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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD LECTURE SERIES 176

The Conflicting Forces Driving Future Avionics Acquisition

(Les Arguments Contradictoires pour les Futurs Achats d'Equipements d'Avionique)

This material in this publication was assembled to support a Lecture Series under the sponsorship of the Avionics Panel of AGARD and the Consultant and Exchange Programme of AGARD presented on 16th—17th October 1991 in Kettering, United States, 4th—5th November 1991 in London, United Kingdom and 7th—8th November 1991 in Madrid, Spain.

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North Atlantic Treaty Organization

Organisation du Traité de l'Atlantique Nord

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— Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture.

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Abstract

There is a growing need to develop flexible/robust avionics to meet ever changing mission needs of the operational forces. Such needs may conflict with other characteristics required such as standardisation, increased reliability, durability and integrity. Weapon system costs and associated avionics costs continue to increase while military budgets continue to shrink due to changing world conditions. Thus it is even more important to intelligently resolve these often conflicting forces driving development efforts.

These evolving trends, conflicts and challenges will be examined in this Lecture Series with a view to enhancing dialogue, understanding and improved planning.

This Lecture Series, sponsored by the Avionics Panel of AGARD, has been implemented by the Consultant and Exchange Programme.

Abrégé

Des équipements d'avionique adaptatifs et robustes sont de plus en plus demandés pour faire face à l'évolution permanente des besoins exprimés par les forces opérationnelles. Or, il se peut que de tels besoins soient en contradiction avec d'autres spécifications qui sont demandées, telles que la standardisation, la fiabilité renforcée, la durée de vie et l'intégrité.

Les coûts des systèmes d'armes et ceux des systèmes d'avionique associés continuent à grimper, tandis que les budgets militaires ne cessent de diminuer en raison de la situation politique mondiale. Il est donc à fortiori nécessaire de résoudre intelligemment les données souvent contradictoires qui sont à la base de l'orientation des efforts de développement dans ce domaine.

Ces tendances, ces conflits et ces défis seront examinés lors de ce cycle de conférences, en vue de favoriser le dialogue, de faciliter la compréhension et d'améliorer la planification.

Ce cycle de conférences est présenté dans le cadre du programme des Consultants et des Echanges, sous l'égide du Panel AGARD d'Avionique.

List of Authors/Speakers

Lecture Series Director: Mr G L Ludwig
Technical Director
Avionics Engineering Directorate
AFSC/ASD/ENA
WPAFB OH 45433-6503
United States

AUTHORS/SPEAKERS

Mr Chris Blake
Chief Avionics Engineer
AFSC/ASD/YFEA
Wright-Patterson AFB, OH
United States

Ms Nancy Clements
Technical Director
Deputy for Avionics Control
AFSC/ASD/AX
WPAFB OH 45433-6503
United States

Ms Natalie Crawford
RAND Corporation
1700 Main Street
P O Box 2138
Santa Monica, CA 90406-2138
United States

I P A Laurent Guibert
Director, Integration Division
STTE
MOD of France
129 rue de la Convention
75731 Paris Cedex 15
France

Dr John C Halpin
Asst. for Prod. Assurance
AFSC/ASD/EN
WPAFB, OH 45433-6503
United States

Mr J.P Lacroix
Thomson-CSF
Radar and Counter-Measures Div.
Service ACTR
178 Bd Gabriel Péri
92240 Malakoff
France

Mr Lester McFawn
Chief, Systems Integr. Div
AFSC/WRDC/AAAS
WPAFB, OH 45433-6543
United States

Dr Helmut Rapp, PE 31
Head, Systems Engr. Branch
Avionics Department
MBB Military Aircraft Div.
Postfach 80 11 60
D-8000 Munchen 80
Germany

Dr John Ruth, Ph.D
Boeing Military Airplane Division
Boeing Defense and Space Group
P O Box 3707, M/S 4C-64
Seattle, WA 98124-2207
United States

Dr John C. Stuelpnagel
Manager, Digital System Dept
Westinghouse Electric Corp
Electronic Systems Group
P O Box 746, MS 5230
Baltimore, MD 21203
United States

Mr John A. Turton
Procurement Executive, MOD
AES 23A Rm 249
MOD (PE) St Giles Ct
1—13 St Giles High St
London WC2H 8LD
United Kingdom

Mr Ronald S. Vokits
Director of Avionics Tech.
Deputy for Avionics Control
AFSC/ASD/AXT
WPAFB, OH 45433-6503
United States

Mr D.R Morgan
Wright Laboratory
Avionics Directorate, WL/AA
Wright-Patterson AFB OH 45433-6543
United States

EVOLUTION OF AVIONIC SYSTEMS ARCHITECTURE, FROM THE 1950'S TO THE PRESENT

Gary L. Ludwig
Technical Director

Directorate of Avionics Engineering
DCS, Int. ;rated Engineering and Technical Management
HQ Aeronautical Systems Division
WRIGHT-PATTERSON AFB, OH 45433-6503
USA

SUMMARY:

This paper describes the evolution of avionic systems architectures in U.S. Air Force fighter aircraft, beginning with the system design typical of the "Century Series" aircraft (the F-100, F-101, etc.) and progressing on through the long list of fielded aircraft to the front-line fighters of today and beyond to the systems currently under development at the Aeronautical Systems Division. In parallel with this description, the forcing functions and catalysts for change of avionic systems architecture are also noted. In this regard, the rapid shift to digital avionics made possible by the transistor and the integrated circuit, wafer-scale integration, and high-density mass memory devices has rapidly driven the evolution of avionic system architecture. Attendant with such technology advancements, pilot interface associated with each new generation of avionic subsystem has also continued to mature and this also has had a major impact on system design. With the ever-increasing capabilities of weapons systems, pilot workload has increased dramatically. The need for simplification, integration, and automation of operator functions has become abundantly clear. The evolution of system design features intended to ease the operator's burden have greatly influenced system design, and these impacts are also reviewed. In conclusion, a quick glimpse at future means of supporting the pilot is provided and the implications on future avionic system design reviewed.

PREFACE:

The purpose of this paper is to document the evolution of avionic systems architecture, as well as the forcing functions responsible for most significant changes in fighter aircraft designs over the past 40 years. The paper will also address the emerging technologies which are affecting our current avionic system design development activities, as well as a[illegible]cipated architecture issues in systems to be fielded throughout the current decade.

INTRODUCTION:

As an introduction to avionics architecture, let's first begin with a definition: avionics architecture is that top level system design characteristic which best describes the manner in which system-level functions have been defined and implemented, allocated to subsystems and integrated into the whole, such that predetermined objectives and operational needs may be satisfied. Architectures may be broadly described as:

(a) FEDERATED ARCHITECTURE. Systems composed of many "stand alone" subsystems, wherein each subsystem is highly dependent upon the operator for management (data inputs) and control (operating mode selection). The operator must continually gather outputs from each subsystem, develop and maintain an awareness of total weapon system state, and make system-level decisions regarding mission objectives and execution.

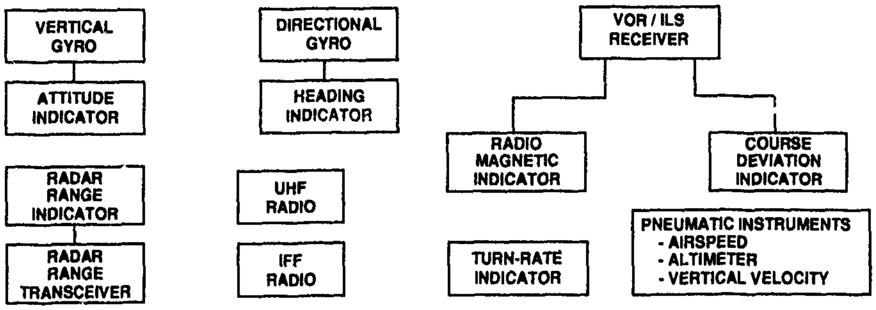
(b) INTEGRATED ARCHITECTURE. Many functions performed autonomously within a system/subsystem, with well-defined means for all subsystem interactions. Little need for direct operator intervention or management of subsystems, except for high-level decisions affecting realization of mission objectives.

(c) HYBRID ARCHITECTURE. System designs possessing both federated and integrated design characteristics, containing mixtures of "stand alone" subsystems and clusters of locally integrated subsystems (supporting common, dedicated functions).

It is important to note that pilot performance plays a very significant role in system design. The pilot's activities and functions must ultimately be integrated before total system performance may be realized. Because of the attention required of the pilot in federated designs, and ultimately because of the continually increasing repertoire of capabilities and related numbers of avionic subsystems in each new generation of fighter aircraft, the trend has been strongly toward integrated system architectures. Such systems greatly relieve pilot workload and permit better focus on accomplishment of mission objectives. As will be seen, there are a myriad of ways and means to satisfy mission objectives and ever advancing technology has had a major impact on system designs. This may be best illustrated by beginning with the typical system architecture of the Century Series fighters of the 1950's, and describing the evolution of avionic system architecture to date.

THE 1950's:

In the "Century Series" fighter aircraft (the F-100, F-101, etc.) of this era, the typical avionics system architecture was a federated design. Most avionic subsystems designs were isolated, stand-alone equipments (see Figure 1). They were largely based upon vacuum tube technology, employing analog (or discrete) interfaces with dedicated controls and displays. The pilot was the principal integrator, gathering information from a multitude of sources and exercising system control through manipulation of toggle-switches or stacked wafer (Ledex) switches. Because of the large number of discrete components (transistors, resistors, connectors, etc.), most subsystems designs could not perform reliably throughout the variety of variety of operating environments. These avionic subsystems were also quite heavy and required significant allocations of volume (which has always been extremely limited in fighter aircraft). These characteristics have been succinctly described by Longbrake (Ref. 1) in his paper on "Avionics Acquisition, Trends and Future Approaches". Specific details and trends have been aptly



TYPICAL CENTURY-SERIES AIRCRAFT: F-100, F-101, ETC. (1950)

Figure 1

captured in figures developed by Longbrake, two of which have been extracted from his paper and included here for reference (Figures 2 and 3). And finally, these subsystems were frequently difficult to integrate electrically due to instabilities associated with analog signals. For all of these reasons, there was little or no backup or system redundancy, and it was incumbent upon the pilot to gather and interpret available information from his limited avionics suite to control the air vehicle, to maintain situational awareness, and to perform his assigned mission. With this limited repertoire of system capabilities, the pilot was able to assimilate all necessary information - and could do so quite reliably, given sufficient training and experience. The greatest chink in the armor was the low reliability of avionics systems (typically on the order of 10 hours MTBF), and the inability to accept failure of a critical avionic subsystem without affecting mission success.

THE 1960's:

During this era, existing avionic systems capabilities began to mature and most importantly, solid-state technology was introduced. The reliability of many avionic subsystems began to improve dramatically as use of the transistor became the norm. In addition, significant advances in operational capability were realized by the introduction of new avionic subsystems such as the inertial navigation system, radar systems, and the head-up display. However, the pilot was becoming more and more burdened as additional subsystems and functions were added, and the list of operator tasks associated with avionic systems began to grow. The need to integrate or consolidate many avionic subsystems into larger, more manageable and efficient units began to be recognized and hybrid avionic system architectures began to emerge. Two good examples of such efforts to control pilot workload were the "Flight Director System" (FDS) and the "Head-Up Display" (HUD) (see Figure 4). In the FDS, a multitude of individual cockpit instruments (attitude indicator, compass, angle of attack indicator, radio navigation indicator, etc.) were integrated into two primary instruments: the Attitude Director Indicator and the Horizontal Situation Indicator. In addition, the FDS presented command steering cues which greatly reduced the burdens associated with radio navigation and instrument landing. Similar capabilities were consolidated into the HUD, which permitted the pilot to gain necessary control information while keeping his eyes out of the cockpit (looking for identifiable landmarks, targets, adversaries, and conflicting traffic, while maintaining formation position). With increasing use of the transistor, system weight and volume requirements would have been expected to be reduced; however, the greatly improved operational performance offered by newer subsystems such as the inertial navigation system, radar, and HUD caused system weight and volume allocations to continue to grow (although at a somewhat reduced rate). System architectures remained largely of federated design, and as in the previous era, there was little opportunity to improve system robustness or offer system redundancy.

THE 1970's:

In this era the transition to digital avionics was fully realized. Truly integrated system architectures began to emerge, and dependence upon the digital data bus began (see example, in Figure 5). More importantly, avionics began to be employed in flight critical applications (electronic flight controls and terrain following systems). Sensor and system capabilities continued to increase dramatically, including smart stores and associated management systems.

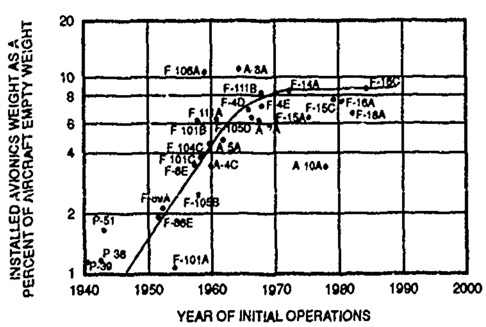
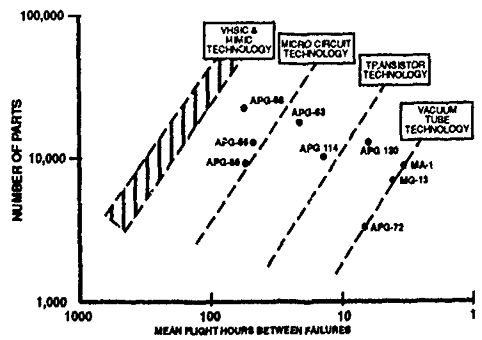
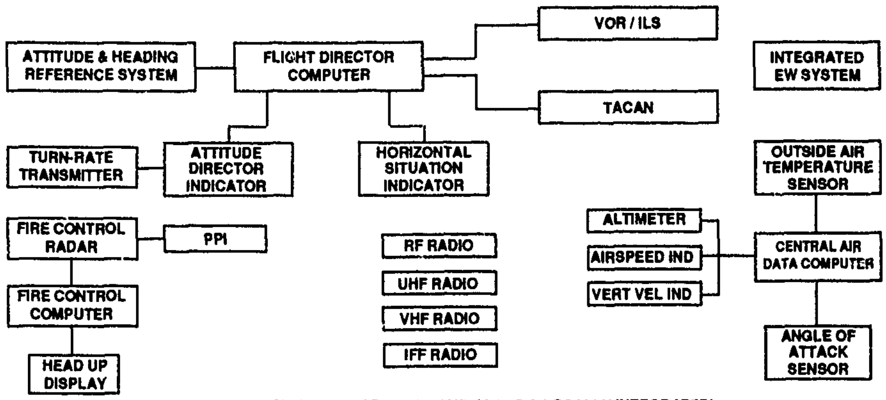


Figure 2



MATURATION OF ELECTRONICS AND IMPACT ON RELIABILITY

Figure 3



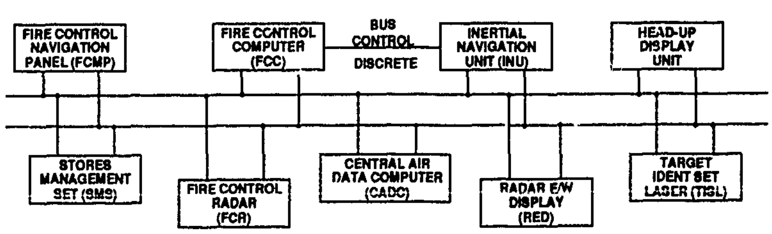
HYBRID SYSTEM ARCHITECTURE (STAND-ALONE & LOCALLY INTEGRATED)

Figure 4

Night/all-weather capabilities began to be realized. Avionics weight and volume allocations began to level off, primarily due to inability of the pilot to accept increased workload associated with the management of additional avionic subsystems. System architectures became highly integrated, and the use of shared time division multiplexed digital data buses (MIL-STD-1553) became the norm. It was during this era that the full impact of the "information overload" in the cockpit began to be recognized. The ability of the pilot to properly select and interpret necessary information, and to manage his weapon system in such manner as to realize its full potential, became recognized as a limiting factor and a significant problem which required resolution before additional capabilities could be supported.

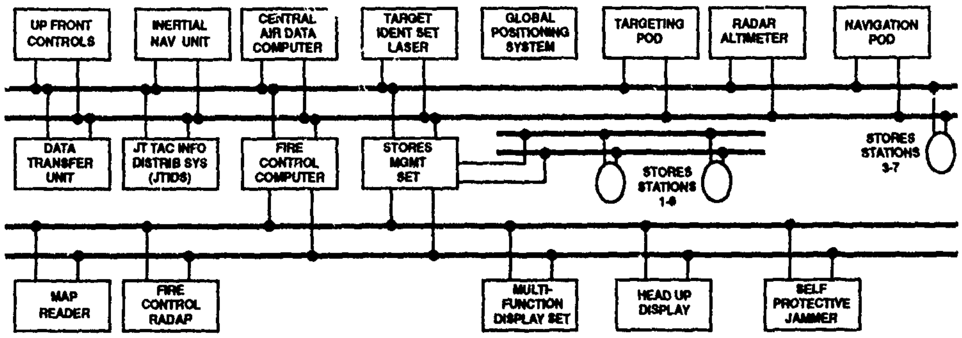
THE 1980's:

In this era very few new fighter aircraft designs emerged; instead, the capabilities of existing aircraft were substantially improved and upgraded, including the upgrading of avionic systems. Digital, highly integrated avionic systems were optimized to the extent that technology allowed. A good example is the F-16C/D architecture (Figure 6), one of many examples illustrated in the Multiplex Applications Handbook (Ref. 2). Pilot workload issues were fully recognized by Jean R. Gebman (Ref. 3) and others, and inroads were made on easing management and control of avionic systems. Controls were optimized such that with minimal switch-throws or key strokes, a single mode of operation could be selected (with many lower-tier control actions performed automatically, under computer control). For example, a simple selection of ground attack mode would automatically prepare the radar, HUD, stores, and the flight control system for this specific mission segment. Large scale integration computing devices/chips enabled a much greater degree of automation, while system weight and volume requirements remained essentially constant. Since physical size of processors was beginning to shrink, we could now afford to build in some redundancy to gain system robustness. However, it became fully apparent that if maximum advantage were to be taken of emerging sensor technologies, further automation of sensor system management would be required. Because of the complexity of such avionic systems, reliability and maintenance issues began to loom ever larger. While the reliability of individual subsystems became much greater (due to the reduced number of electronic components and interconnections within subsystems), the ever growing number of subsystems began to impact overall system reliability. The determination of fault modes and failure locations became ever more difficult, impacting maintenance activities and operational readiness of aircraft. With the development of Very High Speed Integrated Circuit (VHSIC) chips, the enormity of the software development task also began to be felt. With the emergence of immense processing capabilities among various subsystems, the difficulties related to parallel processing, time dependence, and data correlation (i.e., data latency) within the avionic system became a significant issue. By the end of this era it became apparent that significant changes in avionic system architecture would be necessary if we were to take full advantage of the new sensor technology (electronically scanned arrays), high-throughput computing devices, and wafer-scale integration techniques/surface mount technology just beginning to emerge.



EARLY F-16 SYSTEM ARCHITECTURE

Figure 5

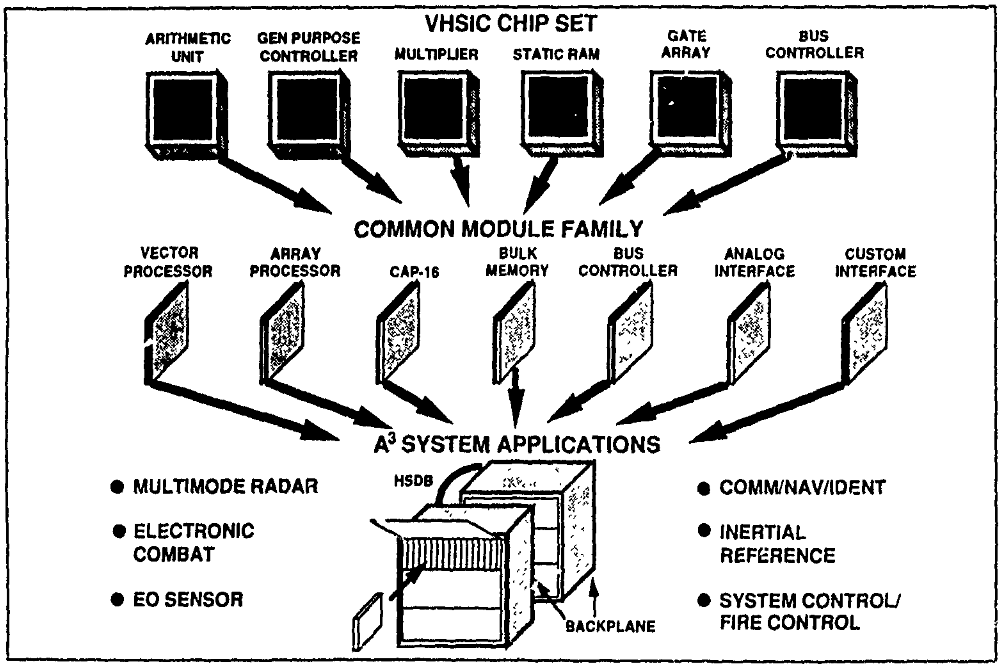


ADVANCED F-16 SYSTEM ARCHITECTURE

Figure 6

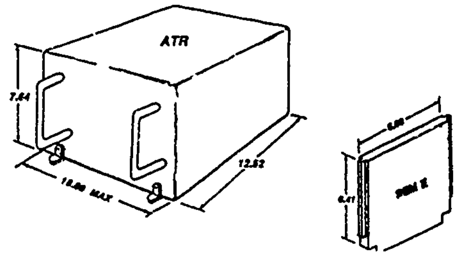
THE CURRENT DECADE (1990's):

The systems architectures in the beginning of this era are exemplified by the preliminary design activities ongoing in the Advanced Tactical Fighter (ATF) program. Due to the severe pressures on the defense R&D budget, Congress mandated that the Tri-Services (Army, Navy, and Air Force) agree on standardized approaches to the development of advanced systems architectures for the next generation of tactical aircraft, including the Army's "Light Helicopter" (LH), Navy's "Advanced Tactical Aircraft" (ATA), and the Air Force's ATF. This activity is ongoing within the Tri-Service sponsored Joint Integrated Avionics Working Group (JIAWG) described in DOD's "Joint Integrated Avionics Plan for New Aircraft", dated March 1989 (Ref. 4). This architecture is a derivative of the "Pave Pillar" architecture recently pioneered by the Air Force Avionic Laboratory (Wright Laboratory). These design standardization initiatives are based on the use of modular avionics, high speed fiber-optic data buses, common processors, and reconfigurable systems architectures employing common modules to support many avionic subsystem functions. These common modules will depend largely upon VHSIC chips and wafer-scale integration (Figure 7), allowing functions which were previously performed in



COMMON MODULES

Figure 7

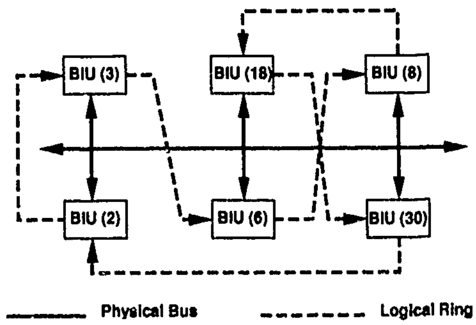


STANDARD ELECTRONIC MODULE SIZE COMPARISON

Figure 8

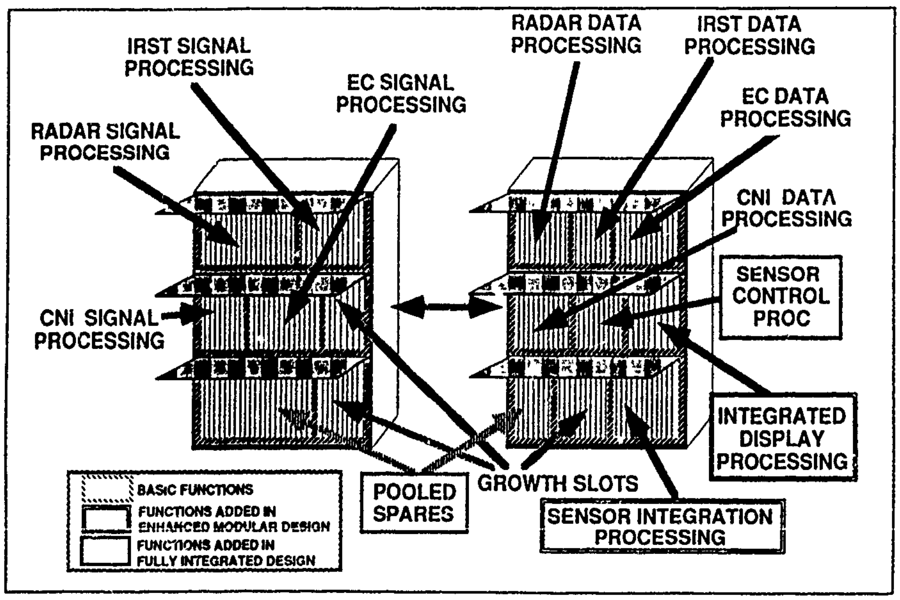
black boxes sized to Air Transport Rack (ATR) standards to be housed in relatively small Standard Electronic Module - Size E (SEM-E) packages (Figure 8). These modules will be housed in a common avionics rack (Figure 9), and will communicate via high-speed (50 gigabits per second) data buses. The currently favored bus design is the Linear Token Passing Bus (LTPB), depicted conceptually in Figure 10. Such a net will permit well disciplined bus management (as exemplified by MIL-STD-1553), plus token passing to aid lower level background communications between subsystems. High speed data buses will also be employed for backplane communications between modules, to permit rapid access to extensively shared data. The common avionics rack will be liquid cooled to ensure a hospitable operating environment. Several modules will be of common design, allowing a very robust design wherein system reconfiguration may be accomplished on the fly, using spare (or idling) modules as mission requirements or equipment failures dictate (Figure 11).

In addition to the advanced capabilities of sensors and processors, and redundancy of flight and mission critical functions, special attention is being devoted to threat and target detection. Sensor correlation in systems utilizing two or more dissimilar sensors will be employed to achieve better identification; target files will be maintained and continuously updated; target prioritization will also be a feature. All of these functions will be automated, and many will depend upon "expert systems" and neural networks (artificial intelligence), a feature which is frequently viewed by the operator as a "computer in the back seat" (i.e., a single-seated fighter possessing the capabilities of a two-seated aircraft). Such computer systems are being developed through the "Pilot's Associate" program by the Defense Advanced Research Projects Agency (DARPA) (Ref. 5), in concert with the military services. Additional research is being pursued by the Air Force Avionics Laboratory and industry into automatic target recognition. This capability will be based upon unique pattern recognition algorithms and the synergistic effects of dissimilar sensors (i.e., "sensor data fusion"). It is envisioned that systems using this technology will offer a capability to



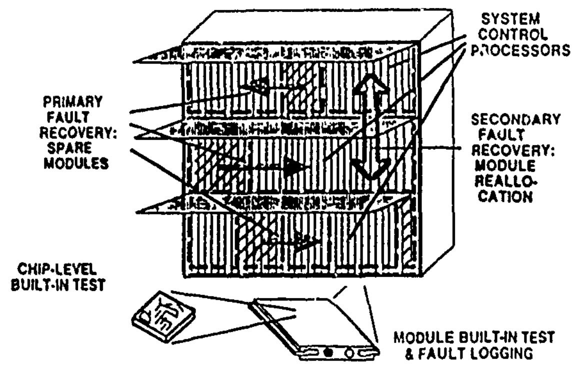
LINEAR TOKEN PASSING BUS

Figure 10



COMMON AVIONICS RACK

Figure 9



RECONFIGURABLE AVIONIC SYSTEM ARCHITECTURE

Figure 11

identify and prioritize targets, assigning target value while assessing risk of engagement, greatly increasing the effectiveness of our weapons systems.

Vehicle management tasks associated with internal weapons system operation will be largely automated, and mission management aids will be available to support in-flight mission changes, perform related risk assessments, etc. The pilot will be able to tailor the performance of such aids during preflight mission preparations, to establish extent of autonomy and control authority to be delegated to the system. The pilot will retain ultimate control authority, but he may confidently depend upon "the computer" to assist him in managing his weapons system and mission functions.

It is also expected that future systems will make extensive use of integrated diagnostics, not only to ease the maintenance burden but to allow in-flight system reconfiguration. Our goal is to develop a next generation fighter which will be extremely reliable and self-sufficient, capable of being sent on routine deployments for up to 30 days without dependence upon additional support staff (maintenance personnel, ground support equipment, and spares). Such weapons systems will be expected to offer greatly improved mission reliability, and will also enhance safety of flight.

In addition to the JIAWG initiative, the Deputy for Avionics Control (ASD/AFALC/AX) is developing a Modular Avionics System Architecture (MASA) design approach (Ref. 6) which closely parallels JIAWG. It is quite likely that the first common modules derived from JIAWG / ATF design activities will form the initial list of common modules; other modules will be developed and added to the MASA list as applications evolve. It is anticipated that the MASA approach will be applied to both the update of older, existing aircraft in inventory, as well as future aircraft to be developed throughout this decade. Similar standardization initiatives are being explored by industry, through several groups:

(1) Aeronautical Radio, Inc (ARINC), by their Airlines Electronic Engineering Committee (AEEC).

(2) The Society for Automotive Engineering (SAE), by their Avionics Systems Division.

(3) NATO Air Standardization Committee, by the Avionics Systems Working Party.

(4) Air Standardization Coordinating Committee, Working Party 50.

The SAE has drafted a number of preliminary standards pertinent to various aspects of modular system architecture, avionic components, and high-speed data bus designs. Formal meetings of SAE's Avionics Systems Division are held twice yearly, to review status and propose updates to draft documentation and to discuss recent industry experience and findings relative to the viability of proposed design guidance. The military services have also participated in this activity, thereby insuring a balanced perspective of evolving requirements (i.e., consideration of operational requirements, operating environment, maintenance support structure, etc.). The AEEC meets formally on an annual basis, and it also has produced draft design guidance. Whether the military services will use any of these specifications and standards in the next generation of weapons systems remains to be seen; it is believed that economic forces may play as large a role as the technical aspects, and the use of common modules in both civil and military aircraft applications could offer significant financial benefits. Reliability or performance of such systems in particularly severe military operating environments will be a major consideration. The NATO and ASCC activities meet independently on 18-month cycles, and are beginning to establish similar standards.

Several different R&D activities within our AF laboratories are focusing on the pilot/vehicle interface. We anticipate that the aircrew interface requirements will become better defined and validated during this period, particularly involving cockpit controls and displays. In the near term we anticipate increased use of high density flat panel display technology (which offers lighter and more reliable displays, but at a cost of increased processing). Helmet-mounted displays are also emerging which offer better situational awareness and enhanced air-to-air tactical engagement effectiveness. Other computer intensive capabilities include in-flight mission planning (which will allow in-flight mission changes, location of moving targets, and related situation assessments/ mission success probability estimations), terrain mapping data (for autonomous navigation, threat vulnerability assessments, terrain following/ terrain avoidance flight, and artificial terrain displays for use at night or in adverse weather conditions), optimal employment of active and passive sensors and countermeasures, and integrated diagnostics to support avionic system reconfiguration decisions and aircraft maintenance activities.

FUTURE APPROACHES:

The manned air vehicle remains the most robust means for assuring a high mission success rate. Acting as the "on scene commander", the pilot is in the most advantageous position to observe, measure, and evaluate progress toward accomplishment of mission objectives. He will be capable of making the most informed decisions regarding continuation or abort of missions. The future challenges are many, but two stand out:

(1) The pilot must be adequately supported in the arena of information management. In addition to threat and target detection, identification, and prioritization, we must factor in all available information (including that which may be available from external agencies) pertinent to the assigned mission We must present this information in a manner which best supports the pilot in his role as a weapon system manager. For example, if the pilot wishes to modify his flight plan to pursue an alternate mission, sufficient resources and information must be available to support thorough evaluation of most viable options (and associated risks). Factors which must be considered include level of exposure to threats and probability of detection, capabilities of on-board counter-measures (including state of expendables), weapon system health, and required coordination with other mission elements (including formation members).

(2) We must develop weapons systems which are reliable, of reasonable cost, and which possess robust design characteristics. Such designs will depend in large measure upon the ability to share resources (for example, common processor modules), and graceful degradation features which will insure a tolerable pilot workload and sufficiently robust system capabilities to assure completion of assigned missions (or capability to abort and safely return to base).

(3) We must carefully examine the viability of knowledge based "expert" systems, with which to ease the pilot's task. Self-learning (neural net based) subsystem architectures must also be included in this review.

When modular avionics system designs and associated component developments come to fruition, we can anticipate that the core avionic system components will be widely available and in numbers which will permit realization of economy of scale. Peculiar system designs (for mission peculiar sensors and applications) will be the principal drivers of non-recurring hardware costs. As can be seen, all of the requirements listed in the preceding paragraphs are software intensive; one may readily envision that the principal costs of future avionic system developments will be associated with the development of software. If we are successful in developing a good library of computer programs, which may become standard programs (or which may be readily modified as necessary for mission peculiar applications), the expenses associated with software development may also begin to level off. We should also mention the need for high-density mass memory devices; it appears that the laser disk memory has great potential to support identified functional requirements Considering the evolving sensor technology (electronically scanned arrays, etc.), shared antennas, flat-panel displays, and common avionic modules, we believe that the weight of installed avionics (as a percentage of aircraft empty weight) has leveled off and will remain at approximately 8 percent; we do not foresee significant changes in this decade. System architectures which accommodate large amounts of parallel processing are assumed, the typical OFP may contain 2-to-4 million words! Further, integrated diagnostics may be expected to identify and locate all failures to the module or system component level without dependence upon ground support equipment.

CONCLUSIONS:

The modular avionics system has high potential for controlling the escalating costs of advanced avionic systems. With its basic simplicity, its building block approach and task oriented functions, we believe that standardization benefits and economy of scale of this approach will ultimately force system architectures to move in this direction. With the large amounts of parallel processing anticipated in future systems, the use of high-speed intra-system (fiber-optic) networks will become the norm. In addition to the transmission of sensor data (and attendant time correlation requirements in the data fusion process), common access to large amounts of stored data will place additional demands on high-speed networks. Of greatest concern will be the development of mission peculiar hardware and system software. With proper management attention and dedicated effort towards building a standardized suite of core modules and a library of standardized computer programs and software development tools, new system designs may be efficiently developed and future costs of avionics may be readily controlled.

REFERENCES:

1. Ronald B. Longbrake.
Avionics Acquisition, Trends, and Future Approaches, AGARD Proceedings No. 424, 1988

2. MIL-HDBK-1553A, Multiplex Applications Handbook, 1 Nov 88

3. Jean R. Gebman, et al,
Fighter Avionics: Making Good on the Promise, Rand Research Review, Summer 1988, Vol. XII, No 2.

4. Joint Integrated Avionics Plan for New Aircraft, Mar 89, Office of the Under Secretary of Defense, Acquisition

5. Banks, Shelia and Carl Lizza, "Pilot's Associate: A Co-Operative, Knowledge-Based Systems Application" (IEEE "Expert" Journal, June 1991, Vol VI, No. 3, Pgs 18-29)

6 Minutes of the MASA Open Forum, June 26, 1989, by the Deputy for Avionics Control, Aeronautical Systems Division, Wright-Patterson AFB, Ohio

AVIONICS STANDARDIZATION IN THE USAF - 1980 TO 1990

NANCY L. CLEMENTS
DEPUTY FOR AVIONICS CONTROL (ASD-ALD/AX)
WRIGHT PATTERSON AIR FORCE BASE, OHIO 45433
USA

1. SUMMARY

USAF avionics standardization increased 83% in applications from 1980 to 1990. Documented cost avoidance of $1.3 billion dollars was achieved along with improved operational effectiveness. For continued success in avionics standardization, efforts are underway to identify and evaluate methods historically used to assess avionics applications and requirements. Standardization measures and lessons learned from past efforts are also being evaluated. Information obtained will serve as the point of departure for assessing the dynamic programmatic, operational, and technical forces affecting current and future avionics system architectures. Results will help determine future standardization and commonality initiatives. Preliminary analysis indicates a need for change in the selection and application criteria for standardization and commonality efforts.

This paper reviews avionics standardization from 1980 to 1990. Background, definitions and anticipated benefits of avionics standardization are presented followed by the current extent of standards application and associated cost avoidance summaries. Lessons learned from the past 10 years are highlighted along with efforts underway to define a set of standardization application and implementation criteria designed to identify future avionics standardization initiatives and quantify anticipated benefits.

2. BACKGROUND

Between 1975 and 1977 there was increasing concern at senior policy levels over avionics management. Examples included: lack of a broad, horizontal (across weapon systems) picture; increasing role of avionics due to technological advances; proliferation of avionics (e.g., 43 unique Inertial Navigation Systems); increasingly complex logistics support; and perceived unaffordable solutions. During the late 70s and early 80s the Air Force established policy to ensure cost effective, reliable avionics meeting required mission requirements. Attention was focused on rational use of standards as a strategy to meet this objective. Use was based upon programmatic, technical, and cost analysis versus "for standardization sake", hence the term "rational standardization". Trades and analysis were to be done early in the acquisition process in order to make the best decision.

Before reviewing Air Force success using this approach, some definitions are provided. These are not standard definitions, but will be used for this paper.

Standard Avionics - Avionics which conform to specific requirements established and documented by at least one Department of Defense (DOD) organization.

Common Avionics - Avionics which have multiple applications within an aircraft or across multiple aircraft.

Core Avionics - Core avionics consist of those avionics systems that are typically found on any aircraft. Examples include radio/communication systems, navigation equipment and displays/instrumentation.

Avionics Standards can be divided into two areas: hardware standards and architectural standards.

Avionics Hardware Standards - Avionics equipment which is developed or adopted to be a standard to fulfill requirements for a functional capability. The highest level of hardware standardization occurs at the line replaceable unit (LRU) level. These LRUs constitute the actual subsystems (i.e. "black boxes"). A common method of hardware standardization involves procuring a family of hardware standards to meet several mission needs verses one. Examples include the Standard Central Air Data Computer (SCADC) and the Standard Flight Data Recorder (SFDR). Examples of avionics hardware standards are: ARC-164 UHF Radio, ARC-186 VHF Radio, ARN-118 TACAN Set, Standard Central Air Data Computer, Standard Flight Data Computer, and Standard INU.

Avionics Architectural Standards - Architectural standards generally govern how avionics equipment and subsystems interact to make up the aircraft avionics suite. These standards describe how avionics systems communicate with each other through buses, computer instruction set architectures or digital information from higher order languages (HOLs) instructions. From 1980 to 1990 the USAF architectural standards in use include: HOLs, MIL-STD 1815 Ada and MIL-STD 1589 Jovial; ISA, MIL-STD 1750; multiplex data bus, MIL-STD 1553; and the aircraft/stores interface, MIL-STD 1760.

Avionics Functional Areas - Avionics functions can be divided into the areas as shown in Table 1.

C	COMMUNICATIONS
CD	CONTROLS AND DISPLAYS
EO	ELECTROMAGNETIC COMBAT
FL	FLIGHT CONTROLS
ID	IDENTIFICATION
N	NAVIGATION
RE	RECONNAISSANCE
SI	SYSTEM INTEGRATION
TA/S	TARGET ACQUISITION/STRIKE

Table 1 - AVIONICS FUNCTIONAL AREAS

Avionics Nomenclature - For designation purposes avionics hardware items are assigned nomenclatures through the Joint Electronics Type Designation System. Examples include ARC-164 UHF radio, ARN-118 TACAN, AAU-34/A Altimeter, etc.

Avionics Installation - Indicates quantity of aircraft a specific nomenclature is installed on taking into account quantity per aircraft.

Class V and IV Modifications - Typically Class IV modifications represent reliability and maintainability (R&M) and safety improvements. Class V modifications provide capability increases.

3. EVOLUTION AND APPLICATION OF STANDARDS

In many cases, the Air Force has elected to adopt a successful avionics subsystem as a hardware standard for subsequent application.These were and still are referred to as defacto standards. In other cases, a subsystem was developed and acquired as a standard item. A large percentage of these ("developed as a standard") replaced older systems to provide reliability and maintainability (R&M) improvements. Architectural standards on the other hand, resulted from pursuit of laboratory technology developments. Once a standard was developed for two or more applications, the system engineering process determined whether it was applied to other platforms. For both hardware and architectural standards, each program office analyzes various avionics alternatives. each program office analyzed various avionics alternatives. Based upon cost, schedule, performance and supportability each program director selected the best approach. Typically, if an avionics standard alternative was picked, it was selected because it provided the required capability at the lowest LCC. In this regard, assuming functional adequacy, cost was the number one measurement or metric.

4. BENEFITS

Several avionics standardization objectives were cited in a 1986 study[1] conducted for the Deputy for Avionics Control (ASD-ALD/AX). They were derived through review of several past avionics standardization programs and interviews with personnel from the military and industrial community. These objectives were identified in the study as criteria by which the avionics community has defined, measured and judged the success of avionics standardization.

WIDE APPLICABILITY
COST AVOIDANCE
RISK REDUCTION
EASE OF INTEGRATION
TECHNOLOGY MATURITY
ADAPTABILITY TO CHANGING REQUIREMENTS
EASE OF TECHNOLOGY INSERTION
ENHANCED RELIABILITY AND SUPPORTABILITY

Table 2 - ANTICIPATED BENEFITS

"Benefits" shown in Table 2 are interrelated, but are not necessarily listed in priority order. For example, high reliability of a mature,low risk standard contributes to the cost avoidance associated with using that standard in lieu of a less reliable item. In the past, the principal tangible benefit was cost avoidance. Previous LCC analyses[2] indicate a 15% to 25% cost avoidance with use of a hardware standard, 30% for ISA, and 85% for a standard bus. These percentages were not substantiated nor discounted because both unique and standard options were not pursued; however, previous government and industry studies supported these percentages.

5. APPLICATION OF AVIONICS STANDARDS

5.1 HARDWARE STANDARDS BY AIRCRAFT TYPE

One measure of standardization progress is the quantitative change in application of standards (hardware and architectural). Using data from the Air Force Avionics Planning Baseline (APB)[3] document, the number of avionics subsystems, i.e., nomenclatures, were totaled for 1980 and 1990. This was a unit count and did not consider cost. Percent standardization was determined based on the number of hardware standards compared to the total number of nomenclatures. Data indicated that in 1980 11% of the nomenclatures were considered standard (predominately in the area of communication, e.g., ARC-164 UHF radio) and in 1990, 19% of the systems were standard. This represents an 83% increase in application of avionics hardware standards over the past 10 years. As mentioned previously, cost was not a consideration so a $1,0000,000 radar was equal to a $10,000 radio for this single parameter accounting.

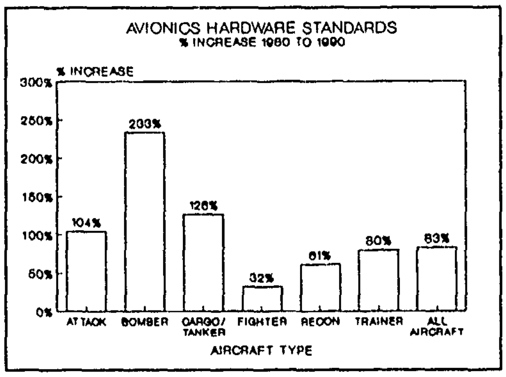


Figure 1

Figure 1 shows this increase by aircraft type. Some obvious results are highlighted. Bombers and cargo/tanker aircraft showed the largest increase. Although fighter aircraft had the smallest increase, this does not imply a significant difference in overall totals.

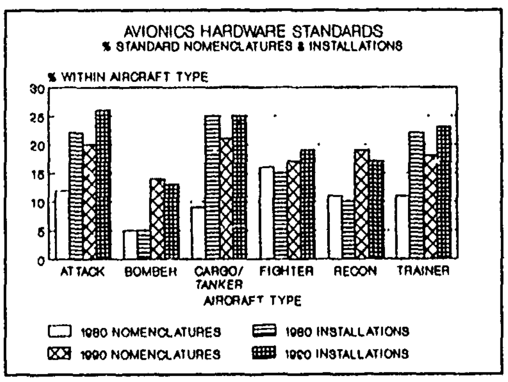


Figure 2

Figure 2 indicates fighters started with a higher number of standards in 1980 than other aircraft; however, their increase over the next ten years was a lower percentage. Figure 2 shows the change in number of nomenclatured items and the change in quantity of aircraft installations. For example, on bomber aircraft in 1980, the standards were evenly distributed, i.e., both 5%; however, in 1980 the cargo/tanker aircraft which had larger quantities, had more standards (9% and 25%).

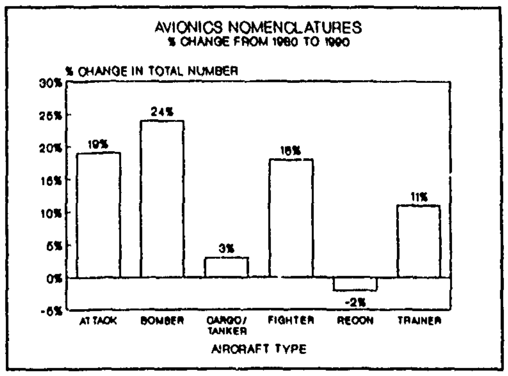


Figure 3

Figure 3 shows the increase in avionics nomenclatures over the last 10 years. This represents the increase in total number of avionics nomenclatures (total suite) and not the total change, i.e. all Class IV and V modifications.

Figure 4 shows the percentage of Class IV and Class V modifications completed based on the number of nomenclatured items in 1980. As this figure depicts, typically there were more capability enhancements than R&M improvements on high performance aircraft, with the opposite true for cargo/tanker aircraft. Figure 5 shows totals for Class IV and V modifications and what portion of these changes were addition of standards.

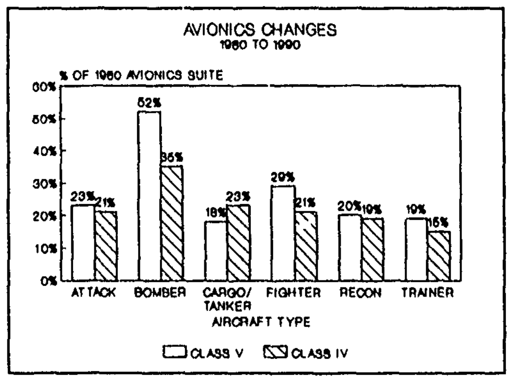


Figure 4

5.2 HARDWARE STANDARDS BY FUNCTIONAL AREA

In prior years, statements indicated that the growth of avionics standards would be in the core avionics area, i.e., communications, navigation, and controls and displays (including instruments). Rationale pointed to the somewhat universal applicability, core avionics subsystems offered. It was not surprising, that after reviewing APB data, this appears to have been substantiated from 1980 to 1990.

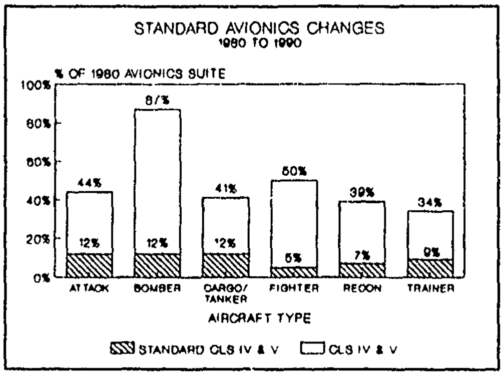


Figure 5

For each of the avionics functional areas listed previously, Table 3 shows the quantity of avionics hardware standards currently in the inventory.

FUNCTIONAL AREA	QUANTITY*	PERCENT OF TOTAL STANDARDS
C	4	12%
CD	14	42%
EC	2	6%
FL	1	3%
ID	1	3%
N	9	27%
SI	1	3%
TA/S	1	3%
TOTAL	33	

* ONE PER FAMILY MEMBER

Table 3 - AVIONICS HARDWARE STANDARDS BY FUNCTIONAL AREA

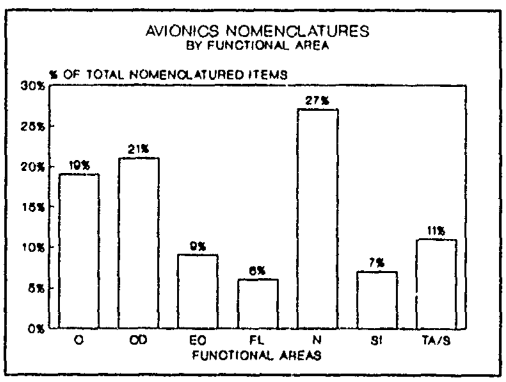


Figure 6

More detailed data concerning the number of avionics nomenclatures and corresponding number of installations (aircraft installs) by functional area was tabulated. The number of nomenclatures is shown in Figure 6. This data does not represent the number of installations, only the number of unique nomenclatured items, i.e. ARC-164, ARC-190, ARN-118, etc.

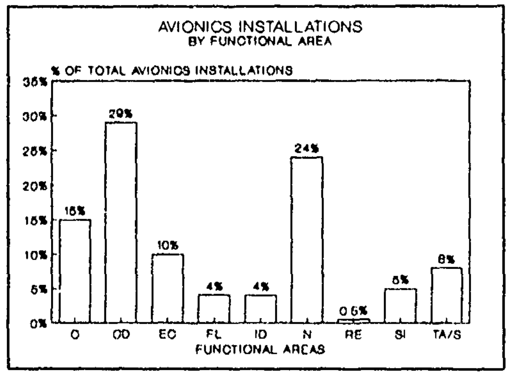


Figure 7

Figure 7 shows how these items were distributed by installation. The data indicates the majority of avionics subsystems were controls and displays, navigation and communications equipment respectively. As a percentage of actual installation, the controls and displays area had far more installations than any other functional area.

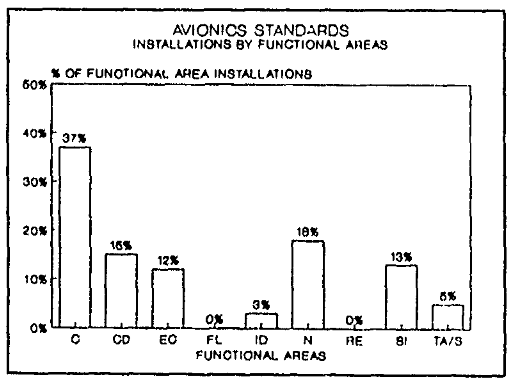


Figure 8

Figure 8 shows the number of standard installations, of which communications had the largest number. Again, data indicates that communications, navigation and controls and displays were the dominate areas. Also, the controls and displays area had a very high installation count (Figure 7, 29%), but compared to the communications area had a low percent of standard installations (Figure 8, 15%).

5.3 ARCHITECTURAL STANDARDS

To examine the use of architectural standards two methods were used. The first examined the use of three standards (MIL-STD-1553, MIL-STD-1750, and MIL-STD-1859) across the fleet by aircraft type. Data was collected on the number of aircraft by Mission-Design-Series (MDS) which used MIL-STD-1553. This was weighted by the quantity of MDS aircraft. For example, if an aircraft MDS had an application of MIL-STD-1553 and there were 200 of these aircraft, this represented a count of 200. Figure 9 provides the results. The overall usage percentage of MIL-STD-1553 is 61%.

aircraft (fighter, bomber, and cargo). Data was collected on usage of four architectural standards. For MIL-STD-1553 the number of total connections to a bus was determined and a percentage taken of those connected to a MIL-STD-1553 bus. For MIL-STD-1750 the total number of 16-bit processors was determined and a percentage taken for those that were MIL-STD-1750. Lines of code which were written in MIL-STD-1589 were counted and a percentage of the total determined. For MIL-STD-1760, the number of MIL-STD-1760 connections compared to total connections was also determined. Figure 10 provides the results.

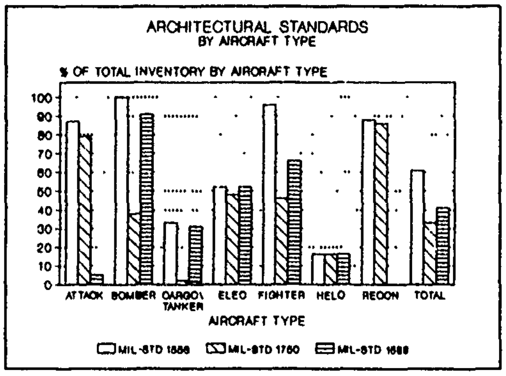


Figure 9

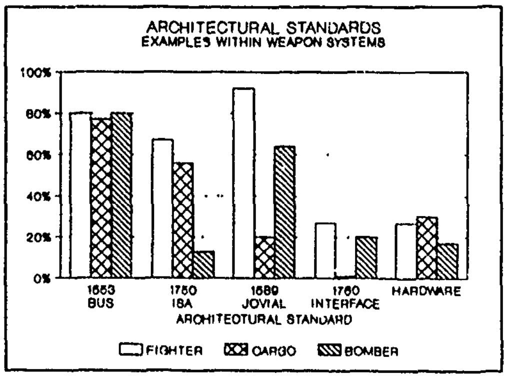


Figure 10

Figure 9 shows that high performance aircraft such as fighters, have extensively used MIL-STD-1553 compared to lower performance aircraft such as cargo/tanker. One possible reason could be that the lower performance aircraft are typically older systems and they pursue fewer major upgrades. The majority of their modifications stem from R&M improvements.

For MIL-STD-1750, the same type of methodology was employed. That is, if MIL-STD-1750 was used anywhere on an aircraft MDS, it was counted. For MIL-STD-1750 the data was not readily available because records did not consistently indicate MIL-STD 1750 usage for embedded computers. Figure 9 shows the results recognizing that it represents a conservative estimate for the number of applications. Again, this standard was used more extensively on the higher performance aircraft with the same possible rationale as MIL-STD-1553. Figure 9 also shows the percent of aircraft which had at least one embedded computer using MIL-STD-1589.

The above methodology does not provide the extent of use on board an aircraft. The second method examined three types of modern

6. AF AVIONICS STANDARDIZATION INVESTMENT

Another measure of standardization progress is the cost avoidance associated with using standards. Recently the Deputy for Avionics Control, while examining the gains and payoffs in avionics standardization over the last 10 years, assessed the current AF investment in avionics standardization. Based upon this, the cost avoidance associated with this AF investment was determined. A gain was defined as the application of standards and a payoff was defined as the cost avoidance associated with using standards. Totals from previous studies indicated a minimum cost avoidance of $1.8 billion. Results from these studies were used as justification to pursue development or use of a standard but were not completely validated, since both alternatives (standard and non-standard) were not pursued. Therefore, there was a need to reassess the current cost avoidance in order to use it as a metric from which future assessments could be measured.

The method used examined life cycle costs associated with weapon systems, avionics systems and standard avionics. By structuring the approach in this manner, relationships were established which showed the portion of overall weapon system LCC associated with standards and also the portion of avionics LCC associated with standards. In order to compare resultant data with previous studies, a 15 year LCC was computed in FY89 dollars. The LCC included development, production and operations and support costs.

Preliminary efforts concentrated on representative aircraft within the attack, fighter, bomber, trainer, cargo/transport, and reconnaissance type aircraft. Two fighter aircraft were examined, one older version and one newer version. This data was then extrapolated to include the total aircraft fleet. For these aircraft avionics LCC and standard avionics LCC was extracted. PODS were not considered. Data sources included AF cost libraries, AFLC data systems (O&S), Government and Industry studies and the ASD-ALD/AX data base. Data elements are summarized in Table 4.

WEAPON SYSTEM:
- AIRCRAFT TYPE
- QUANTITY
- AIRFRAME DEVELOPMENT COST
- AIRCRAFT DEVELOPMENT COST
- FLYAWAY UNIT COST
- 15 YEAR OPERATIONS AND SUPPORT COST

AVIONICS AND STANDARD AVIONICS:
- QUANTITY PER AIRCRAFT
- DEVELOPMENT COST
- UNIT COST
- 15 YEAR OPERATIONS AND SUPPORT COST

Table 4 - LIFE CYCLE COST DATA ELEMENTS (15 YR LCC)

Once the 15 year investment associated with standard avionics was determined, a 20% value was used to determine the cost avoidance associated with the use of these standards. The 20% figure was validated based upon the average percentage cost avoidance previous studies had predicted for use of standard alternatives. It may vary for specific uses ; however, it was used as a baseline at this level of aggregation.

For architectural standards extrapolation was not done. Actual investments were determined for all applications. Based upon previous studies, cost avoidance figures of 30% for an ISA and 85% for a data bus were used.

Figure 11 provides relative estimates from a weapon system perspective of the percent of avionics LCC and standard avionics LCC associated with each weapons system type. The investment in standard avionics indicates the gains made in avionics standardization and can serve as a baseline for future assessments. Also shown is the cost avoidance (payoff) associated with the use of standards related to the overall weapon system cost.

As seen from Figure 11, avionics investment is higher in the more complex aircraft (bomber, fighter, recon) which was due to the high cost of mission avionics. For attack, cargo and trainer aircraft the avionics investment is a smaller percentage of the overall weapon system cost.

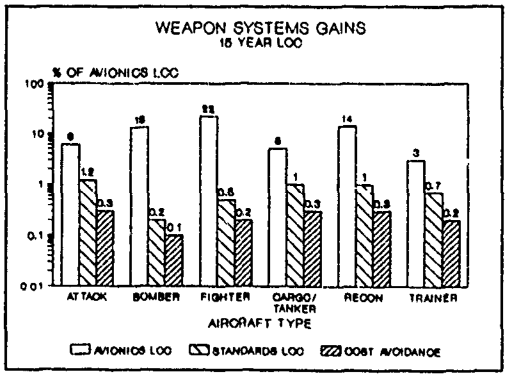


Figure 11

Figure 12 shows the standard avionics investment and standard avionics cost avoidance as a percentage of the total avionics investment. There were no surprises in that the standard avionics investment indicates a higher percentage of the avionics investment on the cargo and trainer type aircraft, than the more complex bomber and fighter type aircraft. This was due to lower avionics unit costs. For example, on a fighter aircraft, the million dollar cost of the radar far outweighed a low cost instrument.

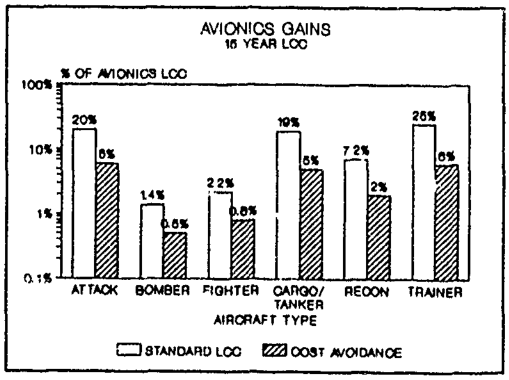


Figure 12

Figure 13 summarizes the gains and payoffs for the last 10 years. This is shown from a total weapons system perspective and from an avionics perspective.

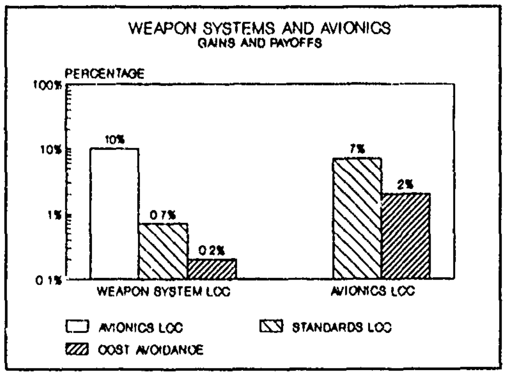


Figure 13

7.0 Lessons Learned

Over the last ten years by virtue of going through the processes of planning, developing and applying standards, there have been several key points which lend themselves to be categorized as "Lessons Learned". These fall into the following areas: Metrics, Timeliness of Standards, Cost Avoidance - Contributing Factors, Avionics Standardization Criteria, and Long Range Modification Planning verses Short Term Requirements.

7.1 Metrics

Past estimates for the increase in application of avionics standards indicated a 300% increase verses the 83% cited in this paper. The 300% and the 83% figure were both derived from APB data; however, data reporting was not consistent between 1980 and 1990 and was not accounted for in the 300% figure. A brief explanation is needed. During the mid 1980s there was a concerted effort to more accurately reflect all avionics nomenclatures on each aircraft. For example, considerable work was done in the controls and displays area, which included instruments. This area had, as Table 3 indicates, a large percentage of standards. Therefore, the reporting of these standards was accomplished; however, in most cases they were on the aircraft in 1980, hence this was not a real increase. This took considerable time to sort out, and required continual interface with the personnel responsible for data collection. Solving this problem for future assessments will require data base refinements.

Another metric used to examine avionics standardization has been cost avoidance. Here again, previous reports indicated a "conservative" $1.8 billion verses the $1.3 billion cited in this paper. The $1.8 billion figure was a tabulation of results from LCC assessments. These assessments (16 total) were done by the Deputy for Avionics Control to support the evaluation of standard alternatives when there was an issue or a user request. The pivotal output from these assessments was the relative delta LCC among the alternatives ,i.e., percent increase or decrease. However, the $1.8 billion tabulation included the dollar delta cited in these analyses. These results have not been validated as mentioned earlier. The $1.3 billion cost avoidance was based upon the AF standardization application investment which represented actual applications. To determine the cost avoidance, the 20% cost avoidance associated with use of hardware standards, 30% for use of ISA, and 85% for the data bus figures were used. Work now needs to be done to substantiate these percentages and establish relationships for use in subsequent assessments.

7.2 Timeliness of Standards

A constraining factor in the ability to have extensive use of standards is the timeliness of those standards. MIL-STD-1553 is extensively used because it was available in the 70s during periods of large weapons systems buys. An example of a standard which was not timely was DOD-STD-1788, Avionics Interface Design Standard. DOD-STD-1788 was conceived in 1980 and formally published in May 1985. It is an Interface Design Standard that specifies the black box physical form factor, electrical connector, aircraft racking system and trays, and specific maximum heat dissipation values for the various size black boxes. In June of 1986 frustration was expressed over attempts to require application of the standard to several programs. Based upon these concerns, a study was done by the Deputy for Avionics Control to validate DOD-STD-1788 as a viable standard, define where and how it should be used, and determine its' future as new standards evolve. The study addressed all planned aircraft and avionics development and modification programs. It also predicted future applications due to planned changes, capability improvement and introduction of new aircraft. Cost factors were determined concerning the implementation of DOD-STD-1788 into aircraft. These cost factors were then applied to a fleet wide implementation. The results ot the study showed that the economic benefits of DOD-STD-1788 as an interface design standard did not appear significant due to the limited application base. DOD-STD-1788 did offer other benefits in the area of reliability and maintainability (R&M). However, these were not unique to DOD-STD-1788 since other design approaches offered the same benefits e.g., rear connectors. The study concluded that it the standard could have been applied in the 70's as was MIL-STD-1553, it would have had wide application;, however, since it was a black box concept new technology passed it by. The decision was to not require its use on new aircraft acquisitions. Therefore, timeliness is a key factor and technology continually needs to be assessed and proper planning done so that future standards have a viable life span such as MIL-STD-1553.

7.3 Cost Avoidance - Contributing Factors

Historically, the standardization benefit associated with cost avoidance has as its main contributing factor reduction of Operations and Support (O&S) costs . Typically, this was attributed to the higher reliability for the standard alternative. Questions as to why the standard alternatives had higher reliability have not been thoroughly investigated; however, it is not dependent solely on the fact that it is a standard. Newer technology, proven design and acquisition strategy all could contribute. It is a fact; however, that avionics reliability has improved and as it improved the cost avoidance contributions associated with reliability improvements is less of a contributing factor to the standard's O&S cost reductions. Efforts are currently underway to investigate factors contributing to R&M improvements to determine relationships between R&M and technology, proven design and acquisition strategy.

7.4 Avionics Standardization Application and Implementation Criteria

The benefits listed previously in Table 2 were identified as criteria by which the Air Force standardization community selected initiatives. Typically these were examined from a subsystem point of view. It is clear that identification of standardization opportunities in future decades must use a broader set than those listed. Not only is the level of system integration increasing, but the acquisition strategies will emphasize continuous improvement, total system responsibility and integrated application of design, engineering, manufacturing and logistics disciplines. Further, the continued introduction of new technology must be accommodated in future acquisition strategies.

Table 5 provides a preliminary list of criteria which attempts to capture the essential weapon system verses "strictly subsystem" considerations. These will help determine the level of expected acceptance of a standard. After assessments using this criteria are done, LCC assessments can be done on the alternatives which meet or exceed the Table 5 criteria.

A brief explanation of each criteria element follows.

STATED REQUIREMENT - Stated Requirement refers to a written explicit requirement from a weapon system perspective to add a capability or improve supportability.

- STATED REQUIREMENT
- INTEGRATED PERFORMANCE
- INSTALLED RELIABILITY
- OPERATIONAL COMPATIBILITY
- MAINTENANCE COMPATIBILITY
- INSTALLATION/ENVIRONMENT
- SCHEDULE COMPATIBILITY
- TIMELINESS

Table 5 - STANDARDIZATION CRITERIA

INTEGRATED PERFORMANCE - The integrated performance of as item is determined by considering all function required of the item by the avionics suite and the system design constraints. Consequently, the integrated performance required of an item may be more complex than that provided by the item specification.

