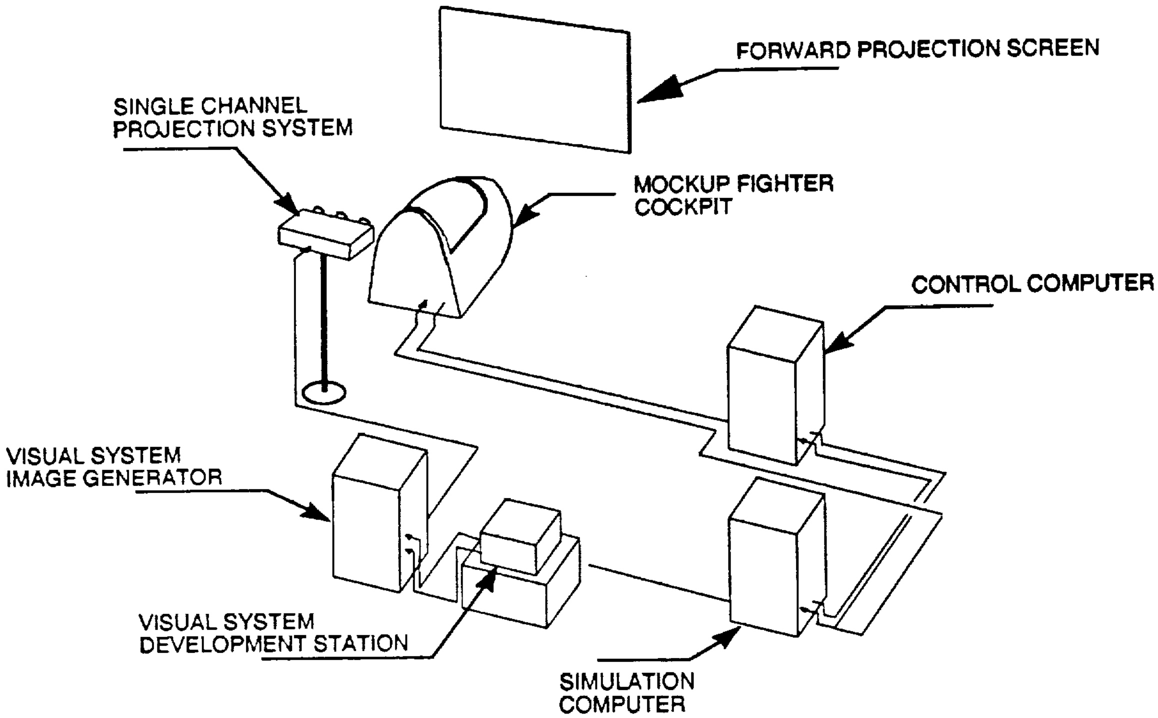

Figure 1. Flight Simulator Facility

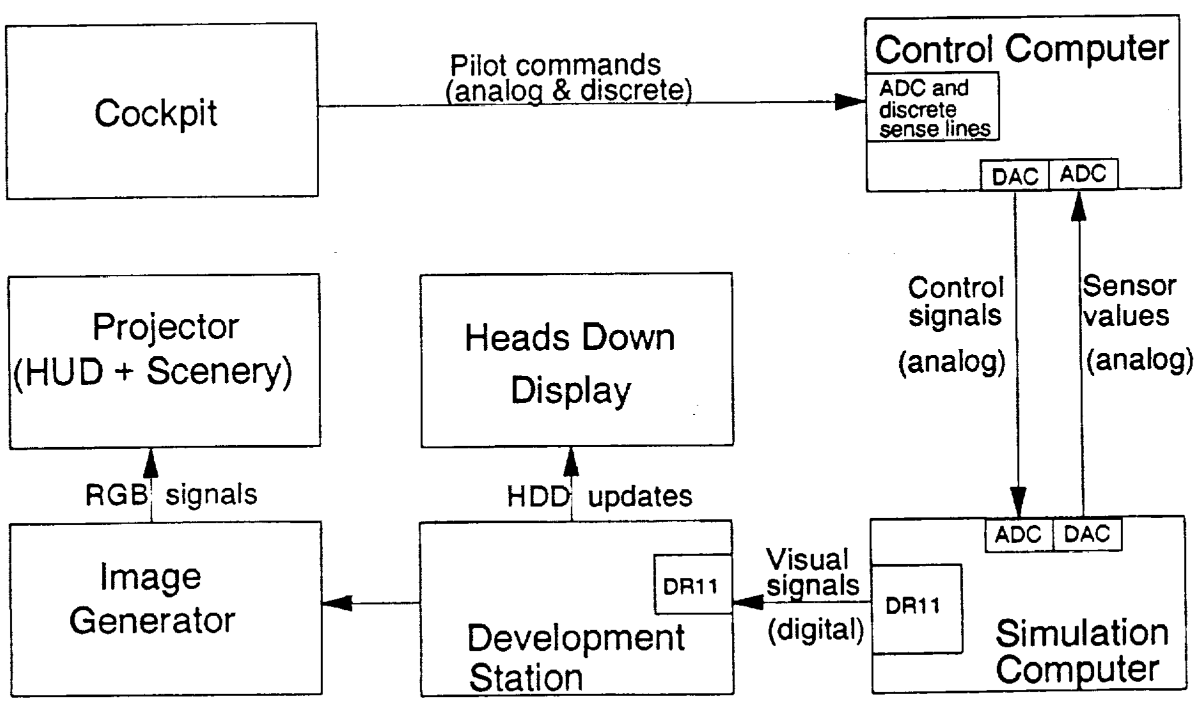

