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Boeing B-777

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29.1 Introduction

The avionics industry has long recognized the substantial cost benefits which could be realized using a large-scale integrated computing architecture for airborne avionics. Technology achievements by airframe, avionics, and semiconductor manufacturers allow implementation of these integrated avionics architectures resulting in substantial life cycle cost benefits. The Boeing 777 Aircraft Information Management System (AIMS) represents the first application of an integrated computing architecture in a commercial air transport.

29.2 Background

Since 1988, the avionics industry has made a significant effort to develop the requirements and goals for a next-generation integrated avionics architecture. This work is documented in ARINC Project Paper 651. Top-level goals of the Integrated Modular Avionics (IMA) architecture are to reduce overall cost of ownership through reduced spares requirements (includes reduction in cost of spare Line Replaceable Modules [LRM]) and reduction in number of LRMs required), reduced equipment removal rate, and reduced weight and volume in both avionics and wiring. In addition, IMA addresses the airlines' demand for better MTBUR/MTBF (Mean Time Between Unscheduled Removals as a fraction of Mean Time Between Failures), improved system performance (response time), increased airborne functionality, better fault isolation and test, and maintenance-free dispatch for extended intervals.

Technology trends in microprocessor and memory technology demand that airborne computing architectures evolve if the avionics industry is to meet the goals of IMA. By exploiting these developments in the microprocessor and memory industries, very highly integrated architectures previously not technologically feasible or cost-effective may now be realized. These functionally integrated architectures minimize life cycle cost by minimizing the duplication of hardware and software elements (see Figure 29.1).