INSTALLED RELIABILITY - Installed reliability is a derived weapon system requirement allocated down to the functional level. The requirement is based upon the system environment, mission completion criticality, and integration constraints.

OPERATIONAL COMPATIBILITY - This is defined as the ability of the standard to operate within the framework of the weapon system operational requirements. For example, weapon system operational requirements such as stealth may dictate an operational mode(s) not typically associated with the standard or unique to one application.

MAINTENANCE COMPATIBILITY - This refers to the current or expected method of supporting the weapon system. The candidate standard must have a support concept that is consistent and compatible with the weapon system approach.

INSTALLATION/ENVIRONMENT - This is defined as the impact of the weapons systems' physical design constraints upon the items' design and performance. Considerations include space availability, weight, power availability, cooling capability, signal interface, external surface/appeture constraints and vibrations.

SCHEDULE COMPATIBILITY - This refers to the schedule requirements for the various weapon system applications.

TIMELINESS - This refers to assessments of current and future technologies which may have an impact on the lifespan of the standard.

7.4 Long Range Modification Planning

A large portion of the modifications for existing aircraft are done on a single subsystem basis. Because of this opportunities for synergistic benefits associated with long range modification planning are lost. This problem is associated with the process in that it does not consider broad or long range planning i.e., considering near term modifications for on single weapon systems or across weapon systems. For example, as was shown in Figure 9, MIL-STD-1553 was not extensively used on the cargo/tanker aircraft. The high payoff associated with use of MIL-STD-1553 (85%) was mainly attributed to the reduction of future integration costs. To take advantage of this and to justify its first application, long term modification planning should be done.

8.0 Conclusions

As stated earlier USAF avionics hardware standardization increased 83% in applications from 1980 to 1990. This increase was concentrated in the core avionics area which included communications, navigation and instrumentation. The bombers and cargo/tanker aircraft had the largest increase for hardware standards while the higher performance aircraft showed the largest application percentage for architectural standards. Cost avoidance summaries indicted .2% of Weapon System LCC and/or 2% of the Avionics LCC was avoided by use of hardware and architectural standards. This amount varied across aircraft type (high performance versed lower performance) because of the different mixes of avionics unit costs comprising the total weapon system avionics LCC. The cost avoidance attributed to architectural standards was a larger percentage on the higher performance aircraft than cargo/tanker type aircraft. For the fighter aircraft this comprised 50% of the cost avoidance. This is due to the high dynamic, complex nature of changes on these aircraft and the ease of integration architectural standards offer. In conclusion it appears the Air Force has shown gains and payoffs associated with avionics standardization. The challenge now, is now to ' .e advantage of the high payoff associa..d with use of architectural standards for all aircraft not just our high performance aircraft.

References

1. " Future Standardization Strategies", Prepared by: ONEIDA RESOURCES, INC, 25 January 1989.

2. ASD-AID/AX Analysis Reports: "E-3 Weather Radar LCC", 1987; "LCC Analysis of Standard Architectural Standards", 1987; "Standard Flight Data Recorder LCC", 1988; "Standard Central Air Data Computer LCC, 1985, 1989; "Compass/AHRS LCC, 1988,1998; "Modular Avionics Handbook", 19 April 1990

3. ASD-AID/AX Documents and Data Base: "Avionics Planning Baseline", 1980 through 1990

Historical Perspective on the Evolution of Avionics Standards

Dr. John C. Ruth
Chief Engineer, Avionics Technology
Boeing Military Airplanes
P. O. Box 3707, M/S 4C-64
Seattle, WA 98124-2207
U.S.A.

SUMMARY

This paper will present the development of interface standards from the late 1960's to the middle 1980's. An Avionics Laboratory major program, the Digital Avionics Information System(DAIS) played a key role in the evolution of these standards.

The DAIS program considered interface standards in its basic concept and the cornerstones of the DAIS concept were·

a. A digital multiplex distribution system.
b. Functional software coded in a Higher Order Language.
c. A functional interface standard for processors in theform of a common instructional set architecture.
d. A glass cockpit with interactive displays.

The DAIS hypothesis was that significant ownership savings could be obtained on an aircraft and other weapon systems if some type of standard interfaces were established. Commonality of hardware was not the driving issue, but standards which defined the key interfaces and did not inhibit creative and innovative technology upgrades was imperative. The DAIS program endorsed many of the standards, 1553, 1589, 1750, and 1760, by which avionics designers now design highly integrated systems.

THE DAIS PROGRAM

In the early 1970's, the designer of military avionics systems was facing a seemingly impossible task. On the one hand, the rapid advances in electronics technology were placing an ever increasing premium on growth, capability, and flexibility - the need to respond to changing threats and missions, and react to operational requirement changes in a very short time; on the other hand, cost pressures from increased system complexity, higher maintenance expense and general economic inflation were forcing the designer to address the total cost of ownership of avionics systems. There was a new approach to solving the dilemma facing the avionics system designer. It is based on recognition of the importance of information systems in the design and development of integrated avionics systems. The cost of the avionics could be amortized over many systems on the aircraft and also between various aircraft. This approach does not advocate commonality, but common (alike) elements in the system would drive down the total costs. Unfortunately there is a down side to the common equipment approach; the present technology tends to be frozen in the system addressed.

The DAIS concept proposed that the processing, multiplex, software language, and display functions be common and serve all the subfunctions on an integrated basis. In this way the DAIS concept, would have the flexibility to adapt to a spectrum of multiplex, processing, software languages, and display needs; yet maintain common interface processing architectures, display concepts, and software standards.

Prior to the DAIS concept the conventional approach for designing an integrated "black box" system configuration was to divide the total system configuration into a number of more or less autonomous subsystems and then to design equipment black boxes to meet the performance requirements of each of the separate subsystems. Each subsystem normally performs most of its functions within itself, indulging sensing, computation, logic, control and display. Furthermore, each of the subsystems has usually been developed and built by separate subcontractors. A certain amount of integration and interface among these separate subsystems is normally provided, but the overall total system design has often been characterized by compartmentalized functions and equipment uniqueness; duplicate functions and equipment, nonstandardized input/output signals with unnecessary conversion from one form to another, resulting in subsystem/system inflexibility. This impacts the entire life cycle cost of an avionics systems - viz. - aircraft installation retrofit costs, numbers and variety of spares required, AGE costs, and extensive training requirements.

The DAIS design approach starts with a total system concept which is functionally oriented rather than hardware-oriented. Although the total system still consists of a number of subsystems, the word "subsystem" will be used in a different connotation. It will be thought of more in terms of subfunctions rather than hardware.

For example, a "navigation subsystem" in DAIS does not refer to a set of black boxes which are identifiable uniquely and exclusively to the navigation function but to a set of navigation identifiable functions which are performed in various places throughout the system. Note the system is not dedicated exclusively to doing the navigation function alone; it is also used to perform the functions of many other "subsystems".

AIR VEHICLE AVIONICS INTEGRATION

Avionics integration, which is defined here as the cooperative use of shared information among avionic subsystems, first became a necessity when requirements for missions and their associated avionic hardware could no longer be met practically in air vehicles with independent and self-sufficient subsystems. Elimination of unnecessary duplication of information sensing and display, performance gains, reliability gains, cost reduction, and lack of space are usually given as the major reasons for integration. Subsystems were forced to depend on each other for basic information. This level of integration began with the most complex subsystem because it had the most capability, as well as the most need for information from other subsystems. As digital technology progressed, the central subsystem was expanded to incorporate mission processing (processing not specifically associated with a subsystem or display). However, problems arose early in the centralization approach because subsystems were designed with no concern for interconnection with other subsystems. Each subsystem had been specialized, and the interfaces reflected this specialization. The central computer input-output (I/O) circuitry was designed to perform the functions of ordering this incoming and outgoing data, and the computer was often small compared to the size and complexity of the I/O. Even so, the central computer concept and its associated integration upgraded the capability of the mission and made sensible use of the shared information. It was then reasoned that some of the centralization problems related to the complexity of the I/O could be solved if the circuitry could be partitioned and distributed, alleviating the central unit's complexity.

Multiplexing, which makes information transfer convenient and simplifies I/O, offered this capability, and the extended computer I/O philosophy was developed. Multiplexing makes information exchange convenient because sensors and processors are all "on the bus". Multiplexing simplifies I/O because the information transfer medium is reduced to a single wire pair. This extended I/O philosophy was adopted extensively by military avionics integrators with the development and use of military minicomputers and the availability of lower cost digital components.

These avionics integration methods began to be referred to as multicomputer systems. This made possible the distribution of the computation and permitted several computers to replace the more powerful central processor. Application of this concept in various forms existed on several aircraft (e.g., B-1, F-16, F-18 and Space Shuttle). From the subsystem equipment point of view, these approaches to integration use both integration units for unmodified subsystem interfaces and embedded interfaces. The integration approach using multiplexing is implemented by defining information transfer formats and electrical interface characteristics. Therefore, the functional performance is accomplished by both hardware and software. Most of the problems associated with the centralized I/O have been eliminated by this approach, while others have surfaced (e.g., software complexity, synchronous operation, multiple executive control, data communication and I/O circuitry).

But with all this, a decided improvement over previous approaches has been achieved. Technology improvements in computers and digital hardware (i.e., microprocessors) and maturation of the software design process allow further extension of the integration approach by a more distributed system concept consisting of both microcomputers and minicomputers.

The newer integration approaches will use more processors and buses to functionally partition the avionics along common military and industry organizational lines (such as navigation, stores management, control and displays and communication).

This functional partitioning should further ease the integration problem by allowing design of the functions to be developed more independently of each other prior to completing the total avionics integration.

MULTIPLEXING ADVANTAGE

The data bus provides a path upon which many users can communicate with each other without requiring a dedicated link to each other. Weight saving is achieved by reduction of wire weight provided by the serial multiplexing of digital data as compared with the point-to-point undirectional interconnection required to achieve similar integration without the data bus. Weight savings vary greatly among the systems being compared with the data bus. If an analog system with analog point-to-point wiring is compared with a digital multiplex system, considerable wire weight savings can be achieved. This weight saving will be reduced so what if the analog sensors and displays are connected with integration units that interface these sensors and displays with the data bus. In other words, the overall weight savings resulting from the reduction of aircraft wiring is offset by the weight of integration units. However, if the subsystem is digital and compatible with the bus interface, the offset is recovered. Another comparison of weight saving (but not as great as in the previous case) is a digital system that uses digital point-to-point data interconnections with a approach to integration, the advantage is in the multiple access provided by the data bus in contrast with the point-to point interconnects previously required. Therefore, smaller gains are achieved because both systems use integration and multiplexing in slightly different ways. Each example represents extremes in weight savings. Most new and existing systems will exist within these bounds with a mixture of both types, thus providing varying weight savings dependent on the actual use.

The integration flexibility that is available is one of the key features of this method of integration. Because of the common serial interface, the high data rate (up to 50,000 words per second), the multiple access, and the command/response data format provides extensive flexibility in the development period as well as during the operational time period.

Other digital integration methods have failed to meet the flexibility requirements necessary in the military environment. These failures have occurred due to the following reasons:

a. Too low a data rate was selected (data rate selected based on initial need with little growth capability).

b. Insufficient definition of interface (difficulty in duplicating the interface).

c. No method for expansion to new sources or deletion of sources (inflexible to hardware additions or deletions).

d. Limited data encoding and decoding capability (restricted to BCD or ASCII).

e. Limited addressing capability

f. Inefficient data transfer (too many wires, too much overhead per data word)

g. Difficult to simulate, which would provide confidence prior to hardware development.

Each deficiency was carefully considered during the development of MIL-STD-1553. The detailed electrical interface of MIL-STD-1553 provides the necessary requirements information to allow multiple suppliers to build compatible interfaces. The multiple access and high data rate allow extensive integration of complex systems.

The capability to simulate any part of an integration using a system integration laboratory prior to hardware and system design commitment reduces the risk of new developments and modifications. The ability to communicate data in a "transparent" fashion (i.e., the MIL-STD-1553 system manages the communication transfer without affecting the data) is an advantage to the user. Thus, the data user can encode data to the user's required format and not to the transfer system's format The use of message addressing per MIL-STD-1553 rather than word addressing allows much more flexibility than can be achieved with the word addressing formats used in some point-to-point digital communication approaches.

A final advantage of this approach to information transfer is the ability to control data flow in a scheduled manner from one location; namely, the bus controller. Changes in the integration can be handled by message changes in the bus controller rather than by wiring and hardware changes to the subsystems.

APPLICATION AREAS

The intended application of the data bus standard includes data communication techniques that require (1) a command/response format, (2) a time-division multiplexed data transmission technique, and (3) application internal to an air vehicle. This has been accomplished with the application of the standard to system designs that accomplish (1) integration of air vehicle functional groups such as navigation, weapon delivery, flight control, propulsion, stores management, defensive systems, communications and control and displays and (2) integration of these functional groups into a weapons system.

The application of these system designs to various vehicles includes fighters, bombers, helicopters, and transport aircraft with missions of attack, transport, reconnaissance, and defense. It has therefore been demonstrated that the MIL-STD-1553 approach to integration has been proved applicable to a wide range of air vehicles, avionic functions, and missions.

MIL-STD-1553 Chronology

The Society of Automotive Engineers (SAE), Aerospace Branch, established a subcommittee of industry and military personnel in 1968 to define some of the basic requirements of a serial data bus. By this means, an exchange of industry and military views was accomplished. The committee, Multiplexing for Aircraft (SAE-A2K), developed the first draft of a data bus standard that was similar to the present military standard requirements and procurement specification requirements. Its format allowed standardization on requirements that could be agreed upon and a slash sheet in the appendix for requirements that appeared to be vehicle particular. This document represented the best that the industry and the military could define at the time. The benefit of this document was that it produced a sounding board for ideas. In this respect, it was successful and provided the step forward required to develop the USAF military standard, MIL-STD-1553, in August 1973.

As time went on, the original aircraft avionic suites designed around MIL-STD-1553 and its forerunner, McDonnell Douglas Aircraft Company's H009, made use of the standard interface feature of the data bus. Avionic upgrades were accomplished by replacing old subsystems with new ones designed to take advantage of increased sensor capabilities and/or to insert new technology. The black boxes were switched with minimum systems impact. Ideally, only the software in the bus controller was effected.

During the years from inception of the SAE-A2K to the release of the first military documents, the industry was designing and producing hardware for various multiplex systems. Some of these systems were developed prior to or during the standardization era (e g , F-15 and B-1) Because of program timing, each system went its own way because no standardization effort existed at the time.

From 1973 to 1975 (when MIL-STD-1553A was released), industry and the military (Air Force, Army, and Navy) coordinated their efforts to determine the degree of standardization required. During this time, several preliminary drafts of Air Force and Navy documents were developed and extensive industry comments were solicited. By 1975, the DOD directed the military to develop a single position and to make the necessary revisions to MIL-STD-1553. Based on this effort, 1553A was released in April 1975 and its first incorporation was on the F-16. Since then, industry and the military have continued to coordinate the standard through symposia, studies, and military development programs. With the standard available, the industry and the military began to apply the data bus to more operational vehicles and systems.

As applications became extensive, certain difficulties were recognized in MIL-STD-1553A. Discussions concerning these difficulties were conducted between the

SAE-A2K and the DOD Tri-services Committee (the group responsible for controlling the military standard). These discussions resulted in the formation of an SAE task group (MIL-STD-1553 Update) in October 1976. The task group's assignment was to develop suggested changes to 1553A. Once again, a task group was formed from several industry and military segments.

The task group solicited comments from industry and the military to support its work. These responses were extensive and involved foreign as well as domestic equipment suppliers and users of the standard. It was from this base that the task group developed and presented the suggested revisions to 1553A. In October 1977, after review and discussion of suggested changes, the SAE-A2K approved a proposed revision; in December 1977 these recommendations were provided to the DOD Tri-services Committee. In addition to the SAE input, industry comments on changes to 1553A were solicited in January 1978 by the DOD Tri-services Committee. Based on these comments, the DOD Tri-services Committee met on several occasions and produced a draft of 1553B. This draft was presented to the SAE's task group in April 1978 for review and comment.

As avionics systems became more sophisticated and more highly integrated, extra protocol features such as mode codes were added to MIL-STD-1553A, but the basic design, operational protocol and physical/electrical interfaces were preserved. No further changes were permitted and the standard was frozen in the "B" version as published in 1978 and was initially incorporated on the F-18.

MIL-STD-1553B contains many features, all defined in detail, however, not all need to be implemented in each systems application. The standard can and should be tailored. In fact, as written, it forces the user to make choices when several options are provided, some of which are mutually exclusive. For example, you can choose either a single or dual-redundant bus architecture but not both; or you must decide if you want to use either transformer or direct coupling of a stub at the main bus interconnection. In other areas you can opt to implement or not implement certain protocol features. An example here might be choosing to implement the "dynamic bus control" mode command which allows you to actively hand-off the master bus control function by passing it to capable (smart) terminals; and not to implement the "broadcast" option which permits one to send the same data simultaneously to all terminals and thus suppressing all terminal status responses (handshakes) which are normally required to confirm receipt of transmitted data. In addition, each system that applies the standard must develop a tailored "application-oriented" multiplex specification defining exactly how the data bus is going to be used. For example it would define such things as the number of terminals, terminal addresses, installation routing, design stub lengths and connectors, etc,. Because each system designer will tailor his application of the standard, the remote terminal (RT) manufacturer cannot predict the exact options that will be actually selected. Therefore, most RTs are designed to handle "all" MIL-STD-1553 options and implements the part of a standard that is not a design specification.

As more and more systems applications fed back their "lessons learned" and as unique service (USAF, USA and USN) requirements developed, an USAF "Notice 1" was issued selecting preferred options in architectural features and protocol. Minimizing the choices did not hinder the data bus operation but did not provide a degree of forced subsystem interface commonality and, therefore, resulted in improved hardware compatibility and system interoperability in aircraft avionics.

Also, because the acceptance of the data bus integration technique spread to other applications such as ships and vehicle electronics, the original military standard, which was primarily designed for aircraft avionics integration use, was sanitized by removing any avionic and/or aircraft unique references. Because this action removed any military unique requirements from the standard, a Tri-Service "Notice 2" was published in 1986. The notice states which options each service wants to implement and any restrictions, interpretations and/or clarification that they felt needed to be defined in order to enhance understanding of the standard as used in their military weapon systems.

An Anecdote

The following is a narrative from Irv Gangl, ASD Engineering, Wright-Patterson AFB, Ohio. Irv was a leading proponent for the 1553 standard, but his personal observations give a certain flavor to the evolution of the standard. It is interesting to see how events and certain circumstances with execution timing can influence the definition of a standard.

"When I was assigned to the FX (F-15) SPO in 1968 which at that time was still in competition with three primes, McDonnell, Rockwell, and Fairchild I told them that I had this idea of simplifying the converter problem by making each subsystem put out a digital link. It was considered high risk and was turned down. After the avionics design was completed by each contractor, all three were determined to be overweight. With a commitment to a total gross take-off weight for the aircraft a weight cutting exercise in every dimension still left them slightly overweight. Then the chief engineer asked me "How much weight might your data bus save on the FX?". Approximately 200 pounds, I said. That was just what we needed to put us over the hump. So I was asked to meet with all three primes and initiate a feasibility demo. This was done. I specified to them how I wanted the bus to function, the dual and redundant architecture and protocol. I did not specify the medium and waveforms.

Rockwell had Autonetics build a coaxial frequency division bus (like the 747 entertainment system). It did not work well. Fairchild was teamed with Hughes and demonstrated a system that worked okay, but was rather complex. McDonnell had a two wire twisted pair (one for clock, one for data) for each bus and successfully continued to operate when one bus was cut with wire cutters. Thus the H009 bus was born. They used a sine/cosine summing technique to transmit the data. At 1 Mhz the twisted pair looked like a transmission line causing data skewing based on wire length and thickness variation. It required precise control techniques and was not the best concept.

I then briefed and sold the B-1 SPO on using the bus for electrical power control promising them 8000 pounds of copper savings It became the EMUX design done by Radiation, Inc. (Harris Systems) under subcontract to Rockwell. They worked with us to come up with the new techniques now in 1553 to use Manchester coding, etc,. It then was directed that the electrical characteristics also be used for AMUX and CITS on the B-1. This was done and Harris developed an encoder/decoder chip to be used with the EMUX. I was challenged by my Colonel to standardize the bus when I told him that even though all three B-1 buses had the same electrical characteristics, they were incompatible and thus CITS, the centralized integrated test system, had to build translator boxes between the various buses. For example the EMUX had a word length of 24 bits while AMUX and CITS were 16 bit, like the F-15.

Thus came the start of trying to standardize the Multiplex Data Bus! This was circa 1970. In struggling to establish a committee to assist in the standardization process, I organized an in-house group in engineering to look at all aspects of the data buses use in avionics, also including in the membership, the personnel from R&M and EMI. To justify such a large group my boss made me write a charter and insisted on the keeping of minutes. The charter was passed on up the line for approval. When it reached the ASD Commander, Lt. Gen. Jimmy Stewart, it was sent back unsigned with the following message: I cannot endorse something I don't understand. This seems high risk to me and I'd rather wait and see what will happen first. Let Gangl do whatever he wants to If he succeeds, we'll take the credit; if he fails we don't know anything about it.

The committee didn't understand the concept either and, rather then getting help from them, it turned into an educational process. Program offices that were approached responded negatively predicting poor reliability and high risk. For example, they could not believe that one could replace hundreds of point-to-point wires and numerous cables/connectors with just "one" puny little wire pair.

This instilled in me the need of extreme reliability. Thus the numerous checks in the bus design sending each bit and its complement (Manchester Code), word parity, word count, time-outs, automatic retransmission if anything is out of place, shielding of the cable, dual redundant buses. Looking for help I turned to a committee of the Society of Automotive Engineers which was working on standardizing a submarine communications bus. The SAE/A2K subcommittee was holding a meeting at SCI in Huntsville which I attended.

With the expert help of industry I found out that there were many ways to build a serial multiplexed data bus; all of the designs were good, meeting perceived requirements, but different enough to make standardization difficult. Each company had their own design including the Navy and the commercial airline standardization committee (ARINC/ASCC). And so did I, but no one wanted to give up their own design. So for months we were at a stalemate; until, a meeting of the A2K committee held in Warminster, PA, hosted by the Navy. At the meeting, after talks that were fruitless again, a half a dozen of us met late that night, after dinner, in the chairman's hotel room at the George Washington Hotel. I found out that each industry member was commissioned to stick by his company's design because of the fact, if he agreed to accept his competitors design, it would give that company the competitive edge in future business.

Thus, I told them that, since the Air Force so far was the only user of the multiplex data bus, the standard would use the electrical characteristics from the B-1 and the protocol from the F-15 To my surprise, that made everyone happy, since losing to the Government was not considered giving in

Before publishing the standard, it was coordinated with the remainder of the Air Force divisions and laboratories known to have an interest in multiplexing Following this, it was sent to all interested industry personnel for comment A tri-service meeting was called in an effort to get DOD approval. No agreement was reached at this time because the Navy was in the process of defining their own multiplex system. While the ASD committee was actively defining its standard, the chairman joined the Society of Automotive Engineers (SAE) A2K committee on aircraft multiplexing.

SEA-A2K membership is a joint DOD/Industry group interested in reducing the proliferation of avionic multiplexing. Their effort entailed the development of a specification for a general EMUX.
After establishment of the AF standard, the Avionics Laboratory, as part of their DAIS project, decided to utilize MIL-STD-1553 as their multiplexing design standard. As a result, the Navy gave up its unique approach to multiplexing in favor of the command/response concept defined in the Air Force standard. The Navy's claim, a valid one, was the MIL-STD-1553 did not go far enough in defining the total multiplex system. Therefore, MIL-STD-1553 has been extended to include the definition of the bus controller and the remote terminal as well as adding the flexibility of subsystem interrupt and block data transfer without destroying the standard's definition of the bus system".

Evolution of MIL-STD-1773, Fiber Optics

The data bus philosophy and the resultant standard interfaces are technology independent. However, the design which implements this concept is limited by the transmission media, the transmit/receive electronics and the encoding/decoding logic chip design selected. It is no wonder that, as fiber optic transmission technology matured and was being applied in the commercial world, an effort was initiated by the military to look into its use as an avionics data bus medium. Fiber optics has several advantages over twisted pair cables that make it the ideal transmission link for the future.

First, it has the capability for transmitting digital data at extremely high speeds (primary limited only by the speed of the electronics on either end). Secondly, it is not susceptible to electro-magnetic interference (EMI) nor does it radiate any signals which provides both electrical design and information content which is Tempest proof. Finally, its ultimate overall systems cost is expected to be considerably lower.

The logic behind the MIL-STD-1773 concept is as follows. A single optical fiber is used as the transmission medium. The bus ties into the subsystem via a fiber optic connector. The transmission waveform is a "light" encoded emulation of the electrical Manchester II, Bi Phase L code used in the MIL-STD-1553 wire system. A light-to-electrical transceiver is developed to convert the light impulses to electrical waveforms, and vice versa. The electrical side is identical to what a subsystem terminal would see if a MIL-STD-1553 manchester-to-electrical transceiver was used. The address and logic decoding electronics is identical since MIL-STD-1773 uses the identical message format and communications protocol. The system throughout is kept at the one megahertz bit rate, and except for the transceiver and fiber optic connector, the data bus medium is transparent to the subsystem (i.e., it does not know, nor care, if it is hooked to a 1553 or 1773 system).

Because the same large scale integrated (LSI) logic chips used in MIL-STD-1773 are used in MIL-STD-1553B, the cost of conversion to fiber is significantly reduced.

Conversely, the design of the command/response protocol embedded in these LSI chips limit the speed at which decoding and communications is programmed, address decoding and other message overhead will actually reduce data bit throughout to less than that. The application of MIL-STD-1773 is a logical evolutionary step towards the future by utilizing optical components to gain all the stated fiber optic advantages (except speed) when used as a bus medium. It will be shown later how this is a necessary step towards an orderly evolution to high speed busing technology.

NEXT GENERATION A HIGH SPEED DATA BUS

A committee of the Society of Automotive Engineers (SAE/AE-9B) had been working on the definition and concept of operation of an avionic High Speed Data Bus (HSDB). As a result of their efforts, two architectures with two transmission mediums were under consideration. These architectures include a ring and linear bus with both coax and fiber optic cabling mediums. Note that a unique requirement of HSDB is that there is no centralized bus controller. This criterion requires a less deterministic approach in that an addressing scheme was developed that allowed subsystems to vie for bus utilization. When multiple subsystems request bus access simultaneously, collisions occur and arbitration has to be initiated. Who gets the bus is based on priority and the arbitration algorithm used, "who's on first?"

Another HSDB requirement is that, when new subsystems are added to the bus or existing ones fail, the protocol must be designed to accommodate this bus configuration modification and continue operating without any bus software reprogramming.

In MIL-STD-1553 for example, it is necessary to reprogram the bus controller to accommodate the added subsystem; but the MIL-STD-1553 protocol has predefined reconfiguration criteria resident in the bus controller on how to handle failed subsystems in order to continue degraded, but uninterrupted bus operation.

In embedded avionics computer systems that operate real time, data utilized in complex equations, such as weapons delivery algorithms, are needed from various functional subsystems in the same time window to provide accurate results. MIL-STD-1553 is especially suited for this kind of problem. Even though the data transmissions do not have to be clock synchronized (i.e., it is an asynchronous data bus), the message traffic, controlled by the bus controller, is handled sequentially in repeatable frames that are very predictable. The bus controller assures that the data needed in the equation is sampled in real time from whatever sensor that provides the information in a sequential, deterministic manner. That is, it assures that the sequence of events that gathers the data for the algorithm are done in the same time window. Data collection is sync (data user) driven keeping unwanted data off the bus and reducing the bus duty cycle. Central control also assures system data flow synchronization and supports testability by accurate event repeatability.

In the HSDB design, data is source-generated and transmitted asynchronously on the bus. When the subsystem gets access to the bus, which also happens in an asynchronous manner, the data generated by the subsystem is broadcast. This approach requires that receivers of information must actively sort through the data looking for the wanted, ignoring the undesirable. Not all data is needed at all times, but the extra sent is not perceived as a problem because of the significantly higher throughput capability of the HSDB.

The HSDB architecture eliminates the need for a bus controller and allows new subsystems to just be added to the network to vie for their own bus time. It is assumed those subsystems needing the new one's data will be reprogrammed to pick it off the bus.

Because bus access is not centrally controlled, arrival of data is unpredictable and, also, the subsystem bus access sequence is not necessarily repeatable. Therefore, the data gathered from the various subsystems is not guaranteed to have been sampled in the "same" real time window. As a result, each data sample needs to be time-tagged at the source. So when the weapon delivery algorithm is solved, for example, all these data samples that define a fixed point in space at any specific instant of time (such as navigational coordinates, altitude above target, range, ground speed, wind, attitude, etc,.) must be adjusted to fall within the same real time window. This requirement establishes a need for keeping track of data samples so that interpolations or trend predictions could be done on these input signals to put them into the proper time perspective. The result is higher subsystem processor software and execution time overhead. It is anticipated that if a very small number of terminals are on the bus there will be no timing problem; however, if even one fourth the maximum of the 64 terminal architecture were to be used, the number of collisions would dramatically increase and most likely cause a serious time skew.

Due to technological advances in recent years, processing speeds have increased manifold. Also, the new HSDB will run at data rate speeds over 50 Mhz with a minimum of 20 Mhz throughput. A lot more information can be transmitted on the bus despite the increased bus arbitration overhead. New weapon systems are in the bus design stages that require this high speed capability now!

The protocol must allow for fault-tolerant architecture, data integrity and self-diagnostics. The general feeling in the acquisition community is that arriving quickly at a reliable, standardized protocol is still a high risk while the fiber optic medium implementation is an acceptable risk. That is, militarized fiber optic components are in development, but few large-scale integrated HSDB decoding logic circuits exist. The use of MIL-STD-1773 control of the high speed digital link for data transfer in avionics can, if desired, be extended to additional wavelength division links that can carry either additional digital data or even analog/video data. The amount of parallelism is only limited by transceiver technology.

HISTORY OF MIL-STD-1589

In the late 60's and early 70's, expert programmers would program in assembly language because the cost of memory was so expensive. If a higher ordered language were used, it would have to be compiled and since the compilers were inefficient it would require more memory than if programmed in an assembly language. With the phenomenal lowering of memory costs, and the ability to produce more efficient compilers and support tools, higher order languages became the way of software programming. The development of a standard programming language is a multi-year effort involving many phases of activity starting with language requirements analysis, leading to language definition, production of compilers and programming utilities, and then configuration management of the support software and documentation. After a study of the requirements for a standard Air Force high order language, the JOVIAL/J73 language was defined by MIL-STD-1589A (later superseded by MIL-STD-1589B). Several years of compiler development has resulted in JOVIAL/J73 compilers hosted on three mainframe computers and targeted to several embedded architectures. The compilers were developed before the other utilities that now exist.

There are four major utilities apart from the compilers. These are:

a. Interactive Debugger - DEC-10 hosted symbolic debug package,

b. Code Auditor - IBM 370 hosted utility to check conformance of JOVIAL/J73 source code to coding standards,

c. Program Support Library - IBM 370 hosted configuration management utility,

d JOVIAL Automatic Validation System - IBM 370 hosted utility to assist in automatic testing of JOVIAL object code.

There are many facets to the development of a standard programming language. Those who were involved with the evolution of JOVIAL/J73 had discovered the complexity of standardization. Many important lessons were learned in bringing JOVIAL to a usable state. These lessons were applicable to the development of other languages, such as, Ada.

The four most important lessons are the following:

a. Optimizing compilers for embedded targets are complex pieces of software. The same standards that are used for application coding should also be applied to compiler implementation. A sufficient design, coding and test period, should be allowed for a compilers development rather than have it driven by the schedule of the operational programs.

b. A changing language specification during compiler development opens the door to an implementation disaster. If a major language change is necessary, be prepared to go back to the design phase of the compiler's implementation.

c A compiler for an embedded target must generate very efficient object code. Plan for this fact in the compiler's design phase rather than try to retrofit optimizations in later.

d A commonly available implementation language on mainframes, such as, FORTRAN (and perhaps later Ada) significantly decreases the cost of compiler rehosting

APPLICATION OF MIL-STD-1589B

JOVIAL J73 as described by MIL-STD-1589B was the current Air Force standard higher order language for embedded computer applications software. JOVIAL is a block structured, strong type checking, procedure oriented language. This version combines the features of many earlier dialects of the language, e.g.; J3, J3B, J4 and J73/I. General Dynamics was implementing all of its flight programs on the F-16 C/D avionics in JOVIAL J73. These OFPs include the Fire Control Computer, the Data Transfer Unit, the Stores Management Set, the Multi-function Display Set and the Up Front Control processor. An integrated JOVIAL J73 support Software System (ISSS) consisting of three separate computer programs (a compiler, assembler, and linker) operating in a common IBM 370 type host environment was developed to support this use of JOVIAL J73.

The host environment forms the major interface between the programs and the user, and provides the means for running the programs and supplying inputs and outputs.

General features of the JOVIAL ISSS are as follows.

a. Portability. Host dependent portions of the system are being minimized and isolated to allow the system to be rehosted with a minimum of effort.

b. Retargetability. Target dependent features of the system are parameterized and isolated to better facilitate changes in the target computer or to totally retarget the system.

c. Appropriateness. The ISSS is being specifically designed to support the performance requirements associated with real-time avionics software

d. Maintainability. The ISSS will be maintainable in source form by organizations other than the developer.

General Dynamics had worked with the USAF to extend this common support software package to encompass all F-16 avionics, including GFE; multiple users results in multiple benefits. Cooperative application resulted in faster maturing of the support package and provided a single, unified, support software package at the ALC.

MIL-STD-1815, Ada

Many of the procedures developed by the Air Force for controlling JOVIAL can be applied directly to Ada. The type of tailoring needed for some of these procedures is the topic of this Section, in which we point out some of the more obvious considerations to be made in preparing for Ada.

a. IMPACT OF DOD-WIDE LANGUAGE. Since Ada is a DOD-wide language, maintenance of the Ada language standard will require coordination among the Air Force, Army, and Navy through the Ada Joint Program Office (AJPO). This will result in a lengthy process unless efforts are made to establish an efficient screening procedure for proposed changes. In effect, the Services would propose changes based principally on criteria of language utility; and the DOD would dispose of or approve those changes based principally on criteria of language and compiler impact and the coordinated satisfaction of the needs of all the Services. The current JOVIAL language control mechanism could serve for the Air Force with adjustment of the criteria for analysis and acceptance

b. GRADUAL TRANSITION TO Ada. One point that nearly everyone in the standardization community agrees with is, "We want to profit from our lessons learned in JOVIAL and not make the same mistakes in the Ada effort." With that point in mind, the trend we observe in the Air Force towards making the Ada transition a gradual one is readily understood. This transition occurred in four carefully planned phases that we might descriptively title JOVIAL, JOVIAL/Ada, Ada/JOVIAL, and Ada. With the benefit of proven language control procedures on which to base the transition and a flexible number of computer resources from which to draw in implementing each phase, the Air Force would enjoy a high probability of success with such an approach.

c. Ada VALIDATION POLICY. The Ada JOINT PROGRAM OFFICE (AJPO), staffed with Air Force, Navy and Army personnel, has the responsibility for ensuring the appropriate validation of Ada compilers throughout DOD. AJPO policy requires that before a compiler can use the name Ada, it must be fully validated, i.e., there must be a current certificate of validation issued for the compiler from the AJPO They may also require renewal of the validation every two years. AJPO presently allows use of the trademark Ada in conjunction with partial implementations if a caveat is included in all associated advertisements These policies mean that frequent retesting of full and partial implementations of Ada may be required, and therefore configuration management of the Ada Compiler Validation Capability (ACVC) test suite will be very important.

A final consideration is that with the explosion of Ada implementations on microprocessors, there is an attending requirement for the ACVC to be adapted to the microprocessor environment It is unlikely that these processors will host an Ada Programming Support Environment. This entire area presents additional new challenges for establishing validation and configuration management procedures and tools.

d. SIZE OF Ada USER COMMUNITY. The DOD standardization policy for Ada obviously resulted in an Ada users community that exceeds the size of the JOVIAL users community by several orders of magnitude. User services is already a big job and that job will increase significantly for the Ada users community. We recommend a direct extension of current JOVIAL users services, with the addition a liaison function to interact with other user groups that may exist There is the JOVIAL/Ada Users Group transitioning to an Ada/JOVIAL Users Group, and by popular demand they have established the "Ada Corner" in the JOVIAL Newsletter.

e. RAPID GROWTH OF Ada EXPERIENCE BASE. With Ada an early emphasis on user support and coordination is anticipated among the Services to assimilate and dispense a common knowledge base. Then, as the users emerge, a rapid growth of the Ada experience base and a high demand for compiler validation services is expected. This means early preparation is essential to become familiar with ACVC and to refine JOVIAL procedures for administering it effectively.

f. Ada AS AN ANSI STANDARD. DOD recognized that to accomplish its long term purpose, it must expose Ada to public review and obtain a national consensus. Therefore, DOD approached the American National Standards Institute (ANSI) about making Ada an ANSI standard. Of three possible avenues for accomplishing this, DOD chose the canvas approach. The canvas has been completed.

As a sponsor of Ada as an ANSI standard, the DOD will be totally responsible for maintenance of the standard Later, DoD intends to make Ada an international standard through the International Standards Organization (ISO). The degree to which the DOD, ANSI and ISO standards are the same will be affected by the review process of the respective organizations.

Once Ada is an ANSI standard, it must comply with ANSI rules, which require that the standards must either be revised, reaffirmed or dropped within a five year period. This means any changes to MIL-STD-1815 will be reviewed by the ANSI technical committee before approval is given to implement those changes in the ANSI standard. Furthermore, if Ada becomes an ISO standard, another level of review is required by an international committee to approve changes to the ISO standard. Notice of plans to revise the ISO standard must be given to the international community at least a year ahead of the target date for revision of the standard.

SUMMARY OF SOFTWARE STANDARDS

JOVIAL was to be the interim standard language for Air Force avionics embedded computers until Ada became available. Language control is the assurance of the integrity, stability, consistency and usability of the language. The four major elements of language control are: (1) a well defined and consistent policy for controlling language changes, (2) a mechanism for making these changes, (3) a mechanism for checking for conformance to the language specification and (4) a centralized knowledge source. The principal control tasks are establishing and maintaining Language Control Facility (LCF) policy, maintaining the language specification, maintaining the validation, performing validations, and providing user and Program Office support. The LCF has developed rigorous descriptions of procedures for these tasks using SADT models. These models promote tight administration of the control function and provide an organized basis for reconfiguring the language control function to new languages, such as Ada.

There are several readily recognized characteristics of Ada that need to be considered in establishing language control for it. First, since Ada is DOD-wide, maintenance of the specification will require inter-Service and AJPO coordination and will be a lengthy process. One approach to streamlining this task was to establish both a component level and a DoD level of LCF analysis, and, in effect, set up a well coordinated double-screening process. Second, the Air Force trend toward transitioning to Ada very gradually suggests we should build the Ada control function to be operated in parallel with that for JOVIAL, then gradually phase out the latter. Third, a need is anticipated for frequent testing and retesting of Ada compilers and a possible need for validating partial implementations, including those on microprocessors. This makes configuration management of the ACVC a very important factor in successful test administration, and it poses many new challenges for language control. Fourth, the large size of the Ada user community makes user support a big job, and liaison among user groups will be necessary. Fifth, a rapid growth of the Ada experience base and an equally rapid transition to a high demand for validation services is anticipated. Finally, with Ada as a military (DOD), ANSI and ISO standard, coordination on changes to the language will be especially important and will affect control activities at all levels.

APPLICATION OF MIL-STD-1750A INSTRUCTIONAL SET ARCHITECTURE

The Air Force wanted to develop a MIL-STD-1750A chip set. However, past DoD contracting for "non-commercial" chip sets had not been supported by the semi-conductor industry because of the low (by their standards) quantity production runs planned. To interest the semi-conductor industry, ASD decided to use a "prime airplane contractor" with a large production run to incorporate the standard chip set. Thus, the F-16 System Project Office contracted with General Dynamics to procure a small, low-power, cost effective implementation of MIl-STD-1750A for use on the F-16 program.

An instruction set architecture (ISA) as described in MIL-STD-1750A includes not only the instruction set, but also the interrupts, fault handling provisions, extended memory addressing, and protection mechanisms as viewed by the machine language programmer. In this design, all features of the standard are partitioned into three sets of requirements: (1) the Central Processing Unit (CPU) incorporating all mandatory requirements for the F-16; (2) the Memory Management Unit (MMU) combining the optional features of extended memory addressing and operating system paging protection; and (3) the Block Protect Unit (BPU) holding the memory write-protection maps. Other optional features within the standard are left to the embedded computer system designer where they may be incorporated easily with standard digital components.

One benefit was the establishment of the MIL-STD-1750 Users Group in August 1979 as a voluntary organization of industry representative to exchange information and status of MIL-STD-1750, and to recommend changes to the standard. This established a pattern for future new technology development. MIL-STD-1750 is the standard for an instruction set architecture. It does not define specific implementation details of a computer.

The benefits of this standard ISA are the use and re-use of available support software such as compilers and instruction level simulators. Other benefits achieved were: (1) reduction in total support software gained by the use of the standard ISA for two or more computers in a weapon system, and (2) software development independent of hardware development.

The Air Force recognizes the group as the sole industry body to recommend changes and improvements to the standard. Although the Air Force and other government representatives participate in the committee and group discussion, they do not vote. The Air Force uses a "Control Board" to accept changes or refer them back to the users group. The control board and the users group is part of the control structure which the Air Force has established for MIL-STD-1750.

The committees are the backbone of the group. The following is a summary of the function of the committees.

Standards - To interpret and clarify definitions and descriptions appearing in MIL-STD-1750; to assess the scope and applicability of the standard.

Architecture - To assess the value and impact of proposed architecture modifications or extensions to the standard.

Verification - To address issues related to verifying and certifying MIL-STD-1750 hardware implementation.

Software Tools - To act as an information exchange to MIL-STD-1750 related software tools, and to assess the need for MIL-STD-1750 support tools.

Liaison - To retain communication and coordination with other related standardization groups.

The group has meetings three or four times a year, each for about two days. The committees elect their own committee officers and make committee reports to the full Users Group at each meeting.

THE STORES MANAGEMENT INTERFACE DEVELOPMENT - MIL-STD-1760

Interoperability between aircraft and stores was precluded by a set of obstructions. Within this set, a primary obstruction was the nonstandard aircraft-to-store and store-to-aircraft electrical interface. Interfaces between aircraft and stores are becoming increasingly sophisticated and complex. At the same time, there is an increasing desire on the part of interoperability between aircraft and stores.

The number of different types of stores is large and continues to grow as a result of development and acquisition programs. Stores include conventional general purpose bombs, guided bomb dispensers, missiles (air-to-air and air-to-ground), nuclear weapons, sensor pods, dropped sensors, camera pods, counter- measure pods, fuel tanks, dispensers, guns, rockets, etc. Interfaces between aircraft and stores are only partially guided by standards and, therefore, have tended to evolve into system peculiar mechanical adapters/connectors, electronic signals, power connections, and other armament assemblies which make interoperability impossible without major modifications to aircraft and/or stores on a case-by-case basis. The trend toward more complex store functions which require increasing amounts of avionics data from aircraft systems is causing the problem to become increasingly acute. Examples of this situation are AMRAAM, HARPOON, PHOENIX, HELLFIRE, ATLAS POD, ALCM, etc,.

On the aircraft side of the interface, Stores Management Systems (SMS) are unique to each aircraft type and sometimes each model. Old aircraft Stores Management Systems are generally hardwired, not integrated not automated and reflect outmoded, obsolescent electronics design.

Although new aircraft SMS designs reflect current technologies in electronics and communications, they are still tailored to a specific store list and were not designed for growth. Invariably, the changing stores list requires modifications almost as soon as the aircraft begins its operational life. The adoption of acquisition methods which result in aircraft systems which are tailored to handle specified lists of stores has limited weapon system capability, growth, and flexibility. These methods yield weapon systems which are well defined within themselves, but are inflexible and costly to modify.

The intent behind developing MIL-STD-1760 was to support achievement of interoperability between independently designed stores and aircraft by imposing specific interface design requirements applicable to each. To accomplish this, the interface characteristics of the aircraft and of the stores must be controlled so that each unit of a given kind, e.g., a carriage store, is functionally interchangeable with any other unit of the same kind.

The overall goal of the standard is to remove non-standard electrical interface as an obstruction to interoperability. Application of the standard will result in a wide range of stores being interoperable with a wide range of aircraft. Modification of aircraft and store hardware to allow individual combinations to operate together will be minimized. The use of adapter modules will be discouraged. In this way, the effort and cost necessary to integrate aircraft and stores will also be minimized.

MIL-STD-1760 was designed to be flexible enough to accommodate individual system peculiarities. In particular, implementation may change with technology advances as long as the interface characteristics are maintained. The MIL-STD addresses only the electrical interface between aircraft and stores.

Compatibility parameters such as size, weight, aerodynamics, avionics capabilities, etc., must be satisfied in addition to the electrical interface in order to realize interoperability. The electrical, or MIL-STD-1760, portion of the aircraft/store integration effort will ultimately be limited to developing software modifications necessary to accommodate new stores.

To achieve the program objectives, the Aircraft/Store Electrical Interconnection System (MIL-STD-1760) consisted of three hierarchical elements: electrical, physical, and logical. Each element is described below:

a. Electrical: The electrical element quantitatively specifies the signal set the aircraft must provide and that the store must utilize. The signal set for the Aircraft Station Interface was published in July of 1981.

b. Physical: The physical element of the standard defines the intermateability characteristics of a set of armament connectors. It is envisioned that the characteristics of the following three classes of connectors will be specified:

- An umbilical connect for gravity release stores employing the MIL-STD-1760 signal set.

- A low cost connector for simple stores employing a limited subset of the 1760 signal set.

- A blind mating connector for rail launched stores employing the 1760 signal set.

To achieve the goal of interoperability, it is not necessary to completely describe the interconnection component as one would, for example, by calling out a particular part number.

The physical element of the standard defines only those characteristics essential to intermateability. Essentially this means that a particular set of physical dimensions had to be defined. The method of achieving this definition for gravity release and most eject launch stores was to select a set from an existing state of the art connector. Several manufacturers designed similar connectors for MIL-STD-1760 employment under the constraint that each must employ the selected set of intermateability dimensions. The problem of intermateability also includes defining the connector insert physical and functional layouts, particular contacts, crimping tools, and etc,. In all, some ten or twelve piece part specifications were required to completely define a connector as a functionally intermateable system. Most of these have been developed, coordinated, and published for the lanyard release or so called umbilical connector for gravity release weapon.

The umbilical connector described above is intended for relatively sophisticated weapons and as such is complex. There was an effort under the SAE AE-9 Aerospace Avionics Equipment and Integration committee to define a signal set for simple low cost stores (SLCS). A configuration employing only a single channel MIL-STD-1553 data link, 28 volt dc power, addressing lines, and associated ground returns has been proposed. The major difference was in the method of selecting the intermateability aspects.

Rail-launched weapons pose particular interconnection problems such as the necessity for blind mating. There is also the problem of rocket or jet blast burning of connector contacts. Because of these considerations and others, the definition of the physical interface for rail-launched stores was deferred to following that for gravity release weapons. The first store incorporating the MIL-STD-1760 interface on the F-16 will be the AMRAAM missile which will be added to the existing AIM9 stations.

It was recognized that the interface requirements specified for the AMRAAM program were going to impose very difficult and complex interconnection problems. Since the AMRAAM launcher must meet certain interface requirements unique to each of the F-14, F-15, F-16 and F-18 aircraft, internal space allocation for the connector and its release mechanism was critical. The method of coupling the missile receptacle to the launcher connector was readily adaptable to other rail-launched weapons. That possibility in itself drove the AMRAAM connector toward a standard device.

It was desirable to undergo a long term systematic development program for these three classes of connectors. However, the requirement was for interoperability was now. The approach MIL-STD-1760 had taken was to select and standardize on the best which is available or can be made available in the near term.

c. Logical: The Logical element of MIL-STD-1760 is primarily concerned with the utilization of the MIL-STD-1553 multiplex data bus. Although this multiplex standard defines word types and protocols for general types of data transfers, further definition would be helpful to optimally apply MIL-STD-1553 in the aircraft/store environment.

It was envisioned that the MIL-STD-1760 logical element would be comprised of two primary areas; Standard Data Words and Aircraft/Store Protocols. Standard Data Words are MIL-STD-1553 data words which have been assigned specific bit patterns to represent functions, commands or values. As such, they provide the same information to all users. If data words are not standardized, implementors will by necessity derive their own. Unique words, in turn, complicate aircraft or store interpretive hardware and software. The Aircraft/Store Protocol area provides a definition of rules to transfer data between aircraft and stores. Additional protocols are necessary in such areas as user application data, store addressing, message routing, block data transfer, message encoding, encryption, and fault handling.

MIL-STD-1760 implements a new philosophy in aircraft/store electrical integration. No longer will aircraft be restricted to designs for unique sets of store requirements and, conversely, stores will not be constrained to interfacing with aircraft peculiar electrical configurations. Through MIL-STD-1760, aircraft will offer a standard electrical capability and stores will electrically integrate in a prescribed and orderly manner. Through MIL-STD-1760, interoperability can be enhanced and aircraft modification costs reduced.

ACCEPTANCE OF STANDARDIZATION

The success of any standard is determined by its acceptance in the community at large. It is not enough to simply introduce a standard, it must be applied. The degree of acceptance is often affected by, (1) the manner in which the standards are developed and introduced to system designers, and, (2) how they impact organizational structures. To improve the speed and effectiveness of the standardization process, it is necessary to choose an appropriate administrative approach to standardization.

Four major administrative approaches have been used to introduce standards. These are:

a. Defacto industry standard - an official standard is adopted by manufacturers to increase product compatibility.

b. Technical society committee - the standardization process officially sponsored and monitored by a recognized technical society, such as IEEE, SAE or EIA.

c. User Group - a committee of interested military and industry personnel meets regularly to develop or mature a standard. Examples include the JOVIAL User's Group and the 1750 User's Group.

d. Unilateral government - an interested government organization develops a standard and requires its use on related programs.

Neither the defacto industry nor the unilateral government approach have high success rates since only one side of the product development partnership is involved. Both the technical society committee and user group approaches have worked very well. For systems with purely military applications, the user group approach is favored since the military can sponsor the group. The military can then determine the participants in the meeting, set the frequency of the meetings, and fix target dates for the availability of draft standards.

By itself standard modular executive software provides only limited improvements in the system software design and integration effort. Much greater improvements can be achieved if the standard modules are combined with standard interfaces between the executive to applications and application tasks, and to the buses. A rigid executive to application interface, such as the one developed for the DAIS program, permits the applications software design tasks to be undertaken without detailed knowledge of either the executive or the system control procedures. In addition, the applications software can be functionally partitioned allowing independent design groups to define and develop portions of the system. As long as each software module adheres to the standard interface, and as long as the standard interface module includes the bus control functions, the system integration process becomes a simple mechanical task.

Technology is becoming available to significantly increase the effectiveness of military aircraft operating at night, weather and in a severe threat environment. The potentially of this technology can be realized through improved integration design based upon modular hardware and software concepts and proper application of a program of military standards acceptable to industry.

The technical approaches selected during these efforts need to be rapidly reflected in additional military standards that will encourage industry wide acceptance of common modular design techniques.

When the modularity concept is fully exploited, resultant availability and performance levels will be equivalent to a larger operating fleet, thus providing force multiplication. Current Air Force avionic integration technology programs should be supported to provide a forum and proving ground for these initiatives.

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AVIONICS STANDARDIZATION IN EUROPE

by
L. GUIBERT
DGA/DCAé/STTE
129, Rue de la Convention
75731 PARIS CEDEX 15

SUMMARY

I will first try to recall the different bodies which deal with standardization at both french and european levels.

Avionics standardization in Europe relies up to now on common standards, such as Stanags. That approach is not large enough to ensure real interoperability, as will be demonstrated with the Link 16 example.

It is foreseen that one of the major challenges for future avionics standardization will be the modularity. For some reasons, there must be international commonality in order to obtain minimization of costs.

One important issue is clearly the applicability of modular avionics on board european aircraft. This has been studied in France with relation to the Rafale. The results of that study will be discussed in some details.

Another issue is the standardization of Instruction Set Architectures (ISA) in the field of data processing. That concept helps solving some problems, such as software interchangeability and reconfigurability, but has also severe drawbacks. A solution to the need which does not imply common ISAs is envisaged in France : the software bus. That concept, related to EXTRA (for Real Time Ada Extension) is proposed.

It is clearly understood in Europe that modular avionics will gain maximum advantage if its F3I specifications are common to the different nations and services within NATO. This enforces the need for cooperation at both governemental and industrial levels. Europe has launched two multinational programmes in order to define and validate a common avionics architecture for application in the 2000's : the ASAAC (cooperation between UK, GE, FR and hopefully US) and the EUCLID CEPA 4 (within the IEPG) The scope and content of first phase of these programmes will be described.

INTRODUCTION

This lecture will be divided into five main parts :
- A review of the different bodies in charge of aerospace standardization in Europe.
- The relationship between standardization and interoperability.
- An example of area where standardization has large implications : modular avionics.
- Another example · the Software Bus.
- Conclusion.

I - NORMALIZING ORGANIZATIONS IN FRANCE AND IN EUROPE

The organization globally in charge of normalization in France is the AFNOR (Agence Française de NORmalisation), which is subordinate to the Ministry od Industry. It elaborates the national standards (NF) in every industrial sector, in concert with other specialized normalization offices.

At the european level, the counterpart of the AFNOR is the CEN (European Standardization Committee), which works out the European Norms (EN). The AFNOR is representing France within the CEN, while other national organizations represent their countries. The aerospace industry party to the CEN is the AECMA, which gather a number of national trade associations.

In that aerospace sector, the BNAE (Bureau de Normalisation de l'Aéronautique et de l'Espace) is in charge of elaborating and editing the french standards (NFL). For that purpose, it works in relation with the ministry of Defence, via the DGA (Délégation Générale pour l'Armement), and with industry, via the GIFAS (Groupement des Industries Françaises Aéronautiques et Spatiales, the french ad hoc trade association), which secure most of the necessary fundings.

The BNAE may also assume other tasks, such as
- technical support to the elaboration of new standards, both at national and international levels,
- conducting inquiries in France regarding international draft standards.

This is particularly the case for NATO standards (Stanags) in avionics (AVS and AI NATO groups). For that purpose, it has set up several specialized working groups, to which the industry and the DGA take part.

The BNAE is also representing France at ISO (International Standardization Organization) in its area (TC 20).

Figure 1 describes the relationships between the different standardization bodies in France, in Europe, within NATO and worldwide. Figure 2 shows the participating countries to the international bodies.

II - STANDARDIZATION AND INTEROPERABILITY

It is generally agreed that interoperability necessitates the conformance to common standards. The pending question is : is that sufficient? In order to answer it, it is usefull to consider a particular exemple . the link 16.

Briefly described, the link 16 is a protected, networked data link, that is defined by the Stanag n° 5516, which amongst others, describes the usable messages, part of which are mandatory and other are not. The organization of the networking and of the messages is to be in accordance with another NATO document, the AdatP16.

In this case, interoperability lies in the ability to exchange and understand messages among different participants : Air, Land and Sea Forces from one or several allied contries. This means that the following must be defined :
- the multi-forces or multi-national networks that will allow the exchange of information,
- the messages that will be exchanged within each network, together with their emission order and time by the terminals,
- the content, formatted at the bit level, of the messages (field).

For each net, it is necessary to define data transmission frames in the same way it has to be done for such a multipexed bus as 1553B. This implies some inter-forces office in charge of organizing the communication nets and channels.

It is clear in this case that the pure implementation of common standards (stanags, AdatP) does not fulfill the need for interoperability. This requires additional tasks, to be done commonly by all parties. Moreover, complete interoperability cannot be guaranted unless the participants utilize the same hardware and the same software. If not, the amount of trials and tests that it would necessitate is well beyond the feasible

This exemple learns two lessons.
First, common standardization cannot ensure interoperability in all cases.
Second, some requirements in that field, given the amplitude and the difficulty of the tasks to be performed, may lead to cooperative work, including the industrial one.

III - MODULAR AVIONICS - AN APPLICATION STUDY

Modular avionics is another field where cooperative approaches are needed, from the design phases on, in order to ensure a certain level of interoperability.
This part of the lecture is divided in four chapters :
- review of the concepts,
- review of the programmes,
- applicability to an european fighter aircraft,
- conclusion.

III-1 - The Concepts

Actual avionics systems are composed of pieces of equipment (black boxes), connected to several data nets (busses), each of which performs one or more functions. Each box is optimized for its functions, and the system architecture is fitted to the missions of the aircraft, taking into account the constraints, such as the arrangement of the equipment cases, the volumes, weights, consumption of thehardware, the cost/performance ratios, etc. The system components are defined, in theory, following a functional analysis which leads to determining and sizing the necessary functions and to assign them to such or such box. There are however some functions that can only be completely described during the development. In such a case, the sizing of the material resources is defined with some margin. This is also done in order to allow the future system evolution (pre-planned product improvement), whenever possible. There is obviously in that approach some potential problems, such as under- or over-estimation of the capabilities and performances of the equipment.

In addition, given the increasing complexity and integration of the functions and the number of missions in one hand, and the technological break through in the other hand, that kind of architecture has today some clear drawbacks.

This is true at the technical level, because in addition of the problems already mentionned, it induces very important data exchange volumes, and thus an increasing complexity for the communication nets. The data fusion capability is also bounded by the multi-location of information and of the related processing. Consequently, integration and validation become difficult to deal with.

At the operational level, the availability and survivability are hindered, because redondancies of functions are only possible by doubling the hardware that implement them, which is not allways possible and is only efficient after one first deficiency.

For maintenance purposes, each failure leads to the replacement of one (at least) box. The spare parts stocks are therefore heavy and costly, and many skilfull people are needed.

As far as costs are concerned, some drawbacks have already been showed (maintenance, availability). Some other ly in the black boxes approach, due to the separate development and acquisition of each of them, with generally very few common components, which obviously multiplies the spendings.

The modular avionics offers to cure these illnesses.

The main idea is to gather within a small number of digital centers all the digital processings, which represent the large majority of the future systems. One such center is composed of an electronic rack, in which standardized, interchangeable processing elements are plugged.

The potential advantages of that concept can be described as follows.

All the functions of one type, realized up to now by a piece of equipment or another one, are performed by generic modules. The number of the different modules (electronic boards) needed is therefore much lower for the entire system. This reduces the complexity of the system and the development costs (and the production costs because of higher volumes).

The modules are provided with full self-test capabilities, in order to allow the detection and localisation of the failures on one of them. They are replaceable in line. Thus, the maintenance is highly simpler, and the spare stocks are less voluminous and less expensive.

One process can be realized by whatever module of the right type in the rack. The related operational software is stored in mass memories. This allows multiple path reconfiguration, with an installed capacity much lower than needed with classical architectures. The resulting availability and survivability are increased significantly, up to the point where the spare modules in a rack, together with their high reliability allow to start a mission with an initial failure ratio without loosing every reconfiguration capability. Theoretically, the scheduled maintenance operations may adequately ensure the needed availability.

The processing capacity provisions may also be utilized for system improvements and makes them easier and cheaper.

Modular avionics shall globally allow the system volumes, weights and power consumption to decrease, with the synergetic regroupment of functions (in that area, the comparison with other solutions must be done considering equivalent capacities, in particular in the field of reconfiguration), and the reliability to raise because of different factors (use of leading edge technology for every module, lower dissipated power and interconnection, etc).

It is however at the financial level that the benefits must be definitive, particularly in the context of diminishing defense budgets. In that area, the reduction factors have been raised above : in acquisition cost (for development, with the reduced number of different hardware, and of the associated tools for software and validation too, and for production) and in life-cycle cost (maintenance, logistics, improvements).

It must be clear that the ability to reduce costs with depends heavily of the obtained level of standardization. The more platforms will make use of the same modules, the more attractive will be the scale savings. This is the reason why the success of modular avionics lies in its universal application to every military aircraft, in the same way. This is particularly true in Europe, where the national military fleets are not large enough to completely achieve the potential savings, with regards to the investment that is necessary to develop the concepts.

In that wide area, the completion of common standards to several nations requires to take into account the specific needs and constraints of each of them : here, the need for standardization leads to a high degree of cooperation between the nation, at both governmental and industrial levels.

This brings to a new sophisticated kind of interoperability. The modular avionics concepts open the way towards new objectives : be able to implement on a platform a function that was developped for another one, by means of standardized hardware and software, and to maintain the systems of several aircraft with common means (tools and spare parts). These objectives are ambitious, but not irrealistic from a technical point of view. They are perhaps one of the key-points for our ability to keep a highly efficient defense with limited budgets.

III-2 - The programmes

The modular avionics concepts have come out in the United-States, in the frame of the PAVE PILLAR programme conducted by the USAF Wright Laboratories. This programme was started in 1982 to provide the preliminary architecture definition, and was terminated in 1987 with the production of detailed design specifications for the architecture.

On that basis, a US tri-service committee, the JIAWG (Joint Integrated Avionics Working Group), was settled to identify and develop joint avionics components and software, for application on the Advanced Tactical Fighter (ATF) and the Light Helicopters family (LHX).

In Europe, several projects have been launched in that area.

In Germany, the NAS (Neue AvionikStruktur), started in 1986, is intended to define the next generation of avionics suite and to investigate its applicability in retrofit programmes. Its phase 1, terminated in 1988, provided a concept definition for advanced modular avionics and a concept evaluation. In phase 2, started in 1989, a risk reduction demonstration for subsequent developments has been undertaken, and will lead in 1991 to preliminary architecture specifications.

In the United Kingdom, a continuous research programme is running since 1986, for identifying relevant technology and concepts and modeling life-cycle cost benefits. Subsequent work has been aimed at investigating critical areas. A flexible research rig is being developed that will enable new concepts and components to be tested.

In 1988, the UK MOD began a programme to demonstrate advanced modular avionics architecture : the A3P (Advanced Avionics Architecture and Packaging). The first phase, which is complete, was intended to study emerging concepts and technologies and to assess the benefits in operational performance. Phase 2 will consist of subsequent architecture definition and phases 3 and 4 of validation of the feasibility and of the definition.

In France, the development of data processing, high-speed data bus interface and mass memory modules, compliant with the PAVE PILLAR standards, was began in 1988, in cooperation with the United-States (USAF). Validation is expected in 1992. The applicability of a modular avionics suite to a fighter aircraft has been studied in an effort started in 1989. The results of that study will be adressed in the next chapter. It willbe followed by a definition and validation phase, in the frame of an exploratory development, A3 (Architecture Avionique Avancée). Some risk reduction studies are also started in 1991.

All these efforts require the knowledge of many aeronautical compagnies, and must be coordinated in order to ensure the convergence towards common specifications. The BNAE, in its role of technical support for future standards, has been tasked to do that coordination, for the purpose of which several working groups have been formed, which are comprised of members from the whole french aeronautical industry and from the DGA.

In another hand, several efforts have been initiated for the application of the concepts of modular avionics in the field of the CNI (Communication, Navigation, Identification). In the United-States, the ICNIA (Integrated CNI Avionics) led to the realization of advanced development models which integrate the CNI functions in the 2Mhz-5GHz spectrum and whose evaluation has begun in 1990. In the United Kingdom, the RAE (Royal Aircraft Establishment) has realized a technology demonstrator designed to show the capability of an integrated communications suite. In Germany, the NAS has dealt with the CNI and in France, the need for integrated CNI and the associated architecture are being studied under the SIERA project (Système Intégré d'Equipements de Radio Aéroportés), lauched in 1990. The results will form the bases of an exploratory development to be initiated in 1991, that will be aimed at the architecture validation.

This brief listing shows that the different countries have the same preoccupation and the same general objectives. But the related efforts are national ones. As has been demonstrated earlier, getting international standards in that domain necessitate extensive cooperation. This requirement is still enforced by the heavyness of the investment involved in the validation of a modular architecture for the whole avionics suite.

This is the reason why the four countries above mentionned (USA, UK, GE, FR) have worked since 1988 to the initiation of a cooperative programme for the definition and validation of a common avionics architecture, aiming at application in the years 2000-2010 timeframe. It is the ASAAC (Allied Standard Avionics Architecture Council). Its mission is to develop the technical specifications for an A3 consisting of functionally interchangeable (form, fit, function, interface), integrated avionics modules that can be used by different aircraft as needed to perform their mission. The ASAAC end objective is to propose a set of validated Stanags for a common A3 and associated avionics building blocks (common modules), allowing to ensure their interchangeability.

A partcular emphasis will be put on core avionics and the CNI. however, the programme will tackle the problems related to the entire sensors system in an aircraft. It will comprise several phases : definition, validation, evolutions.

The ASAAC is the object of a memorandum of understanding signed by the ministries of defense of Germany, the United Kingdom and France in 1990. Due to budgetary constraints, the United-States DOD (USAF) was not able to sign it at that time, although it had participated very actively to its preparation. It shall do so in 1991. By signing this memorandum, the ministries recognise that their main emphasis in future avionics standardization lies within ASAAC. For the european countries, this will lead to reorient towards this cooperative programme most of the actions above mentionned that are not yet started, such as the exploratory developments A3 and SIERA in France.

