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Prepared for
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SECTION 1
INTRODUCTION

General Aviation serves an important role in transportation and in the Nation's economy. But operating procedures are complicated, regulations are restrictive, and the demands of the National Air Traffic Control (ATC) system are increasing. All of these factors contribute to an increasing dependence on avionics and to a corresponding increase in their cost and complexity. Furthermore, such diverse considerations as safety, rising fuel costs, and the desire to improve single pilot IFR operation will stimulate the demand for even more avionics.

To date, the avionics industry has been able to meet the increasing requirements for avionics at affordable prices by aggressively applying new technologies. The application of new technology has been along traditional lines, however, with integration occurring only in a few specific areas such as navigation/communication systems and integrated flight director/autopilot designs. Using this approach, the addition of more sophisticated capabilities -- such as a performance computer, a pilot alert system, or a ground-proximity warning system -- is expensive and cumbersome because of the need for separate computers, separate displays and controls, and signals from aircraft sensors that either do not have an appropriate output, or are not easily accessible. However, as a result of recent developments in microprocessors, busing, displays, and software technology, it may be possible to configure an integrated avionics system that is better suited for accommodating these future requirements.

In 1975, a research and development program was initiated within the National Aeronautics and Space Administration to determine the feasibility of developing an integrated avionics system suitable for general aviation in the mid-1980s and beyond. The objective was to provide information required for the design of reliable integrated avionics. This avionics was to provide expanded functional capability that would significantly enhance the utility and safety of general aviation at a cost commensurate with the general aviation market.

The program has emphasized the use of a data bus, microprocessors, electronic displays and data entry devices, and improved function capabilities. As a final step, a Demonstration Advanced Avionics System (DAAS) capable of evaluating the most critical and promising elements of an integrated system will be designed, built, and flight tested in a twin-engine general aviation aircraft.

A contract was awarded to Honeywell, Inc., teamed with King Radio Corp., in August 1978 for the design and fabrication of DAAS. The specific objectives were (1) to fabricate an integrated avionics system based on the information obtained in the investigations described in the foregoing paragraph (2) to incorporate in this system a set of functional capabilities that will be beneficial to general aviation, and (3) to design the displays and controls so that the pilot can use the system after minimum training. The system will be installed in the Ames Research Center's Cessna 402B in the early part of 1981; engineering flight testing will begin at King Radio in Olathe, Kansas, in mid-1981. Flight tests at Ames Research Center are expected to start in late 1981. During the flight tests, guest pilots from various segments of the general aviation community will be invited to evaluate the DAAS concept.

The DAAS Program also includes definition and analysis of a projected Advanced Avionics System (PAAS). PAAS extrapolates the DAAS concept of integrated, fault tolerant avionics to a potential operational version for the mid-1980s. PAAS was analyzed to determine reliability, cost, etc., and impact of the DAAS concept in comparison to conventional architecture. The results are contained herein.

This report documents the DAAS Program Phase I System Design, and includes the following:

- DEMONSTRATION ADVANCED AVIONICS SYSTEM (DAAS)
  - DAAS Functional Description
  - DAAS Hardware Description
  - DAAS Operational Evaluation
  - DAAS Failure Modes Effects Analysis
- Project Advanced Avionics System (PAAS)
  - PAAS Description
  - PAAS Reliability Analysis
  - PAAS Cost Analysis
  - PAAS Maintainability Analysis
  - PAAS Modularity Analysis
- Conclusions and Recommendations

Additional detailed design information is contained in the following documents:

- 'Demonstration Advanced Avionics System (DAAS) Functional Description,' 15 October 1980, NASA CR-152405, by Honeywell Inc. and King Radio for Ames Research Center, NASA.
- 'DAAS-System Specification (YG 1210),' 20 December 1979, Honeywell Specification DS 28150-01.
- 'DAAS Central Computer Unit (BG1135),' 3 October 1980, Honeywell Specification DS 28151-01.
- 'EHSI (Electronic Horizontal Situation Indicator) JG12D4AA,' 13 December 1979, Honeywell Specification D538153-01.
- 'IDCC (Integrated Display and Control Center), DAAS HG1052AA,' 13 December 1979, Honeywell Specification DS28154-01.
- 'NASA-Honeywell DAAS Radio Adapter Unit P/N 066-1083-00,' 14 September 1979, King Radio Corp. Specification 001-5018-00.
- 'Software Development Specification For Y61210 NASA DAAS Avionics System,' Honeywell Specification DS28152-01.

SECTION 2
DEMONSTRATION ADVANCED AVIONICS SYSTEM (DAAS)

DAAS is the demonstrator system intended to physically demonstrate the characteristics of a fault tolerant integrated avionics system in a Cessna 402B aircraft. Following is description of the demonstrator system including functional description, hardware description, documentation of the DAAS operational evaluation conducted on the DAAS simulator, and documentation of the failure modes and effects analysis conducted to verify DAAS flight safety.

2.1 DAAS FUNCTIONAL DESCRIPTION

The DAAS is an integrated system. It performs a broad range of general aviation avionics functions using one computer system, and shared controls and displays. Following is brief description of the DAAS functions, controls and displays, and DAAS architecture.

2.1.1 DAAS Functions

- Autopilot - The autopilot is a digital version of the King KFC200 modified for compatibility with DAAS. The basic autopilot modes are:

  - Yaw Damper
  - HDG SEL (Heading Select)
  - ALT, ALT ARM (Altitude Hold, Altitude Arm)

- NAV, VNAV Coupled Control
- Approach Coupled Control

- Navigation/Flight Planning - The navigation/flight planning function computes aircraft position with respect to an entered flight plan, and blends dead-reckoning position (as determined from airspeed and heading) with position extracted from automatically tuned VOR/DME receivers. Functions are:

  - 10 Waypoints, 10 NAVAID Storage
  - Kalman Filter Blending
  - Moving Map Display

- Flight Warning/Advisory System - DAAS includes extensive monitoring, with warning capability. For example, the DAAS system monitors engine performance (MAP, RPM), aircraft configuration (gear position, flap position, etc.) with respect to flight condition, and ground proximity and informs the pilot of undesirable situations. Monitoring includes:

  - Engine Parameter Monitoring Warning
  - Aircraft Configuration Monitoring, Warning
  - Airspeed and Stall Monitoring, Warning
  - Altitude Advisory Function
  - Marker Beacon Advisory Function
  - NAVAID Identification Monitoring
  - Autopilot/Flight Director Monitoring
  - BIT Fault Warning

- GMT Clock Function - The DAAS computer serves as a GMT clock.

- Fuel Totalizer Function - Fuel flow is integrated to totalize fuel used.

- Weight and Balance Computations - Weight and balance, and takeoff cruise performance calculations can be quickly and conveniently performed using DAAS controls and displays.

- Performance Computations - The DAAS system will determine fuel and time required to fly specific segment distances given altitude, temperature, wind data, and engine power setting. Performance computation functions are:

  - Takeoff Performance
  - Cruise Performance
  - Fuel/Distance/Time Computation

- DABS (Discrete Address Beacon System) ATC Communication, Weather Reporting - ATC text messages (e.g., CLIMB AND MAINTAIN 1200 FT) or weather information at destination can be communicated to the DAAS pilot via DABS data link and displayed on the DAAS electronic display.

- BIT (Built-in Test) - The DAAS system will detect and localize its own faults via BIT. Provisions are also included for troubleshooting the DAAS hardware through DAAS controls and electronic displays.

- Normal, Emergency Checklists - Normal and emergency checklists are stored in the DAAS computer, and are available for display at the push of a button.

These functions are managed via shared controls and displays, and performed in the common DAAS computer system.

2.1.2 DAAS Controls and Displays

The DAAS Cessna 402B aircraft contains --

- Controls and displays necessary to manage DAAS functions.
- Additional instruments necessary for IFR flight operations.
- Independent safety pilot instrument installation.

These controls and displays are layed out in the 402B control panel as indicated in Figure 2-1, Cessna 402B Layout. The DAAS pilot is in the left seat, and the safety pilot in the right seat. Electronic displays -- the Electronic Horizontal Situation Indicator (EHSI) and Integrated Data Control Center (IDCC) -- are key elements of the panel.

The EHSI presents a moving map display showing aircraft position with respect to desired course. The display is a 4.5-inch monochromatic Ball Brothers 103C CRT raster display unit. The display unit has 256- by 256-dot matrix display capability. P43 phosphor is used together with an appropriate narrow band optical filter to allow operation in bright sunlight. The EHSI is controlled by functional control buttons and a map slew controller.

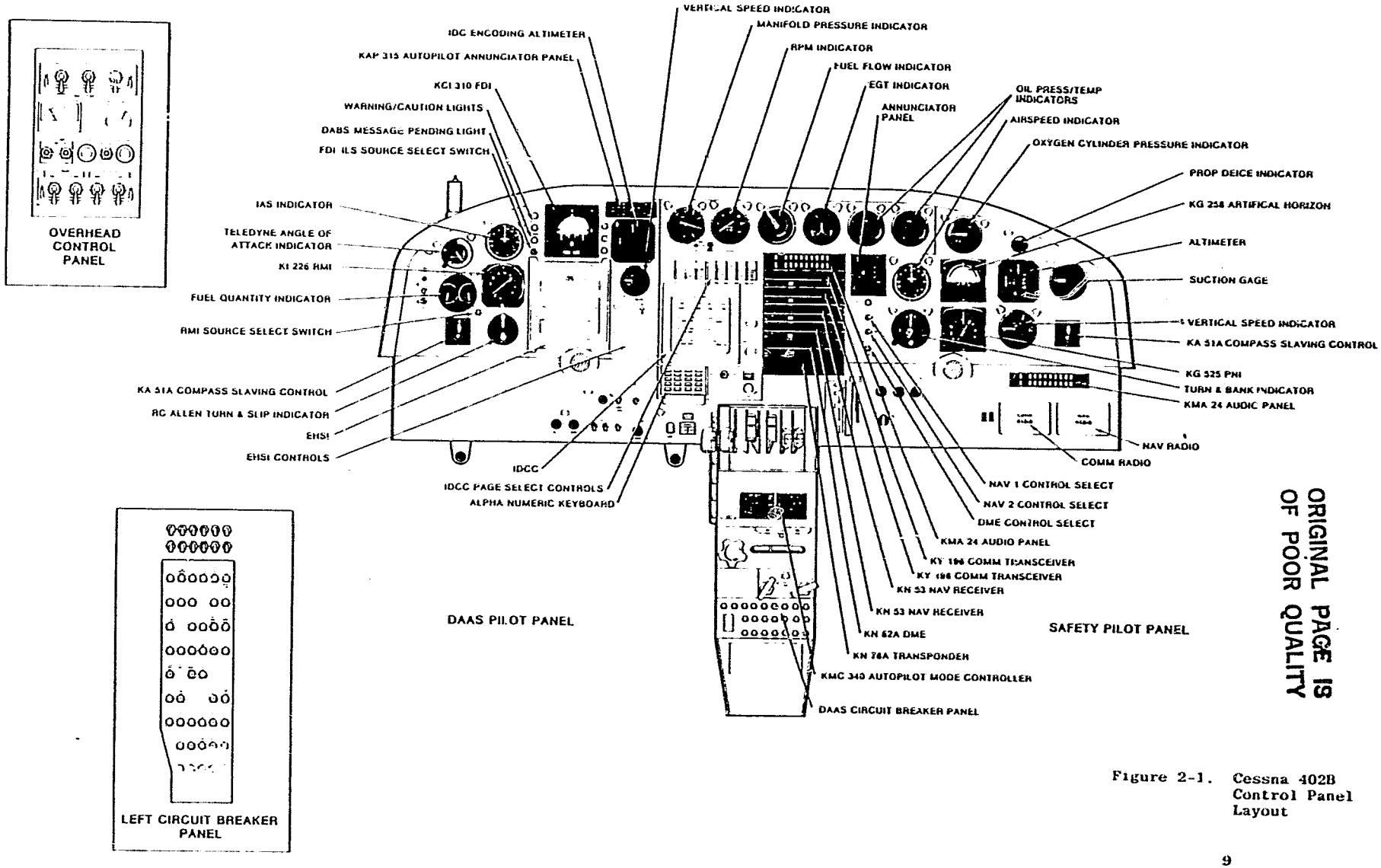

Figure 2-1. Cessna 402B Control Panel Layout

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The Integrated Data Control Center (IDCC) is the pilot's primary means of interacting with DAAS. Included are a keyboard at the bottom of the unit and a set of function buttons along the top. The function buttons include a set of page select buttons which determine the information that is displayed on the IDCC display.

The IDCC display CRT is identical to the EHSI; i.e., 4.0-inch by 4.5-inch Ball Brothers monochromatic unit. The IDCC can display 16 lines of 32 characters each. Line spacing is 0.25 inch, character height is 0.162 inch, and character width is 0.125 inch.

The IDCC is implemented with menu select buttons along each side of the CRT, or with a pressure sensitive plastic screen overlay for touch point menu selection. The alternate approaches can be implemented to allow comparison during flight test.

The DAAS EHSI is surrounded by the conventional "T" pattern of flight control instruments.

The ADI used in DAAS is the 4-inch King KCI 310 Flight Command Indicator.

The altimeter is an IDC Encoding Altimeter type 519-28702-571. An altitude alert light is mounted on the altimeter.

The rate-of-climb indicator provides vertical speed information to the pilot. The display presents rates of climb, or descent, in feet per minute. The face is 2-1/4 inches wide.

The King KI 226 RMI displays heading and bearing to a selected VOR station.

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The DAAS Autopilot Mode Controller is located on the pedestal, and the Autopilot Mode Annunciator is located above the altimeter.

DAAS engine instruments and radio stack are centrally located and are accessible to the DAAS pilot and the safety pilot.

Unique DAAS switch controls located on the panel include:

- NAV 1-DAAS/MANUAL Tune (located to the right of the NAV 1 radio)
- NAV 2-DAAS/MANUAL Tune (located to the right of the NAV 2 radio)
- DME TRANSFER (located to the right of the DME)
- VOR source switch (located to the lower left of the RMI)
- ILS source switch (located to the lower left of the ADI)

NAV Receivers can be tuned manually (MANUAL) or automatically (DAAS). The DME transfer switch allows the DME receiver to be tuned by either NAV receiver 1 or 2. The DAAS position slaves the DME to the NAV receiver being controlled by DAAS.

The safety pilot instrument set is independent from the DAAS instruments, and adequate for safe flight with DAAS inoperative.

The safety pilot's Pictorial Navigation Indicator displays aircraft magnetic heading (gyro-stabilized), selected heading and selected course. Also, VOR and localizer course deviation, glideslope deviation and a TO-FROM indication are presented.

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The safety pilot's KG-258 artificial horizon is an air driven unit. It is the safety pilot's basic attitude/horizon reference indicator.

Aircraft master power controls are centrally located overhead. Circuit breakers are located on the pedestal.

2.1.3 DAAS System Architecture

DAAS system architecture is presented in Figure 2-2. The architecture is characterized by a modular computer system structure; i.e., multimicroprocessors interconnected by an IEEE 488 data bus. Each processor block in Figure 2-2, except for the radio system, represents an Intel 8086 16-bit microprocessor, 2k by 16 PROM memory, and 4k by 16 to 16k by 16 RAM memory. The radio System uses the Intel 8048 microprocessor.

Each processor performs a function, and interfaces directly with the subsystems associated with that function. At power-on, the bus controller Computer CPU-1 takes functional programs from the nonvolatile bubble memory, and sequentially loads each processor at the rate of approximately 2 seconds per processor. When all processors are loaded, the bus controller activates the system. The bus controller then manages bus communications during normal operations.

A portable TI Silent 700 cassette unit can interface with the bus controller to allow load or modifications of the functional software.

CC-CPU 5 is a spare processor. If processor CC-CPU 3 or CC-CPU 4 fails and the bus controller detects the failure,

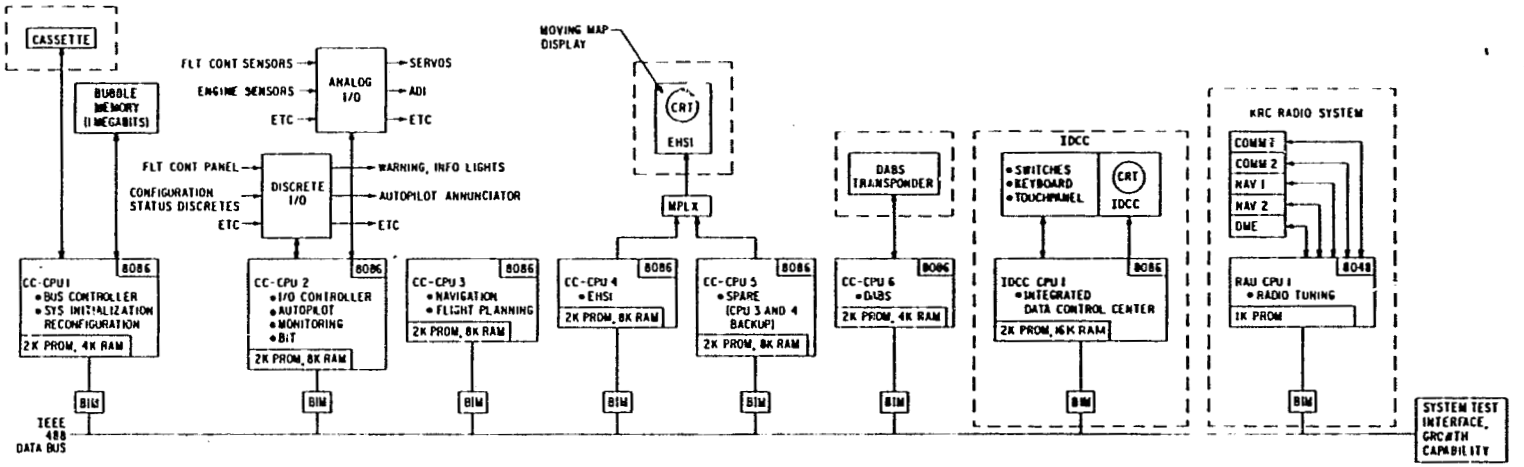

Figure 2-2. DAAS System Architecture

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the bus controller will load CC-CPU 5 with appropriate software from bubble memory, and CC-CPU 5 will take over the function of the failed processor. (Note: This reconfiguration capability is especially important when an EHSI and an EADI are included in the PAAS system. With a failure in one display, the spare processor could be loaded to allow time sharing of the remaining good display as both EADI and EHSI.) Such reconfiguration could be extended to other processors such as CC-CPU 2, the autopilot. However, for such reconfiguration the spare processor must interface with autopilot subsystems, which requires additional multiplexing of hardware. Reconfiguration was thus applied only to a limited degree in this demonstrator system.

The DAAS architecture is modular. Functions can be added by adding necessary standard processor modules onto the 488 data bus, and interfacing these processor modules with the devices associated with the new function.

Six processors are contained in the DAAS Central Computer Unit. One processor is contained in the IDCC, and one processor is contained in the radio adapter unit.

2.2 DAAS HARDWARE DESCRIPTION

DAAS system components, and their interconnections are depicted in Figure 2-3, DAAS System Diagram. Interconnection between the DAAS panel instruments, sensors, and the DAAS computer system is shown. The DAAS Central Computer obtains data from the radio system (radio adapter unit, radio stack), flight control sensors, engine instruments, configuration status sensors, and IDCC.

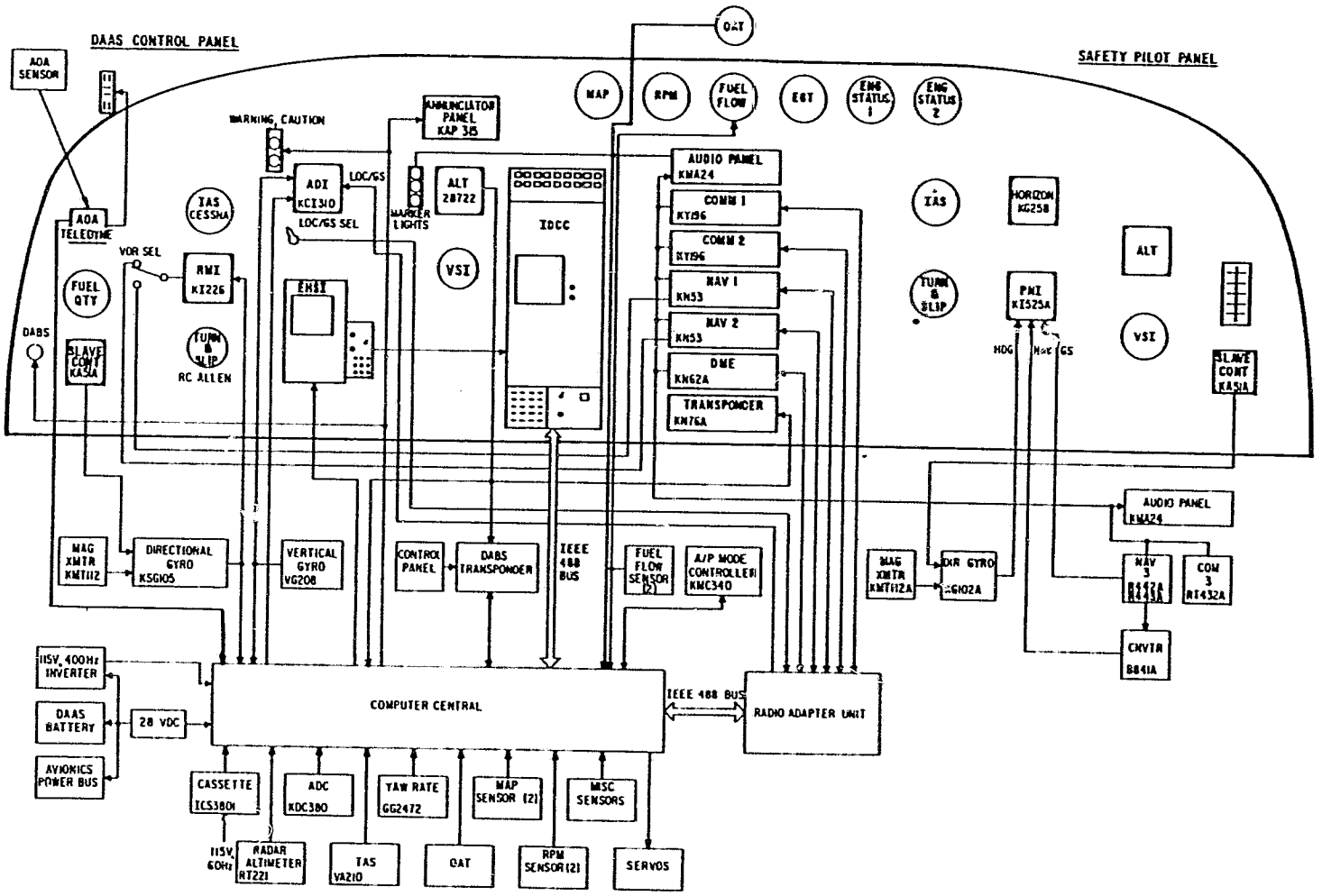

Figure 2-3. DAAS System Diagram

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Functional computations are performed on the input data and the results applied to EHSI, FDI, warning/caution lights, and autopilot servos.

Following is a description of new design DAAS flight hardware including:

- Central Computer Units
- IDCC
- EHSI
- Radio Adapter Unit

The hardware is shown in Figure 2-4.

2.2.1 Computer Control Unit (CCU)

The CCU, Figure 2-5, consists of the following computer processing units (CPUs) and their associated I/O interfaces:

- Autopilot CPU
- Bus Controller CPU
- EHSI CPU
- NAV CPU
- DABS CPU
- Spare CPU

In addition, the CCU contains a one mega-bit bubble memory and the regulated power supplies for the DAAS system.

2.2.1.1 Mechanical -- The CCU is packaged in a full ATR Chassis. The dimensions of which are given in the installation drawing

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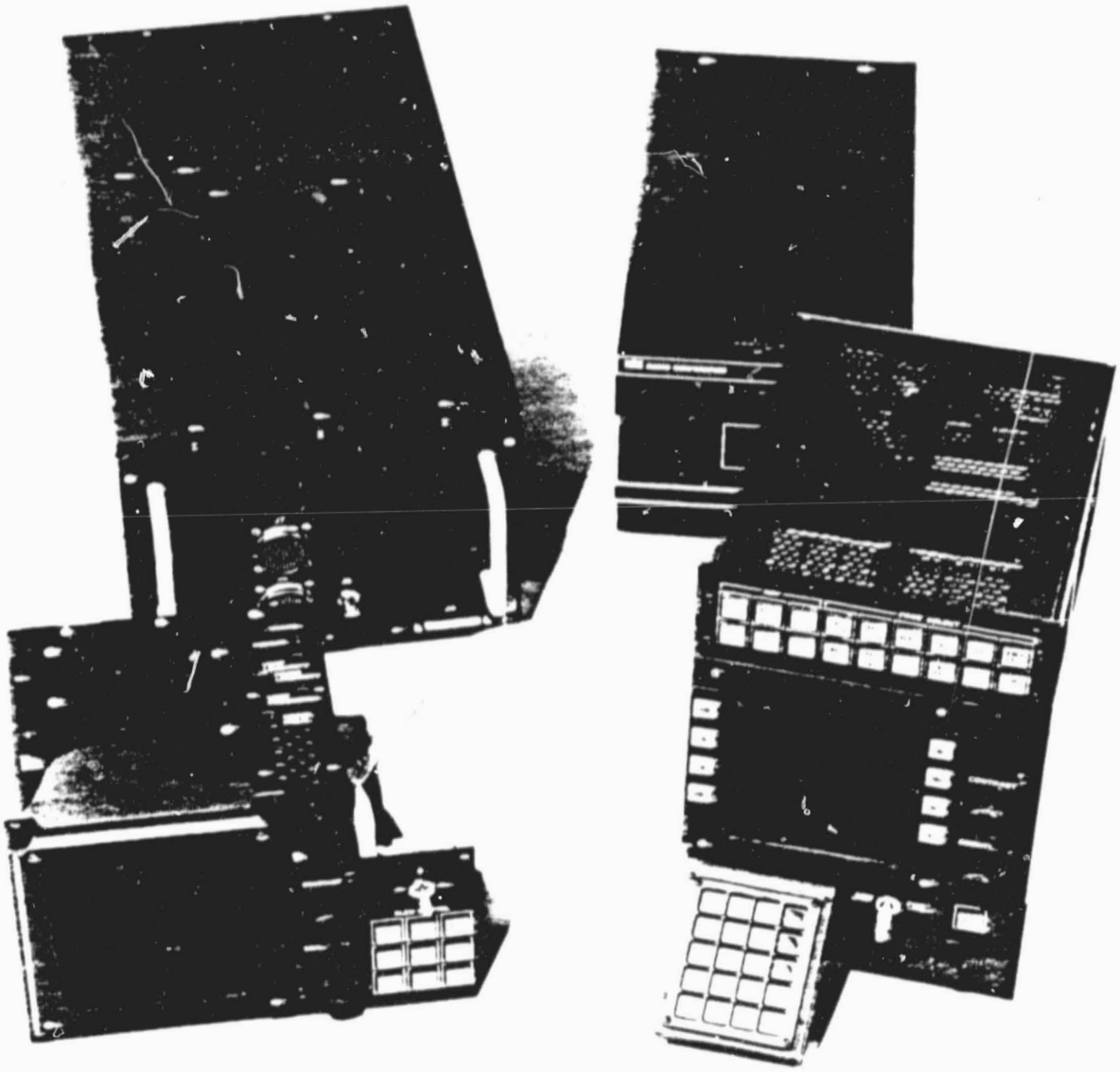

Figure 2-4. DAAS Flight Hardware. From left to right: Electronic Horizontal Situation Indicator, Central Computer Unit, Radio Adapter Unit, and Integrated Data Control Center.