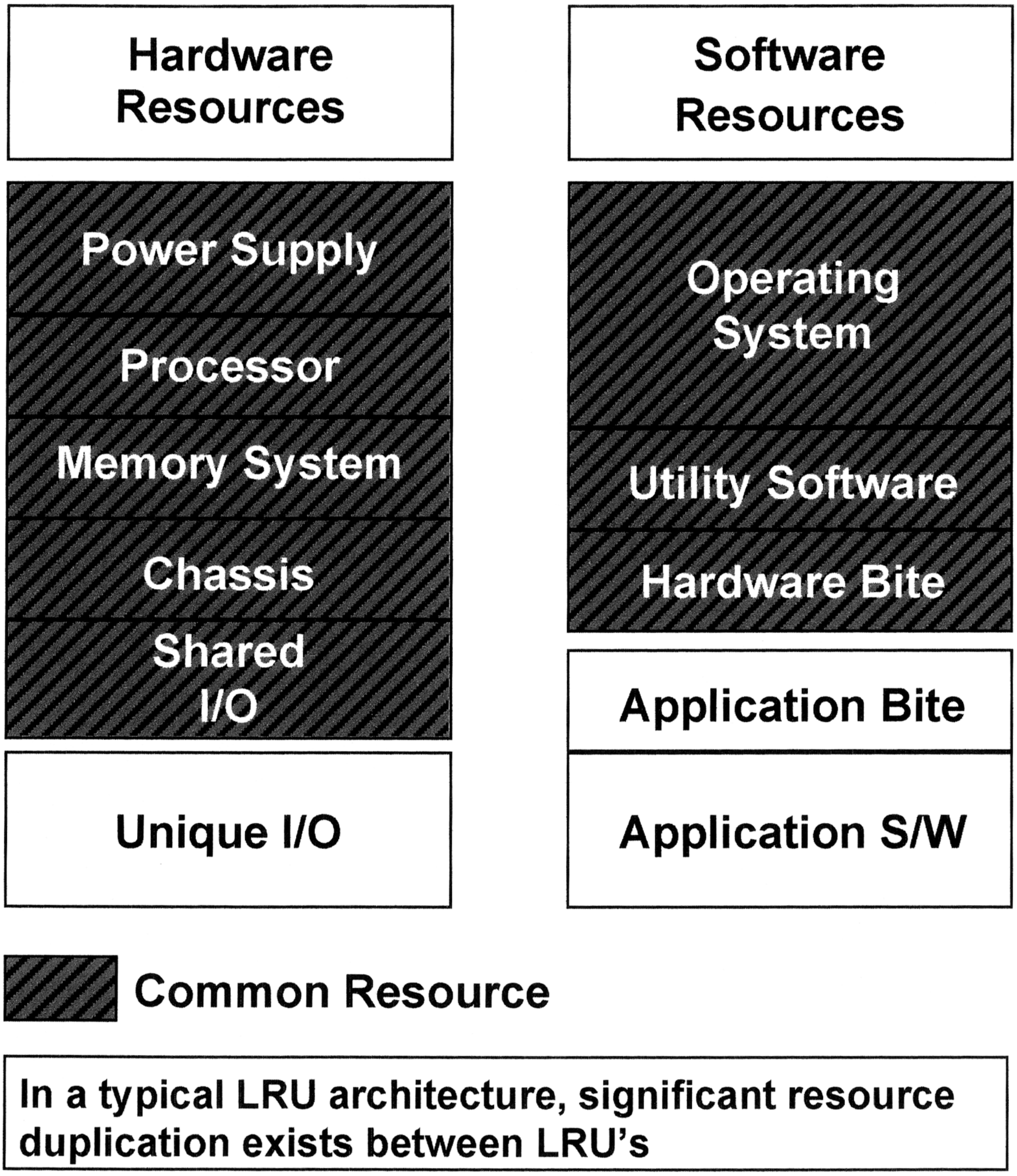

FIGURE 29.1 Components of a typical LRU.

High levels of functional integration dictate availability and integrity requirements far exceeding the requirements for distributed implementations. Resource availability requirements must be sufficient to probabilistically preclude the simultaneous loss of multiple functions utilizing shared resources. These availability requirements imply application of fault-tolerant technology. Although fault tolerance is required to meet the integrity and availability goals of IMA, it is also directly compatible with the airline goal for deferred maintenance. Furthermore, since fault-tolerant technology requires high-integrity monitoring, it also is compatible with airline desires for improved fault isolation, better maintenance diagnostics, and reduced unconfirmed removal rate (MTBUR). Current IMA implementations are realizing a more than six times improvement in unconfirmed equipment removals over a typical federated LRU-based architecture.

High functional integration also implies the requirement to maintain functional independence for software utilizing any shared resource. Strict CPU separation is not sufficient to ensure that functions will not adversely affect each other. I/O resource sharing demands a backplane bus architecture which has extremely high integrity and enforces rigid partitioning between all users. Processor resource sharing requires a robust software partitioning system where all partition protection elements are monitored to ensure isolation integrity.

Robust partitioning protection must be performed as an integral part of the architecture, and isolation must not be dependent upon the integrity of the application software. In this environment, the robust partitioning architecture would be certified as a standalone element allowing functional software to be updated and certified independently of other functions sharing the same computational or I/O resources. Since it is anticipated that airborne functionality will continue to increase and that the majority of this increase will be accommodated via software changes alone, this partitioned environment will provide flexibility in responding to evolving system requirements (e.g., CNS/ATM).

29.3 Boeing 777 Airplane Information Management System (AIMS)

The Boeing 777 Airplane Information Management System implements the IMA concept in an architecture which supports a high degree of functional integration and reduces duplicated resources to a minimum. In this architecture the conventional Line Replaceable Units (LRUs) which typically contain a single function, are replaced with dual integrated cabinets which provide the processing and the I/O hardware and software required to perform the following functions (see Figure 29.2):

Flight Management
Display
Central Maintenance
Airplane Condition Monitoring
Communication Management (including flight deck communication)
Data Conversion Gateway (ARINC 429/629 Conversion)

The integrated cabinets are connected to the airplane interfaces via a combination of ARINC 429, ARINC 629, and discrete I/O channels (see Figure 29.3 Note that for clarity the 429 and discrete channels are not shown).

29.4 Cabinet Architecture Overview

The heart of the AIMS system consists of dual cabinets in the electronics bay that each contain four core processor modules (CPMs) and four input/output modules (IOMs), with space reserved in the cabinet to add one CPM and two IOMs to accommodate future growth (reference Figure 29.4). The shared platform resources provided by AIMS are

Common processor and mechanical housing,
Common input/output ports, power supply, and mechanical housing,
Common backplane bus (SAFEbus™) to move data between CPMs and between CPMs and IOMs,
Common operating system and built-in test (BIT) and utility software.

