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ELECTRONICS STANDARDS SURVEY:
ANNOTATED BRIEFING

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September 1993

Prepared for
Office of the Under Secretary of Defense Acquisition
Tactical Systems

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13. ABSTRACT (Maximum 200 words) This briefing documents the findings of a survey of electronic standards and architectures. The objective of the survey was to determine the role DoD could pursue to take advantage of the large commercial electronics technology base for future military systems. Conducted by a team comprised of OSD and IDA personnel, the survey reviewed past, present, and evolving future electronic standards, focusing on computer processors, interfaces, data buses, and software technologies. The overall conclusion was that there was no single universal technology or standards solution that meets all military application needs. Rather, families of standards are needed to cover the broad scope of DoD systems requirements. The team recommended that OSD take a more active role to encourage the military services to work with industry to formulate families of open systems standards that promote the application of commercial technologies where appropriate.				
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INSTITUTE FOR DEFENSE ANALYSES

Contract MDA 903 89 C 0003

Task T-F7-1010

PREFACE

This document was prepared by the Institute for Defense Analyses (IDA) for the Office of the Under Secretary of Defense (Acquisition)/Tactical Systems under a task entitled "Assessment of Technical and Schedule Risk of Tactical Air Programs." The document is an annotated version of a briefing that documents the findings of a survey of past, present, and possible future electronics standards and architectures. The principal objective of the survey was to determine the role that the Department of Defense should pursue to take advantage of commercial technology and common approaches for future military system applications. The survey was conducted under the joint chairmanship of Mr. Pete J. Luppino (Office of the Secretary of Defense/Tactical Systems/Air Systems) and Mr. David Hickman (Office of the Secretary of Defense/Production and Logistics/Production Readiness. Other team members were drawn from the Office of the Secretary of Defense and IDA.

This document was reviewed within IDA by Waynard C. Devers and Richard R. Legault.

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Summary

This briefing summarizes the results of a survey of past, present, and potential future commercial and military electronic (including software) standards and system architectures. The primary objective of the survey was to determine the role the Department of Defense (DoD) should pursue to take advantage of commercial technology and standards for future DoD system requirements. The technologies addressed focused primarily on computer processors, system interfaces, data buses, communication protocols, and supporting software.

Background is provided on prior and current technology and transfers between the DoD, other government agencies, and industry. Increasing cost trends of weapon system electronics were contrasted to the decreasing cost of major commercial electronic components such as computer processors. The similarities and differences in system requirements among business systems; command, control, communication, and intelligence (C³I) systems; and tactical/strategic applications were reviewed in terms of physical operating space, environment, real-time and other performance needs, market potential, manufacturing practices, and logistics issues. While differences do exist among these applications, the significant commonality found could open the way for greater interchange of technology between the commercial and military markets.

Standards application and technology trends for current DoD business, C³I, tactical, and strategic system applications were reviewed. It was found that C³I and business systems were making good use of industry standards and are actively supporting new standards development. However, OSD needs to continue pressure to assure that new standard developments are accelerated to fill remaining technology voids.

Current technology trends were reviewed related to system costs, component development (processors, data buses, and input/output devices), software, and module standards. It was concluded that technology capability continues to grow rapidly and that standards must foster such growth, not inhibit it. Due to the wide range of military system needs, it was observed that families of standards are needed to cover all requirements. Further, it was judged that the near-term focus should be on developing standard real-time operating systems to address a critical requirement.

Examination of the tactical and strategic systems and programs indicated there is little common usage of hardware or software standards. Systems developed by the military services tend to reflect their organizational autonomy. A range of service initiatives (e.g.,

JIAWG, JIAD, TACOM/SAVA, JSRC, MASA, and NGCR) are attempting to institute greater use of electronic system standards (hardware and software), but greater central coordination and management oversight by the Office of Secretary of Defense (OSD) are considered necessary to assure maximum success.

The overall conclusion drawn from the survey was that no single universal standard or set of standards can be applicable for all military systems applications. It was also observed that technology will lead standards development and industry will play the dominant role. However, the availability of open system technology standards will allow more competition and facilitate system upgrades, thus forming a highly desirable objective for future technology selection. Commercial products and technology will be cost-effective for many C³I and DoD business applications, but will be of little use for tactical and strategic weapon systems that require real-time capability and face stringent weight, volume, and environmental constraints.

It was recommended that OSD take a stronger role in developing, approving, and implementing new technology standards. OSD organization oversight is needed to fully coordinate the many on-going standards activities within the DoD. High-level sponsorship of advanced development and test programs is needed to ensure the applicability and interchangeability of emerging electronic technologies.

Introduction

Tasking

Survey past, present, and potential future electronics standards and architectures, including processors, interfaces, data bases, protocols, and software to determine the role DoD should pursue to take advantage of commercial undertakings and to determine future role of DoD overall

The introduction to the briefing presents the tasking to be addressed by the survey team in its investigation of commercial technology and the possible role of open system standards for DoD applications. Principal members of the survey team are identified along with the briefings the team received from the government, services, industry, and other organizations engaged in standards development, review, and implementation.

A number of military and commercial standards and architectures that define hardware interfaces, buses, communications protocols, and software exist or are being developed today. The degree to which these standards have been or could be used for new military systems development forms the basic question to be addressed. The use of such standards can facilitate the use of common modules, interchangeability, and interoperability among military weapon systems requiring electronic components and associated software.

Some of the available (or developing) standards are being formulated by the DoD/services through activities such as the Joint Integrated Avionics Working Group (JIAWG), Standard Army Vectronics Architecture (SAVA), and Next Generation Computer Resources (NGCR). Organizations that set commercial industry standards, such as the Institute of Electrical and Electronics Engineers (IEEE), the American National Standards Institute (ANSI), and the Society of Automotive Engineers (SAE), are also active in the formulation of both electronic hardware and software standards. Other federal agencies, the National Institute of Standards and Technology (NIST), the National Aeronautics and Space Administration (NASA), and the Federal Aviation Administration (FAA), are establishing and participating in the establishment of open (non-proprietary) standards on data exchange, communication protocols, and data processing.

The tasking directed that a survey team be formed to investigate the available or emerging electronic standards for both military and commercial applications to determine their performance utility and impact on life-cycle cost effectiveness if adopted for use in new military system applications. The investigation should further make recommendations on the role of DoD in future standards development.

OSD Electronics Standards Survey Team

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OSD/P&L/PR
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OSD/DDR&E/S&T
OSD/TS/LS
C³I/T&TC³
DARPA/CSTP
OSD/S&SS/AS
OSD/P&L/PR
OSD/TS/MS
OSD/TS/MS
OSD/TS/ECS
IDA
IDA
IDA Consultant
IDA Consultant

To accomplish the investigation tasking, a team was selected to conduct the electronics standards survey. A total of seventeen members were drawn from within OSD with representatives from Tactical Systems (TS), Production and Logistics (P&L), Research and Engineering (DDR&E), Defense Advanced Research Projects Agency (DARPA), C'I, and Strategic and Space Systems (S&SS). The survey team was aided by staff from the Institute for Defense Analyses, who participated in the discussions and served as a secretariat for the team.

Briefings

- **Government**
 - DARPA
 - Air Force
 - Pave Pace
 - Technology Trends
 - Navy
 - NGCR
 - COPERNICUS
 - COSIP
 - Army
 - SAVA
 - AARDC
 - AVSCOM
 - Joint
 - JIAD
 - Open Systems Architecture
 - DISA
 - Strategic
- **Industry**
 - Hughes
 - IBM (Manassas and Owego)
 - TRW
 - Westinghouse
 - CDI
 - DEC
- **Other**
 - IDA
 - ARINC

The survey was accomplished primarily by inviting government and industry experts to brief the survey team on their experience, status, and knowledge of electronic technology standards, programs, and activities. Briefings to the team occurred over the period June 19, 1992, through September 16, 1992, as follows:

Topic	Activity	Presenter
<u>6/19/92</u> High Performance Computing and Communications Centralized Management of DoD Standards	DARPA DISA	G. Weigand D. Marzetta
<u>7/7/92</u> Current JIAWG and Beyond NGCR POSIX Futurebus+	Westinghouse SPAWAR NGCR NGCR	H. Mendenhall S. Brooks R. Voigt
<u>7/14/92</u> Open System and Integrated CNI, SIGINT Software and Navy Open Architecture Future ARINC Standards	TRW IBM, Manassas ARINC	P. Camana G. Plunkett D. Martinec
<u>7/17/92</u> Tri-Service Open System Architecture PEO Aviation Army C&C System Standard Army Vetronics Architecture	Air Force Army PEO CCS TACOM	I. Caro J. McDermont S. Levine D. Sama
<u>7/21/92</u> Integrated Processing Architecture	Hughes	D. Singledecker et al.

Topic	Activity	Presenter
<u>7/29/92</u> COTS Technology Technical Reference Model Joint Integrated Avionics Directorate PAVE PACE Program	IBM, Owego CIM Air Force Air Force	D. Reisiger D. Marzetta/Keane D. Bond Ostgaard
<u>8/4/92</u> Space and Electronic Warfare Advanced Electronics Packaging Strategic (Bomber) Computing Defense Standardization Program	SPAWAR AF/WPAFB OSD, S&SS OSD, P&L	J. Hensley S. Wagner H. Dahljelm R. Gagnon
<u>8/18/92</u> Aircraft Fiber Optics Navy Tactical Processors and Standards Advanced AYK-14 Avionics Architecture Computer Open System Program	AIR 546 PS-412 PMA-209 AIR-546 PMS-412	D. Glista W. Burgess J. Patterson F. Schobert W. Burgess
<u>9/16/92</u> Computer Technology Development History of Computers and Software Real Time System Analysis	DEC IDA IDA	W. Hefner R. Naper N. Howes

Background

Background

- **Compare commercial industry product requirements and technologies with major DoD systems**
- **Contrast decreasing computer technology costs with rising avionics costs**
- **Review existing electronic module packaging standards**

To place the electronics technology survey in context, several background issues were examined. The purpose was to review the requirements and technology similarities and differences between the commercial industry and the major DoD system sectors.

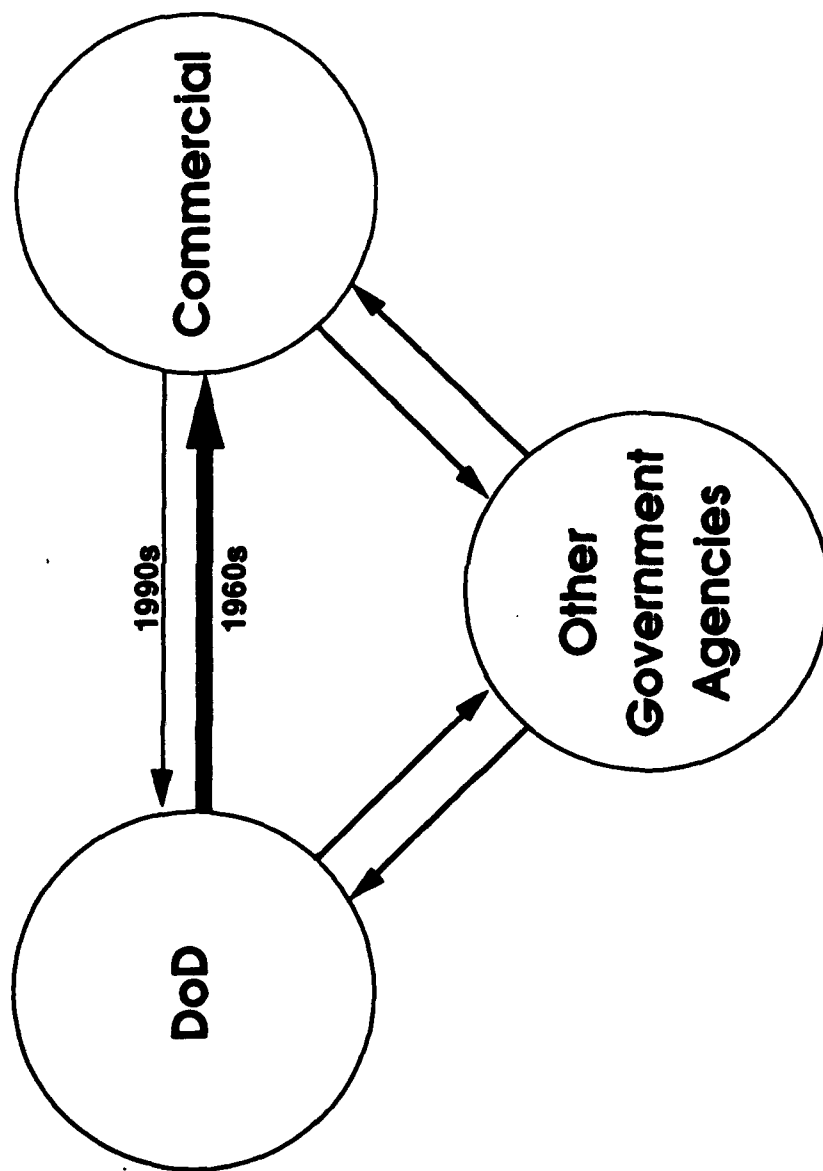
The historical record of technology development and flow between commercial industry and the government sectors was noted. The survey team found that the dominance the government once held in technology is being eclipsed by the dynamic growth of the private sector in many areas.

The decreasing cost trends over the past several decades in computer technology were reviewed and contrasted to the rising cost of avionics systems. The basis for this disparity was explored in terms of similarities and differences between commercial and DoD requirements and environments. The principal difference was found to be the DoD's need for highly accurate real-time system performance.

Electronic module packaging standards that have been developed by the services and commercial industry were reviewed. The standards were found to be similar, but not interchangeable. Logistic and maintenance concept differences were also examined.

Overall, the team found that there are significant requirements and technology commonality between the commercial industry and DoD for most of the DoD's business systems and some C³I systems. The DoD's requirement for high-performance real-time weapon system technology are generally not being met by commercial industry technology programs or standards.

Technology Flows

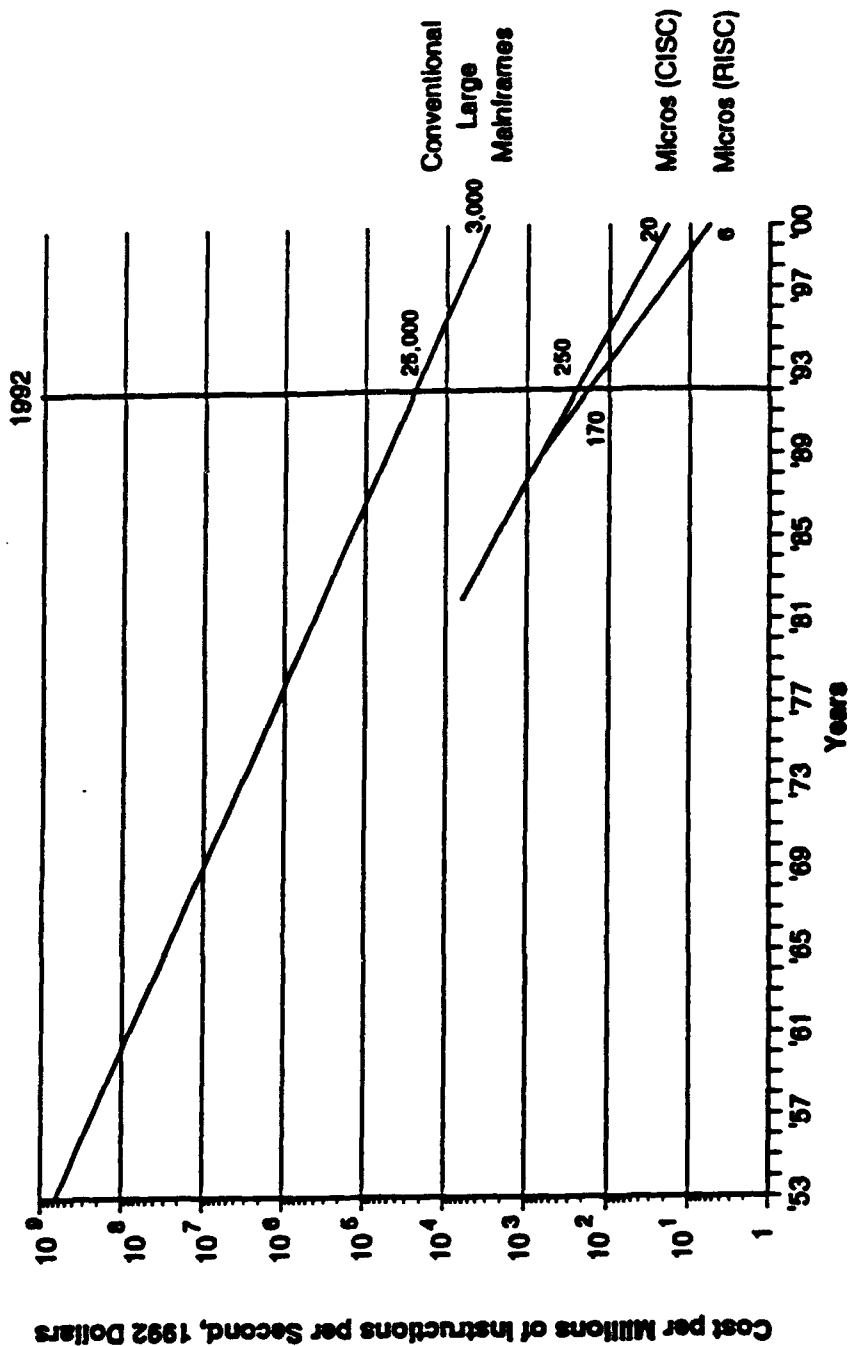


Over the past 40 years, technology development has taken place in the DoD, other government agencies (NASA, Department of Commerce, and Transportation), and commercial industry. For example, the DoD during the 1960s provided much of the funding for development of solid-state and integrated circuit components. Through the space program, NASA contributed to real-time computer and guidance-system technology in the late 1960s and 1970s. During this period, the private sector was the beneficiary of these developments through technology transfer.

As a result of huge increases in the commercial computing market, and to some degree, exploitation of earlier DoD advances and diminished DoD budgets (both in total dollars and as a percentage of the gross national product), the DoD is no longer the dominant player in the 1990s electronics market. Current estimates place the DoD consumption of electronics at less than 10 percent of the total market. As a consequence much of the development of technologies for large-scale information processing is now being directed to the commercial market rather than at the DoD.

Fortunately, there appear to be some commercial electronic developments that the DoD can use in weapon and business systems. Technologies of mutual interest include items such as microprocessors, data buses, and software. In addition, some commercial products are sufficiently reliable and rugged to be used directly in some DoD system applications. One purpose of this survey was to better understand the utility of this technology for DoD applications and to determine how the DoD can best benefit from the commercial electronic developments.

