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14. ABSTRACT

The U.S. Government originally funded the development of the Common Airborne Instrumentation System (CAIS) to address industry-wide compatibility, maintenance, and commonality issues. Although initially targeted for U.S. Department of Defense (DOD) programs, CAIS is also being used throughout the world in many commercial applications. This paper provides a fresh look at the evolution of the CAIS concept starting with some historical background of the CAIS Program, an overview of the CAIS System Architecture and recent trends in the use of "Commercial Off the Shelf (COTS)" products and technology.

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Common Airborne Instrumentation System (CAIS); Commercial CAIS Products, Commercial Off The Shelf (COTS); Data Acquisition Unit (DAU); Department of Defense (DOD); Flight Test Instrumentation; PC-104; Pulse Code Modulation (PCM), Telemetry

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# COMMON AIRBORNE INSTRUMENTATION SYSTEM; A FRESH LOOK

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**ABSTRACT**

The US Government originally funded the development of the Common Airborne Instrumentation System (CAIS) to address industry-wide compatibility, maintenance, and commonality issues. Although initially targeted for US Department of Defense (DoD) programs, CAIS is also being used throughout the world in many commercial applications. This paper provides a fresh look at the evolution of the CAIS concept starting with some historical background of the CAIS Program, an overview of the CAIS System Architecture and recent trends in the use of "Commercial Off The Shelf (COTS)" products and technology.

**KEY WORDS**

Common Airborne Instrumentation System (CAIS), Commercial CAIS Products, Commercial Off The Shelf (COTS), Data Acquisition Unit (DAU), Department of Defense (DoD), Flight Test Instrumentation, PC-104, Pulse Code Modulation (PCM), Telemetry.

## CAIS PROGRAM OVERVIEW

### Introduction

The Common Airborne Instrumentation System (CAIS) was funded by the United States Department of Defense (DoD), through a tri-service program office, located within the Test Article Preparation Department at the Naval Air Warfare Center. The purpose of CAIS is to facilitate commonality of flight test instrumentation between aircraft types and interoperability between DoD test facilities. CAIS was designed to support a broad range of airborne applications -- from a small test program requiring a few parameters to a full-scale major weapon system test program -- while remaining independent of any test platform.

### Background

The Army, Air Force, and Navy have traditionally developed new airborne instrumentation systems for each new major weapon system. This led to a proliferation of instrumentation systems across the services. This proliferation is further amplified by the requirements of each test platform within the services. Each of the Major Range and Test Facilities maintain and support a wide variety of instrumentation systems for varying test platforms. Historically, these systems have had limited spares and minimal commonality. Reutilization of these systems in other programs has been minimal, making the cost of ownership high.

In order to increase supportability, interoperability, and reduce cost, the Office of Secretary of Defense directed the development of CAIS. Successful use of CAIS by the F-22 and F/A-18E/F test programs has led to growing support for CAIS. The CAIS program evolved from development of a core set of hardware to the establishment of a DoD instrumentation bus standard. This was driven by policy changes within the DoD and eventually led to a change in the CAIS acquisition strategy. Industry acceptance of the CAIS bus interface standard has improved supportability, reduced cost and enabled test facilities to leverage from each other's investments while increasing options available to CAIS users.

CAIS has changed the way DoD and major aircraft manufacturers develop and procure instrumentation systems for major weapon system acquisitions. Rather than develop a new instrumentation system, the CAIS bus interface standard enables integration of COTS with much of DoD's existing instrumentation hardware to meet performance requirements at the lowest cost.

## CAIS STANDARDS AND PLANS

The CAIS Program Office developed several documents to help facilitate the commercialization of CAIS. These documents are briefly described in the next several paragraphs.

### Bus Standard

The CAIS Bus Interface Standard was written to provide a single document for equipment designers to ensure interoperability among units on the CAIS bus. The standard establishes the requirements for digital command/response, time division multiplexing techniques for a single CAIS bus. The interface standard encompasses the physical, electrical, and protocol aspects of the CAIS bus. However, it is not the intent of the standard to provide operational details for any unit.