Instead of individual applications residing in a separate LRU, applications are integrated on common CPMs. The IOMs transmit data from the CPMs to other systems on the airplane, and receive data from these other systems for use by the CPM applications. A high-speed backplane bus, called SAFEbus™, provides a 60-Mbit/s data pipe between any of the CPMs and IOMs in a cabinet. Communication between AIMS cabinets is through four ARINC 629 serial buses.

The robust partitioning provided by the architecture allows applications to use common resources without any adverse interactions. This is achieved through a combination of memory management and

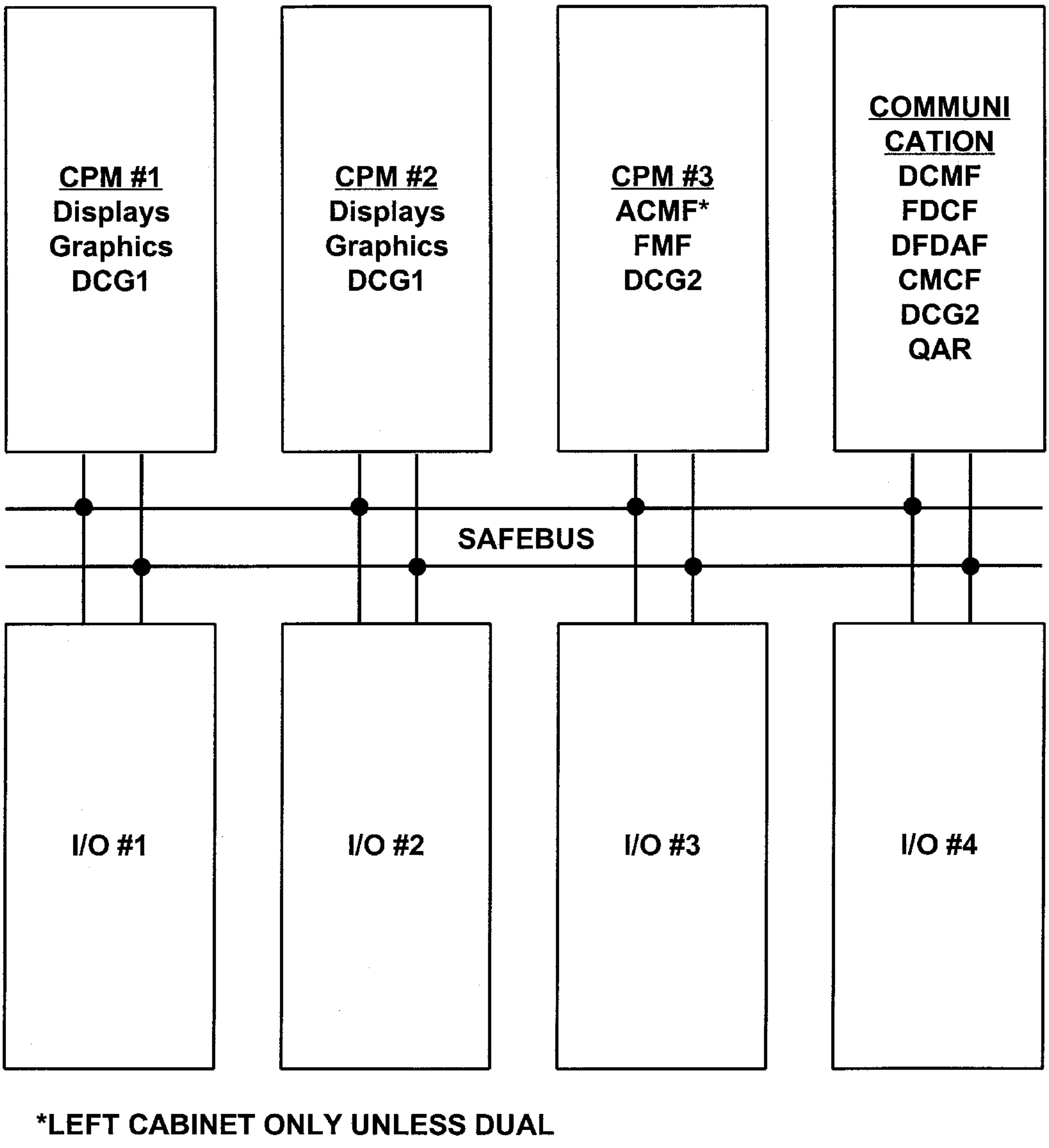

FIGURE 29.2 AIMS baseline functional distribution.