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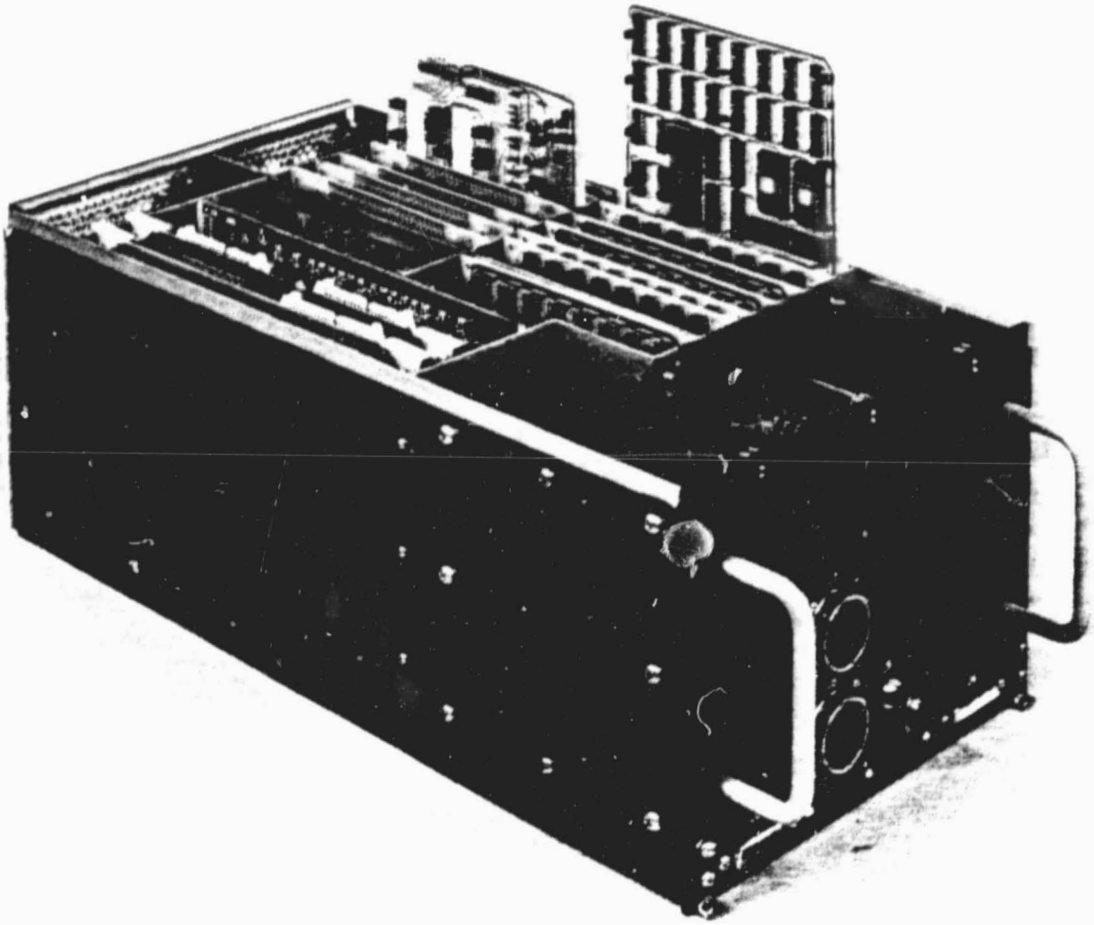

Figure 2-5. DAAS Central Computer Unit

shown in Figure 2-6. The chassis has been constructed to accept up to twenty-three 6.25 by 6.25 inch card assemblies plus four larger 10 by 6 inch card assemblies. All interconnections of the card assemblies are via a wirewrap mother board.

2.2.1.2 CPU and Memory -- Each CPU has been designed to fit on a single printed circuit board card assembly as shown in Figure 2-7. A CPU consists of the 8086 microprocessor, 4K by 16 of RAM memory, 2K by 16 of UV-EPROM, an 8259 programmable interrupt controller, and the IEEE-488 bus interface circuitry. In addition to the 8086 microprocessor IC, the processor also contains an 8284 clock generator, bus buffer logic, and memory chip select logic.

To facilitate software development, the 8086 is mounted in a quick-eject socket. This allows easy replacement of the 8086 with an in-circuit emulator (ICE-86). The 8086 is operated at 4 MHz by driving the clock generator with a 12 MHz crystal. This clock frequency was selected to be comptaible with the ICE-86 which has a maximum limit of 4 MHz.

The 8259 programmable interrupt controller provides the capability for eight vectored interrupts. The IEEE-488 bus utilizes the highest priority interrupt with the rest of the interrupt lines connected to special functions associated with each processor.

The IEEE-488 bus interface is implemented with 9914 GPIB adapter and two bus transceiver ICs. The 9914 is a 40-pin LSIC that can be programmed to be a talker/listener or as a bus controller while meeting all of the requirements of IEEE-488. This feature of the 9914 allowed all of the CPUs to be designed identically. Communication between the 8086 and the 9914 is carried out via memory

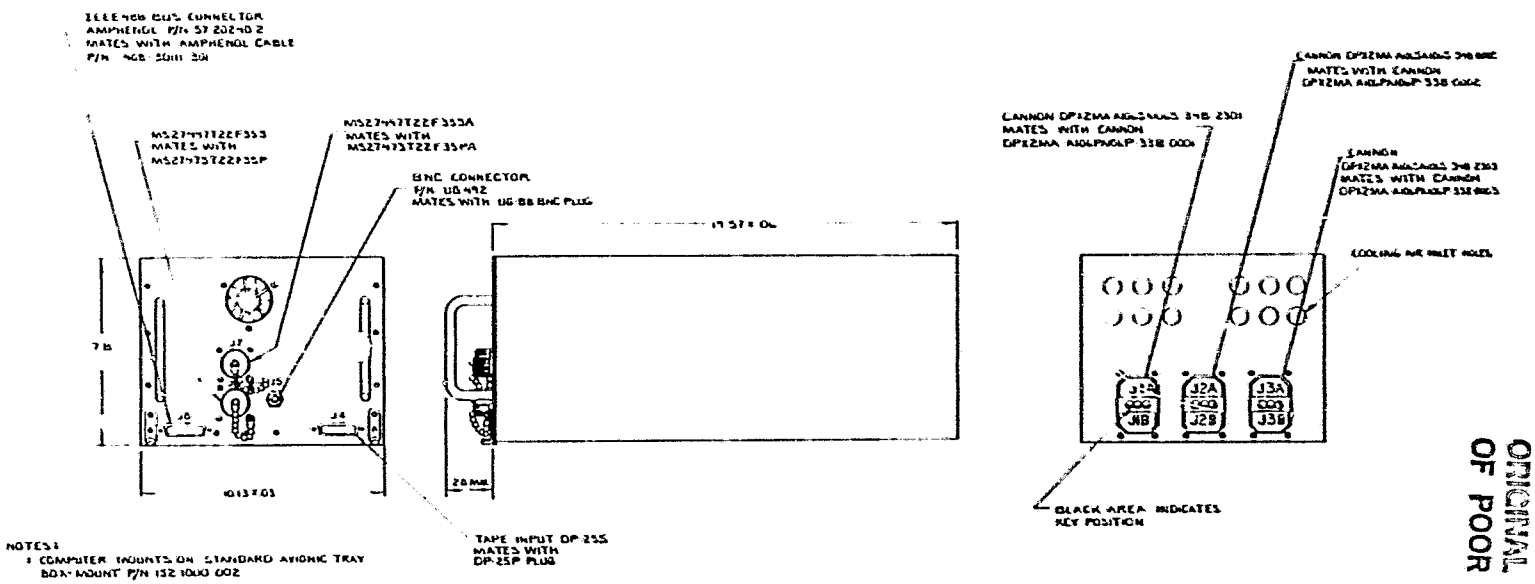

Figure 2-6. DAAS Central Computer Unit Installation Drawing

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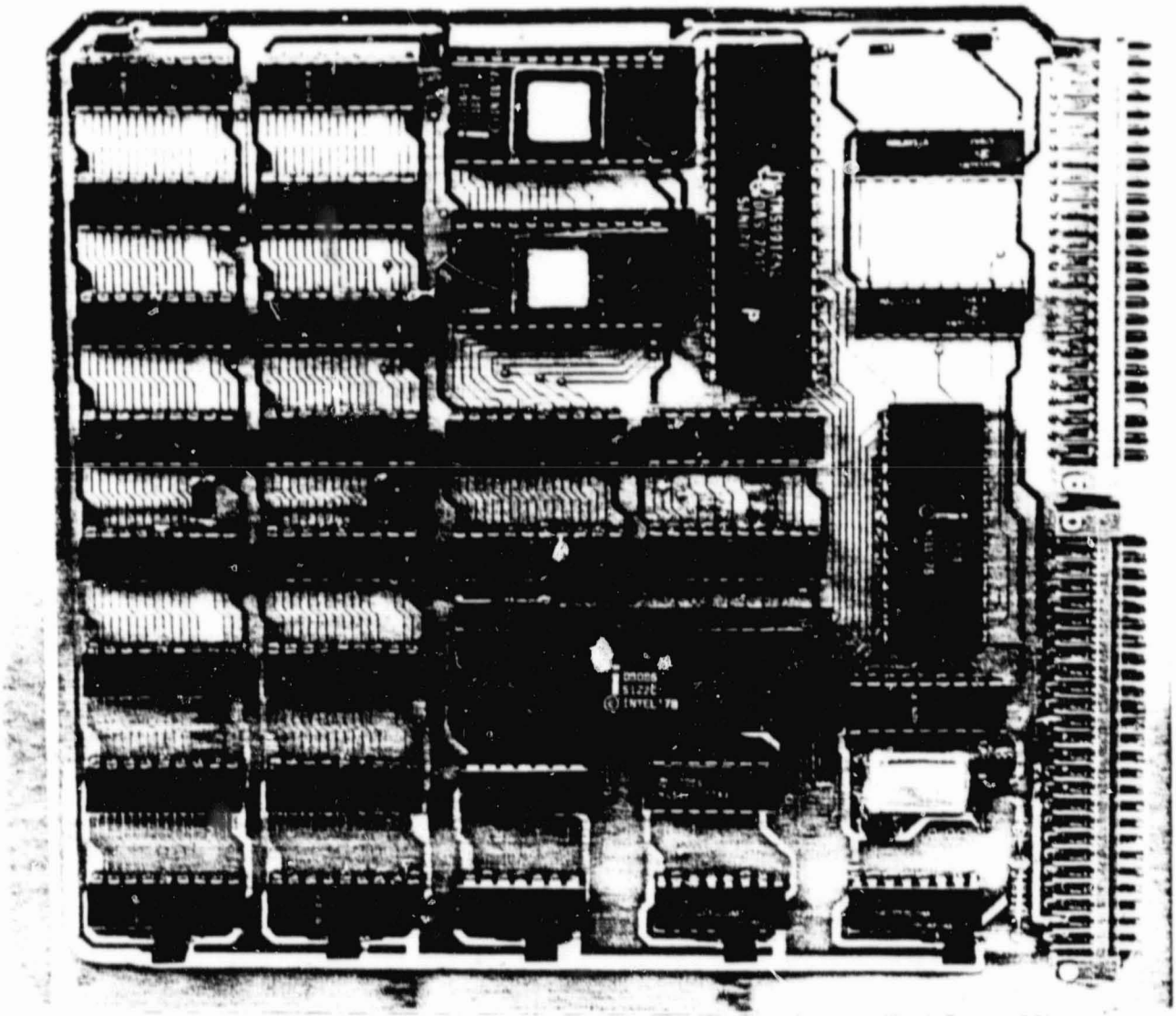

Figure 2-7. DAAS Processor Module

mapped registers. There are 13 registers within the 9914, 6 of which read and 7 write. These registers are used both to pass commands or data to, and to get status or data from, the device.

There are 4K of RAM memory and 2K of UV-EPROM available on the CPU card assembly. An additional 4K or 8K of RAM memory is available with the memory expansion card assemblies. Memory expansion card assemblies are provided for the autopilot, EHSI, NAV, and spare CPUs. Also provided on the memory expansion card assemblies is the I/O address decoding logic associated with that CPU. From a software standpoint, all of the I/O addressing is treated as memory mapped.

2.2.1.3 <u>CCU Bubble Memory System</u> -- A Rockwell bubble memory system is used for the nonvolatile storage of the CPU software programs. The bubble memory system, Figure 2-8, consists of two card assemblies, a 1-megabit memory assembly (RLM 658), and a controller assembly (RCM 650). The RLM 658 assembly provides the 1-megabit of storage via four 256K-bit (RBM 256) devices which are operating in parallel. The RLM 658 also contains the sense amplifiers, coil drivers, operator logic (transfer, replicate and generate pulses), and the chip mapping PROM. The chip mapping PROM contains the redundancy information on the good and bad loops in each of the REM 256 devices. The RCM 650 controller organizes the memory to appear as an 8-bit byte parallel operation with 128-byte blocks. Thus the memory is addressed by blocks (1 to 1024) with 128 bytes per block. The RCM 650 uses a preprogrammed 6502 microprocessor to accomplish the controller functions. Also, included on the RCM 650 is a 1k by 8 buffer memory which is the main interface between the bus controller CPU and the bubble memory.

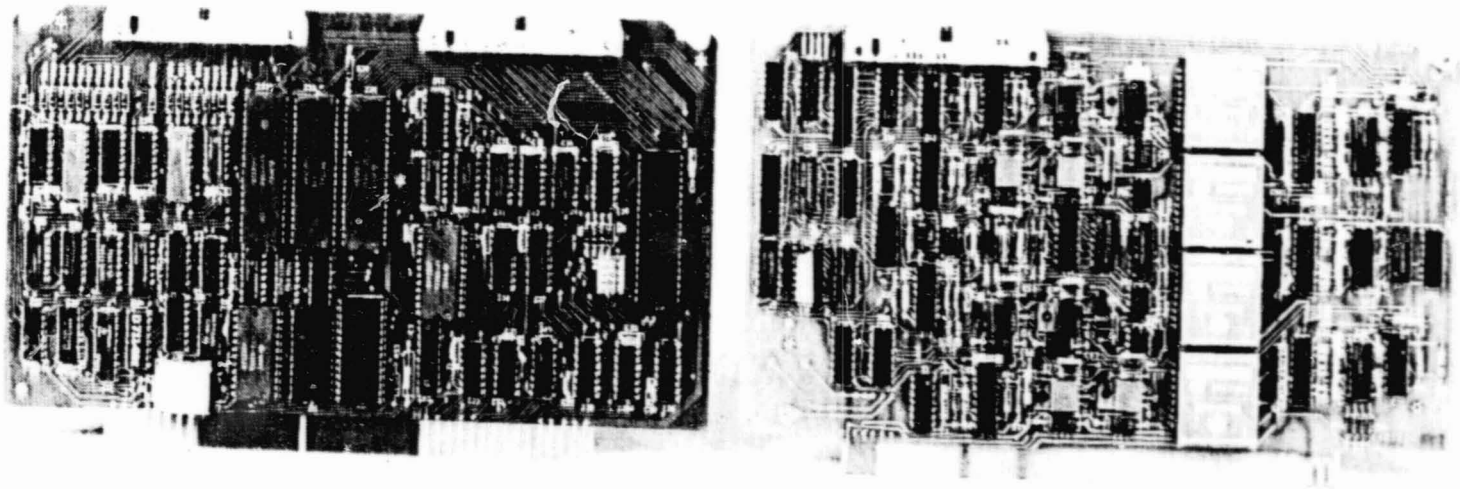

Figure 2-8. DAAS Bubble Memory System

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2.2.1.4 CCU Cassette Interface -- Tape cassettes are used for initially loading the bubble memory with the software programs for all of the CPUs. A PROM program in the bus controller CPU, allows the bus controller to read the ASCII data from the cassette, convert it to binary, and transfer the binary data to the bubble memory. A standard RS-232 interface is used between the bus controller CPU and the ASR733 data terminal with dual cassettes. This RS-232 interface, along with additional bubble memory address decoding, is contained on the cassette and bubble memory I/O card assembly.

2.2.1.5 Display Controller -- Two ALT 512 graphics display controllers are used to generate the video signal for the EHSI. Each ALT 512 contains its own 131,021-bit refresh memory, TV sync, and video generator. The display field for each ALT 512 consists of two 256 by 256 by 1 planes. The two-plane arrangement allows eight different display formats. The mode of operation selected for the EHSI is to display one plane while the EHSI CPU erases and updates the other plane. Two ALT 512s are required to increase the throughput on the EHSI. The display information that requires faster updating is programmed in one of the ALT 512s while the slower information, which is updated at a slower rate, is programmed in the other ALT 512. The two ALT 512s are operated with one as the master, and the other as the slave (i.e. the slave receives its video clock and sync timing from the master). The combined video output is then transmitted to the EHSI CRT monitor.

The ALT 512 utilizes a standard S-100 bus for all of the I/O interfaces. In order to provide the reconfiguration capability of letting either the EHSI CPU or the spare CPU drive the EHSI, the multiplexing of the address, data, and control lines from these CPUs to the ALT 512s must be provided. This multiplexing

circuitry is provided on the memory expansion cards associated with those CPUs. Control of which CPU is driving the EHSI comes as a discrete output from the bus controller CPU.

2.2.1.6 CCU DABS Interface -- Both the standard message (SM) interface and the extended length message (ELM) interface have been implemented for communication between the DABS transponder and the DABS CPU. The SM interface consists of a gated clock controlled by the transponder, and a bidirectional data line for serial transmission of data. For up-linking of information, data received from the transponder is converted from serial to parallel and stored in a 16 by 8 buffer memory. Upon receipt of a complete COMM-A message, an interrupt is generated to the DABS CPU which causes this CPU to read the contents of the buffer memory. For down-link information, the reverse process is required. The DABS CPU loads a 16 by 8 buffer memory and then sets the B-bit in the SM interface format. Upon receipt of a COMM-B message to the transponder, the data is converted from parallel to serial and transmitted to the transponder.

The ELM interface is a full duplex, synchronized serial binary data interface in accordance with RS-449. The following interface circuits are provided:

ST - send timing (from transponder)

SD - send data (to transponder)

RS - request to send (to transponder)

CS - clear to send (from transponder

RT - receive timing (from transponder)

RD - receive data (from transponder)

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DM - data mode (from transponder)

IS - terminal in service (to transponder)

All of these interface circuits are bipolar, balanced circuits that operate at voltage levels and impedance levels as specified in RS-422. Operation of the ELM interface is similar to the SM interface except that the buffer memory is 256 by 8. This allows 16 COMM-C or COMM-D segments to be received or transmitted as a block respectively. The transponder takes care of all the COMM-C and COMM-D decoding and downlink message initiation. The circuitry required to implement the SM and ELM interfaces is contained on the DABS SM card assembly and the DABS ELM card assembly.

2.2.1.7 CCU I/O Interface -- With the exception of the previously discussed interfaces, all of the I/O devices (aircraft sensors, engine monitors, mode control panels, etc.) interfaces directly with the autopilot CPU. This I/O interface provides the capability for:

48 discrete inputs

48 discrete outputs

64 analog inputs

16 analog outputs

CCU Discrete I/O -- The discrete inputs are multiplexed into 4 words of 12 bits each before being read by the autopilot CPU. One of the discrete input words is reserved for self test (wrap-around) of the flight critical discrete outputs. Each discrete input is signal conditioned and prefiltered (0.8 msec. time constant) before being multiplexed to a comparator to determine its logic state.

The discrete outputs are organized into 3 words of 16 bits each. The discretes are stored in three 16-bit registers which are written into directly from the autopilot CPU. The outputs of these registers are buffered with high voltage open collector drivers, thus providing either an open or ground. The majority of the discretes are used for annunciation and the drivers tie directly to 28-volt lamps. The autopilot clutch engage and the auto-trim discretes require additional drive capability. This is provided with a discrete transistor stage added to the regular drivers.

The discrete input circuitry and the discrete output circuitry for 16 of the outputs is contained on the discrete I/O card assembly. The circuitry for the rest of the discrete outputs including the special drivers is contained on the discrete output card assembly. The real-time clock is also included on this card assembly. The real-time clock is a counter running from the autopilot CPU Crystal Controlled Clock. It generates an interrupt 40 times per second to the autopilot, NAV, IDCC, and spare CPUs.

CCU Analog Inputs -- Four DG 506 16-channel multiplexers are utilized to allow up to 64 analog inputs to be multiplexed to a 12-bit (11 bits + sign) A/D converter. Each analog input is signal conditioned, scaled, and prefiltered prior to the multiplexer. The AC signals are demodulated using an LF 198 sample-hold IC with the sampling synchronized to occur at the peaks. A frequency to voltage converter is used for signal conditioning of the true airspeed signal.

The A/D converter and 32 channels of multiplexing are contained on the ADC and MUX card assembly. The A/D converter is a

successive approximation type converter with a conversion time of 32 microseconds, including multiplex and settling time. The converter is composed of a 562 type D/A converter and two 8-bit 2503 successive approximation registers. The input scaling is setup such that ±10 volts at the input to the A/D converter corresponds to full range. The additional 32 channels of multiplexing is contained on the DC Inputs and MUX card assembly.

Also contained on this card assembly is the signal conditioning (differential buffer amplifiers and prefilters) for the dc inputs. The ac input card assembly contains a Scott-T transformer for converting the heading synchro signals to sin and cosine, second-order prefilters for the pitch and roll attitude signals, and the demod amplifiers for converting these ac signals to dc. The yaw servo amplifier, the pitch and roll command bar amplifiers, the VNAV deviation indicator drive circuitry, and the true airspeed frequency to voltage converter are also contained on this card assembly.

CCU Analog Outputs -- Each analog output consists of an LF 198 sample-hold which is updated from a 12-bit D/A converter. Of the 16 analog outputs provided, 8 are used for inflight recording, 3 for the pitch, roll, and yaw servo amplifiers, 1 each for pitch command bar, roll command bar, and VNAV deviation, and the other two are spares. The D/A converter is a 562 type that is operated in the bipolar mode with a signal range of ±10 volts. The D/A converter, 16 sample-holds, 16-channel decoding, and the pitch and roll servo amps are all contained on the DAC and Servo Amp card assembly.

2.2.1.8 CCU Power Supplies -- All power for the CCU and the IDCC is generated from the aircraft +28 Vdc bus. An Abbott BN1000

power module is used for the +5-volt supply. This dc-to-dc converter uses a pulse width modulated inverter switching at 18 to 20 kilohertz to achieve an efficiency up to 70 percent with output capability to 20 amps. Similarily, an Abbott BBN500 power module provides a dual output ±15-volt supply. This supply has an output current capacity of 1.67 amps on each output. The bubble memory and the ALT-512 require ±12 V dc which is supplied from a linear regulator operating from the ±15-volt supplies. All of these supplies require approximately 10 amps from the 28-volt bus.

2.2.2 Integrated Data Control Center (IDCC)

The IDCC, Figure 2-9, consists of two basic assemblies: the CRT monitor assembly, and the chassis assembly. The over-all dimension of the IDCC are shown in Figure 2-10. The CRT monitor assembly is mounted in the IDCC chassis assembly which, in turn, is mounted in the aircraft.

2.2.2.1 CRT Monitor Assembly -- The CRT monitor assembly is a standard, solid state, monochromatic television monitor designed for avionics display applications. The monitor is 7.7 inches wide, 6.0 inches high, by 11.0 inches deep. It is a raster type monitor capable of 525 lines with a 2:1 interface at 30 frames per second, or a non-interlaced 262-line field at 60 fields per second. The latter is used in this application. The monitor is designed with P-43 phosphor and a narrow bandpass optical filter to produce a sunlight readable display. The display area is 4.5 by 4.5 inches.

2.2.2.2 IDCC Chassis Assembly -- The IDCC chassis assembly contains the following subassemblies in addition to the CRT assembly:

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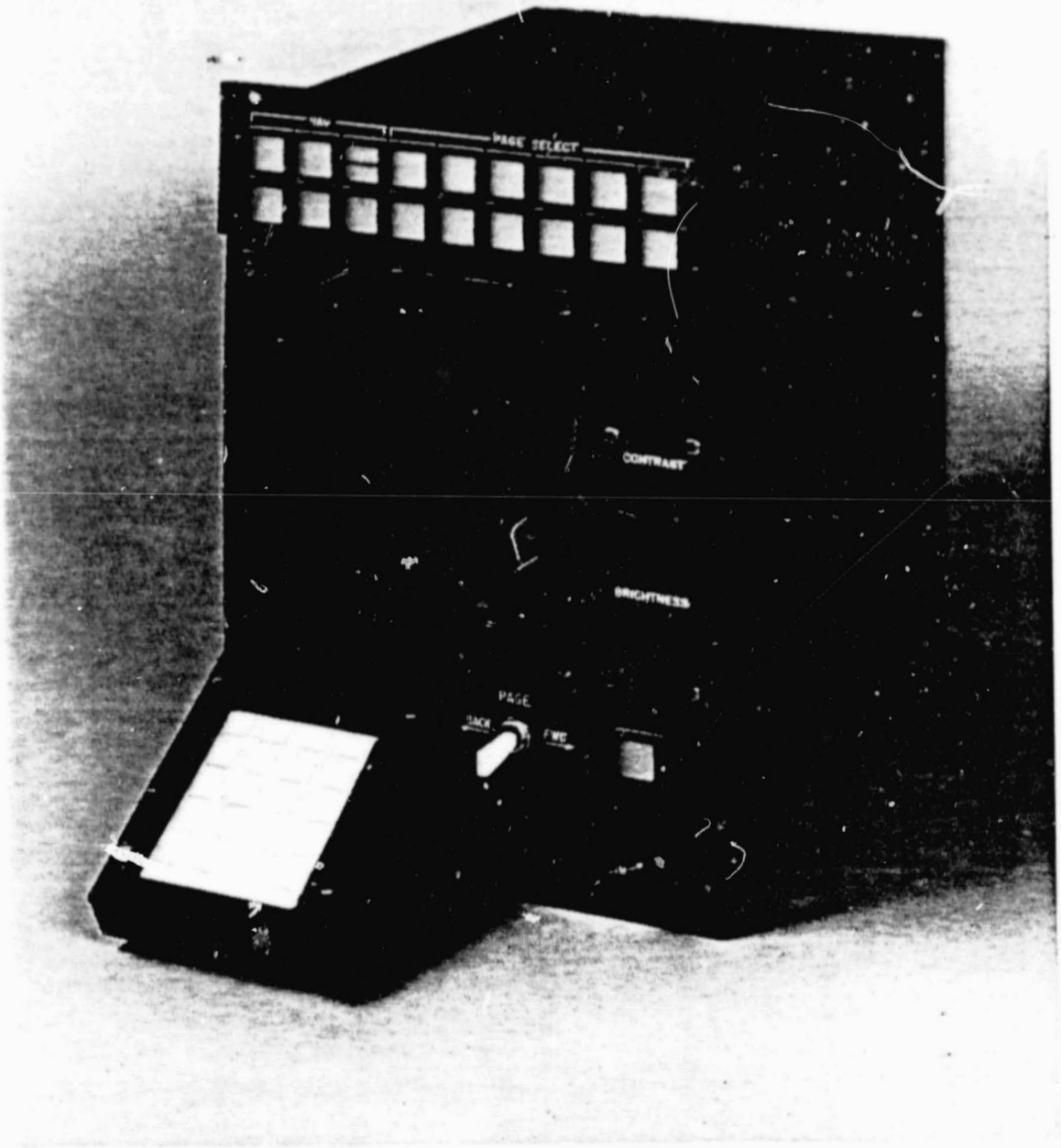

Figure 2-9. DAAS Integrated Data Control Center (IDCC)

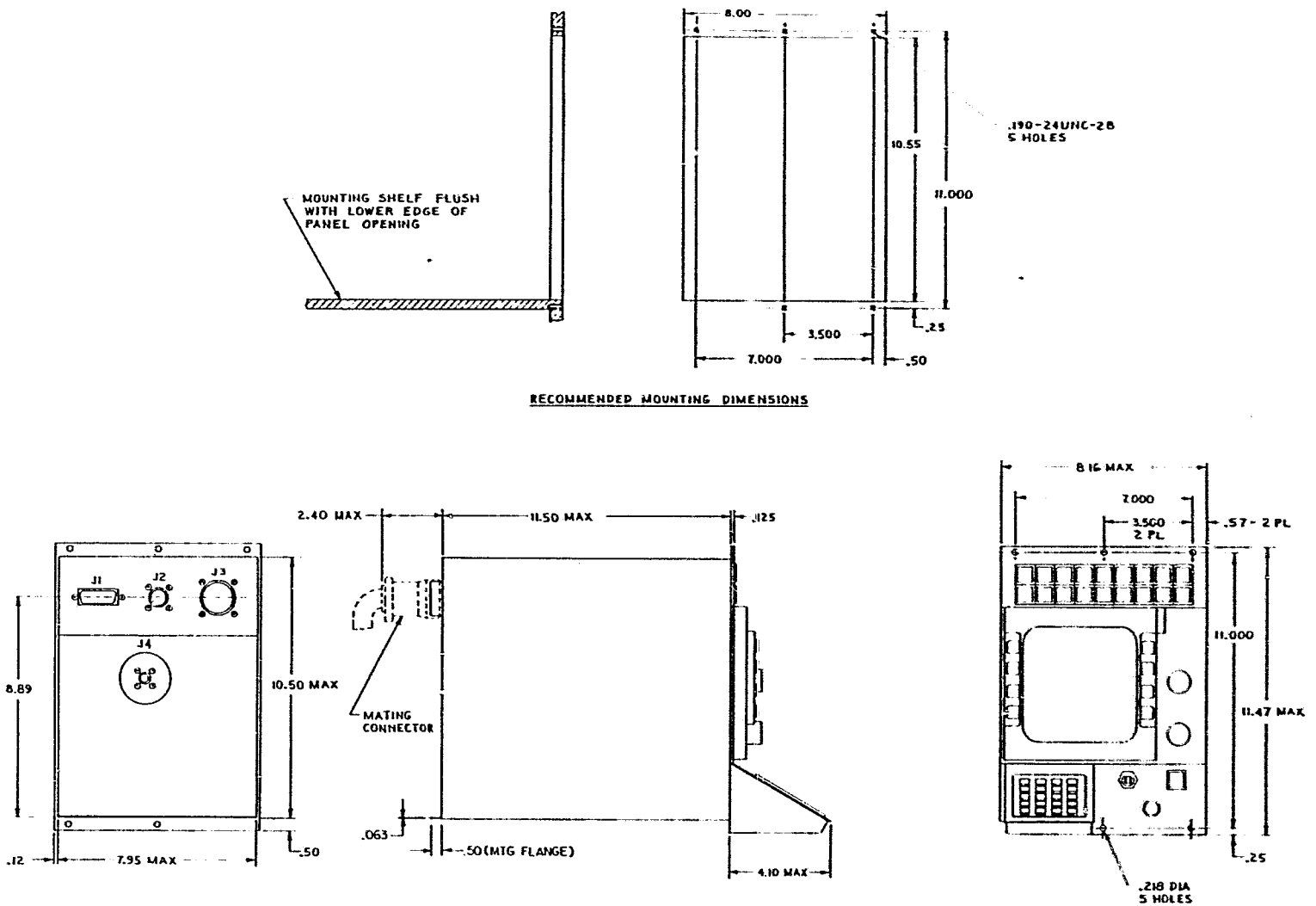

Figure 2-10. IDCC Installation Drawing

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- CPU and memory
- Keyboard
- Pushbutton switches
- Touchpoint switches
- Miscellaneous controls

IDCC CPU and Memory -- The IDCC contains its own central processing unit (CPU) and associated memory. The CPU is an 8086 16-bit microprocessor. The memory consists of 16K by 16-bit RAM and 2K by 16 bit ROM. The RAM is used for both program memory and scratchpad memory, and the ROM is used to store the initialization programs. The CPU, together with 4K of RAM and the bus interface circuitry, is packaged on one card. A second card contains 8K of RAM. A third card contains 4K of RAM. The fourth card contains the CRT refresh memory and the I/O circuitry.

