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THE DEVELOPMENT OF AN AIRBORNE INFORMATION MANAGEMENT SYSTEM FOR FLIGHT TEST

Glenn A. Bever*
NASA Dryden Flight Research Facility
P.O. Box 273
Edwards, California 93523-0273

Abstract

An airborne information management system is being developed at the NASA Dryden Flight Research Facility. This system will improve the state of the art in managing data acquisition on-board research aircraft. The design centers around highly distributable, high-speed microprocessors that allow data compression, digital filtering, and real-time analysis. This paper describes the areas of applicability, approach to developing the system, potential for trouble areas, and reasons for this development activity. System architecture (including the salient points of what makes it unique), design philosophy, and tradeoff issues are also discussed.

Nomenclature

A-D	analog to digital
AICS	airborne instrumentation computer system
AIMS	airborne information management system
CPU	central processing unit
DFRF	Dryden Flight Research Facility
DPRAM	dual-ported random access memory
EPROM	electrically programmable read-only memory
I/O	input-output
MIL-STD	military standard
mini-TAICS	minitransputer airborne instrumentation computer system
NASA	National Aeronautics and Space Administration
PC	printed circuit
PCM	pulse code modulation
RAM	random access memory
SMD	surface-mounted device
STD	standard
VME	virtual memory extension

Introduction

Modern aircraft have become extremely complex systems vehicles. Instrumenting such aircraft for flight test and research is no longer a matter of applying a few sensors and connecting them to a pulse code modulation (PCM) system. On-board computers for cockpit display, navigation, and flight control have added hundreds of parameters to the classic instruments examined in a flight-research activity.

In the flight-research data-acquisition process, flight data requirements and sample rates are increasing. On the other hand, allowable bandwidths for real-time-transmitted data are fixed.

With more channels of data being of interest and higher sampling rates required, methods of compressing or preprocessing data on board the aircraft would greatly enhance the data-acquisition process. In addition, the increase of avionic suites on small aircraft has made space a premium for add-on instrumentation systems. Minimizing the intrusion of wiring inside aircraft saves wiring time and keeps the structural integrity intact. Distributing the system, allowing for fault tolerance, and placing systems in harsh environments have also become important issues.

Managing flight-research information involves collecting, filtering, and storing data in a form that can be retrieved and correlated. This filtering includes hardware and computations. Management of several

*Electronics Engineer.

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hundred parameters is common on research aircraft. Such management could require significant amounts of real-time processing at high rates.

Often, making decisions about data before transmission is more appropriate than processing the data upon reception; therefore, processing the data on board the aircraft before transmission is preferable in many cases. If, for example, the data have not changed, then there is no need to retransmit. This example represents a simple form of data compression. If a high-frequency signal must be analyzed in real time and the transmission bandwidth is limited, then analyzing the data before transmission can reduce the transmission bandwidth requirements. This on-board data compression makes more transmission bandwidth available for other parameters. On-board computation also allows for other types of data enhancement, such as improving transmission integrity by computing cyclic redundancy codes, CRC, before transmission.

This paper describes an airborne information management system (AIMS) being developed at the NASA Dryden Flight Research Facility (DFRF). The design goals and basic architecture as well as the development approach are discussed. In addition, electronic design and fabrication issues, heat transfer considerations, mechanical connections, and programmable signal conditioning are presented. Current and potential applications for this system are discussed. Lessons learned are reviewed.

System Design Goals and Basic Architecture

The main thrust of this development project is to improve the state of the art of on-board acquisition, processing, storage, and transmission of research aircraft data. To avoid repeating the whole development process every few years, attention must be paid to the system architecture; therefore, a top-down solution was designed. Initially, this solution considered all the things that were desired for the system to do. Lack of technology and resources forces a temporary scaling down of the implementation. If, however, the architecture is considered adequately, technology advances will allow an increase in system capability without requiring an architectural urban sprawl or unplanned expansion paths.

In considering the architecture of the system, key issues that are not directly or traditionally concerned with data acquisition for research purposes were kept in mind. These issues included on-board data processing, fault tolerance, and artificial intelligence. Also, separate from instrumentation issues, any on-board activity that requires high-speed computation could use the inherent computational abilities of the system. These activities include flight control, cockpit display, and other avionic systems interaction.

Hardware

After a survey of current and projected flight-research requirements, the basic design goals for a new system were formulated. The AIMS was envisioned as a multiprocessing system whose processing nodes could be collocated or distributed throughout the aircraft. This system should be small and modular so that the physical size could reflect the processing and input-output (I/O) requirements. The smallest foundation set should fit in one hand for ease of use in small areas and function in harsh vibration and temperature environments, such as engine bays or hypersonic vehicles.