deterministic scheduling of application software execution. Memory is allocated before run time, and only one application partition is given write-access to any given page of memory. Scheduling of processor resources for each application is also done before run time, and is controlled by a set of tables loaded onto each CPM and IOM in the cabinet. This set of tables operates synchronously, and controls application scheduling on the CPMs as well as data movement between modules across the SAFEbus™.

Hardware fault detection and isolation is achieved via a lock-step design of the CPMs, IOMs, and the SAFEbus™. Each machine cycle on the CPMs and IOMs is performed in lock-step by two separate processing channels, and comparison hardware ensures that each channel is performing identically. If a miscompare occurs, the system will attempt retries where possible before invoking the fault handling and logging software in the operation system. The SAFEbus™ has four redundant data channels that are compared in real time to detect and isolate bus faults.

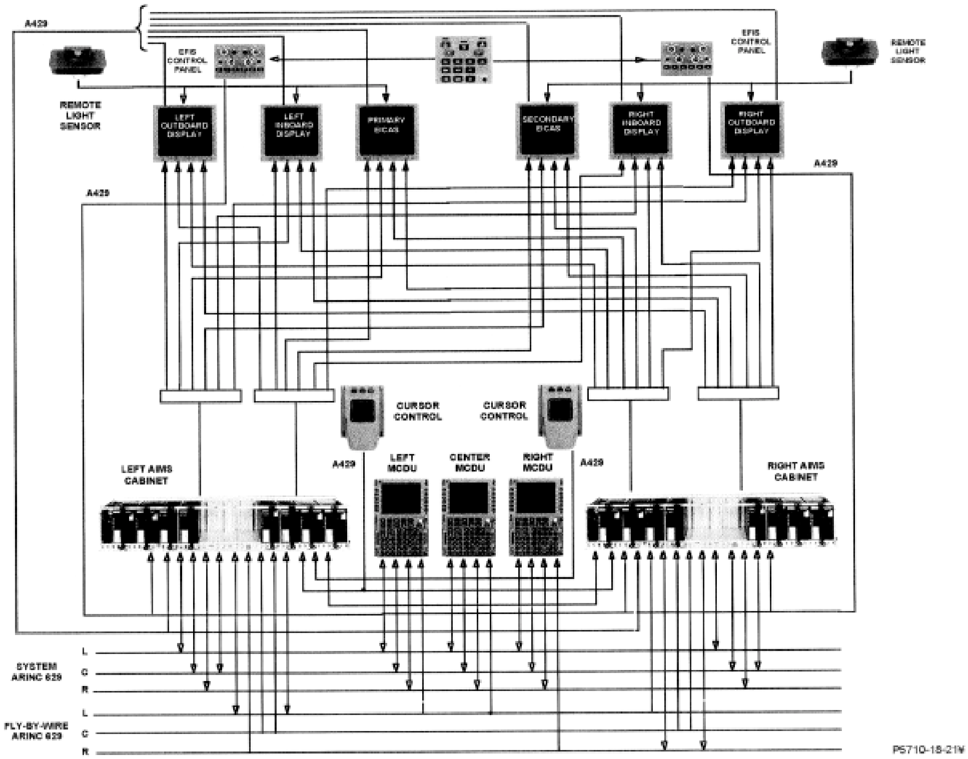

FIGURE 29.3 Airplane interface schematic.