The CPU, together with its memory, performs the following functions:

- Message storage.
- Message formatting.
- Output of messages to display refresh memory.
- Scanning of switches and touchpoints.
- Outputting and receiving intercommunications with the Central Computer Unit over the IEEE 488 bus.

IDCC CRT Refresh Memory -- Since the CRT monitor has no memory, it must be re-refreshed at the 60-Hz field rate. A CRT controller circuit is used to accomplish this function. This circuit accepts data from the CPU defining the alpha-numeric characters to be

displayed on the CRT display. It then outputs the appropriate video signals to the monitor to display these characters at the 60-Hz field rate. The display field consists of 16 lines of 32 characters.

IDCC Switch Scanning -- The IDCC provides for scanning of the switches and touchpoints on the IDCC as well as the switches on the EHSI. The switches on the IDCC consist of the pushbutton switches (mode and page select) located across the top of the IDCC, the keyboard switches, the forward and back page switch, the message acknowledge switch, and the light touchpoints. The switches on the EHSI consist of the nine switches used for EHSI control, and the eight switches used for slewing the display and cursor. The switches are scanned and debounced using IC hardware. The results of the scanning are entered into the CPU via memory mapped I/O and vectored interrupts.

IDCC Keyboard -- The IDCC keyboard is mounted at the lower left corner of the IDCC. It projects outward and downward at approximately a 30-degree angle for ease of operation. The keyboard consists of 20 keys arranged in a four horizontal by five vertical matrix.

It should be noted that the keyboard has full alpha-numeric capability. Numeric entry requires only pressing one key. Alpha entries, however, require two key entry. Each key has three alpha characters in addition to the one numeral. The alpha characters are entered by first pressing the key with the triad of alpha characters that includes the desired character and then pressing one of the post designation keys, in the bottom row, to select left, middle, or right alpha character of the triad.

The keyboard is back lighted for night operation.

Pushbutton Switches -- The IDCC has 18 pushbutton switches located across the top to the unit. In the current mechanization, 14 of the 18 pushbuttons are used.

The pushbuttons are backlighted for night operation. One pushbutton (AUTO SEQ SEL) incorporates a green light indicator. The green light is on when the auto-sequence mode is on.

IDCC Touchpoints -- The IDCC incorporates touchpoints that are used to interact with the CRT display. There are eight touchpoints arranged in two vertical columns of four each. The touchpoint switches are implemented in two different configurations.

The normal touchpoint configuration is implemented with eight individual switches located in the bezel of the CRT display.

An alternate touchpoint configuration can be installed by removing the switch mounting bezel and replacing it with a plastic overlay. This overlay incorporates a touchpoint matrix that can be activated by finger pressure on the CRT face. The touchpoints in this configuration are also located in two columns of four each.

The two different configurations are electrically compatible and interface to the system thru a chassis mounted convertor.

IDCC 488 Bus Interface -- The IDCC communication with the central computer unit is over the IEEE 488 bus. The bus interface module (BIM) used in the IDCC is the same as that used in the central computer. It utilizes the TI 9914 488 bus controller IC.

IDCC Power Requirements -- The CRT monitor portion of the IDCC requires 60 watts maximum of 28 volts dc power, 28 VDC. The chassis portion of the IDCC requires approximately 2 amps of +5 volts dc. The only other power required by the IDCC is the switch lighting power derived from the 28-volt dc.

2.2.3 Electronic Horizontal Situation Indicator (EHSI)

The EHSI, Figure 2-11, consists of two basic assemblies - the CRT monitor assembly and the EHSI controls assembly. The overall dimensions of the EHSI are shown in Figure 2-12.

2.2.3.1 EHSI CRT Monitor Assembly -- The CRT monitor assembly is idential to the IDCC CRT monitor assembly. For a detailed description of the CRT monitor assembly refer to paragraph 2.1 of this report.

2.2.3.2 EHSI Controls Assembly -- The EHSI controls assembly consists of a face plate, nine pushbutton control switches, and a slew control switch subassembly.

EHSI Pushbutton Switches -- The current mechanization uses eight of the nine available pushbutton switches. The pushbutton switches are white lighted for night viewing. In addition, green lighting is provided for mode annunciation. The heading-up/north-up map orientation select switch and the map slew or cursor slew select switches are split legend annunciators. Either the top half or bottom half may be lighted green to indicate the mode selected. All other switches are full legend annunciations. Since the map return is a momentary mode, the green annunciator is not used on this switch.

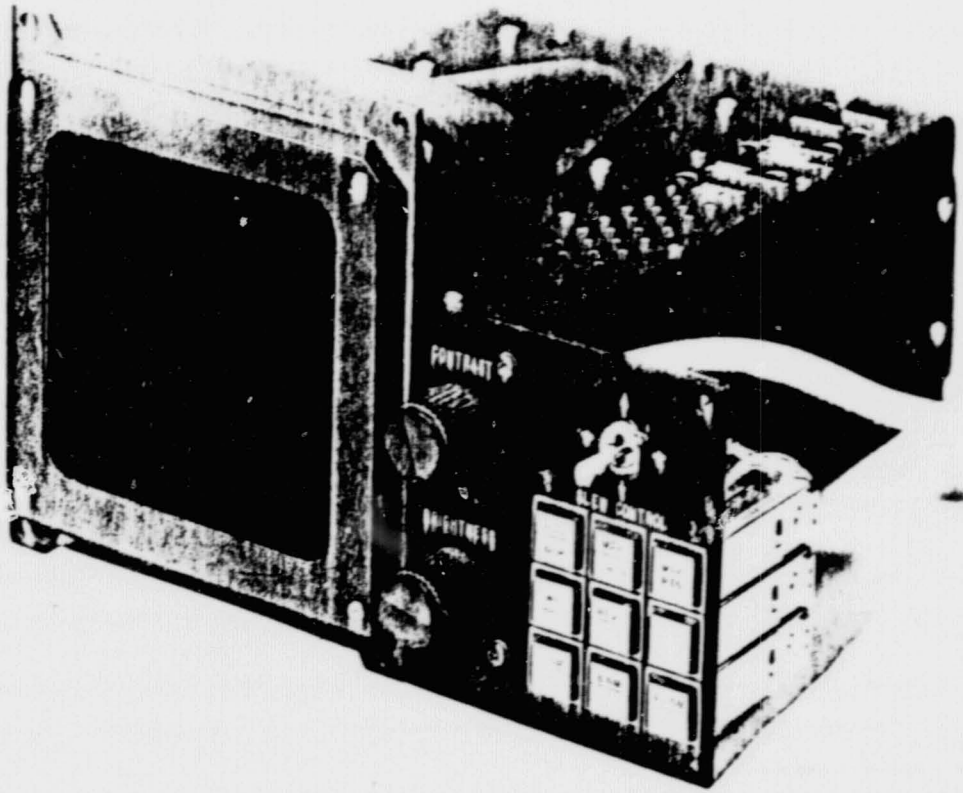

Figure 2-11. DAAS Electronic Horizontal Situation Indicator (EHSI)

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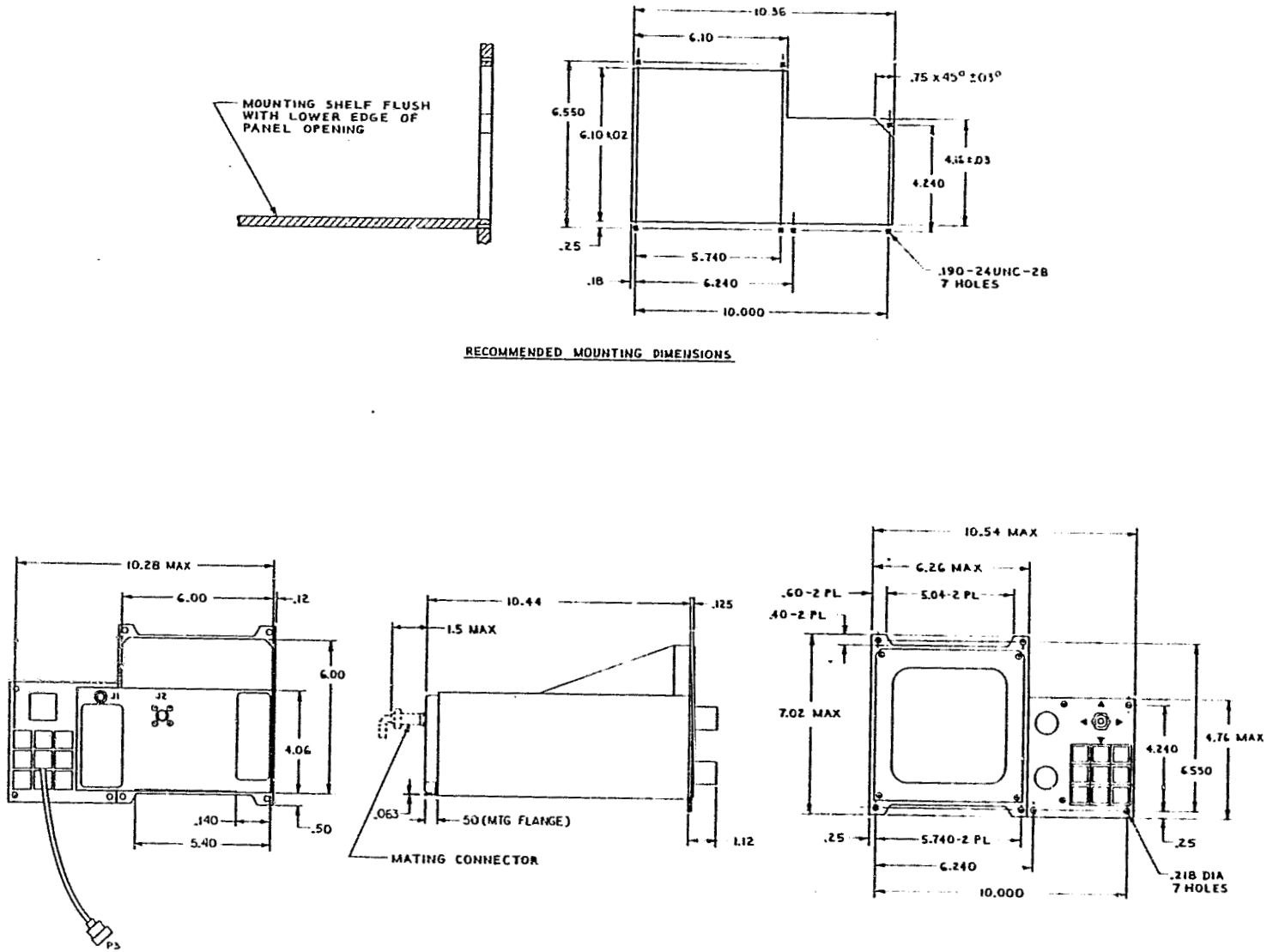

Figure 2-12. EHSI Installation Drawing

All switch actions are momentary. The mode latching is done in the IDCC CPU. As discussed in paragraph 2.2.2.2, these switches are scanned by the IDCC CPU. The IDCC CPU also controls the annunciator lighting.

EHSI Slew Control Switch -- The slew control switch consists of a single lever operating light switch. The lever is mechanically constrained so that either horizontal or vertical movement only is allowed. The lever is spring loaded to the center off position. The lever actuates one or two switches in each of the four directions, up, down, left, or right. The first switch activation causes a slow slewing effect, the second causes a fast slewing effect.

2.2.3.3 EHSI Power Requirements -- The CRT monitor portion of the EHSI requires 60 watts maximum, 28-volts dc power. The control switch portion requires only the signal level scanning power from the IDCC CPU. Nighttime lighting and annunciator lighting power for the switches is derived from the IDCC.

2.2.4 DAAS Radio Adapter Unit (RAU)

The following functions are performed by the RAU, Figure 2-13.

- Tune the radios as commanded by the DAAS computer
- Process VOR/LOC/CS data from NAV 2 and NAV 2
- Process station identifiers
- Process DME distance
- Generate a radio system status word
- Format the data for block transfer

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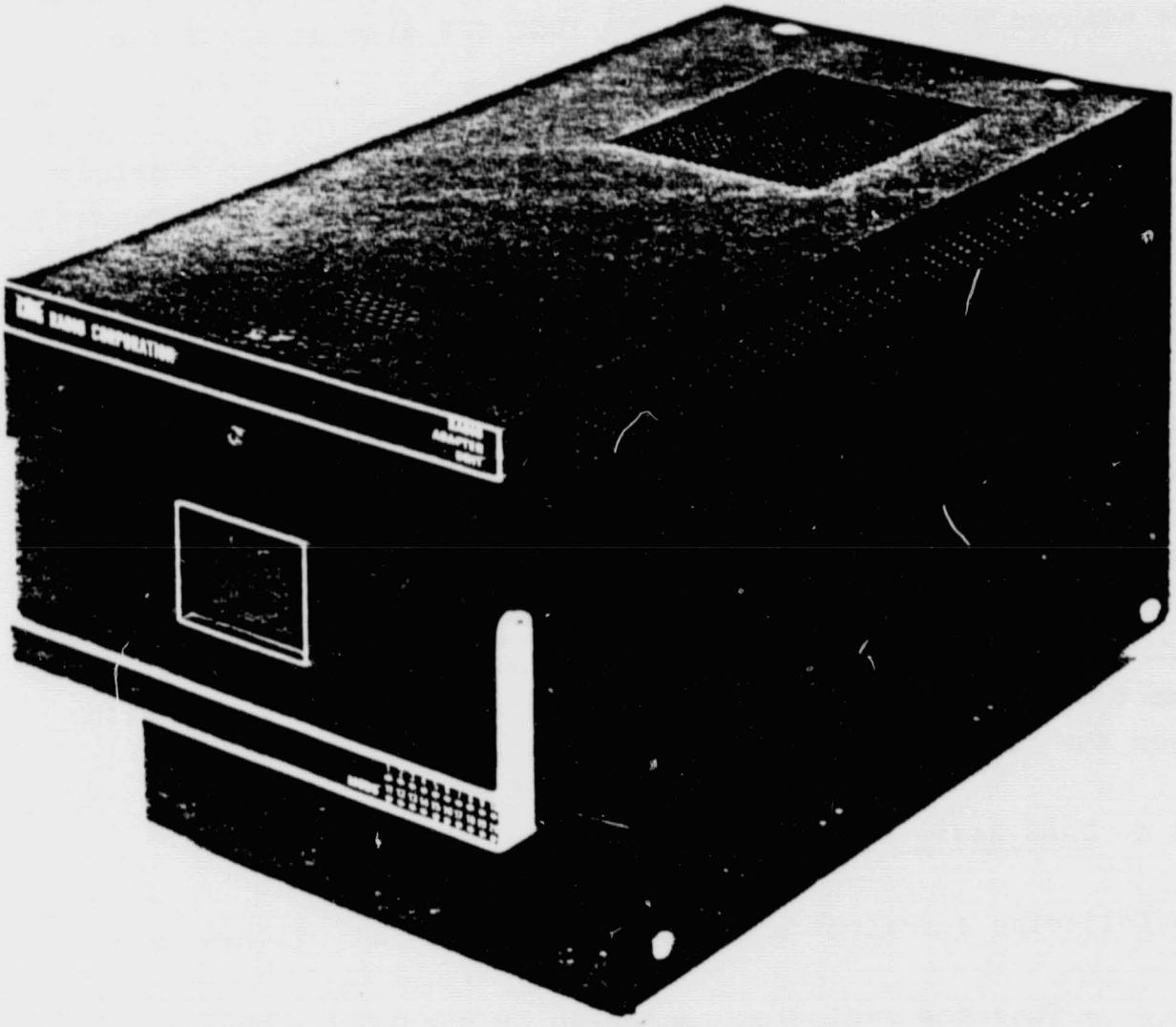

Figure 2-13. DAAS Radio Adapter Unit (RAU)

- Exchange information with the DAAS computer via the IEEE 488 bus

In addition to interfacing with the radio units, the RAU also interfaces with --

- 28-V dc aircraft power
- KMA 24 audio panel (with KA 35A)
- KCI 310 ADI (through ILS source switch)
- KI 226 RMI (through the VOR source switch)
- DME channeling switch and ILS source switch
- DAAS/Manual status switch for each NAV receiver

The DAAS system RAU uses a microprocessor system for a flexible interface for control and data processing. The interface exchanges data on the 488 bus using standard talker/listener functions and handshaking protocol. Also, the system monitors the radios, retaining and refreshing a defined data block for the data exchange process.

The processor sends the proper tuning commands to the radios, processes the received position data and transfers this data in block format to DAAS. The data block transfers occur at a fixed rate of approximately 20 updates per second as required by the bus controller.

The radio adapter unit will exchange data over the IEEE 488 bus. A dedicated general purpose interface buffer (GPIB) will handle the standard talker/listener protocol for transferring data. Data will be stored in a buffer to eliminate slowing down the

processor. Bus setup time is $\leq$ 45 μs and data transfer rate is $\leq$ 15 μs per byte.

NAV 1 and NAV 2 provide a video composite with either VOR or LOC information modulated onto the 9960-Hz subcarrier. The interface circuit identifies what type of information is present, demodulates the composite, and digitizes the result. The VOR/LOC data from NAV 1 and NAV 2 can also be displayed on the KI 226 and the KCI 310 indicators. The specific display mode is a function of the status switches.

Glideslope information is also available from the KN 53 Navigation Receivers. The signal will be conditioned in the interface for digital conversion. The digitized data will then be processed and maintained in the data block for transfer to DAAS. As with VOR/LOC, glideslope information can also be displayed on the KCI 310 Indicator. The program will select the navigation unit to be displayed when in the DAAS mode.

To validate active channels of the navigation radios, the identifiers will be read electronically, converted to the ASCII equivalent of the received Morse code, and stored as part of the data block.

The similarity in tuning procedure for the KN 53 and KY 196 allows a common method of tuning these radios. The interface simulates the actions of the front panel rotary knobs by closing increment/decrement switches electronically to change frequency. The standby frequency only is affected by the tuning switches. To change the active channel, standby is turned to the selected frequency, and an active/standby exchange is executed. The approximate worst case tuning time for a KY 196 or KN 53 to sweep full

band is 250 milliseconds. To execute an active/standby exchange, approximately 50 milliseconds is required. The hardware for tuning the KY 196 receivers is included in the RAU, but not the necessary software.

The KN 62A can be tuned by DAAS NAV 1 or NAV 2 through a common bus. Then the DAAS mode of tuning is enabled at the DME, one of these three sources will supply the DME tuning data. The DME channeling switch then enables the desired tuning source. The KN 62A tuning format is the 2 by 5 code. Approximately three seconds are required to tune the KN 62A and acquire valid distance.

To verify the auto tuning function, or to read the DME channel, data is read from the internal tune bus. This data is serial BCD information. A sync and clock are available to strobe this data into the interface.

The following switches are used by the pilot for radio system mode selection:

NAV 1	Manual/DAAS
NAV 2	Manual/DAAS
DME	NAV 1/DAAS/NAV 2
ILS Source	NAV 2/DAAS/NAV 2
VOR Source	NAV 2/NAV 2

Complete pilot backput in a manual mode of operation is assured by the Manual position of the switches.

Range information from the KN 62A is 18 bits of serial BCD data. A synchronous clock is provided to shift the data into the interface for processing. The microprocessor will convert this data

to a 15-bit binary word (LSB = 0.02 NM) and maintain the current distance code in the data block.

2.3 DAAS OPERATIONAL EVALUATION

Pilot evaluation of the DAAS functional configuration has been conducted on the DAAS flight simulator, Figure 2-14. Extensive refinement of the functional configuration has resulted. Following is a description of the simulator evaluation program and the evaluation results.

2.3.1 Summary of Results

A simulator program was conducted with the objective of determining areas where system improvement might be accomplished. Specific system improvement proposals were identified and discussed by the simulator pilot subjects and the DAAS system engineers. Changes were defined based on both their desirability and their effect on DAAS complexity.

System improvements are those changes which would enhance the operational acceptability of the DAAS pilot/system interface. An iterative approach to the simulator program allows the verification of the DAAS functional performance, including improvements as they are defined.

Simulator program change proposals were judged in light of the over-all objectives of DAAS; i.e., improve the safety and dependability of general aviation IFR operations without increasing pilot proficiency requirements or the cost of the avionics.

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Figure 2-14. DAAS Simulator

Two General Aviation pilot evaluations were conducted during the development of DAAS prior to this report. In addition, NASA Research Pilot Gordon Hardy examined DAAS frequently during DAAS development.

The first evaluation was conducted in October 1979. Three General Aviation pilots participated. The three pilots were: J. Lindberg, Instrument Flight Training, a Division of Van Dusen; R. Albertson, representing King Radio; and W. Unternaehrer, Honeywell Avionics Engineering. All three have airline type pilot ratings, although they have never flown for an airline. Two pilots, Lindberg and Albertson, are designated FAA Flight Examiners. Pilot participant experience is described in Section 3.1 of this report.

A four hour system briefing was conducted followed by one hour of simulator time for each evaluation pilot. Following this exposure to the system, a four hour debrief and discussion was conducted on all functions examined in the simulator. Comments were favorable, and a number of DAAS features were considered excellent. For example, the capability of map slewing and automatic waypoint generation received high ratings. The evaluation results were positive for the most part, though some concerns were pointed out. An example of a concern was the effectiveness of touchpoint data entry both on the ground and during flight. The problem centers around inadvertent entries and concern for difficulty making data entries during flight turbulence.

There were thirty-five pilot comments made regarding suggestions for improvements to the DAAS. Many of these have subsequently been incorporated.

The second evaluation was conducted on March 1980. Four General Aviation pilots participated. The four pilots were: D. Rodgers, King Radio; R. Albertson, King Radio; W. Unternaehrer, Honeywell; and Larry Peterson, Honeywell. A detailed briefing was performed. The pilots then flew a scenario (see paragraph 2.3.2, scenario) in the simulator which required input of initial data, navigation data, checklists, interaction with EHSI and autopilot. Man Machine Science specialists monitored each pilot in his performing the scenario. Questions and comments of a human engineering nature were recorded. Following the flights each pilot filled out a questionnaire. The combination of close monitoring during the scenario flight, the questionnaire data, and individual pilot debriefs provided comprehensive evaluation of the DAAS. This information has been assessed and the results are discussed in section 3 of this report.

The evaluation participants were generally enthusiastic about the DAAS concept and functional configuration. Access to data was considered to be significantly enhanced. Navigation, with stored data base and map display, was considered to reduce pilot workload and improve pilot capability in the terminal area. DAAS capabilities to support good pilot practices in weight and balance computations and take-off performance computation, as well as DAAS precise navigation capability, were judged to potentially improve general aviation flight safety.

Evaluators generally agreed that (1) DAAS type systems can provide greatly expanded functional capabilities, and (2) minimizing complexity and optimizing the pilot system interface is a major challenge.

2.3.2 Simulator Description

2.3.2.1 General Purpose Facility -- The DAAS simulator is a general purpose facility consisting of the following primary components:

- Data General Eclipse S/200 CPU
- Data General Nova 3/12 CPU
- 16-bit parallel DMA between above CPUs
- Datel System 256 Hybrid I/O Unit with 32 D/A and 64 A/D channels
- Discrete I/O with 16 inputs and 16 outputs
- Megatek MG552 Graphics Generator Unit
- Pace 231R Analog Computer

The Nova 3/12 CPU and Megatek graphics unit generate multiplexed alphanumeric and graphic formats with associated blanking signals to drive two independent direct-draw CRT displays. Other digital simulation tasks and hybrid I/O are performed by the Eclipse S/200.

2.3.2.2 DAAS Simulation Hardware -- The fixed base mockup of the pilot's control station includes seat, instrument panel, flight controls, and engine controls configured to the approximate dimensions in a Cessna 402. Since outside visual scene generation was not available, only IFR flight conditions were simulated.

Functional Controls -- The following pilot controls are functional in the simulator:

- Ailerons and Elevator -- Spring centered control wheel with hydraulic dampers on each axis.
- Rudder -- Spring centered pedals.
- Elevator Electric Trim Switch -- On control wheel.
- Flap Position.
- Autopilot Mode Control -- King KMC 340.
- Control Wheel Steering Switch -- On control wheel.
- Autopilot Dump Switch -- On control wheel.
- Go-around Switch -- On left throttle grip.
- Throttle -- Left lever functional.
- RPM -- Left lever functional.
- Mixture -- left lever functional.
- Gear Switch.
- IDCC Touch Panel -- Eight touch points.
- IDCC Function select Keys -- 18 keys.
- IDCC Alphanumeric Keypad -- 15 keys.
- IDCC Enter and Backspace Keys.
- EHSI Cursor Slew Control

Functional Displays -- The following pilot displays are functional:

- FDI -- King KCI 310
- EHSI -- 4 x 5-inch direct draw CRT (Tektronix Mod. 608)
- IDCC -- 4 x 5-inch direct draw CRT (Tektronix Mod. 608)
- RMI -- King KI 581
- Mode Annunciator -- King KAP 315
- Airspeed Indicator -- 2.75-inch meter with 250-deg. pointer range
- Baro Altimeter -- three pointer DC servo drive
- Vertical Speed -- 250-deg, 2.75-inch meter
- Manifold Pressure - 250-deg, 2.75-inch meter
- RPM -- 250-deg, 2.75-inch meter
- Fuel Flow -- 250-deg, 2.75-inch meter
- Aircraft Clock
- Master Caution and Warning Lights

The KI 581 Radio Magnetic Indicator, listed above, is similar in appearance to the KI 226, and was recommended by King Radio for use in the simulator. Simulated IDCC and EHSI displays differ from the 4.5-inch-square displays with in-raster symbol generation presently planned for use in DAAS. The simulator facility is currently limited to direct-draw display generation. Tektronix 608 Monitors approximate the planned for use in DAAS. The simulator facility is currently limited to direct-draw display generation. Tektronix 608 Monitors approximate the planned DAAS display dimensions to within 0.5 inch, and can be driven by the X,

Y, Z, and blanking outputs produced by the facility's existing graphics generator unit.

Installation of one King KY 196 Comm Transceiver and a KT76A Transponder in the simulator is included to provide the means for exercising these functions in the pilot's procedural sequence.

Labeled paste-ups of all remaining indicators are included on the simulated instrument to demonstrate DAAS and backup pilot panel layouts.

Simulator Hardware Interfaces -- Figure 2-15 summarized interfaces between the facility computers and control/display devices. The analog computer is used only for gain and null settings on proportional controls and DC-meter panel instruments.