Price of Computing Power



A historical review and projection are provided of computing power cost in terms of 1992 dollars per million instructions per second (MIPS). For conventional mainframe computers, the cost has decreased by more than a factor of 10 about every decade. Even more dramatic cost reductions have been experienced by microprocessors.

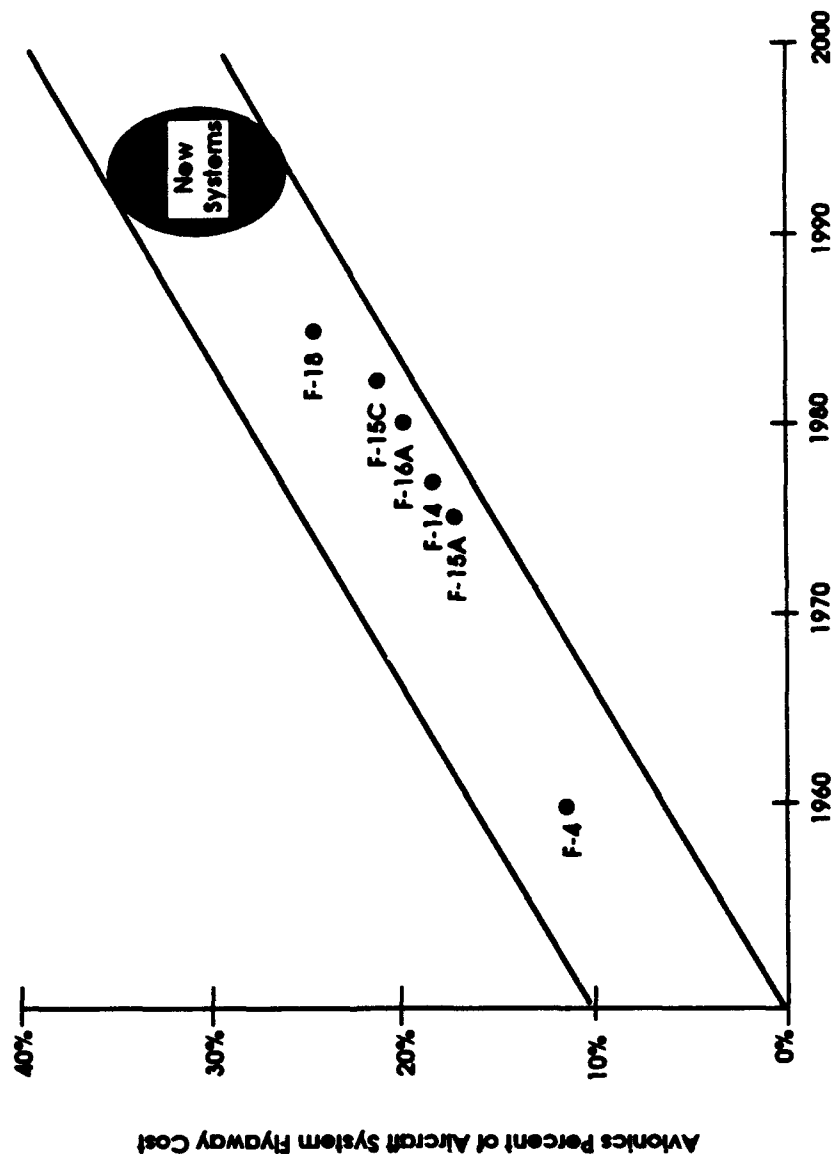
This decrease was the direct result of the introduction of integrated circuits into computer design. Integrated circuits have experienced significant growth in packaging density. For example, the number of transistors typically contained on a chip increased from less than 1,000 in 1970 to as many as 4,000,000 equivalent transistors per chip in 1990. Since the processing cost per chip has been held nearly constant, this growth has provided major cost reductions for the total functions needed to configure a computer.

Microprocessors that can provide sufficient computing power are providing a significant cost gain over mainframes. In 1992, the cost per MIP for the complex instruction set computer (CISC) is estimated to be \$250 versus \$25,000 for a mainframe. The recently introduced reduced instruction set computers (RISC) offer an even greater cost advantage.¹

Since computer technology forms a significant part of many current DoD systems, it would follow that the cost reductions seen for computers would be reflected in the cost of the overall systems. Unfortunately, this has not proved true, largely because the modern weapon system has demanded ever-increasing functionality. This issue will be examined in more detail later in this briefing.

¹ RISC microprocessors for some applications may require more machine cycles to perform a given task than a CISC.

Avionics Cost Trends

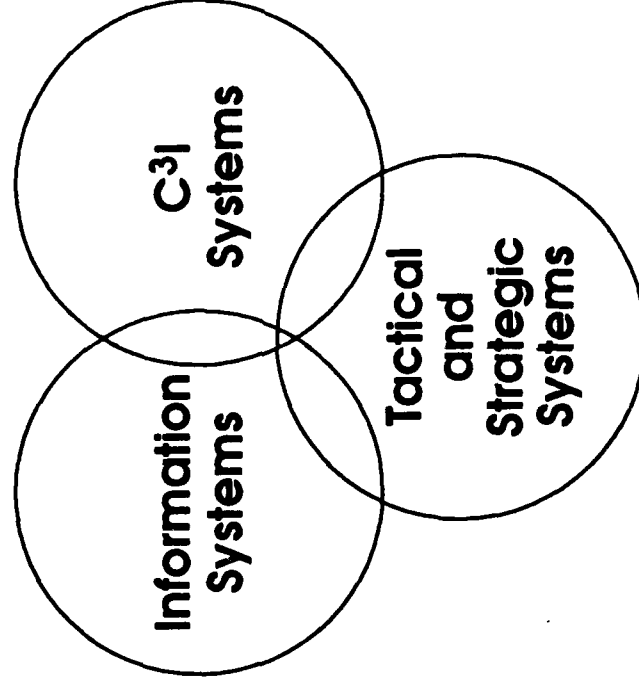


Avionics as a percentage of weapon system cost has been rising steadily over the past 40 years. In 1960, avionics represented approximately 10 percent of the total aircraft cost. The F-22 avionics cost is expected to range from 25 to 35 percent of the total cost. Since aircraft cost during this period have risen by over a factor of 10, the cost of avionics has increased at an even faster rate.

A significant part of avionics is composed of computing components, the commercial cost of which has fallen by a factor of 10 every decade, a fact that should lead to lower avionics cost. Unfortunately, as the avionics cost trend indicates, this has not happened. The dramatic cost increase for avionics has resulted from a combination of increased system performance functionality, the added cost to integrate complex systems, the expanded cost of providing extensive system software (5-10 percent of total weapon system cost), and the failure to make extensive use of cost-saving common hardware and software standards.

Ways to mitigate the rising avionics cost must be sought. The use of standards, commonality, and commercial technology may provide some amelioration.

Systems Requirements and Technologies Have Similarities and Differences

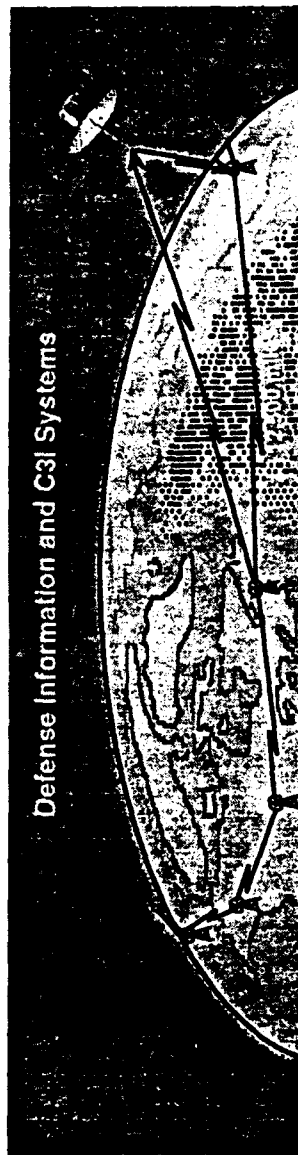


The DoD owns and operates a broad range of systems that can be broadly classed as information (business) systems; command, control, communications and intelligence (C³I) systems; and tactical and strategic systems. As would be expected, these systems have both differences and similarities as shown conceptually by the three overlapping circles in the figure. Similarities include the technologies used to derive the systems along with their associated characteristics such as portability, affordability, and security needs. Differences include the requirements for real-time performance, range of operations, and warfighting capability.

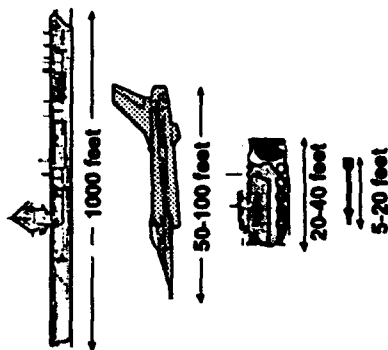
The degree of difference or similarity can impact the ability to use common technology and standards. The next several charts examine the differences and similarities of DoD and commercial systems.

DoD Range of Applications

Defense Information and C3I Systems



Tactical and Strategic Systems



The distances over which elements of DoD systems must interoperate provides graphic evidence of system differences. Defense information and C³I systems are arrayed in world-wide networks and must intercommunicate passing voice and data over thousands of miles. Tactical and strategic systems contain complex, highly integrated electronic systems that are interconnected using a variety of low and high data rate buses, operating both in serial and parallel modes. These data buses may be required to provide communication between system components that are a few inches up to more than a thousand feet away. The data rates may vary from 600 bits per second to 50 million bits per second. To meet this scope of applications, a range of inter- and intra-system communication technology is needed to provide the proper balance of capability and affordability.

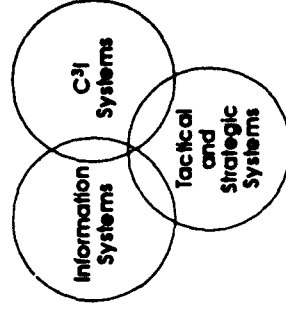
Similarities/Differences of Applications

- **Similarities**

- Portability
- Affordability
- Move with technology advances
- Competition
- Leverage commercial products where practical
- Security

- **Differences**

- Real-time versus non-real time
- Environment (benign and active)
- Inter-netting versus intra-system
- Weight and volume
- Reliability and maintainability
- Warfighting capability
- Redundancies, fault detection, and corrections



The leading similarities and differences among DoD business, C³I, and tactical and strategic systems are highlighted on the accompanying chart.

Similarities:

Portability is the ability to transfer a device or software from one system environment to another and, therefore, is desirable for all system types. Failure to provide portability dictates that each new device or software application will require significant tailoring or, in some cases, unique design and development effort. Building hardware and software to standard functional and interface specifications provides the needed portability characteristics.

Affordability is a universal requirement that is of the utmost concern when systems are bought in quantity (thousands).

Technology advances are of particular importance for tactical and strategic systems to maintain a competitive performance edge over potential adversaries. Technology advances often provide cost/performance gains and thus are appropriate for all systems areas.

Competition in the market place is vital in all system areas for both technical performance and cost control. It has been repeatedly proved that fair competition can yield superior cost-effective products.

Due to the cost lead maintained by some commercial technology, all DoD system areas are reviewing these developments to determine where they may be effectively used. The use of commercial open system technology standards by the DoD can provide a cost-effective means to utilize commercial technology. Unfortunately, the cost of qualification and other testing that must be performed to adopt commercial technology may erode the apparent cost advantage.

Security concerns surround the use of all DoD systems. Technology can be used to encode and decode data to provide varying levels of protection. The search for a cost-effective, multilevel secure system continues.

Differences:

Real-time response (50 microseconds or less) to operational stimuli is often a need for tactical and strategic weapon systems. Such responses are needed to perform flight, weapon, and protection system functions. The system architecture, device technology, and

controlling operations must be specifically designed to meet these levels of performance. While all system applications can benefit from fast response time, the cost to achieve the 50 microsecond (or less) end-to-end response is not warranted for non-critical system applications.

A wide range of environments are encountered among DoD business, C³I, and warfighting systems. Business and some C³I systems often operate in air conditioned, temperature- and humidity-controlled buildings. This is contrasted to the extremes of temperature, humidity, dust, and shock environments that tactical, strategic, and other C³I systems may encounter. Equipment must be specially developed or protected to withstand these environments.

Internetworking is often used for business and C³I systems to provide the means to share data and information among units separated from a few hundred feet to over thousands of miles. This is accomplished using wide or local area network technology operating at data rates of a few thousand bits per second. Tactical and strategic systems are highly integrated, complex architectures that must share data on an intrasystem real-time basis. This data exchange is accomplished by either very high-speed, parallel back-plane data buses or through the use of data matrix switches (or both). Data rates required for these applications can exceed 50 million bits per second.

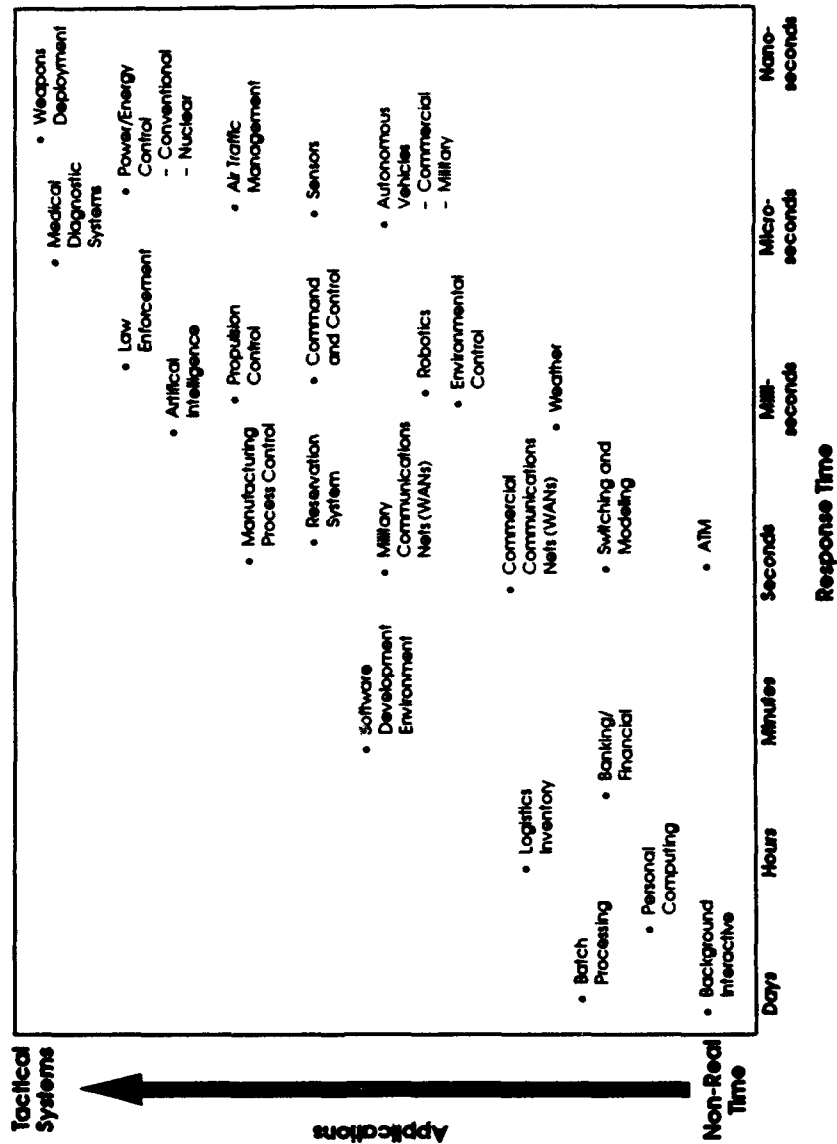
Although current electronic equipment is generally highly reliable, it can be expected to fail on occasion. DoD business and some C³I systems being located in environmentally benign locations can be easily maintained. Tactical and, to a lesser degree, strategic systems are operated in harsh environments remote from established facilities. As a consequence, warfighting systems should contain self-test capability and be designed to be supported by the two-level line replaceable module concept.

Reliability, while an attribute that is of concern for all system applications, is critical for systems that impact safety of flight, personnel injury, or loss of property. Where safety is an issue, special design considerations must be taken (see discussion below).

Systems that provide warfighting capability contain special capabilities that are unique to tactical and strategic systems and have no counterpart in business or C³I applications. Examples of special functionality include weapon fire control, electronic warfare and chemical detection/warning systems. While some of the underlying technology developed to perform the warfighting functions may find use for other business areas, no direct application can be made.

Tactical and strategic systems employ redundancy and data fault detection and correction techniques to ensure the integrity of essential functions that impact safety. Fault detection and correction techniques ensure not only that vital data are correct, but that these procedures are compatible with real-time performance requirements. While all DoD systems require data accuracy, slower, less expensive procedures may be used in the business and C³I systems.

Real-Time versus Non-Real-Time Applications



The chart above presents an array of system applications' response times required for critical functions performed against their relative degrees of tactical performance. As previously noted, real-time operations are generally defined as operations that must take place in 50 microseconds or less.

Those systems that fall in the upper right corner of the chart are considered to have the shortest response time needs and include most weapon platforms. Real-time functions include weapon deployment, medical diagnostics, power and energy system control, law enforcement, and air traffic control.

Overall, system time and throughput requirements form a continuum that ranges from days to a few nanoseconds. It is not cost-effective to seek systems or technology capable of meeting the total range of needs. Rather, families of equipment and associated standards should be provided with capability tailored to the response time and throughput needs of the specific applications being addressed.

Basic Electronics Characteristics

Market	Automotive	Commercial	Military
Production Volume	High	High	Low
Cost	Low	Low-Moderate	High
Reliability	High	Moderate	High
Product Life	Moderate	Moderate	Long
Product Cycle	Short-Moderate	Moderate	Long
Environment			
Temperature	-40° to 125° C	0° to 70° C	-55 to 125° C
Humidity	85% RH/85° C	Controlled	85% RH/85° C
Shock	150 g	Minimal	200 g
Vibration	20 g/20-2000 Hz	Minimal	20-200 g/20-2000 Hz
Chemical Resistance	Salt spray, automotive fluids	Generally not resistant	Salt spray

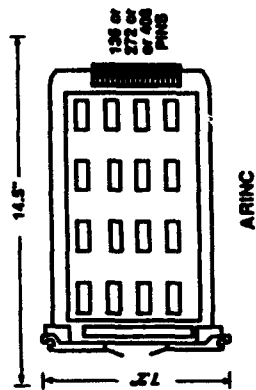
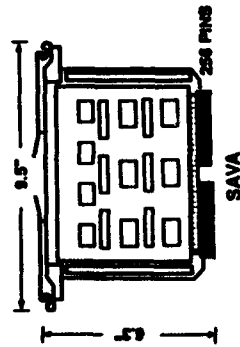
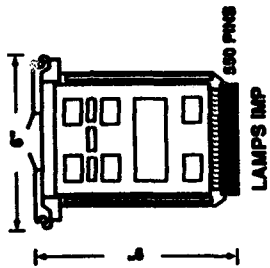
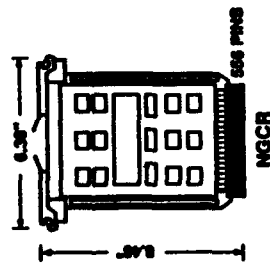
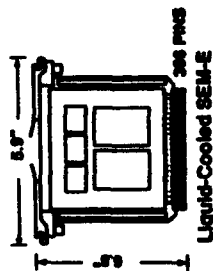
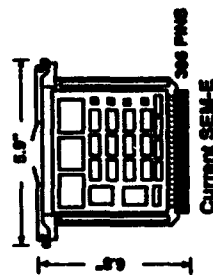
A comparison is presented of the market and environmental factors associated with electronic technology targeted for automotive, commercial, and military applications.