The circuit boards should be large enough to accommodate reasonable circuit designs and avoid forced use of hybrid circuits. These boards should also be small enough to achieve maximum volume savings. If the module cases were too small, then hard-to-work-with connectors would be required, thus necessitating the building of connector blocks. In other words, after a minimum size, diminishing returns are seen by shrinking the system further.

A survey of the industry revealed that no satisfactory system existed. Industry standards, such as the virtual memory extension (VME) bus, were considered too large. Indeed, the system to be replaced, the airborne instrumentation computer system (AICS), was smaller than the VME system. Developed at DFRF, the AICS uses the standard (STD) bus and is too large for many applications.[1] Instrumentation systems commercially designed for flight test were becoming increasingly modular, but none planned to use the processor as the controlling element for the acquisition process. When the goal is to manage rather than simply acquire data, this processor control is important.

Weighing these concerns, a module form size was designed (Fig. 1). Note that the system is modular. If a "logical" block or computational node requires more modules than will fit into a given area, the architecture allows the logical set to be divided into smaller blocks for placement in convenient areas (Fig. 2). Keeping analog sensor leads as short as possible to reduce the noise pickup is desirable. For this reason and to minimize the quantity of wire bundled throughout the aircraft, placing parts of the system in each wing, in the tail area, in the avionics bay, or in the engine compartment may be desirable.

Connectors will be used that are easy for instrumentation crews to grasp, connect, or disconnect or to insert and remove pins. This requirement is a practical

limitation in how small the modules can be (Figs. 1 and 2).

Software

Simultaneous or quasi-simultaneous sampling using high-speed analog-to-digital (A-D) converters will be used to minimize time skewing of sampled data. Enough on-board processing power will be available through multiprocessor expansion, if necessary, to perform such high-speed computations as digital filtering, data compression, and display formatting.

The AIMS will be remotely programmed, so complete system reprogramming can occur without removing or opening the hardware. Analog channels, filters, excitation voltages, and amplifiers will also be remotely programmable. Such programming will also avoid removing or opening the hardware.

Plans include a ground-based workstation to allow the flight systems engineer to describe, in a high level fashion, what the system will do. The system would work out the implementation details and report back the optimal configuration.

The AIMS will also write, time-tag, and format engineering unit data to memory or on-board storage systems. Such data would be appropriately compressed before storage or transmission. For example, vibration analysis systems that require frequency modulation systems to report safety of flight structural modes could instead be acquired in a sampled mode and processed on-board. The frequency domain results could be transmitted through PCM at a considerable reduction of bandwidth.

Development Approach

Once the beginnings of the architecture were formulated, a search for an appropriate microprocessor for the core of the system was done. The basic criteria were for the microprocessor to be a single chip solution, be physically small, have built-in serial communications, and provide high-speed processing.

A decision was made to center the architecture around the transputer™ family of microprocessors. Transputers have several desirable and notable features that allow them to function well in the envisioned environment. These features are listed below.

- Single-chip microcomputer
- Minimum number of support chips required
- High-speed processor-to-processor serial links
- Operating speed of 10 million instructions/sec
- Built-in floating point processor
- Multiprocessing architecture
- On-chip, high-speed random access memory (RAM)
- Single clock speed of 5 MHz for whole processor family
- Internal operating speeds from 10 to 30 MHz

In addition to challenging standard ideas about data collection, the AIMS project required new techniques and technologies to bring it to fruition. For example, use of surface-mounted devices (SMD) and liquid cooling was needed. Sealing of modules because of liquid cooling and use of heat-transfer devices in aircraft that have no cool spots (hypersonic) had to be addressed. A completely software programmable system was required because there is little room for and no access to internal parts while the system is on the aircraft. In addition, an artificially intelligent front end for system configuration was required.

Electronics Design and Fabrication Issues

Because of the size and complexity of the modules, techniques must be explored to reduce the size of the circuits. Two techniques are available: hybrid circuits and SMD. Hybrids allow for the increased circuit density but require higher skill, higher cost, and more specialized and expensive tools. In the initial stages of the project, SMD will be the predominate technique used, except where appropriate commercial hybrids can be found.

Each circuit board is slightly larger than a credit card. Figure 3 shows the central processing unit (CPU) board. The SMD components are mounted on both sides of the board. This size allows some standard dual in-line packaged integrated circuits to be used but forces most of the logic to be surface mounted or hybrid.