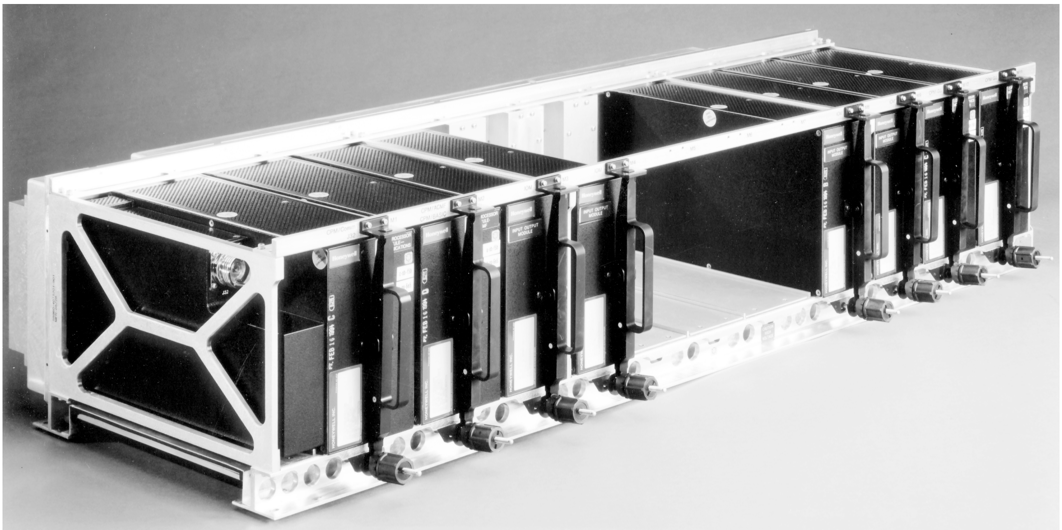

FIGURE 29.4 AIMS cabinet.

The applications hosted on AIMS are listed below, along with the number of redundant copies of each application per shipset in parentheses:

Displays (4)
Flight Management/Thrust Management (2)
Central Maintenance (2)
Data Communication Management (2)
Flight Deck Communication (2)
Airplane Condition Monitoring (1)
Digital Flight Data Acquisition (2)
Data Conversion Gateway (4)

All of the IOMs in the two AIMS cabinets are identical. The CPMs have common hardware for processor, memory, power, and SAFEbus™ interface, but have the capability to include a custom I/O card to provide specific hardware for an application "client." The client hardware in AIMS includes the displays graphics generator, the data communications management fiber optic interface, the digital flight data acquisition interface to the data recorder, ACARS modem interface, and the airplane condition monitoring memory.

The other flight deck hardware elements that make up the AIMS system are

Six flat panel display units
Three control and display units
Two EFIS display control panels
Display select panel
Cursor control devices
Display remote light sensors.

29.5 Backplane Bus

As stated previously, the cabinet LRMs are interconnected via dual high-speed serial buses called SAFEbus™ (see Figure 29.5). These buses provide the only communication mechanism between the processing and I/O elements of the integrated functions. As such, extremely high availability and integrity requirements are necessary to preclude the simultaneous loss of multiple functions and to preserve robust partitioning of I/O resources. In addition, SAFEbus™ itself is required to provide and enforce the integrity of this key shared resource. Absolute data integrity must be ensured independent of hardware or software failures within any module. In this environment, SAFEbus™ behaves as a generic and virtual resource capable of supporting high levels of I/O integration.

The SAFEbus™ protocol is driven by a sequence of commands stored in each Bus Interface Unit's (BIU) internal table memory. Each command corresponds to a single message transmission. All BIUs are synchronized so that at any given point in time all BIU's "know" the state of the bus and are at equivalent points in their tables. Because buffer addresses are stored in tables they do not need to be transmitted over the bus, and since all transactions are scheduled deterministically, there is no need to arbitrate the bus. This allows for extremely high bus efficiency (>94%) with no bits required to be dedicated to address control and minimal bits required to control data. A more detailed description of SAFEbus™ operation can be found in ARINC Project Paper 659 and also in Reference 3.

29.6 Maintenance

The requirements for fault tolerance allow increased design flexibility and capability for deferred maintenance operation. By taking advantage of the high-integrity hardware monitoring which fault-tolerant design provides, the AIMS cabinets are capable of instantaneous fault detection and confinement. This increased fault visibility allows the cabinet to suppress most faults prior to producing a flight deck effect. This is an important step in reducing the mean time between removal (MTBR) of the equipment.