In terms of market potential, automotive and commercial (business computing, communications, etc.) electronic technology share similar characteristics in terms of production volume, cost, reliability, product life, and product cycle.

Military technology tends to be low production volume with associated high cost.

An examination of the environmental characteristics reveals that automotive and military technology have similar requirements. This would suggest that some sharing of technology and standards between the automotive industry and the military could be achieved. Such sharing has recently occurred with the military making use of data bus standards developed by the Society of Automotive Engineers (SAE).

Major Programs Electronic Module Packaging



The growth in integrated circuit density (4 million transistors per chip) has led to the ability to develop electronic modules, with significant functionality, although modest in size. This ability has further led to the development of line replaceable modules (LRMs) used to support two-level maintenance concepts.

A complex avionics system design can be accomplished with a few hundred LRMs of the appropriate type. If LRMs could be standardized, an opportunity to save through reduced research and development, production, and support would be presented.

An important factor in developing a system of standard modules would be the selection of a standard form factor for LRM design to permit physical module interchangeability. The above chart reviews selected LRMs now being developed by the military and supporting industry.

The SEM-E format was adopted by the JIAWG and intended for the F-22, RAH-66, and the A-X aircraft. The SEM-E design can accommodate high-density surface-mounted devices on both sides of the module board. Because of increased heat dissipation problems, the original forced-air-cooled version has been augmented with a liquid-cooled option. The JIAWG module employs the parallel intermodule (PI) data bus (back plane) architecture.

Two Navy programs (NGCR and LAMPS improvement) are developing LRM format standards that are similar in dimension and connector size, but are not interchangeable with each other or with other LRMs. The NGCR LRM is designed to make use of the Futurebus+ backplane data bus.

The Standard Army Vetrronics Architecture (SAVA) format was developed as a module standard for U.S. Army armored vehicles. The SAVA module was modeled after the double-Euro card to accommodate the VME data bus connector. Its surface dimensions are similar to the Navy LRMs, but it is intended to use pin-mounted components (one side only) with only convection cooling.

The Airline Electronic Engineering Committee has developed a much larger ARINC LRM format. It is intended to be used with a high-speed serial backplane data bus (Safenet) that will significantly reduce connector pin requirements. The larger board size was suggested by avionic manufacturers to reduce board design, production, and support costs and to provide a cooler environment for electronic components.

Unfortunately, although similar, the LRM formats are not interchangeable either physically or in terms of the data bus architecture supported. Developing standard LRM formats for future system development should be given high priority. Format selection should be based on power dissipation, signaling speed, cooling, test capability, technology growth, and reliability needs.

Logistics Maintenance

- Commercial Business Systems
 - Call service representative
- Commercial Aircraft
 - Contractor warranty
- DoD Tactical and Strategic, C³I
 - Organic maintenance (do it ourselves)

The logistic and maintenance practices and support services available vary significantly among different user communities. Logistic and maintenance practices form an issue that must be considered in the process of selecting the technology and standards for a specific systems area.

Commercial business systems are generally supported by either factory service representatives or third party organizations that provide maintenance on a contract basis. These services are typically available within a few hours after a request for service. The service organizations provide trained and properly equipped service technicians supported by an inventory of spare parts.

The commercial airlines make extensive use of warranty repair services supplied by equipment manufacturers during the initial life of the product (3-5 years). After the warranty expires, most airlines establish equipment repair operations augmented by varying degrees of avionics manufacturer support for spare parts and factory service.

DoD tactical, strategic, and C'I systems most often develop the capability to maintain equipment they acquire. This action is dictated because of the world-wide scope of operations, often in remote locations. Some limited use of system warranty has been made by the DoD (AN/ARN-118, F-16, and air-launched cruise missile), but, normally, organic maintenance capability is established. Due to the uniqueness and long service life of most DoD systems, the government must make major investments in training, maintenance facilities, and life time spares. Systems newly introduced into the inventory may be supported by contractor maintenance for some initial period before the establishment of DoD facilities.

Order of Preference for Standards (MIL-STD 970)*

- **Multi-national treaty organization standardization agreements and federally mandated rules and regulations**
- **Non-government standards**
 - **Adopted international standards**
 - **Adopted U.S. non-government standards**
 - **Other international/U.S. non-government standards**
- **Commercial item descriptions**
- **Federal specifications/standards**
- **Fully coordinated MIL/DoD specifications/standards**
- **Limited coordinated MIL/DoD specifications/standards**
- **Locally prepared one-time-use purchase descriptions**

*** Replaces MIL-STD 143**

DoD MIL-STD 970 (replacing MIL-STD 143) has been issued to provide an order of preference for the use of technology standards in the design of new or modified DoD systems. The above chart presents the required preference in descending order.

Use of NATO or other multi-national treaty organization standards and other federally mandated rules and regulations form the primary preference. Since these requirements often are mandated by law, it is essential that appropriate use be made where possible.

The second preference is to make use of adopted international standards, adopted U.S. non-government standards, or other international/U.S. non-government standards. Because of the current lead in technology development held by commercial industry, this preference forms a rich source for low-cost, state-of-the-art technology.

The third and fourth preferences represent documented technologies that are available to support system development. Since these items may have been in the DoD inventory for some time, they may not represent the state-of-the-art technology.

The next two preference levels relate to MIL/DoD specifications and standards. Because of the unique nature of some weapon system performance functionality, it is often necessary for the DoD to develop specifications and standards for the unique items required. Purchase order descriptions for small, one-time acquisitions form the last preference level.

Clearly, this standard provides a basis on which to make use of available and appropriate commercial electronic standards.



Current DoD Applications

C³I and Business Systems

- **Intercommunication networks**
- **Open system architectures**

This portion of the survey investigated the major classes of systems used by the DoD: business, C³I, tactical, and strategic systems. This investigation focused on the availability of system standards to support system development and the degree to which these standards have been employed.

Open system architecture is defined and the concept of operation reviewed. The efforts of the DoD to make use of open system concepts are noted in terms of the standards being developed and the organizations charged with their development and implementation.

For C³I and business (information) systems, progress has been made in adopting, developing, and applying a broad range of system standards that should provide significant long-range cost savings. For tactical and strategic systems, the survey team concluded that, while there is some use of standards *within* the services, there was very little use of standards *across* the services. Although a number of standard development initiatives are now in progress, there is overlap and duplication of effort.

The DoD makes extensive use of both C³I and business systems. These systems, although addressing different application functionality, share many common attributes. The next several charts review typical characteristics of these systems.

Intercommunication networks are common to both system areas. Such networks provide the ability to transmit information and data among operational entities separated by thousands of miles. Standards are necessary in order to develop the complex networks that provide the required inter- and intra-system connectivity.

The role and status of open system architecture for C³I and business systems are also reviewed. Open systems disclosure provides industry access to non-proprietary system interface design information. This access affords the means for development of technology compatible with new systems in a competitive environment.

- Internet is global
 - Close to 4,000 announced networks as of June 1991
 - Essential tool for sharing information through file transfers, electronic mail, and interest-group mailing lists
 - Became operational in 1983
- Spin-off from ARPANET, which became operational in 1969
 - Split into MILNET and ARPANET in 1983, which together formed Internet
- Internet uses either TCP/IP or OSI protocol suites
 - Gateways exist that translate between two protocols
 - ASD (C3I) mandated TCP/IP protocol for all ARPANET hosts
 - ASD(C3I) decommissioned ARPANET in June 1990; NSFNET continued its functions

Internet is a network that ties together thousands (estimated to be 4,000 as of June 1991) of local, wide area, and national networks. The network provides users the ability to exchange data base information through file transfers and electronic mail. Originally intended to tie together research or education sites, Internet is expanding this original focus to include private and commercial enterprises.

Internet traces its origin to ARPANET, which became operational in 1969. In 1983, the original ARPANET split into the MILNET and ARPANET, which together formed Internet. In June 1990, the Defense Communications Agency (DCA) decommissioned ARPANET. The National Science Foundation's NSFNET now carries out the system functions under the Internet umbrella. NSFNET includes a national backbone network and several mid-level networks (see next page).

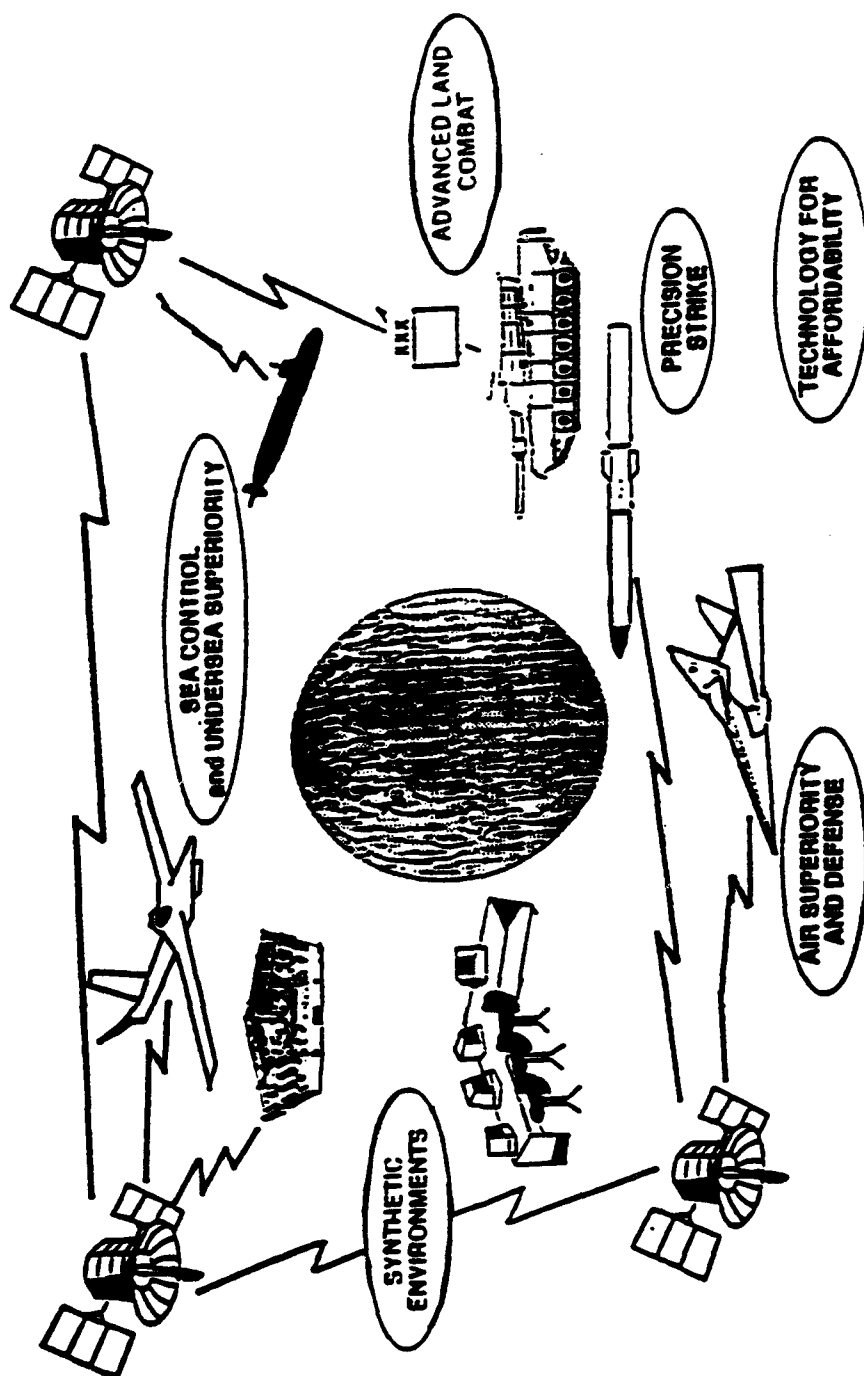
Internet makes use of either Transmission Control Protocol/Internet Protocol (TCP/IP) or the Open System Interconnection (OSI) data transfer protocols (ARPANET mandated TCP/IP for all ARPANET host processors). Users of the network must be able to support one of these data exchange protocols. Network gateways have the facility to translate between the two protocols.

Internet would be unworkable without the use of data exchange standards, which are key to its utility and success. The ability of the processor hosts to translate between two standard protocols provides some flexibility in system configuration. This experience needs to be applied to other electronic system areas, making use of interface standards to permit their interoperation.

The chart shows the topology of the NSF-sponsored inter-processor networks that comprise a significant part of Internet. The legend on the chart identifies the location of current and planned network nodes. The network configuration will provide coverage for most of the populated areas within the United States.

No single agency handles Internet connections. Rather, each component network has its own administration authority establishing connection procedures, pricing terms, and policies regarding usage. The NSF Network Service Center (NNSC) maintains lists of mid-level network service providers offering access to Internet.

Global C³I Systems



Command, control, communication and intelligence (C³I) systems form the means for the military command structure to function. C³I systems must permit the flow of information from remotely located sensors to both fixed and mobile command centers. The national command centers follow a hierarchical command structure to provide instructions to field units so that they can accomplish required operations. A properly functioning C³I system can be a significant force multiplier.

As shown on the accompanying chart, the C³I system is comprised of hundreds of nodes dispersed over thousands of miles at locations around the world. Communications include satellite links, telephone, and radio transmission facilities. Communications formerly consisting of voice with some data is changing to largely data, including graphics and video.

To function properly, the various communication systems operated by the services and the national command organizations must be able to interoperate having standard signals-in-space characteristics or the facility to seamlessly translate across media. Some progress has been made in establishing interservice communication compatibility through the efforts of the Defense Information Systems Agency (DISA) and the services.

C³I networks have also transitioned from manual message handling to fully automated computer-to-computer data-handling. The switch to automation requires that data transmission protocol, data elements, and message formats be standardized. Work has begun to develop the required data exchange standards within the individual Services with programs such as the Army's ATCCS and the Navy's COPENNICUS initiatives that are addressing C³I information flow. These efforts need to be extended to include all services, as well as the national command structure.

Open Systems Architecture Definition

Open System:

A system that implements sufficient open specifications for interfaces, services, and supporting formats to enable properly engineered components to be utilized across a wide range of systems with minimal changes, to interoperate with other components on local and remote systems, and to interact with users in a style which facilitates user portability.*

- Industry trend toward multi-vendor interoperable products
- Not a computer design
- Well-defined, widely used, non-proprietary interfaces/protocols
- Framework for systems designs
 - Technology/environment insensitive

* Paraphrased from IEEE P1003.0, "Draft Guide to the POSIX Open Systems Engineering," NGCR Briefing

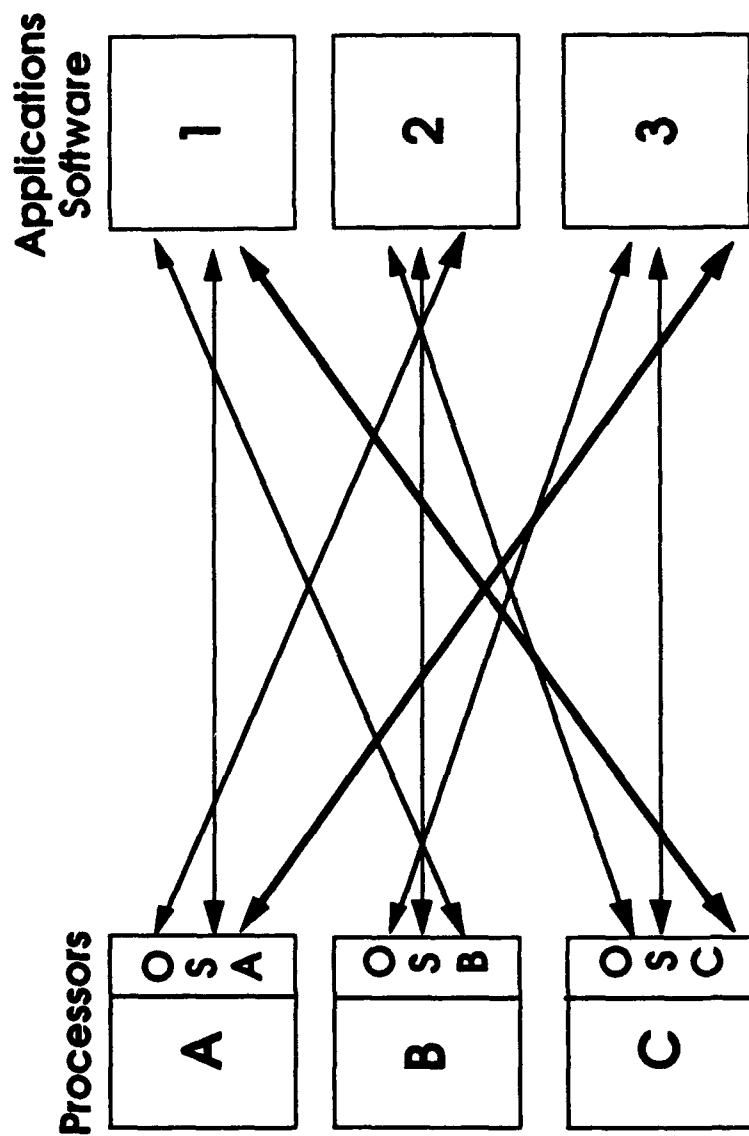
The development of a highly integrated complex system such as tactical fighter avionics requires a well-structured architecture that can meet the operational real-time performance requirements. In the past, system architectures were developed by the aircraft prime contractor and often contained company proprietary concepts that were tightly held and were often unique to each aircraft. This practice resulted in duplicated research and development plus incompatibility among major subsystems, creating high production cost and support and system upgrade problems.

The development of an open system architecture has the potential to ameliorate these problems. The open system architecture implies that the key system interfaces and services would be derived from non-proprietary industry standards. This would permit a number of manufacturers to design subsystems that would interoperate with the central system. Openness promotes competition and reuse of subsystem components, both hardware and software, across many systems.

The creation of an open system requires the development of an underlying system architecture that has the capability to meet a range of application requirements. To facilitate architecture development, reference models are often established that describe the generic structure of the architecture. Reference models typically define the *generic processing and inter/intra-system communication* in terms of standards for message formats, protocols for data transmission, internet addressing, and physical electrical connection.