In addition to the physical desirability of building small systems, another reason is electronic. When dealing with high-speed logic, smaller wiring runs cause fewer problems because of time skewing and reflections.

To minimize heating problems and conserve power, low-power complementary metal-oxide semiconductor parts are used wherever possible. High-speed logic is important to AIMS. The extremely fast machine cycle time of the transputer ($\leq$ 25 nsec) requires that support logic have very small gate delays. The advanced complementary metal-oxide semiconductor technology logic family is characterized by low power consumption

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as well as high speed — and thus was chosen as the backbone of the logic systems.

Heat Transfer Considerations

The SMD introduces some problems. Conventional methods of conductive heat transfer through metal rails cannot be applied because the geometry of SMD will not permit it. The targeted locations of the AIMS, remote locations and harsh environments, make convective and forced air cooling impractical in many cases.

The potential for placement in remote locations and harsh environments and the circuit density of the boards caused a decision to explore a technique used by supercomputers — liquid cooling. Using a colorless, odorless, nonflammable, nontoxic, electrical nonconductor fluid called Flourinert™, the electronics can literally be bathed in liquid to facilitate heat conduction.

Liquid cooling has three notable advantages. First, this approach allows direct heat conduction from all parts. Next, temperatures inside the system can be limited to a predetermined boiling point. Lastly, heat can be removed from this system by one of three methods. Conduction through the case to a mounting surface will be the first and most commonly used method. In high-temperature environments, liquid can be piped to a heat exchanger. This method works much like a radiator in a car. In severely high-temperature environments, liquid can be piped to a stearate compound that absorbs heat by changing phase. This method allows heat exchanges when no cooler environment exists to pipe the heat to, such as in hypersonic vehicles.

As a disadvantage, the liquid-cooling approach greatly complicates construction of the AIMS unit. Being a modular stack, the AIMS requires each section to make a good fluid seal with the adjacent module. This modular stack also drives the requirement to remotely program the units because separating the modules is apt to be troublesome. The liquid, which is heavier than water, adds weight to the system and is amenable to wicking up between wires and insulation. As a result, attention must be paid to the proper sealing of connectors.

This technique allows operation of AIMS in the widest range of applications, while allowing use of temperature-ranged parts which do not meet military specifications in extreme temperature environments. Thermal transfer coefficients in fluid are more than five times higher than that of air, so higher ambient temperatures are more tolerable in fluid than they would be in air.[2] Fluorinert compound FC-72™, which has a boiling point at one atmosphere of 56 °C, was selected. Most nonmilitary specified parts have a temperature range extending to 70 °C. In a nonpressurized system at one atmosphere of pressure, the temperature of the FC-72 fluid could not exceed 56 °C.

The AIMS must be a closed system because decreasing ambient pressure would depress the boiling point and, therefore, lead to less efficient heat transfer. As the temperature elevates in the closed system, pressure increases and elevates the boiling point. To minimize pressure increases in the closed system and keep the boiling point at an acceptable level, fluid expansion is allowed by including a volume of compressible trapped gas. The volume of trapped gas required depends on the expected ambient temperature range and power dissipation inside the AIMS.[3]

Figure 4 shows an end view of a module, including the sealing area and the Fluorinert flow holes. In systems that require active pumping of the fluid, these inner holes provide the conduits for circulating the fluid.

If a processing task is required in a nonharsh environment, then a module can probably be used without liquid cooling. Others examined the thermodynamic issues involved.[3–5]

Mechanical Connections

Figure 5 illustrates two ways to connect the modules. Power stack (a) shows two electronics modules, labelled CPU/analog module and analog module, which share the same internal power module and local bus (c). Four boards are on local bus (c). One transputer CPU board is used for each local bus. Note that power stack (a) is connected to a pump module and to the expansion modules. These modules would be used to pump fluid through the stack and allow for thermal expansion of the fluid in harsh environments. Power stack (b) shows a single module with a CPU board and a military standard (MIL-STD) 1553 interface board making up local bus (d). Unlike power stack (a), module (b) derives power from a source external to the stack and requires no special cooling. Figure 6 shows the assembly of a single module containing two circuit boards.

Programmable Signal Conditioning

In most instrumentation systems, the largest physical part is the signal conditioning. These electronics tie directly to the sensors and convert the signals to a form useful to the data collection system. The signal-conditioning electronics contains presample filtering, signal-level shifting, and bridge completion. Recent commercial developments have made it possible to shrink these important tasks onto a few programmable

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chips. A circuit board has been designed to provide general-purpose, multichannel, end-to-end signal conditioning for many sensors. The basic design represents a significant enhancement of existing signal-conditioning techniques commonly in use at DFRF.