III-3 - Application of modular avionics to an european fighter : one example

3-1 Objectives

Applying the modular avionics concepts to an existing aircraft raise a number of problems that have to be studied. In such a case indeed, some constaining factors lie in the fact that a number of elements are already defined and shall not hopefully or cannot be modified. This is conditionning the ability to examine the feasibility to carry out these concepts, particularly for a mid-life update. It is moreover a mean to mesure the advantages over classical architectures.

In order to investigate that question, the STTE has awarded a contract to the french industry dealing with the implementation of modular avionics on the Rafale aircraft. It has been carried out by five major aerospace companies (Dassault Aviation, as lead contractor, Dassault Electronique, Sextant Avionique, SAGEM and Thomson-CSF) and was terminated in mai 1991.

The main objectives were :

- getting the bases of a modular architecture that could be used for the following developments in France and in cooperation,
- examining the characteristics affecting the whole system,
- evaluating the degree of applicability of the main concepts to an existing platform, and the relatec constraints,
- determining a set of standardisable modular resources with the technology available today.

The main constraints taken into account were :

- the already defined arrangement of the equipement cases and of the volume available for avionics,
- the utilities definition : electric power generating, cooling and conditioning systems,
- the security objectives related to the very low level and terrain following missions.

The operational functions are those alrready defined or planned, with the hypothesis that the functional architecture is independant of the physical organization on which it is projected. The aim of the study is not a global validation of the concepts, but to propose a modular construing of the physical resources representing the system architecture (the ANS : Attack and Navigation System), considering identical functions, and to highlight the benefits, drawbacks and constraints.

3-2 Hypotheses

The fundation for determining the ANS specifications are the operational functions (OF) that it must fulfill. In the frame of this study, only the main OF, which affect directly the system definition, i.e. which allow to dimension it, have been considered. Other minor functions coulb be added, but without inducing heavy modifications of the physical resources. The considered OF were :

- navigation
  - control
  - localization/updates
  - approach and landing
  - flight management,
- communications (clear and jammed modes),
- identification,
- aircraft systems (utilities) management,
- Man-Machine Interface (MMI),
- breakdoown and alarms management,
- on-line maintenance,
- mission preparation/restitution,
- air to air fire-control,
- air to ground fire-control,
- very low altitude flight,
- self-protection,
- tactical situation awareness.

In the already defined system, these OF are realized by means of material resources comprising 29 black boxes and 3 multiplexed Stanag 3910 busses.

It is worth to note thet the fly-by-wire system is not part of the study, and that the resources related to the self-protection(ECM) and the forward looking optronic (FLIR) systems were not taken into consideration, because of lack of sufficient progress in their definition at the time of the study.

3-3 Method

From a system point of view, modular avionics run into notions like fault tolerance and dynamic reconfiguration of the functions. This is the reason why a breakdown structured approach into boxes and elementary modules (LRM : Line Replaceable Modules) cannot lead to an optimized architecture, because it does not take into account every possible regroupment and commonality of the processing treatments, nor their possible standardization.

The adopted method is a top-down approach, starting from the existing results of the ANS functional analysis. In a first stage, the defined OF have been gathered within some entities having physical characteristics of the same nature : the Homogeneous Entities (HE).

That approach allows to determine the different primary components that are capable of fulfilling one function with close relation to their paterial caracterisrics : the Material/Functional Modules (M/F-M). For instance, there are :

- a multispectral receiver module, whose function is the multispectral RF reception,
- A DSP module (Digital Signal Processor), whose function is the execution of one or more digital signal processing algorithms,
- etc.

At that stage, a M/F-M is not a LRM, because commonalities leading to physical module standardization has not been sought. In addition, one M/F-M may be composed of several LRMs. This partitioning allows to :

- assess the different processings associated to each M/F-M and to identify their specific characteristics,
- determine the Inpout/Output of each of them, from an informational point of view (type, flow, caracterisrics of the data) and from the physical point of view (type of link, encoding, frequency, throuput, etc),
- assess the constraints related to each M/F-M : location in the aircraft, temporal (dating, response time, synchronization), working safety, confidentiality (red/black isolation), power supply, volume, conditioning, etc.

Each M/F-M being defined, it is possible to envisaged their gathering according to such criteria as

- safety (gathering in one rack redondant modules, or separating two parts in order to avoid a simple failure to hinder a whole function),
- vulnerability (physical separation of subsets for damage hardening purposes),
- facilitating the integration and validation (by homogenizing the functions in one rack),
- minimizing the data throughput between racks (by gathering the modules exchanging a great volume of information among them),

and taking into account such constraints as :

- the number of LRM in a rack,
- the number of racks in a case,
- the disposal and arrangement of the cases,
- the maximum power consumption of a rack,
- the number of links to a bus,
- the maximum distance between transceiver on a bus
- etc.

This lead to defining 7 Homogeneous Entities, as shown on figure 3 :

- HE1 : Fly-by-wire and powerplant system (not studied)
- HE2 : Aircraft Systems (utilities) Interface (ASI)
- HE3 : CNI (Communication, Navigation, Identification)
- HE4 : Core system
- HE5 : MMI (Man/Machine Interface)

- HE6 : SSI (Stores-System Interface)
- HE7 : REO (Radar, ECM, Optronics)

On figure 3 appears a System Communication Net (RCS Réseau de Communication Système), which reflects the total integration of the architecture. It is in fact composed of sub-nets.

Figure 4 shows, as an example, the break-down of HE2 into M/F—M. HE2 comprises the following sub-systems : landing gear, electric power, starting, conditioning and fuel. The content of the four M/F—M is :

- sensors/actuators

They may be taps, valves, electro-valves, pumps, gauges, tachymeters, switches, etc. As afsr as the electic supply is concerned, they are mainly switching and protection units.

- sensors/actuators interface

This module realizes the electrical interfaces of all sensors and actuators for each sub-system.

- sensors/actuators signal concentration

It collects every signal generated by each interface to allow their processing by the management module. It may be implemented on the same LRM(s) as the interface M/F—M.

- resources management

This module gathers the intelligent part of each sub-system. It realizes the processing of the controls, regulation and supervision of every circuit, of the failure analysis, etc. It is linked to the RCS in order to exchange data with the other HEs.

This HE necessitate some redondancies and reconfiguration capacities at control and management level, in order to ensure a sufficient availability, and some supervision and data merging mechanisms for safety purposes.

The other HEs are comprise :

<u>HE 3 & 7</u> (CNI and REO)
Antennae
Hyper-frequency stage(s) (analog)
Pre-processor stage(s) (digital)
Signal processing stage(s)
resources management

<u>HE4</u> (Core system)
There is here one sole M/F-M, which realizes the following :

- Technical management
  - initialization
  - ground maintenance
  - sensor fusion
  - information synthesis (localization, tactical situation, malfunctions)
  - resources management (power supply, compatibility, sensors, armaments)
- Mission control
  - cooperation
  - flight conduct (elaborating the trajectories and the guidance and control information)
  - macro-functions such as fire controls, counter-measures, flight management
- failures and alarms management
- System management
- MMI management
  - synthesis
  - displays assignment
  - controls assignment
- Mass memories management
  - map data base
  - mission preparation/restitution data base
  - reconfiguration software

<u>HE5</u> (IHS)
Displays and controls
Video interface and concentrator interface

Graphic and signal generation and commands interpretor
MMI resources management

HE6 (SSI)
The stores interfaces are standardized following the MIL-STD-1760. The interfacing and distribution functions are implemented by a specific MIL-STD-1760 interface module (Stores I/O).

3-4 Results

3-4-1 General architecture

Based on the previous functional breakdown, a general architecture has been defined. It is shown on figure 5.

It presents an intermediate solution for modular avionics, since some sub-systems are not completely integrated : REO, CNI and flight control.

The main characteristics are as follows.

Core system
It is the heart of the whole system and it administers the entire avionics suite in association with a set of technical resources (sensors and MMI) located in the other HEs.

Global bus definition
The processing (or management) racks are linked together by a global bus. In order to avoid common mode failures due to the fact that rack intercommunication interface are obligatory waypoints, it is necessary to make use of two global busses to which are connected every HEs. This is a high speed redondant bus, like HSDB or HSRB (high Speed Ring Bus).

Secured system architecture
Taking into account the very low altitude (VLA) function leads to dispose of a dual architecture in order to demonstrate the required safety level. This strengthens the need for two global busses, with connectior to both ones of the related sensors (radar, radio-altimeter, terrain data base), of the Core system and the flight control system.

Secured Core system
The Core system elaborates the VLA trajectories. It must then be secured. This has led to separate it into two sub-sets in order to ensure

- the VLA processing redundancy
- a lower physical vulnerability
- the VLA commands fusion.

However, some safety mechanisms within one rack could be envisaged, which would be more efficient than within one classical black box because of the dual backplane bus and the possibility to duplicate and isolate the processes on different LRMs.

Notions of data base and dispatching bus
Some functions utilize an important volume of stored data. These data users are multiple, especially when considering the software reconfiguration requirements, in case of failure or with regards to adapting it to different missions or system configurations. This leads to propose a "data base" rack, which comprises all necessary storage resources and allows the access to all HEs.

The volume of transfered data may be very high, so there is a special bus for that purpose, which avoids the global bus saturation: the dispatching bus. It may be the same type of bus as the global one in order to achieve standardization (but for the Rafale, a 3910 would be sufficient).

Notion of sensor bus
There is a tremendous need of communication between some M/F-Ms of one HE (for instance, between image building and graphic generation in the MMI, between the pre-processor and the DSP in the CNI, or between the arithmetic unit and the PSP (Programmable Signal Processor) in the radar, with throughputs of about 100 Mbits/s). When these functions are located in different racks, they need a serial (because of the distance between the racks), point to point, 100 Mbits/s bus in order to exchange data : the sensor bus.

Notion of control and status bus (CS bus)

The analysis of the HEs physical breakdown shows a low band communication need for transmitting such information as controls and commands and status data. This is especially the case for the many MMI resources located in the cockpit : there, a 1553B bus fits, but must be doubled. This occurs also between some LRMs of the ASI and SSI, where a 1553B is oversized. In that case, a RS422 type bus should fit.

Integration of the Inertial Navigation Units (INU) into the FCS

The INU resources can be split into two sets : the inertial sensor with its supervision electronics, and the data processing which calculates the pure and optimal inertial data. A hybridization of the inertial sensors to the Flight Control System sensors allow to fuse information and to strengthen the validity of the localization data. for that purpose, the inertial sensors are integrated in the FCS.

3-4-2 Physical breakdown

Each HE is splitted into LRMs. The modules format is double Europe (an implementation study has been carried out with SEM E modules, but the equipement cases arrangement and volumes are not optimized for that format).

Two types of racks have been defined

One has a capacity of 40 LRMs. It will be used for HEs comprising a great number of I/O modules and a small proportion of connections to the backplane parallel busses.

Such a bus being generally capable of a maximum of 15 terminal units, a second rack with a capacity of 18 modules is necessary. Its size is :

Length	324,5 mm
Width	220 mm
Height	273 mm
Volume	19,5 liters

The 40 modules rack is twice this volume.

The composition of each HE and the module list is presented hereunder. There appears some memory modules, which are related to the mechanisms of reconfiguration and dynamic assignment of the resources. Today, such modules are proposed with a capacity of 4Mbytes, which is enough for most of the HEs. However, capacities of twice or four time higher are expected.

HE ASI

This HE comprises, in a 40 modules rack :

- a processing set, in charge of managing all functions. The reconfiguration principles of modular avionics should allow to fulfill the requirement for safety and reliability,
- a I/O set, with the redundancy of the interfaces directly implemented on the LRMs.

A CS bus performs the information exchanges between the two sets. The LRMs of the processing set are connected via a parallel backplane, PI-BUS type, bus.

The list of the LRMs is as follows.

Set	LRM	Number
Processing	CPU 32 bits RISC	2
"	Memory	2
"	global bus Coupling	2
"	CS bus Coupling	2
"	Power supply	3
Sub-Total		1 1
I/O	Discrete Input	5
"	Analog Input	3
"	Discrete Output	3
"	Power Output	2
"	Specific Input	1
"	Specific Output	1

"	Power Sup. for sensors/act.	2
Sub-Total		17
Total		28
Spares		12

HE SSI

The breakdown is similar to ASI, with extra coupling to 1553B (for store interface) and dispatching (for distribution of stored data to the stores) busses.

The list of the LRMs is as follows.

Set	LRM	Number
Processing	CPU 32 bits RISC	2
"	Memory	2
"	global bus Coupling	2
"	CS bus Coupling	2
"	Dispatching bus Coupling	1
"	1553B bus Coupling	2
"	Power supply	3
Sub-Total		14
I/O	28V Switching	9
"	200V Switching	6
"	Armament safety Logic	1
"	Emergency safety Logic	1
"	Vidéo Matrix	4
"	Vidéo Options	3
"	Concentration	2
Sub-Total		26
Total		40
Spares		0

HE MMI

It comprises :

- a processing set, in a 18 LRMs rack, connected to a PI-BUS and to the dispatching bus (map generation, etc).
- a video functions and MMI interface set, which handles the graphic generation and the commands acquisition. It is composed of a 40 LRMs rack and comprises 2 DSP modules for the video processing. The beackplane bus may be PI-BUS like, but a throughput higher than 25 Mbytes/s is probably necessary. It is connected to the displays and control terminals by the mean of two 1553B busses with a high frequency duty cycle (100 to 200 Hz) in order to minimize the response times.

The breakdown into two sets is further justified because their reconfiguration mechanisms are different. They are connected by a redundant sensor bus.

The list of the LRMs is as follows.

Set	LRM	Number
Processing	CPU 32 bits RISC	7
"	Memory	3
"	global bus Coupling	2
"	Sensor bus Coupling	2
"	Dispatching bus Coupling	1
"	Power supply	3
Sub-Total		18
Video & Interface	Sensor bus Coupling	2

"	DSP		2
"	Graphic generator	5	
"	Video processor		2
"	Video insertion type 1	2	
"	Video insertion type 2	1	
"	Digital map generator n° 1	1	
"	Digital map generator n° 2	1	
"	Digital map generator n° 3	1	
"	3D Generator	2	
"	CS bus coupling		2
"	audio analog I/O		2
"	Power supply	4	
Sub-Total		**27**	
Total			**45**
Spares			**13**

HE CNI

The CNI comprise the following primary functions : MIDS, GPS, IFF, V/UHF, R/A, INU and ABC (Anemo-Baro-Angle of Attack) sensors. The concept studies being under way in France, a precise breakdown into LRMs has not been obtained. The estimates undertaken on the basis of available information from the ICNIA programme (TRW), which would permit to largely fulfill the Rafale needs with 70 LRMs, or from the NAS programme (Germany), which corresponds to a CNI suite relatively similar to the Rafale one and which comprises 123 LRM of 26 different types, leads to a CNI HE with 60 modules, plugged in one "digital" rack and three "hyper-frequency" racks (with 12 spare modules). With a rack volume of 19,5 liters, this hypothesis seems to be pessimistic when compared to the SIERA programme (Thomson-CSF) objectives of a 45 liters volume.

HE REO

Since the radar architecture is already modular, and the other sub-systems in this HE have not been analysed, the considered modules for the radar are those already defined : 83 modules of about 20 different types (these modules are of different formats, so the comparisons with other HEs are not easy). Deporting the radar resources after the signal processing stage (PSP) would require an important flow of information (c.a. 500 Mbits/s), which could be realized with sensor busses. Deporting the PSP is not technically possible nowaday.

HE Core system

It is composed of two identical 18 modules racks with a PI-BUS, and is comprised of :

LRM	Number	
CPU 32 bits RISC	5	
Memory		3
Global bus Coupling	2	
Dispatching bus Coupling	1	
Power supply		3
Total		**14**
Spares		**4**

HE Data Base

It has been assumed that half of its 18 LRMs rack was dedicated to the data base itself (which can be implemented with optical disks reader or with hybrid Si memories). The t eakdown into LRMs is then :

LRM	Number
CPU 32 bits RISC	2
Memory	2
Sensor bus Coupling	2
Dispatching bus Coupling	1
Power supply	2
Data Base	9
Total	**1 8**
Spares	**0**

Synthesis

The considered HEs are globally implemented by means of 210 LRMs dispatched the following way :

HE	Racks Capacity	Nb LRM	Spares
ASI	4 0	2 8	1 2
SSI	4 0	4 0	0
MMI	5 8	4 5	1 3
Core	3 6	2 8	8
Data Base	9	9	0
CNI	7 2	6 0	1 2
Total	**2 5 5**	**2 1 0**	**4 5**

Except the CNI (60 LRMs), the 150 remaining modules are of 32 different types, the more frequently used being :

CPU 32 bits RISC	2 3
DSP	2 (out of the radar)
Memory	1 5
Global bus Coupling	1 0
CS bus Coupling	4
Dispatching bus Coupling	5
Sensor bus Coupling	6
1553B bus Coupling	4
Power supply	2 1

The racks can be installed in the equipment cases where the replaced black boxes were previously housed.

It is worth to note that some optimization have not been taken into account in these results, as for example for the CNI, or for the global and dispatching busses which could be identical. The results are thus pessimistic, compared to those that could be ontained with a complete compliance with the concepts of modular avionics.

This study did not consider a complete avionics system. However, it shows that the implementation of the operational functions of a small size aircraft like the Rafale is possible with a modular system, while fulfilling the severe safety requirement linked to the VLA missions. No significant benefit appears in terms of avionics volume or weight, but it must be considered that the reconfiguration capabilities are greatly improved, and that significant spares are available (17% of the installed capacity).

3-5 Conclusion

This study was a first step in France towards modular avionics.

It allowed the industry and the ministry to assess the feasibility of these new concepts. However, and this is not the least lesson, it did not demonstrate that all potential benefits are obtainable, especially from a financial point of view.

It has also led to identify some areas of high risk, such as the packaging or the implementation of a global operating system being capable of automatic reconfigurations within a rack, whose mastership will still require great efforts.

The related work will continue in the frame of cooperative programmes, such as ASAAC, already mentionned, or EUCLID (European Cooperation for the Long term In Defense, whose Common European Priority Area n° 4 is on modular avionics). This is absolutely mandatory, in one hand because of the required budget for carrying out such a development, and in the other one in order to ensure the widest standardization within NATO, which is the only way to ensure an optimized use of the resources and interoperability within the alliance.

IV - THE SOFTWARE BUS

The previous chapter shows an extensive use of the arithmetic logic unit (CPU) module within an avionics suite. This reflects the importance of that kind of processing, which results in exponentially growing software bulks. The necessary standardization of the CPUs intends to meet three main objectives :

physical interchangeability, which is ensured via the F3I specifications,

- dynamic reconfiguration; this demands that in one system, or at least one rack, all CPU modules are able to work the software stored in the bulk memory,
- portability of the software, and eventually of the modules themselves, from a system to another one.

This is inviting to infer the need to standardize an unique Instruction Set and an unique Real Time Executive.

However, the solution has already been investigated and has led to some severe disappointments. The US DOD have done so with the MIL-STD-1750A. Now it appeared that the processors using this 16 bits Instruction Set have been fast outmatch in performance by 32 bits items, especially RISC (Reduced Instruction Set Computer), before their large scale implementation in aeronautics. The french MOD experienced the same troubles with the CMF programme (Calculateur Militaire Français), that was intended to meet every military need and had practically no application, although it was based on a 32 bits Instruction Set.

Standardizing an Instruction Set for all military platforms presents among others the following drawbacks :

- it is an obstacle to technological break-through,
- it precludes from utlizing the best available technology at one time,
- it hinders to profit from synergy with the professional sector, which in this area benefits from a much higher growth than the military sector, both at hardware and software tools levels,
- it implies substantial fundings in order to maintain the performances.

It could be envisaged to use as a standard an Instruction Set of the commercial shelf. But there, the same objections arise, because any choice, be it the good one (which is very difficult to assess on a medium term basis), is considerably limiting the capacities.

One potential solution to that problem would be to design a standard interface between the application software and the real time executive (RTE) : this is the notion of Software Bus.

Three interface standardization levels can as a matter of fact be defined :

- one for exchanges between sub-systems, or racks, by the mean of multiplex busses like the HSDB,
- one for exchanges between modules within a rack, by the mean of backplane busses like the PI-BUS,
- one between the application software of a module and its RTE.

The objevtive is to obtain a complete portability of the operational software from a processor/executive set to every other one, with the accepted constraint of recompiling it (the modules of a same rack will need a higher level of standardization, in order to allow some reconfiguration). This leads to :

- a real independance in regard to the hardware,
- the portability of the applications,

- software reuse.

Within the DGA, the DEI (Direction de l'Electronique et de l'Informatique) has initiated some actions in this area, comprising several facets.

A Real time Executive is generally composed of several functionalities :
- interrupt handling,
- Ada rendez-vous,
- asynchronous primitives,
- I/O handling,
- distribution (sharing of the global executive into local ones, at the module level, in order to meet in particular the reconfiguration objectives).

Some of these functions exist in the Ada Runtime and is thus standardized.

As far as distribution is concerned, the DEI has developped a complement to the executive, called EXTRA (EXtension du RunTime Ada). The targets are the MIPS, SPARC, 680X0, 88000 and I 960, with the Ada tecnologies from Verdix, Telesoft and Alsys, which allow to cover a large range of products.

Ada does not provide such well-known asynchronous mechanisms as events or semaphores. However, the need exists, in order to :
- accomodate existing application designs,
- support asynchronous communication and signaling operations,
- enhance the application performance,
- enhance the application portability and reuse.

Such services can be realized in pure Ada using the rendez-vous mechanism. However, it is at cost of extra server tasks and rendez-vous operations. Thus, the DEI has proposed a list of primitives for insertion in the Ada language. They represent a coherent model of asynchronous cooperation mechanisms that promotes clean, efficient application architectures which avoid usage of non-portable solutions. The entries relative to these primitives are :
- counters : "resources" and "buffers",
- states : "events" and "blackboards",
- pulses : "pulses" and " broadcasts".

They are preliminary to the Software Bus notion, on which the studies are just beginning.

The Software Bus notion implies that the requirements and constraints of all potential users shall be taken into account. This enforces once again the need to conduct this design in a cooperative way, which could be optimally done in the frame of the international programmes on modular avionics.

V - GENERAL CONCLUSION

This lecture does not intend to deal with all the avionics standardization aspects in Europe : this is too large a topic. But by considering some aspects of avionics, it intended to demonstrate that:

- standardization and interoperability are substantial financial and operational stakes for the future. In this way, standardization itself is a brand new requirement, that will have more and more importance,

- the objectives can only be met by extensive cooperation, at every level.

The illustrations to this Section can be found on pages 4-16 to 4-20, which immediately follow the French translation.

LA STANDARDISATION AVIONIQUE EN EUROPE

par
IPA L. GUIBERT
DGA/DCAé/STTE
129, Rue de la Convention
75731 PARIS CEDEX 15

INTRODUCTION

Cet exposé comprend cinq parties :
- Rappel des différentes organisations en charge de la normalisation aéronautique en Europe.
- Les rapports entre la standardisation et l'interopérabilité.
- Un exemple de domaine pour lequel la standardisation a de fortes implications : l'avionique modulaire.
- Un autre exemple : le Software Bus.
- Conclusion.

I - LES ORGANISMES DE NORMALISATION EN FRANCE ET EN EUROPE

L'organisme responsable de la normalisation en France est l'AFNOR, qui dépend du Ministère de l'Industrie et de l'Aménagement du Territoire. L'AFNOR élabore, en concertation avec des bureaux de normalisation sectoriels, des normes nationales (NF) pour tous les secteurs de l'industrie.

Au plan européen, l'homologue de l'AFNOR est le C.E.N. (Comité Européen de Normalisation), qui élabore les Normes Européennes (EN). C'est l'AFNOR qui représente la France au C.E.N., de même que d'autres organismes nationaux y représentent leur pays. L'industrie aérospatiale est représentée au C.E.N. par l'AECMA, qui regroupe plusieurs syndicats professionnels nationaux. L'AECMA est, pour le CEN, le bureau européen de normalisation dans le domaine aérospatial.

Dans le domaine de l'aéronautique et de l'espace, un bureau particulier, le BNAE (Bureau de Normalisation de l'Aéronautique et de l'Espace) a en charge l'élaboration et la diffusion des normes françaises (NFL). Pour cela, il est en relation avec le Ministère de la Défense, par le biais de la DGA, et avec l'industrie par le biais du GIFAS (Groupement des Industries Françaises Aéronautiques et Spatiales), qui assurent la majeure partie du financement de son fonctionnement.

Le BNAE peut aussi assurer d'autres tâches, telles que
- la soutien technique pour l'élaboration de nouvelles normes, aux plans national et international,
- la mise à l'enquête en France de projets de standards internationaux élaborés par ailleurs.

C'est en particulier le cas pour les standards OTAN (Stanags) en avionique (groupes AVS et AI).

Cela le conduit à mettre en place un certain nombre de groupes de travail regroupant des représentants de l'industrie et de la DGA.

Il représente aussi la France à l'ISO (International Standardization Organization) dans son domaine (TC 20).

La figure 1 montre les divers organismes en charge de normalisation en France, en Europe, au sein de l'OTAN et dans le monde, et les relations entre eux. La figure 2 précise la participation des divers pays aux différents offices de normalisation internationaux.

II - LA STANDARDISATION ET L'INTEROPERABILITE

Il est communément admis que l'interopérabilité nécessite la conformité à des standards communs. Mais est-ce suffisant? Pour répondre à cette question, il est utile de prendre un exemple : la liaison 16.

La liaison 16 est essentiellement une transmission de données protégée, en réseaux, définie par un Stanag, n° 5516, qui décrit entre autres choses les messages possibles, certains étant obligatoires et d'autres facultatifs. L'organisation des réseaux et des messages est régie par un autre document OTAN, l'AdatP16.

L'interopérabilité, dans ce cas, consiste simplement à pouvoir communiquer entre les différents intervenants : Armées de l'Air, de Terre et de Mer d'un pays, et de plusieurs pays alliés. Pour cela, il faut définir :

- le réseaux interarmes ou interalliés sur lequel les informations seront échangées,
- les messages qui seront échangés sur ces réseaux, et leur ordre d'émission par les différents terminaux,
- le contenu formaté au bit près de ces messages (champs).

Il faut en fait organiser les trames d'échange des informations, de façon similaire à ce que l'on fait pour un bus multiplexé du type 1553B. Cela nécessite la mise en place d'organismes interarmes ou internationaux pour gérer les réseaux L16.

Il est clair dans ce cas que l'application de normes communes (Stanags, Adat) ne suffit pas à assurer l'interopérabilité. Celle-ci exige un travail important en commun. De plus, elle ne pourra être véritablement garantie que si tous les participants utilisent le même équipement et le même logiciel. Dans le cas contraire en effet, sa démonstration demanderait pour couvrir tous les cas possibles une somme d'essais irréalisable.

Il y a donc deux leçons à tirer de cet exemple

La première, c'est qu'une normalisation commune ne suffit pas toujours à assurer l'interopérabilité.

La seconde, c'est que certains besoins d'interopérabilité, selon la difficulté et l'ampleur des tâches à accomplir pour l'obtenir, peuvent entrainer des besoins de coopération, y compris au niveau industriel.

III - L'AVIONIQUE MODULAIRE - UN CAS D'APPLICABILITE

L'avionique modulaire est un cas exemplaire de domaine où l'interopérabilité nécessite une approche coopérative au stade de la conception.

Cette partie de l'exposé est décomposée en quatre chapitres :

- rappel des concepts,
- les programmes,
- applicabilité à un avion de combat européen,
- conclusion.

III-1 - Les concepts

Les systèmes avioniques actuels sont composés d'équipements, qui réalisent chacun une ou plusieurs fonctions, reliés entre eux par plusieurs réseaux d'échange d'informations, les bus. Chaque équipement est optimisé pour ses fonctions, et l'architecture du système est adaptée aux missions de l'avion en fonction de contraintes telles que l'aménagement des soutes, les encombrements, poids, consommation des équipements, l'optimisation du rapport performance/coût, etc. La composition du système est élaborée, de façon théorique, après une analyse fonctionnelle qui permet de définir et de dimensionner les fonctions nécessaires et de les attribuer à tel ou tel équipement. Pour les fonctions qui ne peuvent être totalement définies ou dimensionnées que pendant le développement, on est amené à prendre certaines provisions pour le dimensionnement des ressources matérielles nécessaires à leur implantation. Il en va de même pour les évolutions futures du systèmes (évolutions pré-programmées), quand cela est possible. On le voit, il y a déjà là un certain nombre de sources potentielles de problèmes au niveau du système (sur- ou sous-évaluation des capacités et des performances des équipements).

De plus, étant donnés le nombre, la complexité et l'intégration croissants des fonctions, la multiplicité des missions et les percées technologiques, ce type d'architecture présente aujourd'hui des inconvénients certains.

Au plan technique, car outre les problèmes déjà évoqués plus haut, il induit des volumes d'échanges d'informations importants et donc une complexité croissante des réseaux de communication. La capacité à fusionner les données est aussi limitée par la multi-localisation de ces données et des traitements qui leur sont appliqués. En conséquence, l'intégration et la validation peuvent devenir difficilement maîtrisables.

Au plan opérationnel, la disponibilité et la survivabilité sont limitées par le fait que la redondance d'une fonction ne peut être assurée qu'en doublant l'équipement qui la réalise, ce qui n'est pas toujours possible et n'est efficace qu'après une seule panne.

Au plan de la maintenance, tout équipement en panne doit être déposé et remplacé. Il faut donc avoir un stock de rechange volumineux et coûteux et du personnel qualifié pour chacun d'eux.

Au plan des coûts, enfin, outre ceux inhérents à la maintenance et à la disponibilité évoqués ci-dessus, d'autres inconvénients résident dans le fait que chaque équipement est développé et approvisionné séparément, avec très peu de composants communs, ce qui a un effet multiplicatif évident.

L'avionique modulaire se propose de remèdier à tous ces maux.

L'idée directrice est de regrouper dans un nombre réduits de coeurs informatiques l'ensemble des traitements numériques, ce qui représente la quasi-totalité des systèmes futurs. Un coeur est composé d'une étagère électronique sur laquelle sont enfichées des modules de traitement standardisés, interchangeables.

Les avantages de ce concept sont en théorie les suivants.

Toutes les fonctions de même type, jusqu'à présent réalisées par tel ou tel équipement, le sont par des modules génériques. On a donc besoin d'un nombre significativement moins élevé de modules différents pour réaliser un système complet. Cela diminue d'autant la complexité du système, et permet d'économiser sur les coûts de développement ainsi que sur ceux de production par effet de serie.

Les modules (cartes électroniques) sont munis d'autotests permettant de détecter et de localiser les avaries sur l'un d'entre eux. Ils sont remplaçables au premier niveau. Ainsi, la maintenance est considérablement simplifiée, et le stock de rechanges, qui ne comporte que des modules, est réduit en volume et en coût.

Un traitement peut être effectué sur l'un quelconque des modules standardisés du même type dans une étagère. Cela permet d'obtenir des possibilités de reconfiguration multiples en installant une capacité supplémentaire pour la reconfiguration en cas de panne bien inférieure à ce qui est nécessaire avec une architecture classique. Les logiciels de traitement sont pour cela stockés en mémoire de masse pour chaque rack. On obtient un accroissement de la survivabilité et de la sécurité. De plus, en fonction du nombre de modules en réserve, et de leur fiabilité, il est possible de commencer une mission avec un certain taux de panne initial tout en ayant encore une capacité de reconfiguration. Théoriquement, on peut arriver à un niveau de disponibilité accru à un point tel que la maintenance programmée suffirait à maintenir l'aéronef en état de combattre.

Les réserves en capacité de traitement peuvent aussi permettre d'accroître les fonctionnalités du système de façon plus aisée et à moindre coût.

L'avionique modulaire doit aussi permettre de diminuer globalement les volumes, poids et consommations des systèmes (par regroupement des fonctions, les comparaisons devant être faites à capacités égales, notamment en matière de reconfiguration) et d'augmenter la fiabilité par le jeu de plusieurs facteurs (utilisation de la technologie la plus avancée pour tous les modules, déverminage d'un petit nombre de produits, diminution de la puissance dissipée et du nombre d'interconnections, etc).

Mais c'est sans doute au plan financier que les avantages doivent être déterminants, particulièrement dans le contexte actuel de diminution des budgets. Les facteurs de réduction ont été mentionnés plus haut : en coûts d'acquisition (de développement, par le nombre réduit de modules différents, mais aussi d'outils associés, pour le logiciel, les tests et la validation, et de production, pour les mêmes raisons) et en coûts de possession (maintenance, logistique, évolutions).

Il est clair que la capacité du concept à réduire les coûts dépend du niveau de standardisation obtenu. Plus le nombre de plateformes utilisant les mêmes modules sera élevé, plus les économies d'échelle seront attractives. C'est pourquoi un facteur déterminant pour la réussite de l'avionique modulaire réside dans l'universalité du concept et son application à l'ensemble des aéronefs militaires de façon identique. C'est particulièrement le cas pour les pays européens, pour lesquels les flottes nationales d'aéronefs sont trop peu nombreuses pour profiter pleinement des économies potentielles.

Dans ce domaine, très vaste, l'élaboration de standards communs à plusieurs nations nécessite la prise en compte des besoins et des contraintes spécifiques à chacune d'elles : là particulièrement, le besoin de standardisation nécessite une coopération poussée entre les nations, aux niveaux gouvernemental et industriel.

Cela conduit à une forme d'interopérabilité sophistiquée. Le concept d'avionique modulaire ouvre en effet la voie vers des objectifs nouveaux : pouvoir installer sur un aéronef une fonction développée pour un autre, tant sur le plan matériel que logiciel, et pouvoir maintenir un système avec des moyens communs (outils et rechanges) à plusieurs plateformes. Ces objectifs sont certes très ambitieux, mais pas irréalistes au plan technique. Ils sont peut-être une des clés de notre capacité à maintenir une défense performante avec des moyens financiers limités.

III-2 - Les programmes

Le concept d'avionique modulaire a vu le jour aux Etats-Unis, dans le cadre du programme PAVE PILLAR mené par les Laboratoires Wright de l'USAF. Ce programme a été lancé en 1982 par l'étude de la définition de l'architecture et s'est terminé en 1987 avec l'élaboration des spécifications détaillées de conception de l'avionique PAVE PILLAR.

Sur cette base, un groupe tri-service a été mis en place pour identifier et développer des composantes et des logiciels avioniques communs, destinés à être appliqués sur l'ATF et la famille LHX entre autres : le JIAWG (Joint Integrated Avionics Working Group).

L'Europe a aussi mis en place plusieurs programmes sur le sujet.

En Allemagne, Neue Avionikstruktur (NAS), lancé en 1986, est destiné à définir une nouvelle génération d'avionique et d'étudier son application à des rétrofits d'aéronefs. Il comprend une première phase de conception, terminée en 1988, et une deuxième phase de réduction de risques qui doit aboutir en 1991 à des spécifications préliminaires d'architecture avionique.

Au Royaume Uni, un programme continu de recherches est en place depuis 1986 pour identifier les technologies et les concepts applicables, étudier les domaines critiques et modéliser les bénéfices en termes de coûts. Dans ce cadre, un banc de recherche est développé pour permettre de tester de nouveaux concepts et composantes de systèmes. En 1988, le programme A^3P (Advanced Avionics Architectures and Packaging demonstrator) a été lancé pour étudier les nouveaux concepts et technologies en avionique et déterminer leurs avantages opérationnels (phase 1, qui est terminée), puis pour définir une architecture (phase 2) et valider sa faisabilité et sa définition sur un banc d'essais (phases 3 et 4).

En France, le développement de modules de traitement de données, d'interface pour bus optique et de mémoire de masse conformes aux standards PAVE PILLAR a été lancé en 1988, en coopération avec les Etats-Unis (USAF), pour une validation prévue en 1992. Une étude d'application de l'avionique modulaire à un avion de combat a commencé en 1989, dont les résultats seront abordés dans le chapitre suivant. Cette étude doit se poursuivre par une phase de définition et de validation d'architecture dans le cadre d'un développement exploratoire, A^3 (Architecture Avionique Avancée). Des études de réduction de risques sont aussi lancées en 1991 dans les domaines du packaging et de la reconfiguration. L'ensemble de ces actions requiert les compétences de nombreuses sociétés aéronautiques, qui doivent se coordonner pour assurer une convergence vers des standards communs. C'est naturellement au BNAE, dans son rôle de soutien technique pour l'élaboration de nouvelles normes, qu'à été confiée cette tâche, pour laquelle plusieurs groupes de travail réunissant l'ensemble de l'industrie aéronautique française et les services de la DGA ont été créés.

D'autre part, plusieurs programmes ont été lancés pour l'application des concepts d'avionique modulaire dans le domaine des CNI (Communications, Navigation, Identification). C'est le cas aux Etats-Unis, avec ICNIA (Integrated CNI Avionics), qui a conduit à la réalisation de modèles de développement intégrant les fonctions CNI dans un spectre de 2MHz à 5GHz, dont l'évaluation a commencé en 1990. Au Royaume Uni, le RAE (Royal Aircraft Establishment) a réalisé un démonstrateur technologique orienté vers l'évaluation des capacités d'un système intégré de communications. En France, l'étude SIERA (Système Intégré d'Equipements de Radio Aéroportés), lancée en 1990, a pour but de définir les besoins en matière de CNI intégrées et leur architecture. Elle doit aboutir au lancement d'un développement exploratoire en 1991 pour en assurer la validation.

Ces efforts, plus ou moins importants, sont d'ordre national. Comme il a été montré plus haut, l'obtention de standards internationaux nécessite des coopérations importantes dans ce domaine. Cette exigence est encore renforcée par l'investissement lourd que représente la validation d'une architecture modulaire pour l'ensemble de l'avionique.

C'est pourquoi les quatre pays déjà cités (USA, RU, RFA, FR) ont travaillé depuis 1988 à la mise en place d'un programme en coopération de définition et de validation d'une architecture avionique commune, visant des applications dans les années 2000-2010. Il s'agit de l'ASAAC (Allied Standard Avionics Architecture Council). Sa mission est de développer les spécifications techniques d'une architecture avancée composée de modules intégrés interchangeables pouvant être utilisés sur tout aéronef. Son objectif est de proposer, après validation, des projets de standards OTAN (Stanags) définissant une architecture commune et ses constituants et permettant d'assurer lour interchangeabilité.

L'accent sera mis plus particulièrement sur le coeur des systèmes avioniques et sur les CNI. Cependant, le programme traitera des problèmes associés à l'ensemble des senseurs d'un aéronef. Il comprend plusieurs phases : définition, validation, évolution.

L'ASAAC fait l'objet d'un protocole d'accord signé entre les ministères de la défense de la RFA, du Royaume Uni et de la France en 1990. Les Etats-Unis, bien qu'ayant très activement participé aux travaux de préparation, n'ont pu signer à cette époque pour des raisons budgétaires, mais doivent le faire en 1991. En signant cet accord, les ministères ont reconnu que l'ASAAC constitue leur axe prioritaire d'effort en matière de standardisation en avionique. Cela va conduire à réorienter la plupart des actions nationales mentionnées ci-dessus qui ne sont pas encore lancées vers ce programme en coopération, comme par exemple pour la France les développements A^3 et SIERA.

III-3 - Application de l'avionique modulaire à un avion de combat européen : un exemple

3-1 Objectifs

L'application des concepts de l'avionique modulaire à un aéronef existant pose un certain nombre de problèmes qu'il convient d'étudier. En effet, dans ce cas, il faut tenir compte des contraintes liées au fait que certains éléments sont définis et qu'il n'est pas souhaitable ou impossible de les modifier. C'est à cette condition en effet que l'on pourra se prononcer sur la faisabilité de mettre en oeuvre ces concepts, à l'occasion d'un retrofit à mi-vie par exemple. C'est de plus un moyen de mesurer les avantages de l'avionique modulaire par rapport à des architectures classiques.

Pour étudier ces problèmes, le STTE a passé un contrat à l'industrie française sur l'application de l'avionique modulaire au Rafale. Cette étude a été réalisée par cinq sociétés aéronautiques majeures (Dassault Aviation, maître d'oeuvre, Dassault Electronique, Sextant Avionique, SAGEM et Thomson-CSF) et s'est terminée en mai 1991.

Les objectifs de l'étude étaient :

- obtenir les bases d'une première architecture modulaire pouvant être utilisées pour la suite des développement en France et en coopération,
- recenser les caractéristiques dimensionnant le système d'arme,
- évaluer le degré d'applicabilité des principaux concepts à un avion existant, et donc les contraintes qui en découlent,
- déterminer un ensemble de ressources modulaires standardisables avec la technologie disponible aujourd'hui.

Les principales contraintes prises en compte sont :

- la définition de l'aménagement des soutes à équipements et les volumes alloués à l'avionique,
- la définition des servitudes : génération électrique, système de refroidissement et de conditionnement,
- les objectifs de sécurité liés aux missions basse altitude tous temps et suivi de terrain.

Les fonctions opérationnelles sont celles qui sont déjà définies ou prévues pour cet avion, l'hypothèse de base étant que l'architecture fonctionnelle est indépendante de l'organisation matérielle sur laquelle elle est projetée. Le but de l'étude n'est donc pas de valider le concept en général, mais de proposer à iso-fonctions opérationnelles les décompositions modulaires des ressources matérielles représentatives de l'architecture du système (SNA : Système de Navigation et d'Attaque) et d'en déduire les avantages, inconvénients et contraintes.

3-2 Hypothèses

Pour déterminer le cahier des charges du SNA, on s'appuie sur les fonctions opérationnelles (FO) qu'il doit réaliser. Dans le cadre de cette étude, il a été pris en compte les FO principales qui influence directement la définition du système, c'est à dire celles qui permettent de le dimensionner. D'autres fonctions pourraient être ajoutées, mais sans induire de modifications profondes des ressources matérielles. Les FO considérées sont les suivantes :

- Navigation
    - Pilotage
    - Localisation/recalages
    - Approche
    - Gestion du vol
- Communications (modes clair et brouillés)
- Identification
- Gestion des systèmes avions (servitudes)
- Interface Homme/Système (IHS)
- Gestion des pannes et des alarmes
- Maintenance en ligne
- Préparation/restitution de mission
- Conduites de tir Air/Air
- Conduites de tir Air/Sol
- Vol très basse altitude (TBA)
- Autoprotection
- Elaboration de la situation tactique

Dans le système actuellement défini, ces FO sont réalisées par des ressources matérielles comprenant 29 équipements et 3 bus multiplexés conformes au projet de Stanag 3910.

Il faut noter que les Commandes de vol électriques n'entrent pas dans le cadre de cette étude, et que les ressources liées au Système d'autoprotection (CME) et à l'optronique secteur frontal (FLIR) ne sont pas prises en compte étant donné le faible avancement de leur définition au moment de l'étude.

3-3 Méthode

L'avionique modulaire débouche essentiellement sur des notions de tolérance aux pannes et de reconfiguration dynamique des fonctions. Pour cette raison, l'approche classique de décomposition en équipements, puis en modules élémentaires (LRM : Line Replaceable Modules) ne peut conduire à une optimisation de l'architecture car elle ne prend pas en compte toutes les possibilités de regroupement et de commonalité des traitements, ni de standardisation.

La méthode suivie est de type top-down, à partir des résultats de l'analyse fonctionnelle du SNA déjà réalisée. Les fonctions définies ont dans un premier temps été regroupées en entités possédant des caractéristiques matérielles de même nature : les Entités Homogènes.

Cette approche permet de déterminer les différents constituants élémentaires susceptibles de remplir une fonction particulière étroitement liée aux caractéristiques matérielles : ce sont les modules Matériel/Fonctionnel (M-M/F). Par exemple, on trouvera :

- un module récepteur multi-bandes dont la fonction est la réception radio-fréquence multi-bandes,
- un module DSP (Digital signal Processing) dont la fonction est l'exécution d'un ou de plusieurs algotithmes de traitement numérique du signal,
- etc.

A ce stade, un module M/F n'est pas un LRM, car il n'y a pas encore eu recherche de commonalité conduisant à une standardisation matérielle des modules. De plus, un M-M/F peut être composé d'un ou de plusieurs LRM. Cette décomposition permet de :

- Connaître les différents traitements associés à chaque M-M/F et identifier leurs spécificités.
- Déterminer lesEntrées/Sorties de chacun d'eux, sur le plan informationnel (type, flux, caractéristiques des information) que matérielles (type, support, codage, fréquence, débit, etc).
- Recenser les contraintes associées à chaque M-M/F (de localisation géographique dans l'avion,

temporelles (datation, temps de réponse, synchronisation), de sûreté de fonctionnement, de confidentialité (ségrégation "noir/rouge"), d'alimentation, de volume, d'environnement, etc).

Quand chaque module M/F est ainsi défini, il est possible d'envisager les regroupements selon certains critères comme

- la sûreté de fonctionnement (regroupement dans un même rack de modules redondants ou séparation de deux sous-ensembles pour éviter qu'une panne simple ne rende indisponib'e la totalité d'une fonction),
- la vulnérabilité (séparation physique de sous-ensembles pour la résistance aux impacts),
- la difficulté des tâches de validation et d'intégration (qui conduit à homogénéiser des fonctions d'un même rack),
- la minimisation des volumes d'échanges d'informations (regroupement des modules ayant à s'échanger un grand nombre de données),

et avec des contraintes comme

- le nombre de LRM par rack,
- le nombre de racks par soute,
- la disposition et l'installation des soutes,
- la dissipation maximale d'un rack,
- le nombre d'abonnés sur un bus,
- la distance maximale entre emetteur et récepteur sur un bus,
- etc.

Cette approche a conduit à définir 7 Entités Homogènes, comme indiqué sur la figure 3 :

EH1 : CDVE et moteurs (non étudiée ici)
EH2 : Interface Systèmes Avion ISA
EH3 : CNI (Communications, Navigation, Identification)
EH4 : Coeur Système
EH5 : IHS (Interface Homme-Système)
EH6 : Interface Système-Emports ISE
EH7 : RCO (Radar, CME, Optronique)

La figure 3 fait apparaître la notion de Réseau de Communication Système (RCS), qui permet l'intégration totale de l'architecture, sans préjuger de sa nature exacte : il est composé de plusieurs sous-réseaux.

La figure 4 montre un exemple de décomposition de EH2 en modules M/F. L'EH2 comprend les sous-systèmes atterrisseurs, électrique, démarrage, conditionnement et carburant. Le contenu des M-M/F est le suivant :

- Capteurs/actuateurs

Ils peuvent être des robinets, valves, vérins, pompes, jauges, capteurs de température, tachymètres, électro-valves, contacteurs. Pour la distribution électrique, ce sont essentiellement des éléments de commutation et de protection.

- Interfaces capteurs/actuateurs

Ce module réalise les interfaces électriques de tous les capteurs/actuateurs pour chaque sous-système.

- Concentrateur signaux capteurs/actuateurs

Il assure la concentration de tous les signaux générés par chaque interface pour permettre leur exploitation par le module de gestion. Il peut être réalisé sur le(s) même(s) LRM que le module interface.

- Gestion ressources

Il constitue la partie intelligente de chaque sous-système. Il execute les traitements liés aux commandes et aux surveillances des circuits, aux différentes régulations, à la synthèse des pannes, etc. Il présente une liaison avec le RCS pour les échanges avec d'autres EH.

Cette EH nécessite des redondances et des reconfigurations au niveau des traitements de commande et de gestion pour en assurer la disponibilité et des surveillances et consolidations, etc, pour la sécurité.

Les autres EH sont décomposées comme suit.

EH3 et 7 (CNI et RCO):
Antennes
Etage(s) hyper-fréquence (analogique)
Etage(s) préprocesseur(s) (numérique et conversion A/N)
Etage(s) traitement du signal
Traitements et gestion de la ressource

EH4 (coeur système)
On trouve ici un seul M-M/F, qui effectue les traitements suivants :
- Gestion technique
    initialisation
    maintenance sol
    fusion des capteurs
    synthèse des informations (de localisation, situation tactique, pannes)
    gestion des ressources (alimentations, compatibilités, capteurs, armements)
- Conduite de la mission
    coopération
    conduite du vol (élaboration des trajectoires et des informations de pilotage)
    macro-fonctions telles que les conduites de tir, les contre-mesures, la gestion du vol
- Gestion des pannes et des alarmes
- Gestion système
- Gestion de l'IHS
    synthèse
    affectation des visualisations
    affectation des commandes
- Gestion des mémoires de masse
    base de données cartographique
    base de données préparation/restitution de mission
    logiciels de reconfiguration

EH5 (IHS)
Visualisations/Commandes
Interface vidéo et Interface/concentrateur
Générateur de tracé/signal et Interprêteur de commandes
Traitements et gestion de la ressource IHS

EH6 (ISE)
Les interfaces avec les emports sont standardisées selon la norme MIL-STD-1760. On trouve donc des fonctions d'interface et de distribution réalisées par un module d'interface spécifique MIL-STD-1760 StoresI/O).

3-4 Résultats

3-4-1 Architecture générale

Sur la base de la décomposition fonctionnelle précédente, une architecture générale a été élaborée. Elle est présentée en figure 5.

Elle représente une solution intermédiaire pour l'avionique modulaire, puisque certains sous-ensembles ne sont pas entièrement intégrés : RCO, CNI et CDVE.

Les principales caractéristiques en sont les suivantes.

Notion de coeur système

L'architecture repose sur le coeur système, qui gère la totalité de l'avionique à l'aide d'un ensemble de ressources techniques (capteurs et IHS) que constituent les autres EH.

Définition des bus globaux

Les rack de traitements (ou de gestion) sont reliés entre eux par un bus global. Pour éviter des modes de panne communs liés au fait que l'interface de communication de ces racks sont des points de passage obligatoires, il est nécessaire de disposer de deux bus globaux, auxquels sont connectés toutes les EH. Ces bus sont du type HSDB ou HSRB et sont redondés.

Architecture système sécurisée

La prise en compte de la fonction opérationnelle TBA impose une architecture de type double chaîne pour démontrer le niveau de sécurité recherché. Cela renforce la nécessité d'un bus global double, avec couplage aux deux bus des capteurs (radar, radio-altimètre, base de données géographique) ainsi que du coeur système (qui élabore les trajectoires) et des CDVE.

Coeur système sécurisé

L'élaboration des trajectoires TBA par le coeur système impose là aussi d'en sécuriser le fonctionnement. On est donc amené à le séparer en deux sous-ensembles pour assurer

- la ségrégation des traitements TBA
- une moindre vulnérabilité physique
- la consolidation des ordres TBA.

Cependant, il serait possible d'envisager des mécanismes de sécurisation au sein d'un même rack, plus faciles à mettre en oeuvre dans une structure modulaire grâce à le redondance du bus de fond de panier, et la possibilité de dupliquer et de ségréguer des traitements sur des LRM différents.

Notions de base de données et de bus serveur

Certaines fonctions nécessitent des volumes importants de données stockées. Les utilisateurs de ces données sont multiples, surtout en tenant compte des besoins de reconfiguration des logiciels en cas de panne ou selon la mission ou l'état du système. Cela conduit à proposer un rack "base de données" qui concentre toutes les ressources de stockage nécessaires et permet l'accès de toutes les EH.

Le volume d'informations transféré pouvant être très important, un bus serveur à haut débit auquel tous les utilisateurs sont abonnés est spécifié pour éviter de pénaliser les performances des autres échanges sur le bus global. Ce bus peut être du même type que le bus global par souci de standardisation (mais un bus 3910 est suffisant pour le Rafale).

Notion de bus capteur

Il y a un besoin de communication entre M-M/F d'une même EH (par exemple : pour l'IHS, entre la constitution d'image et la génération de tracé, un débit de 40 Mbits/s est nécessaire. De même entre le préprocesseur et le DSP des CNI et entre l'Unité Arithmétique et le PSP (Programmable Signal Processor) du radar, avec des débits de 100 Mbits/s). Si ces fonctions sont dans deux racks différents, il faut définir un bus série (car la distance entre racks peut être importante) de débit 100 Mbits/s utilisé en poin à point.

Notion de bus de commande et de contrôle (bus CC)

L'analyse des décompositions matérielles des EH montre un besoin de communication à bas débit pour la transmission de commandes et la saisie d'informations de contrôle (status). C'est le cas entre les diverses ressources de l'IHS placées en cabine : un bus de type 1553B convient, mais doit être doublé. C'est aussi le cas entre différents LRM des ISA et ISE, pour lequel le couplage à un bus 1553B est surdimensionné; là, un bus de type RS422 doit suffire.

Intégration des Centrales Inertielles (CI) aux CDVE

Les ressources des CI sont constituées de deux sous ensembles : le senseur et son électronique de contrôle et le traitement des données pour obtenir des informations inertielles pures et de l'inertie optimale. L'hybridation des capteurs inertiels à ceux des commandes de vol permet d'effectuer une synthèse des informations et donc de consolider les données de localisation. Pour cela, le sous-ensemble senseur des CI est intégré dans les CDVE.

3-4-2 Décomposition matérielle

Chaque EH fait l'objet d'une décomposition en LRM. Le format retenu pour les modules est le Double Europe (l étude d'implantation a aussi été effectuée avec des LRM au format SEM E, mais le nombre de modules reste le même et les volumes des soutes ne sont pas adaptés à ce cas).

Deux types de racks ont été définis.

Le premier peut comprendre un ensemble de 40 LRM. Il peut être utilisé pour des EH comprenant un grand nombre de modules d'Entrées/Sorties et un faible nombre d'interfaces aux bus parallèles de fond de panier. Un tel bus ne pouvant en général relier plus de 15 abonnés, cette contrainte a conduit à définir un rack de 18 LRM.

Les dimensions du rack de 18 modules sont :

Longueur	324,5 mm
Largeur	220 mm
Hauteur	273 mm
Volume	19,5 litres

Le rack de 40 LRM est d'un volume double.

La composition et la liste des LRM de chaque EH est présentée ci-dessous. Il apparaît des modules mémoire qui sont liés aux mécanismes de reconfiguration et de gestion dynamique des ressources. De tels modules sont aujourd'hui proposés avec une capacité de 4 Moctets, qui semble suffisante pour la plupart des EH. Cependant, des capacité deux ou quatre fois supérieures sont envisageables.

EH ISA

Cette EH comprend, dans un rack de 40 modules :

- un ensemble de traitement, effectuant la gestion de toutes ses fonctions. Les principes de reconfiguration offerts par l'architecture modulaire doivent permettre de répondre aux besoins de sécurité et de fiabilité,
- un ensemble d'Entrées/Sorties. La structure redondante des interfaces est implantée sur chaque LRM.

Les échanges d'informations entre ces deux ensembles s'effectue par un bus CC redondant. Les LRM de l'ensemble de traitement sont reliés par un bus de fond de panier parallèle, de type PI-BUS.

La liste des modules est la suivante :

Ensemble	Nom	Nombre
Traitement	UT 32 bits RISC	2
"	Mémoire	2
"	Couplage bus global	2
"	Couplage bus CC	2
"	Alimentation	3
Sous-Total		**11**
E/S	Entrées discrètes	5
"	Entrées analogiques	3
"	Sorties discrètes	3
"	Sorties de puissance	2
"	Entrées spécifiques	1
"	Sorties spécifiques	1
"	Alimentation capteurs/act.	2
Sous-Total		**17**
Total		**28**
Réserve		**12**

EH ISE

La composition est semblable à celle de l'ISA, avec des couplages supplémentaires a des bus 1553B (pour l'interface emports) et serveur (distribution de données stockées aux emports).

La liste des modules est la suivante :

Ensemble	Nom	Nombre
Traitement	UT 32 bits RISC	2
"	Mémoire	2
"	Couplage bus global	2
"	Couplage bus CC	2

"	Couplage bus 1553B	2	
"	Couplage bus serveur	1	
"	Alimentation	3	
Sous-Total			**14**
E/S	Commutation 28V	9	
"	Commutation 200V	6	
"	Logique sécurité armements	1	
"	Logique sécurité détresse	1	
"	Matrice vidéo	4	
"	Options vidéo	3	
"	Concentration	2	
Sous-Total			**26**
Total			**40**
Réserve			**0**

EH IHS

Il comprend :

- un ensemble de traitement, implanté dans un rack de 18 LRM, reliés par un PI-BUS. Il est abonné au bus serveur (cartographie, etc).

- un ensemble de fonctions vidéo et interfaces IHS qui réalise toute la génération de tracé et la saisie des commandes. Il est réalisé dans un rack de 40 LRM. Il comprend des LRM DSP pour le traitement des vidéos. Le bus de fond de panier peut être du type PI-BUS, mais avec un débit qui peut excéder les 25Moctets/s. Il est relié par deux bus 1553B à l'ensemble des terminaux de visualisation et de commande, avec une fréquence de fonctionnement plus élevée (100 à 200Hz) pour diminuer les temps de réponse.

La décomposition en deux ensembles est justifiée par le fait que leurs mécanismes de reconfiguration sont différents. Ils sont reliés par un bus capteur redondant.

La liste des modules est la suivante :

Ensemble	Nom	Nombre	
Traitement	UT 32 bits RISC	7	
"	Mémoire		3
"	Couplage bus global	2	
"	Couplage bus Capteur	2	
"	Couplage bus serveur	1	
"	Alimentation	3	
Sous-Total			**18**
Vidéo et E/S	Couplage bus Capteur	2	
"	DSP		2
"	Générateur de tracé	5	
"	Traitement vidéo		2
"	Incrustation type 1	2	
"	Incrustation type 2	1	
"	Cartographie numérique n° 1	1	
"	Cartographie numérique n° 2	1	
"	Cartographie numérique n° 3	1	
"	Génération 3D	2	
"	Couplage bus CC		2
"	E/S analogiques audio	2	
"	Alimentation	4	
Sous-Total			**27**
Total			**45**
Réserve			**13**

EH CNI

Les CNI regroupent les fonctions élémentaires suivantes : MIDS, GPS, IFF, MLS, V/UHF, R/A, Centrales inertielles et capteurs ABC (Anémo-Baro-Clinométriques). Les études du concept étant en cours en France, une décomposition précise n'a pu être obtenue. Les estimations réalisées à partir des données disponibles sur ICNIA (TRW), qui permet de couvrir largement les besoins du Rafale avec 70 LRM, sur le NAS (RFA) qui correspond à une configuration proche de celle du Rafale et qui comprend 123 LRM de 26 types différents, conduisent à une EH CNI composée de 60 modules dans un rack "numérique" et trois racks "hyper-fréquence" (avec une réserve de 12 LRM). Un rack ayant un volume de 19,5 litres, l'hypothèse retenue semble conduire à un surdimensionnement par rapport à l'objectif de l'étude SIERA (Thomson) d'un volume de 45 litres.

EH RCO

L'architecture du radar étant très modulaire, et les autres sous-ensembles de cette EH n'ayant pas été analysés, la liste des modules retenus pour le radar est celle déjà définie : 83 modules de 20 types différents (Ces modules sont de formats divers, ce qui rend les comparaisons difficiles avec les autres EH). Le fait de déporter les ressources du radar après l'étage de traitement du signal (PSP) amènerait un débit de communication très important, qui pourrait être réalisé par plusieurs bus capteurs (de l'ordre de 5). Le déport du PSP n'est par contre pas envisageable actuellement.

EH Coeur Système

Elle est implantée dans deux racks identiques de 18 LRM et comporte :

Nom du LRM	Nombre	
UT 32 bits RISC		5
Mémoire		3
Couplage bus global	2	
Couplage bus serveur	1	
Alimentation	3	
Total		**14**
Réserve		**4**

EH Base de données

Il a été supposé que la moitié du rack de 18 LRM qui la compose est réservée à la base de données elle-même (qui peut être réalisée avec des lecteurs de disques optiques ou des mémoires silicium hybridées, par exemple). La décomposition en LRM est alors :

Nom du LRM	Nombre	
UT 32 bits RISC		2
Mémoire		2
Couplage bus capteur	2	
Couplage bus serveur	1	
Alimentation	2	
Base de données	9	
Total		**18**
Réserve		**0**

Synthèse

On arrive pour les EH etudiées à un ensemble de 210 LRM répartis ainsi :

BH	Capacité des racks	Nb LRM	Nb réserve
ISA	40	28	12
ISE	40	40	0
IHS	58	45	13
Coeur	36	28	8
Base Données	9	9	0
CNI	72	60	12
Total	**255**	**210**	**45**

Hors les CNI (60 modules), les 150 modules restants sont de 32 types différents, ceux les plus utilisés étant :

UT 32 bits RISC	23	
DSP		2 (hors radar)
Mémoire		15
Couplage bus global	10	
Couplage bus CC	4	
Couplage bus serveur		5
Couplage bus capteur		6
Couplage bus 1553B		4
Alimentation		21

Les racks ainsi définis se logent dans les soutes où sont actuellement installés les équipements qu'ils remplacent.

Il faut noter que certaines optimisations ne sont pas prises en compte dans ces résultats, comme par exemple pour les CNI, ou pour les bus globaux et serveur, qui pourraient être identiques. Les résultats sont donc pessimistes par rapport à ceux qui devraient être obtenus en appliquant totalement les concepts de l'avionique modulaire.

Cette étude ne porte pas sur l'ensemble d'un système avionique. Elle montre toutefois qu'un système modulaire permet de réaliser les fonctions opérationnelles d'un avion de taille réduite comme le Rafale, tout en respectant les contraintes de sécurité très sévère liées aux missions TBA. Il n'apparaît pas de gain significatif en matière de volume ou masse de l'avionique, mais il faut considérer que les capacités de reconfiguration sont largement augmentées, et que l'on dispose de réserves appréciables (17 % des ressources installables).

3-5 Conclusion

Cette étude représente un premier pas vers une avionique modulaire en France.

Elle a permis de conforter l'industrie et le ministère dans leur foi en la faisabilité de ces nouveaux concepts. Elle ne permet pas actuellement cependant de confirmer tous les bénéfices, en particulier financiers, qui en sont attendus.

Elle a aussi permis d'identifier des problèmes techniques compliqués, comme le conditionnement ou la réalisation d'un système d'exploitation global permettant les reconfigurations automatiques au sein d'un rack, dont la maîtrise demandera encore beaucoup d'efforts.

La poursuite des travaux, pour des applications futures, sera réalisée principalement au titre de programmee en coopération comme ASAAC, déjà cité, ou EUCLID (dont le domaine prioritaire n° 4 a pour objet l'avionique modulaire). C'est nécessaire, d'une part à cause des sommes requises pour mener à bien un tel développement et d'autre part pour assurer la standardisation la plus large dans l'OTAN, qui seule peut amener une optimisation de l'utilisation des ressources et de l'interopérabilité au sein de l'alliance.

IV - LE SOTWARE BUS

Le chapitre précédent montre une utilisation intensive de module de traitement arithmétique et logique (UT) au sein d'un système. Cela reflète l'importance de ce type de traitement, qui se traduit par des volumes de logiciels en croissance exponentielle. Ces UT doivent être standardisées, avec trois buts principaux :

- l'interchangeabilité physique, qui est assurée par la conformité aux spécifications F3I,
- la reconfiguration dynamique, qui impose qu'au sein d'un même système, tous les modules UT puissent fonctionner avec les logiciels implantés en mémoire de masse,
- la portabilité des logiciels, voire des modules UT eux-mêmes, d'un système à l'autre.

Il est tentant d'en déduire la nécessité de standardiser un code d'ordre unique et un système d'exploitation temps réel unique.

Cependant, cette voie a déjà été explorée et a conduit à de sévères désagréments. Le Département à le Défense Américain a standardisé un code d'ordre, le MIL-STD-1750A. Or les unité centrales réalisées avec ce code d'ordre, à 16 bits, ont été rapidement dépassées au plan des performances par des matériels 32 bits, en particulier RISC (Reduced Instruction Set Computer), avant leur mise en application à grande échelle en aéronautique. La France a fait la même dure expérience avec le programme CMF (Calculateur Militaire Futur), qui bien qu'étant basé sur un code d'ordre 32 bits, n'a pratiquement pas eu d'application.

La standardisation du code d'ordre pour toutes les plateformes militaires présente donc des inconvénients, que l'on peut lister de la façon suivante :

- elle constitue un frein à l'innovation technologique,
- elle ne permet donc pas d'utiliser la meilleure technologie disponible à un moment donné,
- elle ne permet pas de profiter de la synergie avec le secteur professionnel civil, qui dans ce domaine bénéficie d'un développement plus rapide que le secteur militaire, à la fois au plan des matériels que des outils logiciel,
- elle implique l'immobilisation de budgets considérables pour maintenir à niveau les performances.

On pourrait imaginer d'utiliser comme standard un code d'ordre du commerce. Mais là encore, les mêmes inconvénients surgissent, car tout choix, fût-il bon (ce qui est difficile à prévoir à moyen terme), restreint considérablement les possibilités.

Une solution pour sortir de cette impasse consiste à avoir une interface standardisée entre le logiciel d'application et le système exécutif temps réel (RTX) : c'est la notion de software bus.

Par analogie, on peut en effet discerner trois niveaux de standardisation d'interfaces :

- celle pour les échanges entre sous-systèmes, ou entre racks, par l'utilisation de bus multiplexés comme le HSDB,
- celle pour les échanges entre modules d'un rack, par l'utilisation de bus de fond de panier comme le PI-BUS,
- celle entre le logiciel opérationel d'un module et son exécutif.