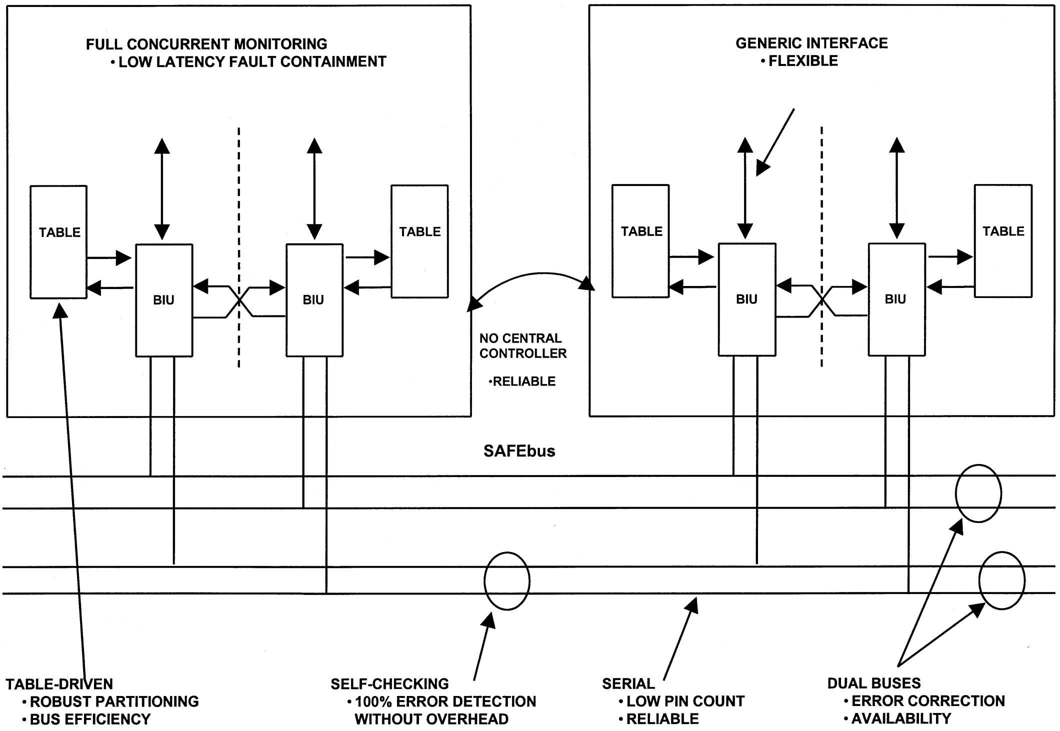

FIGURE 29.5 SAFE bus™ dual serial buses.

In addition, fault tolerance also provides the capability for deferring maintenance to regular (and thus schedulable) intervals. Depending upon the "fail-to-dispatch" probability that the airline is willing to endure, dispatch can continue for 10 to 30 days without maintenance following any first failure in the AIMS.

29.7 Growth

Functional growth is provided in the cabinets through two paths: spare computing and backplane resources provided as part of the baseline AIMS, and three spare LRM slots provided in each cabinet. Spare computing and backplane resources may be used by any function (new or existing) which requires additional throughput or I/O. Existing spare I/O hardware, for example 629 terminals, 429 terminals, and discrete I/O are also available for use by any function integrated into the cabinet. Spare LRM slots may be used for additional processing, I/O, or additional unique hardware which may be required for a specific function due to the generic backplane interface. Additional processing modules may be added as required without changes to existing cabinet hardware. Addition of I/O may require wiring changes if new airplane interfaces are needed.

References

1. Kelly, Michael R., Honeywell, Inc., "Airborne Computer Technology Initiatives," RTCA Paper, December 3, 1990.
2. ARINC Project Paper 651, Draft 6, Design Guidance for Integrated Modular Avionics.
3. Hoyme, Driscoll, Herrlin and Radke, Honeywell, Inc., "ARINC 629 and SAFEbus™: Data Buses for Commercial Aircraft," Scientific Honeyweller, Fall 1991.

Further Information

This chapter is substantially a reprint of material originally presented in:

Morgan, Michael J., Honeywell, Inc., "Integrated Modular Avionics for Next Generation Airplanes," IEEE AES Systems Magazine, August 1991.

Witwer, Robert, Honeywell, Inc., "Developing the 777 Airplane Information Management System (AIMS) A View from Program Start to One Year of Service," August 1996.