Figure 7 shows a simplified block diagram of a single signal-conditioning channel on this board. Four such channels have been built onto one AIMS-printed circuit board. Two of these boards can be installed into one module (Fig. 6) for a total of eight channels. As technology improves, as many as 16 channels could be installed in 1 module and still fit the connector definitions.

Current Applications

The AIMS project is an ambitious one, given the limited resources available. The development personnel also have responsibilities in instrumenting active flight-research projects. As a result, in moving from concept to reality, an evolutionary approach is being taken. Pieces of the AIMS architecture are being incorporated into existing flight systems to enhance the supported flight projects at reduced risk and to test the feasibility of this architecture.

The DFRF has been flying a small, relatively low-processing-power system for some years called the AICS.[1] A mini-transputer airborne instrumentation computer system (mini-TAICS) processor board has been designed to act as a high-speed, auxiliary processor in existing AICS. The inherently distributed architecture of AIMS will allow the transputer AICS to communicate easily with the full-blown AIMS configuration. The mini-TAICS board communicates with the existing system through dual-ported random access memory (DPRAM) (Fig. 8).

The first application was designed to support a NASA project that examined the feasibility of using high-performance jet aircraft to quickly determine the winds aloft. A mini-TAICS board was built that handled most of the on-board computations required for this Space Shuttle launch-support project. The transputer proved to be highly effective in providing the required information.

A MIL-STD-1553 bus interface was built incorporating a transputer. This interface combined with the mini-TAICS board provided a network of two transputers. This combination provided practical experience with multiple transputer communications and processing. The application was to act as a MIL-STD-1553 bus controller for an optical airdata system and collect data from it for telemetering.

The F-16XL aircraft (General Dynamics, Ft. Worth, Texas) has a requirement to monitor some MIL-STD-1553 data. The existing on-board acquisition system could not handle another MIL-STD-1553 interface, so an AICS with the mini-TAICS and transputer MIL-STD-1553 interfaces was incorporated. This time, however, the interfaces monitored instead of controlled the bus.

For the Space Shuttle, landing gear loads at various ground speeds require study. A project has been initiated to modify a Convair 990 (General Dynamics, Convair Division, San Diego, California) to study these loads. The mini-TAICS boards will be an integral part of the on-board evaluation and acquisition of loads information.

Potential Applications

While the thrust of the system design is directed toward classical instrumentation augmentation, overall project requirements make it desirable to use common types of hardware to solve differing problems. The DFRF personnel have been approached to develop capability in interacting with avionics data buses and provide cockpit displays as well as processing power for airborne artificial intelligence applications. Flight simulation groups are interested in the system to provide commonality with aircraft systems as well as augment their processing capabilities. Flight control groups have expressed interest in pursuing use of the transputer because of its potential for addressing fault-tolerance concerns. In designing the overall system architecture, DFRF personnel have attempted to keep these requirements in mind.

Lessons Learned

Construction of the AIMS involved several design techniques that were new to DFRF instrumentation. The SMD required new design techniques and testing mechanisms. Liquid cooling required sealing, pressurization, testing for leaks, and studies of environmental impact. Traditional prototyping stages were omitted because the high-speed circuitry required printed circuits. In addition, the design required integration of digital techniques into analog data acquisition (programmable switching).

A major problem seemed to be finding the balance between planning and empirical testing. Locking the design too early is a mistake. Locking it too late causes incompatibilities to arise. Too much planning leads to lack of perceived progress and too little incurs excessive iteration in design cycles. Balancing these needs required planning the overall architecture, building the pieces, and altering specific definitions until becoming reasonably sure that the desired result could be achieved. The definitions were frozen at that point, and any further changes required strong motivation.

Much work remains, but the project has proceeded far enough that DFRF personnel have gained confidence that all major goals can be met. Goals already met are as follows:

- Using parallel processing in distributed processors
- Interfacing flight-tested interfaces to a transputer design
- Using a transputer board in flight to perform real-time computations on data for real-time display
- Defining and fabricating a modular form factor
- Using high-density SMD in hardware designed for flight
- Demonstrating the viability of a sealed, liquid-filled system

A printed circuit board that incorporates programmable signal conditioning is currently under test. Goals still to be demonstrated are as follows:

- Complete the programmable signal-conditioning testing
- Test environmentally the AIMS form-factor hardware
- Use the AIMS form-factor system in a flight-research program

Concluding Remarks

An airborne information management system being developed at the NASA Dryden Flight Research Facility promises to enhance data management techniques for on-board instrumentation. The development approach of testing pieces of the architecture in existing aircraft systems has allowed timely, cost effective testing of crucial elements of the design. Using a high-speed, 32-bit microprocessor as the central element of a parallel-processing architecture allows on-board computation to enhance the management of data. The small, modular system is designed to allow for remote positioning and programming of processors and signal conditioning. The option of bathing the electronics in an inert fluid allows use in high-temperature environments. The airborne information management system promises to solve many of our airborne data acquisition and computation requirements into the 21st century.