Le but est d'obtenir une portabilité totale du logiciel opérationnel d'un ensemble processeur/exécutif à l'autre, en acceptant la contrainte d'une recompilation (les modules d'un même rack devront donc avoir un niveau supérieur de standardisation, pour assurer les reconfigurations). Cela permet d'obtenir :

- l'indépendance vis à vis du matériel,
- la portabilité des applications,
- la réutilisabilité du logiciel.

La DEI (Direction de l'Electronique et de l'Informatique) de la DGA a lancé des études allant dans ce sens, qui comprennent plusieurs volets.

Un exécutif temps réel comprend plusieurs fonctionnalités :

- la gestion des interruptions,
- le rendez-vous Ada,
- des primitives asynchrones,
- la gestion des E/S,
- la distribution (répartition sur plusieurs modules de l'exécutif global, en particulier pour satisfaire les objectifs de tolérance aux pannes).

Une partie de ces fonctionalités se retrouvent dans le Run Time Ada, et est donc standardisée.

En ce qui concerne la distribution, la DEI a fait développer un complément d'exécutif, appelé EXTRA (EXtension du RunTime Ada). Les cibles sont les codes d'ordre MIPS, SPARC, 680X0, 88000 et I 960, avec les technologies Ada de Verdix, Telesoft et Alsys, ce qui permet de couvrir une très large gamme de produits.

Pour les mécanismes asynchrones, Ada n'offre pas de services tels que les sémaphores, événements, etc, bien connus dans d'autres langages. Cependant, le besoin existe, pour :

- prendre en compte les application existantes (portabilité)
- permettre les communications et opération de signalisation asynchrones,
- améliorer les performances,
- améliorer la portabilité et la réutilisation.

Ces services étant extrêmement coûteux en temps d'exécution avec le mécanisme du rendez-vous, le DEI a proposé une liste de primitives pour insertion dans le langage Ada, qui constitue un modèle cohérent de mécanismes de coopération asynchrones, qui permet des architectures d'application propres et efficaces en évitant l'utilisation de solutions non protables. Cela doit permettre une meilleure adéquation de ce langage aux application fortement temps réel, et assurerait une portabilité plus facile des applications. ces primitives sont :

- des compteurs : "resource" et "buffer",
- des états : "event" et "blackboard",
- des impulsions : "pulses" et "broadcast".

Ils sont un préalable à la notion de software bus, dont les études ne font que commencer.

En ce qui concerne le software bus, il existe là encore un besoin de prendre en compte les exigences et les contraintes de tous les utilisateurs potentiels. C'est pourquoi cette approche doit être menée en coopération, de façon optimale dans le cadre des programmes internationaux d'avionique modulaire.

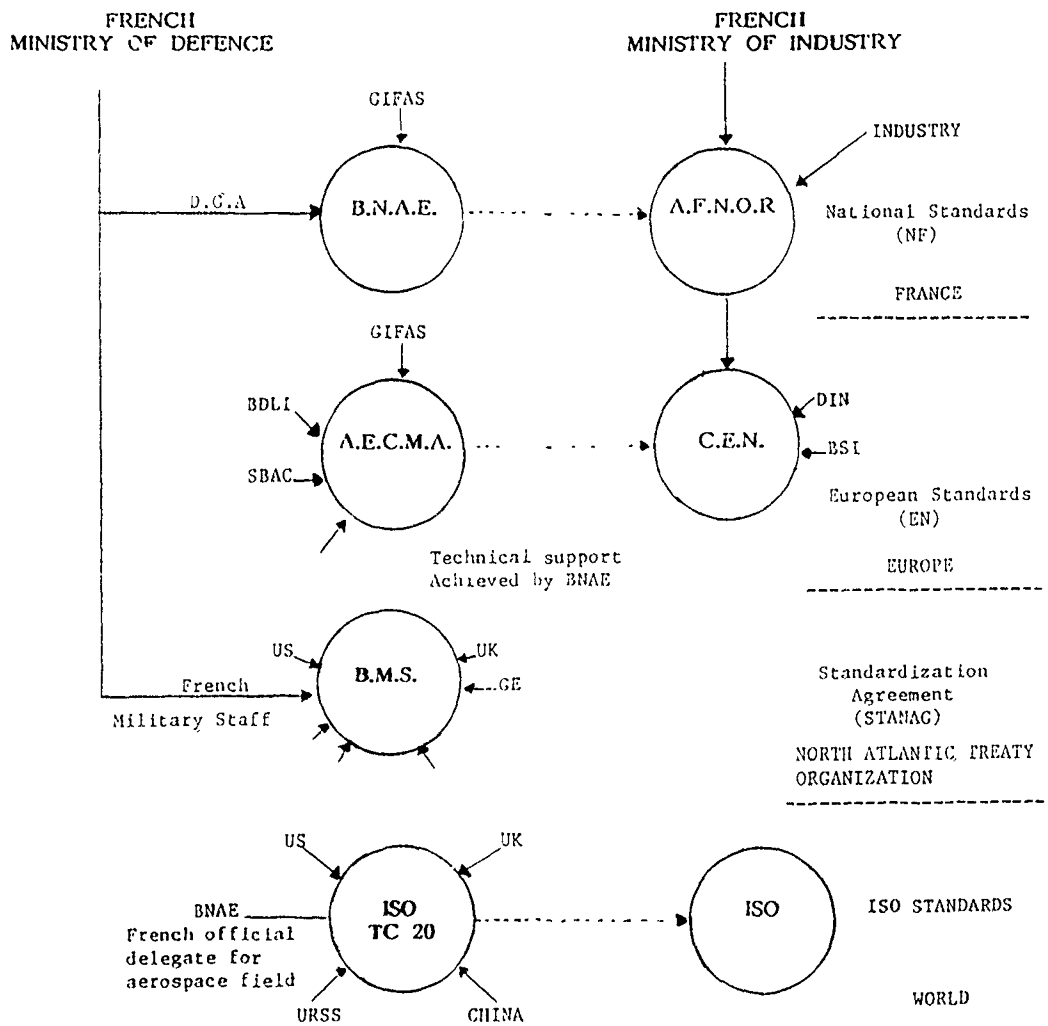
V - CONCLUSION GENERALE

Le présent exposé ne prétend pas avoir fait le tour de tous les problèmes de standardisation aéronautique en Europe : le champ est beaucoup trop vaste. Mais en abordant certains secteurs de l'avionique, il a essayé de démontrer que :

- pour le futur, la standardisation et l'interopérabilité sont des enjeux considérables, opérationnels et financiers. En ce sens, la standardisation est à elle seule un besoin nouveau, qui sera de plus en plus important,

- ces enjeux ne pourront être gagnés que par la coopération, à tous les niveaux.

AEROSPACE STANDARDIZATION



GIFAS	FRENCH AEROSPACE INDUSTRY NATIONAL ASSOCIATION
B.N.A.E.	AEROSPACE STANDARDIZATION BUREAU
C.E.N.	EUROPEAN STANDARDIZATION COMMITTEE
AECMA	EUROPEAN AEROSPACE MANUFACTURER ASSOCIATION
ISO	INTERNATIONAL STANDARDIZATION ORGANIZATION

FIGURE 1 : STANDARDIZATION BODIES

Pays représentés dans les divers organismes : AECMA - OTAN - CEN - ISO/TC 20 - Pacte de Varsovie.

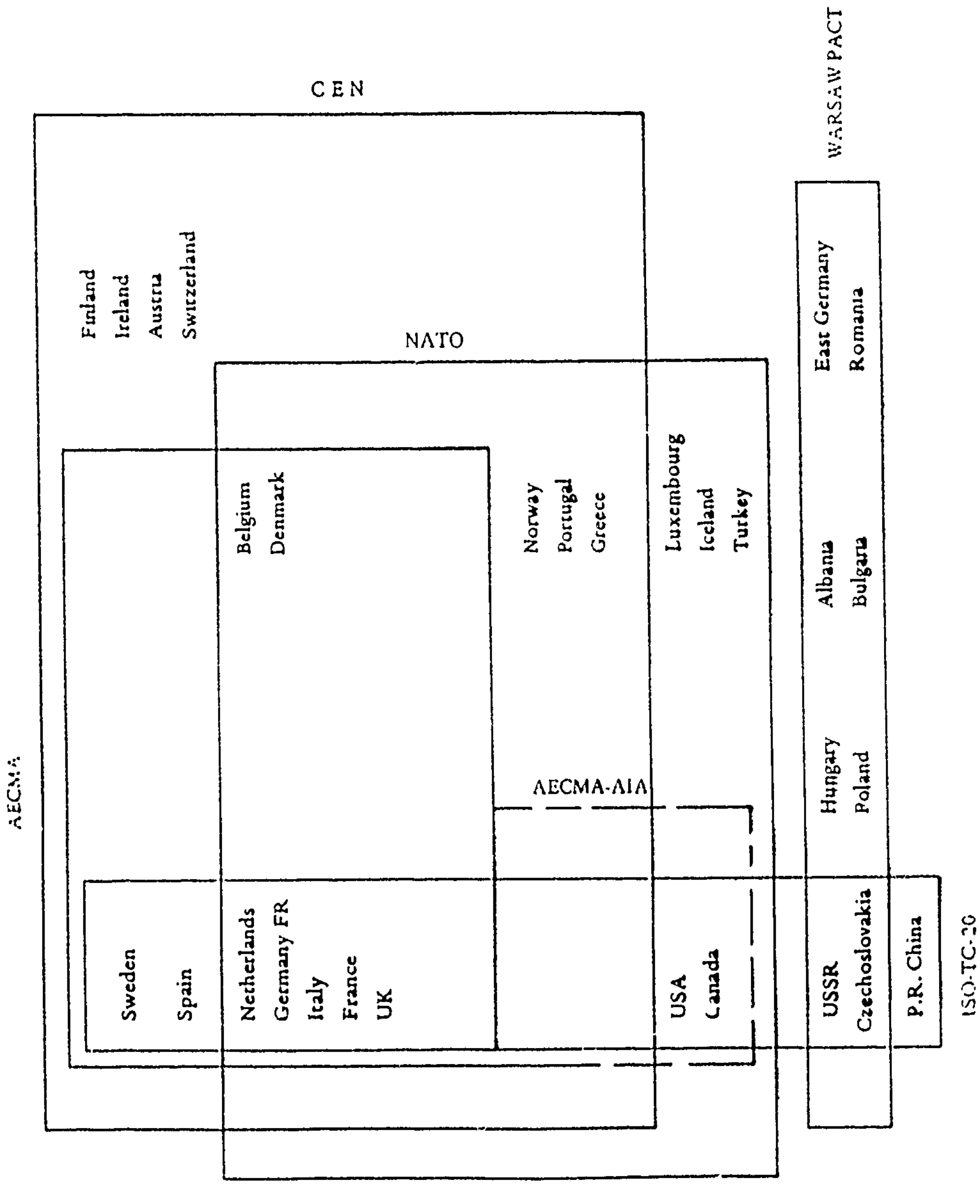


FIGURE 2 : TABLE OF COUNTRIES

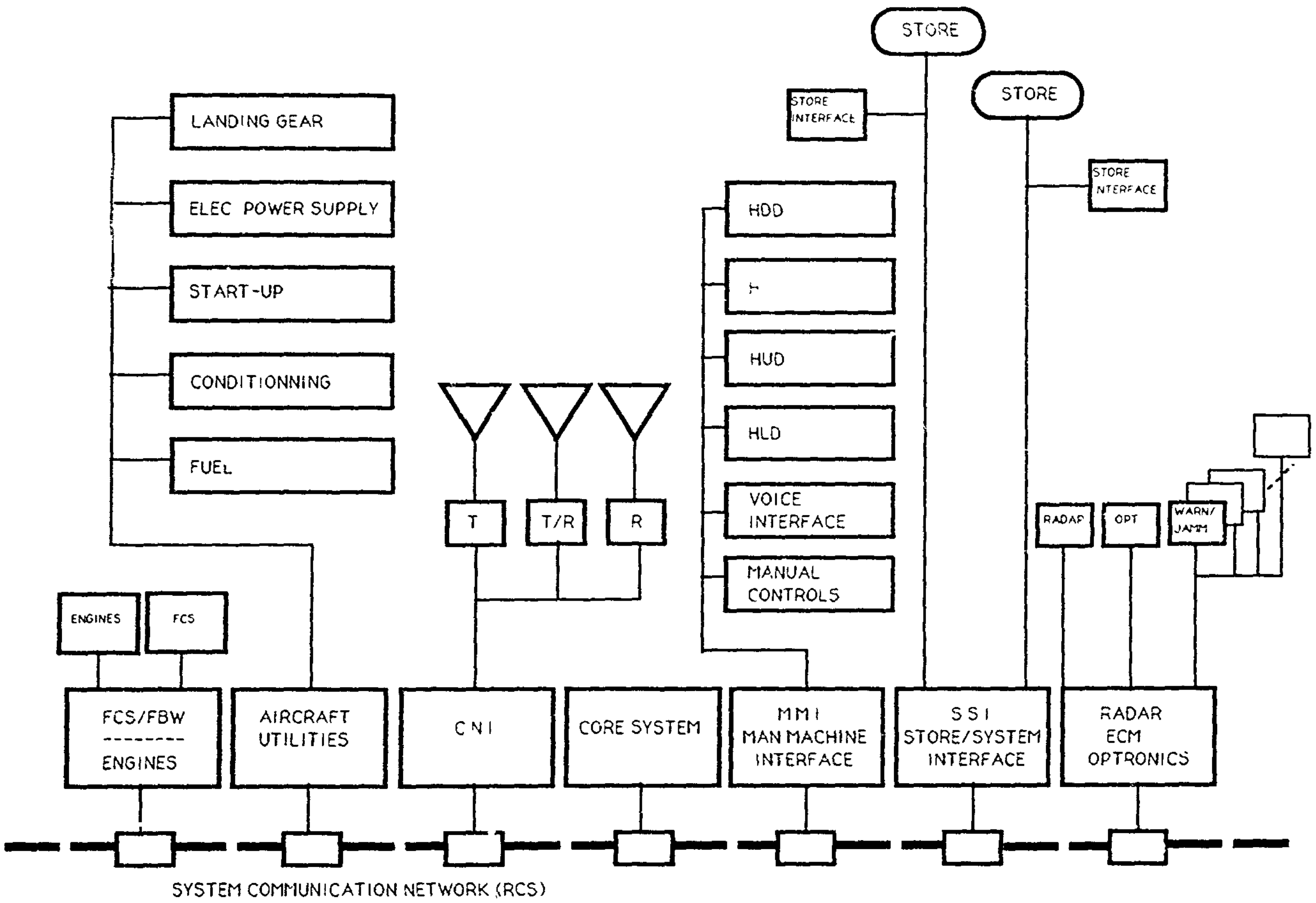
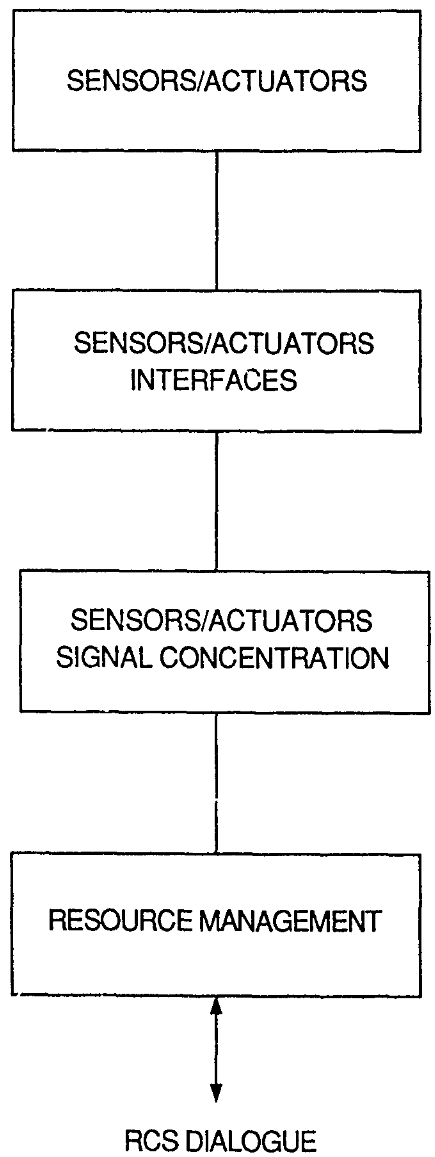


FIGURE 3 SYSTEM BREAK-DOWN INTO HEs

FIGURE 4

EH2 (ASI) BREAK-DOWN INTO MODULES



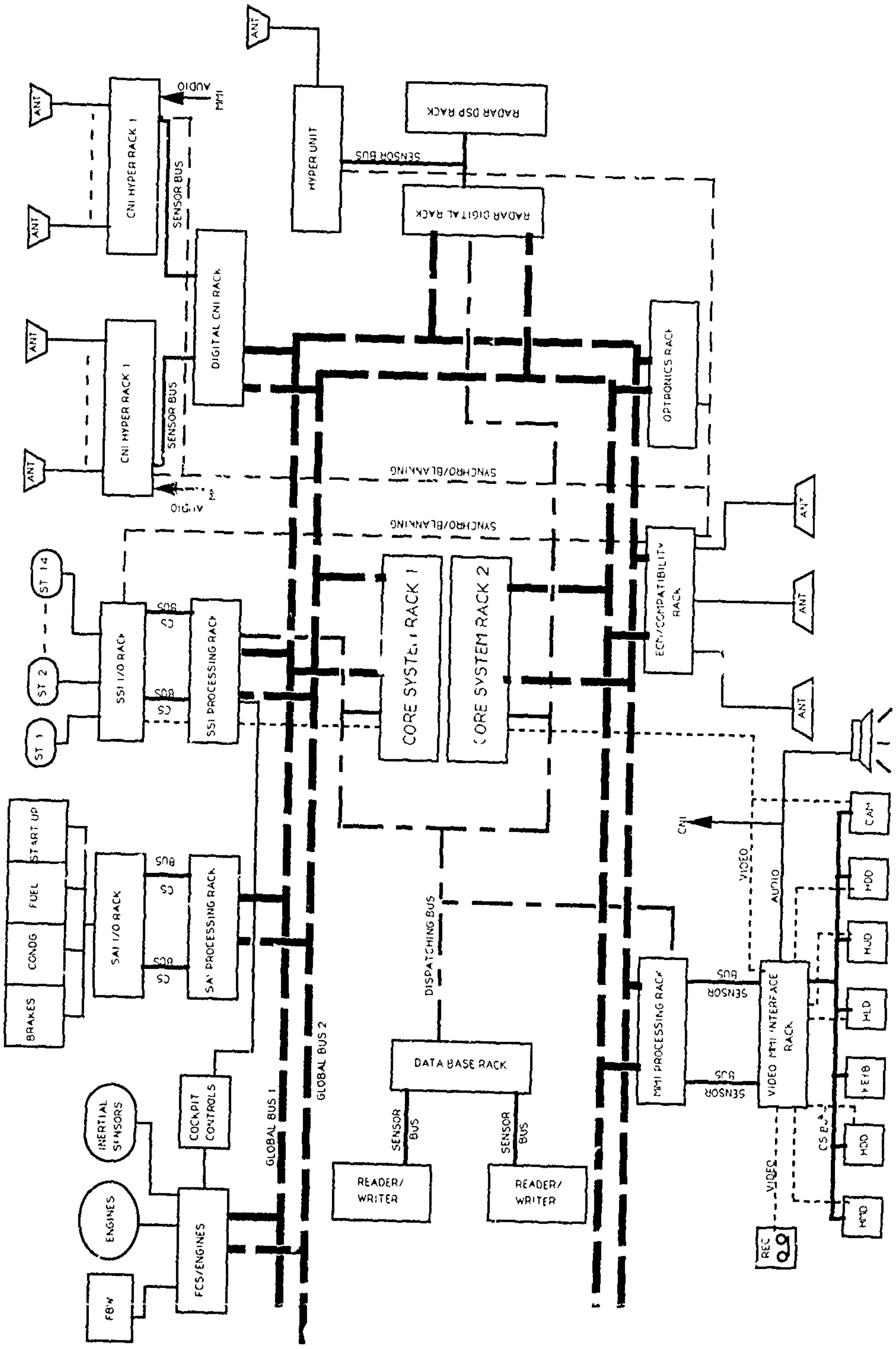


FIGURE 5 GENERAL SYSTEM ARCHITECTURE

MIXED APPROACH TOWARDS MODULAR AVIONICS CONFLICTING REQUIREMENTS

by
J.P. LACROIX
THOMSON-CSF RCM
178 Boulevard Gabriel Péri
92240 MALAKOFF FRANCE

1 MODULAR AVIONICS CONFLICTING REQUIREMENTS

1.1 INTRODUCTION

New avionics development efforts like PAVE-PILLAR and PAVE-PACE in the USA, EUCLID CEPA 4 in Europe, aim at architecture selection or standards recommendations in order to satisfy at least three requirement domains:

- LCC (Life Cycle Cost) requirements
- Performances requirements
- Availability requirements

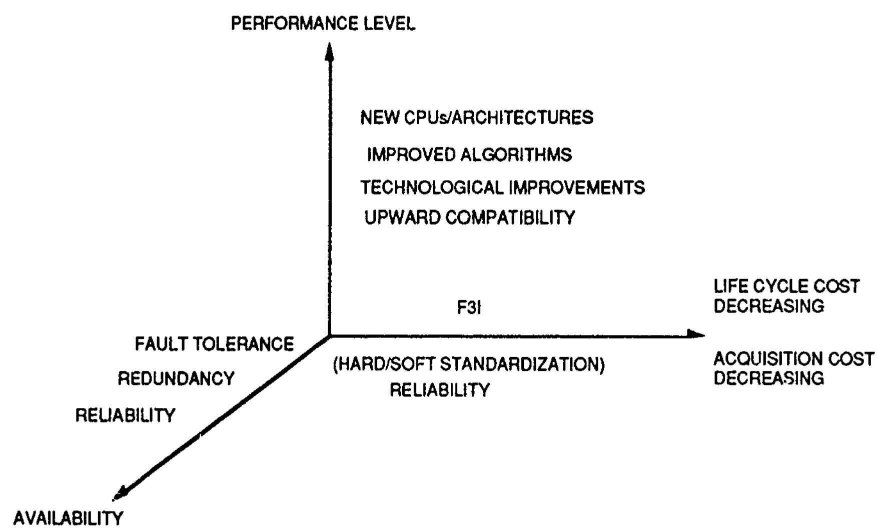


Figure 1.1: MODULAR AVIONICS REQUIREMENTS

(Ends of axis stand for domains to be optimized; along axis are some means allowing to achieve that goals)

1.2 LCC REQUIREMENTS

LCC requirements reflect customers as well as airframe manufacturers expectations:

- to lower procurement and acquisition costs
- to minimize field exploitation costs

Some recognized policies seem able to cope with these requirements:

- rely on standard products (F^3I modules), mass produced in order to share the NRE costs on many parts and get low unit prices; but tradeoffs have to be made on the number of suppliers, so as to have second sources without disseminating the production volume on too much companies,
- put a premium on reliability, which depends on cooling efficiency among other factors like components quality level,
- skip at least one maintenance level by having a very thorough Built In Test on each LRM.

These policies seem obviously able to offer benefits, but all have not been yet demonstrated in the field.

Neththeless, there is a trend in new programs to put a high priority level on these problems by requesting that design should be ILS(Integrated Logistic Support)-driven .

1.3 PERFORMANCES REQUIREMENTS

The basic idea of Modular Integrated Avionics is to concentrate in the same rack many CPUs previously spreaded in severall boxes This computational teaming should, at a given time, deliver a sufficient amount of processing power while benefitting from resources sharing and offering some incremental power enhancement capabilities (*"graceful upgrade"*).

But progresses have been made since the era of 16 bits processors, and new 32-bit RISC or CISC processors are currently able to replace (on a computation capability point of view) severall 16-bit CPUs with a significant cost saving. Graceful upgrade (in term of stress effect on the rest of the system), could be achieved by relying on technological improvement, assuming use of upward compatible micro-processors (yet compatibility requirements could be a progress limiting factor).

Nethertheless, on a development/ production point of view, having less CPUs to produce could mean to add more NRE amortization on each unit while having higher unit cost.

1.4 AVAILABILITY REQUIREMENTS

Availability requirements are due to operational people. They need very high avionics availability (current figures are in the range of 150 working hours - without unpairing failures) and the answer comes from built-in reliability, fault-tolerant architecture and reconfiguration capability and that will be the drawback which could hamper this approach with cost overhead (typically 200 % to 300%).

Method	Hardware penalty	Latency time	Correction time	Reconfiguration delay	Overhead due to spurious errors	Nb of faults
DUPLEX	100%	Computation Cycle			Computation Cycle	1
TRIPLEX	200%	Computation Cycle			Computation Cycle	2
MAJORITY VOTING	200 % proc and voting circuits	Instruction Cycle	Instruction		Instruction Cycle	2
PARITY	12% memory	Instruction Cycle	Exception handling	Not Handled	Exception handling	1
ECC	25 % memory	Instruction Cycle	Clock cycle	Not Handled	Instruction Cycle	1
M for N	(M/N) %	Test cycle	Isolation+selftest	Selftest+Loading	Correction time	M

Table 1.4 Fault detection policies

1.5 INTERACTIONS/CONFLICTS BETWEEN REQUIREMENTS

They are mainly in the field of the architecture; everybody will agree on the benefits of higher reliability and Built-In-Test capabilities.

But the most significant parameter is the architecture choice:

Starting from performances requirements, one may use severall identical medium performance CPUs or only one powerful CPU able to do the job.

In the first case, some organization schemes provide fault tolerance and reconfigurability with a low price penalty (in % of total cost), and also graceful upgrade if the Real Time Executive is able to offer transparency for task localization/ allocation; but latency time in case of defect remains questionnable (see Table 1 4). Nethertheless, the total price could be high, due to the number of CPUs used which does not offer a good cost per Mips, even if a great number of them will be put in production. High reliability figures are also difficult to achieve in such configurations.

In the second case, using only one CPU (obviously based on one unique micro-processor) can't provide fault-tolerance, so the architecture has to be designed as a dual processor one or better as a triplex, majority voting architecture (see Table 1.4). In this approach, cost overhead is high, graceful upgrade difficult or costly, but total cost could be advantageous, despite there is obviously less CPUs to produce.

So it's difficult to find the best (or the least bad) compromise at a given time; and technological progresses are also cha... the hypothesis every two years, and may ... the future Avionics has to wait for the multi-million transistors chips which could offer parallel, redundant and self reconfiguring/ repairing architecture at an affordable cost.

The greatest risk remains to overdesign the modules, because the aim to standardize for a wide range of platforms will surely lead to retain the highest level of performance/ environment requirements in every domain, and that could not be right for some aircraft retrofitting where a good balance between airframe and avionics capabilities has to be made.

2 EQUIPMENT MANUFACTURERS CONSTRAINTS

2.1 DESIGN FOR CUSTOMER'S NEEDS

On an industrial point of view, there is a will to design for a right adequacy with customer's needs and for the lowest internal production cost. This requirement could be not well satisfied by standard products: for exemple, at the CPU side, it's difficult to get the correct amount of processing power needed as well as of memory . This problem arises also for I/O processing where dedicated boards are often to be designed while some standard ones are under-utilized.

So, if every one agrees on the benefits of building prototypes from standard (eventually under utilized) parts, it could be profitable to bring cost effective adjustements for mass production.

2.2 ROBUST DESIGN / GRACEFUL UPGRADE

Another difficulty of the designer's job is to cope with short technological cycles: standards need currently more than five years to mature, while technologies change every two years. The dilemna is to become rapidly obsolete when using stabilized technologies or to miss deadlines when using too emerging technologies.

So there is a need of "robustness" at each level of the system (board, chassis, rack, avionics suite) in order to accept without major redesign some technological improvements (related to costs savings for the final product) as well as to provide growth capabilities for evolution of customer's specifications or even some errors in system sizing during the design phase. This need is currently addressed by choosing upgradable components and designing-in flexibility through programmable devices.

2.3 SHARED DESIGN/ DEVELOPMENT

There is a trend for design and development teaming inside companies, between companies in a country and also between countries:

- EUCLID, PAH-2 and EFA programs in Europe,
- International cooperation programs like ASAAC, Nun-Bennett agreements.

This kind of business, contractual matters being put apart, demands a very accurate Work Break-down Structure and a clear system definition and partitioning, as well as interface definition. Tools are lacking in this field, and a part of this need is tentatively addressed by the tool described in the later part of this paper.

3 CANDIDATE APPROACHES

No panacea seems able to solve all the depicted problems, and a combination of methods, tools, tricks is currently used.

3.1 IMPLEMENTATION INDEPENDANT DESIGN

The aim of this approach is to exercise methods allowing to be (almost) free of the final hardware implementation.

Such methods are already in use in the ASICs business: Silicon compilers are tools which offer some protection versus process change or discontinuing by the semi-conductors' manufacturers; they are also useful for doing request for quotation and price comparison among potential suppliers.

In software development, in order to try to decrease the climbing costs, there is a need for modules re-use; Ada and (perhaps more) Object Oriented Languages should provide the right answer .

At the LRM level, it seems difficult to ask for implementation independance if interchangeability at the binary level is requested; if not, one may argue on a strict conformance to the F^3I requirements by attaching priorities to requirements:

- Form interchange relies to mechanical/ thermal constraints and must be satisfied,

- Fit interchange could be understood as a top-and-bottom conformance:
  * at the top by compatibility with some HOL (usually software written in Ada with standardized Real Time Extensions),
  * at the bottom by compatibility with a given backplane: connector, pins allocation, data exchange protocol,

- Function interchange should be achieved for various micro-processors through a combination of software layers and hardware additions (ASICs), assuming that they all can satisfy to a given level of computational capabilities and response time.

This approach could offer transparency of the inner part of the LRM and allow to use for maintenance purposes CPUs based on different micro-processors, but at the price of software recompilation at flight line depot, and less reconfiguration capability if different types are used within the reconfigurable entity (usually one rack).

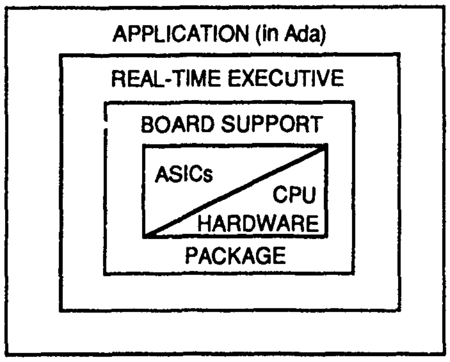


Figure 3.1 Hardware encapsulation

3.2 MIXED APPROACH

3.2.1 BOTTOM-UP

3.2.1.1 INTERACTIONS/LOCKS BETWEEN STANDARDS

One of the first conclusion when conducting a bottom-up approach is that there is a close relationship between potential standards.

For the hardware:
- Board size will put constraint on board density (eventually leading to a two sided board).
- Board density will have influence on package type.
- Package type will have influence on cooling management (it's difficult to use conduction-cooling for PGAs).
- If surface mounted package type is choosed, it could force to develop hybrids or ASICs.

For the software:
- CPU type and power will determine if multi-processing is required.
- Communication between tasks will have influence on the backplane bus (message oriented rather than memory oriented) and on the Real-Time OS (to be tied to Ada).
- Bus width could influence the hardware (connector size).

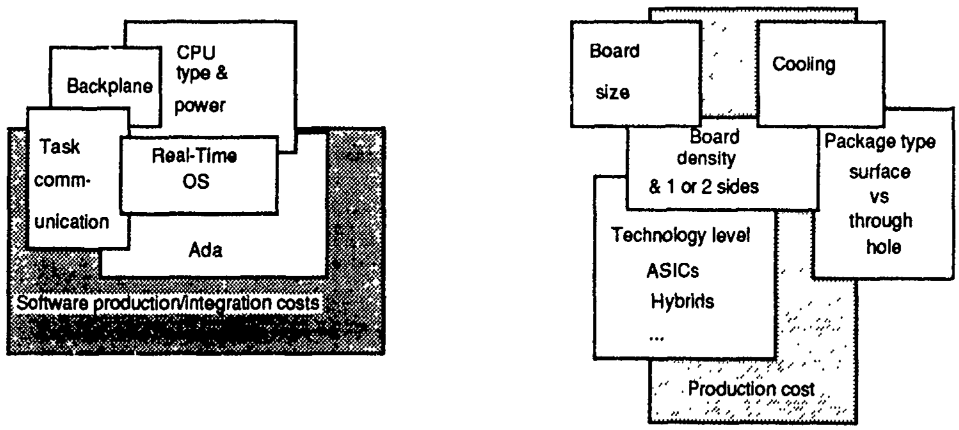


Figure 3.2.1.1 Cross-coupling of standards

3.2.1.2 CORE FAMILY BUILDING

This approach aim at building a family of the four main types of LRMs from which a large part of any avionics suite could be developped. It uses a layered method:

- 1-st layer BUS LEVEL defines:
  * backplane bus
  * Test/ Maintenance bus
  * Down-loading/ Debug bus (if dedicated bus is needed)

- 2-nd layer INTELLIGENCE LEVEL defines:
  * main classes of micro-processors
  * companion ASICs (if any)
  * service serial links
  * bulk memories

- 3-rd layer PERIPHERAL LEVEL defines:
  * functionalities requested to interface with the system (Avionics Bus, AC/DC I/O, Discrete bits,..)

Using these three levels, a set of boards can be built, some with or without intelligence (Dumb I/O or I/O controller, Bulk Memory or File Sever), all intelligent boards using the same kernel.

One flexibility advantage was to place, for some families, an on board power supply; when considering racks' composition, there is a need for a redundant power supply, which should have a very wide range of delivered power. Adding one LRM could force to add two PS modules. This problem does not arise with local on-board power supplies, which offer natural incremental power capabilities.

This method is applied since 1980 in Thomson for 680X0 based designs, targeting various form factor boards (1/2 ATR, Double-Europe, ARINC 600, ...) and functionalities. Development cost and time savings offered by the family concept are a major argument when answering RFPs.

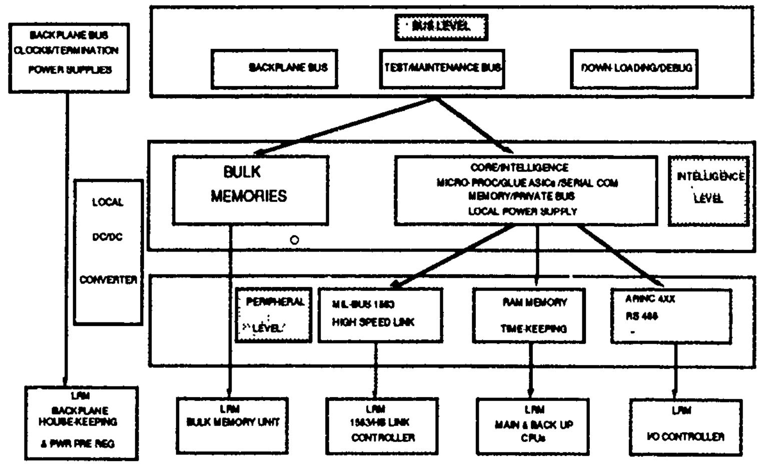


Figure 3.2.1.2 Layered approach of LRMs family

3.2.1.3 VIRTUAL MODULE

The very best solution is to have truly F³I modules, and use them in all products, but in some cases, like partial revamping of old products, it could be useful or profitable to port designs towards other board sizes or different backplane bus, or to add functions to a previous design.

There are also compromises to find when looking for standards acceptance within a company; a way to fight the well known NIH (Not Invented Here) position is to leave some creativity to people.

The "virtual module" is a soft way to do standardization because it remains at a conceptual level: the standard is a combination of a thoroughly validated schematic together with software layers (BSP, BIT, ...). This Hardware/Software Kernel could be considered as a part of a library of high level functions. The good side for users is that they get some freedom of implementation; the good side for standardization is that expensive developments which insure software portability are locked.

This approach is used in Thomson-CSF for a new family of RISC based modules, allowing (non-predictive) software to run on any cached or no-cached architecture developped within the company.

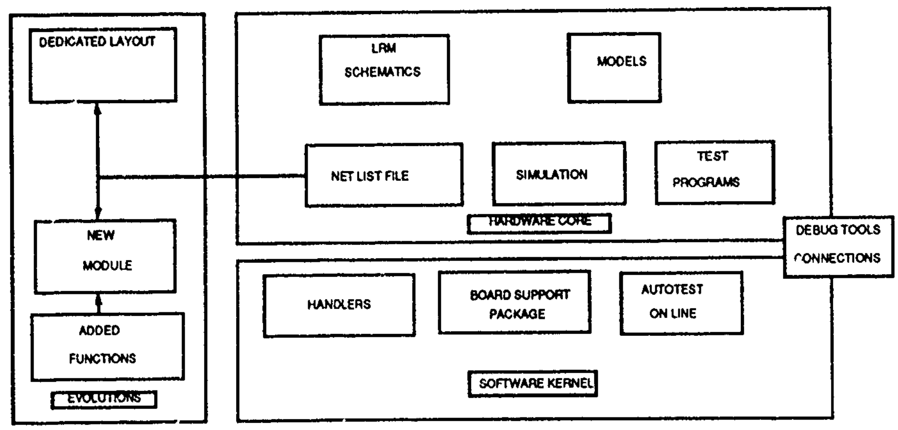


Figure 4.1.3 Virtual Module (or SHAPE: Software Hardware Adaptable Processing Elements)

Don't try to sell Virtual Modules: you could be paid with virtual money!

3.2.2 TOP-DOWN

When building an Avionics system, and starting from operational and functional requirements, the problem is to answer at least three questions:

- were are the functions?
- what amount of resources (memory, I/O, computation power,...) do they need?
- which is the volume of data exchanged between them?

Misplacement of functions could lead to avionic bus bottleneck by unuseful data movements.

Local underestimate of processing power could force to add computation capabilities or to use remote ones.

Underestimate of data traffic could lead to increase data rate or to add busses to the system.

In the case of Integrated Avionics, the problem is widened to system bus and backplane bus; and also because this concept has not been yet used in any conflict, and vulnerability issues are not known, Top-Down approaches have to handle centralized as well as distributed Avionics.

Starting from some knowledge of the system, from a software load balancing point of view, the aim is to find the best repartition of processing power among different racks in order to cope with backplane bus bandwidth and system bus capability; the ultimate (technically speaking) goal should to be able to place tasks anywhere (CPU, Rack, Avionics Suite): it would make worksharing and reconfiguration easier.

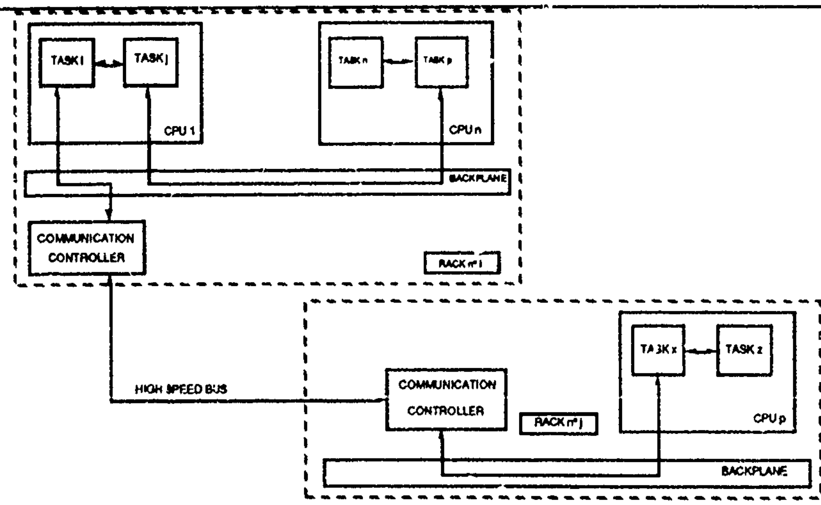


Figure 3.2.2 Tasks communication system's transparency

3.2.3 TOP-DOWN METHOD

It was decided to start from a known part of the RAFALE aircraft system. Thomson-Csf being main contractor for the Radar, Counter-Measures, Optronics and Communication equipments, it was possible to get all needed informations to describe the equipments and do method validation.

The first step was to build a common equipment description form, then design cature tool, simulation method, and, if needed, the simulator.

3.3 TOOL DESCRIPTION

3.3.1 DESIGN OF A MODULAR INTEGRATED AVIONICS SYSTEM

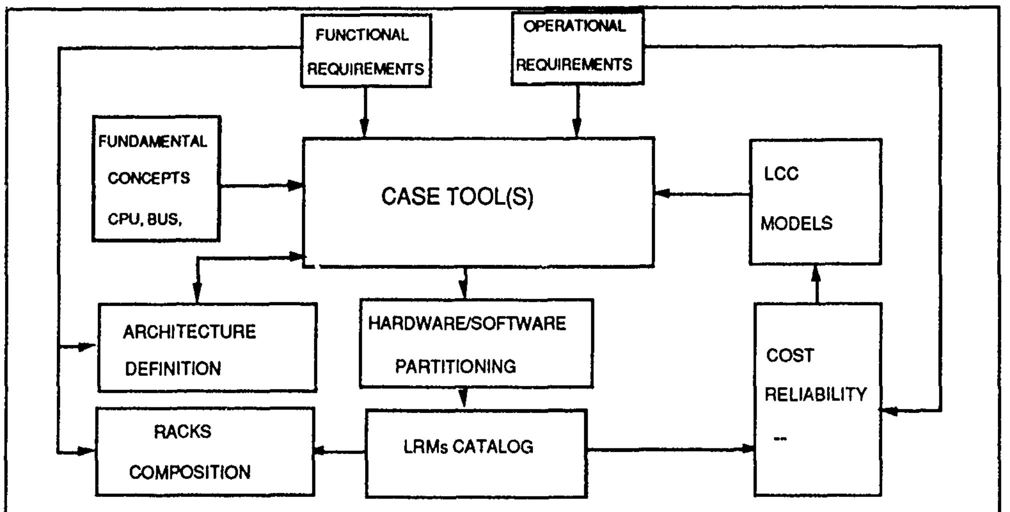


Figure 3 2.3 Required CASE tools

The designer's dreamed CASE Tool could look like the one depicted in Figure 3 2 3.

One of the candidate architecture for future avionics system leads to place in the same rack/ chassis severall identical modules (CPU or I/O oriented) which were previously spreaded among different boxes.

The design of the CPU itself is not a tremendous task, according to the current state-of-the-art and the many off-the-shelf available micro-processors; the main difficulties to solve are in the field of the behaviour of such many CPUs dealing with an unique backplane.

By the time this study was launched, there was no tool allowing to forecast the bus efficiency/ load in an not well known context of bus accesses scheduling; tasks scheduling inside the CPUs must be aware of bus activity, and vice-versa.

The second unknown factor is the actual efficiency of the CPUs; the current upgrade in the available memory space and the computation power leads to a TBD shrink of resources.

The third unknown factor is the initial system sizing; by the time being, some laws seem to appear between successive generations of avionics systems (ratios between 17 and 27), but there is a lack of methods for a more accurate system sizing.

All these unknown datas/ factors make uneasy the design of an efficient (in term of requirements/ product adequacy) if there is no help available through some Computer Aided Tools.

3.3.2 SYSTEM SIMULATION

The simulation of any avionics system, whether centralized or distributed, is useful to the designer to get a rough idea of how the data processing parts of the various LRMs are acting.

The main figures of interest are the scheduling of the events (harware and software), the dynamic bus load balancing and the resources allocation/ sharing.

3.4 PRELIMINARY REQUIREMENTS OF THE TOOL

3.4.1 TARGET APPLICATION

The tool is dedicated to the simulation of a network of data processing racks, in respect to the internal tasks scheduling and the communication between data processing modules. The activities of task creation and execution are to be simulated with their timing aspects in mind, as well as with their hardware resources consumption.

The tool is a complementary approach in regard of some commercialy available products which are more suited to algorithms simulation, network simulation and to global systems simulation.

A particular care has to be given to the modelization of data communication between computation modules as well as between racks, in the future attempt to find the best place of these modules in the most suited rack of an Integrated Avionics Suite.

3.4.2 PROGRAMMING ENVIRONMENT AND HOST

The language(s) for the programmation of the tool must be supported by a wide range of workstations; the perennity of the tool itself is insured by not using specific or exotic environment, bound to any non standard workstation.

3.4.3 MAN-MACHINE INTERFACE AND EASE OF USE

The tool was designed for people being not familiar with capture/ simulation arcana, in order to have a short training time.

3.5 TOOL DESIGN

3.5.1 APPLICATION FIELD

The tool is based on a simplified, macroscopic approach considering that there are only two useful levels in an avionic system:

- the computation module level
- the global system level

This concept allows an easier relocation of the modules in a modular avionic system.

The analysis of the software side of the system is made through the representation of linked software modules: there are three types of modules and four types of links.

The description is done in an hierarchical way: for exemple, an I/O module can be built through a combination of elementary software modules.

3.5.2 SOFTWARE ENVIRONMENT AND HOSTS

The graphic capture and simulation package is written in C. It should be easily portable on any workstation with some care to exercise for the graphic library.

The very first release of the tool used the SUNVIEW graphic library developped for the SUN TM workstations but the design was rapidly ported under X Window (of the MIT) with the Xview toolkit offered by SUN; this toolkit is under port on DEC stations by a third party (Unipress).

The current version of the tool is fully operational on SUN workstations and in beta-test on DEC stations, both types being used within the author facilities. The design should have be made with the Xlib library of X window in order to run on any X Window workstation, unfortunately this library was not available at the beginning of the study. TBD

3 5.3 USER FRIENDLY INTERFACE

The simulation package user's interface relies on pull-down menus and multi-windowing for a higher flexibility.

The capture and editing of the modules (segments and links description) is made easy by optional "help on the syntax" placed in the pull-down menus.

3.6 GRAPHIC CAPTURE

3 6.1 CAPABILITIES

The graphic capture utility allows the system designer to describe in a modular way the application software packages running on severall computation modules.

3.6.2 METHODOLOGY

As said in § 3.5.1, the methodology is based on three types of software modules and four types of links.

Each software module is made of a collection of segments, which represents an execution time corresponding to instructions cycles, memory cycles and I/O operations.

Transactions from module to module are executed by transfer between segments.

3.6.3 TYPES OF MODULES

3.6.3.1 Running CPU module

This module is made of a serie of segments where the CPU is running freely and does not rely nor is constrained by any external event.

3.6.3.2 Waiting CPU module

This module represents a serie of segments where the CPU is denied any external access cycle. This module is used to describe a CPU in a passive wait state.

3.6.3.3 Synchronization module

This module is referenced to a global (in a system point of view) event. This event will synchronize severall CPUs; it is issued by an unique source, but may be received by more than one CPU.

The Syncronization module encompasses "active wait" segments corresponding (for exemple) to the response time (delay) of an I/O device.

This module is used to describe a CPU in an active wait state.

3.6.3.4 Modules' hierarchy

The tool has the capability to represent a set of modules by an unique module (of an higher level). The graphic capture package alows such an ascending approach.

The reverse approach (descending) is also offered, in order to get a more detailed view inside the functionning state of a module.

3 6.4 GRAPHIC CAPTURE CAPABILITIES

The graphic capture package allows the designer to open simultaneously severall editing windows. Each of them is dedicated to the description of one CPU (block diagram) and works on one hierachical level. Using the views is orthogonal to the combinations CPU-Hierachical level.

3.6.5 FILES GENERATION

3.6.5.1 Description file

The graphic capture package produces a texte file containing all the software modules described. This text file is correctable and modifiable. All software modules are referenced to the same level, but they remain tied to a particular CPU.

3.6.5.2 Other files

The package generates four other files:

- A global file saves all CPUs block diagrams as well as the contents of the modules.
- An utility file safeguards the memory space allocated to the CPUs description and the graphic context. This file is useful in case of crash of the capture package; the user can restart from a previous stage, preceding the crash.
- A report file saves all error , warning and help messages.
- A "help to debug" file records the operator's last commands (in a 1024 steps moving window); this file is helpful for the debugging of the tool itself, by allowing to replay the commands producing a malfunctionning.

3.6.5.3 Printer output

All block diagrams of the CPUs edited on any window of the workstation can be sent to a Postscript printer.

3.7 SIMULATOR

3.7.1 POLICY

Using an off the shelf behavioural simulator (VERILOG, VHDL,...) makes mandatory to design a source code generator. Designing this generator proved to be as complex and difficult as designing a discrete events simulator. The final choice for this part of the study is not definitively made, but the best way seems to look for a discret event's simulator.

3.7.2 ENTRY PARAMETERS

The description of the software modules uses as references some hardware (in the sens of performances) parameters of the CPUs (μ-processors cycle time, message travelling delay,...).

All these parameters are entered as text datas and are interactively modifiable during the simulation.

3 7.3 SIMULATION

The simulation belongs to the "discrete event" type: the likelyhood of apparition of an event is computed for each previous event.

Between each event, all memory accesses and I/O transactions are saved for each CPU for further statiscal analysis purpose

The discrete event simulator has to be compared to the scheduled simulator: the previous will chain the events, whatever the time between two succeding events; the following will exercise its scheduler at each time slot.

3.7.4 SIMULATION RESULTS

The simulation output is a graphic one, which represents the current activity of each CPU, expressed as segments referenced to the software module which contains them.

It will be possible to appreciate the interactions between CPUs by examining the activity diagrams. The statistical analysis of resources use should be offered in a later version of the tool.

3.8 IMPROVEMENT OF THE ACCURACY OF THE SIMULATION (SYSTEM LEVEL)

3.8.1 WEAKNESSES OF THE DESCRIBED TOOL

For the available version of the tool, all CPUs are executing their tasks at the same rythm, whatever the context.

In order to add some flexibility in the tasks scheduling, conditional execution of the software segments has to be provided.

Another problem is the access to a shared resource, which relies on priority modelization and resolving mechanism.

3.8 2 CONDITIONAL EXECUTION

The first improvement will be to launch the execution of some particular segments of the software modules by global system conditionning parameters. These parameters will be either defined by the user when setting up the current simulation, or dynamically generated by some software modules during the simulation. The method for generating these global conditionning parameters is not yet defined.

3.8 3 ACCESS PRIORITIZATION

If any CPU has to access to a common, shared resource, the synchronization module, which is in charge of this request, must receive acknowledgement or denied access from this resource: the priority access mechanism to a shared resource is yet to be modelized

4. CONCLUSION

The described tool (graphic capture and simulation) aims to bring some methodological help for designing modular integrated avionics systems, by allowing a more accurate analysis of their dynamical behaviour.

The refinement of the system modelization is tightly dependant on the performance of the simulation package. Additional work will be performed during the current year in this area and more results would be shown at the lecture time.

5 ACKNOWLEDGEMENTS

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AVIONICS SOFTWARE EVOLUTION

John A Turton,
UK Ministry of Defence,
St Giles Court,
1-13 St Giles High St,
London WC2H 8LD
UNITED KINGDOM

SUMMARY

The paper reviews the critical software-related aspects where thorough planning and implementation of philosophies and principles are needed, in order to be able to develop software-based avionic systems to meet target timescales and budgets; identifies some of the critical software technologies that will facilitate this process, both today and in the near future; and briefly describes the implications for software resulting from the currently-emerging modular avionic architectures. A central theme of the paper is that the system and software generation process should be placed on as formal a theoretical basis as possible This is in order to be able to deal effectively with the complexity of the software-based avionic systems that are 'just around the corner'

1 INTRODUCTION

1.1 The magnitude of the software component within military avionic systems has grown considerably over the past twenty years The technology has come a long way from the earliest systems, containing some 16kbytes of code embedded in a central processor, to the architectures under consideration today that feature many megabytes of code within a distributed processing environment. The enormity of the software development task has required a move away from the assembler language technology of the early years, to the use of standardised high level languages such as Ada, in order that overall Life Cycle Costs may be minimised. Advances in semi-conductor technology over the same period have provided the system designer with the microprocessor and memory building blocks that were unavailable to those early digital systems. Those components have the performance capability to accommodate the code expansion common to most high level language implementations. The software content of avionic systems seems set to continue increasing, with the next generation of military aircraft likely to feature distributed processing architectures based upon a modular construction.

1.2 In parallel with this growth in size and complexity, there has been an evolution in the understanding of how these systems should be developed in order to meet performance, cost and time-scale targets. The rapidly increasing capabilities of the hardware that can be fitted into an aircraft provides more and more scope for software-based functionality. This must be supported by the software engineering technology to handle the definition and design of those functions within reasonable costs and timescales.

1.3 A central theme of this paper is that we need now to be placing the system and software generation process on as formal a theoretical basis as possible. This is in order to be able to deal effectively with the complexity of the software-based avionic systems that are 'just around the corner'. Formality will allow automation to be applied to the fullest extent in the development process. The result is that efficiency of the generation of the system can be maximised, and an ability is provided to minimise the number of errors that pass through to the later development stages, where they are very costly to correct.

1.4 From the perspective of the customer for these advanced software-based systems, the risks associated with the software content of projects continue to grow, as a result of the rapidly increasing complexity that is achievable and demanded Large real-time embedded software projects are prone to timescale overruns and budget overspends, or fail to meet their operational requirements The result is increased cost, late service entry, a need for further development after service entry to meet original requirements, or in extreme cases cancellation

1.5 This paper reviews the critical aspects where thorough planning and implementation of philosphies and principles are needed, in order to be able to develop these very complex systems to meet target timescales and budgets; identifies some of the critical software technologies that will facilitate this process, both today and in the near future, and briefly describes the implications for software resulting from the currently-emerging modular avionic architectures

1.6 This work has been carried out with the support of the Procurement Executive of the UK Ministry of Defence (UKMoD(PE)). The views expressed in this paper are those of the author, and do not necessarily represent those of the UKMoD(PE).

2. THE IMPORTANCE OF THE LIFE CYCLE MODEL

2.1 Evolution of the software functionality of avionic systems has necessitated a parallel evolution in the overall approach to the development of the software component. A variety of idealised lifecycle models for the development of software based systems currently exist; lifecycle being defined as the complete process from initial definition of system requirements, through development, production, in-service support, to eventual disposal.

2.2 A potential difficulty in the development of complex software-based systems is the conflict between the need to freeze the design requirements at some point, in order that the system can be designed, manufactured, tested, etc, and the reality that it is often not possible to define fully the requirements for the deliverable system until experience has been obtained in the application of something that represents it. To this end, a considerable proportion of the overall design/development budget should be assigned to the process of simulation, modelling, prototyping, animation of specifications, etc prior to commitment to design; furthermore, as much scope as possible should be provided to allow the functional requirements of the system to be further refined throughout the development programme.

2 3 One thing is certain; a positive decision must be made from the outset of any software intensive project, as to what model or paradigm is to be applied, in order to set the framework upon which the detailed project development process is built (Paradigm defined as something serving as an example or model of how things should be done)

3 LIFECYCLE MODEL EVOLUTION

3 1 The Waterfall Model

3 1 1 The conventional model for many years has been the internationally known 'Waterfall' Model (see Fig 1). This evolved from early experiences in the development of software based systems. It was formalised in DOD-STD-2167 'Military Standard - Defense System Software Development', and has been carried forward into the the current version A of the document[1] issued in 1988.

3 1 2 The Standard requires that developers implement a process of managing the development of deliverable software. A sequence of phases is defined for the definition of requirements, the design, integration and testing of software in parallel with the system hardware development process.

3 1.3 An implication of the Model is that the development process should start at a software systems highest level of functional requirement. Design definition proceeds progressively 'top-down' through a successive breaking down into lower level software components, down to the ultimate component level, the module. The coding and integration to build the complete system is then carried out 'bottom-up', allowing full testing of the component software assemblies before integration into the next level up

3 1 4 The DOD (Department Of Defense) Standard also introduces the concept of baselines, to provide assistance in the process of management control A baseline represents a configuration identification at a formally specified point in a configuration items' lifecycle. The completion of one phase of the development process is determined by the satisfactory assessment of the deliverables of that phase, and may be identified as a baseline. The products of the next phase are formally verified against the previous baseline, as part of the quality assessment, before themselves being subsequently incorporated into a new baseline.

3.1 5 The Model has come in for some criticism over the years, as it is considered by many not to reflect what actually happens during the lifecycle of software development. The concept of phasing through the development process, with detailed design being completed before coding and test being carried out, and not being revisited, does not match what has to really happen in a project, where the design process may be reiterated throughout the development phase, and probably on into the in-service phase as well.

3.1.6 However, I would suggest that the basic concept behind the Waterfall Model must be present in whatever, more refined model, is employed. The fundamental requirements of 'top-down' design definition, and 'bottom-up' coding and integration, are essential to ensure design traceability in the final delivered product However, for the complex systems of today and the future, other processes must be included to achieve a workable life-cycle model. These more advanced models may in fact be considered as further elaborations of the basic concept

3.1 7 It is vital that the individual system developer is given the freedom to arrive at the final product by whatever way he chooses, provided that he can demonstrate from the outset that this is consistent with the basic requirements of the Waterfall Model. He should have the scope to choose the development life-cycle/methods that best suit his organisation and/or the task requirements

3 2 V-Model

3 2.1 A development of the model appears in the UK STARTS Guide[2] (See Fig 2), prepared by the UK Department of Trade and Industry and the UK National Computing Centre. The STARTS Initiative (standing for Software Tools for Application to large Real Time Systems) provides a collation of information on available tools and techniques for the development of software based systems.

3.2.2 The V-Model explicitly introduces links between design decomposition phases and integration and test phases. It is the documentation and reviews which provide the tangible and objective milestones throughout the software development process. Each phase can only be considered complete when all the required documentation has been completed and reviewed to have met the requirements The subsequent phase can only be started when all the input documents are complete and available

3 3 Incremental and Evolutionary Development

3.3 1 The incremental approach (see Fig 3) achieves the final full-function deliverable, by building the total system capability in ever increasing increments Successive builds have increasing capability, which is formally demonstrated at pre-planned points in the programme. Of particular concern in this process is the co-ordinated, parallel development of the hardware needed to support the software at these milestones

3.3.2 The evolutionary approach is similar to the incremental, but instead of achieving full capability over a single development phase, the process spreads over a number of phases, probably including in-service A limited-capability system is taken into service as part of a pre-planned programme, which sees further development to full capability in parallel with the initial in-service period.

3 3 3 The incremental and evolutionary approaches can help to reduce the risks involved in single phase development to full functionality of very complex systems They also help where the requirements are 'fuzzy' i e where the general requirements are known, but the details are lacking The building of a limited functionality system allows 'hands-on' experimentation in a real or simulated scenario, increasing understanding of what is actually required, and leading to refinement of the requirements.

3.4 Models for the '90s and Beyond

3 4.1 A recent proposal[3] is a further development beyond the incremental approach. Instead of a rigid number of phases, successive levels of prototypes are used (see 4 2 1) to iterate towards the final requirement. The use of continuous evaluation and risk analysis provides a good basis on which to make necessary decisions over options that may be open. When the prototype has iterated to the

point where it meets the requirements, it is engineered as necessary to provide the design soundness required by the original Waterfall Model, in order to provide the deliverable product. This approach is known as the Spiral Model (see Fig 4).

3 4.2 Another possibility is the 'Third Generation' Model, proposed by A O Ward[4] of BAe (see Fig 5). This again recognises the importance of the rapid prototyping process in defining the requirements for the eventual design of the system.

4. THE REQUIREMENTS DEFINITION PROCESS

4.1 It seems clear that great emphasis will be placed upon the requirements definition process in future models, as a result of the present difficulties in precise definition from the early stages of a project. It is here that the requirements are set to be transformed through the development process into the final design. If the initial requirements are wrong, then so will be the system and software that appears at the end of the development process If we can only describe precisely what it is that we want, in complete and consistent detail, then the process of developing it, whilst by no means being trivial, does become a realistic, relatively low risk task A further complication is the design of the hardware on which the software will run, which often has to be tackled from an early stage in the development process (see Fig 6), because of the long lead times involved in obtaining the components, designing enclosures, environmental testing leading to qualification for the application, etc.

4 2 Techniques and Tools

Techniques and tools available to assist in the requirements definition process include.

4 2.1 Rapid Prototyping

Enables the system developer to assess design and specification decisions through the implementing of part or all of the system, without consideration of integrity and formality requirements. The rapid prototype can then be exercised in realistic situations.

4.2.2 Animation

i Animation of a systems requirement specification is a process which facilitates the examination and demonstration of the specification. The specification is converted into an operating, visible representation, which can then be exercised by the customer or designer with the aim of checking that the specification does actually record what is required

ii. Rapid prototyping and animation may be applied iteratively, with repeated modification to the models or specifications generated, until a satisfactory solution has been demonstrated. In the case of rapid prototyping, there is also the option for the prototype to be developed further into the deliverable product.

4.2.3 Notational Tools

Notational tools provide support to the process of detailing the requirements A number of such tools now exist in proven forms, but are likely to need further development if they are to support adequately the very complex systems now being considered. In particular, mathematical formality needs to be introduced as far as possible, in order to facilitate automation of the process.

4.2.4 Analysis Tools

Automated tools are required to detect mis-specifications and errors during the early stages of the specification process.

5 THE EVOLUTION OF ADA

5.1 Ada today

Ada was originally developed by the US DOD to provide a standard language for the development and maintenance of large real-time embedded systems. The language was initially standardised as MIL-STD-1815[5] in 1980, and subsequently revised as ANSI-MIL-STD-1815A[6] in 1983. The tools to support the development of systems with the language have progressively become more capable, and more widely available for application on a broad range of development hosts As at February 1991 there was a total of 135 validated compilers[7] for use with the Ada language, covering a broad range of both host and target machines. A number of these compilers are second or third generation developments, and the efficiency of target code produced is believed to be becoming very good indeed. A wide range of other development tools are also available to support the development of Ada based systems. A significant amount of demonstration and development has taken place for real avionic applications, including applications having flight safety implications. Offsetting any increase in code required to carry out a particular function is the increase in the capabilities of target processors; there seems to be very little reason today to oppose the use of Ada for the development of systems on grounds of performance alone, for a broad range of avionic system functions

5.2 Ada 9x and the future

5 2.1 Since the Ada 83 Standard was issued, there has been a considerable progression in the capabilities of computing systems appropriate to military applications. There has also been a realisation from practical experience that there were a number of aspects of the original Standard that were less than perfect. As a result of these factors, the Ada 9x project was started, with the intention of defining an updated Standard for applications in the '90s and beyond. The project was initiated in October 1988, with an invitation to the public to submit revision requests, and over 750 were subsequently received. A number of meetings and workshops were also initiated, to assist in the process of further refining and prioritising user needs

5.2.2 The Requirements Definition Phase was completed in December 1990, with the publication of the Ada 9x Requirements Document[8]. It appears that there is still some way to go to the publication of the updated Standard, and that it will also be some time after that before the development tools are available in order that the Ada 9x Standard can be applied in real projects.

5.2.3 The overall goal has been to balance the necessary changes for the languages' growth in terms of applications in the 1990s, with the need for stability in terms of preserving the integrity of existing Ada software and tools. Thus, upward compatibility has been a guideline (but not a rule) for the activity; legal Ada 83 programs should in general be legal Ada 9x programs, and should retain the same functional characteristics. There are exceptions to this guideline, and it will be interesting to see how much upward compatibility Ada 9x eventually allows.

5.2 4 Upward compatibility is likely to be of significance in avionic applications, where large amounts of specialist software are required, often performing safety-related real-time functions. Upward compatibility should allow significant amounts of software to be carried forward from one project to the next; lack of it would require redesign and comprehensive reverification at the changeover from Ada 83 to Ada 9x, imposing a considerable cost burden on that development project.

5.2 5 At a more detailed level, there are several aspects identified in the Requirements Document that will be of particular significance to the avionic field:

i The need for the Ada 9x solution to accomodate both parallel and distributed processing

ii. Support for modern programming paradigms

iii Provision of facilities to support real-time applications

iv Requirements for safety-critical applications

6. AUTOMATED TOOLS, AND THE INTEGRATED PROJECT SUPPORT ENVIRONMENT

6 1 Automated Tools

Automated, integrated software tools are vital to the achievement of the increased software productivity needed to match the rapidly increasing size and complexity of software-based avionic systems Estimates today of realised productivity in the production of software for avionic systems vary in the range 1000-3000 lines of fully-tested code per man year In the future, the total software load for an aircraft may amount to more than the equivalent of 40+ million lines of source code. Maximum productivity will be essential in order to contain development and support costs, and will need to be greatly improved over that typically achieved today if the systems are to be remain affordable. An objective should be that each stage of the lifecycle is supported by a fully automated tool

6.2 The Integrated Project Support Environment

6 2 1 As the complexity of avionic systems and their software increases, so there is a need for their development to be supported by more sophisticated tools As the total amount of software content increases, so the number of people who need to access these tools and the design itself increases, as does the required productivity of the software development process Hence, the need for these tools to be interfaced together, and supported by a system which allows access by a number of people at the same time The picture is further complicated by the needs of international collaboration on development projects, leading to a possible need for access to be spread over a wide geographical area The Integrated Project Support Environment (IPSE) is the ultimate goal, featuring an integrated set of tools providing complete support for the design/development process, through the in-service phase as well as during initial development (see Fig 7).

6.2.2 Integration comes in two forms; information sharing between development tools for analysis, specification, design, coding, testing and integration; and information management via configuration control, change control, requirements traceability, and project management support

6.2.3 With the current generation of avionic system, the Support Environment needs to feature a wide range of tools, each phase of the life-cycle being supported by an automated tool. Each tool has the facility to interface with others within the integrated toolset, supported by a common data-base recording the design itself, its configuration and so on.