2.3.2.3 DAAS Simulation Software -- Software was developed for digital simulation of the following system and environmental components:

- Aircraft and engine
- Flight control system
- Mean wind and gusts
- Ground navigation
- Navigation algorithms
- Sensor outputs
- IDCC functions, paging and display formats
- EHSI display formats
- System failures and other unplanned events

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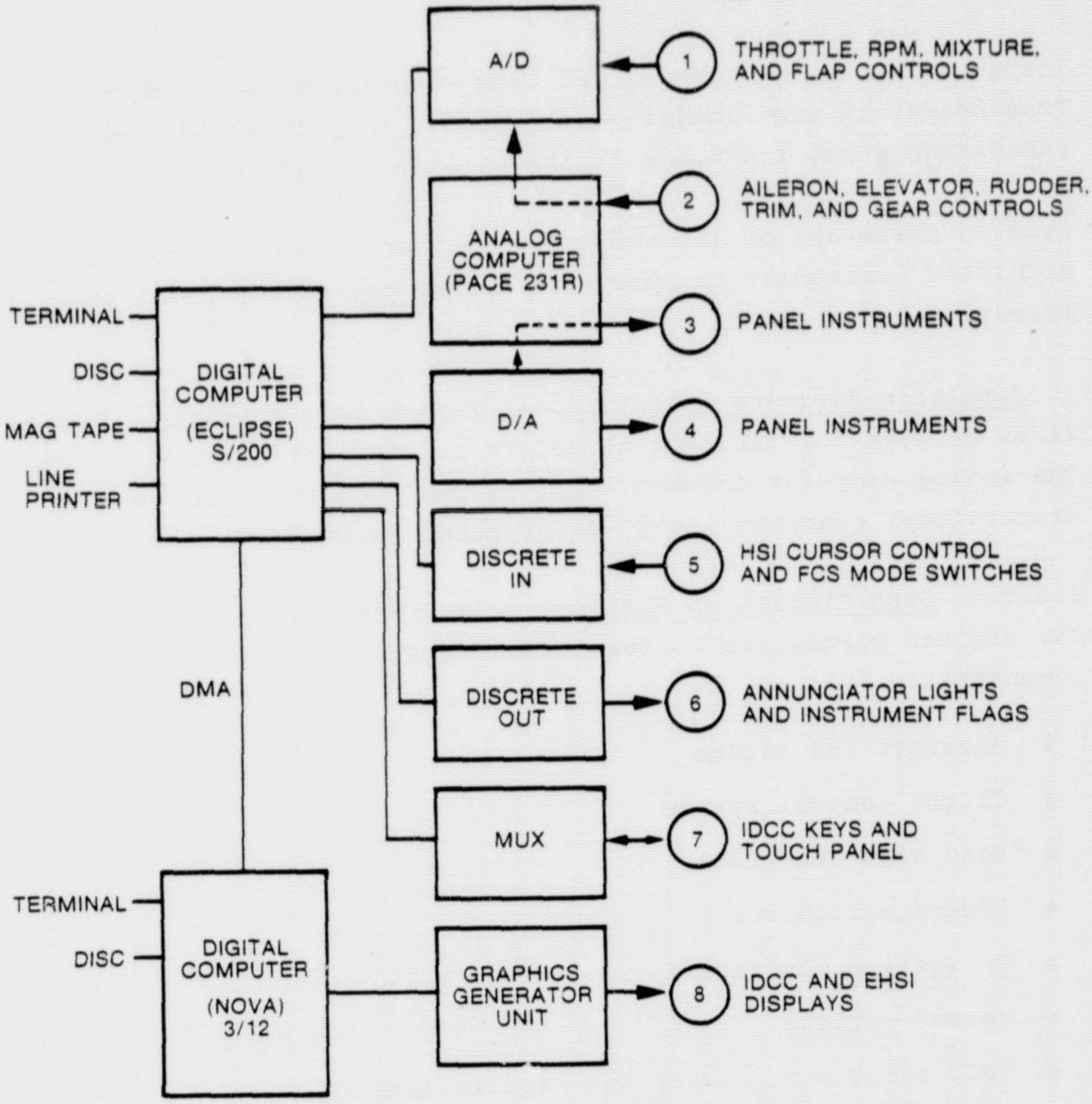

Figure 2-15. Simulator Hardware Interfaces

Digital Program Description -- The digital program is divided into a set of modules or subroutines, all sharing a common data base. This data base consists of two arrays: one real array consisting of up to 1000 real variables, and the second an integer array consisting of up to 500 integer or logical variables. Each element of the arrays is equivalenced to a mneumonic of six letters or less. The following software subroutines are included:

ARPLN -- Aircraft equations of motion

LACL -- Lateral axis control law

PACL -- Pitch axis control law

ENGIN -- Engine model

MODSL -- Mode select logic

ADC -- Analog to digital converter

SERVO -- Servo model

DISIO -- Discrete input/output processing

SNMOD -- Sensor model

ALTHLD -- Altitude hold model

NAVCM -- Navigation computations

SERIO -- Serial input/output processing

IDCC - IDCC display processing

EHSI -- EHSI display processing

INSTR -- Instrumentation signal processing

All subroutines are called by an executive routine which also controls system timing by utilizing an interrupt driven real time clock.

2.3.3 Pilot Evaluations

Several indices were used to assess the pilots' responses to the DAAS system simulation. These included observation of the pilots during the actual simulation exercise, as well as a paper-and-pencil questionnaire and informal debriefings following each session. The combination of these evaluation techniques yielded a relatively comprehensive assessment of the pilots' impressions of DAAS. These results are presented in section 4 of this report. In addition to evaluative data, the pilots were also asked to provide general background information. Each pilot was asked to fill out a brief questionnaire outlining his previous flight history and current credentials. Appendix A contains the subject profiles that were compiled from the completed questionnaires.

2.3.4 Evaluation Procedure

The DAAS evaluations consisted of four elements:

1. Pilots were briefed on the DAAS system and the aspects of it that were to be evaluated.

2. Pilots then flew the simulator following a scenario for a planned flight of approximately 15 to 20 minutes.

3. Immediately following the simulator exercise, each pilot filled out a questionnaire while elaborating verbally on their responses.

4. Debriefing by means of an informal, on-going discussion with one or more pilots present completed the evaluation procedure.

2.3.4.1 Briefing of Subjects -- Briefings were given to the DAAS evaluation pilots who were not directly associated with the design of DAAS. These briefings emphasized the functional characteristics of DAAS and the particular aspects that were to be evaluated.

The briefings followed the outline as follows:

1. Objectives of DAAS
2. Description of Controls and Displays
    - 2.1 Airspeed Indicator
    - 2.2 Attitude Director Indicator
    - 2.3 Mode Annunciator Panel
    - 2.4 Altimeter
    - 2.5 Altitude Rate Indicator
    - 2.6 Electronic Horizontal Situation Indicator and Controls
    - 2.7 Engine Instruments
    - 2.8 Integrated Data Control Center
        - 2.8.1 Display
        - 2.8.2 Touchpoints
        - 2.8.3 Page Select Buttons
        - 2.8.4 Navigation Buttons
        - 2.8.5 Keyboard
    - 2.9 Caution and Warning Lights
    - 2.10 Autopilot Control Panel
    - 2.11 Miscellaneous Controls

2.11.1 Flap Control

2.12.2 Throttle Quadrant

2.11.3 Go Around Switch

2.11.4 Trim Switch

2.11.5 Autopilot Disengage Switch

2.11.6 Control Wheel Steering Switch

3. IDCC Functions and Pages

3.1 Initialization

3.2 Weight and Balance

3.3 NAVAID Data and Storage

3.4 Waypoint Data

3.5 Flight Status

3.6 Take Off and Cruise Performance

3.7 Check Lists

3.8 Emergency Procedures

4. EHSI Functions and Features

4.1 Heading Indication & Heading Select

4.2 Display Format

4.2.1 RNAV linked

4.2.2 RNAV unlinked

4.2.3 VOR

4.2.4 ILS

4.3 Vertical Track Angle and VNAV

4.4 Waypoint Bearing Indicator

4.5 Miscellaneous Indications

MDA or DH

Waypoint in use and available

Course

Distance to Waypoint

Time to Waypoint

Waypoint Altitude

Radios in use

4.6 Heading/North Up

4.7 Map Scales

5. Navigation Features

5.1 Map Review

5.2 Map Slew

5.3 Map Return

5.4 Use Button

5.5 Course Select

5.6 Auto Sequence

5.7 Horizontal Direct To

5.8 VNAV

5.9 Waypoint Generate

5.10 Delete Waypoint

5.11 Insert Waypoint

5.12 Cursor Use

6. Attitude Director Indicator

   6.1 Horizon

   6.2 Command Bars

   6.3 Localizer Deviation

   6.4 Glide Slope Deviation

   6.5 VNAV Deviation

   6.6 MDA and DH Indicators

7. Autopilot Mode Select Panel

   7.1 Yaw Damper

   7.2 Flight Director

   7.3 Autopilot

   7.4 Altitude Arm, Hold and Trim

   7.5 VNAV

   7.6 Heading Select

   7.7 Approach

   7.8 Navigation

2.3.4.2 Evaluation Scenario, Minneapolis Area -- The evaluation scenario was planned for approximately 15 to 20 minutes of flight starting with a takeoff from the Minneapolis, St. Paul International Airport as waypoint 1; hence to waypoint 2, STILS intersection; hence to waypoint 3, RENEW intersection; hence to waypoint 4, BONNA Initial Approach Fix for an RNAV approach to Rwy 29 Right, with waypoint 5 the missed approach point located at the landing end of Rwy 29 Right. Figure 2-16, Minneapolis local area victor airway IFR map, describes the flight route.

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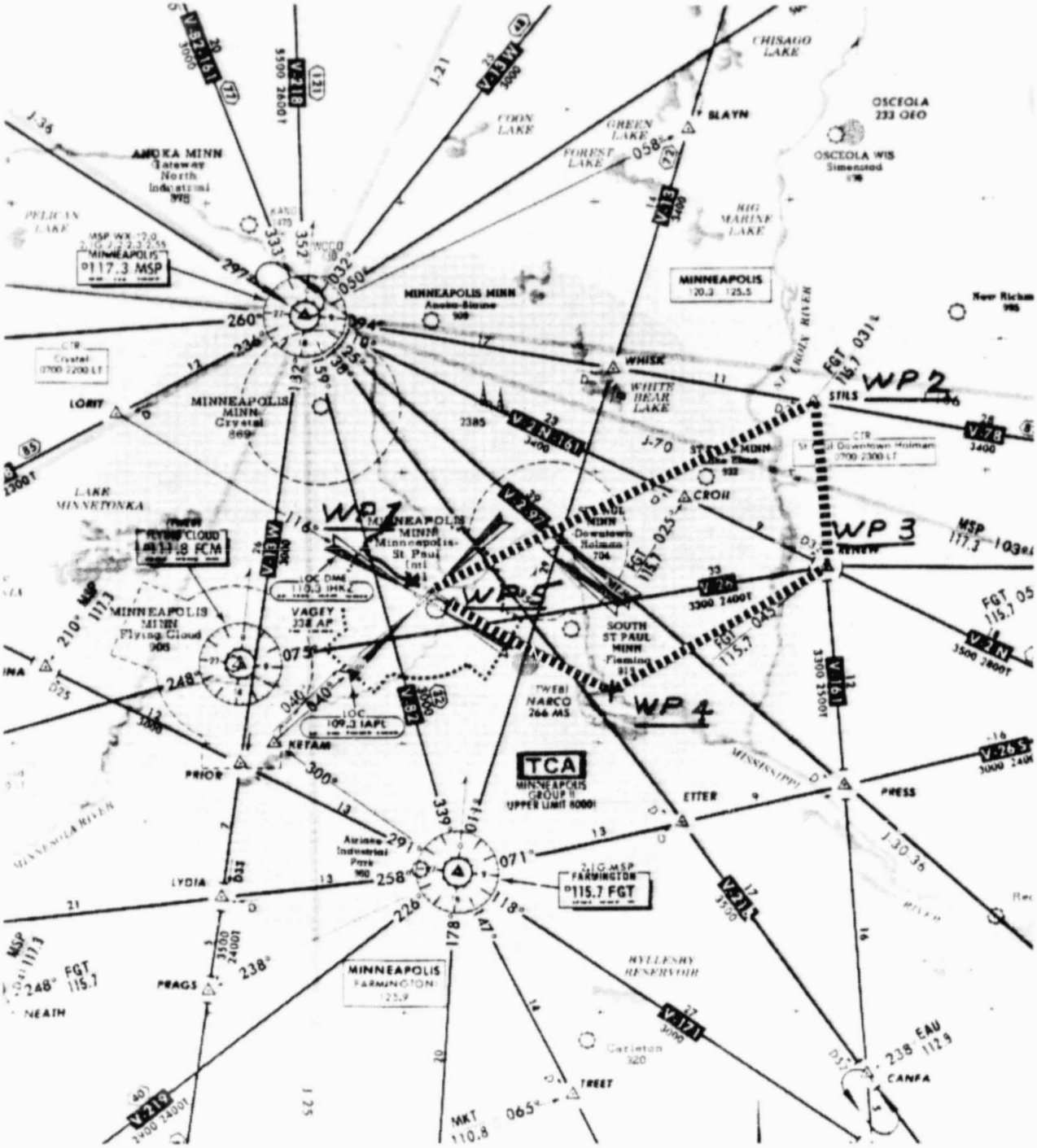

Figure 2-16. Evaluation Scenario Chart
(Minneapolis Local Victor Airway Chart)

The flight time of 15 to 20 minutes was of sufficient duration to permit the exercising of the DAAS functions. Preparation for the flight, the entry of data via keyboard into the IDCC such as take-off performance calculations, weight and balance etc., took an additional 15 to 20 minutes. Thus, the evaluation pilot was in the simulator seat for about 40 minutes, which was not long enough for either fatigue or boredom to enter the evaluation equation.

The NAVAID Data entered into DAAS is described in Table 2-1 and consists of the VOR/DME stations used for waypoint definition. Table 2-2 lists the waypoints and describes the vertical navigation profile. Figure 2-17 is the RNAV approach chart for Minneapolis, St. Paul, International Airport Rwy 29 Right.

The following is a description of the scenario in the order of actual events:

1. Review flight plan as shown in Figure 2-16.

2. Power-up system - IDCC INIT PAGE appears. Pilot enters zulu time (GMT).

3. Press MENU button and select touchpoint WEIGHT & BALANCE

4. WEIGHT & BALANCE, Pages 2 through 3 - Enter passenger, cargo and fuel weight as appropriate. Review results on page 3 to see that the calculated CG is between the forward and aft limits and that the maximum takeoff weight is not exceeded. Transfer results to INIT page.

5. Press MENU button and select touchpoint TAKEOFF PERFORMANCE.

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Table 2-1. NAVAID Data for Evaluation Scenario

NAVAID No.	Frequency I.D.	Elevation	Latitude	Longitude	Variation
1	MSP 117.3	880	N4508.7	W09322.4	6E
2	FGT 115.7	930	N4437.9	W09310.9	6E
3			N	W	
4			N	W	
5			N	W	
6			N	W	
7			N	W	
8			N	W	
9			N	W	
0			N	W	

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Table 2-2. Waypoint Data for Evaluation Scenario

DAAS Waypoint Data Sheet											
WP	NAVAID No. ID	Frequency	Elevation (Ft)	CRS1 (Deg)	CRS2 (Deg)	Radial (Deg)	Distance (NM)	Altitude (Ft)	Offset (NM)	RNAV/VOR/ILS	MDA
1	1 MSP					151.0	17.1				
2	1 MSP					094	28.0	3000	4.0		
3	1 MSP					110	32.0	4000	2.0		
4	2 FGT					035	13.0	4000			
5	2 FGT					352	15.0	1400	1.6		1400
6											
7											
8											
9											
0											

Initial Approach Fix
IAF

Missed Approach Point
(MAP)

MDA

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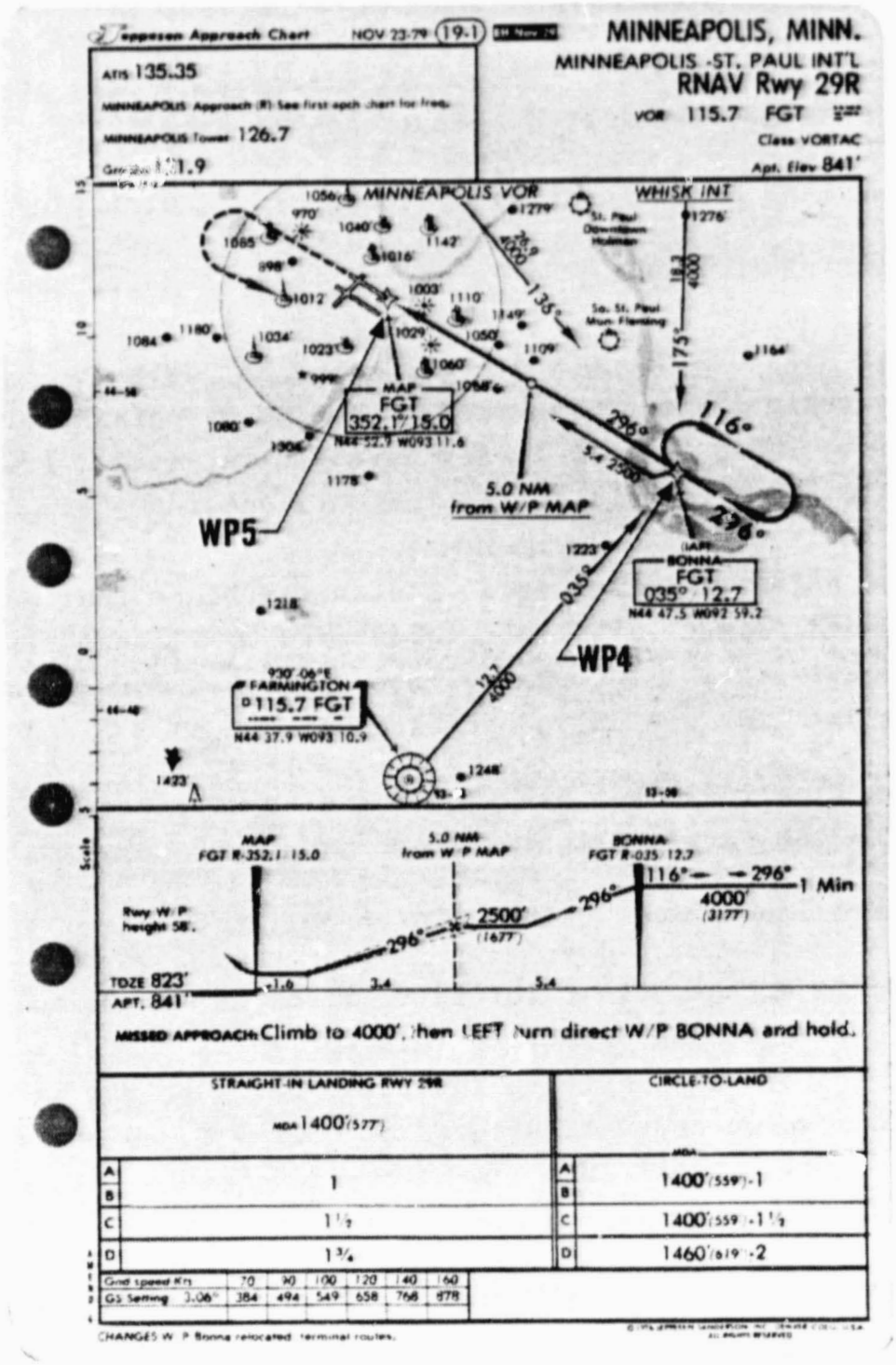

Figure 2-17. Minneapolis-St. Paul International RNAV Rwy 29 Right

6. TAKEOFF PERFORMANCE - Enter all appropriate data for takeoff. Review results of computation on page 2.

7. Press MENU button and select touchpoint CRUISE PERFORMANCE

8. CRUISE PERFORMANCE - Enter appropriate data for cruise.

9. Press NAVAID DATA button - enter VOR/DME data for appropriate NAVAID stations required to define waypoints for flight planned. See Table 2-1 for NAVAID data entry. Press NAVAID SUM button to review the data entered.

10 Press WAYPOINT DATA button - enter waypoints that define intended flight. Review data entered by flipping through waypoint pages 1 through 5. See Table 2-2 for waypoint (WP) data for evaluation scenario.

11. Using Electronic Map Slew lever and appropriate map scales, review the entire flight.

12. Prepare for takeoff using IDCC checklists.

13. Takeoff; engage auto pilot after airborne; climb to 400 feet; use heading select to turn for an intercept with course 1 of WP2; activate autopilot NAV ARM; and as aircraft couples and settles down on course 1, select autopilot VNAV. Press AUTO SEQ button for course 1 to switch automatically to course 2.

14. Halfway to WP3, make WP3 active and press USE button.

15. Press FLIGHT STATUS button for true airspeed, ground speed, wind, ETA, and fuel available.

16. Halfway to WP4, make WP4 active and press USE button.

17. Waypoint 4 is BONNA, the initial approach fix (IAF) for approach to Rwy 29 Right. At 3 miles from WP4, slow aircraft to 120 kts and review landing checklist. See Figure 2-17, RNAV Approach Chart Minneapolis Rwy 29 Right.

18. Over WP4, extend landing gear and flaps.

19. Select WP5 MAP active and press USE button.

20. Monitor indicated airspeed to 100 kt and glide slope to about 3 degrees on the EHSI Vertical Track Angle indicator.

21. At the minimum descent altitude (MDA) the aircraft goes to altitude hold and passes over WP5 MAP. End of evaluation scenario.

2.3.4.3 Post-Scenario Questionnaire -- A post-scenario questionnaire was developed to provide quantitative assessment of pilot response to the human factors characteristics of the DAAS simulation scenario exercise. Rating scales were used to assess responses to overall system operation, as well as specific characteristics of the IDCC and EHSI keyboards and displays. The questionnaire addressed each of the following areas:

- Overall System Operation
  - Workload assessment
  - Adequacy of information provided
  - Relevancy of information provided
  - Time assessment
  - Potential training requirements

    - Time
    - Method (simulator versus isolated CRT displays)

- IDCC Keyboard and Display

  - Ease of data entry

    - Time required
    - Keyboard location
    - Keyboard format

  - Adequacy of information displayed

    - Major functions/menu selections
    - Feedback for error corrections

- EHSI Keyboard and Display

  - Ease of data entry

    - Waypoint insertion
    - Keyboard location

  - Adequacy of information displayed

- General Comments

The post-scenario questionnaire was given to each pilot immediately following the simulation exercise. Administration of the questionnaire was informal, and verbal comments from the pilot elaborating on their responses to each item were encouraged. Thus, the questionnaire also served as a point of departure for the debriefing discussions which followed.

2.3.4.4 Debriefing -- Debriefing involved informal ongoing discussion with one or more of the pilots present at any given time. Thus, pilots were able to discuss the simulation from several

viewpoints. The result was an indepth analysis of both the functional characteristics of DAAS and its general acceptability as a future on-board system.

2.4 FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

The intention of this FMEA is to analyze the effects of failed DAAS elements, the probability of the failures, and how the pilot workload and the flight safety situation are affected by the failures. The importance of the safety pilot is discussed. DAAS compatibility to FAR Parts 23 and 91 is also assessed.

Assessment of DAAS compliance with FAR requirements, and analysis of failure effects in general can be summarized as follows:

- <u>Failure Effects with Respect to FAR Requirements</u>

  - Of the 86 DAAS elements analyzed, FAR Parts 23 and 91 VFR and IFR CAT 1 requirements are applicable to 36. There are no conflicts for fault-free DAAS.

  - 25 DAAS elements may fail without violating any FAR requirements.

  - 11 failed elements violate FAR 23.1329.e for the initial DAAS design. These 11 failures violate FAR 23.1329e which says:

    "Each system must be designed so that a single malfunction will not produce a hardover signal in more than one control axis."

Recommendation -- The FAR 23.1329.e conflict was resolved by introducing 3 hardware limiters located down stream of the pitch, roll, and yaw D/A converters. These limiters will prohibit any DAAS computer failure from commanding the servos hardover.

- Failure Effects, General -- The 86 DAAS elements were split into the 4 failure categories:

  22 Elements - Category 1, Failure Effects Negligible

  36 Elements - Category 2, Failure Effects Inconvenient

  26 Elements - Category 3, Failure Effects Demanding

  2 Elements - Category 4, Failure Effects Critical

The two critical failures are Aircraft 28-Vdc and Avionics 28-Vdc bus. The category 4 failure probability is very low, less than 10^{-6} for a 4-hour flight.

Recommendations

1. The DAAS failure effects are not critical with the exception of the Aircraft and Avionics 28-Vdc bus failure. The probability of these failures happening is low enough to make them negligible. No action required.

2. Flight safety is dependent on the safety copilot. He should closely monitor the DAAS performance, especially at low altitude, take-off, and landing conditions.

Following are the details of the analysis including description of the DAAS system analyzed, assessment of DAAS compliance with FAR requirements, and description of the FMEA results.

2.4.1 DAAS System Description

The present DAAS is defined in the following documents:

1. Functional description, NASA DAAS Phase 2, dated October 15, 1980.

2. DAAS System Specification (YG1210) preliminary copy December 1979.

3. Software requirements for the DAAS FCS, Version 5, October 1979.

4. Miscellaneous diagrams and papers describing the Cessna 402B cockpit, servos, etc.

2.4.2 Assessment of Compliance With FAR Requirements

FAR Parts 23 and 91 are applicable to DAAS. The applicable FAR paragraphs are restated below and comments given as to how they are net by DAAS.

2.4.2.1 FAR Part 23 Equipment, Systems and Installations -- The DAAS, when installed in the aircraft, must meet the following restated FAR Part 23 requirement:

Requirement, 23.1309

(a) Each item of equipment, when performing its intended function, may not adversely affect:

(1) The response, operation, or accuracy of any equipment essential to safe operation; or

(2) The response, operation, or accuracy of any other equipment unless there is a means to inform the pilot of the effect.

(b) The equipment, systems, and installations of a multiengine airplane must be designed to prevent hazards to the airplane in the event of a probable malfunction or failure.

(c) The equipment, systems, and installations of a single-engine airplane must be designed to minimize hazards to the airplane in the event of a probable malfunction or failure.

Comment:

The DAAS development program should eliminate adverse affects specified in item a. Tests in simulators, qualifications tests, and checkout in the aircraft shall verify that no undesired interaction exists.

The DAAS design and included limiters, monitors, warnings, etc., satisfy the item b or c requirements.

2.4.2.2 FAR Part 23, Requirements of the Autopilot -- The Autopilot (sensors, computer, servos) must meet the FAR Part 23.1329 requirement as follows:

Requirement, 23.1329 a to g

(a) Each system must be designed so that the automatic pilot can;

(1) Be quickly and positively disengaged by the pilots to prevent it from interfering with their control of the airplane; or

(2) Be sufficiently overpowered by one pilot to let him control the airplane.

b, c, g requires a certain cockpit design in order to eliminate pilot confusion and simplify use of the autopilot.

a,d,e,f requires a certain system design to minimize the impact of autopilot malfunction.

Comment:

The autopilot dump switches (control wheel, N_z-accelerometer) and the slip clutch included in the elevator, aileron, and rudder servos provide the required protection.

The slip clutches are designed to prevent excessive accelerations.

Requirement 23.1329 b

(b) Unless there is automatic synchronization, each system must have a means to readily indicate to the pilot the alignment of the actuating device in relation to the control system it operates.

Comment:

The position of the control wheel, pedals and the trim indicators indicate the alignment.

Requirement 23.1329 c

(c) Each manually operated control for the system operation must be readily accessible to the pilot. Each control must operate in the same plane and sense of motion as specified in 23.779 for cockpit controls. The direction of motion must be plainly indicated on or near each control.

Comment:

DAAS panel layout agrees with the FAR requirements.

Requirement 23.1329 d

(d) Each system must be designed and adjusted so that, within the range of adjustment available to the pilot, it cannot produce hazardous loads on the airplane or create hazardous deviations in the flight path, under any flight condition appropriate to its use, either during normal operation or in the event of a malfunction, assuming that corrective action begins within a reasonable period of time.

Comment:

Met by

1. Software limiters, 3-axis
2. Software "faders" in pitch and roll

3. Slip clutches

4. Pitch trim monitor

5. The Nz> "1G-Dump accelerometer".

Requirement 23.1329 e

(e) Each system must be designed so that a single malfunction will not produce a hardover signal in more than one control axis. If the automatic pilot integrates signals from auxiliary controls or furnished signals for operation of other equipment, positive interlocks and sequencing of engagement to prevent improper operation are required.

Comment:

This requirement can be met by implementation of hardware servo command limiters. (Note: Limiters have been added to flight system.)

Requirement 23.1329 f

(f) There must be protection against adverse interaction of integrated components, resulting from a malfunction.

Comment:

Met by

1 . Buffers eliminating part damage.

2. Limiters and monitors eliminating excessive commands.

Requirement 23.1329 g

(g) If the automatic pilot system can be coupled to airborne navigation equipment, means must be provided to indicate to the flight crew the current mode of operation. Selector switch position is not acceptable as a means of indication.

Comment:

The annunciator panel provides the requested information.

2.4.2.3 FAR Part 91, Instruments, and Equipment Requirements -- FAR Part 91.33, a to e, specifies instrument and equipment required for powered civil aircraft with U.S. air worthiness certificates as follows:

91.33 (a) General

(b) VFR flight, day

(c) VFR flight, night

(d) IFR flight, category I

(e) IFR flight, category above 24,000 feet

(f) IFR flight, category II

IFR category II is not applicable to DAAS.

The requirements are summarized as follows.

Requirement 91.33b

(b) Instruments required for VFR Flying, Day

(1) Airspeed indicator.

(2) Altimeter.

(3) Magnetic direction indicator.

(4) Tachometer for each engine.

(5) Oil pressure gauge for each engine using pressure system.

(6) Temperature gauge for each liquid-cooled engine.

(7) Oil temperature gauge for each air-cooled engine.

(8) Manifold pressure gauge for each engine.

(9) Fuel gauge indicating the quantity of fuel in each tank.

(10) Landing gear position indicator, if the aircraft has a retractable landing gear.

Comment -- The DAAS instrumentation includes the basic instruments required for VFR flight during daytime.

Requirement 91.33c

(c) For VFR night flights additional lights and an anticollision light system are required.

Comment -- It is assumed that the DAAS aircraft is properly equipped in this respect.

Requirement 91.33d

(d) For IFR flight the following instruments and equipment are required:

(1) Instruments and equipment specified in paragraph (b) of this section and for night flight, instruments and equipment specified in paragraph (c) of this section.

(2) Two-way radio communications system and navigational equipment appropriate to the ground facilities to be used.

(3) Gyroscopic rate-or-turn indicator.

(4) Slip-skid indicator.

(5) Sensitive altimeter adjustable for barometric pressure.

(6) A c ock displaying hours, minutes, and seconds with a sweep-second pointer or digital presentation.

(7) Generator of adequate capabity.

(8) Gyroscopic bank and pitch indicator (artificial horizon).

(9) Gyroscopic direction indicator (directional gyro or equivalent).

Comment -- The above listed instrumentation are included in DAAS. There is no requirement on redundancy stated in this paragraph.

Requirement 91.33e

(e) IFR flight at and above 24,000 feet MSL.
If VOR navigational equipment is required under paragraph (d) (2) of this section, no person may operate a U.S. registered civil aircraft within the 50 states, and the District of Columbia, at or above 24,000 feet MSL unless that aircraft is equipped with approved distance measuring equipment

(DME). When DME required by this paragraph fails at and above 24,000 feet MSL, the pilot in command of the aircraft shall notify ATC immediately, and may then continue operations at and above 24,000 feet MSL to the next airport of intended landing at which repairs or replacement of the equipment can be made.