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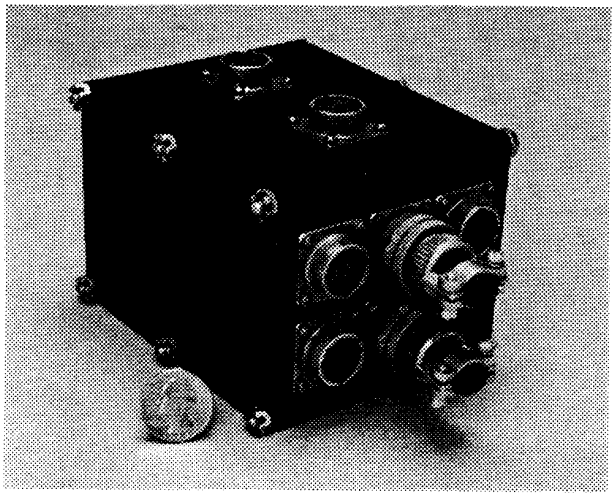

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Fig. 1 Airborne information management system stack of three modules.

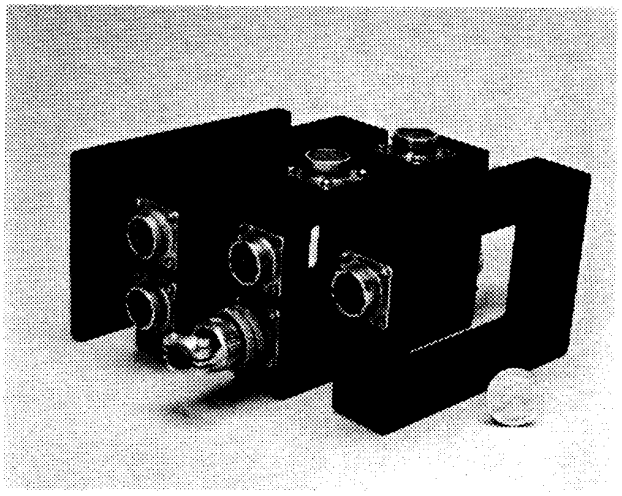

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Fig. 2 Disassembled airborne information management system module housings.

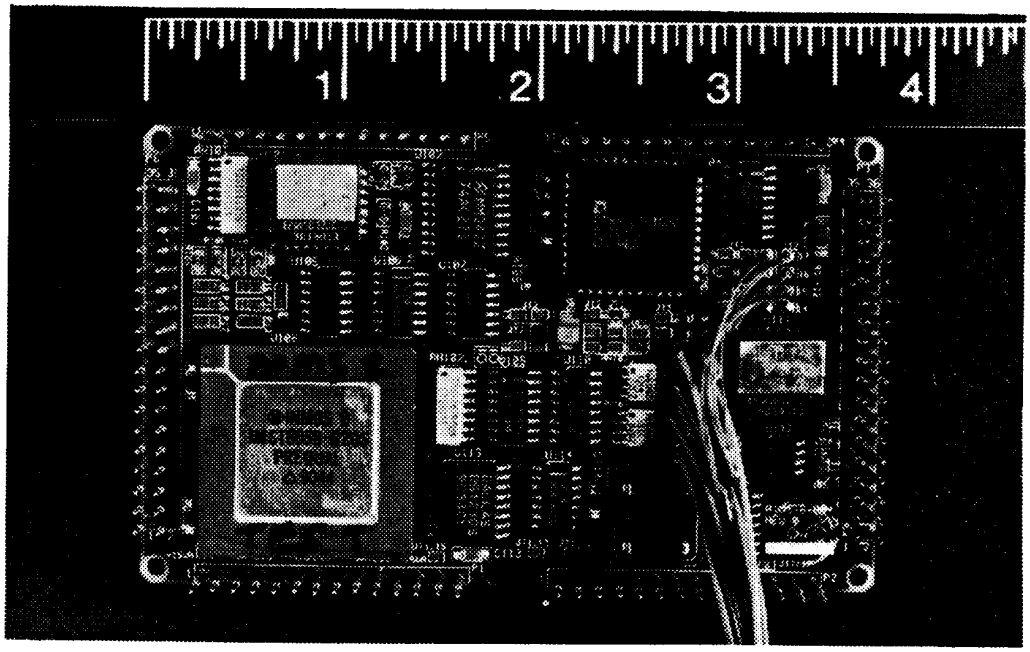

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Fig. 3 Airborne information management system central processing unit board.