Figure 2. System Communications

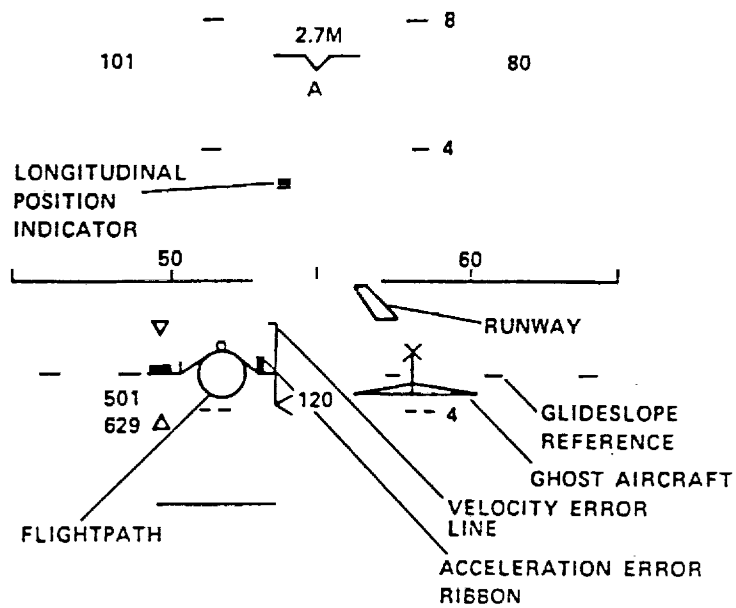

Figure 3. Heads Up Display Format [6]