2.4.3 DAAS Failure Modes and Effects Analysis Results

The DAAS FMEA was conducted to determine effects of failures in the DAAS hardware. Assumptions for the analysis were as follows:

- DAAS is designed for category I IFR operation
- All single failures and dual failures with high failure rates are studied.
- Any failure in any element is assumed to result in a lost function of that element, which makes this a "worst case" analysis.
- The autopilot slip-clutches, the pilot (and N_z) dump switches, and the pilot and copilot override possibilities provide the pilots adequate means to safely handle any single control axis hardover servo failure.
- The probability of a critical situation less than 10^{-6} in a 4-hour flight is judged to be negligible.
- Preflight test and inflight bit are performed. Autopilot dump switching, normal acceleration dump switch, and servo clutch switches must be checked.

The preflight test coverage will be less than 100 percent due to nontestable elements. Expected fault detection coverage is:

Sensors	70-80%
Computers	90-95%
Indicators and Servos	80-90%
Monitors, Dump Switches, Clutches	100%

Some takeoffs may take place with faulty system elements due to less than 100 percent preflight test coverage.

- Effective DAAS software validation will be performed.

- The four Failure Categories are:

  1. Negligible to the pilot
  2. Inconvenient to the pilot
  3. Demanding to the pilot
  4. Critical, evident risk for catastrophe

  Fault categorization assumes a single pilot. In the conclusions, judgments are given on how the safety pilot improves the DAAS flight-safety situation and how failure probabilities affects the DAAS flight safety situation.

- FAR Part 23 and 91 requirements are assumed to define a minimum avionics system, which is normally safe to fly.

- DAAS failure rates used in the FMEA are as listed in Table 2-3. The failure rate is the probability of a failure in a DAAS element during 1 hour flight.

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Table 2-3. DAAS Elements Failure Rates

Elements	Type No.	Quantity n	Failure Rates	Total Rates	Comments
1. DAAS Elements Hardwired to DAAS-Computers					
Bubble Memory		1	500	500	
CPU & RAM/PROM	8086	7	60	420	(20 and 80%)
Radio Adapt. Box	(8748)	1	40	40	
BIM	(9914)	8	12	96	
488-Bus		1	1	1	Incl. 2 Connectors
A/D, D/A, Mux		1	60	60	
EHSI		1	300	300	
IDCC		1	300	300	
IDCC Keyboard		1	50	50	
ADI	EC1310	1	340	340	
RMI	KZ226	1	330	330	
CX-Sens. & Indic.		1	100	100	
Pitot System L		1	50	50	Not electrically hardwired!
Encod. Altim.	-571	1	200	200	
Audio Cont. Panel	KMA 24	1	200	200	
Comm. Tranceivers	KY196	2	330	660	
VOR Receivers	KN53	2	250	500	
DME Receivers	KN62A	1	500	500	
Transponder	KT76A	1	400	400	
Mode Controller	KMC-340	1	340	340	
Annunciator Panel	KAP-315	1	30	30	
MAG X MTR	KMT112	1	20	20	
Directional Gyro	KSG105	1	330	330	
Slave Control	KA-51A	1	10	10	
Vertical GYRO	VG 208	1	330	330	
Radar Altimeter	RT-271	1	500	500	
ADC	KDC-380	1	200	200	
True Air Speed	VA 210	1	100	100	Incl. F/V Converter
Outer Air Temp.		1	10	10	Incl. Sign. Conditioning
Yaw Rate GYRO	GG 2472	1	50	50	
Engine Map		2	5	10	
Engine RPM		2	10	20	Incl. F/V Converter
Engine Fuel Flow		2	5	10	
Cowl Flap Pos.		2	5	10	
Flap Pos.		1	20	20	
Elev. Trim Pos.		1	20	20	
Yaw Servo		1	70	70	Incl. Clutch & Amplif.

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Table 2-3. DAAS Elements Failure Rates (2 of 2)

Elements	Type No.	Quantity n	Failure Rates	Total Rates	Comments
Roll Servo		1	70	70	Incl. Clutch & Amplif.
Pitch Servo		1	70	70	Incl. Clutch & Amplif.
Pitch Trim Servo		1	50	50	Incl. Clutch & Amplif.
2. DAAS Instrumentation not Hardwired to DAAS Computers					
IAS		1	280	280	Pitot System L.
VSI		1	100	100	Pitot System L.
Turn & Bank		1	150	150	
Fuel Quantity		1	150	150	
Map		1	10	10	
RPM		1	10	10	
Fuel Flow		1	10	10	
EGT		1	10	10	
Engine Status		2	20	40	
3. Co-Pilot Back Up Instrumentation					
Pitot System R		1	50	50	
IAS		1	280	280	
Altimeter		1	180	180	
VSI		1	100	100	
Turn & Bank		1	150	150	
Artific. Horizon	KG258	1	670	670	
PNI	KC525A	1	330	330	
Slave CTRL	KA-51A	1	10	10	
Direct. GYRO	KG102-A	1	400	400	
MAG X MTR	KMT112A	1	20	20	
Comm. Tranceiver	422A	1	660	660	
VOR/GS, Receiver	442A/443A	1	500	500	Incl. Nav. Converter
4. Electrical Power System					
A/C 28VDC Bus		1	<.1	<.1	Redundant Alternators
Avionics 28VDC Bus		1	<.1	<.1	pilot disconnect faulty battery!!
DAAS A 28VDC Bus		1	~.1	~.1	Valid as long as DAAS
DAAS B 28VDC Bus		1	~.1	~.1	Battery Lasts (~1 hr.)
DAAS Battery Chrgr		1	5	5	
DAAS Battery		1	100	100	
DC/AC Invertor		1	10	10	
DC/DC Converter		2	15	30	

For the failure probability estimates, 4 hours flight time are assumed.

The failure rates in Table 2-3 are collected from adjusted MIL-HDB-217B data, vendors reliability data, Honeywell predicted failure rates and by comparison to known similarly complex elements.

The failure rates should be representative of components and parts available in 1979/80.

FMEA results are compiled in Appendix B. The DAAS elements are defined on these forms and the type of failure and the failure-rates are also listed. The impact of a faulty element on downstream DAAS elements is also indicated.

Finally, a judgment is made as to how the failed element will increase the pilot effort required to complete his flight. The failures are divided into the four categories on the basis of this judgment.

The DAAS failure category is assigned assuming a co-ilot in the right seat.

Appendix B also indicates whether:

- FAR requirement are applicable and met.
- Failure probabilities are significant to the risk situation.
- DAAS would be safe to fly with the analyzed element faulty.

The FMEA covers the consequences of 86 failed DAAS elements.

Table 2-4 summarizes failure categories and indicates whether applicable FAR requirements are met. Comments on redundancy, failure probability, etc., are given for some failed elements.

These FMEA results indicate that fault-free DAAS meets the FAR Part 23 and 91 requirements. DAAS does provide the required means for override and disengage after a failure.

FAR requirements may more or less be violated if DAAS elements fail. Of the 86 failed DAAS elements studied, FAR VFR or IFR Cat I requirements apply to 36. For these 36 failed elements, 11 violate the FAR requirements. FAR requirements that apply to general VFR flight, and 6 of these are not met. 13 requirements applying to IFR Cat I, 5 are not met. 16 requirements apply to IFR Cat II; DAAS is not certified for Category II.

The violated paragraph is 23.1329(c) which says:

> "Each system must be designed so that a single malfunction will not produce a hardover signal in more than one control axis."

Violation occurs for failures in:

- A/P, NAV, Bus Controller, Processors
- 488-Bus

Table 2-4. Summary of the DAAS Failure Modes and Effects Analysis

Failure No.	Element	Far Req. Met	Failure Category	Comments
1	Encod. Altimeter	OK Cat 1	3	Misleads ATC Proximity W-Error
2	Altimeter Co-Pilot	OK Cat 2	2	
3	Radar Altimeter	OK	2	
4	TAS	N/A	2	
5	IAS Pilot	OK Cat 1	2	
6	IAS Co-Pilot	OK Cat 2	1	
7	ADC (380)	N/A	2	Min. Alt. for ALTH Recommended
8	Pitot System L	OK Cat 1	3	
9	Pitot System R	OK Cat 2	1	
10	Oat	N/A	2	
11	Pilot Mag. XTMR	OK Cat 1	3	
12	Pilot Slave Indic.	N/A	1	
13	Pilot Direct GYRO	OK Cat 1	3	
14	Pilot RMI	OK Cat 1	2	
15	Co-Pilot Mag. XTMR	OK Cat 2	1	
16	Co-Pilot Slave Indic	N/A	1	
17	Co-Pilot Direct GYRO	OK Cat 2	1	
18	Co-Pilot PNI	OK Cat 2	1	
19	Pilot Turn & Slip	OK Cat 2	1	
20	Co-Pilot Turn & Slip	OK Cat 2	1	
21	Yaw Rate GYRO	N/A	2	
22	X-Sensor & Indicator	N/A	2	
23	Pilot Vertical-GYRO	OK Cat 1	2	
24	Pilot ADI	OK Cat 1	2	
25	Co-Pilot Artif. Horiz.	OK Cat 2	1	
26	Map Instrument	OK Cat 2	2	
27	RPM Instrument	OK Cat 2	2	
28	EGT Instrument	N/A	2	
29	Eng. Status 1	OK Cat 2	3	Pilot Action
30	Eng. Status 2	OK Cat 2	3	As if Engine Failure
31	Fuel Flow Sens. 1	N/A	2	
32	Fuel Flow Sens. 2	N/A	2	

Table 2-4. Summary of the DAAS Failure Modes and Effects Analysis (Sheet 2 of 3)

Failure No.	Element	Far Req. Met	Failure Category	Comments
33	Fuel Quantity	OK Cat 2	2	
34	DAAS Map Sensor	N/A	1	
35	DAAS RPM Sensor	N/A	1	
36	Wing Flp. Pos. Sens.	N/A	1	
37	Elev. Trim Pos. Sens.	OK	1	Redundant info. available
38	Cowl Flps. Pos. Sens.	N/A	1	
39	LDG Gear Pos. Sens.	N/A	1	
40	Door Pos. Sens.	N/A	1	
41	Aux. Fuel Pump Sw.	N/A	1	
42	Cws-Switch & Logic	OK	3	A Software Controlled CWS Light Recommended
43	Go-Around Switch	N/A	3	
44	Pitch Trim Switch	N/A	2	
45	Pitch Trim Button	N/A	3	Runaway Not Monitored
46	A/P Dump Sw. & Relay	OK	3	2 Failures Probab. $\sim 10^{-7}$
47 a	Co-Pilot Comm. Transievers, Antennas	OK	1	Duplex Probab. $\sim \zeta \cdot 10^{-6}$
b	Co-Pilot Comm. Transievers, Antennas	OK	1	
48 a	Pilot Nav. Receiver + Antennas	OK Cat 2	2	
b	Co-Pilot Nav. Receiver + Antennas	OK Cat 2	1	
49	DME Receiv. + Ant.	OK Cat 2	2	Single DME
50	Transponder + Ant.	N/A	1	No Outsignal ATC Problem!
51	Audio Headsets	OK	2	DAAS Duplex
52	Switch Nav 1 Sel.	N/A	2	
53	Switch Nav 2 Sel.	N/A	2	
54	Switch DME Sel.	N/A	2	
55	Switch VOR Sel.	N/A	1	
56	Switch Loc/GS Sel.	N/A	2	
57	IDCC Keyboard	N/A	3	Missed Pilot Input Check. Low Probability
58	IDCC Selector Switch	N/A	2	
59	IDCC CPU, Display	N/A	2	
60	EHSI Selector Switch	N/A	2	

Table 2-4. Summary of the DAAS Failure Modes and Effects Analysis (Sheet 3 of 3)

Failure No.	Element	Far Req. Met	Failure Category	Comments
61	EHSI CPU, Display	N/A	2	
62	Annunciator Panel	OK	2	
63	Mode Cont. Trim/Hdg.	OK	2	
64	Mode Cont. Toggle Sw.	OK	2	
65	Mode Cont. Solen. Sw.	OK	2	
66	A/P Yaw Clutch, Servo	OK	2	
67	A/P Roll Clutch Servo	OK	3	
68	A/P Pitch Clut. Servo	OK	3	
69	A/P Pitch Trim Servo	OK	3	
70	Clutches Common Logic	OK	3	
71	A/P-I/O CPU, BIM A/P-I/O A/D, D/A, MUX	NOT OK	3	Fault During Critical Fault Phases
72	NAV/FLT PLN CPU, BIM	NOT OK	2	Probab. No Recon. $30 \cdot 10^{-5}$ Probab. Recon. $6 \cdot 10^{-5}$
73	Spare CPU, BIM	N/A	2	Probab. $<10^{-6}$
74	Radio Adapter Box and BIM	N/A	3	Critical Fault Phase
75	Dabs Transponder CPU + BIM	N/A	1	ATC Problem
76	BUS. Controller CPU, BIM	NOT OK	3	Uncertain Warn.
77	488 Bus	NOT OK	3	Critical Fault Phase
78	Bubble Memory	NOT OK	3	Probab. $<10^{-6}$
79	Cassette	NOT OK	3	Efficient Bite Probab. $<<10^{-6}$
80	A/C Main 28 VDC Bus	OK 1)	4	Probab. $<10^{-7}$
81	Avionics 28VDC Bus	OK	4	Probab. $<10^{-7}$
82	DAAS A-B 28VDC Bus.	NOT OK	3	Probab. $<10^{-7}$
83	DAAS AC Buses	NOT OK	3	Probab. $\sim 10^{-5}$
84	DAAS 15V DC Bus	NOT OK	3	Probab. $\sim 10^{-5}$
85	DAAS 12 DC Bus	NOT OK	3	Probab. $<<10^{-6}$
86	DAAS 5 DC Bus	NOT OK	3	Probab. $\sim 10^{-5}$

1) CESSNA 402B electrical power system with DAAS installed assumed to meet applicable Far requirements.

- Bubble Memory and Cassette
- The Electrical Power Buses

The 23.1329(e) conflict was resolved by introducing three hardware limiters located immediately downstream of the pitch, roll and yaw A/D converters in the DAAS hardware. These limiters prohibit any kind of DAAS computer failure from commanding servo hardover. The limiters reduce any DAAS computer hardover failures to:

- Pitch - 60% Full Scale
- Roll - 30% Full Scale
- Yaw - 45% Full Scale

Appendix B contains the complete Failure Modes and effects analyses. Eighty-six failures were defined and categorized as follows.

Category 1 - Failures are negligible to the DAAS pilot; e.g., copilot instruments, door switches, etc.

Category 2 - Failures that cause inconvenience to the DAAS pilot; e.g., loss of ADC-380 RMI, α -Sensor, Annunciator Panel.

Category 3 - Failures during busy or critical flight-phases which can be demanding to the DAAS pilot; e.g., IDCC keyboard, engine/status instrument, servos, autopilot dump switch, autopilot processor, bus, and electric power.

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Category 4 - Failures that may create a critical situation. The two DAAS Category 4 failures a e loss of the Aircraft and Avionics 28-Vdc Bus. The probability of occurrence is very remote.

Table 2-5 summarizes the number of failures that fall within these failure categories.

Table 2-5. Failure Categorization of the DAAS Elements

	Failure Category			
	1	2	3	4
Number of DAAS Elements	22	36	26	2

The DAAS Category 4 failures have a very low probability of 10^{-6}. They are negligible.

Autopilot Processor failures are demanding during especially low altitude flight phases. The probability of such a failure may be 10^{-5} for a 4-hour flight. It is vital to the DAAS flight safety that the copilot closely monitors the DAAS performance during such conditions.

The DAAS FMEA concludes that, with servo command limiters implemented as recommended, DAAS flight safety is adequate for the demonstration system.

The DAAS system meets the objectives of the program as well as the necessary safety requirements. The conclusions and recommendations pertaining to the DAAS system are presented in Section 4

report. The DAAS design and analysis served as a baseline for the Projected Advanced Avionics System (PAAS), which is discussed in the following section.

SECTION 3
PROJECTED ADVANCED AVIONICS SYSTEM (PAAS)

PAAS is a projected operational version of DAAS. It extrapolates the DAAS concept of fault tolerant integrated avionics to a system that could be produced in the mid-1980s. PAAS is designed to have super functional reliability. The Autopilot/Navigation mean time between loss of function is on the order of 10,000 hours.. PAAS can thus provide the dependable pilot relief that is essential for effective flight management by using the expanded functional capabilities provided.

Following is a description of PAAS and an analysis of its reliability, cost, maintainability, and modularity.

3.1 PAAS SYSTEM DESCRIPTION

The PAAS system, Figure 3-1, extrapolates the DAAS concept to a mid-1980s projected operational avionics configuration. PAAS architecture is similar to DAAS; i.e., it is a reconfigurable multiprocessor configuration. PAAS extends the DAAS spare processor redundancy concept to cover all essential avionics processors. PAAS employs a fault tolerant sensor configuration, dual redundant data busses, and dual autopilot servos. Redundancy in sensors, data bus, and servos -- in addition to fault tolerant processing -- is required to cause significant impact to the avionics functional reliability.

PAAS is designed as a minimum cost system that will allow continued operation of essential avionics functions after any single

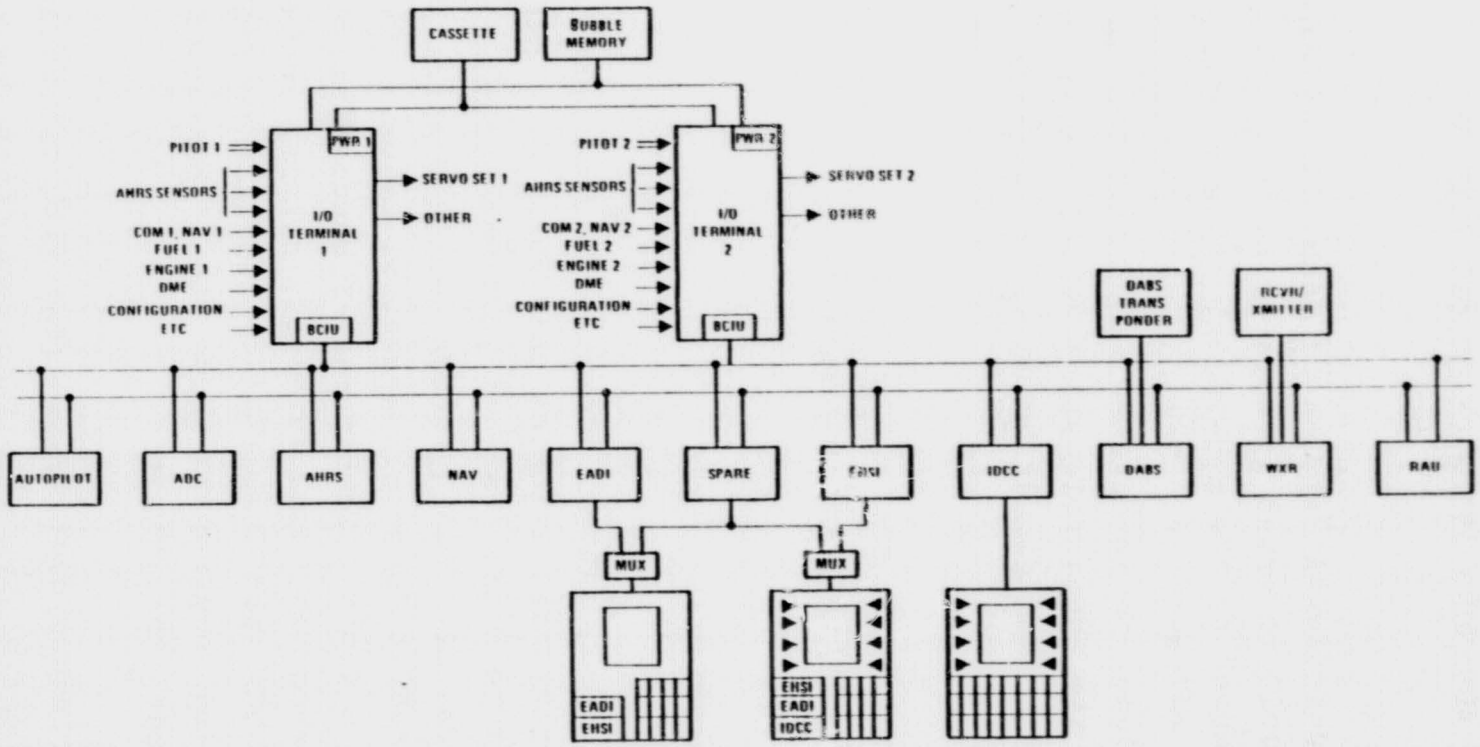

Figure 3-1. PAAS System Architecture

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failure. Functional reliability of navigation and autopilot are emphasized. The PAAS design provides approximately 10,000 flight hours of operation between loss of these functions, as compared to 200 hours for current systems. PAAS includes extensive built-in test for high confidence fault detection (and annunciation) and fault isolation for efficient maintenance.

Following is a description of the PAAS fault tolerant implementation of sensors, data bus, computer, displays, servos, power supplies, and the redundancy management techniques envisioned for the system.

3.1.1 PAAS Sensor Configuration

PAAS sensors required for navigation and autopilot functions are redundant for fault tolerance. Four skewed laser gyros, and four skewed accelerometers are proposed for the projected strap-down attitude heading reference system (AHRS). Dual static and differential pressure transducers are proposed for air data sensing. Dual VOR receivers and single DME are included for NAV inputs. Fuel sensors, engine sensors and configuration monitoring sensors are nonredundant.

Following are details on the unique PAAS AHRS and air data sensor mechanization.

3.1.1.1 PAAS AHRS Mechanization -- The AHRS employs strap-down skewed laser gyros and skewed accelerometers for fault tolerant attitude and rate sensing.

The laser gyro is a solid-state, precision angular rate sensor with a direct digital output. The laser gyro is ideally suited

for strap-down system configurations because it eliminates the need for gimbals, torque motors or other rotating parts. Instead of the rotating mass of a conventional mechanical gyro, the ring laser gyro utilizes two beams of laser light counter-rotating in a closed path. Laser gyro based inertial navigation and inertial reference systems are inherently more reliable and easy to maintain, and they provide the additional benefits of instant on, insensitivity to acceleration error sources, and low life cycle cost.

Four gyros and four accelerometers are employed in a skewed configuration, as shown in Figure 3-2.

Aircraft body rates (and accelerations) are derived from the sensor tetrad as indicated. The three body axis rate components (and accelerations) can be computed from the sensor signals even if one sensor has failed. Fault tolerance is thus provided for the three body rates (and accelerations) with only one added sensor.

A faulty sensor can be detected with high confidence by sensor comparison monitoring, and the fault can be isolated to one sensor either automatically, or by pilot selection should the automatic selection fail as described in paragraph 3.1.7.

The sensed aircraft rate and acceleration signals are converted to digital form in each of the PAAS dual I/O terminals and transmitted to the PAAS AHRS processor for attitude/heading computations. A flux gate signal is also input for long term heading reference. The attitude heading signals are used on the electronic attitude indicator in the PAAS autopilot and navigation functions.

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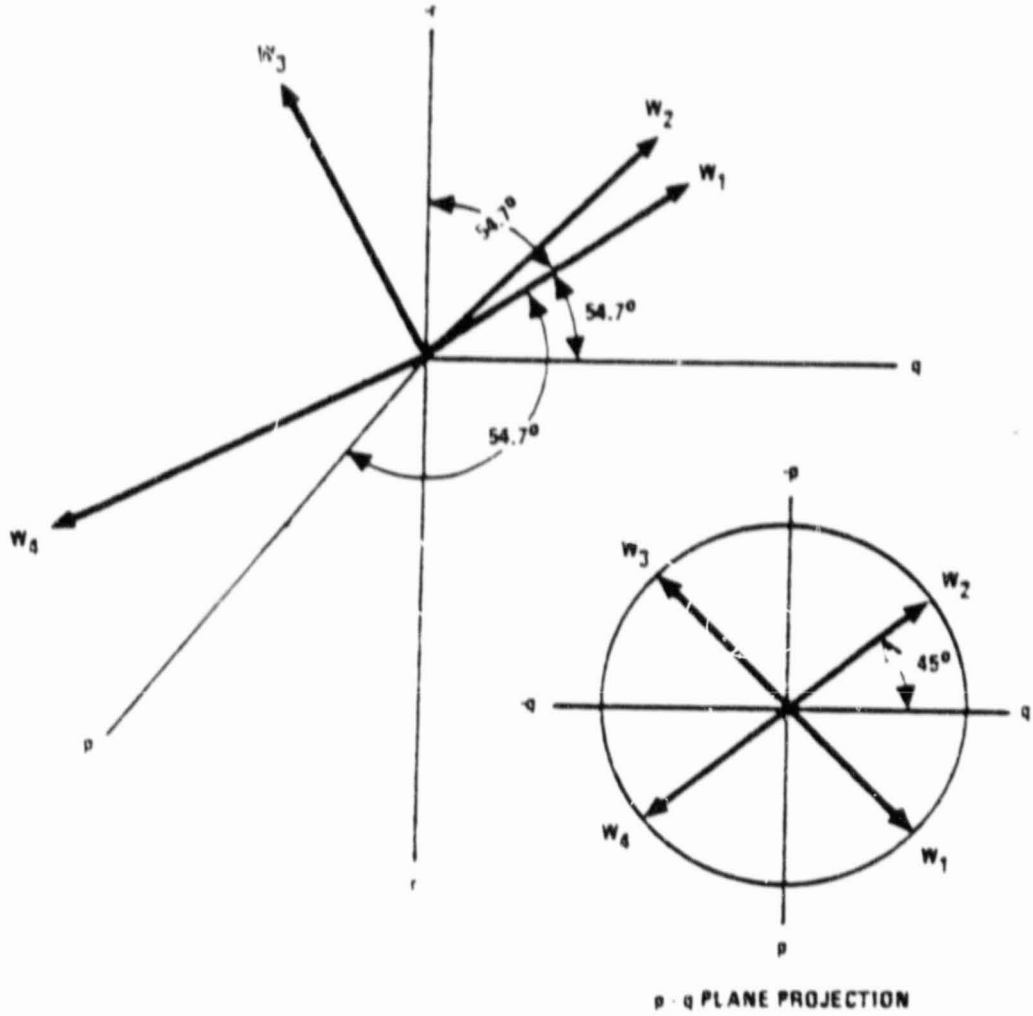

$$\begin{bmatrix} W_1 \\ W_2 \\ W_3 \\ W_4 \end{bmatrix} = \sqrt{\frac{3}{3}} \begin{bmatrix} 1 & 1 & -1 \\ -1 & 1 & -1 \\ -1 & -1 & -1 \\ 1 & -1 & -1 \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix}$$

Figure 3-2. Skewed Sensor Geometry

A general aviation laser gyro AHRS is not currently available, but may become feasible. Honeywell is developing a laser gyro inertial reference assembly for the Boeing 767. Others are working on low cost laser rate sensors using optical fibers.

3.1.1.2 PAAS Air Data Sensors -- Dual solid state static and differential pressure transducers and dual temperature sensors are proposed for PAAS to provide fault tolerant inputs for computation of altitude, altitude rate, indicated airspeed and true airspeed. Honeywell's solid state transducers used in current commercial aircraft air data systems are representative of devices which will likely make the PAAS air data approach feasible in general aviation in coming years.

The Honeywell pressure sensor converts the applied pressure to a usable electrical signal. An N-type silicon diaphragm within the sensor contains two P-type resistors diffused in an orthogonal pattern on the diaphragm. The orthogonal placement of the resistors in the diaphragm creates a change in the bulk resistivity of the resistors that is a function of diaphragm tangential and radial strain. The trangential resistor (R_T) increases resistance with strain (applied pressure), while the radial resistor (R_R) exhibits a corresponding decrease with strain.

The silicon piezoresistors are, therefore, used as strain gage elements.

The resistive elements have nearly identical temperature coefficients of resistance, because they are formed at the same time during the processing operations and are adjacent to each other. This permits temperature-related errors to be largely self-compensating due to the sensor resistance-bridge circuit mechanization.

Sensed static pressure, differential pressure and temperature are converted to digital form and transmitted to the PAAS ADC processor for computation of altitude and airspeed signals for use on electronic flight instruments, and in PAAS autopilot and navigation functions.

3.1.2 PAAS Data Bus

The PAAS data bus is dualized for fault tolerance. One bus controller is located with each I/O terminal. The two busses operate continuously to provide dual redundant inputs to detect (and annunciate) faults with high confidence.

DAAS employs the 16-wire IEEE 488 8-bit parallel data bus. A high throughput serial data bus, for which LSIC interface components are available, is proposed for PAAS. The serial bus would be preferable to minimize aircraft wiring if the PAAS processors are packaged separately.

PAAS data bus throughput requirements have not been established, though PAAS data bus loading is clearly higher than DAAS because air data, AHRS data, and weather radar display data are added to the bus.

3.1.3 PAAS Computer Architecture

The PAAS computer employs the spare processor redundancy concept developed for DAAS, but extends back-up capability to all essential processors. See Figure 3-1. The PAAS spare can take over for any failed processor except the DABS processor, the weather radar processor, or the IDCC processor.

The DABS or weather radar function reliability would not be significantly enhanced by redundant processing because the higher failure rate sensors are not redundant. The IDCC back-up is a reversion mode on the EHSI display; thus IDCC processor backup is not required.

The PAAS processors receive their inputs, and supply outputs to dual I/O terminals via the dual PAAS data busses.