### Test Plans

The CAIS test plans were developed to ensure interoperability among vendor items that operate over the CAIS bus. Currently there are two validation test plans - one for data acquisition units and one for CAIS bus controllers. These general test plans deal only with functions that are described in the CAIS bus interface standard. These plans do not specify tests that check the integrity of data within the subsystem to the bus, nor does it attempt to address the system test requirements.

### Configuration Identification

One of the features of CAIS is the ability to perform a configuration match test. This allows the ground support equipment to interrogate all DAU addresses in the system to ascertain the configuration of the system and identify what DAU addresses are in use and by which DAU type. Therefore, each DAU type and sub-unit type must have a unique identification (ID) value.

## PRACTICAL CHALLENGES AND CAIS SOLUTIONS

The Instrumentation Engineer faces a wide range of challenges in their day-to-day work. Equipment compatibility issues, data systems being maintained beyond their service life, difficulties to expand system capability and cost control are but a few of the practical, every-day problems. Even worse, it seems that the right tool is seldom available to make the overall job easier.

The CAIS System has evolved to address many of these issues through the use of an "Open System Architecture" and the insertion of the latest commercial technology and software products. A few examples will be used to illustrate the point.

**Example #1: The "Old Ground Station"**

Existing (old) systems are big, expensive to use, limited in performance, and often are being used beyond their maximum service life. New CAIS systems are small, fast, cheap, and powerful. Since they are PC-based, they are easily expandable with both software and hardware add-ons with virtually limitless growth potential.

**Example #2: System Pre-flight Checkout**

Existing (old) systems are large, complex, tedious to use, have significant learning cures, sparse documentation, power hungry, and often are lacking performance. New CAIS pre-flight checkout systems are based on portable computer equipment (laptop), with powerful software and hardware features, integrated setup, programming and diagnostic tools, quick-look data capable, data archive to disk capable and low cost.

**Example #3: Vehicle Anomaly Investigation**

Existing (old) systems must be physically brought out to the vehicle, have significant cabling and wiring requirements, require cooling and protection from the elements, are labor intensive, and are costly to maintain. New CAIS diagnostic tools are available in laptop configurations that can be brought out to the vehicle or used within the vehicle, have resources to perform real-time diagnostics and data validation, contain CAIS bus emulators to validate system performance and connectivity, don't require that primary aircraft instrumentation be brought on-line, and do not rely on traditional telemetry or ground instrumentation equipment.

## CAIS SYSTEM EVOLUTION

The primary reason for the current advances within the CAIS System is the use of a proven "Open System Architecture." A set of "core" products forms the backbone of the system, while measurement-specific products can be added to the system as required. Normally this kind of architecture results in compatibility problems and difficulty during system integration. However, the CAIS architecture prevents these problems since it is based on the same kind of architecture used in the commercial sector to allow PC computers to easily work with peripheral hardware and network connections that are manufactured by different companies. A new breed of "Commercial CAIS Products" is now emerging, not unlike the wide range of commercial products and software available to support the PC computer.

The concept to incorporate products and software developed in the commercial sector has resulted in significant cost reduction, improved lead times, and significantly better performance. We have found that, in many cases, commercially developed items surpass equivalent military products in terms of price, performance, and reliability.

In addition, the evolving CAIS concept has enabled existing CAIS users to expand their in-place systems using standard, low-cost commercial add-on products. Airframe manufacturers, vendors and DoD test ranges are now rethinking how the evolving CAIS concept can provide greater flexibility, increased capability and reduced cost.

## CAIS SYSTEM ARCHITECTURE

### System Configuration

CAIS is a time division multiplexed digital data acquisition system whose basic implementation consists of distributed data acquisition units interconnected via the CAIS bus. The system controller orchestrates the operation of the system and provides scalability of the system with additional CAIS buses. A CAIS distributed system allows for the wiring of numerous sensing elements to be routed over a short distance, while the wiring of the system interconnection requires four-wires to be routed over a much longer distance.

The CAIS bus is a full-duplex communications network interconnecting a CAIS Bus Controller with Data Acquisition Units (DAUs). The CAIS bus is a star/daisy-chain hybrid configuration. The bus carries commands from the CAIS bus controller to the various DAUs and returns the collected data to the CAIS bus controller for output. The command/response bus provides the open architecture feature of a CAIS interconnected system.