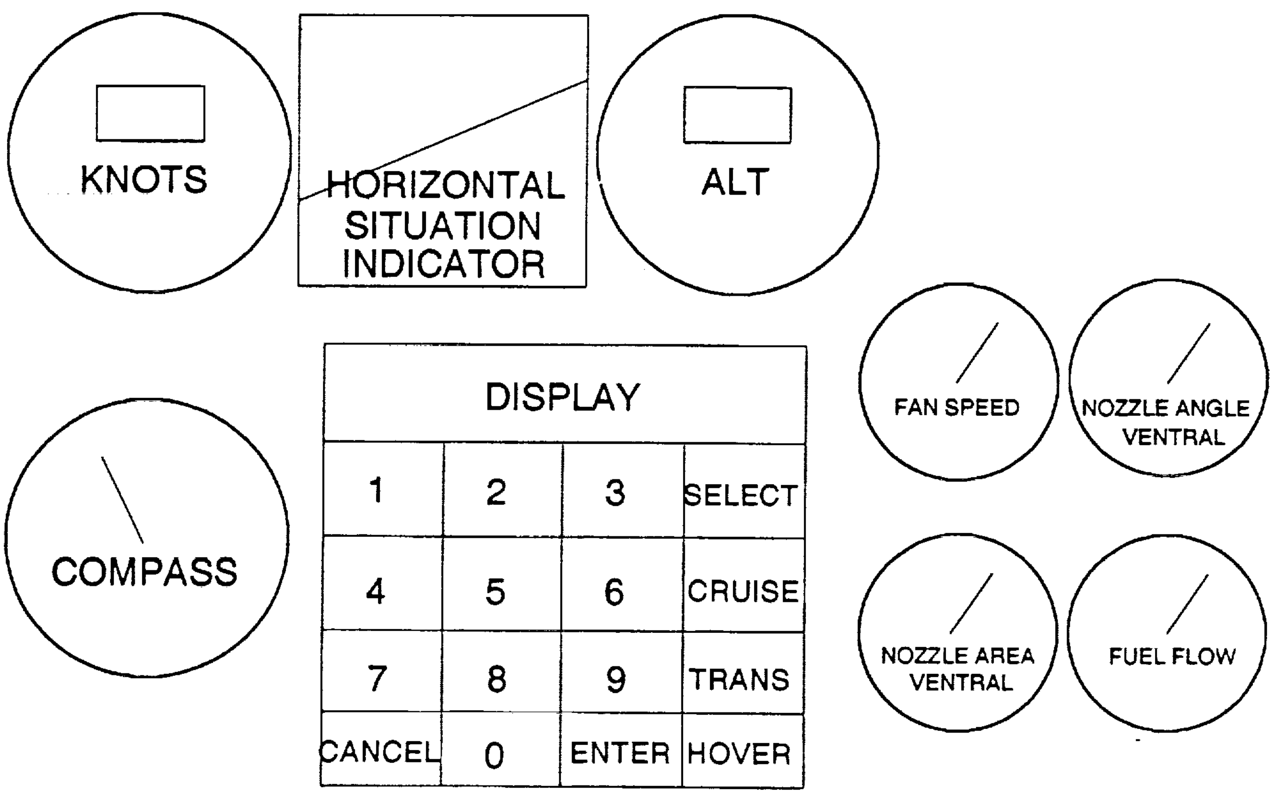

Figure 4. Heads Down Display Format

H = hover T = transition C = cruise

pilot command \ control inceptor	Throttle	Thumb Wheel	Longitudinal Stick	Lateral Stick	Rudder Pedals
accel/decel		H C T			
flightpath	T				
roll/rollrate				C T	
pitch/pitchrate			C T H		
sideslip					C T H
velocity	C			H	
altitude rate	H				