6 2.4 For the future generation of system, more advanced tools, and more of them will be required, with perhaps the facility to tackle safety-critical as well as mission-critical software. A highly complex, integrated toolset featuring a common database and user interface will be necessary, as will be the ability to provide very wide distributed access

6 2.5 Major improvements to overall productivities are required, perhaps by a factor of two or more. This is likely to prove very demanding on the tool suppliers, but software productivity is an area where such improvements are needed if we are to assure that the costs of developing systems for future applications are kept within acceptable limits.

7. FORMAL MATHEMATICAL METHODS

7 1 As systems complexity increases, it becomes ever more apparent that it is impossible to dynamically test large programs to ensure their correctness. To obviate this problem, we need to ensure that the program is correctly designed in the first place, and one of the techniques promising to assist in the achievement of this is the formal mathematical specification of the requirements for the software. This may appear at first to considerably increase the effort required to produce the specification Recent experiences however indicate that in certain circumstances this may be more than recovered in the reduction of time and costs associated with the later stages of coding, integration and test, as a result of a considerable reduction in the number of errors carried forward. The specification may be formally proven, and reliably demonstrated against the system requirement by means of automated animation techniques

7 2.1 The title 'Formal Method' is commonly used to describe a number of aspects of the same idea. The more correct title is 'Formal Mathematical Method'. The three fundamental features of a Formal Method are.

A mathematically formal notation

A mathematically formal development process

A mathematically formal means of proof

7.2 2 The mathematically formal notation allows the unambiguous statement of software specifications; these may then be transformed by a mathematically formal development process into programming languages; these transformations may then be proven to be mathematically correct via the formal means of proof

7.2 3 The following example illustrates how a Formal Method could be applied in a practical project.

i The User Requirement for the system is first set down. This would often be expressed in an informal (i.e not mathematically precise) way, often using conventional language such as english. Because of the lack of precision in any commonly used language, the Requirement will certainly have many inconsistencies, errors and omissions. Even if the drafter managed to set down a correct statement of what he thought was needed (i.e there were no errors in the record of what he wanted, based upon his understanding of the words he used), there is still a certainty that his understanding of the words and the use of words would not be precisely the same as someone else reading and interpreting the specification.

ii The User Requirement is translated into a Formal Specification This is a mathematical object, and it can be precisely shown that properties hold in this specification The properties of this document can be compared with the desired behaviour, as part of the process of verifying that the properties do exist correctly in the specification.

This comparison may also be used to refine further understanding of what properties are actually required, leading to modification of both the User Requirement and the Formal Specification With some specifications an animation process may be applied, where the spec is 'brought to life' via a simulation process, such that the behaviour of the system described in the specification can be physically examined and exercised This then allows iterations to take place, drawing out what the user really wants from what he originally said he wanted

iii. The verified Formal Specification may then be refined into a more detailed, lower level specification This may be repeated a number of times, specifying successively lower levels of detail, which is then verified and documented The process is ideally repeated until the lowest-level specifications can be the subject of direct translation, item for item, into programming language statements At each successive stage of the refinement process, the output is recorded in a mathematically precise and proveable form

7.2.4 There are currently serious limitations to the application of Formal Methods. They do not address considerations such as timing or accuracy, and are currently only practicable for relatively small systems (of the order of 10-50,000 lines of source code) There has been little real standardisation so far in terms of language constructions, languages such as Z and VDM still to some extent being in the research field. The methods are difficult to understand, and there is consequently a difficulty with validation. Tool support is still in its infancy. However, further development of tools into really practical engineering standards seems likely, as a result of moves in both the UK and internationally to encourage their use at least for safety critical software. The fundamental logic that the computer, a mathematical machine, should be programmed using mathematically traceable and proveable techniques cannot be easily dismissed. There is still some way to go before they will be a practical tool for the sort of avionic systems under consideration today, but there seems a strong possibility that they will be seen as essential sooner or later Even if the full application of formal methods to large systems is still some way off, there are still considerable benefits to be had from the application of a notation alone

8. AUTOMATED STATIC CODE ANALYSIS

8 1 Static Code Analysis is defined as the process of examining the behaviour of software without running the software on a computer It seems likely that it will have an important role to play in the near future in the cost effective development of software, as part of the process of 'design-right' rather than 'test-right'. The tools currently available were originally developed for use in the fields of secure and safety critical software, but are inherently suited to any application where the development of correct software is a necessity. Much work has been carried out in recent years in the UK in the development of two particular semi-automatic tools, MALPAS (MALvern Program Analysis Suite), and SPADE (Southampton Program Analysis and Development Environment). Both tools automate the process of static code analysis, which previously had only been possible using largely manual low-integrity techniques such as code reviews, walkthroughs, etc. The tools put the process onto a sound mathematical basis, which lends itself to automation, and therefore potentially makes them a practical proposition when considering the development of relatively large systems.

8.2 In broad terms, the tools first carry out a number of standardised checks using computer analysers (see Fig 8):

i **Control Flow Analysis**, where the analyser examines the program structure to identify all possible starts and ends, unreachable code, black holes, and the location of entry and exit points of loops

ii **Data Use Analysis**, where the analyser checks that all inputs and outputs of the program are identified, and that the data is used correctly e.g data is not read before it is written, or is not written more than once before it is read

iii **Information Flow Analysis**, where the inputs on which each output depends are identified

iv. **Semantic Analysis**, where the relationship between inputs and outputs is determined This is a very powerful part of the process, and allows the program to be compared directly with its specification. This can be further aided by the use of a Compliance Analyser, which allows this process to be carried out automatically

3 3 The principal benefit of the tools is the assistance in the initial design of software. At this stage, the tools can be used to provide an immediate check on how the software meets the requirements, helping to reduce the number of errors carried forward.

9 DOCUMENTATION

9 1 Adequate and timely documentation is vital to the development organisation, as well as to the certifying and accepting agencies. Of critical importance is early discussion and agreement of precisely what documentation the customer and his agencies require of the contractor. Not only is a record needed of the deliverable design, but often a full record of how that design was arrived at.

9.2 The criticality of the documentation produced recording the development process and the design of the software as it progresses through this is clear: No amount of testing of the final system will give anything like assurance that the complex software program in any practical avionic system of today or the future is 100% fault free, that it fully meets the requirements of the specification, and only those requirements. Therefore, we must depend to a large extent upon the software having been 'designed-right' to meet the specification in the first place.

9 3 A basic requirement is therefore that designers must take a disciplined approach to the development of the system. From requirements definition, through design, code and integration, to final testing, there must be a properly structured and recorded process of documentation and review (see Fig 9).

9.4 This is a common requirement in both civil and military avionic applications, and is particularly critical for avionic systems having flight safety implications It should be noted that there is considerable common ground between the documentation requirements of the principal military standard DOD-STD-2167A and the civil document RTCA (Radio Technical Commission for Aeronautics)/DO-178A 'Software Considerations in Airborne Systems and Equipment Certification'[9] There is also a continuing need for refinement of these requirements, in line with the advancement of technology.

10 SYSTEM SAFETY IMPLICATIONS

10 1 The increasing complexity of software based avionic systems brings with it a concurrent increase in the amount of software that has a direct bearing upon the integrity of the aircraft. It is extremely difficult to prove that the software for practical systems is 100% correct, and the problems that result are becoming increasingly significant Techniques that ensure that software is correct to the limits of the 'State of the Art' need to go hand-in-hand with adequate protection at system level from the effects of any remaining bugs in the software

10.2 The design aim must always be the ultimate certification of the system. Target integrities for sub-system components depend upon a number of factors, of principal importance being the overall required integrity of the aircraft as a complete system. It is essential that the software contribution to system integrity is quantified as far as possible from the earliest stages of a development project (principally by a process of hazard analysis); this is in order that an assessment can be made as to whether or not the design will be viable, and so that levels of verification and validation can be determined prior to the process of software design

10.3 In the UK, the potential problems have been recognised for many years We have for some time been successfully applying the requirements of the civil aviation document RTCA/DO-178A to military avionic software having flight safety implications. This document is currently being revised by RTCA, reflecting the considerable advance in technology that has occurred since it was published in 1985

10.4 The requirements of RTCA/DO-178A have been called up in slightly modified form in a UK Interim Defence Standard 00-31 'The Development of Safety Critical Software for Airborne Systems'[10], published in 1987 However, the range and complexity of functions controlled by embedded computer systems in aircraft is expanding rapidly, providing ever more numerous and more subtle opportunities for errors in software design These problems are not solely confined to aircraft systems; it has been determined in the UK that the current approach to the development of such systems, which is based upon system testing and oversight of the design process will, in the long-term, become cumbersome and inefficient for the assurance of safety

10.5 This realisation has led to the recent publication of two Tri-Service Interim Defence Standards that will have major implications on the way that future systems are designed and built. Int Def Stan 00-55 'The Procurement of Safety Critical Software in Defence Equipment'[11], together with an associated Int Def Stan 00-56 'Hazard Analysis and Safety Classification of the Computer and Programmable Electronic System Elements of Defence Equipment'[12] introduce a number of new requirements, the most important of which are briefly listed below:

i. All systems (from the highest level down to the lowest sub-system) to be thoroughly analysed for the existence of safety critical hazards, from the outset of the project lifecycle

ii Safety Planning as a distinct activity to be carried out from the earliest stages of a project

iii. Formal Mathematical Methods to be applied throughout the software requirements definition and design process

iv. Defensive programming techniques to be applied

v The application of automated static code analysis

vi. The formalisation of responsibilities in the project organisations (Procurement Project Manager, Design Authority, etc), together with a requirement for formally independent groups to carry out verification of the software, and assessment of the work of the Design Authority

vii. A comprehensive documentation programme, not only recording the design and its development process, but also how safety aspects had been analysed and controlled

11. SUPPORTABILITY, AND THE ROLE OF SUPPORTABILITY ANALYSIS

11.1 Life Cycle Costs (i e the overall cost of ownership) are an increasingly important design driver in the development of military avionic systems. In-service support costs form a major (perhaps the major) component of this, and therefore refinement and even optimisation of the design to minimise these is an important consideration. Logistics Support Analysis has been available for some time (e g MIL-STD-1388-1A 'Military Standard - Logistic Support Analysis'[13]), as a system-wide technique, with the aim of optimising the design to meet the needs of in-service support, and identifying the most cost-efficient support option for each component of the system (in terms of who should be carrying out the work, facilities, manpower, etc). The increasing software component in systems means that particular attention is needed to this component area, right through from concepts to detail design, due to the great effect upon supportability that software features can have New standards are likely to emerge for the prediction of the support requirements, focussing on the need for rational, structured examination of the software requirements

11 2 The in-service software maintenance task consists of several components

i. Correcting design faults. These include both faults in the software compared to its specification, as well as errors in the original specification itself Many faults in software based systems can be traced back to an incomplete, imprecise, or incorrect description of requirements. Correcting faults once a system has gone into service is the hardest and most expensive option, and every effort should be made to minimise these

ii. Incorporating minor modifications, to meet new operational requirements, or existing requirements that were not fully understood when the original specification was produced

11.3 The Supportability Analysis for Software (SAS) process should be continuous, and should run in parallel with and throughout the life cycle of the subject system Ideally, it should commence prior to the point in time where the need for software has been identified and software requirements analysis is about to start - much of the data needed to start the analysis is available before this, perhaps even as early as during initial feasibility studies. The process can be broken down into four phases (see Fig 10).

i Initial

ii Preliminary

iii. Detailed

iv Update/Tracking

11 4 At each phase, analyses may be carried out that can be grouped under the following headings.

i Software Identification and Categorisation

ii Software Support Analysis

iii Software Supportability

iv Software Support Concept Analysis

11.5 Outputs from these analyses should take the form of a number of standard format reports, which can then be used as a basis for design refinement, as well as to plan for the in-service support phase

11 6 One of the important factors in considering supportability needs is the rate of change traffic that is likely, either to correct faults or to meet new or unforseen requirements Unfortunately, it is most difficult to predict this during the early stages of design, and there are currently no known validated models that provide prediction of this. Further developments here are likely to be of importance

11 7 The SAS process undoubtedly involves up-stream expenditure in order to generate down-stream benefits and cost savings. Looking at current and past programmes over a broad range of applications, between 50% and 70% of the overall cost of the software life-cycle has been consumed by the maintenance phase, when considering a 10-year service life. Given the likely service life of many military avionic systems (perhaps 20 years or more), the likely benefits for optimisation of the design and forward planning of support requirements are not to be ignored

12 THE EVOLUTION OF STANDARDS

12 1 The rapidly evolving technology in the field of software engineering brings with it a parallel need for evolution of the Standards that prescribe design and development requirements Important new techniques such as automated verification and validation tools, formal mathematical methods, etc must be taken account of, following adequate research and demonstration.

12 2 However, care is needed in the Standards generation process not to be over-prescriptive in how a deliverable product is achieved There should rather be concentration on the essential qualities of the product, and avoidance of the specification or discouragement of the use of particular software development tools, methods, techniques, etc An important component is the specification of the vital qualities required in whatever processes are selected by a development organisation, and what information is required to support acc a system as suitable for its intended purpose As much scope as possible should be left to the development organisation to select the methods, techniques, tools, etc that best suit its particular needs.

13. MODULAR AVIONICS

13 1 Present-Day Federated Architectures

13 1 1 Current LRU (Line Replaceable Unit) based 'federated' avionic architectures (see Fig 11) consist of a number of separate subsystems Each subsystem performs a defined set of processing functions, as and when required, and does not have the capability to carry out new functions as a result of changing circumstances e g damage to a subsystem requiring some or all of its processing functions to b transferred to some other subsystem.

13.1.2 Subsystems are connected together, either by hardwire connections, or by one or more standard databuses. The number of physical interfaces of any one subsystem with other subsystems is kept to a minimum, for a variety or reasons, including reliability of connectors, physical space and weight, etc.

13.1.3 Each subsystem may have great internal complexity within its LRUs, containing a number of processors, sensor interfaces, power supplies and so on However, these structures are invisible to the other subsystems with which it operates. Its operation within the avionic system is determined by the characteristics of the messages it can send or receive via its interfaces

13 1 4 The architectural design of this system is functional based. Individual physical components with defined functions, operating together but in a 'loose-coupled' way, provide the total functionality required There is generally great diversity in the range of component enclosures within one aircrafts' avionic systems, and between different aircraft types

13 2 The Modular Solution

13.2.1 The core concept (see Fig 12) is that a processing system built from a range of standardised modular components, or LRMs (Line Replaceable Modules), would form the core avionic architecture, in which many of the processing functions e.g navigation, communications, weapons control, displays, etc would reside These processing functions in the present-day federated architectures would have resided in the discrete LRU enclosures peculiar to the particular function.

13 2 2 Fundamental features of the core architecture are that it is built from a limited range of standardised LRMs providing processor, memory, data bus, etc functions, the system may be expanded, reduced or reconfigured to meet a number of mission requirements in different aircraft types; reconfiguration may indeed be an active feature of the system, to protect against component failures and battle damage, greatly increasing the availability of the system The system will be configured by software into a functioning entity, and the useful functions of the system i e the operations on inputs to produce required outputs will be software driven.

13.2 ? The software problem that this presents poses a major step forward in terms of complexity for avionics, and will require the development of a highly capable Real-Time Operating System to handle the configuration of the hardware components, to provide the distribution of tasks around the network, and to provide the reconfiguration/fault tolerance features needed. Existing, commercial systems may offer some scope to act as a starting point for the development of such a system (although this seems unlikely). A considerable amount of effort and expenditure will be needed to make the Operating System a working reality in the avionic environment

13 3 Principal Impacts of Modular Avionics on Software Design

13 3 1 The definition of an optimised modular avionic architecture and its associated software component is a major task, currently the subject of a number of national and international initiatives. It would be inappropriate therefore at this present time to speculate in great detail about the final form of such a system It is also beyond the scope of this paper to discuss the system engineering and hardware related considerations, such as the optimum range and capabilities for the LRM types; ways of connecting LRMs together, the overall architectural concepts for the assembly of the variety of LRMs together to build a practical system; and so on. There are however a number of general considerations relating to the software component, that may be usefully highlighted:

i With federated LRU-based systems, the wide range of processors and software programming methods available leads to a strong tendency for components that are considered optimum for particular applications to be used The result is a number of different processors and programming methods are used in the subsystems that make up the complete avionics suite This plurality leads to high costs of system maintenance when the system is in service, because of the wide range of hardware and software support, spare parts and maintenance personnel needed Modular LRM-based architectures offer the potential to minimise this component of Life Cycle Costs, because of the ability to standardise on many if not all of the software components, as well as the development and support environments (facilities, software tools, personnel, etc).

ii. Functions may not need to be uniquely assigned to particular processors or groups of processors, making redundant the concept of subsystems each with a defined set of functions. The modular architecture could, in effect, form a single computing system built from a number of identifiable module components. All the processing functions would reside within this system, and the processing would be a function of the whole system rather than of particular modules.

iii Existing federated LRU-based systems can suffer from restricted availability The reliability of individual LRUs within the system may be very high in terms of failures per flying hour, but the overall probability for the aircraft system of loss of one or more functions may be unacceptably high when taking the overall system complexity into account. This situation may be improved to some extent by incorporating redundant processing into individual subsystems, but this carries significant weight volume, and cost penalties which may be as unacceptable as the problem they are trying to solve

The modular LRM-based architecture offers the potential ability to provide fault tolerance efficiently The architecture would be able to continue operation even if one or several of the modular components had failed. If sufficient spare capacity has been built into the system, and there is the facility to configure the functions into the reduced system available, full system functionality can be maintained. The impact on the software design would be that very capable Built In Test (BIT) functions would be needed to detect that components of the system had failed, and to diagnose them correctly; reconfiguration software would be needed to allow processing to continue to meet the full system requirements with the reduced hardware then available. This reconfiguration must be carried out dynamically, during a mission, with minimal effect upon the other functions handled by the system Note that this fault tolerance is in fact a function of the system design (although implemented in the software) rather than due to inherent fault tolerance in the software. It seems unlikely in the foreseeable future that inherently fault-tolerant software will have any practical impact upon the design of such systems

13.4 Software Philosophy for the Modular System

13.4.1 There is a range of top-level concepts that could be applied, including:

i. A single program for the entire system. All the system functions would then be designed in without regard for the way in which functions would be distributed around the system. This step would be accomplished automatically, perhaps as a function of the development system, or perhaps as a capability of the Real-Time Operating System.

ii One program per node. Functions are distributed during development to processing nodes within the architecture, perhaps consisting of a number of closely coupled processors This greatly simplifies the problem of the software needed to distribute functions around the system, but may seriously reduce the ability to reconfigure the system whilst in operation

iii One program per processor. A simpler solution again; existing programming languages such as Ada may be used to develop the programs for each particular processor, which are compiled, linked, and loaded conventionally, to provide a defined set of functions However, this solution restricts the ability to reconfigure the system to meet new situations such as the loss of certain modules. Any reconfiguration options would have to be programmed into the system along with the functional software.

The higher the level of the task distribution process, the more complex becomes the development system and the resident Operating System, and hence the cost of those features Increased automation of the software generation process may lead to reduced direct costs for the development of the target software, but again increased cost of the software development system. The lower the level of distribution, the more restricted becomes the possible scope of reconfiguration software Clearly, a trade-off between a number of such factors is required in order to determine the optimum solution in terms of overall Life-Cycle Costs.

13.4 2 The primary objective of the modular solution is to reduce Life Cycle Costs, compared to those associated with federated LRU-based systems. A major component of these costs is in software maintenance. A key factor in the cost-saving strategy is therefore likely to be a rigid, modular, and multilayer software architecture; this is in order that modifications and updates can be undertaken on parts of the system, without the need for extensive redesign of other parts (see Fig 13).

13.4 3 In broad terms, there are likely to be two principal 'layers' of software in the system:

i **Real-Time Operating System Software** - all software within the system that is independant of the particular application. The Operating System in effect configures the hardware into a functioning processing system, and supports the operation of the application-specific software. Sub-levels of the Operating System may include:

Board Specific Software, the lowest level, specific to the particular processing boards used in the system, interfacing between the bare hardware and the Kernel

Kernel; components of the Operating System that reside on every processing node in the architecture

Operating System Support; components of the Operating System that reside on only certain processing elements

ii **Application Software** - Software specific to the particular mission functions that the avionic system is required to provide to the aircraft Sub-levels of the Application Software may include·

Application Software Support; software that supports operation of the applications, but which does not relate directly to specific mission functions

Applications, software that performs the specific mission functions i e that provides the mission algorithms

13 4.4 The Real-Time Operating System will need to provide effective partitioning of software of different safety criticalities This may only be practically achievable by isolating flight critical functions to a particular area of the architecture, with high integrity control of data entering or leaving that area. A related problem is the control of secure (i e classified) data.

13 4 5 The Real-Time Operating System should provide the capability for additional or updated Application Software components to be added to an existing system, without the need for large parts or even the entire system to be rebuilt

13.4.6 Highly capable BIT (Built In Test) functions will be an important component of the Real-Time Operating System This will need to provide diagnosis down to at least LRM level, and probably to functional elements of an LRM where appropriate Full logging of fault events will also be required to assist in future maintenance Principal areas for BIT include

Data validation
Hardware
Software
Communications

The software will need to adapt the system configuration in the event of events such as LRM failure or battle damage It also needs to provide controlled degradation in situations where insufficient processing resources are available to support the entire application functions demanded.

13 4.7 The Real-Time Operating System will need to provide adequate safeguards to prevent events such as illegal accessing or modification of data in memory by faulty software modules The integrity and reliability of the system will be particularly dependant upon the software that controls reconfiguration and fault-tolerance

13.4.8 As far as possible, the Application Software should be independant of the particular architectures defined for individual aircraft types and/or applications This is to promote the reusability of these software components across a range of aircraft types, and should be achievable by effective layering of the software system, Application Software being isolated from the Real-Time Operating System by some sort of abstract interface.

13.5 Risks

The success of the modular system will be heavily dependant upon the practical realisation of a very complex, distributed Real-Time Operating System, and this must be considered the principal risk area In terms of magnitude of code the Operating System will be equivalent to several million lines of source code, and the development cost will form a considerable proportion of the total integrated system development cost. Summarising, the leading functions of the Real-Time Operating System will probably include exercise of overall system control in this highly distributed processing environment, allocation of processing resources to the Applications Software, and control of the reconfiguration of the system as made necessary by failure of component modules whilst in use.

14 REUSABILITY

14.1 The move towards modular architectures will greatly increase the scope for reusability of software components. The use of common hardware modules across a range of aircraft types has largely been the focus of attention in the activities investigating modular avionics thus far, but it is perhaps in the software that the greatest scope exists for the reduction in Life Cycle Costs demanded

14.2 The major source of commonality is likely to be the Real-Time Operating System At the highest level of abstraction, this has the function of configuring the set of hardware modules into an integrated system, and of providing support for the Applications Software that implements the required system functionality. It is therefore likely to be applicable to all systems making use of the common modules, and may be considered as a reuseable component in itself

14 3 At lower levels, there is also scope for reuse of components of Applications Software from one system to another.

14.4 A potential difficulty however is in the design liability for defective operation. Cost savings in the reuse of software components across a number of manufacturers for different applications are dependant to some extent upon the ability to rely upon verification and validation work already carried out by the original design company. However, it would appear that even if a complete rerun of the V & V activities is considered necessary for each new application, there would still be worthwhile cost-savings. This is as a result of the lack of a need to rerun the design process from scratch

14 5 Increasingly, commercial software systems are incorporating features which are common to the needs of avionic systems, at the system engineering level. Operating systems for distributed processing architectures are already in use for specialist commercial computing applications, and the adoption of Ada for the design of commercial systems is likely to further enhance the potential for commonality.

15 KEY SOFTWARE TECHNOLOGY ASPECTS FOR THE FUTURE

15 1 In conclusion, the key technology aspects for the future of avionic software engineering may be summarised as.

i A need to refine continuously life-cycle models for the development process, in line with advancing technology. Models to be backed up by the necessary procedures, documentation programmes etc

ii A need for more capable requirements definition techniques, capable of handling the very great complexity likely in the next generation of aircraft systems

iii. An increasing use of formal mathematical methods, from the earliest stages of specification, through design, to verification

iv. A progressive increase in productivity of executable code, probably brought about by the increasing automation of each process in the lifecycle

v The development of reusable software components, principally in the area of the Real-Time Operating System for the new modular architectures now appearing

vi A growth in the application of in-service supportability analysis, from the earliest stages of development. This needs to be implemented by a formalised, automated process as far as possible

<u>References</u>

1 Department of Defense Washington DC, DOD-STD-2167A, MILITARY STANDARD - DEFENSE SYSTEM SOFTWARE DEVELOPMENT, 29 February 1988

2 UK Department of Trade and Industry and National Computing Centre, THE STARTS GUIDE, A guide to methods and software tools for the construction of large real-time systems, Second Edition, 1987

3 B W Boehm, TRW Defense Systems Group, A SPIRAL MODEL OF SOFTWARE DEVELOPMENT AND ENHANCEMENT, in tutorial. Software Engineering Project Management, IEEE, 1988

4 A O Ward, British Aerospace Military Aircraft Division, THREE GENERATIONS OF SOFTWARE ENGINEERING FOR AIRBORNE SYSTEMS, November 1988, AGARD Conference Proceedings No 439

5 Department of Defense Washingtion DC, MIL-STD-1815, MILITARY STANDARD - Ada PROGRAMMING LANGUAGE, 10 December 1980

6 Department of Defense Washington DC, ANSI/MIL-STD-1815A-1983, REFERENCE MANUAL FOR THE Ada PROGRAMMING LANGUAGE, 17 February 1983

7. Ada Information Clearing House, Ada IC NEWSLETTER, March 1991

8 Office of the Under Secretary of Defense for Acquisition Washingtion DC, Ada 9X PROJECT REPORT, Ada 9X REQUIREMENTS, December 1990

9 Radio Technical Commission for Aeronautics, SOFTWARE CONSIDERATIONS IN AIRBORNE SYSTEMS AND EQUIPMENT CERTIFICATION, Document No RTCA/DO-178A, March 1985

10. UK Ministry of Defence, Interim Defence Standard 00-31/Issue 1, THE DEVELOPMENT OF SAFETY CRITICAL SOFTWARE FOR AIRBORNE SYSTEMS, 3 July 1987

11 UK Ministry of Defence, Interim Defence Standard 00-55/Issue 1, THE PROCUREMENT OF SAFETY CRITICAL SOFTWARE IN DEFENCE EQUIPMENT, April 1991

12 UK Ministry of Defence, Interim Defence Standard 00-56/Issue 1, HAZARD ANALYSIS AND SAFETY CLASSIFICATION OF THE COMPUTER AND PROGRAMMABLE ELECTRONIC SYSTEM ELEMENTS OF DEFENCE EQUIPMENT, April 1991

13 Department of Defense Washington DC, MIL-STD-1388-1A, MILITARY STANDARD - LOGISTIC SUPPORT ANALYSIS, 11 April 1983

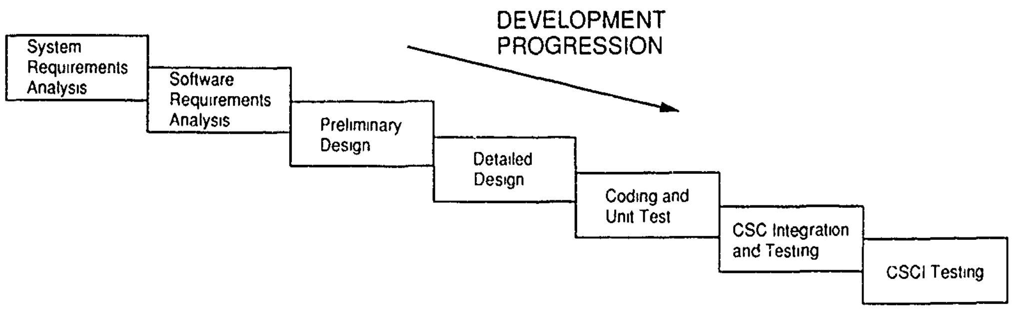


Fig 1 THE WATERFALL MODEL

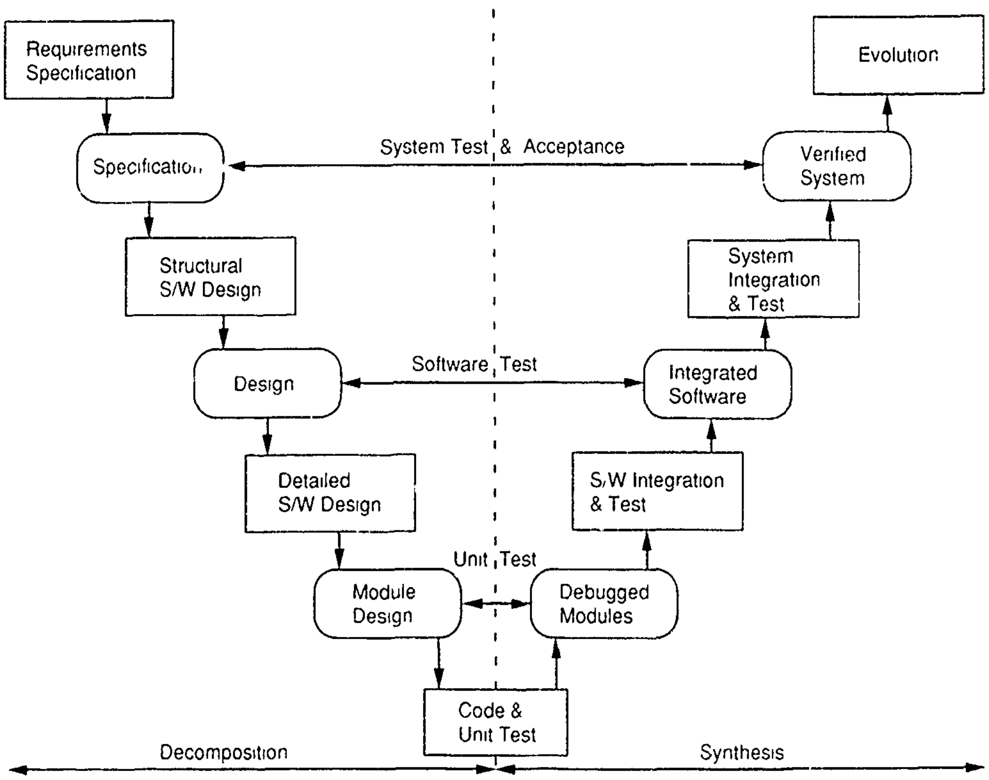


Fig 2 THE STARTS V-MODEL

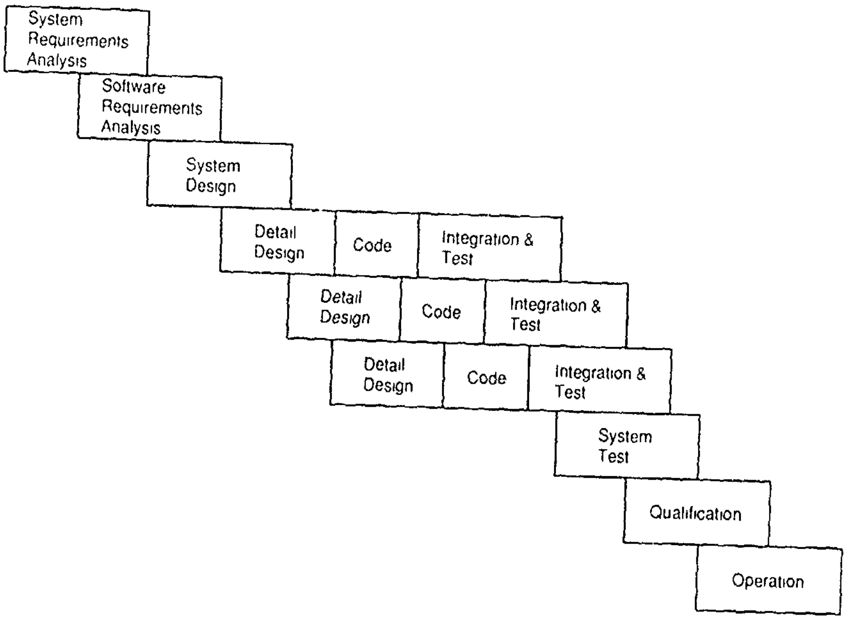


Fig 3 INCREMENTAL DEVELOPMENT

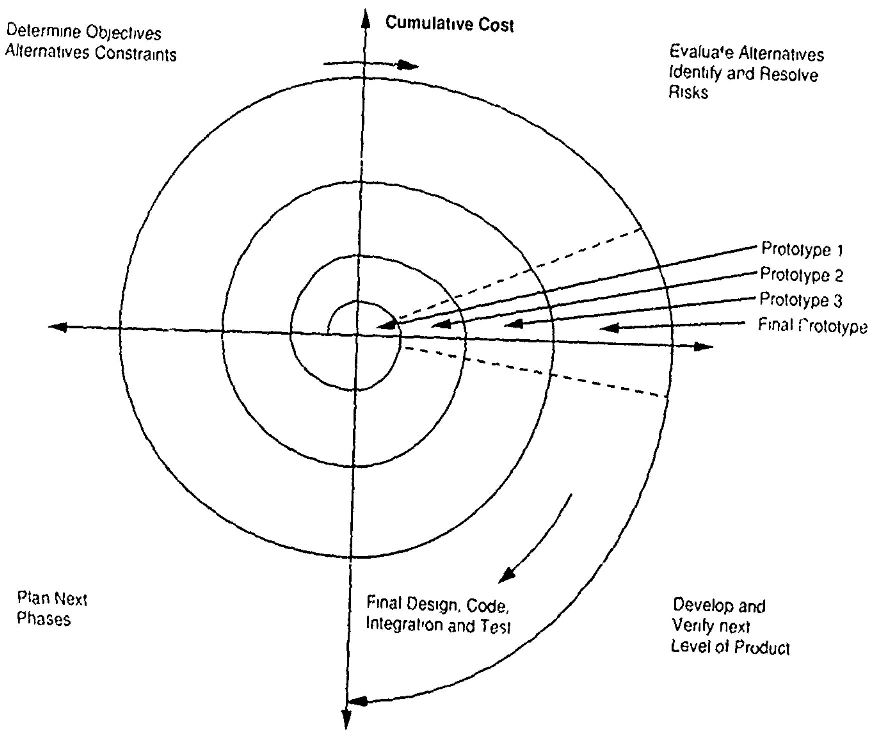


Fig 4 THE SPIRAL MODEL FOR SOFTWARE DEVELOPMENT

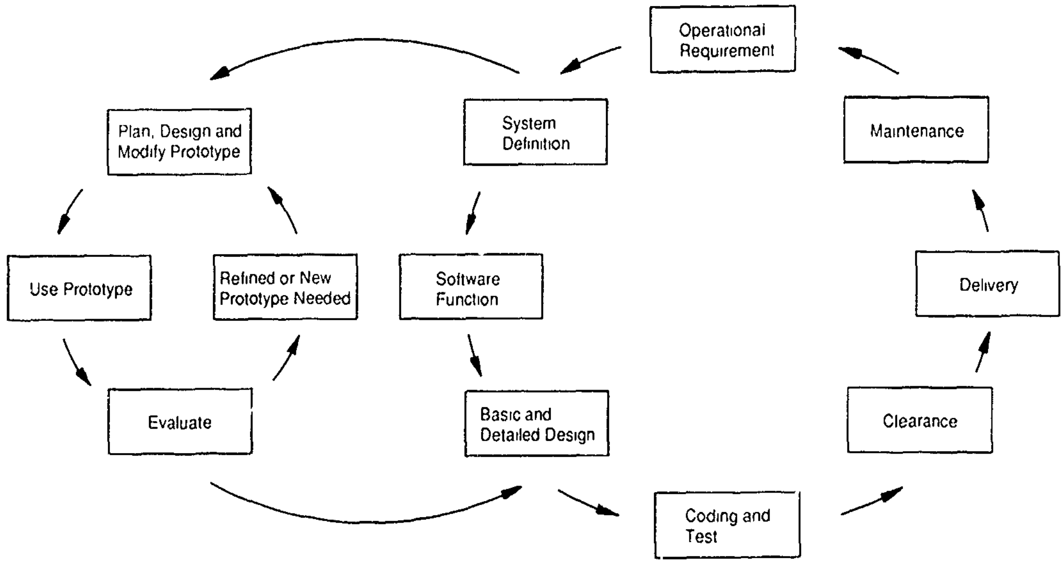


Fig 5 THIRD GENERATION MODEL

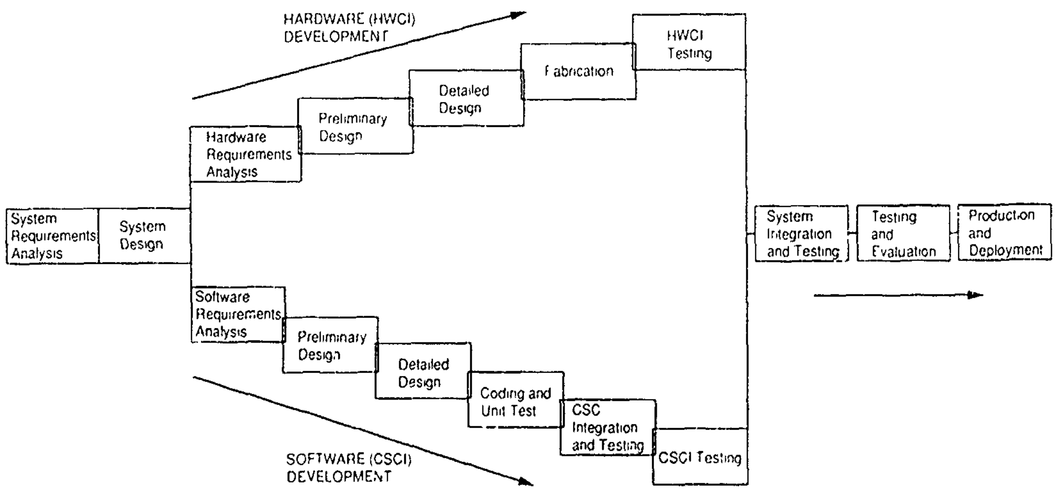


Fig 6 DOD-STD-2167A VIEW OF SOFTWARE-BASED SYSTEM DEVELOPMENT

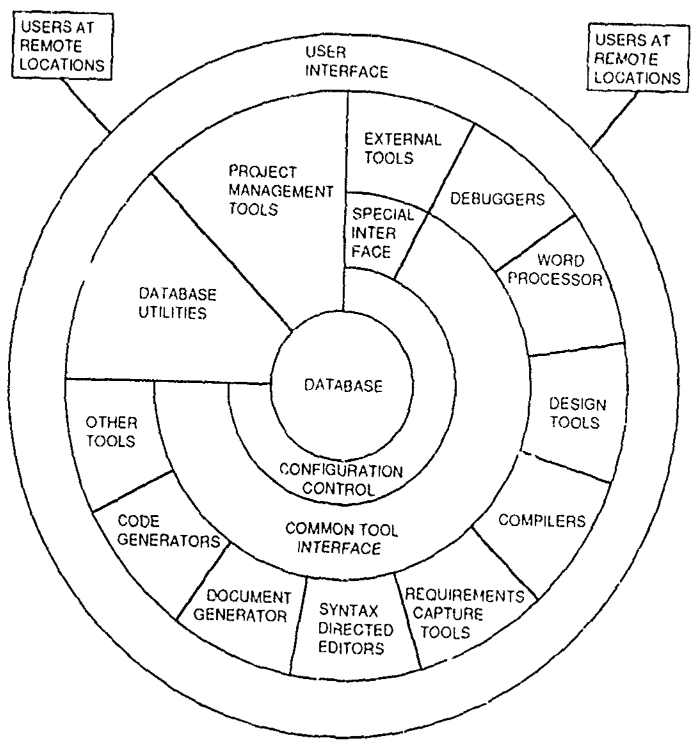


Fig 7 THE INTEGRATED PROJECT SUPPORT ENVIRONMENT

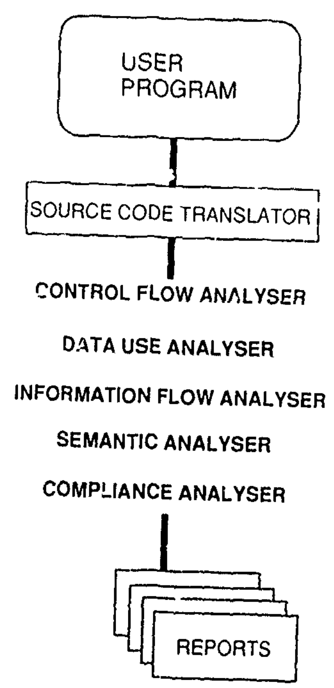


Fig 8 AUTOMATED STATIC CODE ANALYSIS

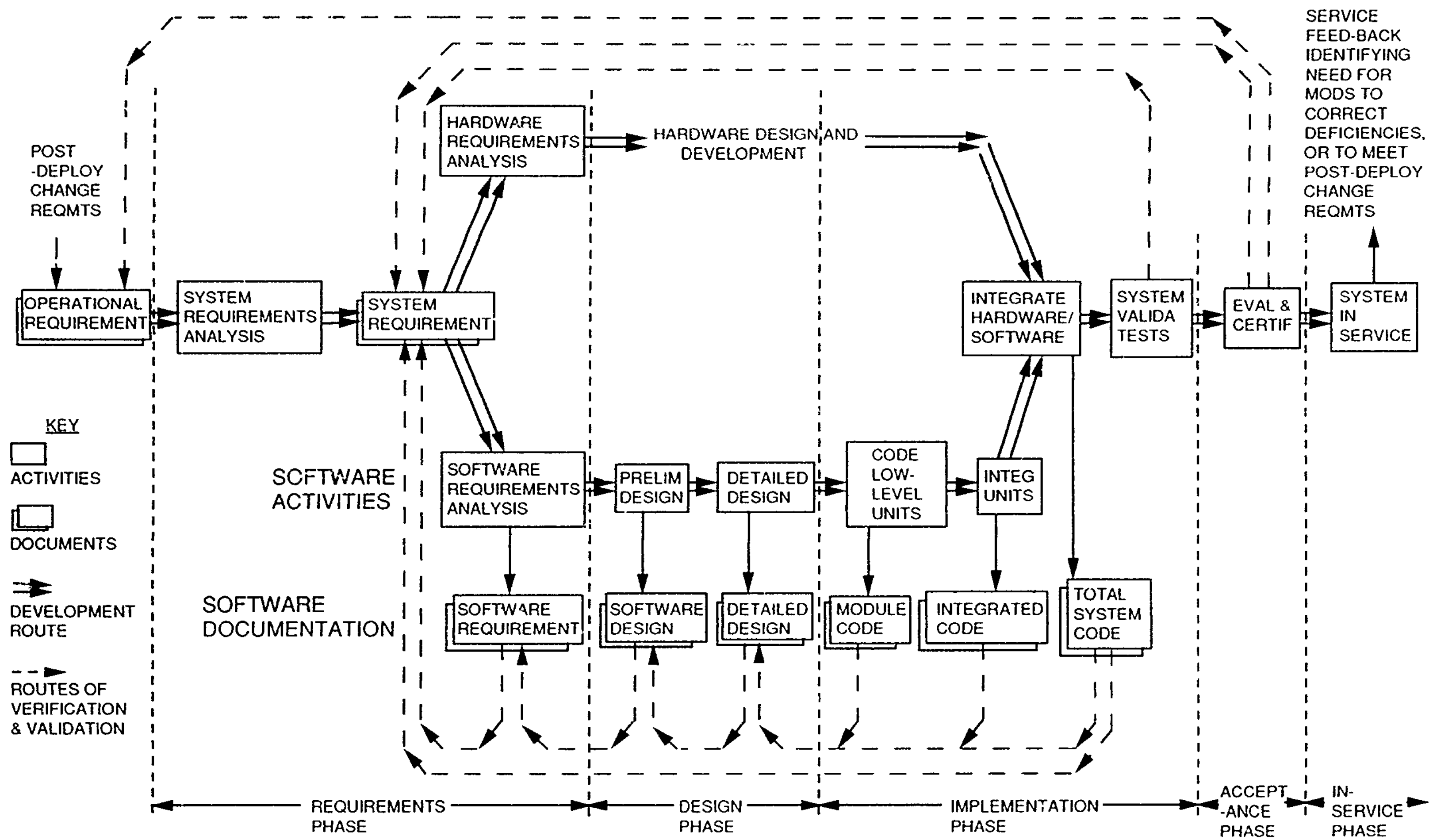


Fig 9 INTEGRATED DEVELOPMENT/DOCUMENTATION/VERIFICATION PLAN

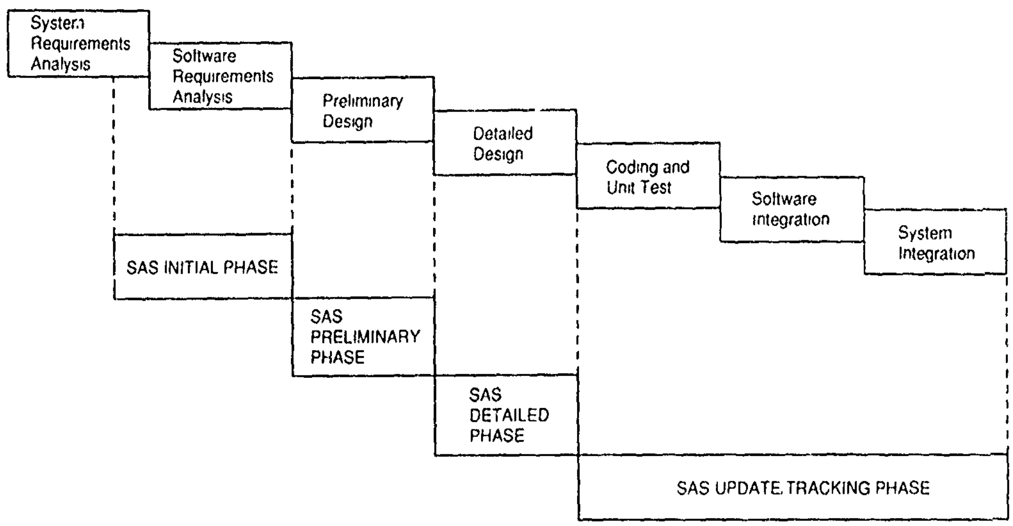


Fig 10 SUPPORTABILITY ANALYSIS

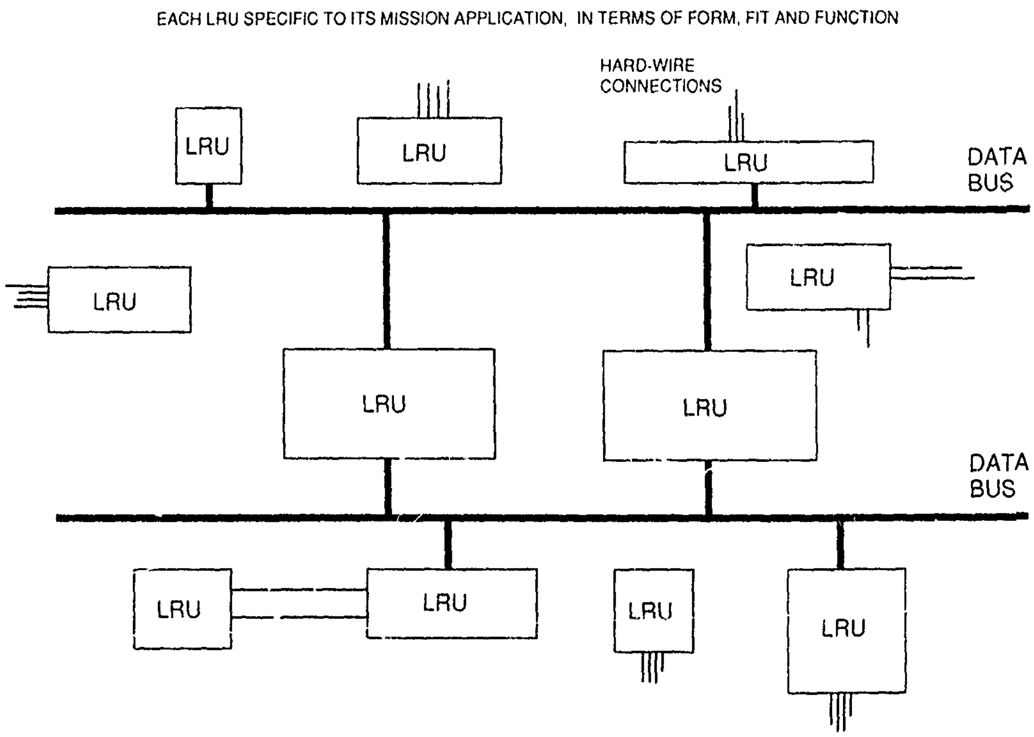


Fig 11 LEADING FEATURES OF LRU-BASED ARCHITECTURE

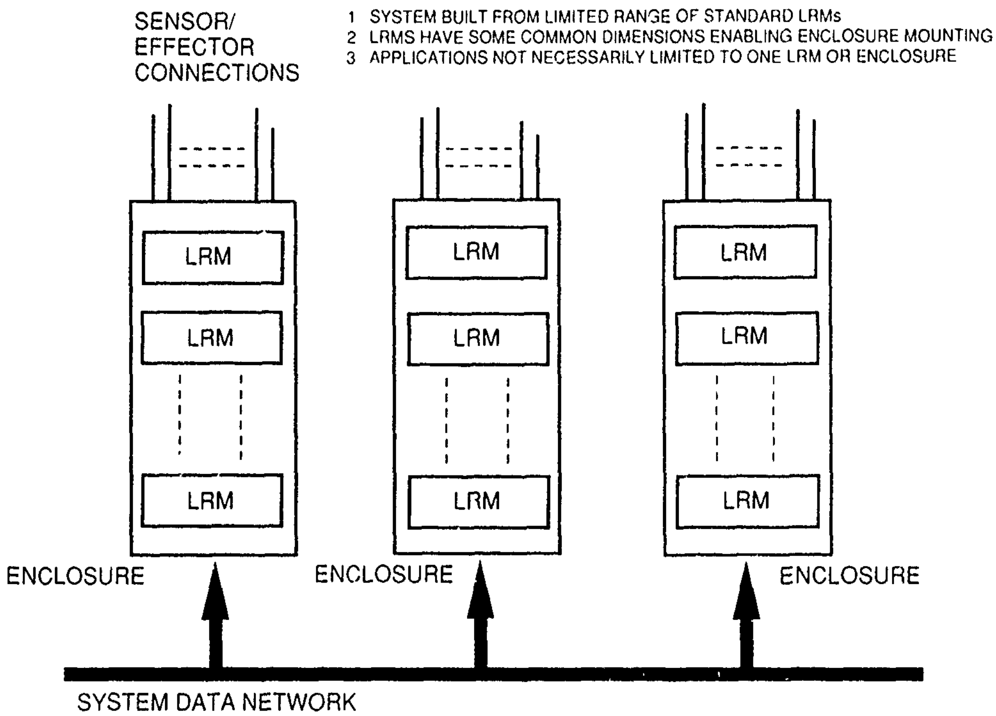


Fig 12 LEADING FEATURES OF LRM-BASED ARCHITECTURE

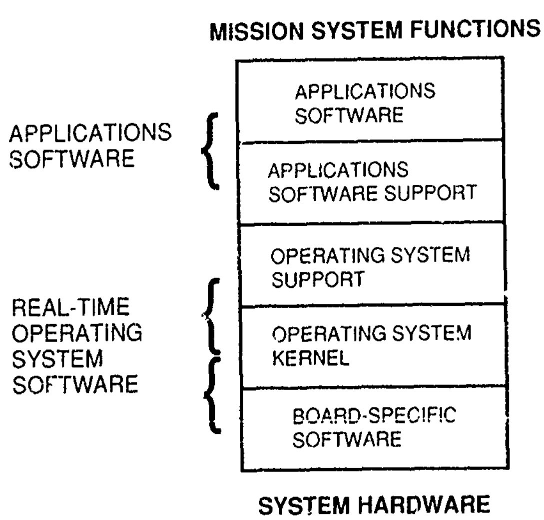


Fig 13 SOFTWARE LAYERING FOR THE MODULAR SYSTEM

COMMON AVIONICS BASELINE THE PRODUCT OF THE JOINT INTEGRATED AVIONICS WORKING GROUP

by
Christopher L. Blake
ASD/YFEA
WPAFB, OH 45433
USA

INTRODUCTION

Because of the rising costs associated with the development and production of aviation electronics (avionics) there is increasing interest in opportunities to more effectively use the United States defense dollars spent on the development and procurement of avionics. Over the last several years, efforts to control the proliferation of avionics have yielded some promising results by simply expanding the application of avionics equipment to more than one aircraft. It is widely postulated that a key to conserving defense dollars may be through broader avionics commonality applications. More recently, evolution of integrated architecture along with significant advances in technology in processing and storage capacity have resulted in a clear opportunity to develop an avionics architecture and a series of avionics building blocks (common standard modules) that may be used in a wide variety of applications, both within a weapon system and between weapons systems. With careful attention to designs which permit growth and technology insertion, this concept could support weapons systems now and for many years into the future. This is the challenge the United States Congress gave to the U S. Army, Air Force and Navy over four years ago and has been the objective of the Joint Integrated Avionics Working Group (JIAWG) since its inception. This paper will present the efforts of the three services to develop a Common Avionics Baseline (CAB), the primary product of the JIAWG.

Today the Common Avionics Baseline is a preliminary set of functional performance specifications for development tools, draft architectures, multiplex busses, common modules and support requirements. These specifications form the basis for a dramatic step toward offering the United States Department of Defense an avionics capability which, with some application specific adjustments, could serve the needs of a wide variety of users well into the future. At this writing, the Common Avionics Baseline is evolving and maturing. As will be discussed, we have actually built prototypes of various hardware and software pieces that will eventually become the validated Common Avionics Baseline. However, due to the complexities of competitive procurement, the wide ranging application dependent performance requirements imposed on these products, and the lengthy process available to produce hardware and software, considerable effort remains before success will be declared. The path to a preliminary CAB has been paved with obstacles ranging from the complexities of completing input/output definitions for a common data processor and the impacts of nuclear Transient Radiation Effects on Electronics (TREE) hardening of the entire Common Avionics Baseline suite, to dealing the proprietary rights of the design of several critical potential common standard processing modules. As will be described, we are presented with an opportunity to eventually realize success in the form of a proven implementation of a Common Avionics Baseline Figure 1 is a generic representation of one possible implementation of the CAB to produce an integrated avionics capability. The opportunity to create this capability is the direct result of the efforts of the JIAWG.

WHY BUILD A CAB

As mentioned earlier, the motivation behind this effort was a recognized need to manage the Defense Budget, in this case by controlling the proliferation of avionics, as rightfully perceived by the United States Congress. As can be seen in Figure 2, the cost of avionics for our newer aircraft has become an increasingly larger part of the procurement and fly-away cost of new weapon systems. The commonly held view is that there are economic advantages in the improved reliability, supportability and interoperability inherent in the new technology available for common avionics, which if achieved can attain the required performance capabilities needed by the implementing weapon systems while offering the potential for substantially reduced avionics cost.

Several years ago, the results of a wide variety of technology based programs targeted to support the next generation of avionics were beginning to demonstrate remarkable advances in processing capabilities using architectural structures compatible with fault tolerant, reconfigurable, multi-application features. Programs such as PAVE PILLAR (focused on advanced architectural concepts), Integrated Communication Navigation Identification Avionics (ICNIA - directed at integration of communication, radio navigation, identification, Joint Tactical Information Distribution System (JTIDS), Global Positioning System (GPS), Instrument Landing System (ILS), Microwave Landing System (MLS), etc., in a common architecture), Integrated Electronic Warfare System (INEWS - integrating electronic combat functions in a common architecture) and DOD VHSIC insertion, all Air Force technology base efforts, were established to individually address growth and enhancement to more reliable specific avionics functions. As word of successes in advancing the avionics state-of-the-art spread, an exaggerated view of the maturity of these discrete technologies emerged. In this case, the exaggeration was good fortune because it added significantly to the empetise to consider the application of an aggressive integrated avionics capability on the next aircraft to be built by one of the services.

Although no demonstration of a full, integrated avionics suite embodying the capabilities of the evolving technology base has been accomplished, a series of windows of opportunity are available in the form of the concurrent developments of the Army Light Helicopter (LH), the Air Force Advanced Tactical Fighter (ATF), and the Navy A-12 (the A-6 replacement), see Figure 3. (At the time this paper was written, the future of the A-12 program and the Navy's specific role in JIAWG and the CAB was uncertain. For that reason, the paper addresses the planned efforts as they exist unadjusted by evolving events affecting the A-12 program). Each of these aircraft were considered prime targets for the application of an integrated avionics capability. Clearly the development of three separate avionics suites for these three weapon systems would continue the avionics proliferation of concern to those who manage the defense budget. Based on both the technical and program opportunities, the decision to pursue a common avionics capability applicable in the broadest

ADVANCED AVIONICS ARCHITECTURE

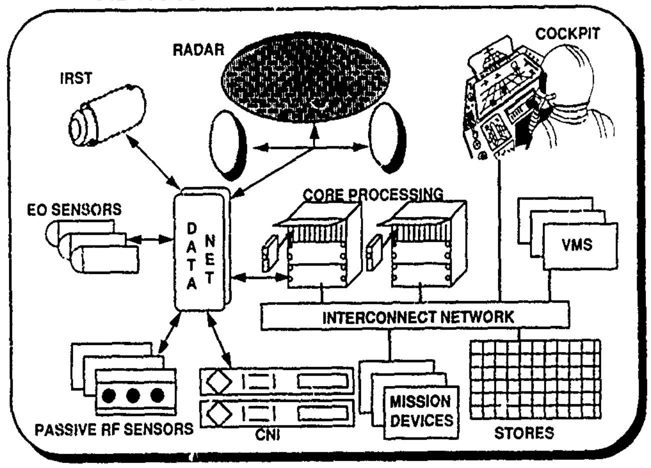


FIGURE 1

AVIONICS COST TRENDS

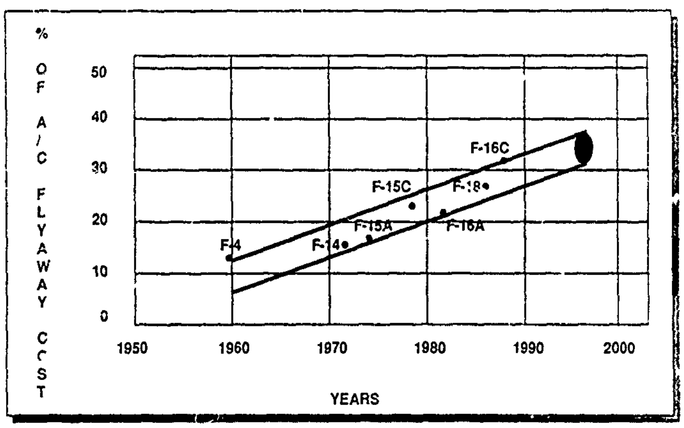


FIGURE 2

PHASES OF JIAWG APPROACH

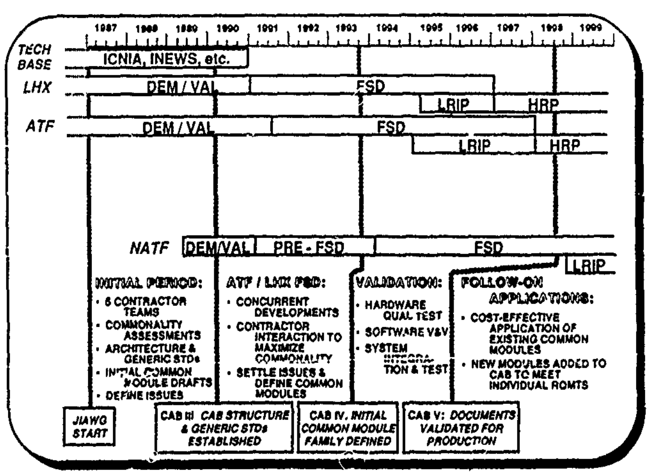


FIGURE 3

sense to all three new aircraft was inevitable. The fundamental obstacle was how to merge the efforts of the three services with sufficient stimulation to produce the desired result.

THE FORMATION OF THE JIAWG

As a result of Office of Secretary of Defense (OSD) and Congressional reaction to the potential for avionics cost control available from advances in reliability and supportability directly available from common integrated digital modular avionics, in October 1986, the FY 87 DOD Appropriation Act Conference Report No. 99-1005 was issued. This report required the U.S. Army, Air Force and Navy to "prepare a joint plan for the inclusion of fully integrated, digital avionics, communications, sensors, embedded communications security, and other electronics on all aircraft under development." In response, the Assistant Secretary of Defense for Command, Control, Communication and Intelligence directed the Air Force to, in coordination with the Army and Navy, prepare a joint plan to meet the intent of the direction contained in the Congressional Appropriation Act. The immediate result of this direction was the tri-service formation of the Joint Integrated Avionics Working Group, the JIAWG.

Some of the ground rules imposed during the formulation of the JIAWG were to exploit the windows of opportunity created by the coincidental timing of the LH, ATF and A-12 programs; to recognize and accommodate the competitive nature of these three focus programs and the constraints of competition on the contractors involved; to deal with the highest levels of classification imposed by these three highly classified programs; to be prepared to work under the almost constant scrutiny of the Office of the Secretary of Defense and Congress to show steady progress; and to balance the desire for maximum long term savings from avionics commonality with the reality of short term cost, weight, and performance impacts to individual weapon systems which might use common avionics.

Of these constraints, the most difficult was dealing with competitive sensitivity. It has been essential that the contractors executing the weapon system programs be fully involved in defining JIAWG baseline requirements. A successful CAB definition requires that multiple design concepts created in a competitive environment be minimized to allow closure on a single common requirements baseline. However, to preserve opportunity of each participant to implement his preferred advanced design, all competitive sensitivities were scrupulously honored when encountered. The contractors involved in the JIAWG have devoted substantial engineering effort to the refinement of CAB requirements through analysis and debate among themselves of the underlying technical issues. In order for this process to work, full and open knowledge of the evolving CAB has been the key. Any future success of the JIAWG CAB can be attributed to the willingness of our contractors to lay aside many of their competitive constraints for the good of the process. A successful leadership role in this effort could present the ATF and LH contractors follow-on business opportunities in both the military and commercial markets.

With these groundrules, the leadership of the LH, ATF and A-12 programs created the JIAWG under a tri-service coordinated charter and published a Joint Integrated Avionics Plan (JIAP). The JIAP was first published in March 1987, and then updated in March 1989, both times under the signatures of all three services' acquisition executives. The JIAP is a three part document presenting: background describing the motivations leading to the JIAWG, as discussed above; a description of the organization called JIAWG, which follows; and information on joint avionics development activities (opportunities for common avionics in the three target programs, the ATF, the LH and the A-12), discussed later. The JIAP is the implementation plan for the JIAWG which, along with the JIAWG charter, generally establishes direction and guidance for the group.

Formed in 1987, the JIAWG has been focused on matters concerning system level avionics architecture and module commonality associated with the target applications of the CAB, the LH, ATF and A-12 (A-12 avionics upgrade program). Those charged with planning the initiation, maturation and implementation of the Common Avionics Baseline have continually pursued the broadest most robust definition of performance requirements essential to satisfying the operational needs of the three target programs.

The significance given the JIAWG efforts by senior DOD representatives is reflected in the formal organization of the group. The JIAWG is organized to respond directly to the three Service Acquisition Executives through the affiliated Program Executive Officers (PEO). The Service Acquisition Executives are responsible to the service secretaries to establish acquisition policy and to assure weapon system development within the guidelines set forth by OSD and Congress, for their programs. The PEO is the single authority between the individual Program Directors and the Acquisition Executive providing development guidance and management overview. Figure 4 shows the relationship of the JIAWG to the formal service acquisition channels. Although the Service Acquisition Executives are effectively the final decision makers, JIAWG issues are routinely resolved at lower levels of the organization, precluding the need to directly involve these senior representatives except for the most significant of politically sensitive issues. Their role is predominantly coordination and authorization to implement decisions that may have substantial program implications. Much the same is true of the PEO Executive Committee.

The Joint Programs Managers Group (JPMG), composed of the Directors of the three aircraft programs, provides specific program related guidance to the JIAWG and reports directly to the PEO Executive Committee. All issues impacting performance, cost or schedule are addressed by the JPMG. The JPMG sets JIAWG operating policies and considers all recommendations for implementation of the CAB which have significant cost impacts. The JPMG is supported by the Industry Executive Council, comprised of corporate executives who have multiple program oversight and are directly associated with top level business management of the LH, ATF or A-12. The Industry Executive Council has been instrumental in opening competition sensitive doors and in assuring ready access to essential performance parameters.