Open system architectures have been developed in the commercial industry for data communications between computers and workstations via local and wide area networks. The open system defines system interfaces, not computer design. The Open System Interconnection (OSI) represents an inter computer communication effort that has received support from both government and industry. Properly conceived, open systems provide a framework for system designs that are insensitive to technology or environment.

System Concept of Operation



Note: Open system provides functionality, not form and fit

Open system architectures provide the means for processor interchangeability and application software portability. Processors developed to open system standards possessing common instruction sets, standard I/Os, and support service functionality can be exchanged. Older and slower processors can be replaced with minimal effort with processors built to the same open system standards, but containing current technology. With processor technology doubling its capability every 18 months, the ability to make such upgrades is essential.

The open system concept permits existing software applications to be transported readily across platforms, provided the processors are equipped with common operating systems, host the required program compilers, and have compatible instruction sets and support environment. The availability of the design interface information is essential to permit multiple computer manufacturers to develop the needed compatible environments. The design information can be obtained either through open system standards or through license arrangements with the original system developer.

While not an open system per se, a personal computer (PC) with the DOS operating system and standard bus structure illustrates the utility that computer systems built to common standards can achieve. Several hundred PC-compatible computer types of varying vintage, produced with different processor speeds and memory capacity, can interchangeably run several thousand software applications with minimal difficulty. This is contrasted to limited interchange of software between Apple and PC-compatible systems due to the fundamental differences in microprocessor instruction sets, operating systems, and support environments.

The open system concept can provide the DoD significant benefits by providing the ability to upgrade processors to take advantage of newer, faster, more capable technology while retaining the ability to reuse existing complex software applications. The key in establishing the open system concept is to select the appropriate level for system interface definition. If set too low, the ability to change out technology may be restricted. Standards set too high may provide too little control on system inter- and intracommunications. Successes such as the PC compatibles should be studied to draw guidance for future development of DoD open system standards .

DISA/Center for Standards Objectives

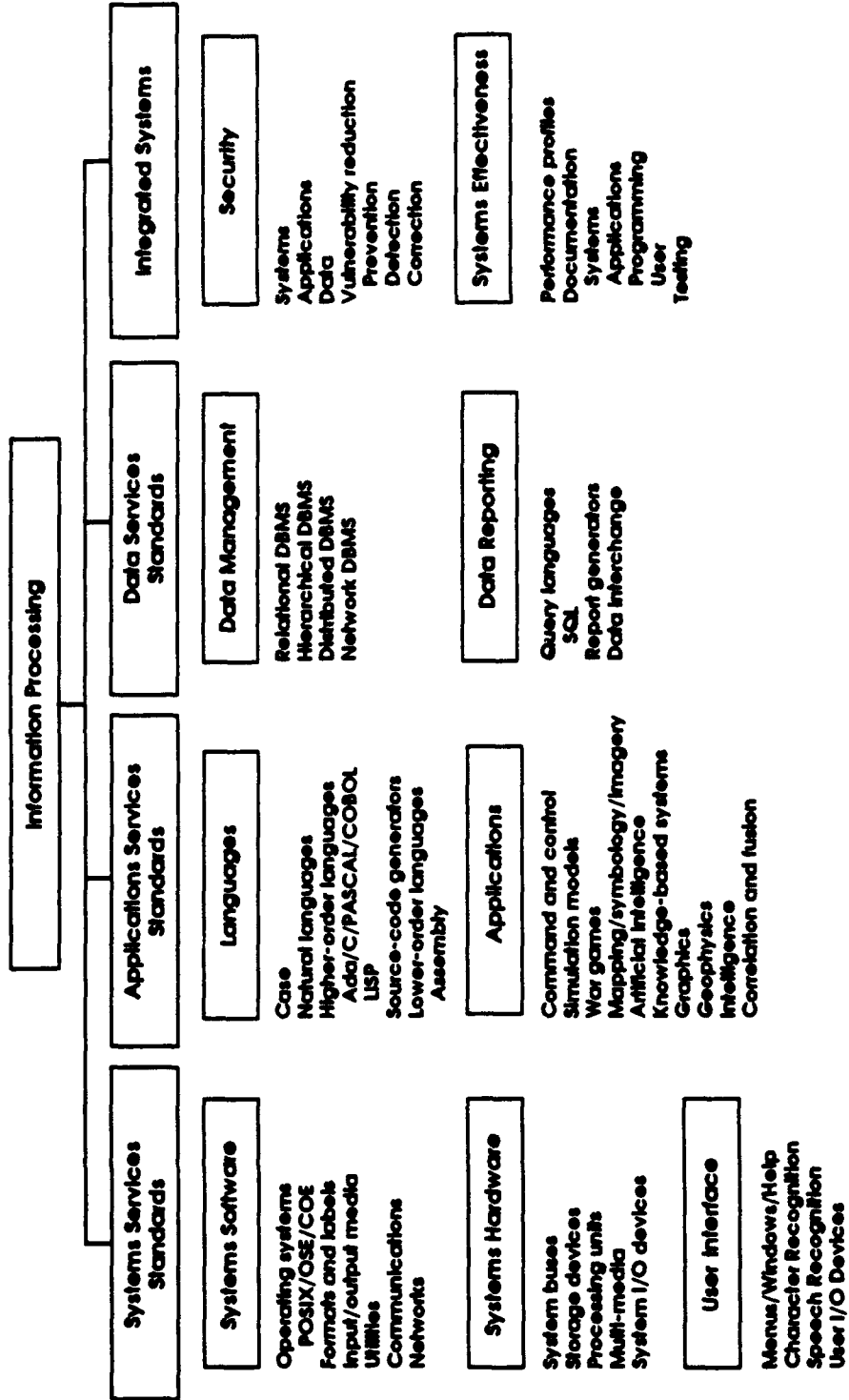
- Establish DoD standards requirements
- Evaluate existing standards
- Provide authoritative DoD voice to standards forum
 - Harmonization
- Manage the development of DoD standards when necessary
- Adopt, maintain and provide access to DoD standards repository
- Assist PMs to properly employ DoD standards

The Defense Information Systems Agency (DISA) Center for Standards (CFS) is responsible for the development and maintenance of all DoD standards related to information processing. This encompasses non-real-time business, C³I, tactical and strategic systems to some yet undetermined degree.

The objectives to be pursued by the CFS are as follows:

- CFS, given input from the services, will determine the need for new or revised standards. The need most often will be driven by technology advances that occur as a result of new system concepts or through obsolescence of existing technology by the creation of new applications.
- Existing standards developed by both DoD and NATO as well as those developed by IEEE, ANSI, SAE, and other federal agencies (NASA, NIST, FAA, et al.) must be evaluated to determine if existing documents in current or modified form, can meet DoD requirements.
- CFS will form a central DoD coordination point for the services and for outside activities on issues related to information processing standards.
- CFS will manage the development of new standards by drafting documents with CFS staff, by coordinating the development with one or more of the Services, or by working with an industry standards committee.
- CFS will maintain a repository for all DoD information processing standards and provide access to all services and to qualified industry.
- CFS will assist System Program Managers (PMs) to assure that the appropriate system and technology standards are applied during DoD systems development and acquisition.

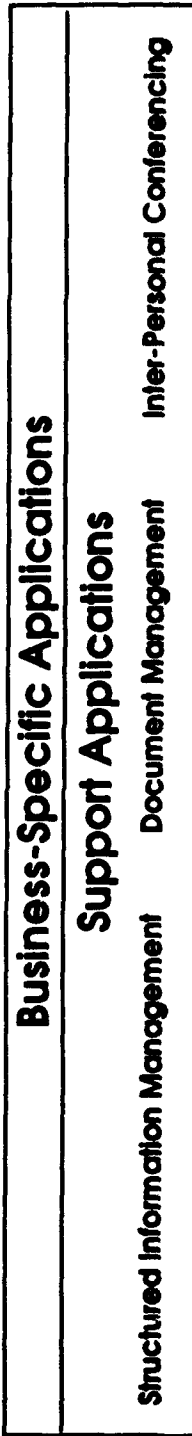
Center for Standards Information Processing Directorate



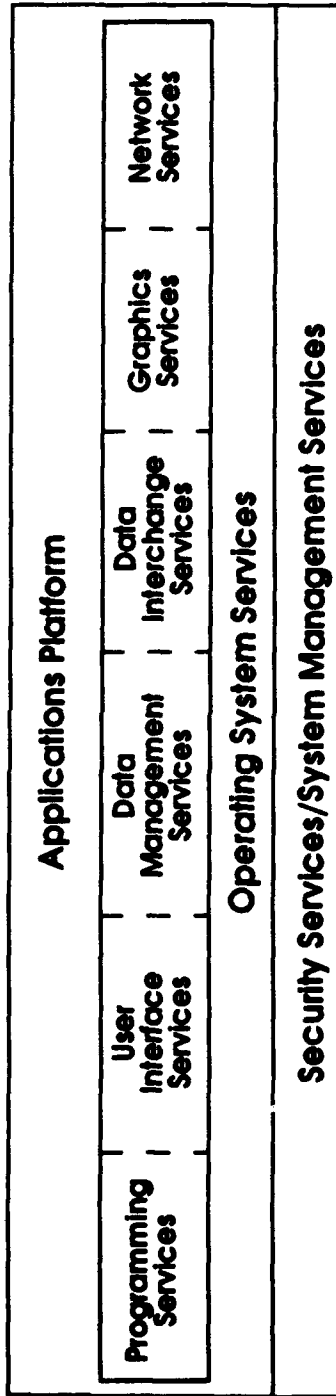
CFS's Information Processing Directorate (IPD) has the responsibility to accomplish the objectives listed in the prior chart. For this purpose CFS/IPD has been organized into four major areas including:

- Systems Services Standards:
 - Systems software such as operating systems, formats and labels, input and output media, utilities, communications, and networks.
 - Systems hardware standards encompass data buses, storage devices, processing units, multimedia, and system numbering devices.
 - User interface standards entail menus/windows, character recognition, speech recognition, and user numbering devices.
- Application Services Standards:
 - Programming language standards to develop application programs and address computer-aided software environment (CASE), natural languages, higher-order languages, (Ada/PASCAL/COBOL/LISP), source code generators, and lower-order languages.
 - Applications standards are developed for command and control, simulation modules, war games, mapping/symbology/imagery, artificial intelligence, knowledge-based systems, graphics, geophysics, intelligence, and data correlation and fusion.
- Data Services Standards: Data Management Standards
 - Data management includes standards for relational, hierarchical, distributed, and network data base management systems (DBMS).
 - Data Reporting forms the second part of the data services area. Standards now being considered encompass structured query languages (SQL), report generators, and data interchange standards.
- Integrated Systems:
 - Security is directed to the hardware components, application programs, data and vulnerability reduction through compromise prevention, detection, and correction.
 - System effectiveness standards provide performance profiles, documentation, and testing guidance.

CIM Reference Model High-Level View



Applications Program Interface



Hardware/Software/External Environment

Complementary to the Center for Standards, the Center for Information Management (CIM) within the DISA organization is charged with implementing the DoD Corporate Information Management Plan. An initial product of the Center for Information Management has been the development of the CIM reference model. Per IEEE Standard P1003.0, a reference model is "an unambiguous specification of a system or problem area that promotes understanding between the system user and the system developer."

The CIM reference model presented above provides a general framework that depicts the interface between business-specific applications (software) through the intervening layers of system hardware/software contained within the computer, to the system external environment (terminals, local area network, and wide area network).

The chart identifies the basics of the model in terms of support applications, applications program interface, applications platform, operating system services, security services/system management services, and hardware/software/external environment. Subsequent charts will examine these areas in more detail.

Having defined the reference model framework, the CIM effort intends to select specific open system standards/specifications that should be used to perform the functionality for each element of the model. Information systems that are configured in accordance with the standards specified by the reference model will be interoperable and applications software will be portable.

The developed CIM reference model applies primarily to business systems and to a lesser degree to C³I systems. It has limited application to tactical and strategic systems. The initial CIM reference model was derived from sources that principally included the services' previously developed DoD Intelligence Information System (DoDIIS) reference model and the NIST applications program profile. The final CIM model resulted from discussions with the Defense Intelligence Agency (DIA), the services, and Defense agencies, NIST, and the Open Software Foundation about the initial CIM model. Future efforts call for expansion of the model to include management and display of multimedia services, distributed computing services support, tactical system interfaces to CIM systems, and system/capacity management services and standards.

Approved CIM Standards

CIM Technical Reference Model 1.1

PROGRAMMING SERVICES

Ada (FIPS Pub 119)

DATA MANAGEMENT

IRDS (FIPS Pub 156)

SQL (FIPS Pub 127-1)

RDA (Future)

GRAPHIC SERVICES

GKS (FIPS Pub 120-1)

PHIGS (FIPS Pub 153)

OPERATING SYSTEM

POSIX (FIPS Pub 151-1)

GNMP (Draft FIPS)

DATA INTERCHANGE SERVICES

ODA/OD/F/ODL (Future)

IGES (GAP Filler)

SGML (FIPS Pub 152)

CGM (FIPS Pub 128)

SECURITY

USER INTERFACE SERVICES

X-Windows (FIPS Pub 158)

P1201.x (Future)

NETWORK SERVICES

GOSIP (FIPS Pub 146-1)

The CIM Technical Reference Model 1.1 defines a number of specific standards that are approved for use with information processing systems being developed in accordance with the CIM reference model. Highlights of these selections include:

- Programming Services: Ada (FIPS Publication 119) forms the initial approved programming language.
- Operating System: POSIX (FIPS Publication 151-1) implementation of UNIX is specified as the operating system of choice. GNMP, currently in draft, will be added when available.
- User Interface Services: X-Windows (FIPS Publication 158) was selected to provide interface with system users. IEEE P1201.x is being considered for future addition.
- Data Management: Information Resource Dictionary System (IRDS, FIPS Publication 156) and Structured Query Language (SQL, FIPS Publication 127-1) form the Initial data management standards. RDA is targeted for future addition.
- Data Interchange Services: Initial Graphics Exchange System (IGES) is the gap filler for graphic image data exchange with ODA/ODF/ODL being considered as the future standard. Standard Graphics Markup Language (SGML, FIPS Publication 152) and Computer Graphics Metafile (CGM, FIPS Publication 128) serving as supplementary data standards.
- Graphic Services: Graphics Kernel System (GKS, FIPS Publication 120-1) and PHIGS (FIPS Publication 153) form initial graphics standards.
- Security: None specified.
- Network Services: Government Open System Interconnection Profile (GOSIP, FIPS Publication 146-1) defines the data exchange protocol to be used by CIM systems. GOSIP defines the standards that will comprise the seven layers of the protocol to be used in data exchange between government information processing units.

Approved CIM Standard

CIM Technical Reference Model 1.2

PROGRAMMING SERVICES

OPERATING SYSTEM
P1003.6 (Security)

DATA MANAGEMENT

DATA INTERCHANGE SERVICES
ED (FIPS Pub 161)

GRAPHIC SERVICES

SECURITY
DoD STD 5200.28
DRS-2600-5502-87
(Compartmented Mode
Workstation)

USER INTERFACE SERVICES
DoD Style Guide

NETWORK SERVICES
IEEE 802.10
ISO 7498-2
NLSP/TLS

The CIM Technical Reference Model 1.2 augments the model 1.1 by the addition of standards in the following areas:

- Operating System: IEEE standard P1003.6 on security operating systems was added.
- User Interface: DoD Style Guide was added as a documentation preparation reference.
- Data Interchange: FIPS Publication 161 was appended to cover Electronic Data Interchange (EDI).
- Security: DoD Standard 5200.28 was added as a reference and DRS-2600-5502-87 was incorporated to address compartmented mode workstations.
- Network Services: IEEE 802.10 added to provide a Standard for Interoperability LAN Security (SILS) and Local Area Network (LAN) key management security. International Standards Organization (ISO) standard 7498-2 and NLSPTLSP were also included.

Approval has been received from DoD, its agencies, and the services for standards selected. The Center for Information Management will review and select additional standards necessary to complete the technical reference model in accordance with requirements of the DoD, its agencies, and the services. Standards developed by commercial industry will be used where appropriate.

Summary of C³I and Business Systems

OSD/services working toward:

- Compliance on standards
 - need to move toward closure
- OSD continuing pressure to accelerate process to create standards where none exist

Significant progress has been made in establishing open system standards for use with DoD business systems, and to a lesser degree with C³I systems. The creation of the CIM technical reference model and associated standards provides an architectural framework to be used to develop or modify business and C³I systems that are interoperable and provide software application portability. Several open areas within the technical reference model structure must be brought to closure. Security, real-time operating system extensions, graphics, and imagery are the major areas to be addressed.

With the technical reference model in place, it is essential that compliance with these standards is secured. It is equally important that products developed in compliance with the requisite standards have their performance verified. Methods and procedures to accomplish these activities need to be defined.

OSD must provide the necessary oversight and pressure to assure that the needed standards are developed in a timely manner and that compliance throughout DoD and the services is maintained with the technical reference model and associated standards.

Tactical and Strategic Systems

- DoD standards
- Service standards

Tactical and strategic warfighting systems consume the major part of the DoD budget investment. The electronic systems can comprise 25-45 percent of the cost of a total weapon system; therefore, any initiative such as adoption of open system standards that can potentially reduce costs is of interest. This section will examine the tactical and strategic weapon system designs of the three services to determine to what extent use has been made of DoD and service electronic/processing standards.

Tactical DoD Standards (Embedded Systems)

Processors

- MIL-STD 1750

Input/Output

- MIL-STD 1553
- MIL-STD 1760
- MIL-STD 1773

Software

- Ada: MIL-STD 1815
- MIL-STD 2167

A number of DoD standards have been developed that apply to the various elements of data processing and are considered applicable to tactical weapon systems. Available standards include:

- Processors: MIL-STD 1750 defines a processor with a 16-bit instruction set and a 20-bit address bus, applicable to general air tactical system data processing.
- Input/Output: MIL-STD 1553 provides a low-speed (1 megabit per second) data bus designed for tactical applications. MIL-STD 1760 and MIL-STD 1773 define more capable tactical data bus systems.
- Software: Ada programming language as specified by MIL-STD 1815 is required to be used for developing both tactical operational software and system support software. Software development must follow the design disclosure, control, and testing procedures defined in MIL-STD 2167.

The next several charts will show to what extent the services' tactical system developments have made use of these DoD standards.

Navy Tactical Ships

Shipboard Standards:

- Processors
 - CP-642B (30 bit)
 - AN/UYK-7 (32 bit)
 - AN/UYK-20 (16 bit)
 - AN/UYK-43/44
 - AN-UY-1/2
- Input/Output
 - 30 bit parallel (full duplex)
 - Standard displays/peripheral devices/symbology
- Software
 - CS-1
 - CMS-2
 - SPL-1
 - Ada: MIL-STD 1815

The Navy has adopted a number of standards to support the development of data processing functions for tactical shipboard weapon platforms. Standards provided include processors, input/output interfaces, and supporting software.