3.1.4 PAAS Displays

Proposed PAAS display configuration is illustrated in Figure 3-3. Three-color CRTs are included. One display normally presents:

- Attitude/Director Indicator
- IAS Indicator
- Altimeter
- Vertical Speed Indicator
- Etc.

The second panel mounted display is a horizontal situation indicator similar to the DAAS EHSI. A third display would be mounted in the pedestal for use as an IDCC.

The first display could be periodically switched to present the EHSI if the second display failed, and vice versa. The second display could also be switched to operate as a primitive NAV function IDCC if the primary IDCC failed.

Multifunction controls are provided for each display. The controls are relabeled when the display function changes.

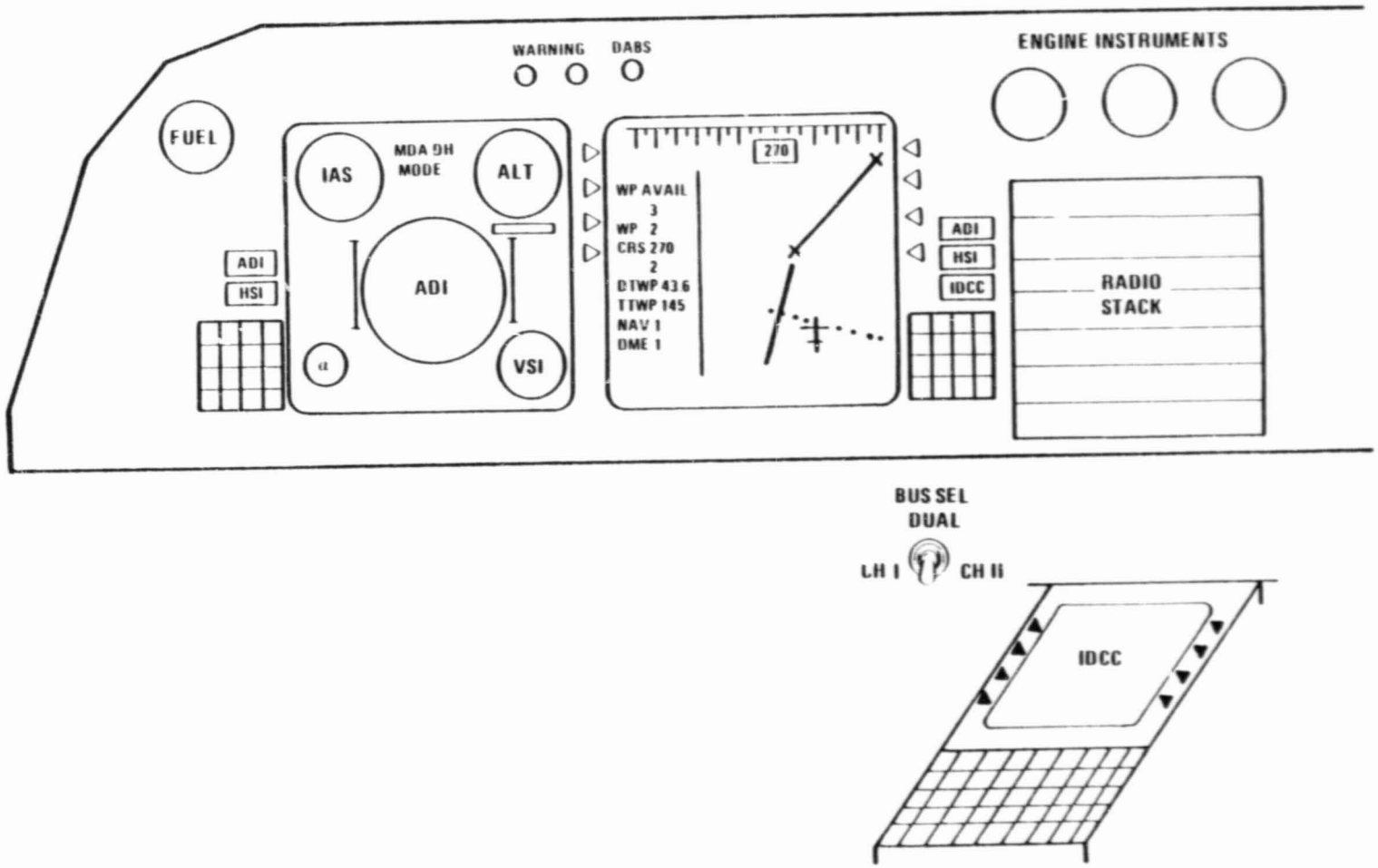

Figure 3-3. PAAS Panel Concept

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Communication control heads are panel mounted to provide tuning capability independent of the PAAS display system.

3.1.5 PAAS Servo Mechanization

PAAS servos are dual with clutch arrangements to allow switching between servos for continued operation after one servo failure. Each servo in a dual pair is driven from one of the dual I/O terminals. A servo model would be implemented in PAAS software for each mechanical servo, and model output would be compared to servo output to detect and isolate servo faults.

3.1.6 PAAS Power Mechanization

Dual, monitored power supplies are included in PAAS. The power references to the essential PAAS components are switched in event of a power supply failure.

3.1.7 PAAS Redundancy Management

PAAS would include extensive built-in test to detect and isolate faults to facilitate automatic reconfiguration. Fault detection confidence could exceed 99 percent for dual elements through use of simple comparison monitoring. Automatic fault isolation is feasible with confidence on the order of 80 to 90 percent for the dual sensors, and approaching 100 percent for the dual model-comparison-monitored servos.

PAAS could include capability for manual redundancy management as backup to the automatic fault localization/reconfiguration. The PAAS data bus could be switched manually from dual operation to Channel I or Channel II as indicated in Figure 3-3. Sensor and

servos could be manually selected on IDCC pages as shown in Figure 3-4.

3.2 PAAS RELIABILITY ANALYSIS

PAAS is configured to provide an order of magnitude improvement in functional reliability at a reasonable cost with respect to conventional architectures. Effectiveness of the PAAS architecture is therefore analyzed by comparing PAAS Autopilot and Navigation function reliability with respect to a hypothesized "conventional" system. The reliability analysis also compares the maintenance failure rate of PAAS and the "conventional" system to give some indication of PAAS relative life cycle cost.

The "conventional" system component list, and associated failure rates, are compiled in Table 3-1. This system includes current devices required to give functional capability similar to that of PAAS. Communications, navigation, flight control, performance computations, configuration monitoring, and weather radar are included. Where possible, failure rates are King Radio Corporation tabulations of actual operational experience. Honeywell Reliability Engineering Group provided generic estimates where operational experience was not available. The PAAS computer unit reliability prediction is extrapolated from the DAAS hardware mechanizations.

The "conventional" system maintenance failure rates are summed to determine a total failure rate of 1061.5 percent per 1000 hours, for a total system mean time between failure of 94 hours.

The "conventional" system autopilot/navigation functional reliability was determined by summing failure rates of components

REDUNDANCY MANAGEMENT P1 OF 2

- AHRS IN SEL
  > AUTO
  MAN (CH X)
- AHRS GYRO OFF
  > AUTO
  MAN (GYRO X)
- AHRS ACCEL OFF
  > AUTO
  MAN (ACCEL X)
- NAV IN SEL
  > AUTO
  > MAN (CH X)
- ADC IN SEL
  > AUTO
  MAN (CH X)
- PS SEL
  > AUTO
  MAN (CH X)
- IAS SEL
  > AUTO
  MAN (CH X)

REDUNDANCY MANAGEMENT P2 OF 2

- RUD SERVO SEL
  > AUTO
  MAN (CH X)
- AIL SERVO SEL
  > AUTO
  MAN (CH X)
- EL SERVO SEL
  > AUTO
  MAN (CH X)
- TH SERVO SEL
  > AUTO
  MAN (CH X)

REDUNDANCY MANAGEMENT P1 OF 1
STATUS

AHRS SEL/CH.....AUTO/1
AHRS GYRO/ACCEL FAIL.....X/X
ADC SEL/CH.....AUTO/1
ADC PS/IAS FAIL.....X/X
NAV SEL/CH.....MAN/1
NAV FAIL.....2

Figure 3-4. PAAS Manual Redundancy Management

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Table 3-1. Reliability Estimate for a Conventional System

DEVICE	FAILURE RATE (%/1000 HRS)	QUANTITY	MAINTENANCE FAILURE RATE CONTRIBUTION (%/1000 HRS)	AUTO PILOT/NAV FUNCTION FAILURE RATE CONTRIBUTION (%/1000 HRS)	COMMENT
NAV/FLT CONTROL SENSORS/INSTRUMENTS					
Yaw Rate Gyro	5.	1	5.	5.	
Magnetic Transmitter (KMT 112)	2.	1	2.	0	Manual slaving assumed if failed.
Directional Gyro (KSG 105)	33.	1	33.	33.	
Slave Control (KA 51A)	1.	1	1.	1.	
Vertical Gyro (VG 208)	33.	1	33.	33.	
Pitot System, Left	5.	1	5.	5.	
Pitot System, Right	5.	1	5.	5.	
Encoding Altimeter (ID 571)	20.	1	20.	20.	
Air Data Computer (KDC 380)	20.	1	20.	20.	
VOR Receiver (KN 53)	25.	2	50.	2.5	
DME Receiver (KN 62A)	50.	1	50.	-	
Angle of Attack Sensor, Ind	10.	1	10.	-	
Turn and Bank Indicator	15.	1	15.	15.	
OAT Sensor	1.	1	1.	-	
			256.	141.5	
CONTROLS AND DISPLAYS					
Autopilot Mode Controller (KMC 340)	34.	1	34.	34.	
Autopilot Annunciator Panel (KAP 315)	3.	1	3.	3.	
ADI (KCI 310)	20.	1	20.	0	Artificial horizon backup, degraded performance.
HSI (KPI 553)	20.	1	20.	0	RMI backup, degraded performance.
RMI (KI 226)	33.	1	33.	0	HSI backup.
Audio Control Panel (KMA 24)	20.	1	20.	-	
Failure Annunciator Panel	3.	1	3.	-	
Airspeed Indicator	28.	1	28.	28.	
Artificial Horizon (KG 253)	67.	1	67.	0	
			228.	65.	
COMPUTER, ELECTRONICS					
Autopilot Computer (KAC 325)	55.	1	55.	55.	
Flight Computer (KCP 320)	85.	1	85.	85.	
RNAV System (KNC 665)	90.	1	90.	90.	
VNAV Computer (KVN 395)	45.	1	45.	45.	
Performance Computer	20.	1	20.	-	
			295.	275.	

Table 3-1. Reliability Estimate for a Conventional System (Sheet 2 of 2)

DEVICE	FAILURE RATE (%/1000 HRS	QUANTITY	MAINTENANCE FAILURE RATE CONTRIBUTION (%/1000 HRS)	AUTO PILOT/NAV FUNCTION FAILURE RATE CONTRIBUTION (%/1000 HRS)	REMARKS
SERVO ACTUATORS	7.	1	7.	7.	
Pitch Servo	7.	1	7.	7.	
Roll Servo	7.	1	7.	7.	
Yaw Servo	7.	1	7.	7.	
Pitch Trim Servo	5.	1	5.	5.	
			26.	26.	
MONITORING					
MAP Sensor	0.5	2	1.	-	Not required for Autopilot, NAV function.
RPM Sensor	1.	2	2.	-	
Cowl Flap Position	.5	1	.5	-	
Flap Position	2.	1	2.	-	
Elevator Trim Postion	2.	1	2.	-	
Radar Altimeter	50.	1	50.	-	
			57.5	0	
WEATHER RADAR					
Transmitter/Receiver	50.	1	50.	-	Not required for Autopilot, NAV function.
Display Unit	5.	1	5.	-	
			55.	0	
COMMUNICATIONS					
Comm Transceivers (KY 19)	33.	2	66.	-	Not required for Autopilot, NAV function.
DABS Transponder	40.	1	40.	-	
DABS Control/Display	30.	1	30.	-	
			136.	0	
ELECTRICAL POWER SYSTEM					
A/C 28VDC Bus, Aircraft Battery	.01	1	NOT INCLUDED	.01	
DC/AC Inverter	1.	1	1.	1.	
DC/DC Converter	3.	1	3.	3.	
			4.0	4.01	
			TOTAL: 1056.5	6.51	
			MTBF = 94.6 HRS	201. HRS	

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required to provide these functions. Failure contribution of dual VOR receivers was considered negligible. The total conventional system autopilot/navigation function failure rate, assuming a 1-hour mission, is 496.5 percent per 1000 hours for a mean time between loss of function of 201 hours.

Corresponding PAAS maintenance reliability and autopilot/navigation function reliability are compiled in Table 3-2. PAAS maintenance reliability is 50 percent better than the conventional system because:

- High reliability digital electronics employed
- High reliability solid state sensor technology employed
- Electronic displays replace conventional instruments
- PAAS integrated avionics architecture eliminates hardware

PAAS autopilot/navigation function reliability is improved by a factor of 50 with respect to the "conventional" system, primarily due to the fault tolerant PAAS architecture. A PAAS gyro, accelerometer or air data sensor failure can be tolerated without loss of a function. A PAAS processor failure, a power supply failure, and a servo failure can be tolerated without loss of function. This PAAS fault tolerance is accomplished with the minimum of redundant hardware, as described in section 3.1.

PAAS would suffer gross loss of function for certain failure combinations. For example, the PAAS configuration would be totally incapacitated by two like bus controller failures. The probability of such failures occurring during a 1-hour flight is extremely low, however; for example:

Table 3-2. Reliability Estimate for PAAS

DEVICE	FAILURE RATE (%/1000 HRS)	QUANTITY	MAINTENANCE FAILURE RATE CONTRIBUTION (%/1000 HRS)	AUTO PILOT/NAV FUNCTION FAILURE RATE CONTRIBUTION (%/1000 HRS)	COMMENT
NAV/FLT CONTROL SENSORS					
Magenetic Transmitter (KMT 112)	2.	1	2.	0.	Manual periodic heading alignment required if KMT 112 fails.
Laser Gyro, Interface Electronics	5.	4	20.	2.	90% fault isolation capability assumed.
Accelerometer, Interface Electronics	5.	4	20.	2.	90% fault isolation capability assumed.
Pitot System, Left	5.	1	5.	.5	90% fault isolation capability assumed.
Pitot System, Right	5.	1	5.	.5	90% fault isolation capability assumed.
Static Pressure Transducer	5.	2	10.	1.	90% fault isolation capability assumed.
Differential Pressure Transducer	5.	2	10.	1.	90% fault isolation capability assumed.
VOR Receiver (KN 53)	25.	2	50.	0.	Manual switching if required.
DME Receiver (KN 62A)	50.	1	50.	-	
Angle of Attack Sensor	5.	1	5.	-	
OAT Sensor	2.	1	2.	.1	90% fault isolation capability assumed.
			179.	7.1	
CONTROLS AND DISPLAYS					
Autopilot Mode Controller (KMC 340)	34.	1	34.	0	IDCC page for backup.
EADI Display, Controls	35.	1	35.	0	Manual switching of displays.
EHSI Display, Controls	35.	1	35.	0	Manual switching of displays.
IDCC, Display, Controls	35.	1	35.	0	Basic NAV page available on EHSI displays.
			139.	0	
COMPUTER, ELECTRONICS					
Processor (8086, Memory)	6.	11	66.	1.8	Autopilot, NAV, ADC, AHRS, RAU, Bus Controller processors only. 95% fault isolation capability assumed.
A/D, D/A, MUX	6.	2	12.	.6	95% fault issolation capability assumed.
Bubble Memory System	50.	1	50.	0	Not required unless another failure occurs.
			128.	2.4	
SERVO ACTUATORS					
Pitch Servo	7.	2	14.	0	Servo-model comparison monitoring for fault isolation.
Roll Servo	7.	2	14.	0	Servo-model comparison monitoring for fault isolation.
Yaw Servo	7.	2	14.	0	Servo-model comparison monitoring for fault isolation.
Pitch Trim Servo	5.	2	10.	0	Servo-model comparison monitoring for fault isolation.
			52.	0	

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Table 3-2. Reliability Estimate for PAAS (Sheet 2 of 2)

DEVICE	FAILURE RATE (%/1000 HRS)	QUANTITY	MAINTENANCE FAILURE RATE CONTRIBUTION (%/1000 HRS)	AUTO PILOT NAV FUNCTION FAILURE RATE CONTRIBUTION (%/1000 HRS)	COMMENT
MONITOR SENSORS					
MAP	0.5	2	1.	-	Not required for Autopilot, NAV function.
RPM	1.	2	2.	-	
Cowl Flap Position	.5	1	.5	-	
Flap Position	2.	1	2.	-	
Elevator Trim Position	2.	1	2.	-	
Radar Altimeter (RT 221)	50.	1	50.	-	
			57.5	0	
WEATHER RADAR					
Transmitter/Receiver	50.	1	50.	-	Not required for Autopilot, NAV function.
			50.	0	
COMMUNICATIONS					
Comm Transceivers (KY 19[illegible])	[illegible]	2	66.	-	
[illegible] Transponder	40.	1	40.	-	
			106.	0	
[illegible]					
A/C 28V [illegible] Battery	.01	1	NOT INCLUDED	.01	Pilot [illegible]
PAAS Battery	10.	1	10.	0	PAAS design must operate without battery.
Laser Gyro Power Supply	1.	1	1.	1.	
DC/DC Converter	3.	2	6.	.3	95% fault isolation capability assumed.
			17.	1.31	
			TOTAL: 728.5	10.8	
			MTBF = 137 HRS	9[illegible] HRS	

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$$\text{Dual Failure Probability} = (\lambda_{BC}\ t)^2 = 1 \times 10^{-8}$$

where:

λ_{BC} = bus controller failure rate = 10%/1000 hours

t = time = 1 hour

The two-failure probability is similar to the order of magnitude of Military aircraft fly-by-wire flight control catastrophic failure rate.

3.3 PAAS COST ANALYSIS

PAAS and "conventional" system cost estimates, compiled in Tables 3-3 and 3-4, indicate that the PAAS costs are similar to those for a conventional system.

The cost figures used in the analysis were current King Radio catalog prices where available, or rough estimates based on similarity where catalog prices were not available. The PAAS computer cost estimate is an approximation extrapolated from the DAAS hardware mechanization. No estimate is available for the PAAS laser gyro AHRS, so a cost number corresponding to an electromechanical device was used. Conclusions are not affected even if this number is significantly increased.

PAAS thus provides dramatic improvements in functional reliability without significantly increasing system costs. PAAS total costs are contained because PAAS is integrated and does not require dedicated controls and displays for its functions.

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Table 3-3. Cost Estimate for a Conventional System

Device	Quantity	Estimated Cost (Dollars)	Basis For Estimate
NAV/FLT Control Sensors			
Yaw Rate Gyro	1	1,200	Catalog
Magnetic Transmitter (KMT 112)	1	205	Catalog
Directional Gyro (KSG 105)	1	2,495	Catalog
Slave Control (KA 51A)	1	60	Catalog
Vertical Gyro (VG 208)	1	4,303	Catalog
Pitot System, Left	1		
Pitot System Right	1		
Encoding Altimeter (IDC 571)	1	4,629	Catalog
Air Data Computer (KDC 380)	1	1,785	Catalog
VOR Receiver (KN 53)	2	3,730	Catalog
DME Receiver (KN 62A)	1	3,225	Catalog
Angle of Attack Sensor, Ind.	1	2,566	Catalog
Turn and Bank	1	700	Catalog
OAT Sensor	1	100	Estimate Only
Subtotal		24,998	
Controls and Displays			
Autopilot Mode Controller (KMC 340)	1	885	Catalog
Autopilot Annunciator Panel (KAP 315)	1	520	Catalog
ADI (KCI 310)	1	5,610	Catalog
HSI (KPI 553)	1	7,200	Catalog
RMI (KI 226)	1	2,205	Catalog
Audio Control Panel (KMA 24)	1	675	Catalog
Airspeed Indicator	1	170	Catalog
Artificial Horizon (KG 253)	1	1,250	Catalog
Subtotal		18,515	
Computer, Electronics			
Autopilot Computer (KAC 325)	1	3,035	Catalog
Flight Computer (KCP 320)	1	4,465	Catalog
RNAV System (KNC 665)	1	5,985	Catalog
VNAV Computer (KVN 395)	1	3,305	Catalog
Performance Computer	1	14,200	Catalog
Subtotal		30,990	

Table 3-3. Cost Estimate for a Conventional System (Sheet 2 of 2)

Device	Quantity	Estimated Cost (Dollars)	Basis For Estimate
Servo Actuators			
Pitch Servo	1	2,140	Catalog
Roll Servo	1	2,140	Catalog
Yaw Servo	1	2,140	Catalog
Pitch Trim Servo	1	1,665	Catalog
Subtotal		8,085	
Monitoring			
Failure Annunciator	1	75	Estimate Only
MAP Sensor	2	200	Estimate Only
RPM Sensor	2	1,200	Estimate Only
Cowl Flap Position	1	100	Estimate Only
Flap Position	1	100	Estimate Only
Elevator Trim Position	1	100	EStimate Only
Radar Altimeter	1	2,350	Catalog
Subtotal		4,125	
Weather Radar			
Transmitter/Receiver	1	13,000	Split Estimate
Display Unit	1	7,000	
Subtotal		20,000	
Communications			
Comm Tranceivers (KY 196)	2	3,510	Catalog
DABS Transponder	1	2,000	Estimate Only
DABS Control/Display	1	4,000	Estimate Only
Subtotal		9,510	
TOTAL		$116,223	

Table 3-4. Cost Estimate for PAAS

Device	Quantity	Estimated Cost (Dollars)	Basis For Estimate
NAV/FLT Control Sensors			
Magnetic Transmitters (KMT 112)	1	205	Catalog
Laser Gyro, Interface Electronics		8,000	Estimated of basis of cost of electromechanical replacement
Accelerometer, Interface Electronics			
Pitot System, Left			
Pitot System, Right			
Static Pressure Transducer	2	800	Estimate Only
Differential Pressure	2	800	Estimate Only
VOR Receiver (KN 53)	2	3,730	Catalog
DME Receiver (KN 62A)	1	3,225	Catalog
Angle-of-Attack Sensor	1	828	Catalog
OAT Sensor	1	100	Catalog
Subtotal		17,688	
Controls and Displays			
Autopilot Mode Controller (KMC 340)	1	885	Catalog
EADI Display, Controls	1	7,000	Estimate Only
EHSI Display, Controls	1	7,000	Estimate Only
IDCC, Display, Controls	1	8,000	Estimate Only
Subtotal		22,885	
Computer, Electronics			
Processor (8086, Memory)	11	9,600	Estimate Only
Power Supply and Misc.		6,000	Estimate Only
A/D, D/A, MIX	2	2,000	Estimate Only
Bubble Memory System	1	2,000	Estimate Only
Subtotal		19,600	
Servo Actuators			
Pitch Servo	2	4,280	Catalog
Roll Servo	2	4,280	Catalog
Your Servo	2	4,280	Catalog
Pitch Trim Servo	2	3,330	Catalog
Subtotal		16,170	

Table 3-4. Cost Estimate for PAAS (Sheet 2 of 2)

Device	Quantity	Estimated Cost (Dollars)	Basis For Estimate
Monitor Sensors			
MAP	2	200	Estimate Only
RPM	2	1,200	Estimate Only
Cowl Flap Position	1	100	Estimate Only
Flap Position	1	100	Estimate Only
Elevator Trim Position	1	100	Estimate Only
Radar Altimeter (RT 221)	1	2,350	Catalog
Subtotal		4,050	
Weather Radar			
Transmitter/Receiver		13,000	Transceiver/display Split Estimate
Subtotal		13,000	
Communications			
Comm Transceivers (KY 196)	2	3,510	Catalog
DABS Transponder	1	2,000	Estimate Only
Subtotal		5,510	
TOTAL		$98,903	

3.4 PAAS MAINTAINABILITY ANALYSIS

The projected advanced Avionics System (PAAS) maintenance test concept is depicted in Figure 3-5. Highly effective avionics built-in test (BIT) is anticipated. On-aircraft functional testing and fault localization to a module within an LRU are expected to be feasible with minimal test equipment. The fixed base operator could exploit the BIT capability and minimize his special purpose test equipment and become more a storehouse of replaceable modules. The avionics should include capability for on-aircraft trouble shooting by the fixed base operator. Faulty modules could be repaired at the factory.

BIT design objectives consistent with the above maintenance philosophy are:

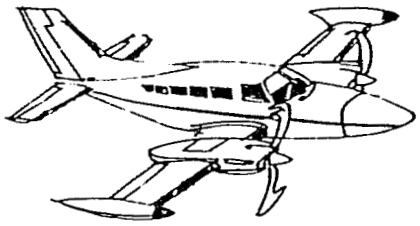
- Minimize fixed base operator test capability requirements
- Maximize BIT fault localization capability

Of course, the resulting BIT mechanization must not significantly increase avionics cost.

DAAS BIT modes include:

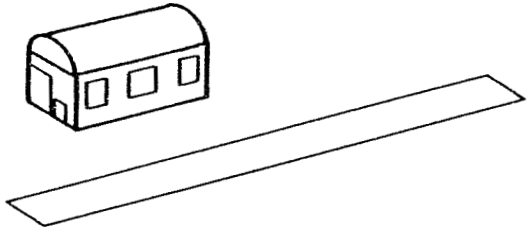
- In-flight test
- Functional test/fault localization - automatic
- Functional test/fault localization - interactive
- Maintenance trouble shooting

In-flight-test is continuous and will generate a warning when a detected failure will disable a system function. The DAAS will automatically reconfigure for computer unit processor failures.



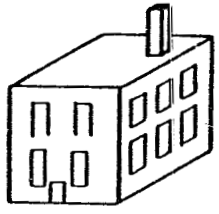
ON AIRCRAFT MAINTENANCE

- FUNCTIONAL TESTING – 95% CONFIDENCE
- FAULT LOCALIZATION TO LRU – 90% CONFIDENCE
- FAULT LOCALIZATION TO REPLACEABLE MODULE – 80 – 90% CONFIDENCE
- TESTING, TROUBLESHOOTING VIA IDCC



FIXED BASE OPERATOR

- ON AIRCRAFT MAINTENANCE
- LIMITED GENERAL PURPOSE TEST EQUIPMENT
- REPLACEABLE MODULE STOCK
- IRU STOCK – – – – (LIMITED RENTAL UNITS)



DEPOT/FACTORY

- MODULE, LRU ATE
- STANDARD LRU ATE BUS INTERFACE
- MODULE, LRU REPAIR
- SPARE PARTS STOCK

Figure 3-5. PAAS Maintenance Concept

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In-flight failures that are detected by BIT will cause the amber warning light to flash. A message will be displayed on the IDCC on the line reserved for warning messages. The message will be, "Device Failure" followed by identification of the failed device. (Vertical Gyro, Compass, etc.).

Functional Test/Fault Localization, Automatic, is performed at power-up, or when commanded by the operator, and tests system components as feasible without operator interaction. This test function exercises DAAS equipment and identifies failed LRUs as well as failed modules within the LRU as feasible.

Functional Test/Fault Localization, Interactive, is performed on command and allows testing of devices where operator actions or observations are necessary to complete a test. IDCC and EHSI test pattern tests are included in DAAS as examples of avionics interactive testing.

Maintenance trouble shooting allows the operator to apply signals and measure signals via IDCC. Memory words can be displayed. Analog and discrete signals can be applied at computer outputs, and various system analog and discrete signals can be measured and displayed.

Fault localization and replacement of a faulty avionics line replaceable unit can be accomplished in mean time of 15 minutes with the level of BIT envisioned for PAAS. Repair of a faulty unit, i.e., fault localization and replacement of a faulty part, can be accomplished in mean time of 1 hour.

PAAS packaging must be designed to allow operator removal of hardware modules and continued operation with only partial loss of function.

3.5 PAAS MODULARITY ANALYSIS

PAAS is designed to be modular. The system is constructed of building blocks that can be configured to provide varying levels of functional capability depending on user requirements. The design is intended to facilitate addition of functions without major upheaval to the existing aircraft control panel or existing avionics.

Modularity is achieved through:

- System architecture
- Controls and displays modularity
- Hardware modularity
- Software modularity.

Basic system architecture, i.e., multimicroprocessors interconnected via data bus, supports modularity. Functions can be added by adding appropriate process or modules, and the processing can interface to the system through the data bus.

PAAS employs programmable controls and displays that can be reconfigured for various functional complements. The IDCC includes basic mechanical controls (keyboard page callup buttons, etc.) and a programmable display. The basic display module is the display page. The page can be used as a function control panel or for required data and information input/output. The EHSI and EADI are displays that can be programmed for the set of functions included in a particular PAAS installation.

PAAS hardware is modular. Standard modules can be added to provide computing power, memory, or I/O required for added functions.

PAAS software is structured and modular. Each of the hardware modules are programmed with independent software modules that require minimum interfaces with other functions. These software modules are developed using structured design techniques. The system modularity has been demonstrated by addition of the DABS function.

The integration of DABS into DAAS late in the DAAS development program demonstrates basic modularity. Incorporation of DABS required --

- Installing a DABS transponder in the aircraft, and interfacing it to the DAAS computer unit.
- Adding a DABS processor module, including software, and two DABS interface electronics modules to the DAAS computer unit.
- Adding three DABS pages to the IDCC.
- Adding a DABS "Message Pending" light to the panel.

The DAAS processor module is appropriate for DABS computations. DAAS keyboard and IDCC page formats are appropriate for DABS. Consequently, DABS readily fit into the DAAS framework. PAAS modularity is further assessed in the following paragraphs.