The Steering Committee, made up of program deputy directors, is responsible for dispute resolution and tri-service coordination of JIAWG Task Group recommendations. An Industry Advisory Group, made up of senior avionics contractor engineering representatives involved in the three weapon system programs, provides definitive corporate positions in dispute resolution and coordination ensuring contractor involvement in JIAWG decisions. Issues involving proprietary restrictions and competition sensitivities as well as basic performance capabilities are a primary focus of these groups

JOINT INTEGRATED AVIONICS WORKING GROUP (JIAWG)

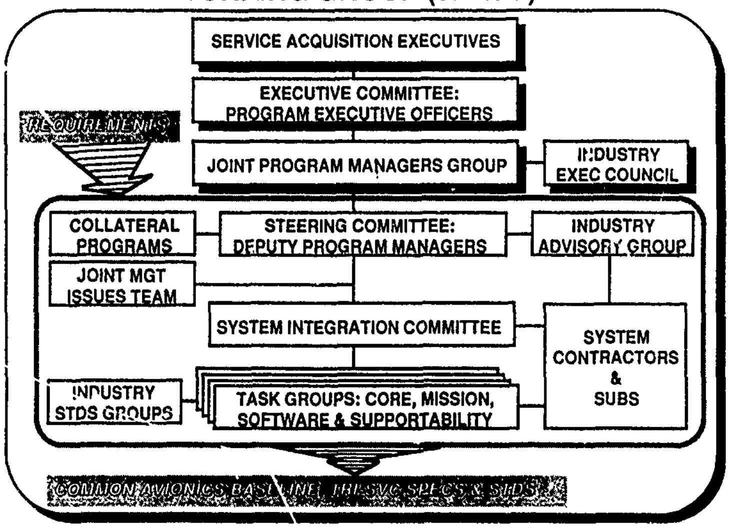


FIGURE 4

The System Integration Committee (SIC) is the working level government and industry group responsible for the efforts of developing alternatives for an Advanced Avionics Architecture (A^3), and the many varied common module candidates to be implemented and used by the three programs as a Common Avionics Baseline. In the Air Force, the efforts of the JIAWG, at and below the SIC, have been principally the responsibility of the former ATF Avionics Director, Col Mike Borky, until recently the Air Force System Integration Committee representative. Much of the JIAWG success to date has been attributed to the inspired and insightful leadership of Col Borky. More will be said of the JIAWG organization Task Groups in the section on the CAB Development Process.

THE CAB ARCHITECTURE

The Common Avionics Baseline is much more than the listing of specifications for development of tools, architecture and modules, seen in Figure 5. In order for the JIAWG structure of the Common Avionics Baseline to work, the basic infrastructure of a "generic" architecture must first be in place. This architecture is defined in the advanced avionics architecture (A^3) standard in terms of physical and electrical characteristics such as package form factor, connector(s), and power supply voltages; environmental requirements such as temperature, vibration, and corrosion atmospheres; interfaces, especially backplane and inter-rack bus protocols; software engineering standards and common software tools; and overall requirements for reliability, maintainability, and supportability (RM&S). The basic configuration units of the CAB are the hardware line replaceable modules (LRMs), generally packaged in a modified Standard Electronic Module - Format E (SEM-E) and reusable software packages written in Ada. Individual common item specifications and standards incorporate the appropriate performance, timing, functional and other parameters needed to complete the definition. The CAB is fundamentally a collection of capabilities which when arranged, adjusted and properly matched to the application, will serve as the processing and, potentially in the future, the sensing elements of an advanced avionics suite. Figure 6 offers a general structure, or orientation, of the CAB elements to achieve an integrated system. The data and signal processing capabilities to support radar, electronic combat, communication/navigation/ identification, control and display, stores management, general processing, etc., will all be available within the current CAB in the form of common data and signal processor modules, memory modules, interface modules, and power supplies modules, etc.

The foundation of the CAB is the advanced avionics architecture, A^3. The fundamental principles of this architecture are that it accepts standard modules (such as those just mentioned) which are interoperable and exchangable in a variety of applications; it meets defined performance standards for system partitioning, interconnects, diagnostics and initialization; it implements a prescribed information security capability; it accommodates technology insertion; and it is readily integrated into fighter and attack helicopter size aircraft.

The A^3 is a derivative of the PAVE PILLAR architecture that evolved in the early 80s. As the A^3 has evolved, the range of implementation variables has gradually narrowed. The fundamental features of the A^3, have been refined and adjusted through a series of tradeoffs, which will be discussed later in this paper. Although the current A^3 standard remains open-ended to some degree with two similar architectural alternatives, which will also be discussed later, both alternatives share essential characteristics. As suggested, the A^3 is an open architecture which permits interface of both 16 and 32 BIT data processors, flexible mass memory and signal processing via high speed fiber optic data and signal networks. The A^3 interface to radar, electronic combat and other sensors is via point-to-point high speed fiber optic networks with more conventional MIL-STD-1553 busses available for less time stressing functions such as flight control and stores management. Other features include a test-maintenance interface (TM bus) to support background fault monitoring, reconfiguration implementation and general maintenance. While much of the A^3 baseline is common between the two A^3 alternatives, there are differences, such as

JOINT INTEGRATED AVIONICS WORKING GROUP
COMMON AVIONICS BASELINE
JIAWG CAB III, REV 1

J87-01 Advanced Avionics Architecture (A^3) Standard
J90-CNI-01 Integrated Communication, navigation, Identification System Standard
J87-G2A Standard Connector Specification
J88-G2B Standard Module Specification
J88-G4 Configuration Management Plan
J88-G6 Integrated Logistics Support Standard
J87-M1 Common Avionics Processor - 16 Bit (CAP-16) Specification
J88-M1A Input/Output and Built-in Test Interface Description (IOBID) Specification
J89-M1D CAP-16 Instruction Set Architecture Specification
J88-M2D Data Processor - Common Avionics Processor - 32 Bit (DP-CAP-32) Specification
J89-M2D1/2 32 Bit Computer Instruction Set Architecture Specification
J89-M3 Extended Memory - 32 Bit Specification
J89-M4 Non-volatile Bulk Memory Module (NVBMM) Specification
J88-M5D Data Processor High Speed Data Bus Interface Module (HSDBIM) Specification
J88-M6D Multiplex Data Bus Interface Module (1553 BIM) Specification
J88-M7 General Specification for Power Supply for Airborne, Electronics Specification
J88-M7A Airborne Standard Power Supply, 50 amp (PS-50) Specification
J88-M7B Airborne Standard Power Supply, 270 VDC Input, Multiple Output, Specification
J88-M7C Airborne Standard Power Supply, 28 VDC, Specification
J87-N1 Module Interconnect Document
J89-N1A JIAWG Parallel Intermodule Bus (JPI-bus) Specification
J89-N1B JIAWG Test and Maintenance Bus (JTM-bus) Specification
J89-N1C Utility Signals Specification
J88-N1F User Console Interface Specification
J90-N1H User Console Interface Specification for 32 Bit Modules
J88-N2 Linear Token Passing Multiplex Data Bus Protocol
J89-S2 DOD-STD 2167A System/Software Engineering Information Requirements Concept Paper
J89-S3 Software Engineering Environment (SEE) Specification
J89-S4 Software Engineering Environment (SEE) Integration Features Concept Paper
J89-S5 Common SEE Life Cycle Support Concept Paper
J89-S6 Tailored DOD-STD-2167A Rationale
J89-S7 Software Reuse Concept paper
J89-S9 Software Reuse Domain Analysis Concept paper
J90-S10 Module Initialization, Test and Software Interface (MITSI) Specification
J89-SP-01 Signal Processor Architecture Specification
JJ89-CH1 Optical Disk Functional Specification
J89-CH2 Data Transfer Units Functional Specification
J89-CH3 Airborne Standard Power Supply Specification

FIGURE 5

CAB STRUCTURE

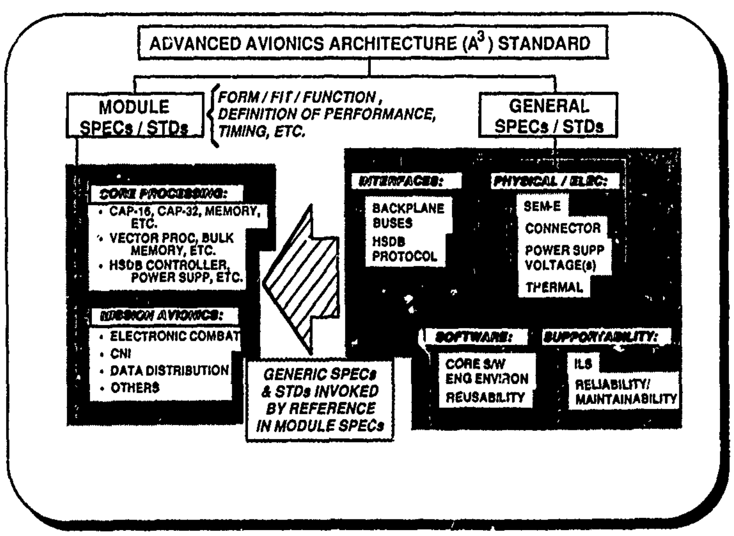


FIGURE 6

the implementation of a parallel intermodule (PI-bus), required by only one of the alternatives. The detailed functional descriptions of both A³ alternatives are contained in JIAWG standard J87-01. It is the intent of those involved in JIAWG to achieve a single advanced avionics architecture during the course of LH and ATF full scale development. The ability to achieve this will be dependent on the success of the LH/ATF commonality working group (to be discussed) in reconciling the differing architectural demands of the two aircraft.

A series of draft specifications and standards, see Figure 5, establishes the basis for form, fit and function (F³) performance capabilities for the proposed modules. As examples of the CAB specifications, extracts outlining the significant features of the common standard module, the common standard power supply and the environmental requirements for all modules are provided in Figures 7, 8 and 9, respectively.

In addition to the specifications and standards for modules, the CAB specification set addresses interfaces (backplane, buses, protocols, etc.); physical and electrical characteristics (modified SEM-E form factor, connectors, power supply features, environmental requirements, etc.); software features (software engineering environment, reuse opportunities, standard language, etc); and basic supportability (ILS, durability, maintainability, etc.). The combined application of the necessary elements of the CAB will provide a very powerful avionics architecture available to military and commercial users.

As with the A³ standard, the details of nearly all these module standards remain to be resolved. However, a specific process to accomplish the necessary tradeoffs and maturation is in place. Further, although the JIAWG CAB efforts have been focused almost exclusively on core processing as the initial commonality opportunity, we are expanding our efforts to pursue portions of the mission avionics (radar, electronic combat, CNI, etc.).

CAB DEVELOPMENT PROCESS

Many different Task Groups have been formed to define and develop preliminary functional requirements specifications for the A³ and common modules, see Figure 10. All Task Groups are led by AF, Army and Navy representatives with participation by both government and contractor engineers and managers. At this level, the many compromises necessary to satisfy the requirements of all participants are formulated. As can be inferred from the process used to develop common specifications, Figure 11, the challenges of settling on a final specification for any particular aspect of the CAB is an iterative effort. To appreciate the magnitude and complexity of this task, a series of examples is useful

The work horse of the CAB is the 32-bit common standard data processing element. This particular module is featured in the implementation of every avionics function, e.g. radar, electronic combat, CNI, controls and displays, etc., see Figure 12. Each module cluster includes at least one 32-bit standard data processing element. Because the baseline architecture offered by the JIAWG participating contractors was initially that of their preferred avionics implementation (one from each LH, ATF, and A-12 contractor), the 32-bit processor originalty consisted of several general definitions (interface, throughput, and memory definitions). Thus, the industry and government inputs for the initial 32-bit data processor specification were rather broadly and loosely established. One challenge was a possible definition of common features between the various candidates. Beyond that, the question was whether or not compromises could be found such that a single standard specification could provide for all the performance and capability needed to support each user without such a severe overhead burden as to make the performance and/or cost of the module completely inefficient. In this case, the process shown in Figure 11 was accomplished many, many times. At one point, frustration nearly prevailed in the form of a forced decision on one specific implementation. That, however, would have violated one of the fundamental principles of the JIAWG by putting at least one participating contractor at a serious competitive disadvantage In this case the Joint Program Managers Group stepped in deciding that the 32-bit data processor definitions would also include two alternatives, thus preserving the competitive nature of both the ATF and LH efforts. At this writing, there is strong commonality opportunity between pairs of LH and ATF architectures and 32-bit processor. Once full scale development contracts are awarded for both programs, work will proceed toward a single common standard for both the A³ and the 32-bit processor.

Another example of the JIAWG specification process involving few but intensive iterations is the effort to establish a set of design physical environments for each module. This particular task sounds rather straight forward, but it became substantially complicated with the insertion of the Air Force Avionics Integrity Program (AVIP). Rather than following a traditional path of setting military standard environmental constraints, for thermal, vibration, acoustic and electromagnetic, the AVIP imposes a detailed aircraft to electronic component level design analysis and verification process to establish and impose the environmental conditions more likely to be encountered by the avionics over its lifetime. This represents a cultural difference between Air Force and Navy engineers. In this case, the applicable Task Group and the Systems Integration Committee evolved a compromise that imposed the military standards desired by the Navy, as a minimum, with the Air Force's AVIP efforts deriving and imposing platform specific requirements when they exceed the Navy's military standard baseline. Early predictions suggest the differences are not severe.

A final example of this process is one that after substantial technical activity and the involved efforts of the SIC, the Steering Committee and the JPMG remains unresolved. One of the most significant issues faced by the JIAWG in terms of potential cost and performance implications is the imposition of nuclear Transient Radiation Effects on Electronics (TREE) hardening requirements. This issue could impede closure on a final set of draft CAB specifications. The Army and the Navy require hardening of JIAWG modules for nuclear TREE, based on LH and A-12 operational requirements. Simply stated, the issue revolves around the level of TREE requirements to be imposed. It is clear that any TREE requirement will add cost. The real issue is that the Army's operational community is faced with the potential need to harden their avionics at levels up 100 times more stressing than either the Navy or the Air Force are interested in dealing with. The cost implications of imposing TREE requirements for such levels of hardening have been established to be very significant. It will be very difficult to justify this cost, especially for the ATF which has no formal user defined operational requirement for TREE hardening.

Such issues have been routinely resolved at or below the System Integration Committee. Because of the

JOINT INTEGRATED AVIONICS WORKING GROUP
ENVIRONMENTAL REQUIREMENTS
(DOCUMENT J88-G2B)

SCOPE: All modules shall be in accordance with the requirements specified in the JIAWG Advanced Avionics Architecture Standard (J87-01)

ELECTRICAL CONFIGURATION: When a module is designed in a new logic/technology family that duplicates an existing module function in a different logic/technology family, the new module shall be designed such that the contact assignments in the new module are identical to those of the existing module (J88-G2B1)

MECHANICAL CONFIGURATION: The basic module configuration and dimensions shall conform with the SEM-E form factor.

CONDUCTION COOLING: The module shall be designed to be conduction cooled through the module guide ribs

MODULE CONSTRUCTION: The module frame shall include module rib structures and insertion/extraction features

MODULE CONNECTOR: The module connector shall be in accordance with the requirements specified in J87-G2A

FIGURE 7

JOINT INTEGRATED AVIONICS WORKING GROUP
ENVIRONMENTAL REQUIREMENTS
(DOCUMENT J88-G2B)

Scope: Establishes the requirements for a 5.0/5.2 volt (v), 50 ampere (A) airborne electronic power supply in a Standard Electronic Module Format - E (SEM-E)

INPUT POWER: 220v, 3PHASE, 400Hz AC or 270 vDC

OUTPUT POWER: Nominal 5.0 vDC, 50 A (Programmable to 5.2 vDC)

PARALLEL OPERATION: Meet all performance when paralleled with up to nine common power supply modules

PHYSICAL CHARACTERISTICS: 1.5 Pounds, SEM-E Form Factor, J87-G2A Connector

EFFICIENCY: 80% @ 100% Load

BUILT-IN-TEST: During Power-up, Continuous Monitoring, Maintenance Fault Detection/Isolation (Test Maintenance Bus Interface)

RELIABILITY: 20,000 HRS MTBF (To be revised per AVIP)

PERFORMANCE FEATURES: (Defined in detail in specification)

FIGURE 8

JOINT INTEGRATED AVIONICS WORKING GROUP
ENVIRONMENTAL REQUIREMENTS
(DOCUMENT J88-G2B)

STORAGE TEMPERATURE: -54 C TO +95 C

OPERATING TEMPERATURE: -40 C TO +75 C (30 Min excursion TO +85 C)

THERMAL SHOCK (non-operating): -54 C TO +95 C

HUMIDITY: 100% operating

SALT FOG: 5% Solution @ 35 C for 96 HRS

SHOCK (impact): 14 Drops of 24 inches to concrete

VIBRATION: 4 HRS each axis sinewave 1.0 TO 1.7 gs (freq dependent)

165 Db from 31.5 TO 8000 Hz acoustic

EMIC: 40 Db case shielding

Conducted/Radiated Emissions/Susceptibility combined Army/Navy/ Air Force requirements

EMP/TREE: Still under consideration

FIGURE 9

JIAWG TASK GROUP
ORGANIZATION

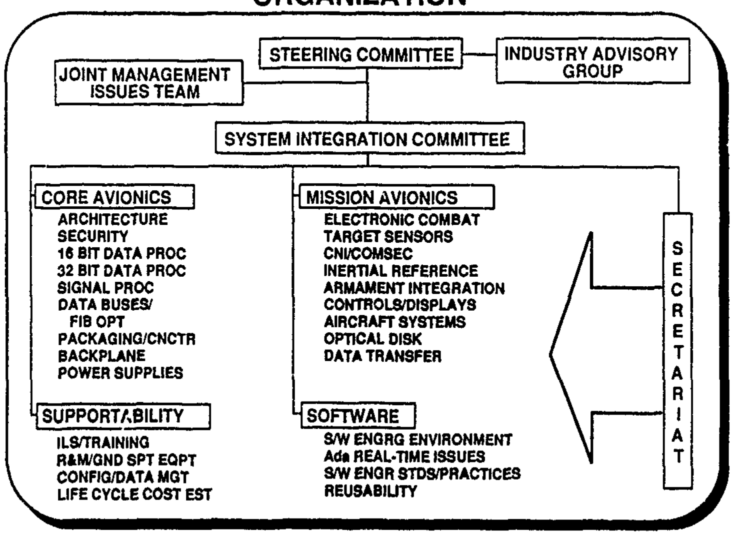


FIGURE 10

COMMON SPECS PROCESS

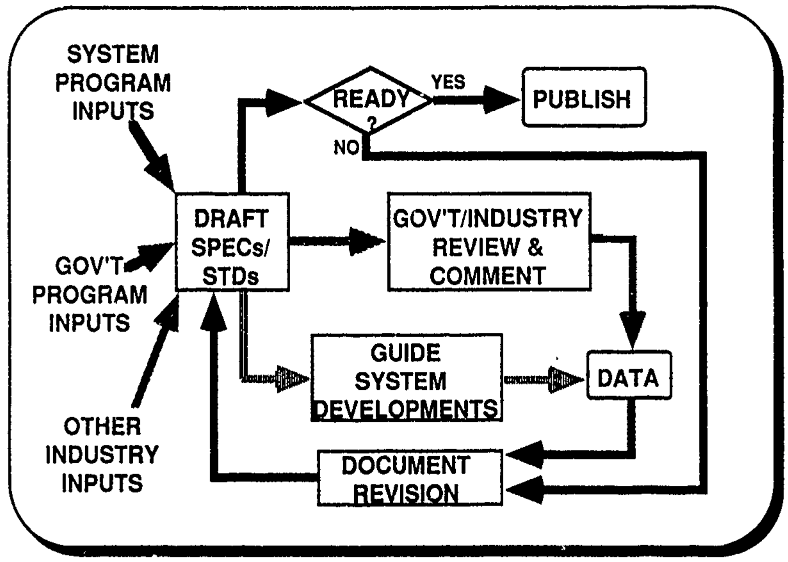
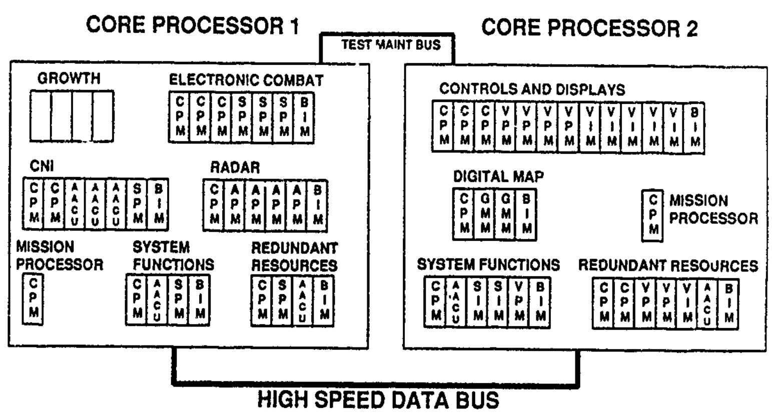


FIGURE 11

CORE PROCESSING CLUSTERS



CPM - COMMON PROCESSOR MODULE
SPM - SPECIAL PROCESSOR MODULE
APM - ARITHMETIC PROCESSOR MODULE
GMM - GLOBAL MEMORY MODULE
BIM - BUS INTERFACE MODULE
AACU - ADVANCED COMSEC MODULE
VPM - VIDEO PROCESSING MODULE
SIM - STORE INTERFACE MODULE

FIGURE 12

significance of this TREE issue, it is in the hands of the Joint Program Managers Group. Because of the significant cost impacts involved, the issue may come to a decision to relax the Army requirement or incur a substantial cost addition to be born by all users of JIAWG modules. These facts are being assessed by the Army, Navy and Air Force in consideration of their individual TREE hardening requirements versus the cost of TREE. It appears the Army is moving toward a compromise that would relax the TREE requirements on all but safety of flight electronics. The Navy's position is also being refined at this time.

These, and many other similar challenges have been confronted by the JIAWG. In every case, some resolution has been achieved to permit continued movement toward a successful Common Avionics Baseline.

EVOLUTION AND STATUS

The JIAWG has established a schedule for the release of successive versions of specifications and standards as the documents mature and the participating weapon system programs proceed through their phases of development. The major CAB releases, identified as CAB I through V, are as follows:

CAB I. Released in June 1987 as Version 1 of the A^3. This release also identified existing MIL Specifications and Standards to be incorporated in the CAB. CAB I served to start the JIAWG dialogue and establish procedural and policy guidelines.

CAB II: Released in January 1989 as Versions 1 and 2 (CAB IIA and IIB) of an initial set of CAB documents, plus documentation of the results of extensive commonality assessments aimed at identifying areas of potential standardization

CAB III: Released in 1990 as Version 3 of the CAB documents and made available for incorporation into the ATF and LH Full Scale Development Requests for Proposal and contracts. Characteristics of these documents include:
Type A specification format defining overall weapon system and avionics segment functional performance requirements.
Defined sufficiently to allow contractual application and to support valid contractor assessment of development effort, risk, and cost of incorporating these capabilities into the intended design. Some technical issues remain open pending the conclusion of the LH and ATF FSD activities.

CAB IV: Scheduled for release in October 1993 as Version 4 CAB documents. These will be in the form of final B-Specifications (Prime Item Development specifications), and preliminary C-Specifications (product function fabrication specifications). These documents will be available subsequent to the ATF and LH Critical Design Reviews (CDRs).

CAB V: Scheduled for release in June 1998 as Version 5 documents. These will be complete product function C-Specifications representing verified and qualified designs ready for production implementation. Additional functional performance specifications can be expected as more modules are offered as JIAWG candidates.

As mentioned earlier, the JIAWG has made excellent progress overall, including areas such as security and software reuse, which were not contemplated in the original JIAP. All aerospace prime contractors involved in the LH, ATF, and A-12 efforts have signed a memorandum of agreement agreeing to support the JIAWG and they have cooperated fully in sharing information and in working on CAB documents. Commonality assessments for all avionics areas have been completed identifying the most likely common modules and have allowed work to be focused on areas of highest potential payoff. In a number of areas significant compromises are leading to final versions of CAB documents well ahead of schedule.

CAB III contains most of the "generic" documents required for LH and ATF contracts; as mentioned, a few items will remain to be resolved in the two FSD programs. The CAB III document set will be refined greatly immediately following LH and ATF source selections as the design alternatives of the losing contractors are removed from further consideration. Also, in areas such as Electronics Combat (EC), Communication/Navigation/Identification (CNI), radar and core signal processing, the JIAWG is currently dealing with equally valid, but mutually incompatible, design approaches by competing contractors The FSD contractor selections will effectively narrow these alternatives as well. Since specifications for all contending approaches will already exist as outputs of the recently completed LH and ATF Demonstration/Validation work, the necessary documents can be added to the CAB relatively easily. Future weapon system programs will have available a mature and validated common avionics inventory as defined in CAB V documents and will be able to incorporate those CAB items identified as required for the necessary functionality and as appropriate, through their own cost/benefit analyses.

ATF/LH/A-12 INTERFACE

As discussed earlier, the LH and ATF are the pacing JIAWG related development programs. Both programs are working toward evolving both a common avionics architectural baseline and as many common modules as practical. The performance demands of a helicopter program versus a high performance fighter aircraft have made progress rather slow and painful; however, as discussed earlier, significant progress has been made and significant commonality opportunities are available. The ATF and LH Requests for Proposal require the winning contractors to work together to mature JIAWG specifications and demonstrate module level interoperablity and exchangeability. These efforts are expected to result in verification of the suitability of the A^3 to support widely diverse applications and in the maturing of a set of common module specifications, culminating in module level interoperability demonstrations and validated specifications, CAB V, Version 5.

At this point, the ATF FSD RFP mandates the application of CAB specifications to set the opportunities for common LH/ATF avionics. The JIAWG's focus is directed to refining the current preliminary CAB, establishing the essential efforts of our FSD contractor in continuing the JIAWG efforts, and in implementing the LH/ATF commonality demonstration plans. This is being accomplished in both the LH and ATF programs by including all draft JIAWG CAB III specifications by reference in the top level Weapon System Specification and by requiring the offerors to define their process for further maturing these specifications during FSD. Also, both programs are requiring the offerors to define a working relationship between themselves through which commonality opportunities will be further refined and matured. This is to be managed by an LH-ATF commonality working group made up of contractor and government engineers and managers.

Considering the premise of JIAWG as evolving a common avionics architecture and a set of common modules from which future avionics suites could be constructed, another FSD task will be joint verification of interoperability and, if possible, exchangeability of avionics modules between ATF and LH. It is the responsibility of the ATF/LH programs offices to jointly validate CAB III specifications and produce the CAB IV and V specification versions. As mentioned, CAB IV specifications will be available at a point when the architecture and module designs are considered capable of achieving the ATF and LH program requirements, around October 1993. The level of commonality of the JIAWG CAB IV will be dependent upon the ability of both programs to achieve their individual requirements under the constraints of commonality. In terms of opportunity, we believe the number of common modules could be as high as 70 to 80, if sensor modules supporting radar, electronic combat, CNI, etc , can be baselined. A more conservative view based on our primary focus on core processing commonality is that approximately 20 modules making up a common core processing capability could reasonably be developed as ATF/LH common items. These 20 some common modules would equate to a validated integrated architecture and a fully capable integrated processing system. The final number is very dependent on the ability of the common module to satisfy both programs' performance requirements at an acceptable cost. Whatever the initial baseline may be, it is clear that the future of advanced avionics is in the direction of this Common Avionics Baseline.

Beyond this joint commonality baseline, all the avionics modules of either the ATF, or the LH, or both, development programs will be available to future programs, in effect, offering the potential for a much broader module set. As discussed earlier, commonality initiatives will be pursued aggressively, but with a healthy regard for both the cost and performance implications. It is the intent of the ATF and LH System Program Offices to foster opportunity for common avionics within the constraints of assuring the weapon systems are capable of meeting the needs of their customers. It is the intent of the JIAWG to assure that all opportunities arising from the ATF and LH program efforts are made available to potential users, see Figure 13. In this manner, the goals of the JIAWG, satisfying the Congress, OSD and the Army, Air Force and Navy can be achieved.

SUMMARY:

The JIAWG CAB is expected to have enormous influence on the entire next generation of avionic systems. It is imperative that good standardization decisions, based on a credible data base of design, test, and analysis, be used as the basis for CAB definition. Premature publication of specifications and standards whose content is not well founded and likely to change could cause resources to be wasted by the industry and could fatally undermine the credibility of this DOD avionics commonality thrust. As noted earlier, the CAB development is concurrent with the development phases of the LH and ATF programs from which the data needed to close remaining technical issues will be derived. The JIAWG process provides a systematic way to define technical issues and alternative solutions and to draw on all valid data sources in establishing the preferred resolution of each issue. This process will be tightly coordinated with the weapon system programs to ensure specifications and standards incorporate adequate and current data from analysis and testing to complete each version of the CAB as part of planned weapon system development milestones.

As the JIAWG CAB matures, specific procedures for document maintenance and CAB update configuration control will evolve. Several proposals are being considered, however, decisions on the long term of JIAWG are still being considered. In the immediate future, anyone wishing information on the JIAWG or the Common Avionics Baseline should contact:

United States Companies - Contact:
VEDA, Inc..
5200 Springfield Pike
Dayton, OH 45431
Attention: JIAWG/Jackie Lane

Foreign Companies - Request information through country embassy:
ASD/YF
Wright-Patterson AFB, OH 45433
Attention: JIAWG Point of Contact

Bibliography:

JIAWG, "Joint Integrated Avionics Plan for New Aircraft", OSD, March 1987.

JIAWG, "Joint Integrated Avionics Plan for New Aircraft", OSD, March 1989.

Ronald Longbrake, "Avionics Systems Engineering", ASD/EN, 1988.

U.S. Congress, "FY 87 DOD Appropriations Act Conference report No. 99-1005, October 1986.

Mike Borky, Mike Richey, Archie Turner, "Joint Integrated Avionics Working Group Report to the Conventional Systems Committee", JIAWG, February 1990.

Terry Venama, "Joint Integrated Avionics Working Group Status Briefing", JIAWG, December 1989.

M. Levantine, "Compliance with JIAWG Specifications", Lockheed, General Dynamics, Boeing, November 1989.

Terry Venama, "Advanced tactical fighter Avionics Overview", ATF System Program Office, April 1990.

Mike Borky, "ATF Common Avionics Status, NAECON 90", ATF SPO, August 1990.

JIAWG CAD Documents, see Figure 5.

CAB APPLICATIONS PROCESS

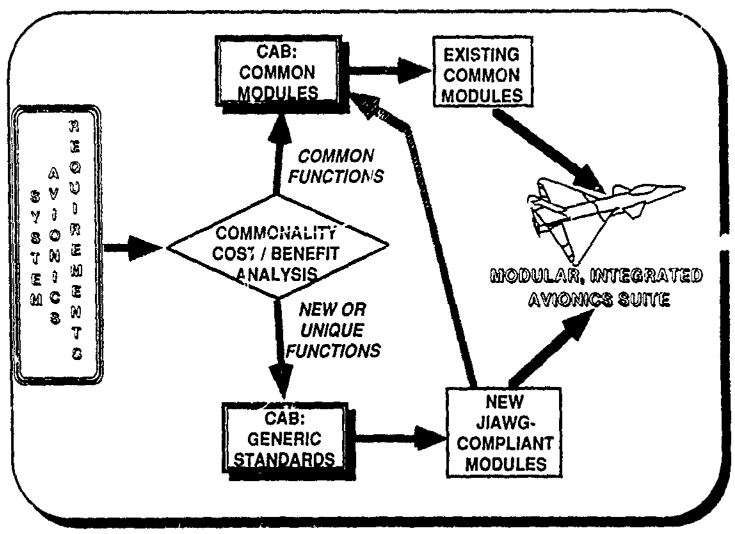


FIGURE 13

AVIONICS SYSTEMS DEVELOPMENT: TECHNOLOGICAL TRENDS, CONFLICTS AND COST ISSUES IN A CHANGING EUROPEAN ENVIRONMENT

by
Dr. Helmut Rapp
Deutsche Aerospace
Messerschmitt-Bölkow-Blohm GmbH
Postfach 80 11 60
D-8000 MÜNCHEN 80

Abstract

Flexibility, survivability, availability and cost of ownership of modern aeronautical weapons systems increasingly rely upon its avionic systems and the capabilities offered by advanced sensors, processors and system software. This especially holds true with regard to upgrade programmes mostly driven by the increasingly sophisticated threat and advances in the avionics field.

The limited ressources of the European countries as well as the rising cost of avionics equipment and software need innovative approaches beyond already established joint European defense projects in order to keep weapons systems affordable. This paper is focussed on equipment standards that allow technology growth, maximize competition and promote reusability of designs, on the avionics system software evolution and on experiences gained in german TORNADO and F-4F upgrade programmes. Indications with regard to possible future upgrade programmes will also be given.

As far as standardization is concerned, this paper will present an overview of objectives and status of actual german research and development projects generally known under the notion "Modular Avionics" and their relationship to international initiatives. Growing system software complexity as well as rising software problems and cost have forced software development into rigid development methods, high order languages and towards increasing standardization. This trend is highlighted on the basis of the above mentioned and new programmes, where the close coupling between system functions, system performance and real time mission software can be observed very prominently.

1. Introduction

The introduction of digital avionics based upon freely programmable embedded and distributed real time computer systems into military fighter aircraft, the accompanying transition from electromechanical to software-intensive systems as well as the current trends towards integrated avionic system architectures have provided new levels of capability, flexibility and availability of flying weapon systems. System functions and system performance are tightly coupled to real time mission software offering different modes and capabilities for various missions and increasingly sophisticated threat environments.

The computing capacity of the Electronic Combat Reconnaissance (ECR) Tornado for example, now in delivery to the German Air Force increased considerably compared to the basic Tornado aircraft within 4 years: The number of on aircraft loadable computers from 1 to 6 and their memory from 128 K words to nearly 3000 K words. 3 of the 6 computers are mission computers programmed by MBB as prime contractor for this aircraft.

Obviously evolutions of this magnitude are no longer only quantitative but also qualitative in nature since they lead to a considerable increase of the complexity of the avionic systems and the development processes that finally provide those systems. Steadily rising costs and development time frames for avionic equipment and software reflect these trends; some 30% of the flyaway costs of current military fighter aircraft are spent for avionics.

The transition from loosely coupled or stand alone "black boxes" to increasingly integrated networks of avionic subsystems held together by avionic busses and real time mission software for information exchange brought also new experiences with regard to system and software development methodologies. As far as software development is concerned, budget overruns, missed schedules and unrealistic planning are common experiences placing the costs for avionics systems integration and acquisition under critical consideration.

The cost issues mentioned are of additional importance in the Europe of today where the Soviet threat has virtually disappeared. Nevertheless a potential capability and the fact that the Soviet Union is and will be a superpower remains and there is a common understanding amongst the European nations that it is essential to maintain a coherent defense posture for the foreseeable future. In addition the war at the Persian Gulf has prompted new conflict scenarios that will lead to a reevaluation of force structures and missions.

The changes in the nature of risks and threats (e.g. new threats with "western" equipment, new climatic environments, new logistic aspects) and more emphasis on mobility, flexibility and reconnaissance will put new requirements on existing and new weapon systems and in turn on avionics systems. But these requirements will have to be fulfilled with shrinking budgets since the end of the cold war spurs the payment of "peace dividends" in the western democracies and the member nations of NATO. Besides budget reductions, less flying hours, less tolerance to noise and accidents in the dense populated Europe, less time and areas for training and the complexity of modern weapon systems and their man-machine-interfaces impose an additional burden to the military forces and their tasks.

Based upon the trends mentioned above the following sections of this lecture will focus on the following topics:

- Predictable consequences from reduced tensions in central Europe, changing threat scenarios and new emerging needs
- Experiences and trends related to avionic system software development and integration
- New avionic architectures and their potential applications
- Possibilities for future upgrade programs.

2. Emerging needs in the 1990's

The European strategic, industrial and economic situation is changing rapidly and profondly. The main driving factors are the disintegration of the Warsaw Pact and the diminishing Soviet Threat in Central Europe, the integration of the European economy towards a single European market in 1993 and the reunification of Germany. As far as the German Armed Forces are concerned there are already visible impacts of the new environment:

- The number of personnel will be reduced to 370 000 up to 1995 and the time to serve in the German Armed Forces decreased already from 18 to 12 months. Therefore failure-free performance of the weapon systems, reliability and maintainability together with more sophisticated on board check out and monitoring systems for the avionics systems will gain in importance. This will also hold true for more automated test equipment on ground.
- Budget reductions are already under way and may become substantial in the next years. This will affect the affordability of advanced avionics systems if no measures are taken to reduce the costs of development and production. More emphasis will be given to life cycle costs and in especially to the operating costs since they make up the major portion of the life cycle costs. These factors promote the reusability of designs, productivity improvements in the area of software development, common developments with longer production runs, the use of commercial parts and equipments wherever possible and again maintainability and reliability.
- The German Air Force has taken over the responsibility for the former East Germany on a national basis. Taking the reduction of the armed forces into account fewer forces will be available to cover larger areas of interest.

  Air defense fighters will be more important since surface-to-air missiles might not be able to cope with the new situation. Since the number of combat crews might be reduced due to lowered states of readiness and since smaller forces lead to heavier reliance on reserves, encreased reconnaissance and intelligence capabilities seem to be necessary.

Besides these most obvious changes there are additional factors to be considered. As new threat scenarios emerge, more flexibility, mobility and the capability to use the already existing weapon systems to the maximum extent possible become more significant.

Upgrade programs of existing weapon platforms can provide cost effective solutions in this regard. The primary targets for improvements taking into account the latest advancements in the avionics field are the man-machine interface (Cockpit), the mission computers in order to obtain more throughput and new capabilities like threat management, advanced mission planning and higher degrees of automation of many functions as well as the capability to perform various complex missions under adverse ECM and weather conditions. Higher degrees of automation and improvements of the representation of the information to the crew to provide higher levels of situation awareness are also necessary to cope with reduced training time and space.

These trends are augmented by the growing integration of the avionics systems into larger

command, control and communication networks.
Therefore crew displays will have to contain information rather than data, adding graphics, colour and other visible and audible cues in order to provide a precise, rapid response with the lowest false alarm rate.

In order to be cost effective new approaches are sought in Europe towards common development programs. In the course of the creation of a single common market 1993 the defense industry will probably be seen in less national terms. New alliances between aerospace firms (e.g. DASA in Germany, Airitalia and Selenia in Italy) form the basis for future European ventures. There will be no "Fortress Europe" but stronger European competitors as well as perspectives towards an "European Aerospace Company" in the future.

There is also a growing tendency towards common European research programs aiming at more effective use of government funds for research and development.
An example is the Independent European Programme Group (IEPG), founded in in 1976 to provide a European forum independant of NATO for discussion of defence equipment programs, research and technology and the harmonization of requirements. MBB's participation in these programs will be discussed later in this lecture.

3. Avionics Systems Software Development

In the last few years MBB has been awarded major system update and development contracts for military aircraft:

- F-4F
  Improved Combat Efficiency Program:
  This Program basically contains the integration of a new fire control system (AN/APG 65 radar, new mission computer as well as new air data computer and inertial navigation systems) and the AMRAAM missile into the F-4F flown by the German Air Force
- The integration of the HARM missile into the Interdiction Strike (IDS) Tornado
- The development of the Electronic Combat and Reconnaissance (ECR) Tornado variant for tactical reconnaissance, surveillance, coordinated recce/attack operations as well as electronic combat including suppression of enemy air defences and counter C^3.

  Key elements for these missions are new, advanced infrared imaging and emitter locator systems and appropriate mission software offering a variety of mission related functions and modes.

These update / modification programs and MBB's participation in the European Fighter Aircraft (EFA) program have clearly shown that from the point of view of an aircraft company avionics system integration basically means avionics system software development and integration.

Mission related software is no longer just one part of the system - it is the system. System software puts together the various subsystems and equipments developed by independent subcontractors and provides essential, increasingly automated functions as navigation, fire control and situation assessment.

Early software quality problems lead to the conclusion that the time frames to complete a new software load within acceptable quality brackets have been grossly underestimated. It is interesting to note however, that the amount of time needed for coding and testing could be predicted fairly accurately, whereas the time needed to establish firm, unambiguous software requirements and to remove the remaining errors had not been taken into account appropriately. The main reasons were:

- the lack of a consistent methodology for system and system software development that is able to cope with larger development and/or update programs and to take the necessary error correction cycles into account
- very tight schedules and the associated tendency to leave the necessary requirement refinements for the following phases
- unsufficient standardization with regard to software languages, software development environments and processor architectures
- the difficulty to cope with software requirements that are ever changing due to inadequately defined, changing or misinterpreted user requirements and the fact that software requirements also need maturity times in order to provide the required levels of consistency, completeness and understandability for software development teams more distant from the system context
- the fact that there are cases where the software requirements can't be implemented in the proposed form due to hardware or system constraints.

The current tendencies to place fixed price contracts upon software development and to reduce the time frames from software requirements specification to software delivery represent additional new challenges. Fixed price contracts contain the risk to deliver software products with marginal performance and quality and therefore preprogrammed conflicts with the final user. In order to avoid these risks, system and software development concepts with built-in quality considerations are sought. The first step towards this goal is the introduction of formal rules and structures comparable to other engineering disciplines. Provided that the basic processes leading to software requirement specifications and the software itself are completely understood, appropriate tools aiming at the automation of the software requirements specification task can be very helpful.

3.1 System Development

MBB took several measures to improve the situation with regard to software quality and delivery schedules. First we introduced a more rigid methodology of designing complete aircraft systems. It had to be applicable for different programs without major changes, it had to support all phases of system development and it had to assure that the interfaces between system engineering groups and software development groups were well defined. The methodology had to allow for iterations in specific phases, for a certain amount of requirement changes during design and for the fixing of software bugs within defined update cycles, nevertheless assuring proper completion of each phase.

The methodology adapted is closely related to DOD Std. 2167 but has been amended by equipment development and some other phases to cover the complete avionics system development process.

For the purpose of this lecture it seems sufficient to discuss the main features of this development methodology on the basis of the generic, underlying development model depicted in Fig. 1. There are three distinct phases starting from the operational needs of the customer and leading to the final avionics system or system update: System definition, system development and system testing. Each phase is subdivided in different steps concluded with defined development results and subject to various reviews and audits. It is important to note that all planning for new projects is based upon this development model. The specific project plans then allow for predefined, cyclic iterations in order to remove residual errors.

The system definition phase leads to equipment, software and system requirement specifications and is the foundation of the full scale development process afterwards. Since software needs long lead times it is important to consider the impacts of new mission related functions on mission software very early in the design process. Currently mission software resides in distributed computers; therefore the development model provides for a system software specification describing the functionality of the various mission computers as a whole. User requirements should be as explicitly as possible, i.e. in terms of clearly stated mission objectives. The design process however should allow for some requirements creep and flexibility by the basic architectural concept and hardware and software partitioning.
This also refers to bus loading and computer sizing; the design should have future changes in mind rather than absolute efficiency.

Avionics system testing comprises software, equipment and system/on aircraft testing and is very expensive in terms of time, people and facilities involved. In order to streamline this process and to optimize the use of the available facilities a specific approach to system software testing has been devised. There are four separate test stages: Stage A testing investigates autonomous software functions or operational flight programs testing the complete software product (CSCI) residing in one individual computer and is concentrated on showing that the implemented software satisfies its specified functional and performance requirements.

Stage A testing also refers to hardware tests where the hardware / software functions of single equipments are demonstrated.

Stage B or partial integration testing is related to tests that will be performed using all computers, all software and all interconnections of the computing system to assure that not only single computer programs but also the system software and the cooperative functions of the system as a whole will perform as specified.

Stage C or system integration testing covers hardware / software integration, subsystem and system testing and leads to a flight test release of the whole system. Finally flight or Stage D testing is performed in order to validate the system performance against the system specification in the real environment.

This testing philosophy offers a high degree of visibility to the final user and allows for quick turn around times between software error detection and correction. Most errors are found during early test phases where the costs for testing and recoding are relatively low. Currently only about 5% of all confirmed errors are based upon flight test results.

Since user expectations are high, but requirements quite often not clearly stated, there is a preprogrammed conflict situation at the end of the development process where early visibility and operational evaluation can be very helpful. This especially holds true under the growing number of fixed price contracts.

Within smaller projects involving smaller engineering groups and therefore less communication overhead deviations from the "waterfall" model (1) underlying DOD STD 2167 have been tried. One example is evolutionary development (2), i.e. a sequence of development

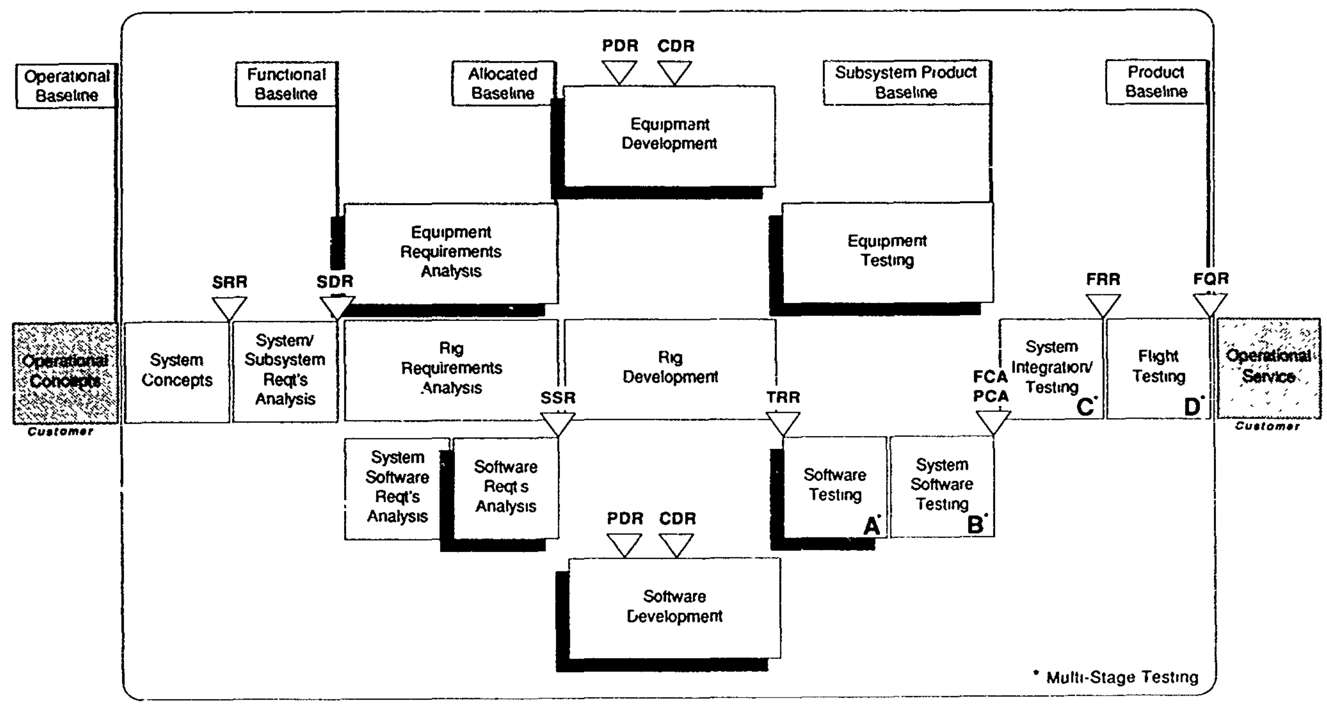


Fig. 1 System Development Model

cycles. During each phase refinements of requirements and software are taking place with the final user actively involved.
This approach assumes, that requirements can't be completely defined at the beginning of a project and that they change during the rest of system development due to a growing understanding of the real needs of the user.

The research and development project chosen in order to demonstrate this approach has been considered to be very successful. It has been developed within budget and within the time frame scheduled and the required functions met the user requirements.

This project indicates that a single software requirements phase leading to firm requirements in one step is rather unrealistic. Software requirements cycles supported by the prototyping approaches to be described below seem to offer greater advantages.

3.2 Tools and Standards

Rigorous configuration control and tool support were other measures taken towards a disciplined approach to software development and in order to improve productivity. Fig. 2 gives an overview in this regard. Tools can help to avoid that bugs are getting in the software; if they do get in, to find them as soon as possible and finally to make maintenance easier. Since configuration control and the application of software development tools are current practice today and not the main objective of this lecture the focus in the following is on experiences made and recommendations for the future.

MBB as well as other leading aircraft manufacturers in Europe are heavily involved in international programs like Tornado or EFA. Part of the work is carried out in international, centralized teams; the other part is subdivided into work packages for the participating companies. In order that this workshare is successful, an international coordination body has to be established and the interfaces have to be clearly defined. For the transition from software requirements to software design a centralized international engineering team has to collect all software requirements to harmonize them and to define the baseline for further work. This also applies for the selection of appropriate tools and development environments. It is this centralized team where the main cost drivers are determined and influenced.
Only after careful evaluation and harmonization of the requirements of the participating nations each software development team for each computer should be allowed to start software design. Any change of the baseline has to be carefully controlled by the centralized team and incorporated by the software development team after authorization only.

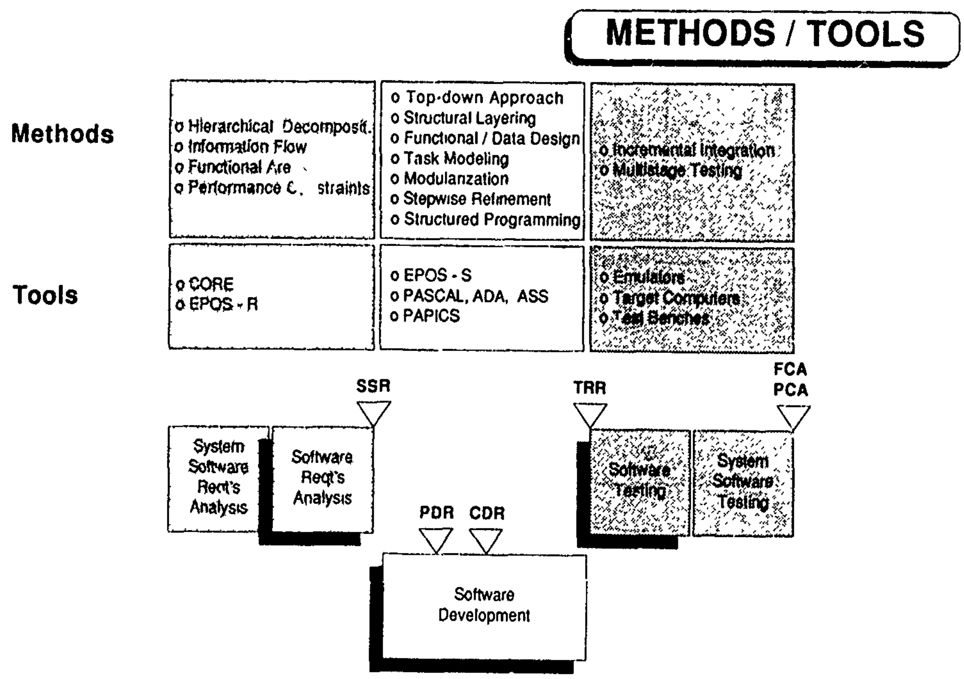


Fig. 2 Software Development Methods and Tools

With regard to tools and their underlying methodologies in international programs it is essential to introduce the same methodology, the same understanding of it and the same tools at all sites involved to avoid costly misunderstandings and duplications. Defining software requirement specifications at different sites asks for an efficient distributed data base. Due to security problems a direct link between the host computers at the different sites has not been realized.
Instead local data bases at different sites are integrated from time to time by a central team to form the central master data base. The latter is then distributed to all parties involved and forms the basis for the next development step.

Current software development methodologies and tools tend to postpone real time aspects to the detailed design phase. This might be appropriate for business computing, but for avionics applications this proved to cause problems. There are cases where the software design had to be radically changed because of too extensive hierarchical decomposition and the resulting execution time overhead. To overcome this difficulty current practice calls for extrapolating this aspect from known systems during the early development phases. Prototyping, to be covered in the next section, can also be very helpful in this regard.

Another difficulty when using state of the art software development tools is that they support the documentation of the lowest levels in great detail but usually fail to produce an easy understandable, complete summary document. One of the reasons is that the tools usually store information in an object oriented way, i.e. objects being functions stored according to their place in the overall functional hierarchy. Combining the description of each of these functions into one document does not necessarily - because of the sheer size - lead to a readable document facilitating the dialoge between system and software engineering and avoiding costly misunderstandings. Documents of this kind are also of limited use for design reviews.

In order to improve productivity and to reduce costs standards with regard to high order languages, processor architectures and development environments are already in place or emerging. Within the EFA program, ADA and STANAG 3910 / STANAG 3838 are adopted. The data bus standard STANAG 3910 provides for the higher data rate requirements of the avionics systems currently under development (Fig.3). The embedded computing systems of EFA are based upon the 68000 processor family indicating a trend to incorporate commercial parts or equipment into military avionics systems and to standardize processor families rather than instruction set architectures (e.g. MIL STD 1750).

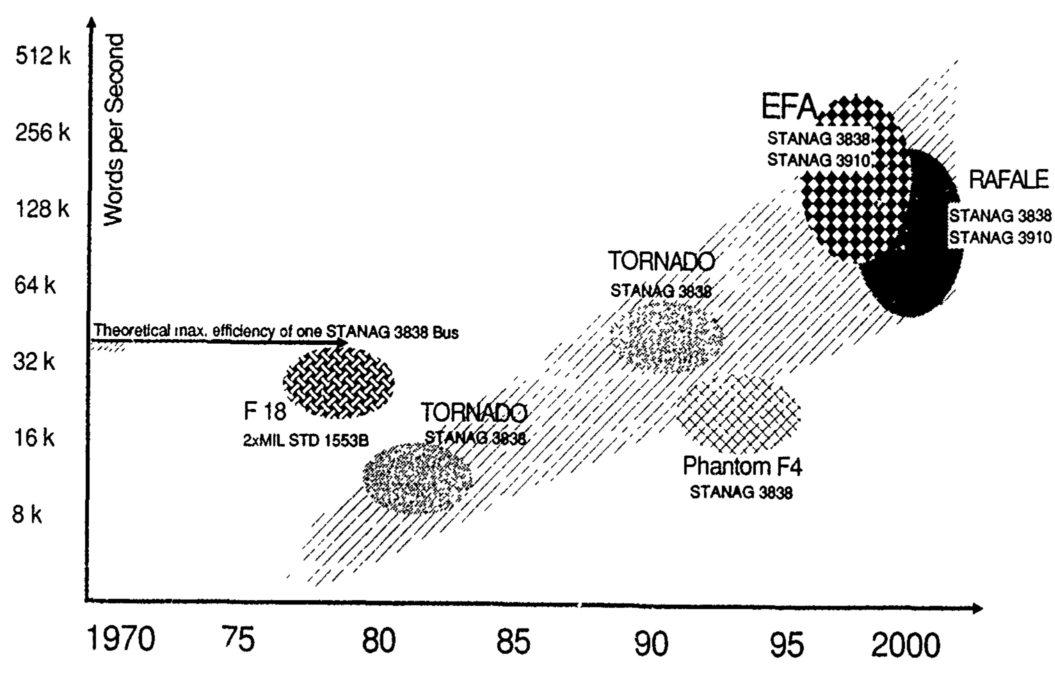


Fig. 3 Evolution of Data Transfer Rates

This trend will grow in the future when specialized military developments or standards are prohibitive duc to the high costs associated with the low production volumes and when commercial alternatives exist. It is also important to note whatever standards are chosen, they must allow for technological obsolescence and changes of the avionic system throughout the useful service life that is - also out of cost reasons - ever increasing. This especially holds true for the system architecture and the embedded processing capabilities.

3.3 Prototyping

The experiences with the programs mentioned have shown, that avionics systems can no longer dealt with in terms of size, weight, cooling power etc. It is also not sufficient to discuss bandwidths, detection ranges and other isolated performance criteria. The system definition process leading to equipment, software and system requirements must include an in depth analysis of the complex and interrelated real time effects of integrated avionics systems very early in the design phase with as much hardware in the loop as possible. Furthermore since user requirements are often not clearly stated cr misunderstood an effective means has been sought to communicate effectively between users, system and software engineers in order to derive well defined requirements.

MBB therefore installed a "System Prototyping Rig" (SPR) that fulfills the same purpose as wind tunnels and test stands for the airframe and engine development.
The main of the SPR objectives are:

- Empirical investigations of new system architectures and their complex real time interaction phenomena
- Experimental feasibility studies including rapid prototyping of software
- Definition of display formats and contents together with air crews
- Investigation of new equipments in a realistic avionics system environment
- Definition and evaluation of critical real time algorithms e.g. for sensor fusion and threat management
- Investigation of data transfer processes between various simulated or real equipments.

The SPR consists of a number of graphic workstations, microcomputers, real aircraft computers and equipments as well as displays and a fully operable cockpit. The different pieces of hardware can be connected in a very flexible fashion via a connection matrix and via different busses to emulate any avionics system configuration required. The software installed offers aircraft models, several sensor simulations, powerful graphics for the cockpit displays, a software development environment for all computers and a powerful test environment. Fig.4 gives an overview of the SPR whereas Fig.5 depicts a representative prototyping environment.

With regard to cost effectiveness, the SPR allows for critical early design decisions on an empirical data base where errors are most costly to correct. It is also used for the evaluation of software development environments for target computers and of test support software. It represents a "front end investment" of effort to reduce technical risks, to deliver the required quality and to get realistic full scale development schedules and budgets. The early evaluation of system performance is significant under fixed price contracts in order to establish a firm development baseline against which the fulfillment of a development contract can be measured.

3.4 Future Aspects

Software in sensor systems and mission computers will continue to play an ever increasing role within avionics systems. Reasons are the more effective evaluation of sensor signals in order to provide the crew with higher level information rather than data, information fusion and the reduction of reaction times of the weapon system. A very important prerequisite is the timely introduction of advanced embedded computers into already existing military fighter aircraft during their lifetime.

As an example, MBB currently performs studies aiming at the replacement of the main computer of the weapon system Tornado by a form, fit and function compatible central computer which shall be programmed in ADA. The existing main computer is programmed in Assembler und represents with regard to hardware and software the state of the art of the 70's. Due to this fact we are faced with a large amount of complex assembler code to be maintained, high software maintenance costs and not sufficiently structured software requirements.

The new computer with its software rewritten in ADA shall provide sufficient performance for at least 20 years, shall improve productivity, quality as well as the development time frames of the software and shall allow cost efficient

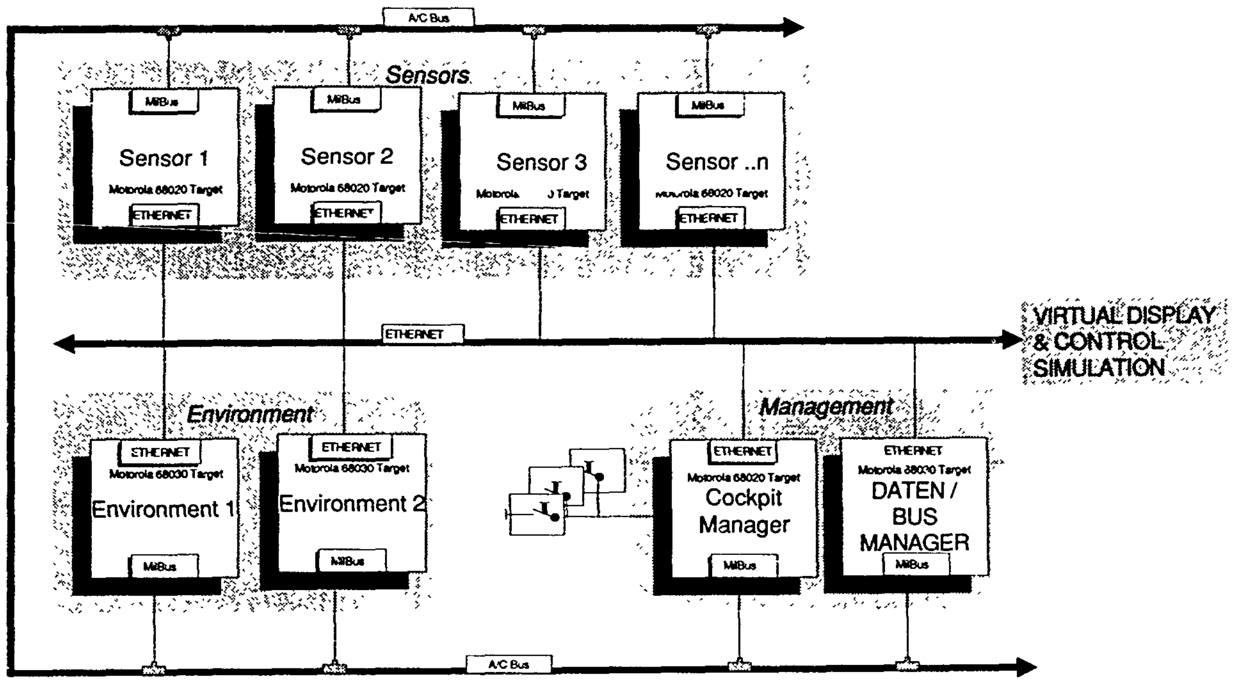


Fig. 4 System Prototyping Rig

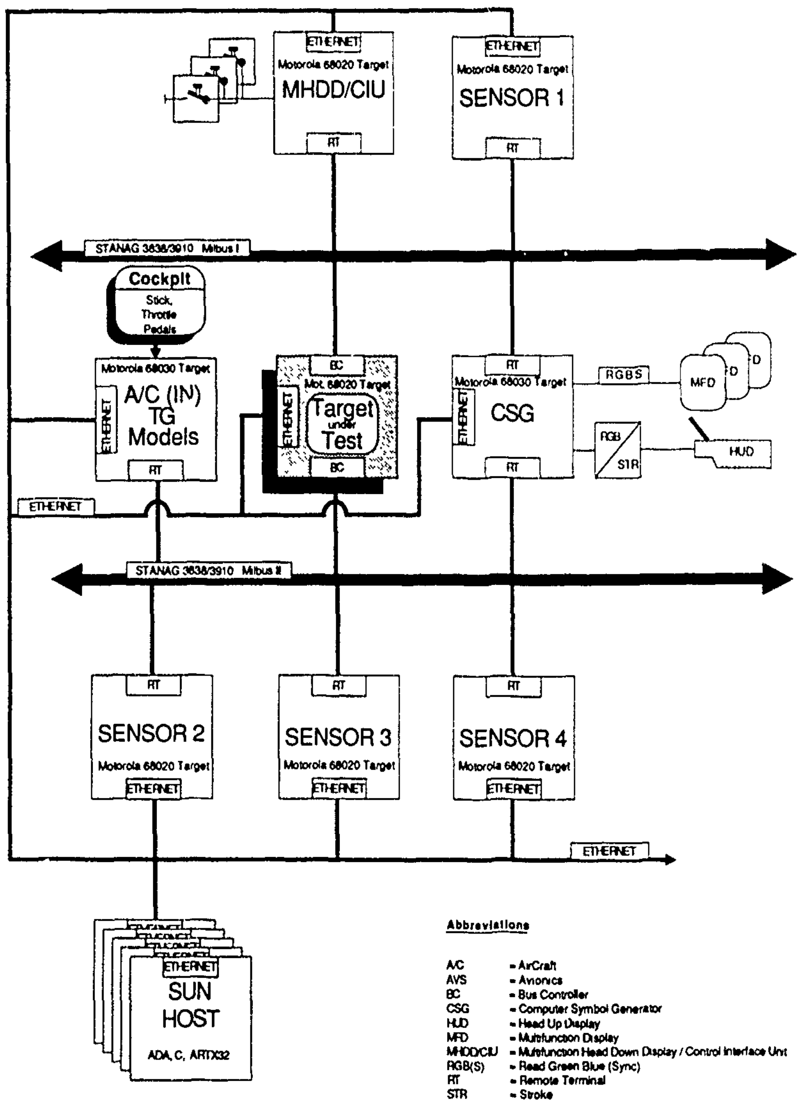


Fig. 5 Representative System Prototyping Architecture

software upgrades and maintenance. This approach shall also provide the necessary growth potential for new functions, e.g. blending of sensor data and threat management in cooperation with the defensive aids subsystem. Finally the transition to ADA might form the basis for reusable software modules. This approach will be supported by the prototyping environment described above and would lead to major development cost benefits.

In the longer run there will be more automated tasks to free the air crew for tactical planning and supervision of the mission. This means that computers will also undertake safety and mission critical functions in order to increase the survivability of the weapon system. Therefore rigid development methodologies, dedicated testing and prototyping will further gain in importance.

4. New Avionic Architectures

Reliability, maintainability and testability are the main drivers for ongoing efforts towards higher integration levels of avionics systems. These efforts, primarily aiming at the reduction of acquisition and life cycle costs, also allow for mission related advancements as increased fault tolerance and reconfiguration in flight.

The design philosophy for these new integrated architectures generally known under the notion "Modular Avionics" is that the system, but not necessarily a single component has to fulfill the mission. Therefore modular avionics concepts are emerging where the resources are shared accross different functional components of both hardware (Line Replaceable Modules) and software (software modules). This architecture supports high degrees of system availability and requires less effort on system maintainability since this approach makes a two level maintenance concept feasible.

A major contribution to the reduction of the acquisition costs is achieved by the use of a limited number of different types of LRM's which in turn leads to larger production lots. In the following emphasis will be given to cost considerations and our activities in this field.

4.1 Modular Avionics

Starting at the mid 80's, several European government agencies have begun with the sponsoring of feasibility studies on modular avionics in order to quantify the user benefits emerging from this new design philosophy.

The results of the German study "Neue Avionikstruktur" have indicated that new aircraft as well as platforms already in service will benefit from the use of modular avionics. With regard to upgrade programs significant increases of the performance / volume ratio seem within reach.