For a number of years the Navy has recognized the need for standards as a cost-reduction technique and, as a consequence, has established families of processors to be used for developing tactical systems. Standard shipboard processors include CP-642B (30 bit), AN/UYK-7 (32 bit), AN/UYK-20 (16 bit), AN/UYK-43/44, and AN/UYK-1/2. Through the Navy's efforts, these computers have found application in a range of shipboard systems, including both real-time and administrative functions.

The Navy has defined a 30-bit parallel, full duplex data bus for shipboard use. In addition, standards have been developed for display systems, peripheral devices, and display symbology.

Source code programming standards applicable to command and control were provided by the CS-1 and CMS-2 languages. SPL-1 provided the Navy a programming resource for signal processing programs. Ada (MIL-STD 1815) is now the Navy standard programming language for both real-time and other software development applications.

AN/BSY-1 Software Summary

- AN/BSY-1 implementation includes:
 - at least 12 different processors
 - utilizing at least 25 different languages
 - requiring support for at least 30 languages
- Relatively small processing granularity (1982 technology)

Software Summary by Language		Processor Types	Software Summary by Function (KSLOC)	
ASM-7	DPE μ Code	AN/UYK-7/43	System Software	671
ASM-43	EDL	AN/UYK-44	Combat Control Tactical	1,168
ASM-44	FORTAN	MC68000	Acoustic Tactical Software	591
ASM-68	Pascal/ASM	MC68020	Microcode	59
ASM-99	Pascal/SPT	T19900	PM/FL-Combat Control	208
ASM-370	Pascal	TMS320	PM/FL-Acoustics	857
AP μ Code	PC/Ada	8085	Support Software	1,022
μ Code	PC/Pascal	29116	Total	4,576
C	PL/1	ASP		
CMS-2	STL/A	DPE		
		LBF		

The AN/BSY-1 is a complex combat system for U.S. Navy attack submarines. The system was developed in the early 1980s and represents technology of that era. The system processes sonar data to identify potential targets and provides target tracking and fire control functionality for selected weapons.

To accomplish these functions, the AN/BSY-1 made use of 12 different processors and utilized at least 25 different software languages. The resultant software contained 4,576,000 lines of code. The architecture took the form of a distributed system capable of automatic and semi-automatic reconfiguration in the event of subsystem failure. An inherent problem with the design was that it resulted in a very long path from sensor to display, which presented both reliability and time delay concerns.

The AN/BSY-1 did make use of several of the Navy standard processors, including the AN/UYK-7/43/44 and the AN/UYS-1, along with the command and control language (CMS-2), the Signal Processing Language (SPL-1), and the current DoD programming language (Ada).

AN/BSY-2 Software Summary*

- AN/BSY-2 implementation includes:
 - at least 9 different processors
 - utilizing at least 10 different languages
 - requiring support for at least 15 language

Software Summary by Language		Processor Types	Software Summary by Function (KSLOC)
Ada-68020	ASM-68020	AN/UYK-44	Accoustics
Ada-68030	ASM-69030	MC68000	C&D
Ada-VAX	ASM-320C30	MC68020	CSS
Ada-Microvax	ASM-56001	MC68030	MT
ASM-68000	ASM-80186	TMS320C30	Non-acoustics (OTH)
		DSP56001	SIM/STIM
		80186	Weapons
		EMSP	PM/FL
		Beamformer	
			Total
			2,763
			Additional reused code
			473

* Data extracted from "Software Development Plan for the AN/BSY-2 Submarine Combat System," 77C950013-C, 28 September 1990.

The AN/BSY-2 was developed by the Navy as the next-generation (1980 technology) combat system for attack submarine application. The AN/BSY-2, which provided relatively small processing granularity along with improved performance over the AN/BSY-1, was able to accomplish this with reduced complexity of both hardware and software. The AN/BSY-2 required 10 different languages, 9 different processors, and 2,763,000 lines of new code, and it reused 473,000 lines of existing code. The AN/BSY-2 architecture remained distributed, and the long data path from sensor to display remained an area for concern. Several of the Navy tactical standards, both hardware and software, found application in the AN/BSY-2 design.

Navy Tactical, Air

Airborne Standards:

- Processors
 - AN/AYK-14 (16 bit)
 - Advanced AN/AYK-14 (32 bit)
- Input/Output
 - MIL-STD 1553A
 - MIL-STD 1760
- Software
 - CMS-2
 - Ada: MIL-STD 1815

The Navy concept of developing a family of processors for weapon systems has extended to tactical air applications. The current airborne standard processors include the AN/A YK-14 (16 bit) and the higher capacity Advanced AN/A YK-14 (32 bit).

Input/output for airborne systems is provided by the MIL-STD 1553 data bus and Aircraft Store Electrical Interconnection System (MIL-STD 1760).

Software standards include the CMS-2 command and control language plus Ada (MIL-STD 1815), the DoD standard.

Air Force Tactical

Aircraft Standards:

- Processors
 - MIL-STD 1750
 - F-22-JIAWG INTEL 80960
- Input/Output
 - MIL-STD 1553
 - MIL-STD 1760
 - PI Bus (F-22 only)
 - High-speed fiber optics (F-22 only)
- Software
 - JOVIAL
 - Ada: MIL-STD 1815

The Air Force makes use of a range of standards for information processing systems contained in tactical and strategic weapon systems. Several of these standards have been developed by the Joint Integrated Avionics Working Group (JIAWG) a joint-service program led by the Air Force to develop electronic standards for the F-22, AX, and RAH-66 aircraft.

Standard processors include the MIL-STD 1750, a 16-bit instruction set with 20-bit address bus microprocessor, and the JIAWG high-performance microprocessor (CAP32A, J89-M2D1), which has a 32-bit instruction set and a 32-bit address bus. The Intel 80960 microprocessor, which meets the JIAWG standard, has been selected for use in the F-22 aircraft applications.

Air Force avionic input/output standards include the MIL-STD 1553 data bus (1 megabit) and MIL-STD 1760, the standard for electrical interface for aircraft stores. The JIAWG backplane data bus standard is the PI bus, a high-speed parallel data bus (50 million bytes per second) being applied to the F-22 aircraft. JIAWG also has developed a high-speed serial data bus standard (J88-N2) operating at 50 megabits and incorporating a linear token passing architecture. For sensor and video information, JIAWG has developed a high-bandwidth, fiber-optics digital system with a bandwidth capacity of 200-400 megahertz.

JOVIAL was a standard command and control programming language previously used by the Air Force to develop operational software for both tactical and strategic weapon systems. Ada, the DoD standard (MIL-STD 1815) is the programming language now used by the Air Force for new system developments for both operational and support software.

Army Tactical

Helicopters:

- Processors
 - LH-JIAWG INTEL 80960
 - MIL-STD 1750
- Input/Output
 - LH MIL-STD 1553
 - JIAWG high-speed fiber-optics bus
 - PI bus
- Software
 - Ada: MIL-STD 1815

Ground Vehicles:

- Processors
 - SAVA Motorola 68020
- Input/Output
 - SAVA VME Bus
 - SAVA fiber-optics bus
- Software
 - Ada: MIL-STD 1815

The Army has selected information processing standards for both aircraft (helicopters) and ground vehicles (tanks and other ground complex armored weapons). The Army has participated in the previously cited JIAWG avionics standards program. In addition, the Army has been developing the Standard Army Vetronics Architecture (SAVA) initiative, which is intended to develop vehicle electronic (vetronics) standards for a range of Army ground weapon systems.

Helicopters:

For helicopters, the Army will make use of the JIAWG high-performance microprocessor (J89-M2D1, Intel 80960). For less demanding applications, use will be made of the MIL-STD 1750 microprocessor.

Avionic input and output requirements will primarily be met with the MIL-STD 1553 data bus. More demanding applications will make use of the JIAWG backplane PI bus. Video information will be distributed with the JIAWG high bandwidth digital fiber-optics bus.

Avionics software for both operational and support programs will be developed using the DoD standard Ada language (MIL-STD 1815).

Ground Vehicles:

The SAVA program has selected the Motorola 68020, a 16-megahertz microprocessor, as the ground vehicle standard. Input/output is provided by the commercial industry's VME standard for system backplane connections. For serial high-speed data distribution, SAVA has selected a token ring architecture capable of 12-20 megabits per second. Ground vehicles make use of the DoD standard Ada programming language.

Tactical and Strategic Applications Summary

- Little common usage of hardware or software standards across programs and services
- Services' systems reflect their organizational autonomy
- Several service organizations are involved
 - NGCR—Navy
 - JIAWG
 - JIAD
 - JSRC-common avionics
 - Open Systems Architecture Working Group
 - SAVA—Army
 - MASA—Air Force
 - AN/AJK-14

Aside from the application of the data bus MIL-STD 1553 and the Ada programming language, there is little common use of hardware or software standards within and across tactical or strategic programs. The joint-service JIAWG initiative to develop avionics standards for current Air Force, Army, and Navy aircraft programs appears to be falling short of its original goals for establishing common hardware and software reuse. The Navy standard computer programs, for both ships and aircraft, have had some successes within their respective target areas. The Army's SAVA program is currently in the early demonstration phase and its application success is yet to be determined.

Success in developing and using electronics standards has been largely limited to within rather than across service programs. This result should not be unexpected since it is consistent with the services' organizational autonomy. To encourage the services to break out of this pattern, the DoD must establish strong management and budget controls to secure cost-saving commonality standards programs.

A number of initiatives addressing electronics standards are currently under way, including:

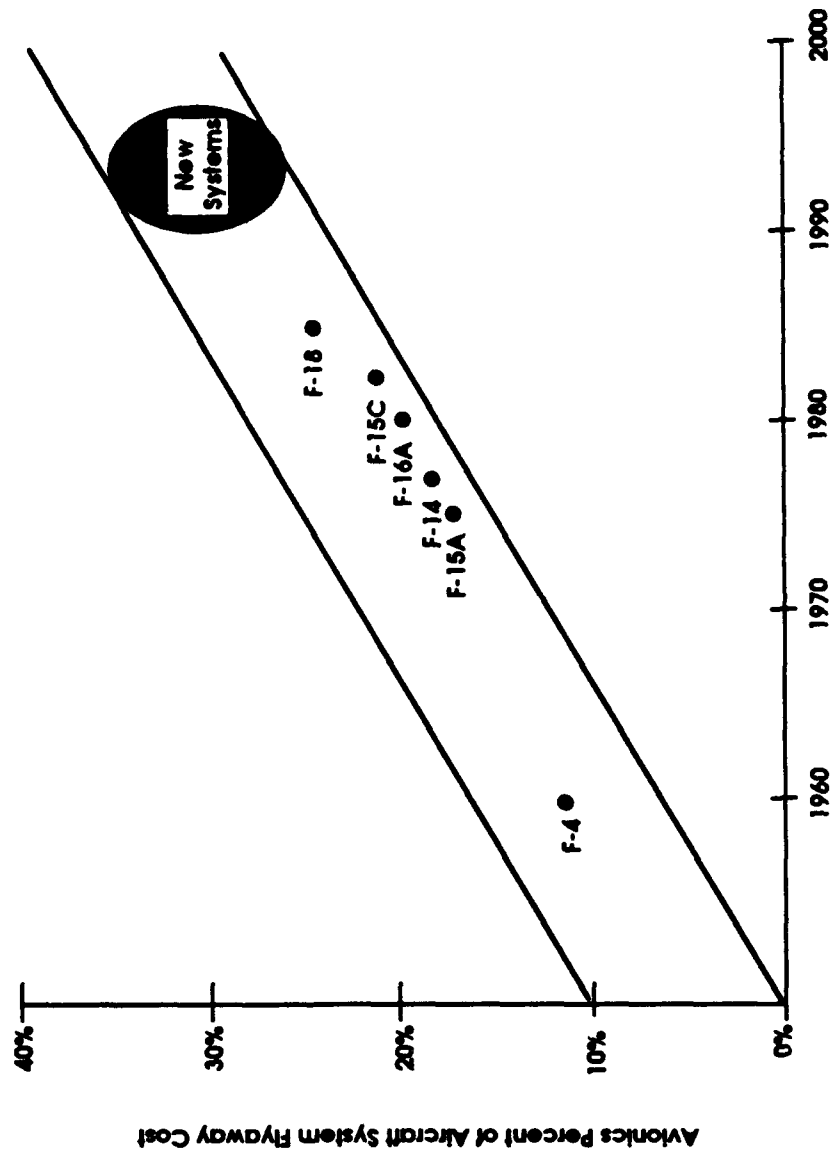
- Next Generation Computer Resources (NGCR): A Navy-led effort to establish standards capable of meeting Navy mission computer resource requirements.
- Joint Integrated Avionics Working Group (JIAWG): A joint-service initiative to develop avionics standards for use with the F-22, RAH-66, and the A-X.
- Joint Integrated Avionics Directorate (JIAD): A joint-service initiative to facilitate joint-service avionics that are affordable, available, supportable, and fully capable of satisfying performance required by operational users. (JIAD was disbanded in March 1993.)
- Joint Services Review Committee (JSRC): A tri-service effort under the guidance of the Joint Logistics Commanders to promote the development of common avionics subsystems.
- Open Systems Architecture Working Group: An initiative to develop open system architecture and specifications for DoD systems.
- Standard Army Vetric Architecture (SAVA): An Army program to develop a standard architecture and common modules to be used to develop integrated electronic systems for Army tanks and other complex armored vehicles.

- **Modular Avionics Systems Architecture (MASA):** An Air Force program to develop alternative avionics architecture comprised of common modules and to determine their cost effectiveness for avionics system upgrades of existing aircraft.
- **AN/AYK-14:** An initiative of the Navy Common Avionics Program Office to develop a family of standard computers for aircraft applications.

Each of these efforts focus on a limited subset of the total tactical/strategic weapons complex. As a consequence, there is some duplication of effort, resulting in the development of similar, but not interchangeable electronic standards (e.g., modules). Stronger DoD management of these technology development efforts could lead to broader-based electronic common standards and could help avoid duplication expense.

Current Developments and Technology Trends

Avionics Cost Trends



This portion of the briefing reviews some of the current technology developments and trends that underlie the use of standards in the formation of complex weapon systems. The rising cost of weapon systems, in association with the budget constraints to be faced by the DoD over the next few years, have created the need to investigate the potential use of technology standards as means to develop and produce systems more cost effectively.

Technology areas that are potential candidates for standardization include computer processors, data buses and input/output (I/O) components, software, and module standards. Each of these areas will be reviewed to highlight standardization status and potential.

U.S. airlines have successfully made use of an array of open system standards to develop cost-effective avionics systems. The scope of this airline experience and lessons learned will be examined.

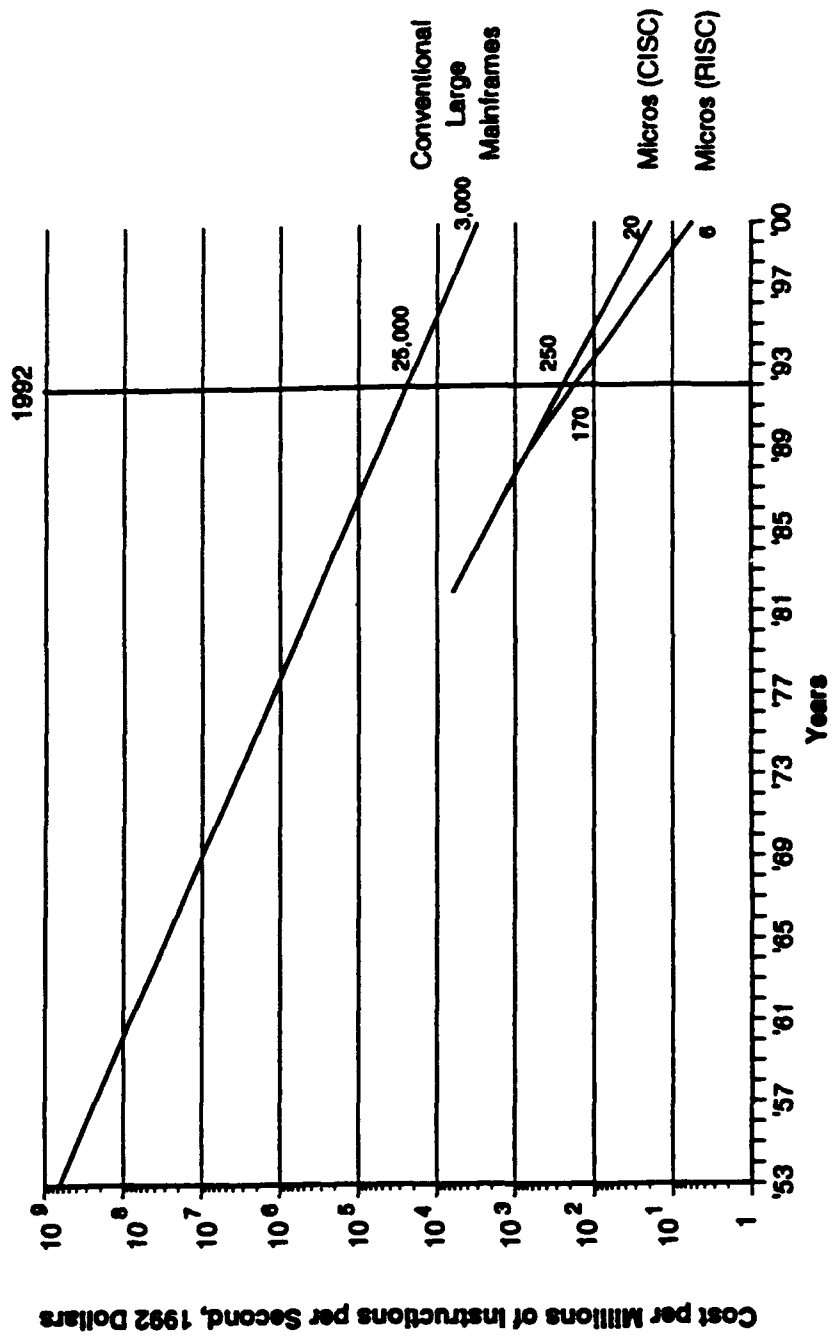
The avionics chart shown previously is repeated here to emphasize the cost magnitude and trends of providing complex modern weapon systems. These trends, when coupled with increasing budget constraints, demand that ameliorative actions be sought.

Aircraft produced to date have made only modest use of technology standards. A previous IDA study² indicated that use of commonality could provide 57 percent savings in development and 2 percent savings in production when standard modules are applied within the core processor for a single aircraft program. IDA further found that, if the standard modules were applied to a follow-on program, the cost savings increased to 77 percent for development and 16 percent for production.