3.5.1 PAAS System Modularity

PAAS system modularity is demonstrated in Figure 3-6. The various levels of functional capability are depicted. The core PAAS functional entity is the autopilot.

The autopilot processor and a basic I/O terminal are required for this function.

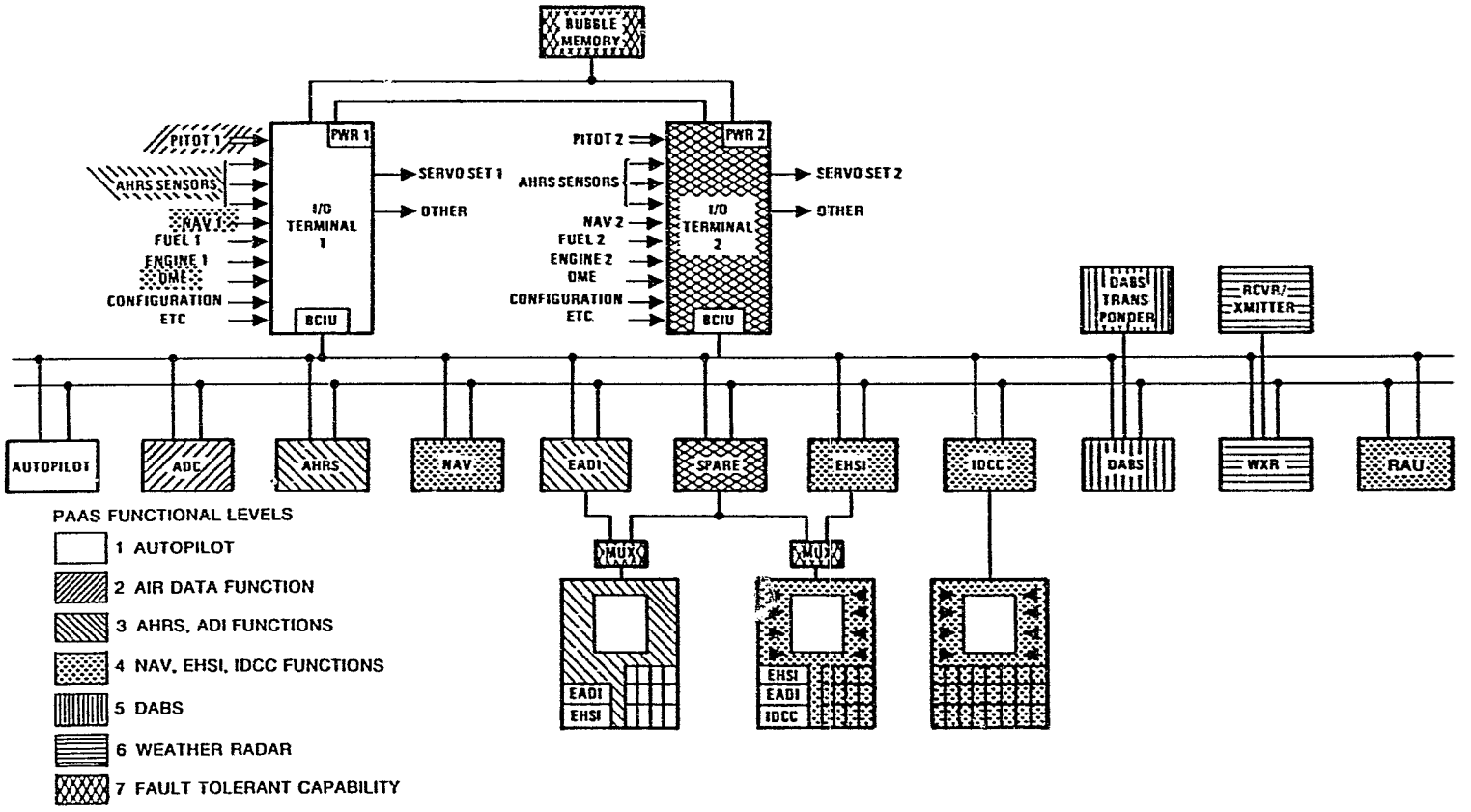

Figure 3-6. PAAS Modularity

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A second version of PAAS could include the autopilot and the air data functions. In this version, the air data function would only supply references for the autopilot. Altimeter and IAS data sources would be independent.

A third version of PAAS could have autopilot, air data, AHRS, and the electronic ADI that includes the altimeter, IAS and VSI displays.

A fourth version could also include the NAV, EHSI and IDCC functions.

A fifth version could have DABS added, and a sixth version could include weather radar data superimposed on the EHSI.

A seventh version could include the necessary redundant hardware for fault tolerant operation.

Each version of PAAS would be complimented by systems necessary for desired functional capability and backup. A particular version of PAAS could include spare room to allow incorporation of some additional capability: either the defined next higher level, or a yet-to-be-defined advanced capability.

3.5.2 PAAS Controls and Displays Modularity

The ideal controls and display configurations from a modularity standpoint, would include only general purpose controls. No controls dedicated to a specific function would be allowed in order to minimize impact on panel hardware when a function was added. In an idealized PAAS configuration, controls would include a general purpose keyboard, and one IDCC page callup button for each function.

DAAS has deviated from this ideal in certain respects:

- Various dedicated NAV function controls are implemented above the IDCC, included with page call-up buttons; i.e., USE, CRS, SEL, LAT DIR TO, AUTO CRS SEQ.

- Dedicated map control buttons are implemented next to the IDCC; i.e., HDG/NOR, MAP/CRSR, MAP RTN, WP BRG, REVU, MAP SCALE.

- Dedicated autopilot mode controller, annunciator panel.

- Other function controls

These dedicated function controls were implemented to maximize their accessibility.

Dedicated NAV function controls could be avoided if these controls were instead implemented in IDCC pages. The penalty for elimination of dedicated NAV function buttons is as follows:

- One additional button push required to activate LAT DIR TO.

- One additional button push required to change waypoint data access from linked waypoint, to unlinked waypoint.

The advantage of this approach, in addition to improved modularity, is elimination of dedicated NAV function buttons above the IDCC, which leaves only page call-up buttons there. This eases system comprehension.

Current dedicated map control buttons do not significantly degrade modularity. They can be an integral part of the EHSI assembly. Spare control buttons should be included, however, for additional

functions which use the EHSI, which will also have dedicated controls; e.g., weather radar.

The PAAS Autopilot mode controller is a dedicated panel. Accessibility to the safety critical mode controller seems to preclude its incorporation into multifunction control facilities such as the IDCC. The autopilot mode annunciator panel would likely be incorporated into the EADI if EADI were included in PAAS.

3.5.3 PAAS Hardware Modularity

The existing DAAS hardware is modular. The basic hardware building block is the processor board, Figure 3-7. This 6.25 by 6.25 inch printed circuit board includes:

- INTEL 8086 16-bit microprocessor
- 2K x 16 PROM Memory
- 4K x 16 RAM Memory
- Crystal clock
- IEEE 488 bus talker/listener/controller
- Interrupt controller

If more than 4K x 16 memory is required for a particular PAAS processor, a supplemental 6.25 by 6.25 inch memory board is used. This memory board can contain up to 12K x 16 additional RAM memory. Other hardware modules that could be employed in a PAAS system include:

- EADI, EHSI display refresh memory module
- Bubble memory module
- Analog/Discrete I/O modules

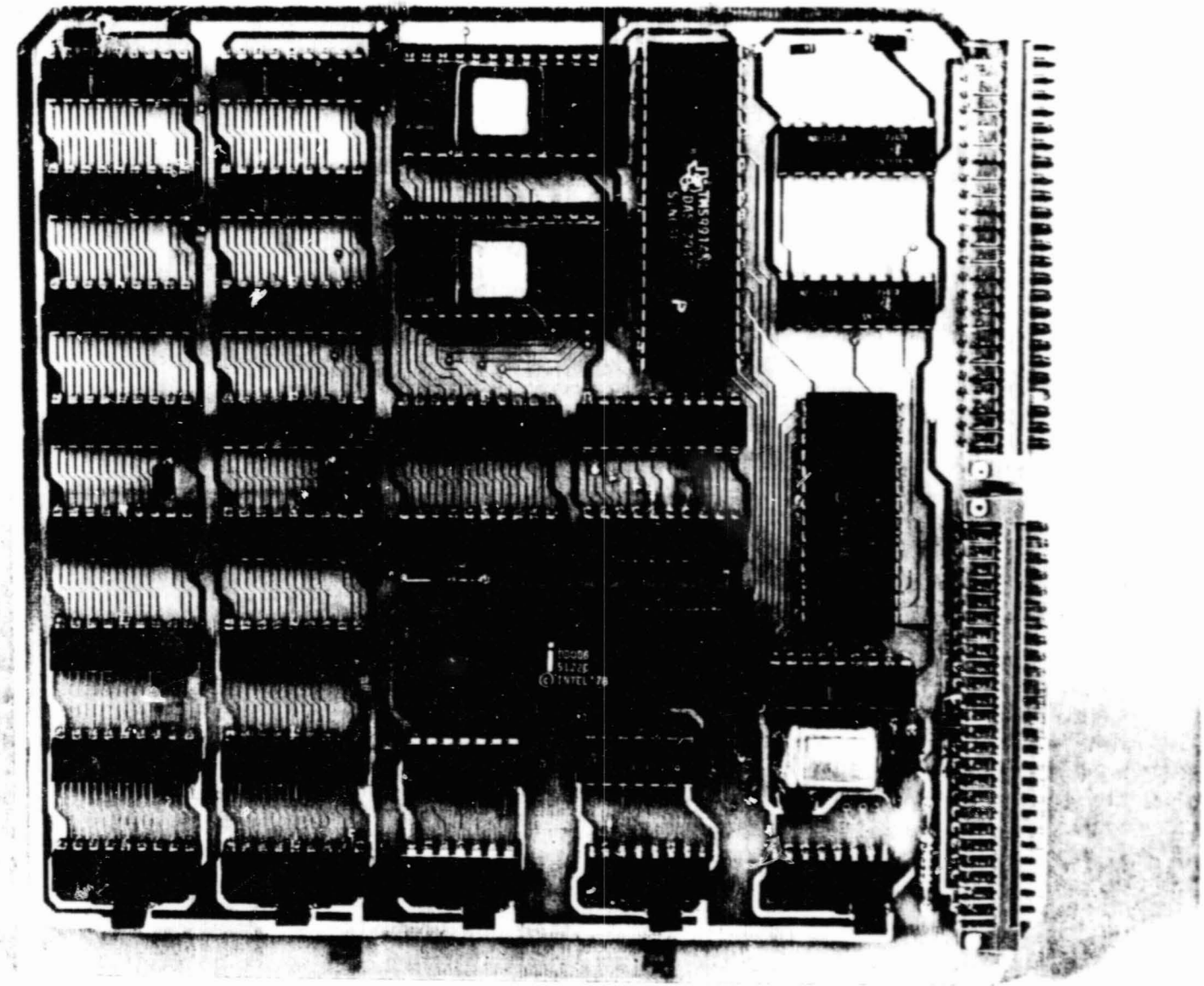

Figure 3-7. DAAS Processor Module

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PAAS would employ a higher level of circuit integration than the existing DAAS system. Custom VLSIC would be economical for PAAS for the basic hardware modules. Exploiting modularity of a production version of PAAS requires the following hardware design considerations:

- The PAAS computer box must have sufficient room and external connector pin capacity to support eventual growth.

- Power supply - The PAAS power supply must have reserve capacity to support eventual system growth or else the power supply must be changed as functions are added.

- Data bus throughput - The PAAS data bus must have sufficient throughput margin to support eventual system growth. The current system IEEE 488 bus is only 30 percent loaded, which is consistent with this requirement. The PAAS data bus would require higher throughput to accommodate the AHRS and weather radar functions.

3.5.4 PAAS Software Modularity

PAAS software must be modular. Functions are implemented in software modules; i.e., independent programs with single entry and exit, separate data locations and clearly defined and controlled interfaces. Data bus communications are managed in an orderly fashion by the bus control processor, with growth in mind.

SECTION 4
CONCLUSIONS AND RECOMMENDATIONS

The DAAS system design is completed, and flight hardware built. Simulator evaluations have been performed. The PAAS configuration has been defined and analyzed on the basis of cost, reliability, maintainability, and modularity. The following conclusions and recommendations are based on the experience associated with this effort to date.

- Functional Configuration - DAAS provides expanded functional capability with respect to currently available avionics and has the potential to significantly improve single pilot IFR safety and efficiency. The DAAS architecture provides the framework for additional expansion without the requirement for added displays. This is accomplished by using the shared data base, displays and bus. The distributed architecture of the system provides for functional independence. This minimizes the number of needed interfaces between functions and thereby reduces data input and subsequent pilot training.

- Function Set - The DAAS function set is comprehensive and suitable for demonstration. Operational simplification and functional additions have been suggested that may be appropriate for an operational system.

- Cost - The DAAS concept is cost effective, and has cost advantages with respect to conventional avionics as the number of integrated functions increase.

- Reliability - The DAAS system architecture reduces computer system failure rate to a negligible portion of the total system failure rate. Sensor and servo failure rates dominate. Low cost sensor and servo redundancy should be pursued with a goal of 10,000 hours in-flight MTBF for autopilot and basic navigation functions to provide extremely reliable pilot relief to facilitate effective flight management. The PAAS configuration promises much higher functional reliability.

- Maintainability - DAAS offers improvements in avionics maintainability through improved reliability, automatic fault detection and isolation, and on-aircraft trouble shooting without special test equipment.

- Modularity - DAAS is functionally modular, with general purpose controls and displays, and hardware and software building blocks to provide varying levels of capability. Expansion of capability has minimum impact on the existing aircraft control panel and existing avionics.

Following is an expansion of these conclusions and recommendations.

4.1 FUNCTIONAL CAPABILITY

The DAAS system provides comprehensive facilities for flight management. Concensus of evaluations is that DAAS provides improved functional capabilities with respect to current avionics, and has the potential to significantly improve single pilot IFR efficiency and safety. Checklists, weight and balance, and performance functions are convenient to use, and they support good pilot practices. The moving map display, IDCC data readout, and

comprehensive warning system inform the pilot of flight status. The autopilot, which couples to the NAV system, provides the necessary relief that allows the pilot to monitor and effectively manage his flight.

The DAAS moving map display is well received and considered a major aid in flight management. However, the following enhancements have been suggested:

- Terminal area display should be expanded to include stored approach plate details. Automated terminal area flight management including coupled NAV and autothrottle functions should be considered.

- It would be desirable to accurately display the runway during landing approach. This could, perhaps, be feasible if 1) a strapdown AHRS with short term INS capability were a part of DAAS, or 2) MLS were included, or 3) GPS were included, or 4) ILS/DME navigation mode were included.

- A color map display would be useful to facilitate increased display information content.

- Expansion of DABS to aid in congested terminal area communications would be desirable.

- Incorporation of an EADI into DAAS would be an appropriate follow-on effort to further develop the concept.

The DAAS function set is considered representative and adequate for demonstration purposes. There are areas where changes might be considered for an operational system. For example, DAAS complexity must be controlled and pilot/system interface must be efficient to maximize pilot access to DAAS functions.

DAAS controls and displays have been generally accepted by evaluators, including the alphanumeric keyboard. The system simulator IDCC touchpoint mechanization was found objectionable because:

- No tactile feedback to indicate signal initiation.
- Smudges on CRT face obscured image.
- Inadvertent data entries possible if touchpoints are not accurately touched.

An alternate approach using bezel-mounted buttons has been added.

The DAAS Kalman filter blending of VOR/DME data with dead reconing position is expected to improve navigation, precision and stability. The addition of DME/DME integration into the DAAS algorithms seems like an appropriate follow-on. Integration of an IRS to augment the blender position should also be considered.

4.2 COST

DAAS includes significantly more functional capability at a cost competitive with conventional avionics, as illustrated in section 3.3. The DAAS cost advantage will become more decisive as more functions are incorporated. For example, DAAS could be expanded to integrate:

- Weather radar
- Air data computer
- Autothrottle
- Automatic storage of airport facility data

- AHRS
- Radar altimeter
- Other functions

Therefore, with each function added total system cost per function would come down since packaging power supplies, and controls and displays are shared in DAAS and need not be duplicated for separate functions.

Consequently, the DAAS concept of integrated avionics is cost effective.

4.3 RELIABILITY, SAFETY

The PAAS system reliability, including sensors, instruments, computers, and servos is estimated to be 137 hours MTBF. This system reliability is expected to improve as integrated circuit technology advances, and electromechanical devices are replaced by solid state devices.

The existing DAAS NAV/Autopilot function reliability is estimated to be 9260 hours mean flight time between loss of function.

The DAAS architecture, using advanced electronics, has produced a very reliable computer system. Consequently, DAAS reliability was affected mainly by sensor and servo failure rates; e.g., system sensors and servos contribute 96 percent of the autopilot failure rate. Since the autopilot and NAV functions are essential to effective flight management, it is recommended that low cost redundant sensor and servo configurations be pursued, with

a goal of 10,000 hour NAV/autopilot flight MTBF. The DAAS architecture can cost effectively provide such reliability.

The failure mode effects analysis of 86 DAAS elements concludes that, with recommended modifications implemented, DAAS failures are tolerable and safe. The DAAS safety pilot's contribution to flight safety is also acknowledged, especially in take-off and landing situations.

4.4 MAINTAINABILITY

DAAS concept offers improved maintainability through:

- Improvements in hardware reliability
- Built-in test for automatic fault detection, localization
- Capability for on-aircraft trouble shooting without special test equipment.

4.5 MODULARITY

The DAAS system is functionally modular. It is composed of hardware and software building blocks that can be configured to provide varying levels of functional capability and cost. Expansion of capability will have minimum impact on the existing DAAS aircraft control panel and avionics.

The DAAS system can be adapted to interface with devices from a variety of manufacturers. For example, hardware and software modules could be developed to allow use of different NAV receivers,

even if the NAV receivers were not equipped for remote tuning. Manual tuning would be required in this version of DAAS, on command from the IDCC. The system can also accept input signals from sensors supplied by a variety of manufacturers. The variety of subsystems with which a production version of DAAS would be compatible would be determined in a marketing study.

DABS integration into DAAS late in the DAAS development program demonstrates basic modularity. Incorporation of DABS required:

- Installing a DABS transponder and control panel in the aircraft, and interfacing it to the DAAS computer unit.
- Adding a DABS processor module, and two DABS interface electronics modules to the DAAS computer.
- Adding three DABS pages to the IDCC.
- Adding a DABS "Message Pending" light to the panel.

The DAAS processor module is appropriate for DABS computations. DAAS keyboard and IDCC page formats are appropriate for DABS. DABS readily fit into the DAAS framework, thereby demonstrating that DAAS is a highly modular system.

GLOSSARY

ADI - altitude direction indicator

AHRS - Altitude Heading Reference System

ALT - altitude, altitude hold

ARM - arm

ATC - Air Traffic Control (National)

BIT - built-in test

CC - central computer

CCU - central computer unit

COM - communication

COMM - communication message

CPU - central computer unit

DAAS - Demonstration Advanced Avionics System

DABS - Discrete Address Beacon System

DME - distance measuring equipment

EHSI - electronic horizontal situation indicator

ELM - extended length message

EPROM - electrically alterable PROM

ETA - estimated time of arrival

FAR - federal aviation regulation

FDI - flight director indicator

GMT - Greenwich mean time

GS - glideslope

GLOSSARY

HDG - heading

IAS - indicated air speed

IDCC - integrated data control center

IFR - instrument flight regulations

LOC - localizer

MDA - minimum descent altitude

MLS - microwave landing system

NAV - navigation

NAVAID - navigational aid

PAAS - Projected Advanced Avionics System

PROM - programmable read-only memory

RAM - random access memory

RAU - radio adapter unit

RMI - radio magnetic indicator

ROM - read-only memory

RPM - revolutions per minute

SEL - select

SM - standard message

UV - ultra-violet

UV-EPROM - ultra-violet eraseable PROM

VFR - visual flight regulations

VHF - very high frequency

GLOSSARY

VNAV - vertical navigation

VOR - VHF omnidirectional (omni) range

VOR/LOC - VOR localizer

VOR/LOC/GS - VOR localizer glideslope

VSI - vertical speed indicator

APPENDIX A
PROFILES OF DAAS TEST PARTICIPANTS

SUBJECT PROFILE #1

Name: Bill Unternaehrer
Position: Design Engineering, Honeywell, Inc.

Number of Years Active Flying: 13 years
Certified Flight Instructor: Yes
Ratings: ATP, MEL, Commercial, SEL, SES, Glider
Flight Instructor - Instrument and Airplane
Experience with HSI; Yes (20 hours)

Aircraft Flown	Flight Hours
Piper (Single & Twin)	550
Cessna (Single)	1500

Currently Fly: Cessna

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SUBJECT PROFILE #2

Name: Larry Pedersen
Position: Supervisor, Test Equipment Field Engineering, Honeywell, Inc.

Number of Years Active Flying: 15 years
Certified Flight Instructor: Yes
Ratings: ATP, Airplane and Power Plan Mechanic
Flight Instructor - Airplane and Instrument

Experience with HSI: Yes (King HSI)

Aircraft Flown	Flight Hours
Cessna (Single & Twin)	825
Beech (Single & Twin)	205
Piper (Single	800
Others 20	20

Currently Fly: Beech Bonanza, Cessna 172, Cessna 421

SUBJECT PROFILE #3

Name: Ron Albertson
Position: Pilot, King Radio Corp.

Number of Years Active Flying: 12 years
Certified Flight Instructor: Yes
Ratings: MEL, ATP, Gold Seal
Flight Instructor - Airplane and Instrument

Experience with HSI: Yes (KFC 300, KFC 200, KFC 250, Bendix 810, Mitchel)

Aircraft Flown	Flight Hours
Beech	3,000
Piper	3,000
Cessna	3,000
Bellanca	3,000
Mooney	3,000

Currently Fly: All above

SUBJECT PROFILE #4

Name: John Lindberg
Position: Pilot, Instrument Flight Training

Number of Years Active Flying: 10
Certified Flight Instructor: Yes
Ratings: MEL, ATP
Flight Instructor - Airplane and Instrument

Experience with HSI: Yes (KFC 300, KFC 200, Collins Bendix, Narco)

Aircraft Flown	Flight Hours
Beech	1,000
Piper	1,000
Cessna	1,000
Bellanca	1,000
Mooney	1,000

Currently Fly: All above

SUBJECT PROFILE #5

Name: Dan Rodgers
Position: Director Special Projects; King Radio

Number of Years Active Flying:
Certified Flight Instructor:
Ratings: MEL, Private Instrument

Experience with HSI: Yes, Project Engineer KFC 300 and KFC 200

Aircraft Flown	Flight Hours
Beech	Not available
Piper	Not available
Cessna	Not available
Mooney	Not available

Currently Fly: All above

APPENDIX B
DAAS FAILURE MODES AND EFFECTS ANALYSIS

FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN. ETC.	FAILURE CATEGORY	COMMENTS
1	Encoding Altimeter	-571	Fault within the Altim.	200	Altimeter Indicator	Erroneous Visual Output	Yes, Power Servo Loop	3	During IFR-conditions. Proximity Warn. do not Detect. Vertical Obstacles
					Dabs Transpond. KT76A "	Erroneous Output "	Error Check Amber Light	3	Misleads Traffic Control.
					A/P CPU	Erroneous "G. Proximity Warn."		3	Wrong Warn. Threshold
					A/P & IDCC CPU	Erroneous "Alt. Advisory" Light Info. (Alt. Alert, MDA & DH.)		2	"Secondary Effect"
					A/P & NAV CPU	Erroneous Parameter T.O. & Nav. Calculation		3	Wrong Fuel or T.O.-Distance Calculation.
			Conclusion:	Far 91 do not require redundant altimeters for Cat. 1 IFR, only for CAt II. The Probability for a failure is ~ 10^{-3} during 4 hours flt. significant! The co-pilot instrumentation required in DAAS. OK.					
2	Co-Pilot Altimeter		Fault in the Altimeter	200	Altimeter Indicator	Erroneous Visual Output	No	2	Will cause some inconvenience until decided which altim. failed.
			Conclusion:	Loss of the co-pilot altitude info is a minor problem to the DAAS pilot. The probability of loss of both baro-altimers during 4 flt. hrs. is: $\lambda \sim (\lambda_{pitot} + \lambda_{altim})_{pilot} \cdot (\lambda_{pitot} + \lambda_{altim})_{co\text{-}pilot} \sim (4 \cdot 250 \cdot 10^{-6})^2 \sim 10^{-8}$. A catastrophe will occur if the A/C collides with an object not detected by the proximity warning system. The probability for this to happen is considerably less than 10^{-6}.					

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FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN. LTG.	FAILURE CATEGORY	COMMENTS
3	Radar Altimeter	RT221	Fault in Rad. Alt. Incl. Ant.	500	A/P CPU & IDCC A/P CPU & EHSI	Erroneous "G. Proximity Warn." Erroneous: Rad. Alt. Info.	Rad. Alt. Valid. (Amber Light)	2	The probability $<<10^{-6}$ for Baro.-and Radar-Altim. Failures
			Conclusion:	No Far 91 requirement on Rad. Alt. if installed, fail. warn. required. Validity signal OK. A critical situation (4) occur if both the Baro. Alt. and Rad. Alt. fails. Negligible probability. OK.					
4	True Air Speed Sensor	VA210	Fault in Tas OR Sign. Cond.	100	A/P & Nav. CPU EHSI	Erroneous inputs to Nav. & Fuel consum. calculations	No	2	Pilot confused. Might create a problem if no radio Nav. available.
			Conclusion:	TAS not required by Far 91. It is very unlikely ($<10^{-6}$) that a TAS failure will cause a critical situation in DAAS due to redundant IAS and VOR/DME information.					
5	IAS Instrument	Panel	Instrument Failure	280	IAS Indicator	Erroneous visual output	No	2	
			Conclusion:	Single IAS instrument OK for Cat 1 IFR, Far 91. 2 required Cat. II conditions. Loss of IAS instrument not critical in DAAS. Redundant visual speed info. available.					
6	Co-Pilot IAS Instrument		Instrument Failure	280	IAS Indicator	Erroneous visual output	No	1	Neglectable to pilot. Redundant info. available (IAS + RPM)
			Conclusion:	Loss of Co-Pilot IAS info. no problem to the pilot. The probability of loss of both IAS indicators are (with reference to fault No. 2): $(4\ 330 \cdot 10^{-6})^2 \sim 2 \cdot 10^{-6}$. The risk for a catastrophe is significantly lower in the DAAS systems since redundant info. such as VOR/DME and angle of attack are available. OK.					
7	Air Data Computer	ADC-380	Instrument Failure	200	A/P CPU	Erroneous A-H Signal	Yes Alt. Valid (Amber Light)	2	Additional Alt. & VS info. available. The pilot monitors Alt. hold.
			Conclusion:	Far part 91 do not require a 3rd IAS/ALT. Sensor. The Alt./IAS valid and available redundant info. will minimize risks.					

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FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN.ETC.	FAILURE CATEGORY	COMMENTS
8	Pitot system	left	faulty PTOT or PSTAT	50	Altimeter VSI-indicator IAS-indicator ADC KDC-380	Erroneous: ALT & Δ-H info. IAS & VSI flight warning proximity " transponder response	NO	3	Confusing info. Risk for wrong action in IFR cond. Pilot or ground control.
9	Co-pilot pitot system	right	faulty PTOT or PSTAT	50	Altimeter VSI-indicator IAS-indicator	Erroneous visual info. to co-pilot	NO	1	Co-pilot not in the control loop.

Conclusion: Dual PITOT systems required by FAR 91 only for CAT. II operations. For DAAS, the co-pilot and the right PITOT system provide adequate redundancy.
The probability of failures in both left and right PITOT systems is ~ $(4 \cdot 50 \cdot 10^{-6})^2 < 10^{-7}$.
Very low risk!

10	Outside air temp.		sensor or sign. cond. failure	5	NAV-CPU	Erroneous input to T.O., cruise, and fuel/distance calculat.	NO	2	Fuel qty. checks will alarm pilot in time for refueling. Probability of failure low

Conclusion: No OAT required by FAR.
OAT failure is not assumed to cause severe pilot problems. It is suggested, however, that inputs to calculations such as OAT ALT etc. are displayed to the pilot when used.

FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN. ETC.	FAILURE CATEGORY	COMMENTS
11	Magnetic Flux Detector	NHT 112	Faulty Mag. North ref. signal	20	Radio Magnetic indicator and EHSI	Erroneous Visual Output. (Dir. GYRO slaved to Mag. Fx. Det.)	No	3	The pilot misled by 2-3 indicators giving consistent faulty information.
					A/P - CPU	Faulty Hdg. Error in Hdg-hold mode		3	KHT112 essential unit!
					NAV - CPU IDCC-CPU	Faulty Navigation and fuel/distance calculations		3	Kalman Filter will output excessive wind, spoiling calculations.
			Conclusion:	Far 91 requires mag. dir. indicator and dir. GYRO for IFR. 2 dir. GYROS req. for Cat II cond. Co-pilot dir. GYRO and Mag. compass makes DAAS ok!					
12	Slave Acces-	KA 51A	Dead or wrong output	10	The indicator	Faulty visual output	No	1	RMI and mag. compass info available to pilot, eliminates confusion.
			Conclusion:	Far 91 do not explicitly state the need of a slave accessory.					
13	Directional GYRO including Scott T/DMA	KSG 105	Faulty Hdg. Output	300	Radio magnetic indicator and EHSI	Erroneous visual output	Yes Hdg. valid (Amber Light)	3	Dir. GYRO essential. See See No. 11 comments.
					A/P - CPU	Faulty Hdg. Error in Hdg. Mode			
					NAV - CPU IDCC-CPU	Faulty navigation and fuel/distance calculations			
			Conclusion:	See fault No. 11 comments. The Dir. GYRO validity-test coverage ~ 70%. Probability for undetected failure ($0.3 \cdot 4 \cdot 300 \cdot 10^{-6}$) ~ $4 \cdot 10^{-4}$ during a 4 hours flight. Still significant!					
14	Radio magnetic indicator	KZ 226	Fault in the RMI	330	RMI indicator GYRO or VOR mode	Erroneous visual output	No	2	Mag. compass, RMI and EHSI provides redundant info to pilot.
			Conclusion:	Far requirement see No. 11. OK.					