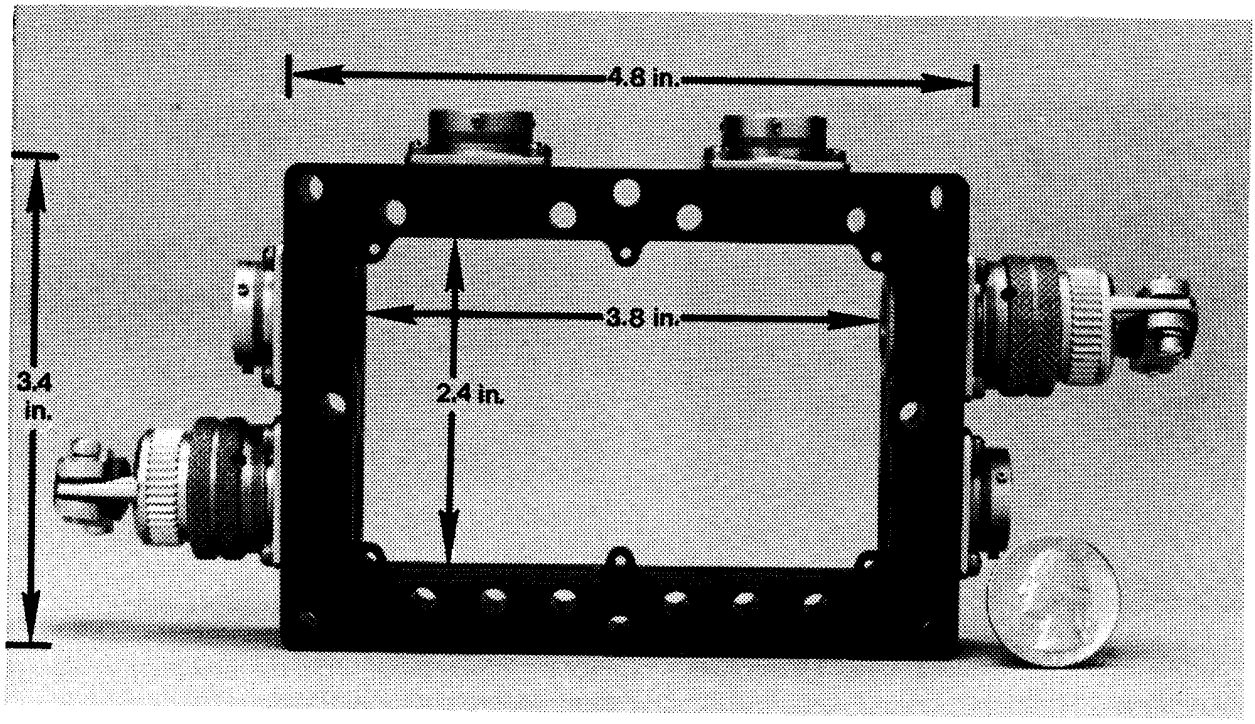

Fig. 4 End view of an airborne information management system module.