The results of that study, coupled with the reported widespread use of open system standards by commercial industry, suggest that the DoD should investigate the possible greater use of technology standards.

² J. R. Nelson, N. B. Davis, B. R. Harmon, S. R. Shyman, S. K. Welman, and K. L. Wilson, "The Costs and Benefits of Common Integrated Avionics for New Systems," Institute for Defense Analyses, Paper P-2547, June 1991.

Price of Computing Power: Historical and Projected

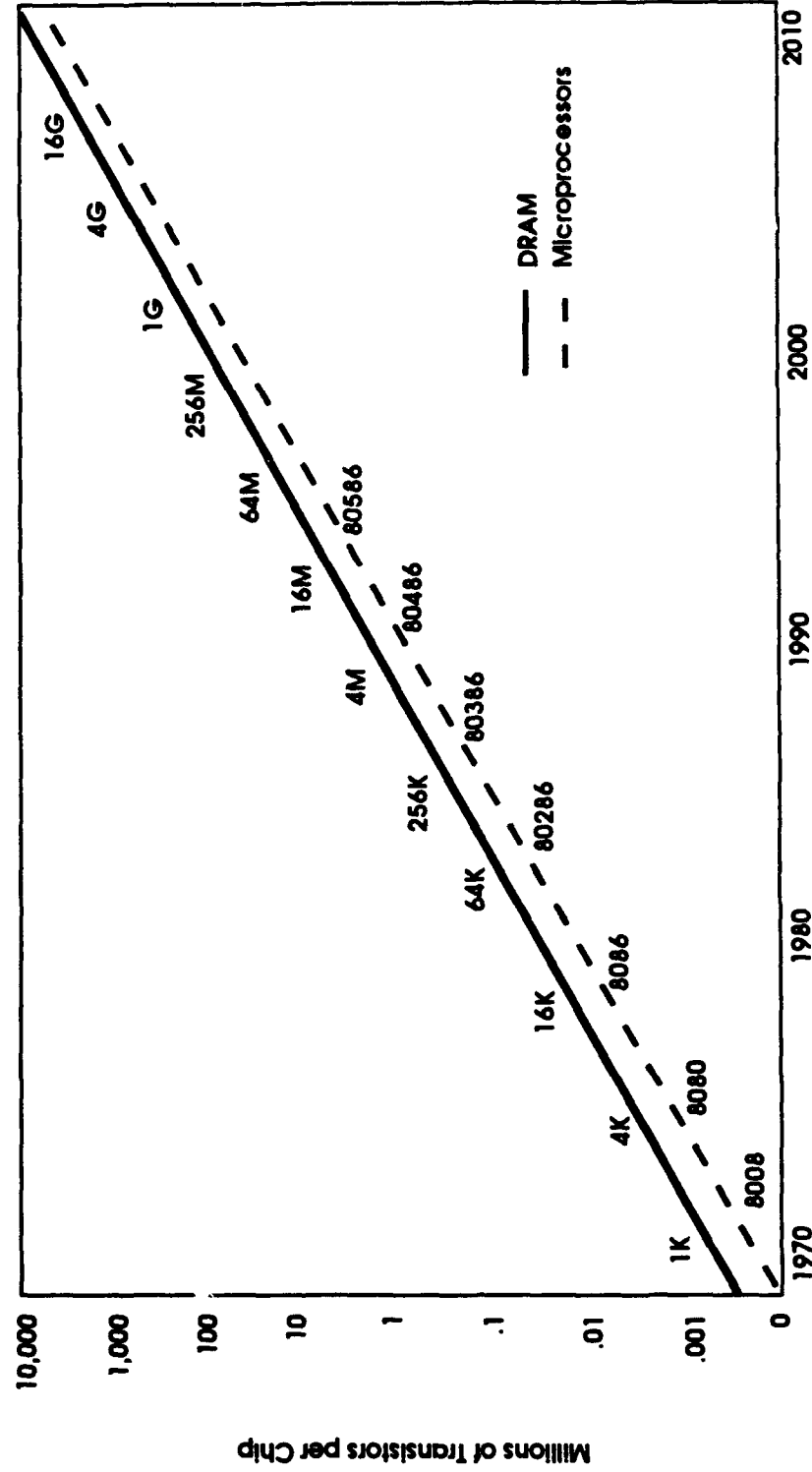


The historical and projected cost trends for conventional large mainframe and microcomputers are revisited to highlight that these costs have been decreasing, counter to the trend exhibited for complex avionics. While decreased computer costs, a key element in current weapon systems, have moderated overall costs, it is clear that additional measures must be taken to stem the rise in weapons cost.

The adoption of open system standards may be the key to reduced system cost. By permitting the use of common module and major reuse of software, significant cost reductions may be achievable. Since the commercial industry, which is driven by economic concerns, has made widespread use of interface standards and common operating environments, it is considered appropriate to explore the potential.

Digital Technology Will Continue To Grow

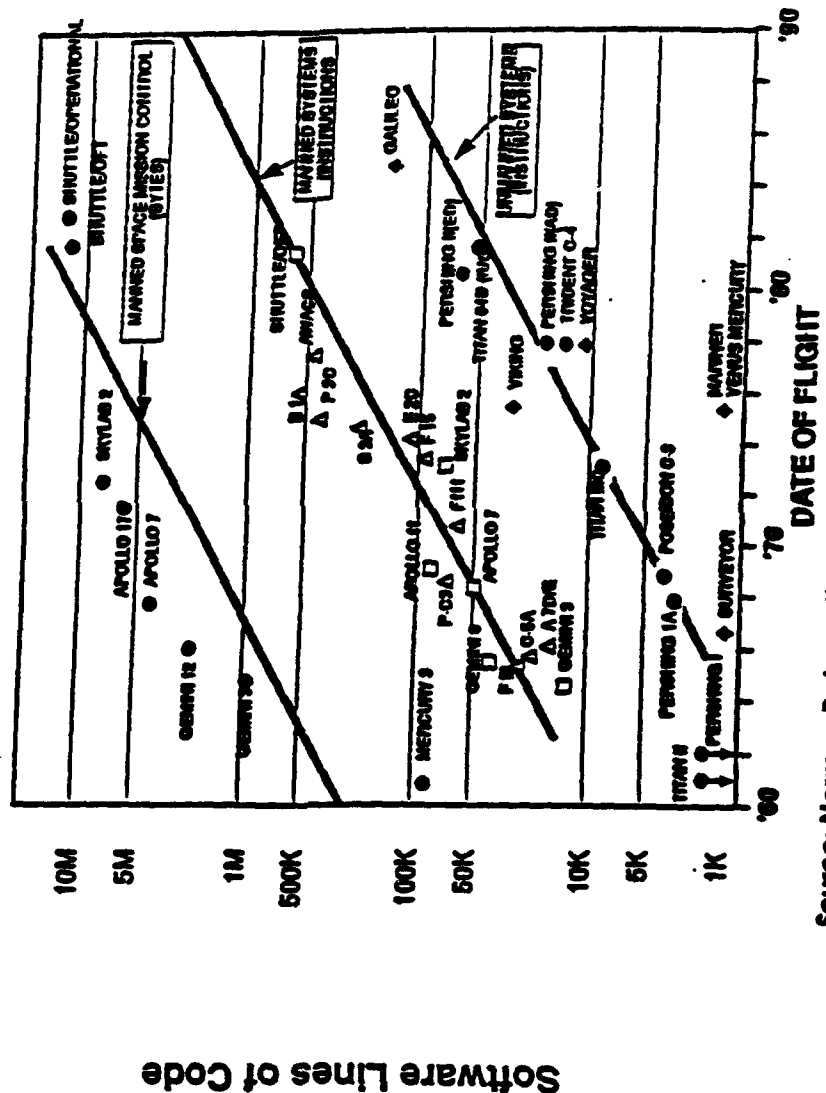
Chip density doubles every 18 months



The growth of digital technology in terms of equivalent transistors per chip is presented for dynamic random access memory (DRAM) and microprocessors. Note that the density, in terms of the number of transistors, doubles approximately every 18 months. Since the cost to process a chip is somewhat independent of the chip contents, the functionality cost of the digital technology has been decreasing proportionally to the increase in complexity growth. This growth experience explains the drop in the cost of computing displayed in the prior chart.

The rise in overall system cost is driven by the major increase in the functionality of modern weapon systems. With the ability to obtain more functionality within limited weight and volume restraints, system designers were able to create significantly greater performance to meet mission requirements. The greater cost stems from the cost to develop, integrate, and test these highly complex systems. The use of standard open interfaces should reduce development cost (both hardware and software) and facilitate system integration.

Software Growth: Aerospace Systems



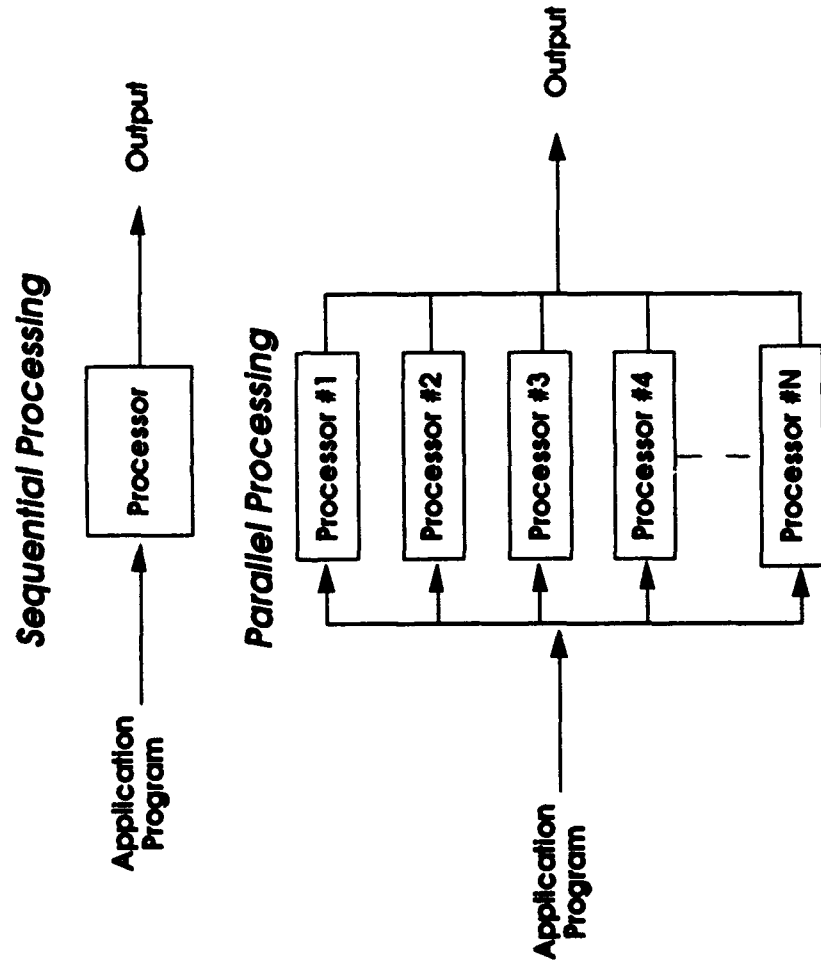
Source: Norman R. Augustine, *Augustine's Laws*, 1983, p. 100

The growth of weapon system performance capability has been accompanied by an exponential increase in the complexity of the software systems they contain. This chart presents the lines of code developed for a range of weapon systems. The lines of code for families of space and weapon systems have increased by roughly an order of magnitude every ten years.

For example, the F-111 aircraft developed in the 1960s contained an estimated 35,000 lines. The B-1, 1970s development software, comprised approximately 500,000 lines. The F-22, developed in the early 1990s, is expected to require 2-3 million lines of code.

With the major investment the services have made in weapon system software, it is essential that it be used to maximum advantage. The adoption of standard operating systems, computer instruction sets, and operating environments can support software reuse and portability.

Parallel Processing



The majority of the processors now used by either the DoD or commercial industry make use of a sequential architecture. This architecture calls for the processing task to be broken down into a logical series of steps. The computer's single logic function proceeds through the steps sequentially, guided by built-in instructions contained in the controlling software, the data being processed, or inputs provided by an operator. The process continues until the analysis is completed and the required output is developed.

The processing speed of sequential computer architectures has been increased in terms of instructions processed per second by approximately an order of magnitude every decade over the past thirty years. While the performance gain is impressive, it has barely kept pace with the demand for ever-greater processing capability in areas such as signal- and image-processing.

Since there is only a single logic function in a sequential computer, the logic function speed of operation controls the system throughput. The processing speed is limited by the physical and electrical properties of the parts used to derive the microcomputer chips and associated components. Switching time, propagation delays, and heat (power) limitations represent the characteristics impacted, and in turn, limit speed.

A logical solution to the computer throughput problem is to replace the single logic function architecture with an architecture that employs multiple logic functions (processors) working in parallel. By adding parallel processors, the throughput is no longer limited directly by logic function speed, but is now controlled primarily by the number of parallel processors.

The parallel processor architecture offers great promise for making major gains in computer speeds. The concept has been proven and has found a range of applications. A major drawback with parallel processors is the difficulty in applying the concept to other than a limited set of problems such as simulations of heat flow or mechanical stress, which entail massive parallel elements in analysis. Lacking are programming languages that can effectively map sequential type problems into a parallel computer architecture. Several efforts are under way by the Defense Advanced Research Projects Agency (DARPA) and commercial industry to solve the parallel processor application problems.

Parallel Processing Developments

- The High Performance Computing and Communications (HPCC) program is developing parallel processor technology
 - Goal: Tera-ops
 - Demonstrated 100 giga-ops
 - Architecture uses scalable building blocks
- Near-real-time operating system for parallel processing also being developed (MACH 2, 2.5, 3.0)

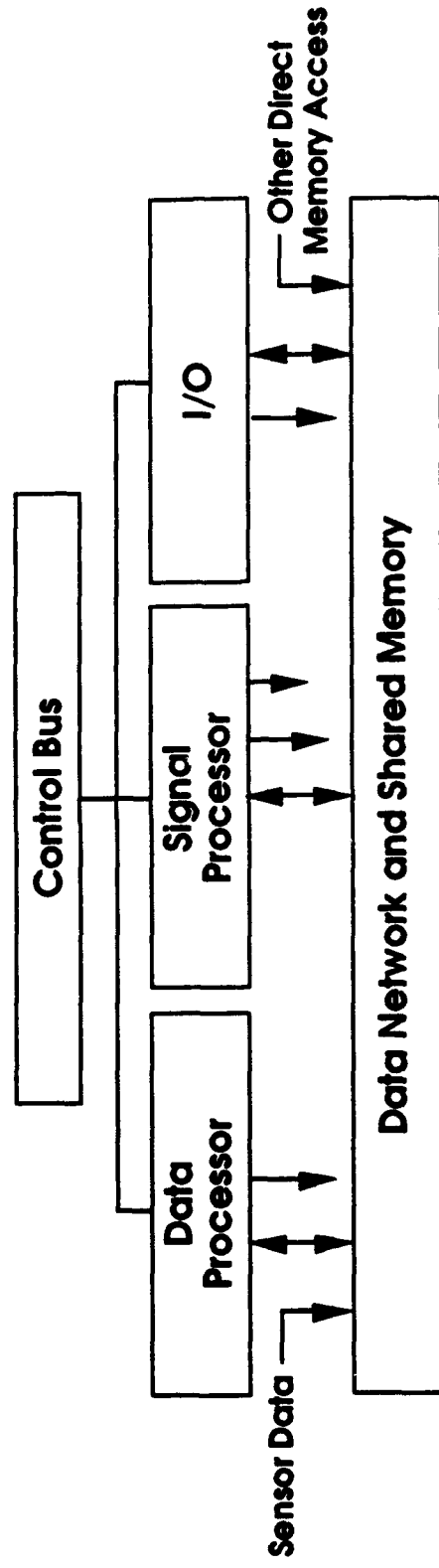
DARPA, as a project under the High Performance Computing and Communications (HPCC) program, is developing a massively parallel processing architecture. The architecture is based on the development of several building blocks (nodes) that can be joined together in a scalable manner to derive alternative levels of parallel computing capacity. The nodes being developed include a processor node, an asynchronous network interface node, and an intercommunication node.

The project expected to demonstrate 10-100 giga (10^9) operations per second in 1992. The ultimate goal is to achieve tera (10^{12}) operations per second by 1996.

A companion DARPA project is the development of new software concepts under the Advanced Software Technology and Algorithms (ASTA) program. DARPA's focus under ASTA is the development of algorithms and tools to facilitate parallel processing. These efforts include the development of the MACH (2.0, 2.5, and 3.0) real-time operating system that will find application for parallel processing.

The development of parallel processing will further accelerate the processing speed growth that has been thus far achieved. The availability of this greater computing power will provide the means to achieve even greater weapon system functional capability. Since the DARPA parallel architecture is based on common building blocks, there is an opportunity to achieve economy of scale through multiple applications of the common units. This can be achieved only if the architecture is implemented using open system standards to describe system interfaces, computer instruction sets, and support environments.

Integrated Avionics Architecture



- Sensor data rates exceed bandwidth of any bus
- Process data at sensor speed
- Must use full-memory bandwidth
 - memory interleave and multiple ports also required
- Control bus usable only for control/low data rates

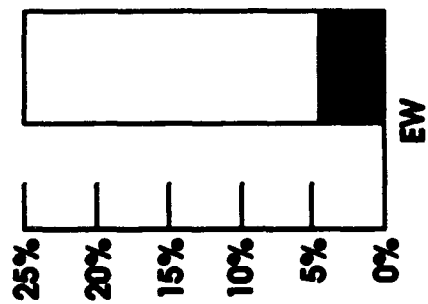
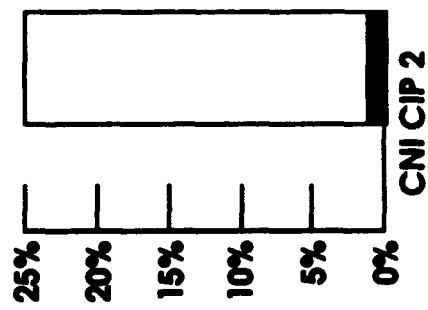
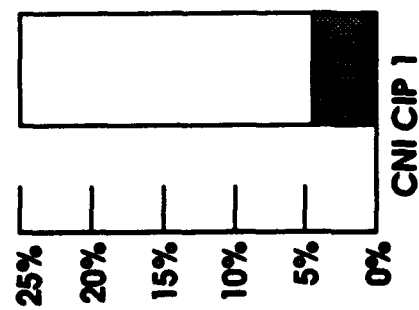
The chart illustrates the application of the data flow network concept previously discussed. In current integrated avionics architecture, the data network composed of electronic matrix switches is tied to banks of computer memory that are shared by both data and signal processors.