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FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN. ETC.	FAILURE CATEGORY	COMMENTS
15	Co-Pilot Mag. Flux Detector	KMT 112	Faulty Mag. North Ref. Signal	20	PNI (Slave Acc.)	Erroneous Visual Output	No		
16	Slave Aceessory	KA 51A	Dead or Wrong Output	10	Slave Acc.	Erroneous Visual Output	No	1	1 to the pilot
17	Directional GYRO	KG 102A	Faulty Hdg. Output	300	PNI (Slave Acc.)	Erroneous Visual Output	No		(2 to co-pilot)
18	Pictural Nav. Indicator (P.N.I.)	KI 525A	Mag. Card Error	330	PNI	Erroneous Visual Output	No		
			Conclusion:	Loss of co-pilot slaved directional GYRO info. is a minor problem to the DAAS pilot. The probability of one failure in the pilot slaved directional GYRO system and one failure in the co-pilot system is $(4.660.10^{-6})^2 < 10.^{-5}$ The probability is remote and the mag. compass and VOR info. available makes the risk very low.					
19	Turn and Slip Instrument	"RC Allen"	Faulty Turn Rate Instrument	150	Turn Rate Indicator	Erroneous Visual Output	No	1	Turn rate determined from roll angle as replacement
			Faulty Slip Instrument	10	Slip indicator	" " "	No	1	Side acceleration sensed by pilot acceptable replacement.
			Conclusion:	Single slip-skid indicator required for Cat. I and II IFR, By Far 91. Loss of this instrument minor problem.					
20	Co-Pilot Turn and Slip Instrument		Faulty Turn Rate Instrument	150	Turn Rate Indicator	Erroneous Visual Output	No	1	
			Faulty Slip Instrument	10	Slip Indicator	Erroneous Visual Output	No	1	
			Conclusion:	Negligible to the pilot and co-pilot.					

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FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN. ETC.	FAILURE CATEGORY	COMMENTS
21	Yaw Rate GYRO	GG 2472	Faulty GYRO	50	A/P - CPU	Worst Case: Rudder transient and convergent Yaw oscillations.	No	2	Inconvenient before Y/D and A/P disengaged.
			Conclusion:	It is assumed that the rudder servo slip clutch protects against dangerous side- and angular-acclerations and that the A/P dump switch is an adequate mean to disengage the Y/D.					
22	Angle of Attack Sensor and Indicator	Type EC	Faulty Output	100	A/P - CPU	Stall warning given at normal α, or not given when needed.	No	2	Visual check of the indicator and crosscheck of speed, vert. speed and attitude will reveal a fault.
			Conclusion:	No Far requirement on angle of attack indicator or stall warning.					
23	Vertical GYRO	VG 233	Faulty Pitch and/or Roll Signal	330	Attitude Direct. Indicator	Erroneous "Artificial Horizon"	Yes "Vert. GYRO Valid" (Amber Light)	2	Difficult Failure to detect, especially for zero output, since ADI, A/P and EHSI all agree. Close observance of other FC-instruments assumed.
					A/P - CPU Servos	Errors in control laws,		2	
					EHSI - CPU	Error in predicted Trendlines		2	
			Conclusion:	Far 91 requires 1 "Artifical Horizon" for Cat. I conditions and 2 for Cat. II. The coverage of the validity test is ~ $(0.3 \cdot 4 \cdot 330 \cdot 10^{-6})$ ~ $4 \cdot 10^{-4}$ significant! Far 23.1329 e) a hardover failure in the vertical GYRO roll output propages via the A/P cont. laws to roll, yaw and pitch axis. This is not acceptable to Far 91 wording. A modification to eliminate the Far-conflict is recommended.					

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FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN. ETC.	FAILURE CATEGORY	COMMENTS
24	Attitude Dir. Indicator "Artifi. Hori."	KCI 310	Faulty "Artif. Horizon"	340	"Artifi. Horiz." Indicator	Faulty Visual Output	No	2	A/P modes and redundant info available.
			Conclusion:	Far requirements, see fault No. 23. The DAAS is OK in this respect.					
25	Co-Pilot "Artifi. Horizon"	KG 258	Fault in "Artifi. Horizon" Unit	670	"Artifi. Horiz." Indicator	Faulty Visual Output	No	1	The DAAS pilot can easily determine that the KG258 is faulty. Several redundant indicators available to him.
			Conclusion:	Loss of the co-pilot Artificial Horizon is a minor problem. The suction indicator shows if "power" is available and provides valuable info to the pilot.					
				The probability λ of failures in both vertical GYROS and "Artificial Horizons" during a 4 hr. flight is ~ $4 \cdot (330 + 340) \cdot 10^{-6} \times 4 \cdot 670 \cdot 10^{-6}$ or $7 \cdot 10^{-6}$. The risk for loss of both "Artificial Horizons" is not negligible and may bring the pilot in a demanding situation.					
26	Manifold Pressure Instrument	Panel	Instrument Failure	10	Map Indicator	Faulty Visual Output	No	2	In case of an instrument failure these instruments and audiovisual feed backs provide enough info. to the pilot to allow correct failure localization.
27	Engines RPM Instrument	Panel	Instrument Failure	10	RPM Indicator	Faulty Visual Output	No	2	
28	Exh. Gas. Temp. Instr.	Panel	Instrument Failure	10	EGT Indicator	Faulty Visual Output	No	2	
29	Engine Status Instrument 2	Panel	Low Oil Pressure or High Temp.	10	Eng. Status Indicator 1	Faulty Visual Output	No	3	Faulty indication of low oil pressure may during some conditions force the pilot to shut off the engine and land A.S.A.P.
30	Engine Status Instrument 2	Panel	Low Oil Pressure or High Temp.	10	Engine Status Indicator 2	Faulty Visual Output	No	3	
			Conclusion:	Far 91 requires with exception of the EGT, the engine instrumentation. DAAS independent of these instruments.			Listed above. (VFR conditions).		

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FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN. ETC.	FAILURE CATEGORY	COMMENTS
31	Fuel Flow Sensor 1		Faulty Sensor	5	Fuel Flow Indicator	Faulty Visual Output	No	2	Fuel Qty. Info. available
					IDCC	Faulty IDCC info: "Fuel Remaining Time" "Estim. Fuel Remaining"	No	2	"Estim. Fuel Remaining" may indicate too much left, which will mislead the pilot.
			Conclusion:	Far 91 do not require a fuel flow sensor. A faulty sensor might result in a pilot decision to continue a flight without sufficient fuel. Fuel qty. cross checks may not reveal the situation. It is a low probability ($<10^{-6}$) that the pilot might end up in a flight safety critical situation (4).					
32	Fuel Flow Sensor 2		Faulty Sensor	5	IDENTICAL TO FAULT NO. 31.				
33	Fuel Qty.	Panel	Faulty Sensor L or R	150	Fuel Qty. Indicator	Faulty Visual Output	No	2	DAAS provides independent and redundant info. regarding remaining fuel.
			Conclusion:	Far 91 requires fuel qty. instrument for VFR conditions. DAAS supports the pilot in his fuel/distance/time calculations, which improves the probability of detecting fuel qty. instrument failures.					
34	Manifold Pressure Sensors	Cele-sco	Faulty Sensor	5	A/P - CPU	Warning + No Map Fault Amber Light No Warn. + Map Fault	No	1	Redundant engine instruments provides adequate info.
35	Engine RPM Sensors and F/V Converter	NASA	Faulty Sensor	10	A/P - CPU IDCC Light	Warning + No RPM Fault Amber Light No Warning + RPM Fault	No	1	Redundant engine instruments provides adequate info.
			Conclusion:	OK.					

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FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN. ETC.	FAILURE CATEGORY	COMMENTS
36	Wing Flap Pos. Sensors		Faulty Potentio-meter	20	A/P - CPU IDCC	Warning + OK flap pos. Amber Light No Warning + OK flaps	No	1	Regular inspection - routines will still be followed by the pilot.
37	Elevator Trim Pos. Sensor		Faulty Potentio-meter	20	A/P - CPU IDCC	Warning + OK flap pos. Amber Light No Warning + OK flap pos.	No	1	Regular inspection - routines will still be followed by the pilot.
38	Cowl Flaps Pos. Sensors		Faulty Switch	4	A/P - CPU IDCC	Warning + OK flap pos. Amber Light No Warning + OK flap pos.	No	1	Regular inspection - routines will still be followed by the pilot.
39	Landing Gear Pos. Sensors		Faulty Switch	4	A/P - CPU IDCC	Warning + OK position Amber Light No Warning + OK position	No	1	Regular inspection - routines will still be followed by the pilot.
40	Cabin Doors Pos. Sensors		Faulty Switch	4	A/P - CPU IDCC	Warning + OK position Amber Light No Warning + OK position	No	1	Regular inspection - routines will still be followed by the pilot.
41	Aux. Fuel Pumps Switch position		Faulty Switch	4	A/P - CPU IDCC	Warning + OK position Amber Light No Warning + OK position	No	1	Regular inspection - routines will still be followed by the pilot.

Conclusion: Far 23 requires pitch trim indicator. (Included in basic instrumentation) DAAS provides additional info. to alert the pilot if the A/C status is OK. It is assumed that the today used pre flight check routines will be followed. (If not, the DAAS may introduced new failure modes.)

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FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN.ETC.	FAILURE CATEGORY	COMMENTS
42	CWS - Switch and related logic	Control Wheel	Failed Switch	5	A/P - CPU Clutches	CWS-Mode Engaged accidently.	No	3	A/P and hold modes disengaged without pilot awareness. No info.
			Conclusion:	Far 23 requests adequate means to disengage the A/P. OK. It is assumed that the pilot by monitoring the instruments will detect a not desired CWS-mode engagement and that he will hold the cont. wheel steady when releasing the A/P.					
43	Go-Around Switch	Control Wheel	Failed Switch	4	A/P - CPU	Go-around mode engaged accidently.	No	2	Information given on the annunciator panel.
						Go-around mode not engaged when wanted.		3	Demanding moments to the pilot, especia ly if in the A/P-Appr/GS mode.
			Conclusion:	If the go-around mode not is available when needed a less experienced pilot may even create a critical situation. ($4 \cdot 4 \cdot 10^{-6}$ x ?,low probability however)					
44	Eng./Disengage-Switch Pitch Trim	Control Wheel	Failed Switch	4	A/P - CPU Trim Motor	Disengage of A/P-modes accidently.	No	2	Annunced!
						Only Aut. Trim available		2	Use Auto.-Trim
45	Deep-Trim Pitch	Control Wheel	Failed Switch	4	A/P - CPU Trim Motor	No Manual Trim		2	Use Auto.-Trim
						Run-away Trim		3	Use Auto.-Trim
			Conclusion:	The Auto.-Trim function replaces Manual Trim in A/P modes.					
46	Autopilot Dump Switch and Relay	Control Wheel	Failed Switch	4+4	A/P - CPU Clutches	Disengage of A/P modes accidently.	No	2	Annunced!
						Not possible to disengage A/P.		3	Demanding in an A/P failure situation over power possible.
			Conclusion:	The probability for this situation involves both a switch failure and failure in another flight safety critical element. Estimated probability x ~ ($4 \cdot 8 \cdot 10^{-6}$ x $4 \cdot 1000 \cdot 10^{-6}$)~$1 \cdot 10^{-7}$. OK.					

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FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN. ETC.	FAILURE CATEGORY	COMMENTS
47	Communication Transceivers Antennas	KY-196	Faulty Radio	330	Communication Aids	No communication	no	1	Assumed Far 91 rules followed.
			Conclusion:	Far 91 requires 1 two-way radio communications system, Cat I and II. DAAS has 3 systems, including antennas. The probability of loss of communication due to faulty transceivers is for DAAS $(4 \cdot 330 \cdot 10^{-6})^2 \times 4 \cdot 660 \cdot 10^{-6} = 5 \cdot 10^{-8}$ (Co-pilot transceiver $660 \cdot 10^{-6}$ fault/FLT hour). OK.				
48	Navigation Receivers Antennas	KN-53	Faulty VOR	250	Radio Adpt. Box NAV-CPU EHSI - RMI Radio Adpt. Box NAV-CPU EHSI - ADI	Faulty Navigation Info. No or faulty VOR/GS directions.	No	2	Traffic control support radar vectoring etc. DAAS dead-reckoning.
			Conclusion:	Far 91 requires appropriate single channel navigation equipment for Cat. I conditions and dual LOC/GS - receiving systems and a FC-guidance system for Cat II conditions. DAAS provides triplex receivers and duplex-antennas, including co-pilot back up. OK.					
49	DME receiver antenna	KN-62A	Faulty Receiver	500	Radio Adapt. Box NAV-CPU EHSI	Faulty Navigation Info.	No	2	Fault detected "Kalman-Wind" etc. VOR available.
			Conclusion:	Far 91 requires DME if flying at and above 24000 feet. Separate antenna. OK.					
50	Transponder Antenna	KT-76A	Faulty Transpond.	400	Radio Adapt. box	No Identification possible	No	1	Traffic control takes proper action.
			Conclusion:	Far 91 do not require transponder. The probability for a failure giving information possible to misinterpret by traffic control is neglected. Separate antenna.					

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51	Audio headsets	KMA-24	Fault in receiving parts Fault in transmit parts	200	Earsets, speakers microphones	No audio info. Talk, Nav. OM MM No outgoing talk	NO	3	One-way comm possible
			CONCLUSION: FAE 91 requires only one communication system. (Single failure allowed to block all audio communication!) DAAS provides 3 separate systems possible to connect to the pilot or copilot headset or speakers via redundant switches on the audio panel. Very good redundancy. OK.						
52	Switch NAV 1 SEL		Stuck in one position	4	NAV-CPU NAV1 - RECEIV	Only one of manual or DAAS control available.	NO	2	Assumed to create a confusing situation before the pilot finds out how a fault affects DAAS function, and how he has to set the switches for correct system operation.
53	" NAV 2 SEL		" "	4	NAV-CPU NAV2-RECEIV	" " "	NO	2	
54	" DME SEL		" "	4	NAV-CPU DME RECEIV	Only one of NAV 1, 2, or DAAS control available	NO	2	
55	" VOR SEL	RMI	" "	4	NAV 1.2 RECEIV RMI	Only VOR 1 or 2 or none of VOR 1.2 avail. on RMI	NO	1	
56	" LOC/GS SEL	ADI	" "	4	Radio adpt. box ADI	Only LOC/GS info. from NAV 1 or NAV 2 or what DAAS selects avail. on ADI	NO	2	
			CONCLUSION: These switches do not represent single point failures in critical single channels. OK. Co-pilot backup.						
57	IDCC keyboard & touch P.		Faulty inputs to IDCC	50	IDCC, CPU NAV-CPU EHSI	Erroneous flt. plan, flight status, way points, map, etc.	NO/YES	3	Keyed in messages displayed on IDCC before entered. Detectable.
58	IDCC Selector switches		Faulty mode selection	40	IDCC, CPU	Wrong & not changeable "pages"	NO	2	Not wanted mode selected & not possible to select desired mode.
59	IDCC CPU, refresh-memory & display		Faulty computation & presentation	75 300	IDCC, CPU	Wrong or garbeled info. displayed, not understandable	YES BITE	2	Pilot misses IDCC AID. Pilot detects the failure.
			CONCLUSION: The probability of the pilot's not detecting "No 57 errors" by IDCC or EHSI checks is very low. Ok in this respect! The BITE detects about 80% of all computer failures, which reduces the probability of undetected failures from $75 \cdot 4 \cdot 10^{-6} = 3 \cdot 10^{-4}$ to $0.2 \cdot 3 \cdot 10^{-4} = .6 \cdot 10^{-4}/4$ hrs.						
60	EHSI Selector switches		Faulty mode selection	20	EHSI-CPU EHSI	Wrong & not changeable modes or scales.	NO		Not possible to select desired mode.
61	EHSI, CPU & BIM, refresh-memory and display		Faulty computation and presentation	75 300	"	Wrong or garbled info. displayed	YES BITE	2	Pilot misses EHSI info. Fault detect possible by pilot.
			The probability for loss of EHSI is $\sim 400 \cdot 4 \cdot 10^{-6} = 1.6 \cdot 10^{-3}$ per 4 flt. hrs. The possibility of reconfiguration (BIM + CPU) reduces the probability to $4 \cdot 325 \cdot 10^{-6} = 1.3 \cdot 10^{-3}$ assuming 100% BITE coverage.						

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		CONCLUSION:	Reconfiguration of the most reliable elements does not improve the risk situation very much! The co-pilot NAV.-facilities makes DAAS OK. BITE reduces undetected computer failures to $15 \cdot 10^{-6}$ per flt. hr. or $60 \cdot 10^{-6}$ per flight.						
52	Annunciator panel & drive circuits	KAP-315	Fault in panel or driv. circ.	30	Annunciator panel	Missed or wrong mode status info.	NO	2	Might temp. mislead the pilot. FC and NAV instruments will tell the truth, however.
		CONCLUSION:	FAR 23.1329 requests means to inform the pilot what A/D -NAV. mode is engaged. Switch positions are not acceptable. DAAS OK in this respect.						
63	Mode controller and drive circuits	KMC-340	Faulty trim or hdg sel. knob	60	A/P-CPU various parts of DAAS	No trim/hdg sel avail. Trim/hdg sel activated accidentally.	NO	2	The pilot overrides and disengages the system.
64	"		Faulty toggle switches	180	"	Engage not wanted mode Disengage wanted mode Not defined mode (e.g. ATT↔ALT)		2	Demanding if a mode change takes place at busy part of the flight, or a mode just quietly opens up.
65	"		Faulty solenoid switches	100	"	Accidental engage or disengage of A/P (Y/D) modes		2	
		CONCLUSION:	FAR 23 requirement on accessibility of controls met. OK.						
66	Auto pilot yaw clutch, servo		Fault in any hardware	70	Control surface	Servo not movable Servo run away clutch not locking clutch allw. locked	NO	2	No Y/D avail. Pilot override Disengage Y/D
67	Roll Clutch, servo		"	70	"	" "	NO	3	No roll A/P avail. Pilot override Disengage A/P.
68	Pitch clutch, servo		"	70	"	" "	NO	3	No pitch A/P avail. Pilot override. Disengage A/P.
69	Trim clutch, servo		"	50	"	Trim not moveable Trim run away	Yes Trim monitor	3	Monitor detects trim runaways open circuitries, but not motor failures (e.g., only one direction.)
70	Clutches common logic		Faulty circuitry	5	Control surfaces	None of the clutches engages. All clutches stay engaged.	NO	3	No A/P engaged. Pilot must override in 3 axes.

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			CONCLUSION:	FAR 23 met regarding possibilities to override. FAR 23 requirement on fault in only one channel not met. The pilot might end up in a critical situation if one or more of the servos or of the clutches are not operational. No warning or info given. The pilot is in a critical situation if he has to override all 3 servos. The probability of not being able to engage all clutches is $\sim 10^{-4}/4$ hrs. The probability of not being able to disengage all clutches is $\sim (4 \cdot 5 \cdot 10^{-6}) \times (4 \cdot 4 \cdot 10^{-6})^2 < 10^{-12}/4$ hrs. The probability of a critical situation is negligible! OK.			
71	A/P-I/O		Fault in any hardware		Almost all elements!	Erroneous:	YES		The A/P-I/O computer is a key element in DAAS. Failure effects of all categories may occur. For instance, a CPU failure may affect separate instructions, e.g. shift which will spoil all mult. and div. A D/A failure may cause all outputs to go high, including all servos and ADI command bars.
	CPU + BIM			60 + 12		Mode status	BITE		
	A/D, D/A, MUX			60	"	F/D-commands			
						servo-commands			
						Flt warning	BITE	3	
						cruise-perform.			
						fuel distance			
						IDDC info			
						EHSI map			
						Annunciator			
						Error may affect only one function, e.g., door warning, or many		1	
						elements, e.g. D/A failure commanding 3 servos hardover.		3	

GENERAL POSSIBLE FAILURE MODES	MUX	A/D	CPU MEMORY	D/A	MUX
All signals high or low	x	x		x	
" zeros	x	x		x	
" faulty	x	x	x	x	x
Separate signals "			x		

The bite coverage is about 95%. It is very likely that BITE will detect even more of the severe failures. A BITE coverage of 99.9% is requested to bring the probability of an undetected failure down to $10^{-6}/4$ hrs.

CONCLUSION: FAR 23 requirement on disengagement and possibility to override is met. (The added 1G-dump-switch is helpful). FAR 23 requirement on only single axix hardover failure is violated. It is probable that failures occur which, detected or not by the BITE, will cause transients and shut down major parts of the DAAS. The DAAS co-pilot will, in such situations, take over and DAAS will be disengaged.

Actions to resolve the FAR conflict is recommended.

72	NAV FLT/PLAN		Fault in any hardware	60 + 12	A/P comm. bars		YES		Undetected erroneous NAV computations may, during a fairly long time, introduce A/C position errors. Several indicators may give consistently faulty info. Loss of NAVAID after a detected fault may also bring problems to an unexperienced pilot.
	CPU & BIM				A/P servos	Erron. comm. references	BITE		
					EHSI	Faulty map		2	
					IDCC	Faulty NAV info.			
					NAV 1, 2	Wrong frequencies			
					BUBBLE MEM.	Store faulty NAVAID data			

CONCLUSION: The probability of faulty NAV calculations is $\sim 4 \cdot 72 \cdot 10^{-6} \sim 3 \cdot 10^{-4}$ without reconfiguration.
The probability of faulty NAV calculations is $\sim 4 \cdot 72 \cdot 10^{-6}(1-\frac{80}{100}) + (4 \cdot 72 \cdot 10^{-6})^2 \cdot (1-\frac{20}{100}) \sim .6 \cdot 10^{-4}$ with reconfiguration.
Reconfiguration improves the availability of the NAV calculations 5 times. Significant improvements requires better BITE coverage.
DAAS with co-pilot OK.

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FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN. ETC.	FAILURE CATEGORY	COMMENTS
73	SPARE CPU & BIM		Fault in any parts	60 + 12	EHSI or by NAV computer controlled elements	Same failure effects as fault 61 EHSI, CPU, and 72 NAV CPU.	YES BITE	2	Similar to faults No. 61 and 72.
		CONCLUSION:	The likelihood that any spare CPU or BIM failure will affect the DAAS performance is negligible. Because 2 similar failures are required, the probability for this is: (NAV. FAIL + EHSI FAIL) · (SPARE FAIL) or $(72 + 72)\cdot 4\cdot 10^{-6} \cdot (72\cdot 4\cdot 10^{-6}) \sim 2\cdot 10^{-7}$. The spare CPU itself will not harm the DAAS!						
74	Radio Adapter Box & BIM	KRC	Fault in any part	40 + 12	EHSI IDCC A/P (ADI)	Mistune NAV/DME receiv. Garble NAV data to NAV A/P CPU, which may affect visual indicators and bugs as well A/P servos.	YES BITE	3	The failure effects are dependent on engaged modes, e.g. during a coupled landing the DAAS may control all indicators (except the RMI) as well as the A/P servos and ADI bugs.
		CONCLUSION:	The co-pilot backup NAV instrumentation makes DAAS OK.						
75	DABS - CPU + BIM Panel		Any part failure	60 + 12	IDCC	No identification possible	YES BITE	1	No readable output. Traffic control takes proper action.
	Transponder					Misleading IDCC info presented to the 1 pilot			
		CONCLUSION:	SEE ALSO FAULT NO. 50 KT-76A TRANSPONDER. DABS NOT FULLY DEFINED.						
76	Bus controller and reconfig. CPU + BIM		Any part failure	60 + 12	All DAAS computers & functions	Power up mode. One or more faults in one or more of the CPU's when loading the programs	YES BITE	1	These failures are expected to be detected by BITE or the pilot.
						Normal Mode			
						1. Misinterpretation of validity signals and shutdown of fault-free CPU.		3	These failures might result in a demanding situation if they occur during a busy flight phase.
						2. No warn. given for some BUS-CPU and IDCC-CPU failures.		3	
						3. Bus control failures may result in missed information or complete bus traffic breakdown.		3	Loss of most of the DAAS functions in a busy flight phase is demanding.
						Reconfiguration Mode			
						The CPU may fail to reconfigure.		2	Results in loss of EHSI or NAV computer.
77	488 Bus		Faults in wires or connectors	1	EQUAL TO BUS CONTROL FAILURES NO. 76				
		CONCLUSION:	Failures in the bus controller may affect more than 1 channel. The DAAS co-pilot provides backup, making DAAS OK.						

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FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN. ETC.	FAILURE CATEGORY	COMMENTS
78	Bubble Mem.		Any part failure	300	All DAAS computers and functions	All kinds of failures might occur from single instruction failure to all CPU instructions faulty.	YES. Mem sum checks in the CPU's	3	A fault happening before flight will be detected by the mem. sum. check or by the pilot before takeoff. A failure during flight followed by a temp. power loss may, in a worse case, mean loss of the DAAS.
		CONCLUSION:	Failures affecting more than 1 channel may happen, FAR 23 violation. The most severe failure is bubble memory failure in air, followed by a temporary power loss during a demanding phase of the flight. The probability for this to happen is estimated at less than $(300 \cdot 4 \cdot 10^{-6}) \times (50 \cdot 4 \cdot 10^{-6}) \sim 2 \cdot 10^{-7}$. The probability for critical failures to occur due to the bubble memory is low enough to make DAAS OK. Action is recommended to resolve the FAR conflict.						
79	Cassette		Any part failure	500	Bubble memory	The failure effects are similar to bubble memory failures.	YES CPU mem. sum. check	3	A fault will be detected before flight.
		CONCLUSION:	Cassette failures will very likely be detected by BIT or the pilot before takeoff. The probability of an undetected cassette failure is judged to be $<10^{-6}$. DAAS OK.						
80	Alternator (Batt.) 28VDC bus		Alternators, Battery, bus failures	$\sim .1$	All electrical units except DAAS-buses	Shuts down all major DAAS sensors.	Obvious	4	Very critical situation.
		CONCLUSION:	No FAR 23 or 91 requirements on avionics el. power bus redundancy or failure probability. It is assumed that the pilot quickly disengages a faulty A/C battery if it fails when any alternator is OK. The probability λ of loss of the 28 VDC bus during 4 flt. hrs. is thus: $\lambda \sim \lambda_{Alt.\ A} \times \lambda_{Alt.\ B} \times \lambda_{Batt.} + \lambda_{bus} \sim (200 \cdot 4 \cdot 10^{-6})^2 \times (100 \cdot 4 \cdot 10^{-6}) + .1 \cdot 10^{-6} \sim .1 \cdot 10^{-6}$ NOTE: The battery will be drained in less than 1 flt. hr. (Before the battery is drained, the probability of open or shorted bus is the most likely reason for electrical power loss).						
81	Avionics bus 28 VDC		Connections, switches bus	$\sim .1$	Audio NAV, DME, X-ponder, etc.	Loss of communication.	NO	4	Affects both the pilot and co-pilot commun. NAV equipment.
		CONCLUSION:	The reduncant lines and switches make the avionics bus as safe as the alternator 28VDC bus. (Pilot and co-pilot instrumentation electrical power should, in principal, be separated.)						
82	DAAS A and B 28 VDC bus		Connections, switches, diods, battery, buses	$\sim .5$	DAAS CPU's memories, EHSI, IDCC, FCS, etc.	Shuts down DAAS	YES BITE	3	Reliability degradation is due to single switches and lines.
		CONCLUSION:	DAAS with co-pilot, demanding 3. Still low probability of electrical power loss!						
83	DAAS bus 115 and 26 VAC		Lines, switches, converters	10	DIR & vert. gyro ADI, RMI, ADC sign condit.	Errors or no attitude references, etc.	YES "VALIDITY"	3	
		CONCLUSION:	Loss of DAAS-AC judged OK.						

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FAILURE NO.	DAAS ELEMENT	NO.	FAILURE	FAILURE RATE*10^6	AFFECTED ELEMENTS	EFFECTS OF FAILURE	DAAS WARN. ETC.	FAILURE CATEGORY	COMMENTS
84	DAAS 15VDC		Lines switches inverter	15	ANALOG I/O	Most sensor inputs missing.	YES BITE	3	
85	DAAS 12VDC		"	18	Bubble Mem.	Reconfiguration not possible.	NO	3	Probability of reconfiguration low.
86	DAAS 5VDC		"	15	IDCC CPU's	Shut down of DAAS	Obvious	3	
		CONCLUSION:	Failures 84 and 86 can be accepted in DAAS due to the co-pilot backup. FAR 23 is not met for electrical power failures 82 to 86. Actions are recommended.						
ADDITION	DAAS Software	ALL	CPU's	unknown	A/P, servos, EHSI, IDCC, etc.	Any type of erroneous comm. and information.	NO	3	
		CONCLUSION:	The DAAS co-pilot will take over and DAAS will be disengaged. OK.						

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