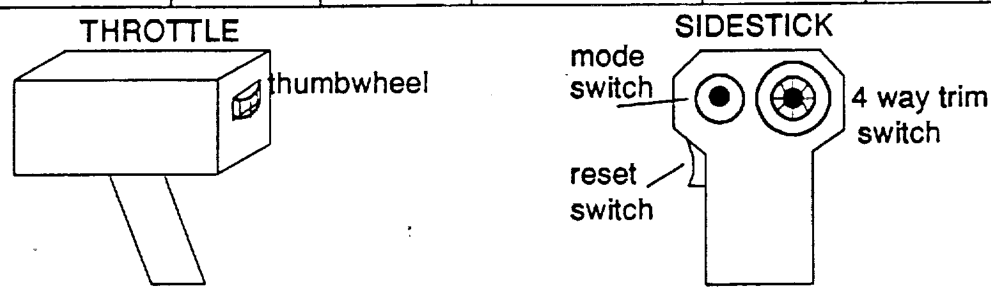

Figure 5. Control Modes in Cockpit

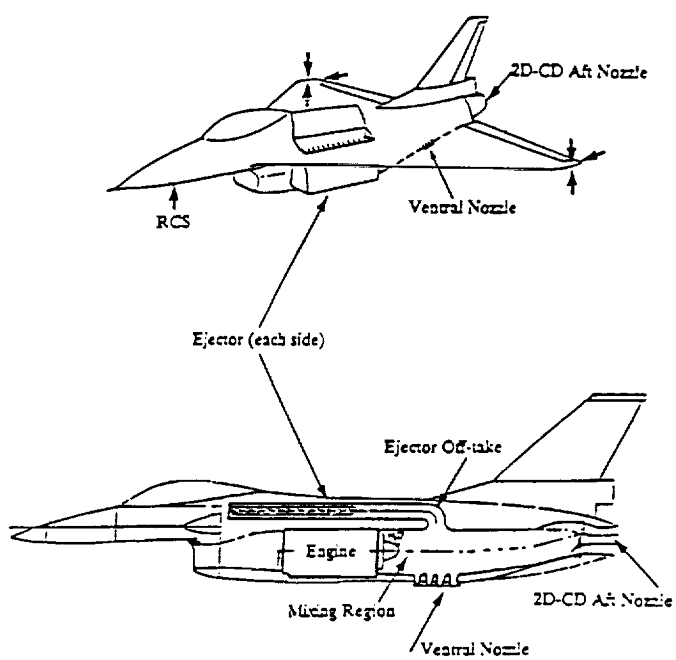

Figure 6. E7-D Configuration Aircraft

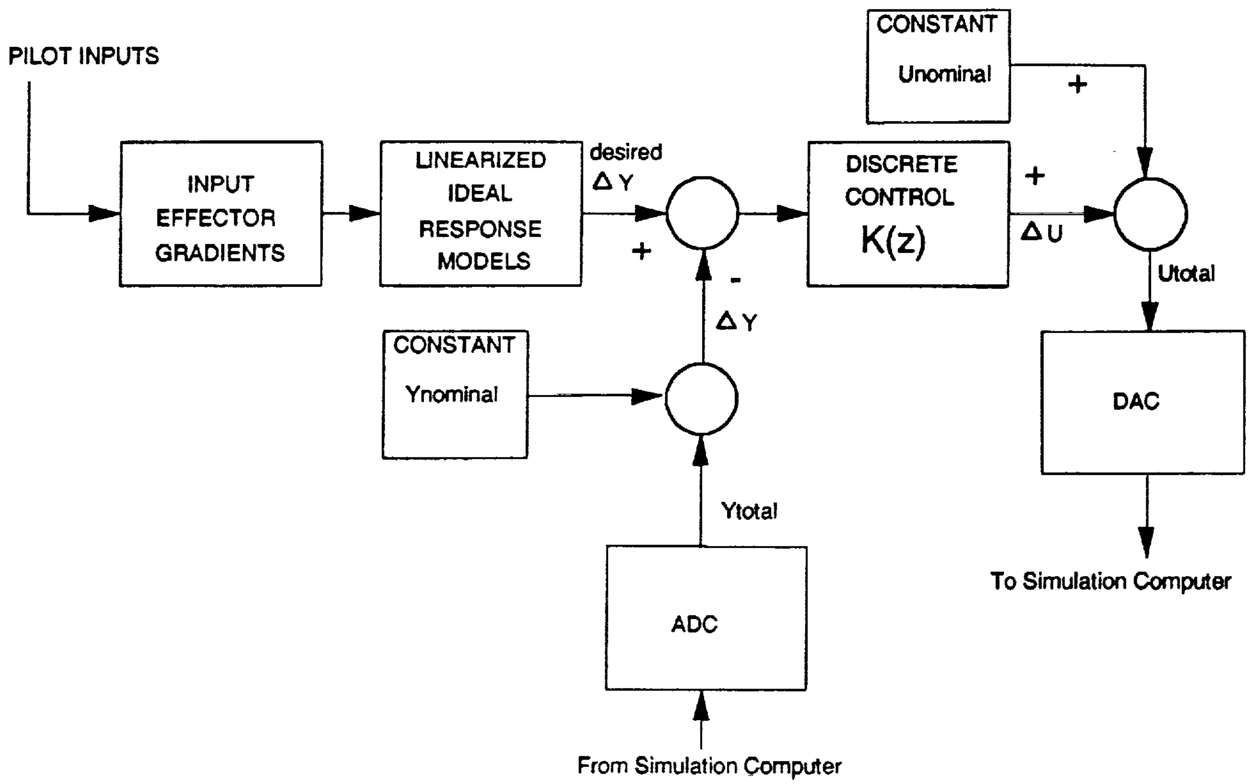

Figure 7. Integrated Control Design on Control Computer