Although the development costs of modular systems might be higher than their conventional counterparts savings during the in service phase will over-compensate the additional initial expenditures.

In 1987 MBB started a company funded R&D project "Modular Avionics" in order to carry out more detailed investigations of these new architectures. Within this project a Life Cycle Cost study has been performed which is based upon a hypothetical upgrade of the german Tornado fleet with new CNI systems.
The objectives of this study were improvements of the existing LCC models and more confidence for assessment.

The cost reductions indicated in these studies are based upon the reduction of parts in new systems, simplified 2 level maintenance due to failure detection to the module level and lower requirements for special to type test equipment.

It should be noted however that these studies do not take into account additional measures to adapt already existing avionics systems and aircraft structures to the new systems.

In order to assess the benefits of modular avionics on a experimental basis a prototype Cockpit Data Video and Voice Management System (CDVVMS) has been devised in cooperation with other companies.

This system (Fig.6), aiming at the management of the audio and video information in the cockpit should allow laboratory demonstrations in 1992.

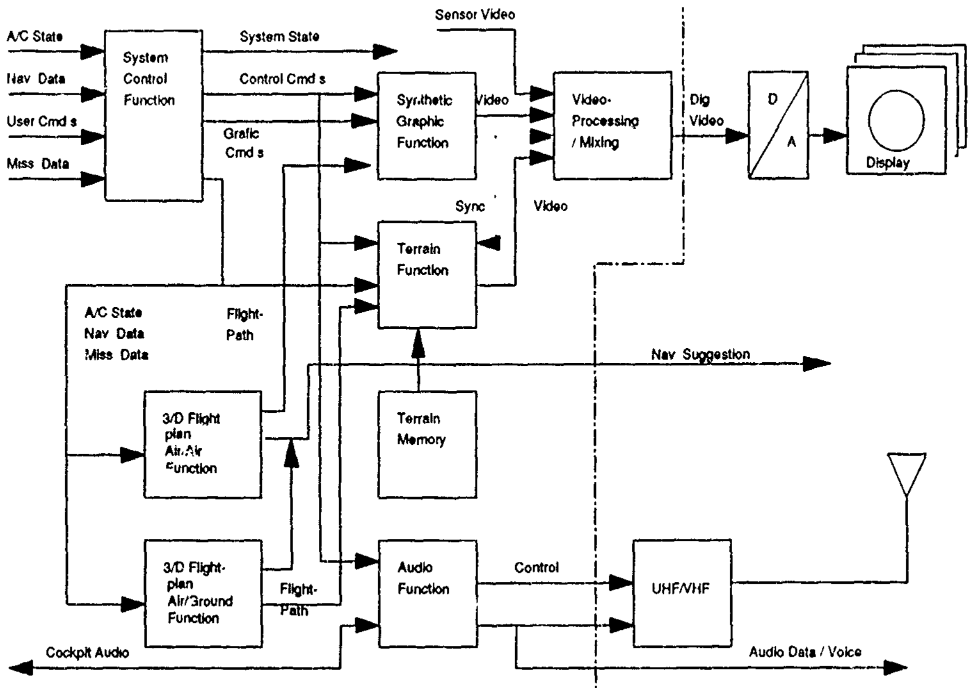


Fig. 6 CDVVMS

4.2 European Initiatives

The Allied Standard Avionics Architecture Council (ASAAC) was borne in 1988 as an initiative of the four Air Senior National Representatives of the US, France, United Kingdom and Germany. This government initiative is mainly directed towards the harmonization of requirements and the generation of standards for the definition and development of modular avionics.

National and joint working goups have been set up in order to develop the appropriate standards until mid 1993.

Beginning late 1993 the validation of these standards shall be performed by means of a common demonstrator. This activity will be carried out as a joint program.

The IEPG also launched an initiative in order to improve the competitiveness of the European defense industry. The European Cooperation for the Longterm in Defense (EUCLID) is aimed at a broad range of research in new technologies and therefore divided in Common European Priority Areas (CEPA's).

CEPA 4 deals with modular avionics and adresses by linked Research and Technology Projects (RTP's) the Europe wide development of emerging technologies for modular avionics.

ASAAC and EUCLID-CEPA 4 are complementary efforts.
While ASAAC will generate and validate standards with a specific demonstration subsystem CEPA 4 will develop and validate technologies for affordable integrated avionics systems in an European environment and shall form the basis for the convergence of the European R&D efforts.

5. Possibilities for future upgrade programs

In the past avionics system development and acquisition have been driven - at least in Europe - by the development of new major weapon systems. With regard to the new strategic situation in Europe, possible new threats, the short useful life of microelectronic technology, technological advancements and the increasingly mission critical role of avionics systems, new development perspectives targeted towards capability and functionality enhancements of already existing platforms are on the horizon. These perspectives must focus on the specific needs of the weapon systems, on cost effectiveness and on minimum out-of-service times, since these systems are already in use.

Reduced tensions in central Europe allow for longer maturity times of new avionics systems. New technologies will be integrated if this process is concluded. New platforms will be rarer, due to the high acquisition costs of new weapon systems their useful in service life will be expanded as much as possible. In order to keep these systems up to date and to adapt to new technologies, preplanned product improvement programs for new systems to be introduced should already be considered in the development phase i. e. system design must allow for a cost effective, long term sequence of upgrades. Design for growth, the use of advanced simulations and extensive war gaming will increasingly be employed to determine the update needs for the years to come.

Within those upgrade programs cost effectiveness can be sought in various ways. The most obvious approach consists of the integration of already existing equipment or subsystems developed for other projects if appropriate. Common European programs like Tornado have pursued up to now common update programs or modifications in order to keep development and acquisition costs low although the military needs of the three participating countries not always converge. This trend will probably continue since the upcoming treaties will limit the number of combat aircraft available and cost effectiveness also means large production runs of avionics equipment or modules.

Since "change" is obviously a requirement throughout the life of a system a certain level of research and developoment funding is necessary during the complete life cycle of a weapon system. In the following potential areas for upgrades and improvements in the 1990's will be discussed.

MBB is currently conducting studies with regard to further improvements of survivability, force multiplication and flexibility of the Tornado weapon system. These studies are centered around crew workload reduction, covert operation and further enhancements of the night fighting / bad weather and electronic warfare capabilities. We also consider new emerging NATO wide requirements as the introduction of GPS, MLS and NIS as well as provisions for future - e.g. stand-off-weapons.

Crew workload reduction is aiming at the full exploitation of the built-in flexibility and multimission capability of this combat aircraft. This seems only possible with higher degrees of automation to free the air crew from time consuming tasks and to enable faster reaction times of the system. In order to address properly the workload associated with the various tasks of the crew we employed an expert system called ESAT ("Expertensystem für Aufgabentaxonomie") developed at MBB. The results of these investigations were fed into the cockpit redesign process. We also use the prototyping of displays described above to evaluate human response. One outcome of these investigations is the decision to propose the additional introduction of tactical colour displays in the front as well as in the rear cockpit and to employ a colour terrain following display. If possible these changes together with the necessary updates of the computer symbol generator will contain concepts based upon the Modular Avionics approach.

The main constraints to be resolved with regard to full application of Modular Avionics within upgrade programs are:

- the additional effort for the integration of modular subsystems into the already existing conventional environment with its many special interfaces, adaptors and connectors
- the existing test and maintenance concept
- the mechanical boundary conditions of the aircraft (this refers to the introduction of a standard integration rack)

Crew workload reduction also means the implementation of automatet real time decision support systems and their data base management systems on board of the aircraft. The first step towards this goal consists of a prototype Threat Management System (TMS) realized at MBB in cooperation with Texas Instruments in order to facilitate the dialogue with the user, to derive early performance data and to verify the design and development environment (Fig.7). The main task of the TMS is the blending of the data of various sensors and the enhancement of these data with the contents of stored knowledge bases in order to analyse the threat and to derive tactical decision support information for the crew in dense air defense environments.

The notion "Covert Operation" refers to the introduction of a Terrain Referenced Navigation (TRN) system. MBB presently conducts flight tests of a german prototype TRN called LATAN in order to derive flight test and performance data of such a system. The TRN shall

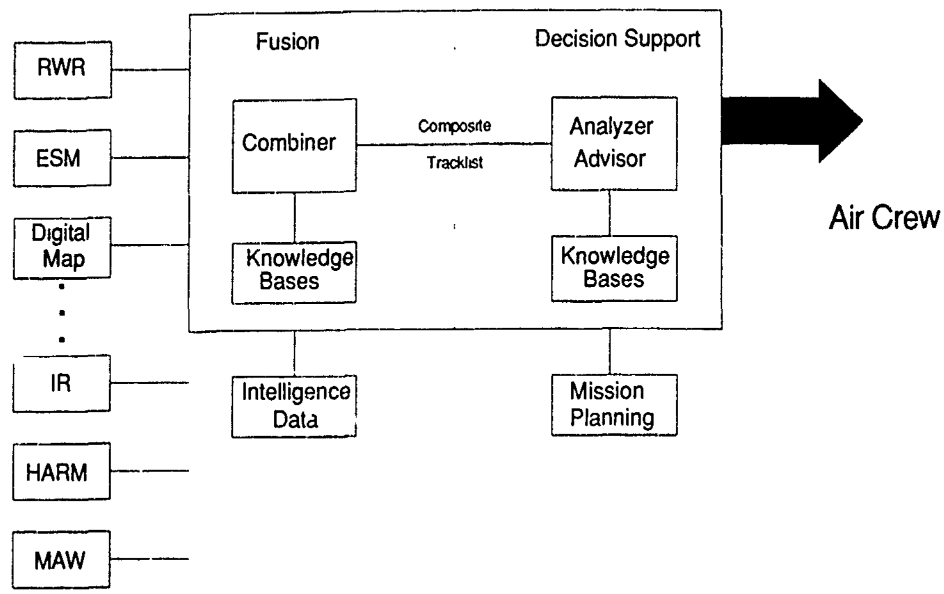


Fig. 7 Threat Management System

allow low level penetration missions where the self-generated vulnerability due to the radiation of the terrain following radar must be avoided. The digital terrain and elevation database of the TRN can be augmented by threat data derived either from intelligence sources or from an on board emitter locator system to support the TMS already described.

Increased situation awareness is also an area under consideration. The advancements in the electro-optics field led to investigations of the integration of a fixed or moveable FLIR sensor combined with a Helmet Mounted Display. Together with corresponding enhancements of the mission software the FLIR sensor data may also be used for fire control during night.

Reconnaissance plays an increasing role in the central Europe of today where fewer forces have to cover larger areas. The RF-4E's of the German Air Force will be taken out of service within the next few years. This will leave the GAF with reduced tactical reconnaissance capabilities if no other measures are taken. Therefore a concept phase is under way aiming at the introduction of reconnaissance pods for a certain number of Tornado aircraft. Out of cost reasons these pods shall be based upon the already existing recce pods of the Tornados flown by the German Navy.

Further cost saving measures could be the use of infrared line scanners developed for other programs, the Infrared Imaging System of the ECR Tornado beeing an example.

Advancements in technology point towards digital image processing, storage and retrieval methods for the infrared images already sent as digital data from the sensor. Digital image processing allows for near real time on board evaluation and manipulation of the sensor data. The images or subsets of them can be transmitted via digital data links to follow on forces or ground stations speeding up even further the near real time dissemination of reconnaissance data. Presently the definition of appropriate system architectures and subsystems is under way at MBB.

6. Summary

Limited budgets, fewer forces and changing threats are the main constraints to be expected during the years to come. Since flexibility, survivability, availability and cost of ownership of modern aeronautical weapons systems increasingly rely upon its avionics systems and the capabilities offered by advanced sensors, processors and system software, cost effective approaches for the development and acquisition of avionics systems are sought.

The examples given in this lecture point towards increased maturity times of new technologies, stronger prototyping efforts in the early design phases and the application of rigid development methodologies including the transition to ADA in the software field in order to keep weapons systems and their inevitable upgrades affordable. Important prerequisites in this regard are stable research and development funds, the exploitation of commercial technologies and the use of already existing equipment wherever possible.

New avionic architectures aiming at higher integration levels will bring further advances with regard to maintainability, reliability and life cycle costs. In order to maximize the benefits resulting from these approaches, joint European initiatives are under way to harmonize the requirements of the participating nations and to validate the necessary standards. Prototyping and modular avionics will support those areas, where upgrade needs in the next years are most obvious, i.e. the cockpit area and the sharing and the expansion of computer resources.

7. References

(1) Boehm, B.W. "Software Engineering" IEEE Trans. Comp. 25 no. 12 (1976)

(2) Floyd, C. "A Systematic Look at Prototyping" in Budde et al.: Approaches to Prototyping

AVIONICS MODERNIZATIONS/UPGRADES IN THE LATE 1990s

RONALD S. VOKITS
Director, Plans
Deputy for Avionics Control
Wright-Patterson Air Force Base, Ohio 45433
U.S.A.

1. SUMMARY

Change is the most prevalent event we can expect during the life of a weapon system. In an avionics system, change is brought about for two primary reasons: correcting problems or adding capability. In many cases it costs less to upgrade older aircraft than develop a new one. How we plan for those upgrades makes the difference.

2. BACKGROUND

Current US military aircraft have a mixed bag of avionics architectures due to the technology available when they were designed. Aircraft from the 60s and early 70s were built using single function avionics subsystems interconnected by point to point wiring. Pilots interpreted displayed information, made assessments and reacted to the stimuli.

Architectures began using multiplex data busses in the 70s. Multiplex busses made it easier to interconnect avionics equipment or black boxes and at the same time, reduced weight of avionics wiring. This resulted in even more information for the pilot to interpret. Distributed architectures and integrated avionics were developed in the 80s. In essence, designers attempted to relieve the pilot and central processor from some of the workload and get raw information to the subsystems needing it without pilot interpretation or intervention.

3. AVIONICS UPGRADES

Avionics upgrades are made for two major reasons: Performance or Supportability. Equipment is not replaced just because it is performs better or is more reliable. Modifications which improve performance usually are a response to a new or perceived new threat. Detection ranges, number of and type of threats, frequency ranges, and target observability are examples of capabilities that change dramatically over the life of a weapon system.

3.1 Capability Improvements

In the past, a new capability often required new displays. Multifunction displays replaced separate instruments because we ran out of cockpit space. Pilot workload became a limiting factor in operating weapons systems originally designed with single function avionics. More computational power was added to help the pilot with situation awareness. And still more computational power is needed now to automate functions.

Few weapons systems were originally design for today's environment in mind either due to technology risk, cost, or unknown threats. Government personnel try to predict growth requirements, but within 5 to 10 years, growth capability is consumed by enhancements needed to meet a new threat. A good example of this is the memory growth experience of one of our fighter aircraft. In 1975, it had 32K of memory. In 1979 it was upgraded to 64K, in 1984 to 128K, and now has 512K.

3.2 Supportability Improvements

Supportability includes the equipment and manpower required to maintain the weapons system. Modifications which improve supportability are usually a response to budget constraints. Low reliability leads to high repair and maintenance costs. Obsolescence is a major problem because repairing old technology becomes costly when parts are no longer available. We resort to restarting component production lines, redesigning equipment to use currently available components, or developing new equipment to keep old weapons systems operational.

3.2.1 Maintenance Philosophy

Currently, aircraft are maintained using a three level maintenance concept - flight line (at aircraft with little test equipment and few tools), intermediate (local base facility), and depot (regional repair facility). Different types of test equipment are used at each level. Reducing the number of maintenance levels, amount of test equipment and spare parts will reduce support costs. This can only be done when equipment reliability is reasonably high. With this high reliability, reduction to two levels of maintenance - flight line and depot, or just one level - flight line, would reduce number of people required to maintain avionics systems. In the first instance, avionics must be designed to be repaired at the flight line, typically a remove and replace philosophy. In the second instance, a depot would not be needed, essentially a throw-away philosophy.

In the 70s we started using multiplex busses which reduce wiring weight. Cost reduction was the reason - lower weight reduces fuel consumption, allowed more fuel for longer missions. Additionally, avionics system reliability improved by reducing the number of connections and providing redundant data paths.

However, there was no reduction in test equipment or manpower.

3.2.2 Availability Improvements

Availability is also a factor. The newer something is, the less likely it is to fail. If aircraft don't break as often, they will be ready when needed, fewer spares will be required and fewer maintainers need be trained and supported.

3.3 Technology's Contribution

In many cases, original avionics have been replaced with more capable, more reliable, lighter, and less expensive avionics subsystems. Technology breakthrough has provided these improvements. New technology has fewer components and requires less manual labor to build. It has proven to be more reliable, thus requires less maintenance. Much has happened over the last 20 years. Reliability is still improving and costs are coming down. Thanks to use of newer technology, computer aided design and computer aided manufacturing.

3.3.1 Diagnostics Improvements

1970s generation of avionics utilized built-in-test (BIT) features designed to identify avionics failures within a line replaceable unit (LRU) and typically signaled only which LRU had failed. The additional circuitry required for BIT increased complexity and reduced reliabilty. Many BIT systems functioned so poorly that only a group of LRUs could be identified, requiring that all related LRUs be removed and tested individually at the local base facility. Aircraft electrical interfaces were not typically part of the avionics LRU built-in-test equipment and had to be tested separately.

New integrated circuits are designed with built-in diagnostics, i.e., the ability to test themselves. Large complex bulky unreliable and expensive automatic test equipment can be replaced with suitcase testers or completely eliminated depending on the level of diagnostics designed into components and systems. This single technological breakthrough is the reason two level maintenance philosophies are now possible. Elimination of need for the avionics intermediate level repair shop (AIS) is a goal of new aircraft avionics systems programs.

3.3.2 Software Improvements

In the past, avionics improvements were accomplished using hardware redesign, an expensive lengthy process which seldom kept pace with changing threats. Equipment complexity further added to the redesign problem. Modern software driven digital technology promises quicker upgrades through software changes. Hardware changes, in most cases, are not required. Modern software engineering environments will be used to correct software deficiencies, develop operational enhancements, and test interfaces. Yet, complex systems will still require thorough and time consuming validation to ensure proper operation in all flight conditions.

3.3.3 Packaging Improvements

Older avionics subsystems are packaged as Line Replaceable Units (LRUs). Most are convection or forced-air cooled. Newer technology avionics will be packaged as Line Replaceable Modules (LRMs) and may be convection, forced-air or liquid cooled. As a comparison, a single (6 inch x 5.8 inch x 0.6 inch) LRM may have capability equivalent to or greater than an (8 inch x 20 inch x 8 inch) LRU.
LRMs will be needed to implement the two-level or one-level maintenance philosophy. LRUs protected electronic components from severe flight line environments in the past. LRMs must provide the same and likely more protection. These almost pocketsized electronic gadgets are likely to be roughly handled, dropped, dunked, and exposed to electostatic discharge, whereas LRUs were usually treated as sensitive electronics boxes.

3.4 Minor Change vs Major Change

How much of a change is economical? An item manager must satisfy his user within a restricted budget and typically on a problem by problem basis. Usually only high priority or safety-of-flight changes are made.

The addition of a new "dumb" bomb might have no impact on aircraft hardware or release mechanisms. As a minimum, new aerodynamic parameters or release computations in operational flight software might be required in the stores management system.

Sometimes modifications impact peripheral equipment. Addition of a guided weapon, smart weapon or new sensor might impact the connector, require additional wiring and/or fiber optic cable, require new control algorithms in operational software, and require modification of other avionics, for example, to provide navigation and air data to the weapon. It is even possible that newer weapons could even impact flight control software. Impacts on aircraft power and cooling capabilities must closely be controlled.

3.4.1 Technology Mix

Old generation avionics are removed from an aircraft and replaced with new components having 10 times the reliability, and weighing less than half the original avionics.

How two radically different technologies can be mixed is one of the big questions.

Newer generation avionics operate at lower supply voltages and are more sensitive to electromagnetic interference. Digital signals within new electronics could cause interference with older generation receivers. Better power filtration may be required when new equipment is used on older aircraft.

Older aircraft often have inadequate cooling for avionics systems. Although a problem to overcome, new equipment operates at lower power levels and may reduce cooling load on other avionics subsystems.

Where does modular avionics fit into modifications of older aircraft?

Most avionics is designed to fit into available space. If modular avionics packaging technology were to be used, remaining older generation avionics may have to be moved to permit installation of a rack for the modules. Long term planning must be done to allow space for other upgrade without impacting completed modificaitons.

How does modular avionics systems architecture (MASA) fit into a force structure that might be made of up all type of aircraft, i.e., fighters, bombers, tankers, cargo aircraft, rescue aircraft and command and control aircraft all belonging to the same deployable unit?

A force structure made up of many types of aircraft today would require a set of support equipment for each aircraft type due to the use of different avionics (and other equipment) in each aircraft. Deploying such a force would be a large effort. If common or standard equipment were used across many aircraft, only one set of test equipment (i.e. the common denominators) would be required.

Is there not some point where it makes sense that portions of the avionics subsystems become interchangeable?

Form fit, function, and interface F^3I standards were seen as the appropriate level of standardization in the 70s and 80s. In a sense, MASA could also be thought of as an F^3I approach to standardization. The MASA and JIAWG concepts require that like modules (built to the same functional specification by different vendors) be validated or certified as being interchangeable. Whether F^3I can be accomplished or not must still be demonstrated - the back up approach is build-to-print standardization. Upgrades of a particular avionics subsystem or function across many aircraft are potential candidates for common equipment or components which are interchangeable.

Upgrades of related avionics functions on a single aircraft, such as communication or processing, are candidates for common equipment or interchangeable components when 3 or more subsystems are replaced by a modular system. Studies have shown that savings begin to accrue when the modular components overhead becomes insignificant (typically 3 or more subsystems). A characteristic of modular avionics is the ability to utilize common or interchangeable modules.

Consideration must be given to related changes in space, cooling and other interface modifications needed to allow installation of a modular system. Upgrades using modular avionics do not reduce support equipment requirements for remaining unchanged avionics, thus changing all communication or processing provides a cultural change to the support environment.

3.4.2 Standards

Years ago, the USAF attempted to create form fit functional standards to allow items like an inertial navigation system to be used across many aircraft. Differences in avionics suites, interfaces and performance requirements limited the success of that endeavor. Current efforts within the Joint Integrated Avionics Working Group (JIAWG) may evolve an avionics suite that can be applied to multiple aircraft. In a sense, this work is providing a means to upgrade older aircraft using current technology. From the Advanced Tactical Fighter (ATF) and JIAWG, there will be a baseline set of common avionics modules, which can be used as building blocks to upgrade or replace subsystems in older aircraft. When not adequate, other models will be developed. Modules designed for multiple applications (i.e. standard modules) will eventually be added to the "module super market".

3.5 Life Cycle

Originally, aircraft are design for a 20 year life cycle, but many are already beyond that. The B-52 was designed in the early 50s. The F-111s were designed in the late 60s. KC-135s are a derivative of the Boeing 707 which was designed in the late 50s. It is possible the KC-135 aircraft will be extended to 2045. Due to high cost of new aircraft, there is strong motivation to upgrade older aircraft. Currently major retrofits are being planned for KC-135, C-130, F-16 and F-15 aircraft.

The following is a list of research and development projects and related modification projects already planned. The list changes daily, based on budgetary and other organizational priorities.

AF Projects[1]

	R&D	Mods.
Offensive Avionics	22	26
Defensive Avionics	26	48
Communication Systems	13	51
Navigation Systems	6	60
Identification Systems	5	1
Controls and Displays	4	16
Flight Control Systems	9	8
Status Monitoring	1	21
Computers and Software	7	7
Tech - Multiple Appl.	15	0
Avionics Modernization	3	10
R&M	5	0
Trainers and Simulators	9	11
Integrated Avionics	9	0
Total Projects	125	259

These projects cover various technology areas and equipment including: paper tape reader replacement, warning receiver improvement, new Identification Friend or Foe (IFF) systems, countermeasures, self protection systems, Reliability and Maintainability (R&M) improvements, Electro-Optical (EO) systems, Laser, Directed energy weapons, Side looking airborne radar sensors, other radar component improvements, modem capability, data transmission and reception, automatic target handoff, anti-jam & secure communication, covert airborne communication, nuclear detection capability, global positioning system (GPS), microwave landing system (MLS), satellite communication, helmet mounted systems, fuel savings systems, airborne data recorders, flight data recorders, crash recorders, autopilots, and target recognition. None of these projects currently employ use of modular avionics.

3.6 Predictions

Looking at our current inventory, it is relatively easy to predict that modifications will be made to replace unsupportable equipment. Reliability is easy to measure. Repair and replacement cost can also be monitored. Technology revolution leaves older technology unsupportable as quickly as 5 years after introduction. Avionics systems that are 10 or more years old are becoming difficult to support.

It is more difficult to predict new threats and required capabilities. Damage tolerant flight control and engine control systems are likely. Flight controls may need to be coupled to navigation information and communication equipment to meet FAA requirements for collision avoidance. Previous studies have identified new requirements for Gunship, a follow on replacement for Wild Weasel based on modifications to F-15s or F-16s; embedded training requirements; special forces aircraft requirements; a close air support aircraft replacement for the A-10; next generation tactical airlift capability; aerial refueling concepts, new tactical air-to-surface weapons systems; farterm F-15, F-16, F-111, and A-10 modernizations, and integrated flight - crew systems - and cockpit systems.

In either case, architectural features are available to allow replacement/ upgrade in an orderly rather than haphazard fashion. The 1553 multiplex bus allowed this in the past. In the future, backplane standards will control physical and electrical interfaces and allow replacement of unsupportable or obsolete modules or addition of new capabilities with little or no impact to the aircraft.

3.6.1 Planning for Periodic Upgrades

Those organizations responsible for identifying development requirements must consolidate need statements from all users and identify similarities. By grouping functional requirements, communication enhancements of all users for instance, a common item might serve all and save development funds as well as serve to eliminate incompatibilities among weapons platforms. Reductions in support equipment development and training follow naturally.

The Avionics Planning Baseline Document contains a list of ongoing and planned modification over a 10 year period for all mission design series aircraft. A sort of this data shows modifications to incorporate the following types of RF systems on most US aircraft: GPS, Have Quick, and MLS. Another sort shows upgrades being made to many radar systems.

Under the right political and economic conditions, a modular avionics systems architecture could be installed to accomodate these and many future changes in a synchronized, coordinated manner.

3.6.2 Example Upgrade - Tanker Transport Common Radar

Current weather radars used in C-130 and others in other aircraft are becoming difficult to support. Many were developed along with the aircraft, eons ago. Some have been improved, but remain dependent on an aging technology base.

Currently, 1900 transport/cargo aircraft[2] have a radar with reliability less than 300 hrs. A life cycle cost comparison of a new radar versus continuing support for older radar systems indicates a break even in 9 years. The following assumptions were used:

Development Costs - $15M
Unit Cost - $150K
1900 Units
Two Level Maintenance Concept
One Depot
72 Hours/Month Operation
One year standard Warranty
MTBF of 750 hrs

A new radar would have digital technology, modular architecture, and standard 1553 and video interfaces. Such a radar could meet all users current requirements. Rather than spend development dollars to upgrade each type of radar in each aircraft, one common new radar could be developed at a savings and be applied to all transports. In the long run, the Air Force will save money by eliminating a radar with poor reliability, save money by consolidating a number of upgrades into one development effort, and by applying this new radar to many aircraft. Upgrades in the 90s will be extremely sensitive to cost factors.

4. References

1. ASD-TR-90-5011, Avionics Planning Baseline

2. Air Force Avionics Roadmap

KEY WORDS USED IN PAPER:

1 level maintenance (on aircraft)
2 level maintenance (on aircraft and depot)
3 level maintenance (on aircraft, intermediate, and depot)
AIS
Architecture
Automatic Test Equipment
Availability
Built-in-test
Common Avionics
Discrete avionics
Diagnostics
Integrated avionics
Integrated diagnostics
LRM
LRU
Maintenance Philosophy
Modular avionics
Reliability
Supportability
SW Correction of Deficiencies (CODs)
SW Engineering Enviornments
Standardization
Technology

Avionics Reliability, Durability and Integrity ....Can They Be Independent of Application?

Harold W. Underwood
Chief Avionics Engineer

Directorate of Avionics Engineering
DCS, Integrated Engineering and Technical Management
HQ Aeronautical Systems Division
Wright-Patterson AFB, OH 45433-6503
USA

Abstract:

The development of avionics through the application of traditional MIL-STD-785, Reliability Program for Systems and Equipment Development and Production, development processes for Avionic Reliability, has proven to have several advantages, disadvantages, and limitations. This process will be contrasted with the Avionics Integrity process which is based upon a knowledge of how the equipment is to be used, the actual environments of the operating equipment and the application of fatigue theory and life laws to design. The process is based upon a detailed understanding of the characteristics of the parts, materials and associated processes used in its manufacturer, and the tailoring of the process controls, inspection and test requirements. The outcome of the process will be avionics with a minimum life that is dependent upon the operational stresses applied. Additionally, a number of conflicts associated with the use of standard environments, standard parts, the use of redundancy, who is responsible for reliability, MIL-SPEC design criteria, Mean Time Between Failure as a metric, and warranties are also addressed.

Introduction:

Avionics standardization has been developing over a period of years to provide a functional capability for the United States and our allies armed forces. Through the development of standard avionic equipments, we have taken advantage of the economics of manufacturing large numbers of equipment to a single design rather than a few equipments from each of several designs to perform a specified function. The net result being a considerable cost savings. These economies also apply to the support of the standard equipments through provisions for spare units, piece parts and the support equipment for one design rather than multiple designs. Although there have been some development problems with standard equipment, the large production quantities and warranties have usually provided sufficient economic incentive for the contractors to correct design and manufacturing process shortcomings, and has generally resulted in acceptable field reliability.

Requirements for many of the standard equipments in the United States inventory have been developed in conjunction with our allies, sometimes to international specifications. Thus standardization has become an integral part of the way we do business.

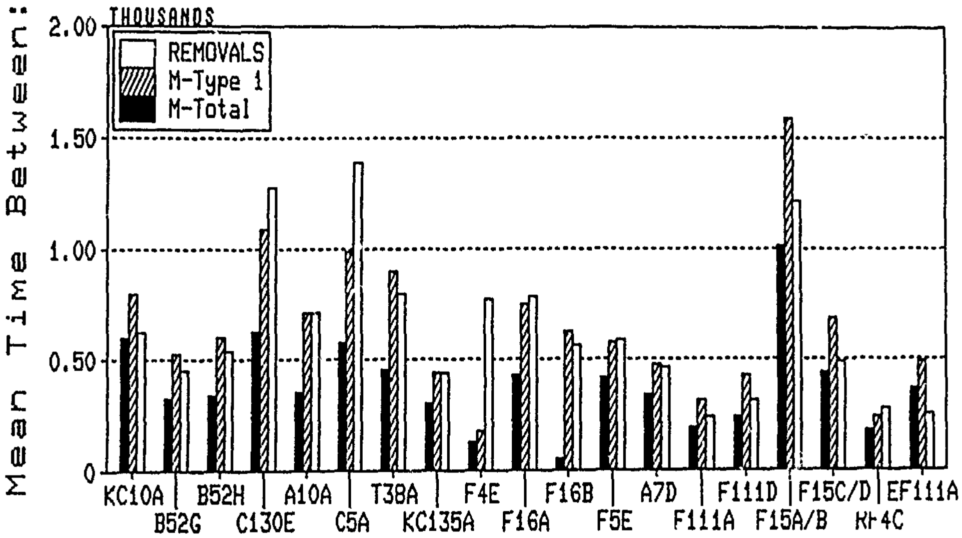
Standard equipments are typically specified based upon their functional performance and reliability at the line replaceable unit or subsystem level. And the performance is based on laboratory conditions rather than the installed performance. This has worked out reasonably well for standard equipments: i.e. inertial navigation systems, Identification Friend or Foe (IFF) systems, the Standard Central Air Data Computer and HF, VHF and UHF radios.

An example of acceptable functional performance would be an inertial navigation system which is essentially the same whether it is installed on a fighter, cargo or commercial aircraft. IFF systems and UHF/VHF radios, on the other hand, are dependent on the performance of the Receiver/Transmitter, the antenna patterns and insertion loss of the antenna cable. The HF radio performance is dependent on the aircraft's antenna coupler/antenna design. The limitations of the HF installation is often accommodated by the judicious selection of frequencies during day to day operations Unfortunately, the reliability or durability of each of these systems may be quite different depending upon how the equipments are used and the working environments. The installation agency has typically been thought to be responsible for making the equipments work in the aircraft, but this has resulted in numerous disputes over who might be ultimately held responsible.

The reliability requirement is stated as a minimum Mean Time Between Failure (MTBF) and may be verified under laboratory conditions to a specified confidence level. The problem arises with the correlation between MTBFs demonstrated in the laboratory and those experienced in the field. The user and maintainer have multiplied the laboratory demonstrated MTBF by a factor to adjust reliability expectations for the particular field conditions. This type of adjustment factor takes into account the logisticians experience with similar equipments, the equipments manufacturer, the individuals tolerance for risk and the budgetary constraints. All these factors are used for maintenance planning, determining how many spare units and piece parts are to be purchased, and the manpower levels necessary to support the equipment. Often the reliability of similar equipment varies widely when installed on different platforms (see Figure 1). The outcome of this process is frustration for the users and maintainers. They have become accustomed to these uncertainties and up to now have been forced to accept them.

Historical Perspective:

There has been an interesting evolution in the way the military and industry addressed reliability. It has involved a series of decisions, each of which were made for good reason with the data available at the time. Unfortunately, these decisions resulted in the formation of a series of disciplines or "ilities" (reliability, maintainability, producibility, etc), a group of engineers in both government and industry to service those ilities. This in turn created a series of tasks and procedures to be accomplished and a set of documents to be prepared The ilities were procedure driven (often based on overly simplistic



ARN-118 Maintenance Experience
Figure 1

assumptions), requiring an inordinate amount of data, and resulting in an inconsistent product.

Early on, aircraft had three basic systems which were mechanical in nature: the aircraft structure, the engine and the flight controls. Preventative maintenance was used to preclude the failure of this critical equipment during flight. The aircraft structure was covered with cotton or linen fabric that deteriorated over time, and it had to be replaced. When this occurred, the aircraft was stripped, and the structure rebuilt to maintain safety throughout the life of the replacement cover. The engine was disassembled, inspected and overhauled based upon a recommended time between overhaul. Preventative maintenance was applied for military aircraft and was required by Civil Aeronautics Agency (CAA, the predecessor of todays Federal Aviation Administration) regulations for civil aircraft. Even though the basic design of aircraft evolved (moving from fabric covered structure to all metal monocoque design) the process continued for commercial aircraft until the mid-1950s when they moved toward the phased inspection process. The regulations requiring annual and one-hundred hour inspections still apply for our general aviation fleet.

After World War II, commercial aviation advanced very rapidly. During the late 1940s and early 1950s the airlines observed that some (possibly many) of the required inspections were being done for arbitrary reasons. United Airlines, working in conjunction with the CAA and the aircraft/engine manufacturers, developed a procedure which is known in the military as Reliability Centered Maintenance. This included a logic process and a series of criteria Safety Critical, Mission Critical, Major Economic Impact, and Durability Critical) that are based upon the consequences of failure and can be used to select the appropriate maintenance (preventative, corrective, or opportunistic) procedure for each piece of airborne equipment. This logic process applies to avionics, although not commonly implemented and is defined in MIL-STD-1843, Reliability-centered Maintenance for Aircraft, Engines and Equipment published in February 1985.

The first avionics, airborne radios, were installed in the mid-1930s. At this time, they were "nice to have," but were not essential to the performance of the mission. This attitude continued through World War II and into the early 1950s, when the Air Traffic Control System was established and the operation of aircraft during Instrument Meteorological Conditions became common place. As a result, communication and radio navigation equipment were then considered mission essential. With the introduction of the radar based weapons delivery system on the F-105 aircraft in the mid-1950s, the avionics became Mission Critical. More recently, avionics such as the fly-by-wire system on the F-16, and Terrain Following/Terrain Avoidance systems have become Safety Critical functions. Avionics now constitutes a third of the fly away cost of a modern fighter aircraft and performing numerous mission and safety critical functions.

In the 1940s, Avionics, and their development processes were in their infancy. Often the development process was unique to the manufacturer, and possibly to the individual designer. Some manufacturers characterized the life of their parts under specified conditions, and reported the results in the literature. Some designers did extensive thermal analysis in order to minimize the degradation of their electronics (tube type equipment operated quite hot). Still others did testing to determine the failure rates of their parts.

During the late 1940 and early 1950s, a series of specifications for electronic parts were developed. They addressed performance and test requirements, but not in a consistent fashion. A consensus on the appropriate content and verification procedures to be included in the piece part specifications had not yet developed. In 1952, The Advisory Group on Reliability of Electronic Equipment (AGREE) Committee was formed to establish order. The committee was made up of representatives of the Office of the Assistant Secretary of Defense (Engineering), the Office of the Assistant Secretary of Defense (Supply and Logistics), plus the Army, Navy and Air Force. This committee worked on the problem for five years and ultimately issued the AGREE Report in 1957.

The AGREE Committee report considered the application of life laws, statistical-based reliability predictions and testing techniques along with the application of preventative and corrective maintenance policies to avionics. However, the committee ultimately recommended that life requirements be defined as a Minimum Acceptable Reliability expressed as a MTBF. They also recommended the establishment of requirements for reliability tests using developmental models, pilot production and production model equipments. The report went on to recommend a major overhaul of the electronic parts and components specification and qualification process and supported government interaction in the process. The report identified requirements for the packaging of electronic devices/equipment prior to storage or shipment, mandated the application of corrective maintenance and recommended the implementation a statistically based reliability program.

These decisions responded to the need for a solution that was supportable within the existing technology and could be implemented quickly. Over the past thirty years, since the AGREE Committee completed their work, there have been tremendous advances in the analytical tools and computational power available. In 1957, the primary tool available to the engineer was the slide rule. Main frame computers were just entering service in the universities and were not yet common place in the industry; computer time was still carefully rationed. The common use of a scientific hand held calculator was still fifteen years away. Thus, by necessity, the methods needed to reach a solution had to be rather simple by todays standards.

Over time, the recommendations contained in the AGREE Report evolved into the MIL-STD-785, Reliability Program for Systems and Equipment Development and Production. This document contains a series of tasks, that were thought to ensure that the resulting product would fulfill operational needs. These requirements have been mandated for most DOD procurements since the introduction of MIL-STD-785.

Inherent in the implementation of the MIL-STD-785, the reliability prediction procedure contained in MIL-HDBK-217, Reliability Prediction of Electronic Equipment was mandated (see Appendix A for further discussion of the reliability prediction procedure). With this understanding, the life testing and part characterization efforts that some manufacturers were accomplishing ceased, since it was no longer considered valuable by their military customers.

There has been considerable discomfort with R&M and the way it is applied to our programs, the effort involved, the cost of the effort and the inconsistency of results. However, few of us have taken the time to understand how the R&M program evolved, its implementation, its impacts on the product and the government/industry motivations

Appendix A addresses several of the R&M Program tasks, their background, and the problems with their application to modern avionic systems. This should provide an understanding of the R&M Programs short comings and why it does not consistently yield a product that satisfies our users needs and outlines several reasons a major change in direction is needed.

Avionics/Electronics Integrity Program (AVIP)

Aeronautical Systems Division (ASD), the largest of the US Air Forces acquisition divisions, has implemented a systems engineering process for the development of avionic and electronic equipment. The process is based upon their experience with the Aircraft and Engine Structural Integrity Programs (ASIP and ENSIP) which have proven to be very successful in achieving functional performance and protection safety. These programs are based upon an understanding of the stresses and related stress cycles the aircraft or engine will experience over its operational life. They examine the physics of failure and works towards a design process whose objective is to preclude in-flight failure rather than limiting the failure rate. Both ASIP and ENSIP involved major changes the logic process used during design. ASIP was initiated in response to a series of in flight structural failures which resulted in the loss of the aircraft, and all too often to the loss of life. ENSIP applied the same logic process, tailored for application to aircraft engines.

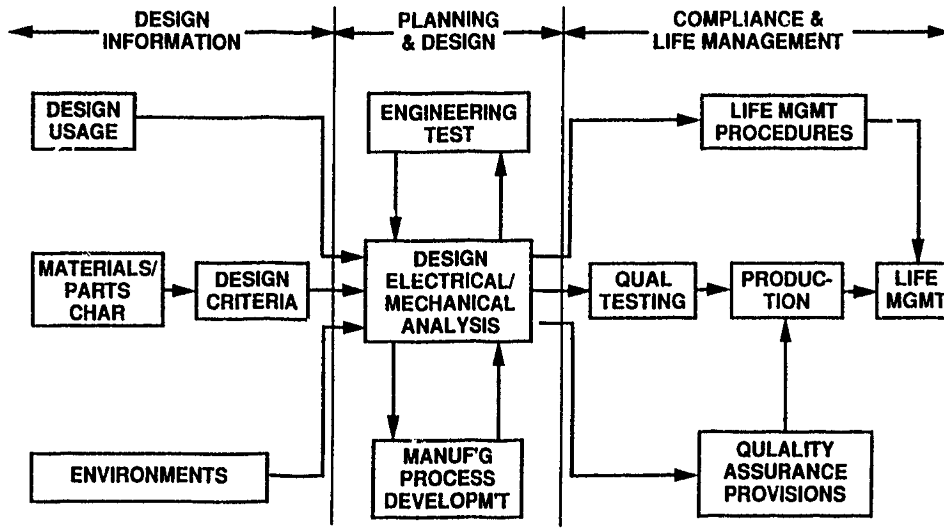
Traditional Reliability and Maintainability (R&M) and AVIP are similar in that their objectives are the same:

To focus attention on the need to improve reliability.

However, there are several significant differences as outlined in Table 1 below:

MIL-STD-785	AVIP
• Activity (Task) Orientation	• Process Driven
• Assumes Failures are Random	• Recognizes Failures are Deterministic Based on Cause and Effect Engineering
• Mandates Corrective Maintenance	• Allows Preventative Maintenance Options - Opportunistic - Corrective
• Functional Performance Protected by Redundancy	• Functional Performance Protected by: - Design - Maintenance Procedures - Redundancy
• MIL-Spec Environments - MIL-Spec Processes	• Installed Environments Freedom to Select Processes that Fulfill Functional and Life Requirements
• Qualification Based upon Statistical Sample	• Qualification Based upon Accelerated Life Test

Table 1



The AVIP Process
Figure 2

The AVIP development process begins with a detailed understanding of how the equipment will be used in operation and the ramifications of the various support decisions. This not only includes the number of operating hours, but such usage factors as the number of turn on/off cycles, mode changes or transmit cycles, etc, that affect the life of the equipment. The process also necessitates an understanding of the environments the equipment will experience as a part of the manufacturing and testing process prior to delivery, during transportation, while installed in the aircraft (both on the ground and in the air) and while being repaired. Environments that are addressed include electromagnetic interference and electric power variations, as well as the usual temperature, altitude, vibration, humidity, sand and dust, etc. This allows the designer to take into account the cumulative effect of the stresses and stress cycles the equipment must endure over it's operational life.

Materials Characterization is a term used to describe the development of a fundamental understanding of the properties of each of the materials and parts that are to be used in the design, their failure mechanisms and the effects of allowable variations (chemical, metallurgy, dimensions, flaws, etc..) in those materials. The process recognizes that failures are largely deterministic in nature Failures occur as a result of the products physical configuration, the stress concentrations, the magnitude and location of the flaws allowed in the product, and the cumulative damage from the stresses and stress reversals that occur over the equipments life.

The fatigue life of these materials is, in large part, determined by the metallurgy and physical dimensions at locations such as solder joints, plated through holes, vias and interconnects within printed wiring boards lead wires, etc[2]. Within the electronic parts, fatigue is also the life limiting failure mechanism of the attachment of the silicon chip to the case[3]. The life of an aluminum conductor internal to the part is determined by the impurities within the aluminum, the grain structure of the aluminum, barrier metals, the cross section of the conductor as well as current and temperature stress[4]. These characteristics are in turn determined by the application, manufacturing process and the dimensional tolerances. Time dependent dielectric breakdown is again controlled by the material properties, physical dimensions and allowable time, temperature and current stress[5]. There are postulated life laws in the literature for each of these failure mechanisms. However, none of these life laws have not been endorsed by the industry as a whole. A great deal of work has been, and continues to be done evolving these models.

During the design process, more emphasis is needed in the application of material characteristics to design. Examples include: coefficients of expansion, fatigue life, arcing and cracking of dielectric materials, strength, etc. These characteristics, and the process controls that are applied during manufacture to protect life, should be used to establish design criteria that will be applied during design. This understanding will warrant greater freedom in the selection of parts, materials and processes; thus allowing relief from many of the government mandated specification requirements such as those contained in MIL-E-5400, MIL-STD-454, etc.

The design team is expected to ensure that fundamental mechanical and thermal analysis are accomplished prior to the release of drawings, when changes can be incorporated with relative ease. This may well be an iterative process, ensuring the design fulfills each of the required design constraints.

The application of fatigue theory to the design may also allow the implementation of a preventative maintenance policy to address many, if not all, of the failure mechanisms that might occur. Many of the basic analytical tools, such as those addressed in Mr. Dave S. Steinberg's books, Cooling Techniques for Electronic Equipment and Vibration Analysis for Electronic Equipment. These tools have been available for almost twenty years, and have been applied by some designers as a normal part of their design practice. They are also frequently applied after the fact when equipment encounters problems with required tests or during operation. These tools should be used to avoid problems, rather than fix problems when the development schedule is in jeopardy and design alternatives are limited.

Mr. Steinberg, in his paper Tools Available for Implementing AVIP (Attachment B) offered an analytical life prediction approach that can be accomplished using a hand held calculator for lead wires and solder joints. New, computer aided design tools are becoming available which will make the analytical effort less time consuming, more user friendly and allow more aggressive designing.

Development of the manufacturing processes, process limits, environmental stress screen/proof tests when appropriate, and inspection/verification techniques are an integral part of the development effort. The effectiveness of the manufacturing process limits, quality controls, life characteristics and the over all suitability of the design will be demonstrated in an durability life test using combined environments, simulating operational use (turn-ons, mode changes, repair cycles, etc.) and applying the proposed maintenance procedures over the life of the equipment. The test may also replace major portions of the traditional engineering qualification test by including excursions to the extreme environmental limits in the test profile.

The remaining environments not addressed by the accelerated life test should be demonstrated by initiating the appropriate portions of a traditional engineering qualification test. Only after satisfactory completion of the verification process, and the demonstration of operational utility, will the equipment be ready for production release.

Since the equipment has been designed using a fatigue theory, and our users are always changing the way they use their equipment, one can then apply the same analytical tools to adjust the life expectations, maintenance intervals, and anticipate the need for modification before an unsupportable situation results. This can be achieved by repeating the key analysis done during design, but with revised design usage and environmental data. This analysis could be incorporated in a life management computer algorithm which would allow the supporting community to keep track of the life expended by the equipments over time, and facilitate the orderly management of the equipment based upon technically sound criteria.

The application of the AVIP in conjunction with a system engineering development process provides the equipment manufacturer much more freedom than has been allowed in the past. This includes the opportunity to establish the dates for major program milestones such as Systems Requirement, Preliminary Design, and Critical Design Review. The manufacturer is also relieved of much of the government mandated specification tree (how to's) and documentation requirements. The output of the process (within the manufacturer's capability to understand the failure processes and the ability to control the key material parameters), will be avionic equipment that has a known minimum life with a given design usage and environments.

The basic requirements for the Avionics Integrity Program are contained in MIL-A-87244 which is a performance specification written in MIL-PRIME format. A MIL-PRIME specification is structured in a way that requires tailoring, and has attached a handbook which guides the user through the tailoring process. Each of the requirements contain a blank that may be filled in by either the procuring activity prior to the release of the solicitation, defined by the offeror as a part of his proposal, or determined as a result of a task (analysis, survey or test) that is to be accomplished as a part of the contracted effort.

The offeror is encouraged to tailor the draft Statement of Work, provided as a part of the solicitation, to include any tasks required to complete the specification, and to include in the Systems Engineering Master Schedule (SEMS) the milestone indicating when the task will be accomplished. The SEMS is an event-driven document where the contractor establishes criteria for the satisfactory completion of each major program milestone. For example, at the Critical Design Review, the contractor might commit to the completion of a fully released drawing package, completion of thermal, vibration, fatigue analysis, the availability of draft test procedures, etc.. Before these milestones can be considered complete, an agreement must be reached between the contractor and their customer.

The procuring activity evaluates the various offeror's proposal, and makes a selection based upon pre-established standards. Thus, the offeror is made an active participant in the requirements definition process, has developed ownership of those requirements, and is expected to successfully implement the process after contract award.

The application of the AVIP design process allows one to move toward avionic designs that will operate for a predictable period of time, number of cycles, or other measurable characteristic with a reasonable probability of success. This makes it possible to move from an on demand (corrective) approach to maintenance to a preventative or opportunistic maintenance concept where appropriate. The decision process should be based on the consequences of ailure: safety, the ability to accomplish the mission and economics. The decision process for airframes and engines is contained in MIL-STD-1843 can be applied to avionics as well.

Thus, the Avionics Integrity Program embodies and effective systems engineering process which, when applied, will result in equipment that fulfills both functional performance and life expectations, and can be effectively managed in the field.

General Discussion of Conflicts:

Any effort to change the way one does business can not occur in a vacuum. AVIP has to be incorporated in a way that allows it to be accommodated within the existing framework of policies, procedures and regulations where possible. Unfortunately, such an approach involves compromises, raises potential conflicts and hurdles that need to be addressed and surmounted. At times, it requires making compromises, incorporating some new concepts while delaying the adoption of others, all the while applying consistent pressure to embrace the total process. Both ASIP and ENSIP experienced a similar birthing process and took over ten years to complete.

Each of the individuals and organizations affected by the change has a different perspective which results in conflicts. It should be recognized that the AVIP process and each of the practicitioners (both organizations and individuals) will under go a series of changes as the implementation matures. It should be recognized that organizational inertia will tend to maintain the status quo no matter how badly the change is needed. However, consistant managerial support and sound engineering will prevail.

As one looks at the change from the acquisition communities perspective, there are several difficult problems that must be addressed. There are those who believe that if the decision makers would issue a written policy, the change would be accomplished with relative ease. Others believe the individuals who are to implement the process have to "buy into" or "take ownership" of the process or the process will fail. The process has to evolve over time, to be tailored with each new application in order to take advantage of unique experiences offered by each new participant.

From a program managers point of view, he wants to know how the process can be implemented with the available resources and time constraints. He also needs to understand that engineering is committed to provide the needed technical support, and he must feel comfortable that the engineers comprehend what is being asked of them. There is a need to know that the product will be accepted by the user, the supporting command, and that the process will be adopted by the industry. Further, he needs to feel comfortable with the way the product will be evaluated during independent and operational testing.

The engineers and logisticians are concerned that process may not be sufficiently mature to warrant its application. They want to feel comfortable with their staffs' skills (or their ability to develop them), and that they are prepared to buy into the concept, their new roles and responsibilities. The logisticians are also concerned that the process uses different metrics, unfamiliar ones, which cannot be used directly in their current Logistics Support Analysis process. They are bothered by the thought of preventative maintenance on avionics which runs counter to thirty plus years of experience.

Procurement is anxious to learn how requirements can be adequately defined in contractual terms, how offerors can be airly evaluated, how the effort can be appropriately priced and that the effort has a definitive conclusion.

The users of standard avionics include the US Air Force (Strategic Air Command, Tactical Air Command, etc.), Army, Coast Guard, Marines, Navy and allies. They need to feel comfortable that the product will fulfil their needs, that they can accommodate the necessary changes in the way they operate and maintain their systems, its effect on their maintenance planning, manpower needs and readiness.

From an industry stand point, the aircraft primes want to understand what they are being asked to do, that their staff has or can develop the skills necessary to do it within the time available, that the necessary information and tools are available and that their suppliers are capable and willing.

From the original equipment manufacturers (OEM) standpoint, they want to feel comfortable that their staff has the skills necessary to accomplish the effort, the time allowed is reasonable, they can accurately cost the effort, the selection process will be fair, the risk acceptable, their suppliers will support and that their participation will not adversely affect future business.

The part vendors are concerned that their participation will necessitate the release of information on their processes, information that proprietary, information that has provided them a competitive edge, and that leakage to their competitors will not occur.

Specific Conflicts:

Standard Environments verses Specific Design Usage, Installed Environments, Storage, etc.

The environmental requirements for standard avionics are established by reference to MIL-E-5400, Electronic Equipment, Aerospace, General Requirements for for Class II equipment and MIL-STD-810, Environmental Test Methods and Engineering Guidelines. MIL-STD-810 defines specific test requirements or vibration, shock, humidity, sand and dust, etc. which have been used for the engineering qualification of the avionics. Earlier versions of MIL-STD-810 contained limits for various environments (i.e. vibration) for different categories of environments such as "uninhabited fighter", "inhabited cargo", etc.

The current release of MIL-STD-810 instructs the user to determine the environments at the installed location for the equipment and use the installed environments during test, but provides default values for the previous categories. Often, these default values are used. This practice has resulted in numerous problems when the equipment is actually integrated into the aircraft. Several progam offices at ASD have encountered instances where the environmental requirements contained in MIL-E-5400 and the default values in MIL-STD-810 have been greatly exceeded, resulting in major reliability problems, long program delays and cost growth.

An example of this type of problem occurred with the LANTIRN (Low Altitude Night Targeting Infra-red Navigation) System. This system was developed using the environmental conditions now identified as default conditions in MIL-STD-810 as the design requirements. When flight testing began, an inordinately large number of failures were encountered on the Navigation Pod. The preponderance of these problems resulted from the failure of solder joints attaching leadless chip carriers to the printed wiring boards due to exposure to vibration and acoustic noise. When the an instrumented pod was installed on the F-16 and flight tested, the actual environments exceeded those called up out in MIL-STD-810 by more than10 db. These problems placed the program in jeopardy of being cancelled. Correcting these problems resulted in a major schedule slippage with an attendant increase in cost. To alleviate this problem, a complete mechanical redesign of the printed wiring boards contained in several line replaceable units was necessary. A highly automated manufacturing process with very close statistical process control was established in order to achieve the needed consistency in the product. With these problems being resolved, the resulting system performed extremely well as demonstrated during the Persian Gulf War.

When equipment is designed based upon the design usage, and the installed environments, as addressed by MIL-A-87244, these problems are avoided. However, this task involves technical, managerial and contractual challenges. Often, a survey of the environment was not accomplished during the flight test of the aircraft or the data can no longer be found. If the data is available, it may no longer be appropriate because the environments may have changed as a result of aircraft modifications. Changes in the avionics suite may result in different heat loads on the cooling system, ambient temperatures in the avionics bays, resonant frequencies of the mounting shelves as the mass of the equipment changes, etc. Thus, one should understand the limitations of available data. However, the data is worth considering.

When standard equipment is bought, it is typically purchased from an avionics supplier rather than an aircraft prime. The aircraft prime may have useful data which is not available in government archives. In this case, the avionics supplier could purchase the data from the aircraft prime as a part of the development effort.

There are also analytical techniques that are used to estimate the environments in a new aircraft before it is ever built. These techniques take into account the rigidity of the aircraft structure, proximity of the equipment to rotating machinery such as the engine, the operating frequencies of the machinery, lever arms about the center of gravity, etc. These analysis techniques could be used for retrofit applications as well. The aircraft prime contractors are well versed in the application of these techniques

Rome Air Development Center has developed a Time-Stress Measuring Device that can be installed at a estimation of the environments. The first generation of these devices are about the size of two packs of king size cigarettes, has a self-contained battery, and can store several weeks of data. These units have been tested on A-7 and A-10 aircraft. With the cooperation of the user, similar units could be installed on operational aircraft and the data collected. This data could then be extrapolated to the limits of the aircraft operating envelope and atmospheric conditions and used for design.

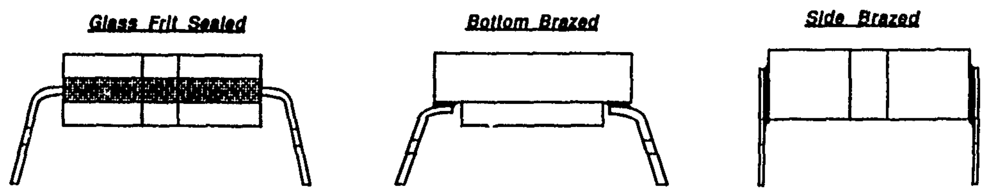
For the Mark XV Combat Identification System, the government recognized that Line Replaceable Units would move from aircraft to aircraft over their life. Using engineering udgement, a series of core aircraft were selected that were thought to be most representative of the total fleet. The environments in these vehicles were then used to develop a composite environmental profile that was to be used in the Mark XV design and verification process. When the equipments are installed on vehicles which were not a part of the core, the modification agency would be required to ensure that the installed environments are no worse than those verified for the core platforms, or modifications accomplished to bring the environments within limits. It is also possible to install the equipment and accept the risk that acceptable life characteristics will not be attained (basically, this is what is done when one uses MIL-E-5400 requirements and MIL-STD-810 default conditions today)

Standard verses Application Specific Parts:

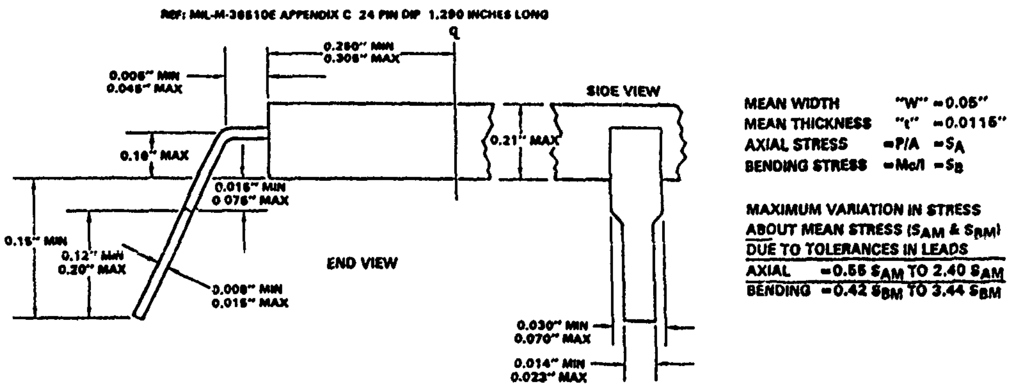
Another source of conflict results from the imposition of the order of precedence of MIL-Specs contained in MIL-STD-454, Standard General Requirements for Electronic Equipment and the MIL-STD-965 Parts Control Program (see Appendix A for further discussion of parts control procedures) These requirements direct the use of standard parts in the design, and manufacturer of avionics. Standard parts are manufactured and tested in accordance with government published general and detail specifications such as MIL-M-35510, General Military Specification for Microcircuits.

These specifications are structured to promote multiple sources for each standard device type. To this end, many fundamental characteristics of the devices allow very wide limits/tolerances on key parameters and some may not be addressed at all. The intent is to permit parts from different vendors, using different materials and manufacturing processes to supply parts under the same standard part number that are supposedly interchangeable. The process of coordinating the detail specification between several suppliers results in a least-common-denominator set of electrical parameters. Allowed variabilities include die attachment materials, bond wire materials, dielectric layer material and dimensions, etc. As an example, the variations allowed in the mechanical configuration of a Dual In-line Package (DIP) microcircuit per MIL-M-38510, includes three different lead frame configurations (see Figure 3), eight different base metal alloys for the leads frame and four different lead plating structures.

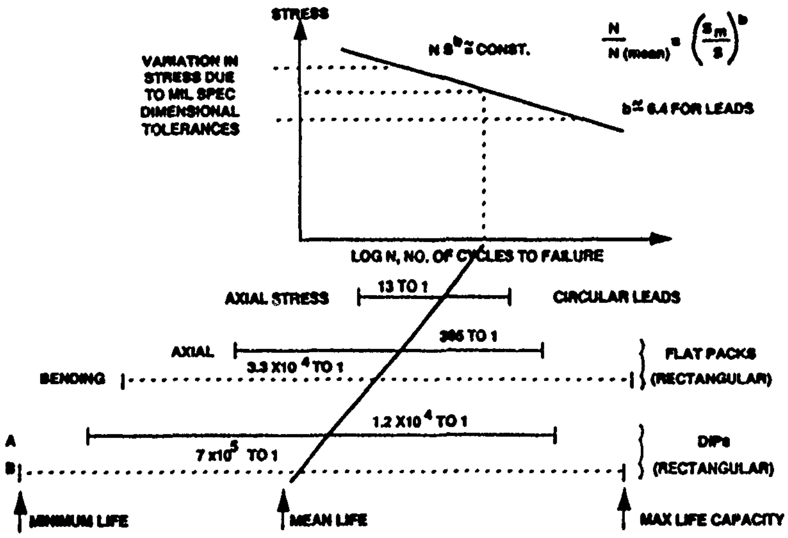
Figure 4 shows the allowable dimensional allowable variations of the lead frame configurations for a DIP.



Allowed Variability Within Mil-M-38510H
Figure 3



Tolerance in DIP Lead Wires
Figure 4



Mil Spec Tolerances Cause Life Variability
Figure 5

Figure 5 depicts the effects of the variability allowed in the lead wire/lead frames of MIL-Spec parts. The calculated variation in the fatigue life resulting from the 10 percent tolerance of a circular lead wire such as those used on a transistors, resistors and capacitors varies by a factor of 13 to 1 The lead frames for integrated circuits contained in both the flat pack and DIPs encounter both bending and twisting motions as the parts are subjected to temperature cycling and vibration. For a flat pack manufactured with the maximum allowable and minimum allowable dimensions, the fatigue life can vary by a factor of 3300 to 1 in bending mode. Similarly, the fatigue for a DIP can vary by a factor of 70, 0 to 1 for the configuration shown in Figure 4. In this case, the allowable variation in fatigue life of these leads exceeds the total number of major thermal cycles that avionic equipments would be expected to experience over its life when installed on a modern fighter aircraft such as the F-16. The situation becomes much worse when the other allowable lead frame configurations and materials are considered.

When ordering standard parts, any of the allowed variations may occur in the delivered product. Because one production lot exhibits appropriate functional performance and life characteristics in a particular application does not ensure that the next lot from the same manufacturer or a part with the same part number from a different manufacturer will also meet expectations.

There has been a trend to use more and more application specific parts within new avionic designs in order to achieve the required functional performance within the available size and weight constraints. As the implementation of AVIP progresses, there will be increased pressures to use more and more application specific parts. To some degree, this allows the customer to take greater control over the parts that are purchased. However, part vendors may resist this increased customer involvement for several reasons. First of all, the OEMs have been asking for a great deal of information with out understanding how they were going to use the information. The part vendors are reluctant to provide detail on their design and manufacturing processes without a clear understanding of how it is going to be used. Further, they are concerned the requested information may give away secrets that are the key to their competitive edge. There may be some relief from this concern as the Qualified Manufacturer List concept which has been initiated by RADC and DESC by making the part vendors process control data visible.

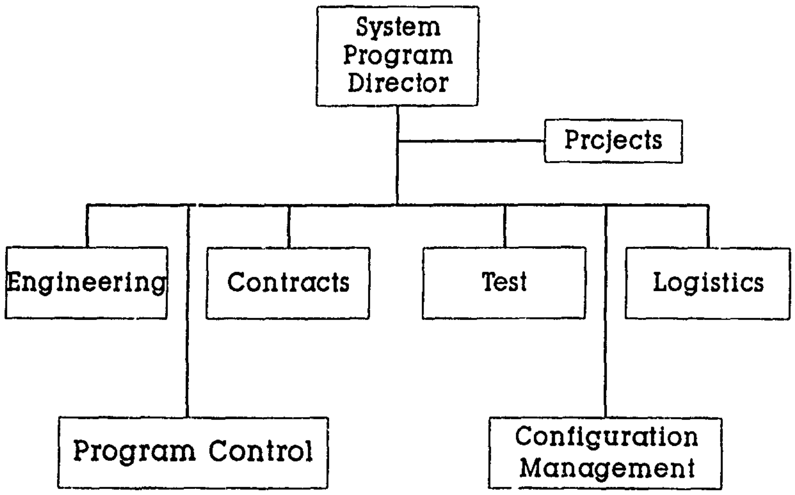
Redundancy verses Robust Design and Preventative Maintenance

Traditionally, redundancy has been used to protect safety and mission reliability. With the implementation of AVIP, redundancy is required to protect safety critical functions, while robust design and preventative maintenance is used to protect mission reliability. Although redundancy is required to protect safety, the level of redundancy (dual, triple, quad) may be reduced. This however is now and will continue to be an emotional issue.

Historically, our aircraft have used two or more radios, which are in part, used to communicate with different command posts, air traffic control facilities, airborne tankers, etc.: but, are also used to ensure mission reliability in event one of the units fail. Many of our aircraft contain triple redundant inertial navigation systems, whose sole purpose is accommodate the failure of one or more of the systems. The International Civil Aviation Organization (ICAO) mandates triple redundant navigation systems for operation in the trans-Atlantic track system.

Conflicts occur when advocates of the AVIP process suggest that mission reliability can be protected by preventative maintenance and robust design rather than redundancy While there is still a great deal of disbelief, these concepts will become more and more acceptable as program successes become visible, as well as continuing pressures to reduce the size and weight of our avionic systems.