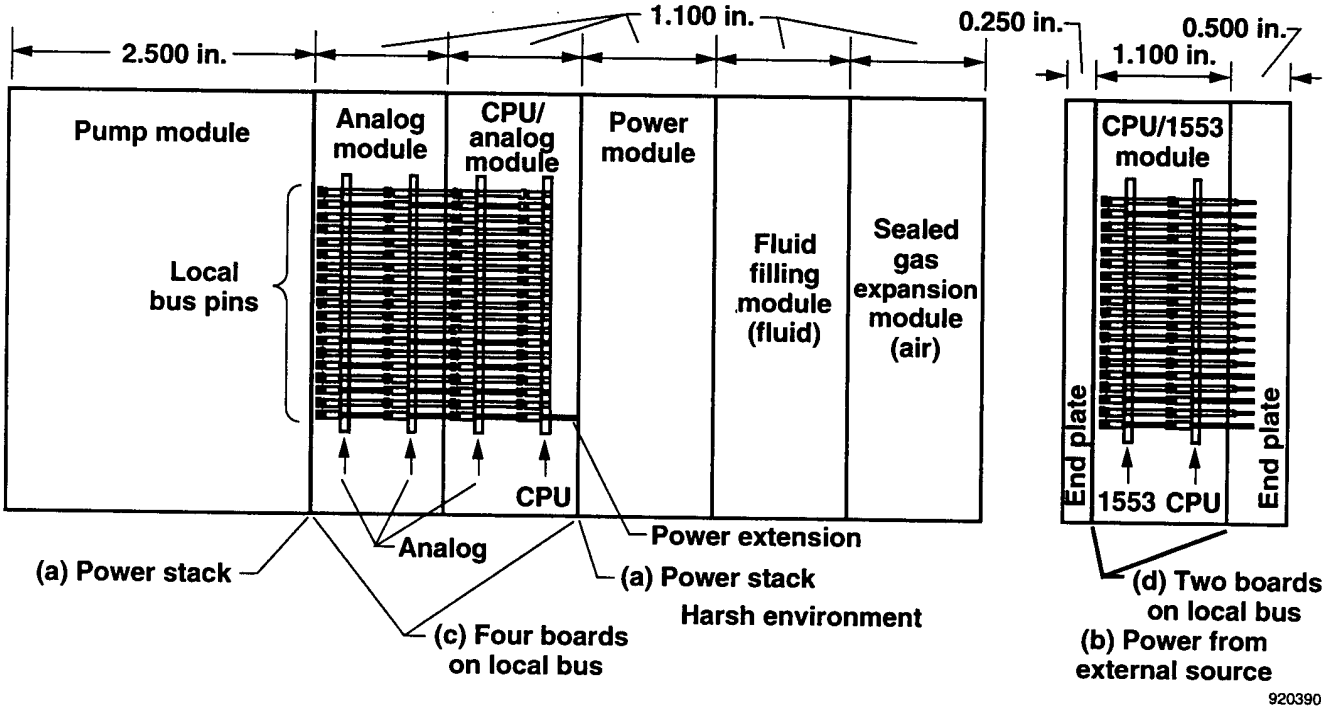

Fig. 5 Sample airborne information management system configurations.

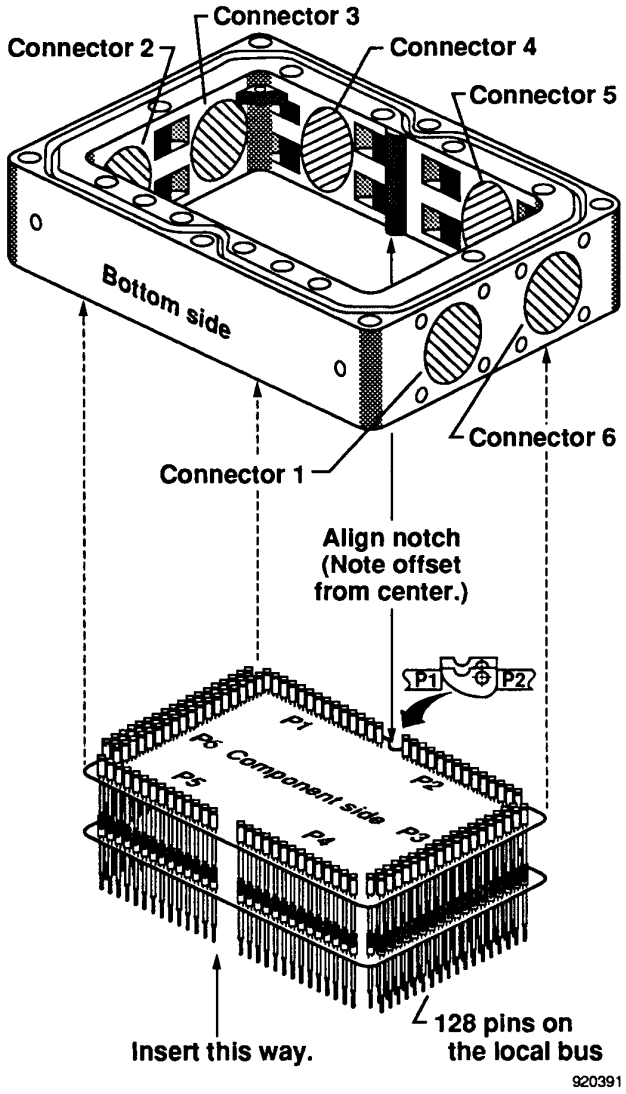

Fig. 6 An airborne information management system module containing two circuit boards.