Sensor data are routed through the matrix switches into the appropriate memory locations. Since the data rate (400 megabytes per second) generated by the sensors often exceeds the data rates of any existing data bus, the direct connection from the sensor to the memory captures data at sensor speed and avoids the data bus limitation.

The processors, through the matrix switches, can access the sensor information as needed to support mission performance data analysis. To achieve performance levels required, the architecture must use full-memory bandwidth supported by memory interleaving, as well as providing multiple access ports. Conventional data buses (PI bus, or MIL-STD 1553) in this architecture are used only for processor/system control and low data rate input/output.

A key problem is the current proprietary, non-standardized nature of the data flow network.

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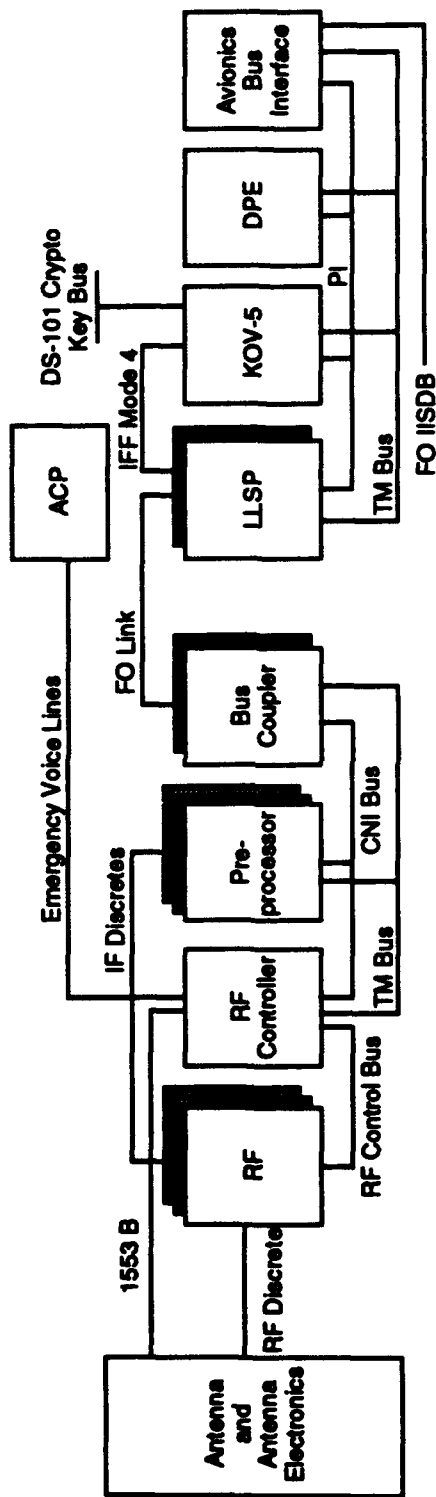


The integrated avionics architecture with the data flow network as discussed on the previous chart has been implemented on the F-22 aircraft. The design integrates the sensor packages [i.e., radar, electronic warfare, and communications, navigation, identification (CNI) in association with two common integrated processors (CIP 1 and CIP 2)]. The CIPs contain both signal and data processors along with bulk memory contained in a data flow network. The JIA WG PI bus is used to tie these system elements together into a working system by providing a path for system control, processed data exchange, and system input/output.

The associated chart presents the PI bus loading that have been recorded for the F-22 application. The total bus utilization is approximately 20 percent with the radar subsystem representing half the total load. The bus loading observed provides ample margin for future load growth and/or handling data bursts. These low performance levels are possible because the data flow network contained in the CIPs handles the direct sensor to memory data flow.

This application clearly illustrates the need for multiple techniques for handling data in high-performance, fully-integrated avionic systems. Selection of open system standards must provide the needed flexibility.

Integrated CNI Interconnection



The integrated CNI program is a long-term Air Force effort to develop an avionics system that combines the previously separate CNI functions. The objectives of this combination was to reduce cost, weight, and volume while improving performance capability and reliability. The program is nearing fruition with design and test models being prepared for incorporation into the F-22 and RAH-66 aircraft.

The associated chart presents the functional flow of the integrated CNI system that has been developed along with the interconnections for key system elements. A major concern in developing the design was to maintain absolute separation between the classified (crypto) CNI functions and the remaining unclassified operations. The design objectives were met by the use of a number of different data bus types that had the requisite speed, low data latency, and/or isolation. The next chart reviews these data interfaces in more detail.

Major Integrated CNI Interfaces

Major interfaces used in integrated CNI:

Interface	Purpose
RF control bus	Control of RF (non-digital) LRMs
CNI bus	Low-latency parallel IF for CNI front-end communications
TM bus	Built-in-test and maintenance
Fiber-optic link	CNI to CIP data links
PI bus	CIP backplane bus

The integrated CNI design incorporates a number of different data buses and associated interfaces. The scope and purpose of each are highlighted:

- **RF Control Bus:** This bus is required to control the radio frequency (RF, non-digital) line replaceable modules (LRMs). Key requirements were low electromagnetic interference (EMI) and deterministic/low latency timing (< 2 microsecond). A unique 8-bit parallel synchronous bus was developed to meet this need.
- **CNI Bus:** A low-latency parallel data bus for signal processing intermediate frequency (IF) discrete was developed. A packetized bus that guarantees access (< 2 microsecond) to high-priority packets was developed.
- **TM Bus:** A test maintenance (TM) data bus was required that was compatible with the JIAWG test and maintenance standard. A six-wire, dual-redundant serial bus operating at 6.25 megahertz was developed.
- **Fiber-Optic Link:** The fiber-optic link provides a nonelectrical connection between the unclassified CNI functions and the classified section. The link used a common ATF/Comanche team design and components. The bus used the same low latency, packetized data structure protocol as employed by the CNI data bus.
- **PI Bus:** The JIAWG standard was used as the backplane data bus for the classified CIP. The implementation was the type 32 (16-/32-bit) operating in the error-correcting mode.

To meet the design requirements in a near optimum manner, the CNI designers had to make use of five different data bus types. It is clear that future data bus standards should be comprised of families of standards to meet the range of needs that will be found in complex highly integrated systems.

Military

COBOL
JOVIAL
CMS-2
Ada

Commercial

COBOL
PASCAL
LISP
FORTRAN
BASIC
PROLOG
C
C++
Simscrip
P/L-1
Assembly

A number of programming languages are in current use by both military and commercial industry. The military has in the past specified that selected standard languages be used for system development programs. In the commercial sector, privately developed programming languages are often documented as industry standards to assure interoperability across compilers supplied by different vendors. The characteristics of a number of the principal military and commercial programming languages are reviewed.

Military Languages:

- **COBOL:** The Common Business Oriented Language (COBOL) resulted from the 1959 work of a group of government users, computer manufacturers, and computer users to develop a language to address business applications. The Navy-led efforts to standardize COBOL, providing the basis for wide-scale application for DoD, other federal government, and industry. COBOL is still in wide usage today. COBOL is also used commercially.
- **JOVIAL:** JOVIAL (J3 and J73) was adopted by the U.S. Air Force as its standard command and control language. JOVIAL later became a DoD interim standard. JOVIAL has been employed in a range of real-time interactive applications. While many JOVIAL programs are still in use, Ada has replaced JOVIAL for new applications.
- **CMS-2:** The CMS-2 language and associated development system is a complete production, delivery, and operations package that became widely used by the U.S. Navy for command and control software. The CMS-2 compiler processes programs developed in either CS-1 or CMS-2 source languages, generating code for CP-642, L-304, ANUYK-7, and other standard Navy computers.
- **Ada:** Ada is the current DoD and other federal government standard programming source language (MIL-STD 1815). Ada is a high-level structured language similar in nature to the commercially developed PASCAL language. Ada recently has found use in DoD embedded weapon system applications and is also being used by commercial industry. There is little usage of Ada in DoD business applications at this time.

Commercial Languages:

- **COBOL:** COBOL, described above, is also used commercially.
- **PASCAL:** A structured high-order language developed in the early 1970s. PASCAL has become the basis for several derivative languages.
- **LISP:** List Processing (LISP), a special-purpose language developed in the 1960s, finds application in artificial intelligence programming.

- **FORTAN:** Formula Translation (FORTRAN) language was introduced by IBM in 1957 as a programming tool for mathematical problems. FORTRAN program statements are very similar to mathematical notation. Industry groups have developed standard editions of FORTRAN that have been widely used by both government and industry.
- **BASIC:** Beginners All-Purpose Symbolic Instruction Code (BASIC) is a simplified mathematical-oriented programming language developed by Dartmouth College in 1964. The language found initial application on time-sharing computers. More recently, it has been used on personal computers. Through its use of English-language commands, it can be quickly learned and applied. Wide usage of the language has been made by both government and industry.
- **PROLOG:** Programming Logic (PROLOG) is a list processing language similar to LISP that finds application in artificial intelligence. The language was developed in France in 1973.
- **C:** The C language was developed by Bell Labs in the mid-1980s. The language consists of a series of functions that run very efficiently. Programs written in C may be compiled into most machine languages. Because of the inherent flexibility and efficiency, C language is becoming increasingly popular in industry as the language of choice. DoD and other government agencies have made use of the C language.
- **C++:** An object-oriented version of the C language created by Bjaime Stroustrup. Object-oriented programming facilitates the reuse of code, greatly improving programmer productivity. C++ produces source code that can be processed by C compilers. C++ has found significant application in industry and government. Standardization of the language and compilers is needed.
- **SIMSCRIPT:** A special-purpose simulation language compatible with FORTRAN. Simscript can be used to evaluate dynamic processes such as flight control system response. Simscript is used by both government and industry.
- **P/L-1:** Programming Language One (P/L-1) was developed by IBM and released in 1966. P/L-1 was intended to serve as a professional programmers language for both business and scientific applications. It is considered bulky and difficult to learn.
- **Assembly:** Assembly languages are unique to the instruction set appropriate to the processor contained within the computer system. Assembly language consists of mnemonic codes that represent the various instructions for processor operation. Programming in Assembly requires the programmer to specify the address of the data, the instruction to be applied and the address of the location to place the result of the operation. Assembly coding is generally restricted to critical real-time applications that must operate very efficiently.

As can be seen, a wide variety of programming languages are available to meet the range of application requirements. No single language can effectively meet all user's needs, although Ada is more standardized than other modern comparable languages.

Real-Time Executives

- Compiler executives
- POSIX—key to open systems
 - Non-real-time
 - Real-time not defined yet
- NTDS Exec-CP-642B
- Common Control-AN/UYK-7
- SDEX AN/UYK-20/AYK-14
- APEX-Airlines
- MACH (DARPA)

An executive is the portion of a computer operating system that directs the dynamic flow of data processing operations. The executive assigns resources, handles interruptions, and directs program execution in accordance to the compiled operational program, the data provided, and operator instructions. The power and efficiency of the executive is critical for real-time high-performance systems such as aircraft and other complex weapon systems.

POSIX (Portable Operating System Interface Unix) is a government industry effort to develop a set of standard interfaces for program executives based on Unix. This standardized interface would facilitate application portability. IEEE standard P1003 covers a range of POSIX interface standards that have been or are being defined. IEEE standard P1003.4/4A/4B and .13, which address real-time applications, are still under development and not fully operational at this time. This is a critical need that should be given top priority.

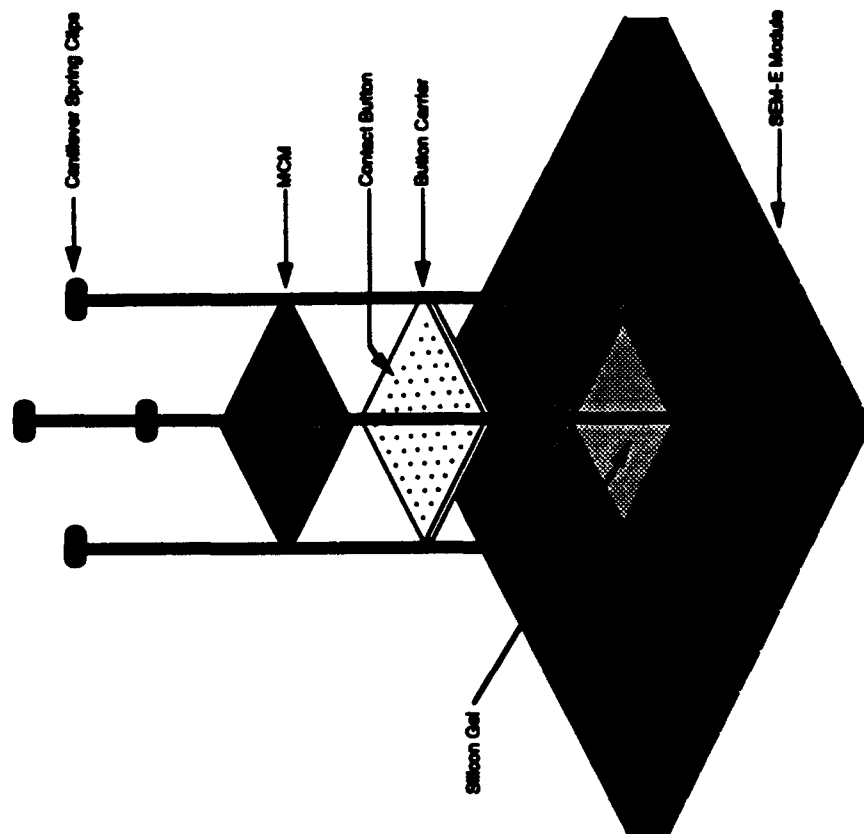
The Navy, as part of its standard computer program, has developed several real-time systems, including the Navy Tactical Data System (NTDS) Exec-CP-642B, Common Control-AN/UYK-7, and the SDEX AN/UYK-20/AYK-14. These real-time systems have found application largely within the Navy.

U.S. airlines, through their Airlines Electronic Engineering Committee (AEEC) and as part of their modular avionics development, are defining application software interfaces to be contained in Application and Executive (APEX) software. APEX will handle program initialization, communication, memory management, task/process manager, interruptions, exceptions, and languages (Ada, PASCAL, or C). Through APEX standard interfaces, software programs developed for avionics applications will be transportable across aircraft and avionic suppliers.

DARPA has an initiative under way to create real-time operating systems to support their computer technology development efforts. The MACH 2.0, 2.5, 3.0 operating system series, now under development, focuses on providing trusted real-time capability.

The availability of a standard fully capable, real-time operating system that can meet the response time and latency requirements of avionics and other complex weapons, is a critical need. The ability to define standard software interfaces that will permit operational software to be reused can provide significant savings from both acquisition and support costs.

Solder-Free Interconnection



Modules used in current avionic systems frequently are built using several individual circuit chips. Modules constructed in this way are known as multi-chip modules (MCMs). The individual MCMs are approximately 1.5 inches square and can contain significant circuitry. The MCMs can be mounted on a SEM-E module board (5.9 x 6.8 inches), which can accommodate 9 MCMs per side for a total of 18 MCMs per module. For example, the Comanche Data Processor Module, which operates at 15 million instructions per second (MIPS) and has 8 megabytes of random access memory, was derived from 14 MCMs placed on a single SEM-E module.

Because of the chip complexity, a typical MCM has 360 connections that must be welded or soldered. Consequently, MCM replacement is extremely difficult, requiring factory conditions to accomplish. To solve this problem, a solder-free interconnection (SFI) method for MCMs is under joint development by several U.S. manufacturers. The SFI method is illustrated in the associated chart.

Under the SFI method, the MCMs are mechanically held in place by screws and cantilever clips at each of the corners. Electrical connection is made by gold-plated wire randomly woven to form contact buttons that are pressed between the MCM and the underlying circuit board at the proper locations. A button carrier assures that the contacts remain in the proper location. Silicone gel is applied to prevent contamination of the contact area.

SFI has undergone most of the appropriate environmental tests (thermal cycling, vibration, humidity, salt, fog, and shock) required by high-performance avionics. Although testing is not yet complete, the expectation is that SFI will meet all requirements. Early results have indicated that SFI has thermal properties superior to conventional construction methods.

SFI will provide the means to easily repair MCM. Early data has shown that repair may be accomplished in five minutes (remove and replace an MCM). Since SEM-E modules individually may cost from \$20,000 to \$50,000, repair is essential. Further, these repairs can be accomplished in the field with only a few common tools.

SFI also opens the door for technology upgrades for fielded systems. This capability can provide the means to easily replace a processor chip with improved technology, provided it made use of a standard instruction set and operating environment.

Airline Avionic Standards (ARINC)

AEEC is the airlines' equivalent of JIAWG:

- The airlines are now embarked on developing an Integrated Modular Architecture (IMA)
 - Line Replaceable Modules
 - APEX Operating System
 - Standard Module form factor
- Chaired by ARINC
- Basis for success:
 - Driven by economic concern of airlines (owners/operators)
 - Focus on interface control and interchangeability
 - Maintain competition; suppliers recover their R&D costs in equipment sales
 - Warranty and design improvements (if needed) part of process

The Airline Electronic Engineering Committee (AEEC) is a group comprised of airline engineering representatives who work together to develop form, fit, and function (F³) specifications (standards) for airline avionics. The AEEC is chaired by Aeronautical Radio, Incorporated (ARINC), a communications company jointly owned by the airlines.

Upon recognizing a need for new or replacement avionics equipment, AEEC conducts background studies through a system of subcommittees that focus on various technology areas. Inputs are solicited from avionic manufacturers, airframe companies, and other experts. With this technical data base, an "ARINC" specification is formulated by the subcommittee for approval by the airlines. The airline process is analogous to the DoD JIAWG specification development process.

The resulting specification is an open document available to any interested organization. Manufacturers who choose to supply the avionics market will develop a product at their own expense that complies with the ARINC standard.

The AEEC process has been functioning for over 40 years, providing the airline industry a full range of avionic and supporting specifications and design guidance. Over the past 15 years, the AEEC has upgraded its avionic technology to an almost completely digital basis.

Recently, the airlines have embarked on forming an Integrated Modular Architecture (IMA) that will focus on using the latest high-speed computer technology to form a highly integrated avionics architecture for aircraft. The architecture features line replaceable modules based on a standard form factor (7.2 x 14.5 inches). To address software transportability, the AEEC is developing an operating system interface identified as Application and Executive (APEX). An avionic computer system to be offered to the airlines must have an operating system that meets the application interfaces specified in APEX.

The ARINC specifications are not mandated for use by the airlines. Rather, each airline is free to select equipment of its own choice. However, the equipment developed (at manufacturer's expense) to ARINC specifications, through its focus on interface and functional definition, have yielded equipment that is performance- and cost-effective. Airline equipment are often acquired with long-term warranties that provide product improvement feedback plus control of support cost. The success of ARINC's specifications process has been driven by the underlying economics and value.