The CAIS bus in its most elemental configuration is shown in the figure below. The data bus functions synchronously in a command/response fashion and transmission occurs in a full-duplex manner by means of a command bus and a reply bus. CAIS is a deterministic bus that provides coherent data based on the sample timing from the placement in the format. The information flow on the data bus is comprised of broadcast commands that set the operating mode of the Data Acquisition Units (DAUs), and DAU commands that request DAU specific actions. Therefore, all data on the reply bus is the result of DAU commands from the bus controller. In addition, the bus can be used to communicate with other system elements such as cockpit displays, recorders. This enables a single-point access to a wide range of system information, as well as allowing the system to monitor critical data such as pilot switch activity, pilot mission screen settings, and telemetry recorder status. Note that the CAIS bus not only operates as an instrumentation bus, but as a vehicle-wide communications bus.

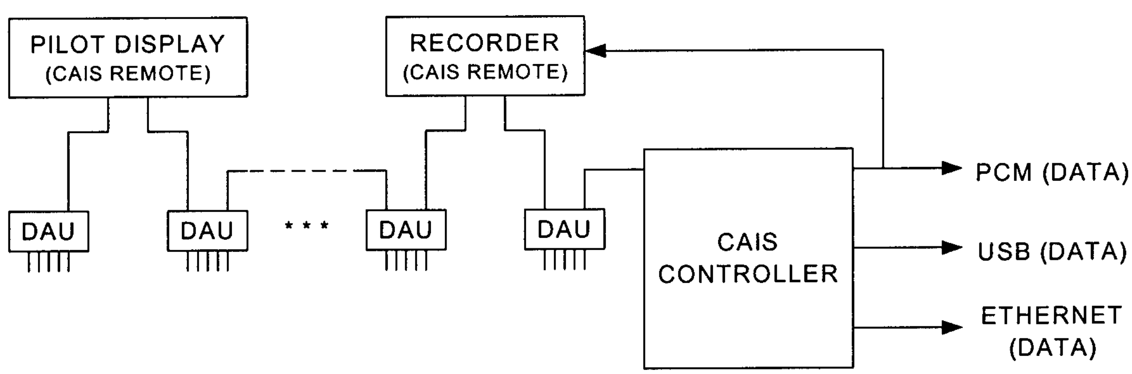


**Figure 1: Simple CAIS Configuration**

A CAIS system can be configured with a single bus controller that controls a single bus or a system controller that controls multiple CAIS buses as depicted in the figure below. The bus/system controller orchestrates the collection and output of data from the system, regardless of data type. A typical controller synchronizes the data output with the commands issued across the CAIS bus(es). Each CAIS bus can handle up to 5Mbps of data; however, the system throughput can be greatly increased and is only limited by the number of CAIS buses within the system. As the system grows it still maintains the deterministic nature of the data acquired over the CAIS bus, including data acquired over several interoperating CAIS buses. CAIS also supports simultaneous sampling of data across all buses.