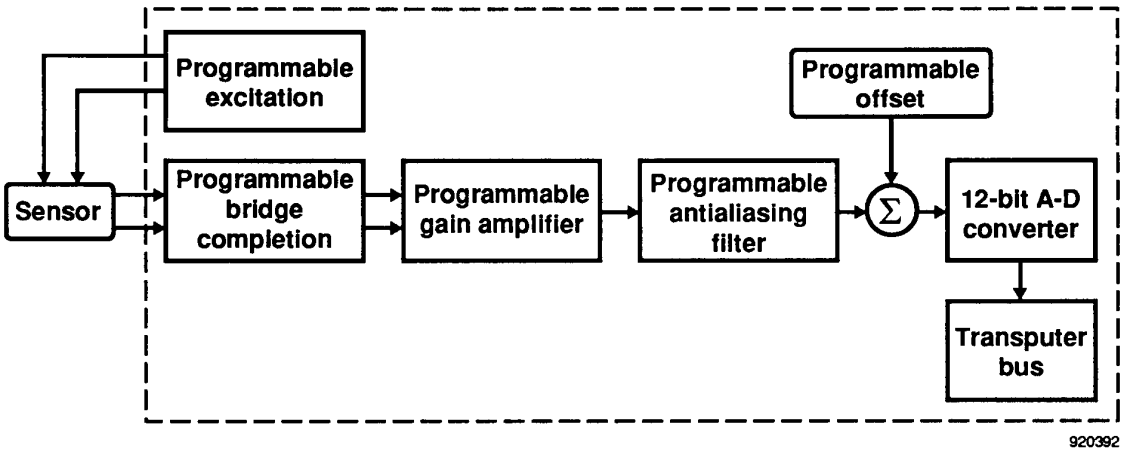

Fig. 7 Analog signal conditioning.

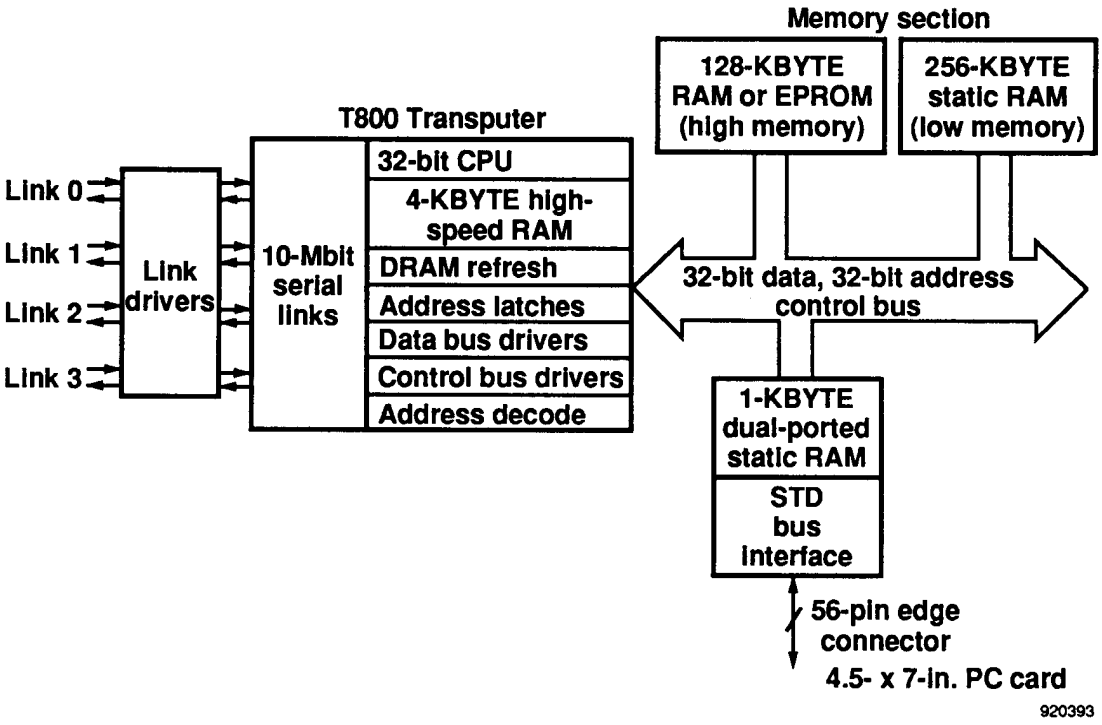

Fig. 8 The mini-transputer airborne instrumentation computer system.

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Glenn A. Bever

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