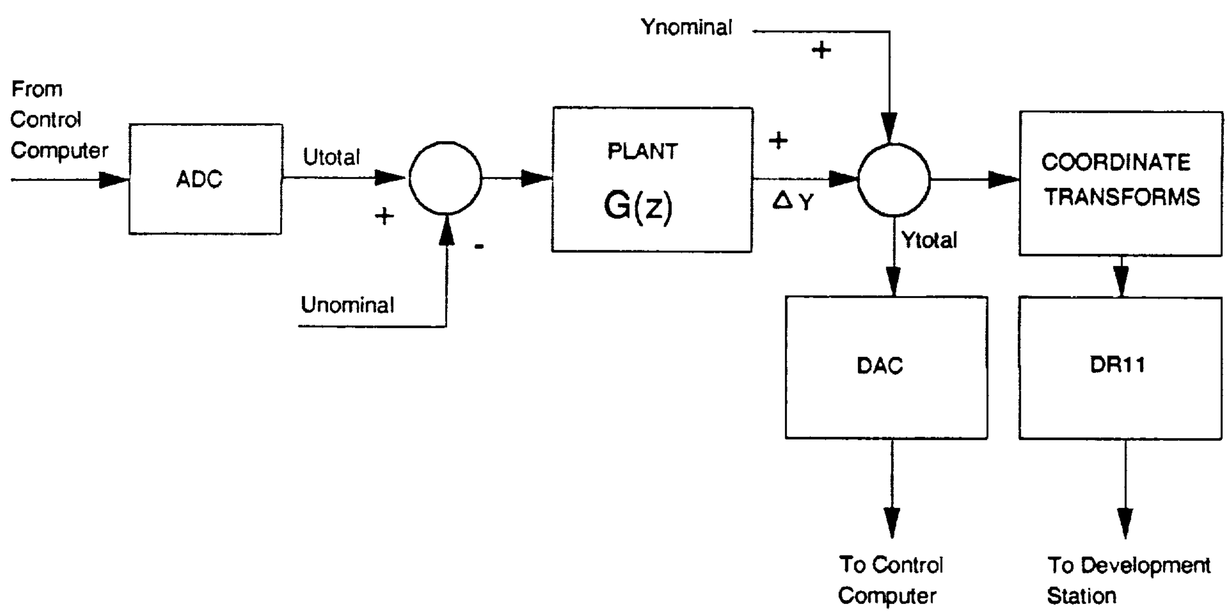

Figure 8. Integrated Plant on Simulation Computer

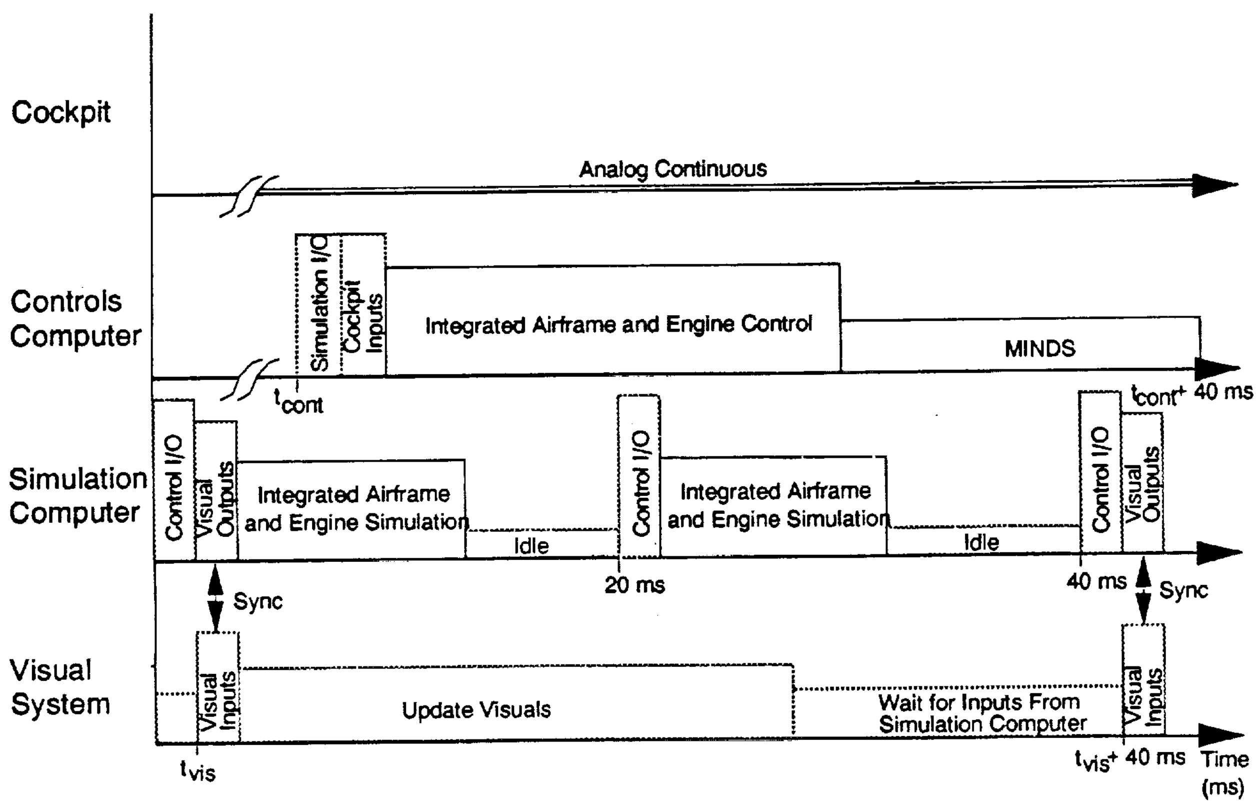

Figure 9. Timing Diagram of Computers

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