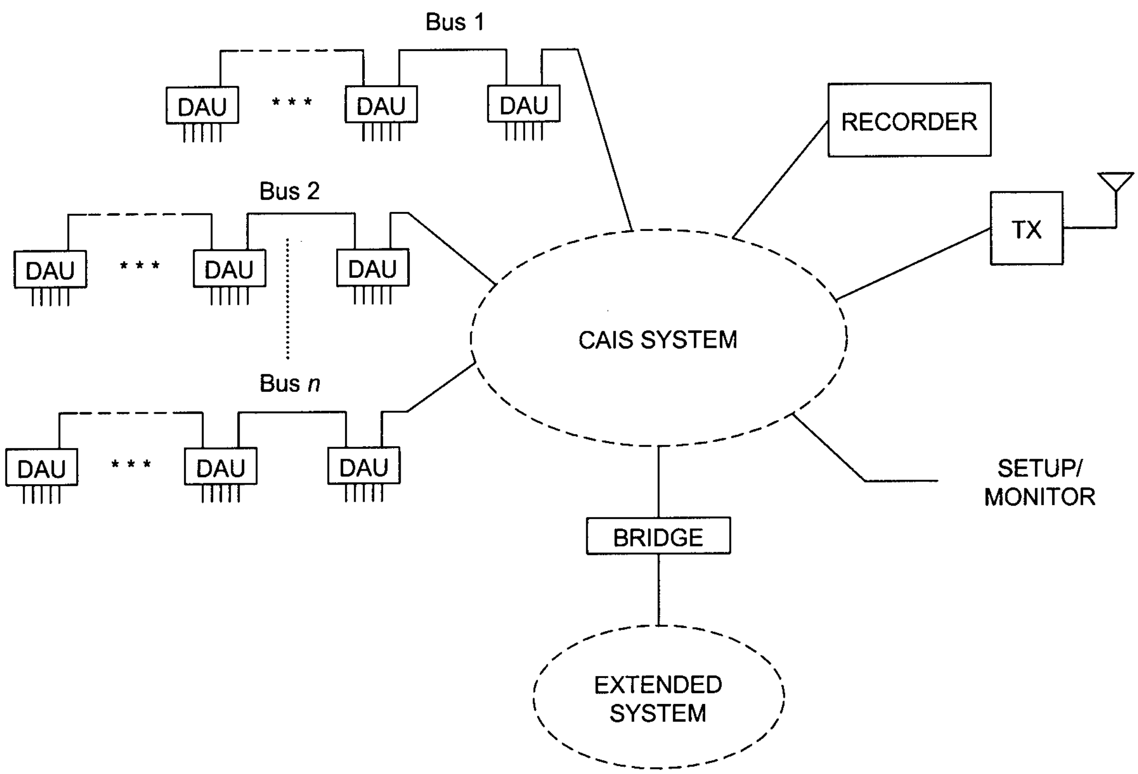


**Figure 2: Expandable System Configuration**

## Measurement Capability and Growth

The CAIS system allows measurement growth through modularity within the individual system elements. The growth can be addressed with the simple addition of a card or module, a remote unit or even additional CAIS buses. Additional interfaces can often be added to system elements without impact to the existing system thereby eliminating the need for retrofits to existing CAIS equipment. The following is a partial list of the kinds of signal inputs and outputs available to the CAIS system:

- Simple Analog (potentiometer, discrete, accelerometers, thermocouples, strain gauge, etc.)
- Differential Transformer (Gyro's, Synchro/Resolver, LDVT/RVDT, etc.)
- Multimedia (Video, Audio, etc.)
- Avionics data (MIL-STD-1553, ARINC-429, etc.)
- Serial data (RS-232/RS-422, Air data transducer, etc.)
- Processing (RMS, Derived parameters, etc.)
- Time and Position (GPS, IRIG, etc.)
- Acoustical (Microphones, Accelerometers, etc.)

- Multiplexed (Pressures, Thermocouples, PCM, etc.)
- Packetized data (Ethernet, USB, Fibre Channel, etc.)
- Display (Analog Indicators, Cockpit Display, etc.)

**System Flexibility**

The figure below depicts a multifaceted system that demonstrates the wide variety of interfaces that can be accomplished with a CAIS system as well as some of the ongoing technology advancements being used in today's CAIS systems. New communication technologies such as Fibre Channel, inter-bus bridges, and interconnection between standard aircraft bus types and the CAIS bus have resulted in unprecedented system flexibility and improved data throughput. New system elements such as solid state recorders, smart transducers, smart display systems, and enhanced performance data acquisition components have found a natural home within the CAIS environment. Results from the current CAIS generation are truly revolutionary. Future incorporation of wireless technologies and network sensors promises to provide even greater performance improvements and cost reduction in the future.