Processing Common Modules

Core Processing:

	<u>F-22</u>	<u>RAH-66</u>
Modules	102	56
Module Types	13	12

New way of doing business:

- Prime Contractor responsible for common module development and application across subsystems within the platform
- Past practice was for prime contractor to allow total subsystem responsibility to be under a subcontractor
 - INTEL 80960/MIL-STD 1750 microprocessors
 - Single software environment/compiler for prime/all subcontractors
- Integrated Product Teams
 - both industry and government
 - concurrent engineering approach

The F-22 aircraft and the RAH-66 helicopter programs are two current major weapon system developments. Under these programs, the prime contractors have the responsibility for common module development and application across their programs. This differs from the past, where subcontractors were permitted full latitude in their design, provided they met performance, interface, weight, and volume specifications.

The associated chart presents the commonality results achieved for the core processing function by the two programs. The F-22 core processor requires 102 modules, which were derived with only 13 module types. Core processing for the RAH-66 is comprised of 56 modules consisting of 12 module types.

The two development programs are part of the JIAWG initiative and will make use of the designated JIAWG standard microprocessors (e.g., Intel 80960/MIL-STD 1750). A single software development environment/compiler will be used by both prime and subcontractors, greatly facilitating software development, test, and support.

The commonality achieved should provide significant cost saving for research and development, production, and support and operations. These two programs can serve as a source of lessons learned for future program commonality/standards applications.

The use of integrated product teams show promise for future systems development, production, and operating and support improvements.

- **Backplane data buses**
 - NUBUS
 - SBUS
 - MULTIBUS II
 - VME
 - PI bus
 - Future bus+
- **Data flow networks**
 - Cross-bar switching
 - No backplane buses
- **High-speed data buses**
 - Fiber-optics
 - Copper FDDI
 - SafeNet

Data buses are key elements of current highly integrated weapon system electronics. Data buses provide common pathways used to connect modules within a subsystem (backplane parallel data buses) or as a means to interconnect subsystems via serial data (both low and high speed). Complementary to backplane data buses, data networks and high-speed (serial) data buses are available to interconnect subsystems.

Backplane Data Buses:

Backplane buses provide the means to transmit complete data addresses and multiple data bytes over a number of parallel interconnecting lines simultaneously. The parallel operation provides much greater data rates than could be achieved with a serial bus for comparable speed semiconductor technology. The greater speed for backplane data buses comes with the cost of a greater number of interconnecting lines and more costly connectors. Representative current backplane data buses include:

- NUBUS: Defined by IEEE standard 1196, NUBUS was developed by Texas Instruments. The design provides a 32-bit address and 32-bit data widths. It operates in a synchronous mode at a maximum data rate of 37.5 megabytes per second. Parity is available as an option.
- SBUS: A backplane bus capable of operating between 55 to 115 megahertz.
- MULTIBUS: Specified by IEEE 796, MULTIBUS was developed by Intel. Address and data widths are 32 bits. Operation is synchronous with a maximum data rate of 40 megabytes per second. Parity operation is mandatory.
- VME: IEEE standard 1014 describes the VME bus design developed by Motorola. The address width is 24 bits (primary) and the data width is 16 bits (primary). The operation mode is asynchronous with a maximum data rate of 57 megabytes. Parity checking is not available. A modified version of the VME bus has been selected by the Army SAVA program as the recommended data bus standard for ground vehicles.
- PI bus: Selected as the avionic backplane data bus by JIAWG, PI bus provides dual, 16-bit paths operating at 25 megabytes per second and provides error detection and correction features considered vital for avionic applications. PI bus has found application in the Air Force F-22 program.
- Futurebus+: Described by IEEE standard 896, the data bus was developed by National Semiconductor. Primary address and data widths are 32 bits. The operation mode is asynchronous with optional parity. The maximum data rate is 117.6 megabytes. Futurebus+ has been adopted as the standard data bus for the Navy's Next Generation Computer Resources (NGCR) program.

Data Flow Networks:

The data rates required to pass sensor data to signal processor memories for selected weapon systems exceed the capacity of current backplane data buses. Data flow networks are being developed to solve this problem. The data flow network is composed of a computer-controlled electronic matrix switch that can provide a direct path from a specified sensor input to a designated memory block. This permits direct memory loads at very high data rates. Designs that incorporate the data flow networks use the backplane data bus to promulgate control messages among the subsystem modules.

High-Speed Data Buses:

High-speed data buses that employ serial transmission of data are used to interconnect the subsystems. Backplane data buses typically are limited to transmitting data a few feet because of electrical limitations. Serial buses have electrical properties that permit data to be sent several hundred feet.

An example of a serial data bus is the standard developed by JIAWG that uses a linear token passing architecture and transmits data at rates up to 50 megabits per second. The JIAWG data bus system makes use of fiber-optic cable as the interconnecting media.

Fiber-Optic Distributed Data Interface (FDDI) specification has been developed to provide a standard for creating fiber optic communication networks based on a ring architecture. Efforts are now under way to develop an FDDI system using copper wire twisted pair operating at 100 megabits per second.

SafeNet is a serial data bus developed by the Navy's NGCR program as a variant of FDDI. NGCR has defined SafeNet-1, which operates at 16 megabits per second, and SafeNet-2, which has a data rate of 100 megabits per second.

Technology Trends Summary

- Standards must take advantage of, not inhibit technology growth
- Families of data bus standards are needed to meet the requirements of fully integrated real-time systems
- Development of fully capable embedded real-time operating system needed to:
 - Support operational requirements
 - Permit software reuse
- Solder-free interconnect offers potential for module repair and P³I upgrades

Technology Growth and Standards:

Digital technology has been growing rapidly and this growth shows no immediate sign of near term abatement. Standards can have the effect of freezing technology at the point in time when they are issued. Considering the time it often takes to develop and select a standard, it runs the risk of either being or soon being obsolete at issue. To avoid this problem, it is paramount that technology standards focus on higher level interfaces, not detailed underlying technology.

It is important that technology lead standards, not the reverse. The very high-speed integrated circuit (VHSIC) initiative is an example where a successful new technology program drove technology and standards implementation.

Families of Standards:

From the review of several avionic system designs, it is clear that no single data bus standard can meet the requirements for all weapon applications. Rather, families of standards must be available that have the spectrum of characteristics necessary to satisfy the range of needs for current real-time high performance weapon systems.

Real-Time Operating Systems:

A critical need identified by the survey was the requirement for a fully capable real-time operating system that could meet the needs of avionic and similar weapon system applications. Although work is currently underway (POSIX and MACH), it is important that proper funding and priority be given this work. Availability of the proper operating system standards will have payback in terms of application software reuse and form the ability to upgrade fielded system with current faster more capable technology.

Solder-Free Interconnection:

The SFI method now under development shows promise for providing the means to repair modules MCMs in the field, providing significant support cost savings. Further, SFI will open the way for field upgrades or pre-planned product improvements (P³I) to take advantage of new, faster, more capable technology. It is important that the proper form factor and interface standards be put in place to support this process.



Conclusions and Recommendations

Conclusions

- No single universal solution for all applications
- Technologies continuing at a fast pace
 - Technologies lead standards
 - Leadership shifting to commercial industry in basic technologies
 - DoD still pursuing integrated systems approaches and manufacturing technologies
- Open systems will:
 - Allow more competition within industrial base
 - Allow system upgrades with advancing technologies
 - Not prevent proprietary designs
 - Expand proliferation of processors
 - Affect logistics and maintenance
 - Need to solve logistics and added maintenance at the tail end of life cycle
 - Need to solve fault tolerance-error detection and correction
- Many organizations attempting to solve pieces of complex problem (and resisting solutions not their own)
 - Organizational focus required

No Universal Solution:

The survey team has concluded that there is no single universal solution or standard within an individual technology area or open system architecture that can meet all application needs, e.g., data bus, microprocessor and/or programming language. Rather, families of standards are needed that can meet the range of requirements that are likely to be found in high-performance weapon systems. This position was supported by a number of industry representatives, as well as by the examination of system designs by the study panel.

Technology Growth and Standards:

Technology has grown at a dynamic pace over the past 40 years. For example, data processing throughput as measured by instructions processed per second has increased by a factor of 10 each decade. To avoid obsolescence, it is important that technology development programs lead and foster standards. The standard-setting process must clearly recognize this need to avoid technology and thus standard obsolescence.

Most early technology growth (1950s-1970s) was sponsored by the U.S. government (DoD and NASA). However, in the 1980s and 1990s, technical leadership has shifted to commercial industry. With the DoD accounting for roughly 10 percent of the total digital electronic equipment market today, it is not likely that this trend will be reversed.

Open System Concept:

An open system is generally defined as a system that implements sufficient open (non-proprietary) specifications for interfaces, services, and supporting formats will enable properly engineered components to be utilized across a wide range of systems with minimal changes and to interoperate with other systems in a style that facilitates portability.

The open system concept applies to both hardware as well as software elements.

A direct result of open system specifications is the introduction of more competition in the industrial base leading to lower system acquisition, operating, and support cost. However, the use of open systems does not preclude the development of selected proprietary designs for some elements of a system.

An open system promotes development of new technology (hardware or software) and because interfaces are defined, new technology may be readily introduced into existing systems to achieve improved performance. For example, with properly specified interfaces, instruction sets, and operating environments, it is expected that the number of processors that are plug-compatible for high usage microprocessors would increase.

Open system can impact the logistics and maintenance by providing the common interfaces to permit support equipment to be used across system types. Replacement parts for many items could be acquired from several vendors rather than sole sourced to the original manufacturer. Since logistics and maintenance occur later in the system life cycle, they are often affected by technology choices made during engineering and manufacturing development. Quite often, the choices are made without regard to the potential operating and support cost consequences.

Organization Focus:

Data bus technology is an area receiving considerable attention by several standards efforts (NGCR, JIAWG, and SAVA). Several of the data bus standards being considered (Futurebus+ and VME), while providing high data rates do not currently provide fault tolerance, error detection, or error correction. These characteristics are essential for high-performance real-time systems whose operation can affect safety of life and high value property. It is important that the standard efforts solve the fault detection and correction problem.

The survey team determined that many organizations are addressing the complex standardization problem (e.g., NGCR, JIAWG, JIAD, DISA, CIM, SAVA, COPERNICUS, and MASA.). However, each of those organizations is working on some element of the problem with little coordination with others. In addition, the organizations often resist solutions not fostered within their own organization (the so-called not-invented-here syndrome). Clearly, there is a need for organizations to work toward cooperative and coherent DoD-wide technology standards.

Additional Conclusions

Commercial Technology will:

- **Provide cost-effective applications to many C³I and business systems**
- **Have limited application "as is" for real-time tactical weapon systems**
- **Not be suitable for some DoD environments**

Commercial information technology addresses a broad range of data processing and data communications issues. Open system standards have been documented by organizations such as IEEE, CCITT, and ISO. This commercial technology base has and will continue to be used by the DoD for business and some C³I applications. For example, the CIM reference model developed by DISA draws heavily upon commercially developed software, data processing, and communications standards.

However, the commercial technology base is not, for the most part, applicable as it now exists to real-time applications. Although commercial industry has real-time requirements, the performance levels typically are much less demanding than military weapon system needs in terms of performance and/or environment. As a consequence, real-time technology remains a need that will continue to be addressed in DoD.

Recommendations

- OSD organizational focus required
- OSD should take stronger role in
 - Setting standards policy
 - Approving standards
- DoD should support standards but not mandate one set of standards
 - No single universal solution for all applications
 - Families of standards cover broad scope of applications
 - Provide for infusion of new technologies while still fielding capability
- DoD should work with commercial industry to apply/influence common standards where appropriate
 - Lead to more affordable programs
 - Leverage commercial components where feasible/practical
- Advanced technology demonstrators and prototype test beds needed even more to ensure applicability and interchangeability

OSD Organization Focus:

A number of DoD and other government organizations are working on technology standards issues. To be effective, it is essential these efforts be focused and directed in a logical and coherent manner to assure compatibility and to avoid duplication and the not-invented-here syndrome.

OSD Role:

To assure that the proper focus and coordination is achieved, OSD should take a stronger role in both setting standards policy and in approving key standards that will affect all of DoD.

DoD should support standards, but should not mandate a single set of standards for all applications. It was clear from the survey that some requirements cannot be met by a universal solution. Rather, families of standards are needed to cover the broad scope of applications likely to be encountered in the full range of DoD systems. It is important that standards be structured in such a way that new technology may be inserted while compatibility with fielded systems is retained.

Commercial Standards Leveraging:

Due to the scope of commercial industry electronic and data processing technology developments, it is important that the DoD take advantage of these developments. This can be best accomplished by working with industry to advise them of DoD needs so that they may be considered during technology and standards development. Securing commercial standards that reflect DoD needs will clearly lead to more affordable programs by leveraging commercial technology where feasible and practical.

Advanced Technology Demonstrations:

DoD advanced technology demonstrations and prototype test beds are needed to address those unique DoD system technology areas that will not be addressed by the private sector. Such programs may be directed at developing new technology, adopting and modifying commercial technology, and validating new system concepts.

Recommendations (continued)

- Life-cycle implications must be addressed to determine full impact of commercialization on military user
- Accelerate open system architecture standards
 - Parallel processing
 - Real-time operating system
- Make DoD repository of reuse software available to commercial users
 - Encourage simplified reuse of software
 - Continue full support of Ada

System Life Cycle Implications:

Decisions regarding families of standards should be addressed from the standpoint of full life-cycle implications. Decisions should consider the impact on spares, maintenance, and support equipment. Technology decisions that seem correct from a design standpoint may not be appropriate when considered from a full life-cycle standpoint. For example, commercial technology incorporated in a design may not be supportable for the full life expectancy of a weapon system.

Open System Utilization:

It is important that the DoD make full use of open system standards. Top priority should be given to developing open system standards for parallel processing and a fully capable, real-time operating system. Parallel processing is needed to provide the capability to continue to increase the signal processing and graphics display functionality of weapon systems. Real-time processing is a critical element of many weapon systems and thus forms a vital technology need.

Software Reuse Repository Access:

Software reuse can reduce the cost of developing new weapon system software. The DoD has established a software repository to aid developers of DoD systems. It is recommended that an arrangement be made to permit commercial users to access this resource. This will encourage the reuse of software and promote continued full support of Ada by commercial industry.

Digital Equipment Corporation (DEC)

September 1992:

- More consumer orientation for computing
- Computing will change more this decade than at any time in the past
- Standards should stay loose and flexible
- Don't standardize on systems or backplane buses

Digital Equipment Corporation (DEC), one of the nation's leaders in developing mini-computer technology, briefed the survey team on its new ALPHA microprocessor and its perspective on future technology development. The ALPHA microprocessor will provide a state-of-the-art advancement by offering 64-bit processing, 64-bit input-output, and clock speeds of 150 megahertz or greater. The processor will use 3/4-micron complementary metal oxide semiconductor technology.

The DEC spokesman noted the major gains that have characterized computer technology over the past four decades. Notably, performance doubled over a period of about 18 months. Despite this record, he stated, "computing will change more this decade than at any time in the past." The basis for this claim rested with expected computer applications development. The resources are now available in terms of memory capacity and computer speed, to address large problems that were previously too complex and costly to address. Special emphasis will be placed on image and video processing. Although many people in the industry are computer-literate, this greater power and capacity can make computers "people literate," thus providing the means to reach new dimensions in information processing.

The DEC spokesman further observed that because of the rapid growth that computer technology has had and should continue to experience, "standards should stay loose and flexible." Open architectures being developed should be capable of accepting new technology and applications. Technology envisioned will make use of ubiquitous networking, quickly-fabricated specialized chips, and new applications development methods.

Abbreviations

AEEC	Airlines Electronic Engineering Committee
ANSI	American National Standards Institute
APEX	Application and Executive
ARINC	Aeronautical Radio, Incorporated
ASTA	Advanced Software Technology and Algorithms
ATCCS	Army Tactical Command Control System
ATF	Advanced Tactical Fighter
BASIC	Beginner's All-Purpose Symbolic Instruction Code
C³I	command, control, communication and intelligence
CASE	computer-aided software environment
CCITT	Comite Consultatif Internationale de Telegraphie et Telephonie (now called Telecommunications Standardization Sector)
CFS	Center for Standards
CIM	Center for Information Management
CIP	common integrated processor
CISC	Complex Instruction Set Computer
CNI	communications, navigation, and identification
COBOL	Common Business Oriented Language
DARPA	Defense Advanced Research Projects Agency
DBMS	Data Base Management System
DCA	Defense Communications Agency
DDR&E	Deputy Director of Defense Research and Engineering

DEC	Digital Equipment Corporation
DIA	Defense Intelligence Agency
DISA	Defense Information Systems Agency
DoD	Department of Defense
DoDIIS	Department of Defense Intelligence Information System
DRAM	dynamic random access memory
EDI	Electronic Data Interchange
EMD	Engineering and Manufacturing Development
EMI	electromagnetic interference
F ³	form, fit and function
FAA	Federal Aviation Administration
FDDI	fiber-optic Distributed Data Interface
FIPS	Federal Information Processing Standards
FORTTRAN	Formula Translation
GOSIP	Government Open Systems Interconnection Profile
GKS	Graphic Kernel System
HPCC	High Performance Computing and Communications
IDA	Institute for Defense Analyses
IEEE	Institute of Electrical and Electronics Engineers
IF	intermediate frequency
IGES	Initial Graphics Exchange System

IMA	Integrated Modular Architecture
I/O	input/output
IP	Internet Protocol
IPD	Information Processing Directorate
IRDS	Information Resource Dictionary System
ISO	International Standards Organization
JIAD	Joint Integrated Avionics Directorate
JIAWG	Joint Integrated Avionics Working Group
JSRC	Joint Service Review Committee
LAN	local area network
LAMPS	Light Airborne Multi-Purpose System
LH	Light Helicopter
LISP	List Processing
LRM	line replaceable module
MASA	Modular Avionics Systems Architecture
MCM	multi-chip module
MIPS	million instructions per second
NASA	National Aeronautics and Space Administration
NGCR	Next Generation Computer Resources
NIST	National Institute of Standards and Technology
NNSC	National Science Foundation Network Service Center

NSF	National Science Foundation
NTDS	Navy Tactical Data System
OSD	Office of the Secretary of Defense
OSI	Open System Interconnection
P ³ I	pre-planned product improvement
P&L	Production and Logistics
PC	Personal Computer
PI	parallel intermodule
PM	Program Manager
POSIX	Portable Operating System Interface Unix
PROLOG	Programming Logic
R&D	Research and Development
R&E	Research and Engineering
RISC	reduced instruction set computer
S&SS	Strategic and Space Systems
SAE	Society of Automotive Engineers
SAVA	Standard Army Vetrronics Architecture
SFI	solder-free interconnection
SGML	Standard Graphics Markup Language
SILS	Standard for Interoperability Lan Security
SPL	Signal Processing Language
SQL	Structured Query Language

TCP Transmission Control Protocol

TM test maintenance

TS Tactical Systems

VETRONICS vehicle electronics