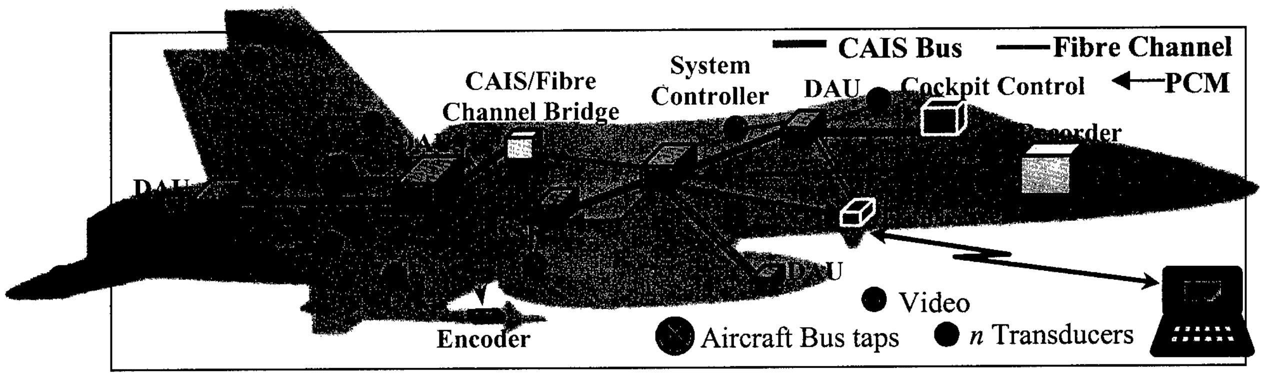


**Figure 3: Dynamic System Configuration**

## CAIS APPLICATION EXAMPLES

**Handling New Requirements**

CAIS was primarily designed for use in a dynamic flight test environment. It is often used in applications that call for frequent system changes, reconfiguration, channel distribution, and sample reprogramming, which occur sometimes on a daily basis. The user of the CAIS system quickly realizes that the best way to handle these kinds of changes is not by re-inventing the system each time a change is required but to meet the need by adapting the existing system.

CAIS products are modular in nature and can be easily adapted to meet new requirements, in most cases through the simple addition of a card or module. New cards/modules can easily be developed to handle new measurement requirements within the need to retrofit the core chassis. This minimizes the impacts to standard installations in satisfying unique requirements.

The CAIS office is continually monitoring the addition and expansion of the CAIS product family, including specific measurement capabilities within the system. As the list grows, it is being offered to all users for consideration on present and future applications. If you have a requirement, contact the CAIS office. They can give you a list of what is currently available, and what is currently being developed.

**Adapting to Installation Challenges**

The CAIS DAUs are offered in a wide variety of form factors including 2" x 2" square and 4" x 5" rectangular shapes that are modularly expandable or fixed volume but card configurable. The variety of sizes allows the user to select the unit that best fits the need. These units are typically designed to fit tight applications (i.e. fighter and trainers) as well as larger versions for "general purpose applications" that are not size-limited and typically provide greater channel capacity. The products are generally available in both commercial and industrial temperature ranges and are suitable for use in harsh environmental applications such as a fighter.

**Adding System Bandwidth**

The CAIS system bandwidth is user-scaleable through the addition of multiple CAIS buses. Each CAIS bus provides 5Mbps of bandwidth. If four CAIS buses are utilized the aggregate bandwidth capability is 20Mbps. In this fashion, multiple CAIS buses can be used to increase the total aggregate bandwidth of the system.

The CAIS system can be configured to provide small networks of individual CAIS buses, each acquiring data from MIL-STD-1553 ("all data" or "selected data"), video, radar, etc., from each network.

The CAIS system is very open ended since multiple buses can be added to provide the necessary system bandwidth. However, in some situations, adding more CAIS buses may not provide the required bandwidth. This may call for the "next level up", involving the incorporation of a high speed multiplexer in order to achieve the necessary system speed.

**Testing and Integrating the System**

The CAIS architecture gives the user a significant amount of flexibility. The system is easily adaptable to changing requirements, modular in nature, and is non-intrusive. Any node within a CAIS system can be tested independently of others. The bus provides considerable flexibility since the CAIS bus continues to operate even when remote units are powered down. In addition, no splices are required to split any CAIS bus wires since all interconnects are made by standardized connectors that are transformer coupled.

The scalability of the system allows the Instrumentation Engineer to bring the system up in a piecemeal fashion. The system can be incrementally assembled and tested in phases in order to simplify troubleshooting and analysis. Individual system elements such as remote units can be added and tested individually rather than testing the entire system as a whole.

### Interoperability

The open system interconnection offered by the CAIS bus enables CAIS units to be integrated into existing instrumentation systems. The CAIS system is interoperable with a wide variety of different vendor hardware, allowing the Instrumentation Engineer to make maximum utilization of existing equipment. This also benefits the user since interoperability allows the use of any vendor's equipment within the instrumentation system that best fits the requirements rather than the best single vendor solution.

CAIS can be easily adapted to work with an existing system through development of a specific Bus Interface Adapter (BIA). This technique can be used to interconnect inventories of heritage equipment. For example, you can turn a PC into an active CAIS remote by putting a commercial PC-104 CAIS bus interface adapter into the computer. Anything occurring on the PC back plane is then available to the CAIS system, including data processed by the computer. In this scenario, the CAIS bus does not just interface with the subsystem but actually converses with the subsystem.

Interoperability can also be as simple as adding a standard BIA card or module to an existing CAIS element. This technique results in immediate interoperability with many common standards such as Ethernet, USB, and other commercial buses.

### Support Tools

Many support tools are available to simplify the Instrumentation Engineers' job. In general, these tools are extensions of existing commercial technology, adapted for use in the CAIS environment. They include such things as handheld PCM decommutators (IRIG 106 Chapters 4&8), Palm Pilot Quick-Look, PCMCIA PCM decommutator, bus interface cards, ruggedized potable support units, notebook computer support units, and many more.

The software to control these computer-based tools has been fully integrated with the instrumentation setup software. The result is that information is entered once and is automatically transferred to ground checkout equipment without the need for data re-entry. This combination of tools and software results in an integrated software/hardware environment for end-to-end development of instrumentation configurations and for ground checkout and processing.

### Modular Software

Software compatibility is a major issue to the Instrumentation Engineer. Object-oriented software development techniques have become accepted throughout the commercial software development industry over the past several years, and are currently making ingress within the military and commercial flight test markets. CAIS's software system has been specifically designed to exploit the inherent technologies and benefits behind object-oriented software, as well as to simplify the integration of software that has been sourced from several different vendors.

The key software technology leveraged for CAIS is the concept of "Software Components." The idea is that multiple vendors produce software components that work within in a common user environment, just as easily as one would add a new printer to their PC computer. The result is that the end user can select hardware solutions based on capability rather than the limitations on the associated support software.

The advantage of this approach is that it facilitates a spiral development process that rapidly demonstrates the functionality within an application. This enables both vendor and customer to benefit by the early validation of requirements and thereby reduces the risk of missing capabilities and integration difficulties associated with the new functionality. This compels the developer to not limit the choices in component designs and to remain flexible in trading off functionality across components until the components are verified and integrated. The component approach allows customers and vendors to add additional functionality from other component developers as well. This ability to plug-in components offers a significant advantage to the user.

A common software platform for configuring CAIS modules developed by multiple vendors greatly enhances the user options in designing and supporting the instrumentation system. In the near future, a component developer's specification will be published that provides an open environment that enables any CAIS hardware provider to develop software components that will install and operate within a component-manager environment. Individual vendors will deliver CAIS products along with the appropriate software component/driver, vastly simplifying integration and reducing startup costs.

## CONCLUSION

CAIS vendors are always evolving their products to keep pace with recent technology opportunities. The use of these technologies in the commercial world has given way to a new paradigm that has provided an affordable means for incorporating those technologies into CAIS systems. This has fueled a new generation of CAIS airborne and ground products.

The implementation of the CAIS architecture in a more network-like fashion has enabled the transition of current and future CAIS systems into the data acquisition network environment. The CAIS architecture maintains the time/data deterministic nature of synchronous time division-multiplexed systems while supporting emerging data packet technologies. These developments increase the value of the CAIS concept and ensure that today's investments will provide benefits well into the future.

New communication technologies such as Fibre Channel, Ethernet, USB, and inter-bus bridges as well as the interconnection between standard aircraft bus types and the CAIS bus have resulted in remarkable system flexibility and improved data throughput. New products such as Solid State Recorders, smart display systems, and enhanced performance data acquisition components have found a natural home within the CAIS environment. Future incorporation of wireless technologies and network sensors promises to provide even greater performance improvements and cost reductions in the future.

Industry acceptance of the CAIS bus standard has enabled DoD's usage of COTS equipment to promote standardization, commonality, and interoperability between Test and Evaluation facilities. The COTS products provide the user with the ability to select the best technical solutions at the lowest cost -- regardless of vendor systems. The commercial CAIS items have enhance and replace instrumentation systems in current platforms and continue to grow into test articles.