Redundancy can protect mission reliability and safety from random failure events, but it can not protect from fatigue failure mechanisms. ASD recently procured a triple redundant digital flight control system for one of our aircraft. Each of the triple redundant computers were installed in a single enclosure, and thus would experience the similar stresses and stress reversals over its life. Each of the computers contained



System Program Office Organization (Typical)
Figure 6

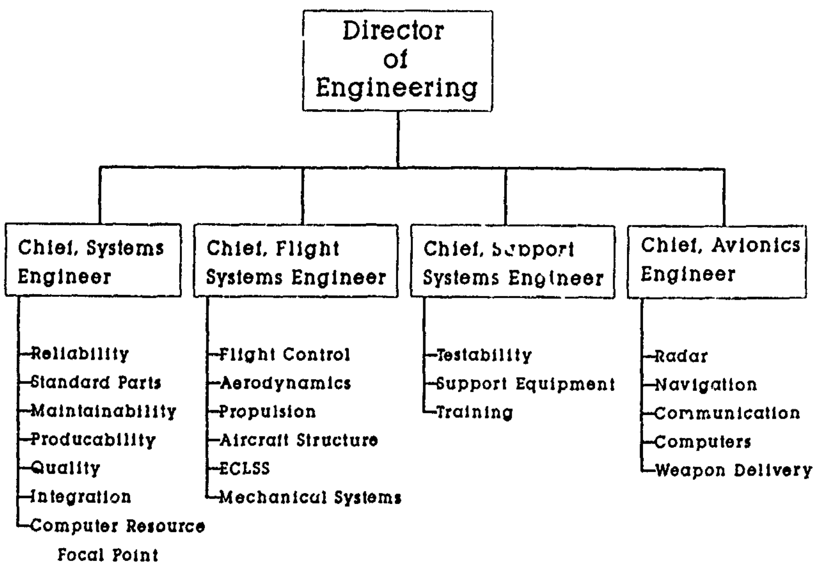
a transistor lead wire that was fatigue sensitive. Thus, when one fatigue failure occurs, the other two computers are likely to fail shortly thereafter. Fortunately, in this instance, the fatigue sensitive part was located in a built in test circuit and thus had minimal effect on safety. However, if this design error had occurred, and had not been discovered before the start of flight test, it could have easily resulted in the loss of all three computers during a single flight with the loss of the aircraft and the possible loss of the aircrew.

Whose Responsible? Reliability Engineer or Designer?

The adoption of the AVIP approach to design requires significant changes in the roles of the electronic design, R&M, manufacturing and test engineers. The organizational structure also requires change to ensure the process is effectively implemented. Figure 6 illustrates the typical System Program Office (SPO) organizational structure that has been in place at ASD for the last twenty years or so.

The engineering structure within the SPO has usually organized as shown in Figure 7.

With this structure, the avionic engineers have direct responsibility for functional performance from the outset, but they have not been responsible for R&M, manufacturing nor test. Responsibility for these disciplines rests with other organizations which are "down the hall." For example, if a difference of opinion should arise between the avionics engineer and the R&M engineer, that problem would rise in the line organization to the Director of Engineering, the individual with the total engineering responsibility for a major weapon system, before resolution could be achieved. Such an organizational structure tends to suppress all but the largest



System Program Office Engineering Organization (Typical)
Figure 7

problems. However, as the development proceeds, and test begin, the avionic engineers inherit the problems. They have to deal with the changes necessary to resolve "ility" problems. By in large, the industry has mirrored the governments organizational structure in order to streamline their customer communications

With the implementation of AVIP, the avionics engineer within the SPO and the design engineer in industry has been asked to take on the responsibility for the total design, including life characteristics, manufacturing, etc. This involves tearing down some organizational, technical, educational and cultural barriers.

When the design engineer steps up to his new responsibilities, he will involve himself in issues that have been the private domain of other organizations and their specialists When he does this, he will encounter friction resulting from the specialists perceived loss of status, the necessity to learn new technical disciplines, and ultimately to deal with the threat to the specialists function. Further, the R&M, manufacturing engineers, etc speak different technical languages, which will require a concerted effort from each engineer to overcome. Often, the specialists will feel that the avionics/design engineers are unprepared to deal with their new responsibilities, they don't have the experience, the education, etc. It will be said: "They simply don't understand."

There will be feelings of inadequacy and distrust from the avionics engineers and specialists as well. In order to overcome these difficulties, it will require patience, sensitivity to feelings, effective training and a lot of encouragemer' Possibly the most difficult part of the transformation is making the change while applying the process under schedule and cost pressures. It should be recognized t[illegible] ss in not something that will occur over night or on a single program. It will evolve with a change in focus and a commitment to make it work through incremental changes. Organizational changes will occur naturally.

MIL-Spec Design Criteria Verses Manufacturer Unique Criteria

MIL-STD-454, Standard General Requirements for Electronic Equipment, and MIL-E-5400,Electronic Equipment, Aerospace, General Requirements for contain a series of detailed requirements dealing with materials and processes that are acceptable for use in the manufacturer of military electronics. Both of these documents reference a myriad of additional specifications and standards which reference more requirements, which reference more requirements, ad nauseam. As one proceeds through the specification tree, the number and level of detailed requirements grow into a totally unmanageable situation. As a result, it has been mandated that the individual preparing the specification is required to identify only the specific requirements that apply to a particular development. Often the contractor is instructed to use the remainder of the documents as a guide, although this is of little consequence from a contractual standpoint.

Most of our contracts also contain a task to derate the electronic parts that are included in our electronic equipment such that they operate well below their maximum rated limits, presumably to ensure that reliability requirements are achieved. Criteria for derating have been documented in AFSC Pamphlet 800-27, Reliability Parts Derating Guidelines, dated June 1982 or USAF activities and NAVMAT AS-4613, Naval Air Systems Command, Department of the Navy Application and Derating Requirements for Electronic Components, General Specification For for USN applications These criteria focus primarily on the limitation of the junction temperatures of semiconductor devices and power dissipation of other devices. The criteria was established using industry input, and takes into account what some of the more successful design teams have implemented. Often, these criteria have been mandated by contract.

With the application of AVIP, the contractors are being relieved from many of the traditional government mandated material and process requirements which the industry has complained about for years. It is expected that the industry will step up to their responsibilities, use the knowledge developed throughout the development process, and produce a product that fulfills the users expectations without this sort of government "help". He is expected to use the government specifications and standards, industry standards, the technical literature in order to establish standards that will be effective in his manufacturing plant using his processes and people. Obviously, this will require rising above past adversarial relationships, dealing with each other fairly, avoiding taking advantage of short term personal gains and developing long term trusting relationship between the customer and the supplier.

MTBF Verses Maintenance Free Operating Period and Cumulative Maintenance Burden

Since the publication of the AGREE Report, MTBF has been the accepted approach for stating reliability requirements for avionic equipment. From a standardization standpoint, with he concept that one black box meets all needs, the notion of a single reliability number is quite attractive. However, this leaves the practitioner in a quandary of relating the required and demonstrated reliability to the reliability that will be achieved in the field. Each of us have recognized there is no single reliability number that will apply universally to all applications. The avionic equipment invariably manifests different reliabilities in each aircraft model (i.e. C-130), and often with different series (AC-130H) within the basic model series. Sometimes reliability varies with different operating bases and possibly different aircraft within the fleet Over the years, the logistics community has come to live with the situation, and has developed a management planning process (Logistic Support Analysis)[7] using the predicted MTBFs and fudge factors to deal with the provisioning of the equipment and establishing the manpower and training requirements to ensure support.

With the application of AVIP, we are now offering to the user, equipment with reliability defined by a different metric—minimum life, time to first maintence event or Maintenance Free Operating Period (MFOP) with a specified set of environments and usage. This recognizes that the equipment will have different life characteristics in each application, and that one can adjust those life expectations based upon the stresses the unit encounters in service. It has been the suggested that one might want to record the stresses during equipment operation so that one can perform preventative maintenance before it fails thus precluding it failing on the vehicle. Based upon past experience with the use of elapsed time indicators and the use of manual data collection techniques, there is a mind set that suggests that tracking these stresses can be a very difficult, if not an impossible task. It will involve a large expenditures in manpower. Fortunately, the technology available today can be used to mechanize this data collection effort.

There is also a conflict with the conventional wisdom that: "If ıt ain't broke, don't fix it!" There ıs some justification for this position since the repair process have been mandated rather than developed and veri ed as a part of the development process. Assuming th repair processes are characterized and well understood (the same as manufacturing process), this situation can be alleviated.

There is a need for a tailoring of the LSA process or possibly a translation from the AVIP metrics to a MTBF. This translation could be used for solving queing problems inherent to the LSA process.

Contract for Warranties Verses AVIP Plus Warranties

There are those who suggest that one need not require and monitor a development process since warranties protect the governments interests. There are fundamental problems with an approach that does not allow the customer the opportunity to intercede if necessary. The customer can not afford to have a program proceed on a course that will result in failure without visibility in its progress, only to discover that the hardware is poorly designed when tests begin. Thus the process is necessary from a both a technical and management standpoint, warranties are optional.

This is not to say that warranties have not had value. They have often been marketed as Reliability Improvement Warranties, although they have fundamentally been priced as interim support contracts with punitive actions resulting if reliability or turn around commitments are not met. Further, they address only the cost of repair which is a small portion of the total cost of a failure. The cost of a failure includes the opportunity costs resulting from the loss in availability of the aircraft, the lost mission, failure to meet training objectives, the manpower to verify a failure, remove and replace the unit, pack and ship the unit to the factory for repair, return shipping, and the investment cost of the unit while it is not available for use. There is no substitute for the application of a disciplined systems engineering process.

Conclusion:

The implementation of the Avionics Integrity Program is an idea who's time has come. It is time to move from the traditional approach of R&M to a more disciplined development process. The avionics will exhibit more predictable life characteristics, based upon the operational usage and environmental stresses encountered. The process provides the capability to adjust life expectations as the equipment is used differently, used on different platforms, or different locations with different environments on similar platforms. This will al'ow t e application of preventative, opportunistic or corre ive r aintenance policies based upon the consequence of failure and economic considerations. The process can be applied for both large and small production runs.

Thus, the application of AVIP takes advantage of the economies of scale and the application of preventative and corrective maintenance support options to achieve the maximum war fighting capability for the minimum expenditure of assets. Thus, AVIP supports the standardization objectives, and maximizes our users war fighting capability

Appendix A

MIL-STD-785 Development Tasks

MIL-STD-785 delineates a series of activities or tasks that are to be accomplished during a development program

MIL-STD-785 Development Tasks

Reliability Program Plan
Monitor/Control of Subcontractors and Suppliers Program Reviews
Failure Reporting, Analysis, and Corrective Action System (FRACAS)
Failure Review Board
Reliability Modeling
Reliability Allocations
Reliability Predictions
Failure Modes, Effects and Critically Analysis (FMECA)
Sneak Circuit Analysis (SCA)
Electronic Parts/Circuits Tolerance Analysis
Parts Program
Reliability Critical Items
Effects of Functional Testing, Storage, Handling, Packaging, Transportation, and Maintenance
Environmental Stress Screen (ESS)
Reliability Development/Growth Test (RDGT) Program
Reliability Qualification Test (RQT) Program
Production Reliability Acceptance Test (PRAT) Program

Unfortunately, only limited guidance is provided on how the tasks are to be time phased, and this guidance is contained in MIL-STD-1521, Technical Reviews and Audits for Systems, Equipments, and Computer Software, which defines the requirements for the various program reviews. Within the broad guidance provided, the time phasing of the effort is left to the discretion of the reliability engineer to define with the concurrence of program management. Since the MIL-STD defines tasks rather than a process, the discipline that is applied to the development often becomes a test of the personalities of the reliability engineers and program managers (both within industry and the customer organizations). When a development effort encounters trouble from either a cost or schedule standpoint, the Reliability Program more often than not is reduced in scope and/or delayed.

The planning and results of the MIL-STD-785 tasks are documented in accordance with the Data Item Descriptions listed below.

DI-R-7079	Reliability Program Plan
DI-R-7080	Reliability Status Report
DI-R-7041	Report, Failure Summary and Analysis
DI-R-7081	Reliability Mathematical Model(s)
DI-R-2114	Report, Reliability Allocation
DI-R-7082	Reliability Predictions Report
DI-R-1734	Report, Failure Modes, Effects and Criticality
DI-R-2115A	Report, Failure Mode and Effect Analysis (FMEA)
DI-R-7083	Sneak Circuit Analysis Report

DI-R-7084	Electronic Parts/Circuits Tolerance Analysis Report
DI-R-35011	Plan, Critical Item Control
DI-R-7040	Report, Burn-in Test
DI-R-7033	Plan, Reliability Test
DI-R-7034	Procedures, Reliability Test and Demonstration
DI-R-7034	Reports, Reliability Test and Demonstration (Final Report)

It is certainly fair to attribute some of the improved field reliability that has been observed over the past twenty years to the diligent application of the MIL-STD-785 tasks by the R&M engineers. However, it should be recognized that there are many other factors that have also contributed. These include the revolution that the electronics industry has undergone which include the engineering design tools, automation of the manufacturing processes and the components that are used in our electronic equipments. Avionic systems have evolved from vacuum tube based systems, to those using discrete semiconductors devices, and later to small and medium scale integrated circuits. At this time, new systems are made predominantly of medium to large scale integrated circuits and are moving toward Very High Speed Integrated Circuit (VHSIC) devices. It is certainly reasonable to attribute a large portion of the improvement to the use of current technology components, computer aided design and automation of the assembly and test processes rather than the application of MIL-STD-785. At this point, it would be instructive to discuss several of the specific tasks required by MIL-STD-785.

Reliability Predictions:

While the Reliability Prediction Task is only one of several tasks required of a Reliability Program, it is one of the two efforts which are key (the second being the Parts Program) in accomplishing the detailed design. MIL-STD-785 directs the reliability engineer to MIL-HDBK-217, Reliability Prediction of Electronic Equipment, for appropriate failure prediction techniques. MIL-HDBK-217 stated purpose is: establishes uniform methods for predicting the reliability of military electronic equipment and systems. It provides a common basis for reliability predictions during acquisition programs for military electronic systems and equipment It also establishes a common basis for comparing and evaluating reliability predictions of related or competitive designs. However, its application and usefulness have rather controversial in recent times.

The Reliability Analysis Center (RAC), a DOD Analysis Center, has published in their April 1990 Technical Brief a defense of MIL-HDBK-217 titled, MIL-HDBK-217, Use and Application by Mr Seymour F Morris, RADC/RBER. Mr Morris observed that. Critics often state that reliability predictions using MIL-HDBK-217 do not compare well to field experience and the results obtained are too often misunderstood and misused Some engineers see the whole prediction process, and MIL-HDBK-217 in particular, as an impediment to good engineering judgement and call for its elimination. Mr. Morris later correctly states that MIL-HDBK-217 is not intended to predict field reliability and, in general, does not do a very good job at it in an absolute sense. The reasons for this are numerous including different failure definitions for field problems that MIL-HDBK-217 does not account for. These problems include maintenance induced failures, intermittent failures (can not duplicate), software problems, and design problems (i.e., overstressed parts operating beyond their ratings). He further stated that The handbook only provides failure rate prediction models which account for manufacturing (e.g., wire bond, package related, etc), temperature, electrical stress and other quality/application considerations which collected field data indicates to be significant problem areas in fielded electronics. These factors are generally generic to systems, manufacturers and field maintenance policies. One should realize that field reliability is the only reliability that is of importance to our users and maintainers and should be a prime concern of the equipment designer.

Mr. Morris listed the purposes for accomplishing the reliability prediction as: (1) feasibility evaluation, (2) comparing competing designs, (3) identification of potential reliability problems and (4) to provide reliability input to other R/M tasks. Mr. Morris goes on to suggest that the lack of an accurate prediction of field reliability does not diminish the value of the handbook or prediction process since none of the purposes described above require an absolute prediction of field reliability. Unfortunately, it is not apparent that the inaccuracies of the MIL-HDBK-217 prediction varies widely from manufacturer to manufacturer, and between design teams and specific plants within a particular manufacturer.

It should be apparent that, if the data used in making system level design trade decisions is as unrepresentative of what will be experienced in the field as Mr. Morris acknowledges, and that the field reliability varies widely, the design trade decisions are themselves questionable. The outcomes of any further analyses based upon inputs derived from MIL-HDBK-217 are suspect.

Parts Program

The AGREE Committee (1957) recommended that: the development of military component specifications, the testing of components for design capability, and the development of inspection methods, be integrated and coordinated by one coordinating group at D.O D. level. The group should be comprised of representatives from industry and from the three Services, including personnel from Research and Development, Standardization, Procurement, and Quality Assurance functions. This recommendation was implemented with the issuance of DoD 4120.3-M, Defense Standardization and Specification Program Policies, Procedures and Instructions[7] which were issued in January 1972 and revised in August 1978 and the establishment of MIL-STD-965, Parts Control Program. MIL-STD-965 invoked a single standardized process on each of the three services and their contractors The implementation of the process is documented by Data Item Descriptions below.

DI-E-7026	Parts Control Program Plan
DI-E-7027	Program Parts Selection List
DI-E-7028	Nonstandard Parts Approval Requests/Proposed Additions to an Approved PPSL DI-E-7029 Military Detail Specifications and Specification Sheets
DI-E-7030	Test Data for Nonstandards
DI-E-1133	Specification Requirements Sheets (SRS)
DI-E-7031	Drawings, Engineering and Associated Lists

The implementation of parts standardization effort has been delegated to the Defense Logistics Agency (DLA) by the Department of Defense. The DLA activity responsible for electronic parts is the Defense Electronics Supply Center

(DESC). DESC is the custodian for the military specifications that relate to electronic parts. For microcircuits, Rome Air Development Center (RADC) is the preparing activity for both general and detail military specifications and has responsibility for their content. They also have the technical capability and laboratory facilities to support the effort.

Changes to the general electronic part specifications may be proposed by government or industry representatives, and are coordinated with the Electronic Industries Association (EIA). Generally the EIA will work toward achieving a consensus within the industry before recommending incorporation, although individual companies may sponsor proposed changes for which consensus has not and can not be reached. RADC may instruct DESC to publish positions developed through industry consensus, recommended by individual companies, or positions opposed by industry.

DESC coordinates new and changes to existing Associated Detail Specifications (slash sheets) and Standardized Military Drawings (SMDs), for which DLA is the preparing activity with appropriate vendors. These documents define the electronic function, performance, form factor, qualification and screening and inspection/test requirements for specific electronic parts.

In order to maintain multiple sources and competition, the slash sheets and SMDs are often silent on key parameters (e.g., timing parameters, output current sink/source capability, etc.) where one or more of the producers are unable or unwilling to comply. These omissions often results from limitations of existing facilities, processes or process/test equipment, yield, or unreconcilable differences in key parameters from one vendor to another. In order to accomplish the design, data from similar commercial parts or CAD/simulation models which are far more detailed are often used. Unfortunately, the manufacturing controls and quality conformance inspections and screens applied to the military product may be less stringent than the commercial or industrial high-rel counterpart. Products that are particularly susceptible to these problems are bought to Qualified Products Lists (QPL) that were established years earlier. Reliability is not addressed by the microcircuit QPL process8. The Qualified Manufacturers List (QML) process has recently been implemented and is expected to alleviate many of the above problems on new Application Specific Integrated Circuits (ASIC).

Upon receipt of a new contract, the contractor is provided with a DESC prepared Government Furnished Baseline (GFB). The GFB includes those parts which DESC, based upon their experience, believes are appropriate for use in the new development system. The contractor then takes the GFB, deletes those parts that are not to be used, adds new parts as necessary to complete the design, and submits this list to the government for approval as the Preferred Parts Selection List (PPSL)

After the approval of the PPSL (which occurs long before the design is complete), the contractor is required to submit requests approval for the addition of either a standard or nonstandard part. For each nonstandard part, a "Nonstandard Parts Approval Request/Proposed Additions to an Approved PPSL" form is submitted to DESC. DESC does a part number Cross reference check to determine if there is an existing part from a QPL or SMD approved source that performs the same function, although not necessarily the same electrical performance or reliability. An approved source may be established as a result of government certification/qualification (QPL) or company self certification (SMD) procedure. If a functionally similar part is found, DESC recommends that it be used.

Although, the documentation requires technical justification, that information is seldom considered in the approval/ disapproval recommendation. From a practical standpoint, the DESC recommendadion is final unless the contractor makes a formal appeal to the procuring agency for reconsideration. The procuring agency can over ride DESC's recommendation for any number of reasons, but they are compelled by regulation to notify DESC of the reasons for over ride. While there are ways of speeding up the procedure through the use of a Parts Control Board, the bureaucratic drill is time consuming and documentation intensive.

Environmental Stress Screen

Subsequent to the release of the AGREE Report, some of our specifications required that burn-in be accomplish on each delivered equipment, and it was instituted on other contracts as corrective action when necessary reliability was not achieved. The inertial navigation system for the F-15 aircraft (circa early 1970s) required that a burn-in (operation at elevated temperature) test be completed prior to delivery, but would either arrive at the aircraft manufacturers plant "dead on arrival" or would fail soon there after. The INS was an intergral part of the avionics suite of the F-15, and its unreliability was delaying the aircraft delivery, which was unacceptable for both the prime contractor and the customer.

The Air Force had considerable experience with silo based missile systems hat contained older technology inertial platforms which operated continuously for months without failure. The airlines were reporting reliabilities on the order of 2000 hours MTBF on their inertial systems that they were using on many of their transoceanic flights and were reporting reliability figures on the order of 2000 hours MTBF. Yet, the Air Force was seldom achieving twenty (20) hours on their fighter aircraft.

Thus, it was suggested that power and thermal cycles may be more important reliability driver than time at temperature. Although the contractor objected, a change to the acceptance procedure was implemented which required a series of power and thermal cycles, including several at the end which were to be failure free. This test precipitated a numerous failures before the equipment was delivered, which provided near real time feedback on design and manufacturing problems. Soon the reliability problems at the prime contractor and the field diminished.

During the mid 70s, the Air Force developed a new standard UHF Radio which experienced similar problems. The basic requirements included a steady state burn-in prior to delivery. When problems were encountered, an experiment was set up where half of the deliverable units would undergo steady state burn-in while the others received thermal and power cycling, a portion being failure free. Before the test approached it's designated decision point, it was apparent that thermal and power cycling were more effective in inducing early failures than operating at elevated temperature. Thus, the decision was made to integrate Environment Stress Screen (ESS) in the way ASD conducts business. Within the vernacular of the reliability engineers, ESS and burn-in have become synonymous.

Reliability Development/Growth Test (RDGT) Program

The purpose of accomplishing a RDGT is to conduct pre-qualification testing (also known as Test Analyze and Fix) to identify reliability problems and make changes to the design or manufacturing processes prior to production release. The test should weed out failure mechanisms that were unintentionally allowed in the design. Test, analyze and fix is useful when applied at the appropriate time in concert with a disciplined development process. Unfortunately, the implementation of RDGT has encountered numerous difficulties. Some contractors have opted to find and fix the problems in RDGT rather than accomplish simple analyses prior to drawing release, when the available design options become more limited. The implementation of RDGT has encourage an abbreviation of the design process by requiring the application of a learning curve to reliability during RDGT as well as a mature reliability. To meet the learning curve required without exceeding the mature reliability requirement, the equipment must begin RDGT with an abysmally low reliability.

Another problem with the implementation of RDGT is that of schedule. At the outset, the schedule includes time for completion of RDGT and changes incorporated prior to the start of flight test and reliability qualification test. Unfortunately, all too often the design encounters problems, cost and schedule priorities prevail and the start of RDGT is delayed. This combined with the short cut design process results in immature equipment being pressed into flight test, often placing the program itself in jeopardy.

Reliability Qualification Test Program

The AGREE Committee recommended a statistically based test which could be used to demonstrate that a minimum MTBF had been achieved. They identified specific environmental limits for temperature, vibration, on-off cycling and input voltages for each of four different test levels. These test levels were designated light, medium, high and extreme conditions and included a rather straight forward accept/reject criteria.

The basic requirements for AGREE Testing were first applied to the development of the C-141 Aircraft. The Reliability Qualification Test was accomplished on pre-production hardware and was in most cases complete before the start of production. This program applied a single test plan (failures verses operating hours) and an accept/reject criteria that was adjusted based upon the required MTBF to each avionic equipment.

When the AGREE Report was written, the implementation of a Reliability Qualification Test (RQT) was practical from a time standpoint. The MTBFs for most avionic equipments were less than 100 hours and the troublesome units were often less than ten (10) hours. With MTBFs of these magnitudes, a RQT could be accomplished with each test sample accumulating multiple MTBFs within an acceptable calendar time period. As the industry moved to more modern technologies, increased automation and better process control, the achievable MTBFs have increased greatly. Thus, it has become impractical and often impossible, to accomplish a RQT with an reasonable number of test assets, test hours and cost or within a reasonable calendar time.

On the C-141 program, the RQT was conducted with prototype equipments which are much more costly than similar units built in production. As the MTBFs of the test hardware grew, the number of test articles required to demonstrate the required MTBF within the available time also increased. Further, it was recognized that the pre-production or prototype equipments were not representative of production hardware. In order to minimize the cost of the test, and use test samples that are representative of production hardware, the RQT was delayed until after the start of production. Unfortunately, the possibility impacting the design with knowledge obtained from the RQT before production release was lost.

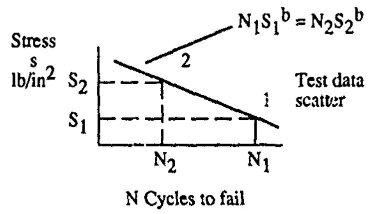
Worse still were the demotivating effects of the delay. After production begins, the contractor is often responsible for incorporating changes in delivered units to achieve the required MTBF. This obligation caused the contractor to resist change where ever possible. This precluded the incorporation of improvements in production hardware as well. While the maintainers want more reliable equipment, they resist programed retrofits that increase their immediate work load. Once production has been begun0, the acquisition community is most interested in completing production and transferring responsibility to the supporting agency. Thus there were an overwhelming set of forces that inhibit improvement of field reliability.

Appendix B

This material was extracted from a technical paper titled "Tools Available for Implementing AVIP" by Mr. Dave S. Steinberg of Litton Guidance & Control Systems and was published in the Proceedings of the Ninth Annual IEEE/AESS, Dayton Chapter Symposium, "Avionics Integrity Program" held in Dayton, Ohio, 30 November 1988.

INTRODUCTION

The approximate fatigue life of an electronic system can be determined from the fatigue characteristics of the various members that carry major structural loads. The fatigue characteristics are typically plotted on log-log paper and presented in terms of stress (S) and number of cycles to fail (N). These S-N curves are shown as straight sloped lines, using the best average values, as shown in Fig. 1. [1]



Typical S-N Fatigue Curve
Figure 1

The general equation for the straight sloped line on the log-log plot is:

$$N_1S_1^b = N_2S_2^b \qquad (1)$$

Where: N = Number of stress cycles
S = Stress level for failure, psi
b = Slope of fatigue line

Considering linear systems, the number of fatigue cycles will be directly proportional to the time (T). Also, the stress level will be directly proportional to the acceleration (G) level and to the displacement amplitude (Z). Therefore, Eq. (1) can be rewritten as follows:

$$\left.\begin{aligned} T_1G_1^{\,b} &= T_2G_2^{\,b} \\ N_1Z_1^{\,b} &= N_2Z_2^{\,b} \\ N_1G_1^{\,b} &= N_2G_2^{\,b} \end{aligned}\right] \qquad (2)$$

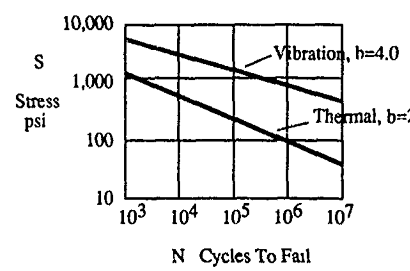
The above equations can be used to determine the fatigue life of various structural load carrying members subjected to different alternating stresses in different environments.

FATIGUE CHARACTERISTICS OF SOLDER

Solder has some unusual physical properties that must be understood in order to design and manufacture reliable electronic equipment. Since solder is a relatively soft metal, with a low melting temperature, the modulus of elasticity and shear strength are reduced when the operating temperatures are near 100 C. Solder shows a tendency to plastically deform and creep under relatively low stress levels of about 800 psi at these elevated temperatures, during slow temperature cycling conditions.

The strength of solder appears to increase as the speed of the applied load is also increased. [2] Solder can therefore withstand higher stress levels during rapidly applied loads, such as vibration, than during slowly applied loads, such as thermal cycling.

The typical fatigue curve for 63% tin 37% lead solder in shear is shown in Fig 2, for room temperature conditions [3]



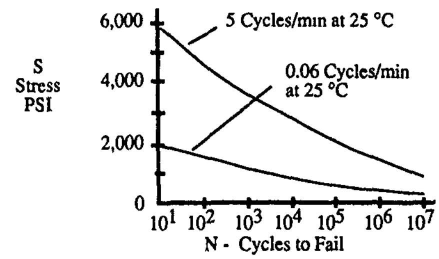
Shear Fatigue Properties of Solder
Figure 2

Extensive experience with solder joints in military programs has shown that solder stress levels should be kept below a level of about 400 psi, to avoid creep failure fatigue effects due to slow thermal cycling over long time periods.

Higher stress levels are often permitted during vibration for short time periods. However, for extended periods of vibration many millions of stress reversals can result because printed circuit boards (PCBs) typically have high resonant frequencies. Solder creep in vibration is not a problem since the stress reversals are very rapid. For extended vibration environments the 400 psi level should be observed to avoid fatigue cracks in the solder due to the accumulation of several million stress cycles.

The fatigue properties of solder under cyclic loads shows that the fatigue strength is reduced when the frequency of the applied load is reduced. A comparison of the fatigue life for a load frequency of 5 cycles per minute and a load frequency of 0.06 cycles per minute is shown in Fig. 3 at a constant temperature of 25 C. This shows that for a given number of stress reversals, such as may be experienced in a temperature cycling environment, a slow temperature cycle is more damaging than a rapid temperature cycle over the same temperature range. [4]

Temperature also has a strong influence on the strength of solder. At low temperatures of -55 C the short time tensile strength is about 6,000 psi. At temperatures around 100 C, where many military components operate, the strength of the solder is sharply reduced.



Solder Alternating Lap Shear Stress 63-37 Tin Lead
Figure 3

EFFECTS OF THERMAL EXPANSION MISMATCH BETWEEN COMPONENTS AND PCB

Thermal expansion and contraction differences between the electronic components and the PCB's must be kept to a minimum in order to reduce thermal strains and stresses in the lead wires, solder joints and plated through holes. Materials must be carefully selected to minimize expansion differences, or the mounting component geometry must be adjusted to reduce the thermal coefficient of expansion (TCE) forces developed in the lead wires and solder joints.

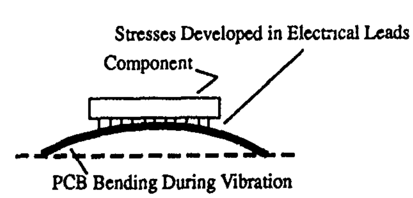
The solder workmanship and control is extremely critical for surface mounted components, since there are no other mechanical supports for the leadless ceramic chip carriers (LCCCs). When the solder joints are not properly made or controlled, then more rapid failures can be expected.

Plated-through holes must be sized properly to prevent cracking of the copper plating in the hole. There must be enough copper in the plated-through hole to carry the forces generated by the expansion of the circuit board in the Z direction Even when the PCB expansion in the X and Y (in plane) axes are reduced with the use of materials such as copper clad invar, the Z axis expansion (perpendicular to the plane of the board) will not be reduced. Therefore, the laminations for multi-layer PCB's must not be made too thick because the Z axis expansion can become a problem The aspect ratio for a plated through hole should be about 3 for a reliable design, [5]where the thickness of the PCB is limited to 3 times the diameter of the hole.

The copper in the plated through holes should have a minimum thickness of 0.0015 inches to prevent cracking of the copper barrel during temperature cycling environments.

ELECTRONIC COMPONENT LEAD WIRE STRAIN RELIEF

Relative motion between the electronic components and the PCB can be developed as the result of a thermal expansion mismatch or as the result of a resonant condition in the PCB. During the resonant condition the PCB is forced to bend back and forth. This motion forces the electrical lead wires to also bend back and forth as shown in Fig. 4.



Bending Produces Strain in Lead Wires
Figure 4

The effects of a large thermal expansion mismatch or a large vibration displacement mismatch between the components and the PCB can often be offset by reducing the stiffness of the wires on the electronic components. When the wire stiffness is reduced, the forces and the stresses in the wires and in the solder joints are also reduced.

Wires can be looped or even coined (by squeezing a round wire into a thin flat strip) to reduce the stiffness. The typical spring rate relation can be used to demonstrate this condition. For a given thermalmismatch condition, or a given resonant condition, where the relative displacement (Y) is fixed, the only way in which the force (P) can be reduced is to reduce the spring rate (K) of the wire, as shown in the following relation:

$$P = K Y \qquad (3)$$

When the spring rate of the wire is due to bending, then the flexing spring rate (K)
is related to the modulus of elasticity (E), the area moment of inertia (I), and the length (L) as follows:

$$K = \frac{E I}{L^3} \qquad (4)$$

Looping the wires increases the length (L) so the stiffness is reduced rapidly due to the cube function. Coining the lead wires reduces the moment of inertia (I), which is a cubic function of the height, so the stiffness is reduced rapidly.
When the spring rate of the wire is in tension, then the area of the wire (A) is required as follows:

$$K = \frac{A E}{L} \qquad (5)$$

A longer wire will reduce the spring rate as a linear relation, so the spring rate changes slowly.

ESTIMATING THE VIBRATION FATIGUE LIFE

The approximate fatigue life of a vibrating system can often be estimated from the fatigue properties of the various members that carry the dynamic loads. Since electronic assemblies make use of non ferrous metals in components, these charac
teristics will be used.
The slope of the fatigue curve shown in Fig. 1 can be determined by considering the endurance limit to be one third of the ultimate tensile strength. [6] Then rewriting Eq. (1):

$$\frac{N_1}{N_2} = \left(\frac{S_2}{S_1}\right)^b \qquad (6)$$

Where: $N_1 = 10^8$ Cycles to fail
$N_2 = 10^3$ Cycles to fail
S_1 = Endurance = 1/3 S_{tu} (ultimate)

Using a stress concentration factor 2:

$S_1 = 1/6\, S_{tu}$
$S_2 = S_{tu}$

Substitute into Eq. (6)

$$\frac{10^8}{10^3} = \left(\frac{S_{tu}}{1/6\, S_{tu}}\right)^b \qquad \text{or } 10^5 = 6^b$$

Take the log of both sides and solve for the exponent b

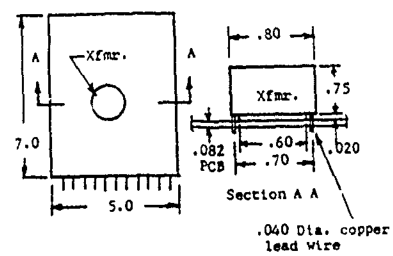
$$b = 6.4 \qquad (7)$$

DEMONSTRATION OF AVIP TOOLS

Sample problems are a convenient way of demonstrating the various tools that are available for evaluating the effective life of an electronic system. In this case a transformer mounted on a PCB was selected because experience has shown the solder joints and electrical lead wires have high failure rates in thermal cycling and vibration environments. The failure mechanisms are not well understood because they are complex and require a great amount of time evaluate.
The transformer (xfmr) selected was the largest size that can typically be mounted by its electrical lead wires only, without any supporting screws. This type of transformer must have at least 7 wires per inch of diameter to support the unit. When only 4 wires are required for electrical operation, then 3 dummy wires must be added to permit the transformer to survive severe thermal and vibration environments.

SAMPLE PROBLEM - TRANSFORMER MOUNTED ON A PCB

An electronic box must be capable of reliable operation in a harsh military aircraft environment for a period of 15 years An examination of the PCB's within the box shows that there are many critical components such as DIPs, hybrids, pin grid arrays and transformers that may experience broken component lead wires and cracked solder joints. All of the critical components must be analyzed to make sure they are capable of surviving the environments. The analysis will start with the transformer .PA mounted on the PCB as shown in Fig. 5 Every critical component must be examined to insure the reliability of the system.



Transformer Mounted on a PCB
Figure 5

The PCB and the transformer are expected to operate in the following environments over the period of 15 years:

A:	ESS Random vibration screen PCS response 11 2 G RMS 3 axes,	1.0 hr
B:	Captive flight vibration PCB response 6 1 G RMS,	2160 hr
C.	Free flight vibration PCB response 15 9 G RMS,	1.0 hr
D.	Ground transportation vibration PCB response 3.8 G RMS,	840 hr
E.	ESS Thermal cycle screen 140 C cycle range	50 cycles
F:	Ground alert thermal cycle 44 C cycle range	2700 cycles
G.	Igloo storage thermal cycle 40 C cycle range	2400 cycles
H:	Airborne alert thermal cycle 102 C cycle range	150 cycles

The random vibration qualification test consists of a power spectral density input (PSD) of 0.15 G square/Hz for a period of 2 hours per axis, or a total time of 6 hrs.

Will the PCB and transformer assembly be capable of surviving these environments for the 15 year period?

In order to answer this question, a vibration fatigue analysis and a thermal cycle fatigue analysis must be performed on the PCB and on each of the most critical components. In this sample problem, only the transformer will be examined.

The number of fatigue cycles accumulated during vibration and during thermal cycling can be obtained, then combined using Miner's cumulative fatigue damage theory, to determine if the transformer will survive the combined environments. Start with the random vibration qualification test to establish the desired PCB resonant frequency and fatigue life.

SOLUTION - RANDOM VIBRATION ENVIRONMENT

The desired resonant frequency of the PCB to achieve a fatigue life of about 20 million stress cycles for the transformer can be determined from the following relation [7]

$$f_d = \left[\frac{29.4\ Chr\ \sqrt{(\pi/2)(PSD)L}}{0.00022\ B}\right]^{0.8} \quad (8)$$

where: C = 1.26 Component Type, Xfmr with bottom lead wires
h = 0.082 in PCB Thickness
r = 1.0 Relative Position at Center of PCB
PSD = 0.15 G^2/Hz Power Spectral Density Input
L = 0.70 Inch Length Across Lead Wires on Xfmr
B = 5.0 in Width of PCB

Substitute into the above equation:

$$f_d = \left[\frac{29.4(1.26)(0.082)\ \sqrt{(\pi/2)(0.15)(0.70)}}{0.00022\ (5.0)}\right]^{0.8}$$

f_d = 275 Hz desired frequency (9)

This resonant frequency for the PCB is only valid when the "Octave Rule" is used. Octave means to double. The PCB resonant frequency must be at least one octave away from the chassis resonant frequency to prevent severe dynamic coupling, which can otherwise shorten the fatigue life.

The response of the PCB to the random vibration can be determined from the following relation:

$$G_{RMS} = \sqrt{(\pi/2)(PSD)\ f_n Q} \quad (10)$$

Where: PSD = 0.15 G^2/Hz PSD input
fn = 275 Hz PCB Resonant Frequency
Q = $\sqrt{275}$ = 16.6 Approximate PCB Transmissibility [7]

Substitute into above equation:

$$G_{RMS} = \sqrt{(\pi/2)(0.15)(275)(16.6)}$$

G_{RMS} = 32.8 (11)

QUALIFICATION TEST TIME TO FAIL

The estimated time for a failure in the electrical lead wires and solder joints can be determined from the PCB resonant frequency and the 20 million cycle life.

$$\text{Life} = \frac{20\text{x}10^6 \text{ cycles to fail}}{\left(275\ \frac{\text{cycles}}{\text{sec}}\right)\left(3600\ \frac{\text{sec}}{\text{hr}}\right)}$$

Life = 20.2 hours (12)

Since the qualification test lasts for a total of 6 hours for 3 axes, the design should be satisfactory for the qual test.

FATIGUE CYCLES ACCUMULATED IN 15 YEAR VIBRATION ENVIRONMENT, CONDITION A

The number of fatigue cycles required to produce a fatigue failure for Condition A can be determined with the use of Eq. (1) and Eq. (2) as follows.

$$N1 = N2\left(\frac{G_2}{G_1}\right)^b \quad \text{Ref. Eq. (2)}$$

Where: G_2 = 32.8 G_{RMS} Ref. Eq. (7)
G_1 = 11.2 G_{RMS} Ref. Condition A
N_2 = 20x10^6 cycles to fail
b = 6.4 Exponent, Ref. Eq. (7)

$$N_1 = 20\text{x}10^6\left(\frac{32.8}{11.2}\right)^{6.4}$$

N_1 = 1.939x10^{10} cycles to fail (13a)

This represents the number of cycles to fail for the 1 (one sigma) stress level. In random vibration, acceleration levels two times the RMS levels can occur, and acceleration levels three times the RMS levels can occur.

Considering the 2σ (two sigma) stress acceleration condition:

$$N_2 = 20\text{x}10^6\left(\frac{32.8}{2(11.2)}\right)^{6.4}$$

N_2 = 229.6x10^6 cycles to fail (13b)

Considering the 3σ (three sigma) stress acceleration condition:

$$N_3 = 20\text{x}10^6\left(\frac{32.8}{3(11.2)}\right)^{6.4}$$

N_3 = 17.14x10^6 cycles to fail (13c)

ACTUAL NUMBER OF FATIGUE CYCLES (n) CONDITION A

The actual number of fatigue cycles accumulated during the random vibration environment described as Condition A can be determined from the resonant frequency and the time. A Gaussian distribution is used where the RMS level occurs 68.3% of the time, the 2 (two sigma) level occurs 27.1% of the time, and the 3 (three sigma) level occurs 4.33% of the time [7]

n_1 = (275 cycle/sec)(3600 sec/hr)(1.0 hr)(0.683)

n_1 = 0.676x10^6 cycles accumulated (14a)

n_2 = (275 cycle/sec)(3600 sec/hr)(1.0 hr)(0.271)

n_2 = 0.268x10^6 cycles accumulated (14b)

n_3 = (275 cycle/sec)(3600 sec/hr)(1.0 hr)(0.0433)

n_3 = 42.9x10^3 cycles accumulated (14c)

FATIGUE CYCLE RATIO n/N

The fatigue cycle ratio n/N can now be computed where n is the actual number of fatigue cycles accumulated and N is the number of fatigue cycles required to produce a failure.

$$\frac{n_1}{N_1} = \frac{0.676\ E6}{1\ 939\ E10} = 0.00003$$

$$\frac{n_2}{N_2} = \frac{0\ 268\ E6}{229.6\ E6} = 0.00117$$

$$\frac{n_3}{N_3} = \frac{42.9\ E3}{17.14\ E6} = 0\ 00250$$

Adding the three cycle ratios for Condition A·

$$\frac{n}{N} = 0.00003 + 0.00117 + 0.00250$$

$$\frac{n}{N} = 0.00370 \qquad (15)$$

This represents the cumulative damage developed during Condition A vibration. These values are shown in Table 1. The same method of analysis must be performed for Conditions B, C, and D for the vibration levels and time designated. The results are shown in Table 1.

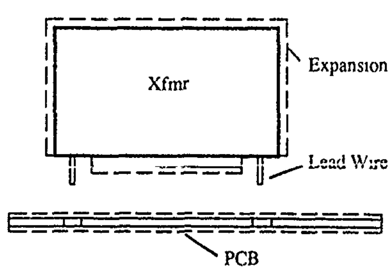
SOLUTION - THERMAL CYCLE ENVIRONMENTS

Thermal stresses are developed in the lead wires and solder joints of the transformer during thermal cycling exposure as defined in Conditions E, F, G, and H for the 15 year environment See Fig. 6

Experience has shown that the most severe condition for the transformer will be the thermal expansion along the Z axis which is perpendicular to the plane of the PCB. The thermal induced forces developed in the electrical lead wires of the transformer can be determined from the equations of equilibrium In the following relation the subscripts 1 refer to the wire, subscript 2 refers to the PCB, and the subscript 3 refers to the transformer. The thermal cycling range used as the base line reference is from -55 C to +95 C, or a delta temperature of 150 C.

$$a_1 L_1 dt_1 + \frac{P_1 L_1}{A_1 E_1} = a_2 L_2 dt_2 + \frac{P_2 L_2}{A_2 E_2} + a_3 L_3 dt_3 + \frac{P_3 L_3}{A_3 E_3} \qquad (16)$$

Where:
- a_1 = 17×10^{-6} in/in/C Copper TCE
- L_1 = Wire length 2 dia. into PCB + 2 dia into Xfmr
- L_1 = 2(0.04)+2(0.04)+0.020 = 0.180 in



Thermal Stresses Produced By Z Axis Thermal Expansion
Figure 6

- dt_1 = Average Component Temperature Change from -55 C to +95C
- dt_1 = (55 + 95)/2 = 75C average
- E_1 = 16×10^6 lb/in^2 Modulus Copper
- A_1 = $\pi/4\ (0.04)^2 = 0.00126$ in^2 wire
- A_1 = (6 wires) (0.00126) = 0.00754 in^2
- a_2 = 70×10^{-6} in/in/C TCE PCB Z
- L_2 = 0.082/2 = 0.041 in length PCB
- E_2 = 0.15×10^6 lb/in^2 Modulus 90 C
- A_2 = Area PCB to Xfmr Irregular Surface 50% Contact Area
- A_2 = $(1/2)(\pi/4)(0.60)^2 = 0.141$ in^2
- a_3 = 30×10^{-6} in/in/C TCE Average Epoxy, Steel, Copper Xfmr
- L_3 = 0.75/3 = 0 25 in effective height in Xfmr
- E_3 = 0.5×10^6 lb/in^2 Average Modulus Epoxy, Steel, Copper Xfmr
- A_3 = 0.141in^2 Same as PCB

Substiture into Eq (16) using 6 wires for the transformer.

$$(17E\text{-}6)(0\ 18)(75) + \frac{P_1\ (0.18)}{(0.00754)(16E6)} = (70E\text{-}6)(0\ 041)(75) - \frac{P_2\ (0\ 041)}{(0\ 141)(0.15E6)} + (30E\text{-}6)(0.25)(75) - \frac{P_3\ (0.25)}{(0.141)(0.5E6)}$$

$$P_1 = P_2 = P_3$$

$$0.000229 + 0.0000014P = 0.000215 - 0.00000194P + 0.000562 - 0.00000355P$$

Solve for P force in 6 wires

P = 78.5 lb on 6 wires

P = 13.1 lb on each wire

SOLDER JOINT SHEAR STRESS AT WIRE

The shear stress at the solder join for the wire in the plated through hole can be determined from the wire diameter of 0.040 in and the PCB thickness of 0.082 inches. Conservatively ignore any solder fillet greater than the thickness of the PCB. This will result in a slightly higher solder joint shear stress, S_s.

$$S_s = \frac{P}{A} \qquad (19)$$

Where: P = 13.1 lb
A = $\pi(0.040)(0.082) = 0.0103$ in^2

$$S_s = \frac{13.1}{0.0103} = 1272\ \text{lb/in}^2 \qquad (20)$$

SOLDER JOINT STRESS CYCLES FOR FAILURE ENVIRONMENT CONDITION F

The number of stress reversals or stress cycles required to produce a shear failure in the solder joint can be determined from the fatigue S-N curve for solder as shown in Fig. 2, along with Eq. (1). The environment conditions for Condition F were used to demonstrate this tool technique.

The reference point for the solder was at 600 psi where the expected fatigue life was about 5,000 stress cycles.

$$N_1 = N_2 \left(\frac{S_2}{S_1} \right)^b \qquad \text{Ref. Eq. (1)}$$

Where. N_2 = 5000 cycles to fail
S_2 = 600 lb/in² to fail
dt = 22 C Condition F Temp Delta

$$S_1 = \frac{22\ °C}{75\ °C}(1272) = 373\ \text{lb/in}^2$$

b = 2.5 Solder fatigue exponent

$$N_1 = (5000)\left(\frac{600}{373}\right)^{2.5}$$

$$N_1 = 16{,}408 \text{ cycles to fail} \qquad (21)$$

THERMAL FATIGUE CYCLE RATIO, CONDITION F

The thermal fatigue cycle ratio n/N based on 2700 thermal cycles expected for the 15 year exposure defined in Condition F can be determined as follows:

$$\frac{n}{N} = \frac{2700}{16{,}408} = 0\ 16455 \qquad (22)$$

This represents the cumulative fatigue damage developed during Condition F thermal cycling environment. This value is shown in Table 2 The same method of analysis must be performed for Conditions E, G and H for the thermal cycling environment. The results are shown in Table 2.

MINER'S CUMULATIVE FATIGUE DAMAGE FOR VIBRATION AND THERMAL CYCLING

The fatigue accumulated during vibration can be added to the fatigue accumulated during thermal cycling to obtain the combined vibration and thermal fatigue effects accumulated over the 15 year environment. This is accomplished by simply adding the vibration cycle ratio n/N (.20544) to the thermal cycle ratio n/N (.40933) to obtain the total value. The maximum n/N ratio allowed is 0.70. [7]

$$R_n = \frac{n}{N} = 0.20544 + 0.40933$$

$$R_n = 0\ 61477 \text{ Total Fatigue} \qquad (23)$$

Damage accumulation is linear, so it is possible to estimate the expected fatique life of the transformer by using a simple ratio as follows:

$$\text{Life} = \frac{0.70}{0.615}(15 \text{ years})$$

$$\text{Life} = 17.1 \text{ years} \qquad (24)$$

The maximum allowable n/N ratio for electronic equipment is 0.70. Since the above value is smaller, the equipment design is adequate for the 15 year environment, based upon the transformer analysis. The same type of analysis must be performed on every critical component on every PCB.

TABLE 1 VIBRATION FATIGUE LIFE OF TRANSFORMER LEAD WIRES

CONDITION	A	B	C	D
PCB Vibration G RMS response	11.2	6.1	15.9	3.8
Vibration time for 15 years, hours	1.0	2160	1.0	840
n_1 (1 σ) actual fatigue cycles	$.676 \times 10^6$	1.46×10^9	$.676 \times 10^6$	568×10^6
n_2 (2 σ) actual fatigue cycles	$.268 \times 10^6$	579.5×10^6	$.268 \times 10^6$	255.4×10^6
n_3 (3 σ) actual fatigue cycles	42.9×10^3	92.6×10^6	42.9×10^3	36.0×10^6
N_1 (1 σ) cycles to fail	1.939×10^{10}	9.5×10^{11}	2.059×10^9	1.959×10^{13}
N_2 (2 σ) cycles to fail	229.6×10^6	1.122×10^{10}	24.38×10^6	2.32×10^{11}
N_3 (3 σ) cycles to fail	17.14×10^6	837.4×10^6	1.82×10^6	1.73×10^{10}
n_1/N_1 (1 σ) ratio	.00003	.00154	.00033	.00003
n_2/N_2 (2 σ) ratio	.00117	.05165	.01099	.00097
n_3/N_3 (3 σ) ratio	.00250	.11058	.02357	.00208
Sum of n/N for each Condition	.00370	.16377	.03489	.00308

Vibration fatigue cycle n/N sum, 15 years = .00370+.16377+.03489+.00308 = .20544

This sum must be added to the thermal cycle fatigue to obtain the total fatigue, which is shown in Eq. (23) above.

TABLE 2 THERMAL CYCLE FATIGUE LIFE OF TRANSFORMER LEAD WIRES

CONDITION	E	F	G	H
Actual temperature range	140 °C	44 °C	40 °C	102 °C
Temperature range used for stress	70 C	22 C	20 C	51 C
Solder shear stress lb/in²	1186	373	339	864
n Actual number cycles accumulated	50	2700	2400	150
N Number of cycles for failure	910	16,408	20,838	2,009
Ratio: n/N for each Condition	.05495	.16455	.11517	.07466

Thermal fatigue cycle n/N sum, 15 years = .05495+.16455+.11517+.07466 = .40933

This sum must be added to the vibration fatigue cycle to obtain the total fatigue, which is shown in Eq. (23) above, and repeated below as follows:

Total fatigue ratio $R_n = \frac{n}{N}$ = .20544 + .40933 = .61477 Ref. Eq. (23)

REFERENCES

1. S. Crandal, Random Vibration, John Wiley & Sons Inc, 1958
2. R. N. Wild, Some Fatigue Properties of Solders and Solder Stresses, IBM Report 74Z00044S, July 1974
3. D. S. Steinberg, Cooling Techniques for Electronic Equipment, John Wiley & Sons Inc, 1980
4. Gert Becker, Testing and Results Mechanical Strength Solder Joints, IPC Meeting September 1979
5. Gerald L. Ginsberg, Automation is Key to Small Hole Processing, EPP Magazine August 1988
6. P. E Peterson, Stress Concentration Design Factors, John Wiley & Sons Inc. 1959
7. D S. Steinberg, Vibration Analysis for Electronic Equipment 2nd Edition 1988

Footnotes:

1. Reliability of Military Electronic Equipment, prepared by the Advisory Group on Reliability of Electronic Equipment, Office of the Assistant Secretary of Defense (Research and Engineering), 4 June 1957.

2. RADC/RBER is the custodian for MIL-HDBK-217, and is the responsible government agency for maintaining the document, coordinating changes and updating the document as necessary.

3. DoD 4120.3-M, Defense Standardization and Specification Program Policies, Procedures and Instructions, Office of the Under Secretary of Defense for Research and Engineering, Washington D. C. 20301, August 1978.

4. MIL-HDBK-217E included for the first time a failure rate prediction technique for Interconnection Assemblies with Plated Through Holes and Connections (solder joints). The primary failure mechanism for properly made PTHs, vias, and solder joints process is fatigue, a process that is deterministic in nature An appropriate life prediction would address the magnitude and number of cycles to first failure rather than a failure rate as provided by MIL-HDBK-217. The life of the PTHs and vias depends on the cumulative stresses applied (thermal cycling and vibration), the thickness of the printed wiring board, the coefficients of expansion of the board materials, the thickness of the PTHs and vias plus the metallurgy (composition and grain structure) of the copper plates. A similar set of variables govern the life of the solder in the joint. Thus, the idea that the failure rate model contained in MIL-HDBK-217 is an over simplification at best.

The following technical papers provide additional insight:

"Some Aspects of Solder Joint Fatigue During Thermal Cycling," Ronald G.Lambert, General Electric, IES Annual Technology Meeting, May 1987.

"Impact of External Lead Design on the Fracture of HIC-PWB Assemblies Subject to Bending," T. F. Marinis, R. C. Reinert, W.M. Sherry, AT&T Bell Laboratory, 1984.

"Mechanical Reliability for Low Cycle Fatigue," Ronald G. Lambert, General Electric, 1978 R&M Symposium.

"Reliability Parameters of Additive Plated Through Holes," William E. Greiner, Kollmorgen Corporation, IPC Annual Meeting, April 1983.

"The Characteristic Wearout Process in Epoxy-Glass Printed Circuits for High Density Electronic Packaging," J. N. Lahti, R. H. Delaney and J. N. Hines; AT&T Bell Labs, Proceedings of 17th Annual Reliability Physics Symposium, IEEE 1979.

"Leadless Chip Carrier Compatible Printed Wiring Boards," R. T. Lamoureux, Proceedings of 28th National SAMPE Symposium, April 1983.

"Fabricating Reliability into Flexible Printed Wiring," S. A. Hays, Proceedings of Technical Program of National Electronic Packaging Production Conference, March 1977.

"Thermal Characteristics of Multilayer Board—Phase II," R. Wild, IPC 20th Annual Meeting Orlando, April 1977

"A Test Method to Determine the Degree of Embrittlement in Electrodeposited Copper," L. Zakraysek, IPC 26th Annual Meeting, 10-14 April,1983. "

Strain-induced Failures in Plated Through Holes," J. K. Hagge, Proceedings of Printed Circuit World Expo '80, 1980.

"Subtle Conditions Leading to Printed Wiring Board Failures," W. P. Hussey, Proceedings of 28th National SAMPE Symposium, 12-13 April 1983

"Deterioration of Electronics in Storage," J. T. Menker, Proceedings of 28th National SAMPE Symposium, 12-13 April 1983

"Some Factors Affecting Leadless Chip Carrier Solder Joint Fatigue Life," J.K. Lake, R.N. Wild, IBM; 28th National SAMPLE Symposium, Apr 1983

"Some Factors Affecting Leadless Chip Carrier Solder Joint Fatigue Life II," R.N. Wild, 12th Annual Electronics Manufacturing Seminar, Feb 1988

"Predicting Fatigue Life of Leadless Chip Carriers Using Manson-Coffin Equation," J.K. Hagge, Proceedings International Electronic Packaging Conference, Nov 1982

"Surface Mount Solder Attachment Reliability Figures of Merit-Design for Reliability Tools," Clech et al, Proceedings of SMART V Conference, New Orleans, LA, Jan 1989

"Surface Mount Attachment Reliability of Clip Leaded Ceramic Chip Carriers on FR-4 Circuit Boards," W. Engelmaier, IEPS Journal, Vol 9, No 4, Jan 1988

"Fatigue Life Prediction for Low-Tin Lead-Based Solder at Low Strains," S. Vaynman and A. Zubelewicz, NWC TP 6986, EMPF TR 0007

"Surface Mount Attachment Reliability of Clip-Leaded Ceramic Chip Carriers on FR-4 Circuit Boards," W. Engelmaier and A. Attarwala, IEEE Transactions on Components Hybrids and Manufacturing Technology, Vol 12, No 2, Jun 1989

"Fatigue Life of a Leadless Chop Carrier Solder Joint During Power Cycling," W. Engelmaier, IEEE Transactions on Components and Hybrids and Manufacturing Technology, Vol CHMT6, No 3, Sep 1983

"Guidelines for Surface Mounting and Interconnecting Chip Carriers," M. Savrin, IPC-CM-78, Nov 1983

"Mass Soldering Equipment for the Electronics Industry," S. Karpel; International Tin Research Institute Paper No 127, 1981

"Solder Joint Fatigue: A Total Strain Versus Life Approach," D. Barker, A. Dasgupta, M. Pecht, J. Vodzak, ASME 89-WA/EEP-35, 1989 4. As reported in Reliability Maintainability Technology Transition-Fact Sheet, dated August 1990, and published by RADC/RBE, Griffiss AFB, NY 13441-5700, Westinghouse has developed new and updated reliability prediction models for Very Large Scale Integrated (VLSI), Memories, Gallium Arsenide (GaAs) Monolithic Microwave Integrated Circuits (MMIC), GaAs Digital and Hybrid components to address: packaging techniques and the use of deterministic models to account for end of life phenomena.... The major departure from previous reliability models in MIL-HDBK-217 is the proposed inclusion of effective hazard rate for the two predominate wear out failure mechanisms: electromigration and time-dependent dielectric breakdown. The fact sheet goes on to say: The failure modes reviewed and evaluated are: wire and wire bonds, die fatigue cracking, and corrosion. Specific time or cycle dependent models have been prepared for each of these failure modes. Unfortunately, the failure prediction model for each of these failure mechanisms has been reduced to a failure rate rather than a time to first failure which would recognize their deterministic. Also, the failure prediction model does not address the variations in design criteria, manufacturing processes, process control limits, etc.. which are used by different manufactures and affect the life of the product.

The following technical papers provide additional insight:

"Thermal Fatigue in Silicon Power Transistors," G.A. Lang, B.J. Fehder, W.D. Williams, IEEE Transactions on Electron Devices, Sep 1970

"Reliability and Control of Semiconductor Parameters for Switching Regulators," L.J. Gallace, W.R. Peterson, R.C.A. Technical Notes, Solid State Div., June 1975

"Reliability of New Plastic-Packaged Power Transistors for Consumer Applications," W.P. Bennett, L.J. Gallace, R.C.A, IEEE Conference on Broadcast and TV Receivers, June 1984

5. The following technical papers provide additional insight:

"Electromigration: An Overview," P.P. Merchant, Hewlett-Packard Journal, Aug 1982

"Electromigration, Thermal Analysis and Die Attach—A Case History," J. Partridge, A. Marques, R. Camp; 1982 International Reliability Physics Symposium

"Aluminum Electromigration Parameters," J. Partridge and G. Littlefield, 1985 International Reliability Physics Symposium

"Aluminum Electromigration Under Pulsed D.C. Conditions," J.M. Towner, E.P. Van de Ven, 1983 International Reliability Physics Symposium

"Breakdown Energy of Metal (BEM) - A New Technique for Monitoring Metallization Reliability at Wafer Lever," C.C. Hong and D.L. Crook, Intel, 1985 International Reliability Physics Symposium

"Wafer Level Electromigration Tests for Production Monitoring," B.J. Root and T. Turner, Mostek Corp., 1985 International Reliability Physics Symposium

"An Investigation on Switching-Rate Induced Electromigration," M.L. Cortes and R.K. Iyer; CRC Tech Report #86-22, Stanford Univ., Dec 1986

6. The following technical papers provide additional insight:

"Low Field Time Dependent Dielectric Integrity," E.S. Anolick and G.R. Nelson, IBM, Proceedings of 17th Annual Reliability Physics Symposium, IEEE 1979

"Method of Determining Reliability Screens for Time Dependent Dielectric Breakdown," D.L. Crook, Intel, Proceedings of 17th Annual Reliability Physics Symposium, IEEE 1979

"Time Dependent Dielectric Breakdown of Thin Thermally Grown SiO_2 Films," K. Yamabe and K. Taniguchi, IEEE Transactions on Electron Devices, Vol. ED-32, Feb 1985

"Model for Oxide Wearout Due to Charge Trapping," W.K. Meyer and Dwight L. Crook, IEEE International Reliability Physics Symposium, 1983

"Acceleration Factors for Thin Gate Oxide Stressing," J.W. McPherson and D.A. Baglee, IEEE International Reliability Physics Symposium, 1985

"Accelerated Testing of Time-Dependent Breakdown of SiO ," I.C. Chen and Chenming Hu, IEEE Electron Device Letters, Vol. EDL-8, No. 4, April 1987

"Behavior of SiO_2 Under Electric Field/Current Stress Conditions," IEEE International Reliability Physics Symposium, 1986

Bibliography:

1. Reliability of Military Electronic Equipment Report by the Advisory Group on Reliability of Electronic Equipment, Office of the Assistant Secretary of Defense (Research and Engineering) dated 4 June 1957

2. MIL-STD-1843 Reliability-centered Maintenance for Aircraft, Engines, and Equipment, dated 08 Feb. 1985

3. MIL-STD-785B, Reliability Program for Systems and Equipment Development and Production, dated 03 Jul. 1986

4. MIL-STD-1521B, Technical Reviews and Audits for Systems, Equipments, and Computer Software, dated 19 Dec. 1985

5. MIL-STD-454J, Standard General Requirements for Electronic Equipment, dated 26 Feb. 1987

6. MIL-E-5400T, Electronic Equipment, Aerospace, General Requirements for, 09 May 1986

7. RADC-TR-82-177, Reliability Parts Derating Guidelines, AD-A22036 dated June 1982

8. AS-1463 Naval Air Systems Command, Department of the Navy, Application and Derating Requirements for Electronic Components, General Specification for, dated 30 July 1976

9. MIL-STD-810D, Environmental Test Methods and Engineering Guidelines, dated 31 Jan. 1986

10. MIL-HDBK-217E, Reliability Prediction of Electronic Equipment

11. MIL-HDBK-217 Use and Application, Technical Brief, dated April 1990, by Mr. Seymour F. Morris, Rome Air Development Center, RADC/RBER, Griffiss AFB, NY 13441-5700, published by the Reliability Analysis Center-A DoD Information Analysis Center.

12 DoD 4120 3M, Defense Standardization and Specification Program Policies, Procedures, and Instructions dated August 1976.

13. MIL-STD-965A, Parts Control Program, dated 13 December 1985.

14. Reliability Review, March 1990

15. Reliability Maintainability Technology Transition-Fact Sheet, dated August 1990, Rome Air Development Center, RADC/RBE, Griffiss AFB, NY 13441-5700.

16 Cooling Techniques for Electronic Equipment, by Mr. Dave S. Steinberg, Published by John Wiley and Sons, 1980

17. Vibration Analysis for Electronic Equipment, by Mr. Dave S. Steinberg, published by John Wiley and Sons, 1973 (revised 1988)

18. Thermal Cycling Reliability Life Model for Avionics, AFWAL-TR-87-3075, Apr. 1987, WRDC/FIVE, WPAFB, OH 45433

19 Vibration Stress Analysis of Avionics, AFWAL-TR-87-3023, Apr. 1987, WRDC/FIVE, WPAFB, OH 45433

20. Vibration Reliability Life Model for Avionics, AFWAL-TR-87-3048, Sep. 1987, WRDC/FIVE, WPAFB, OH 45433

21. Tools Available for Implementing AVIP, Dave S. Steinberg, AVIP Conference, IEEE/AESS, Nov. 1988

22. MIL-A-87244, Avionics/electronics Integrity Program Requirements, dated 31 Jul. 1986

IMPLICATIONS OF INTEROPERABILITY AND STANDARDIZATION FOR THE INDUSTRIAL BASE

DR. JOHN C. STUELPNAGEL
MANAGER, DIGITAL SYSTEMS
WESTINGHOUSE ELECTRIC CORPORATION
BALTIMORE, MARYLAND 21203

SUMMARY

A persistent problem for NATO forces has been the difficulty of standardization and interoperability, due to conflicting political, economic, national and industrial pressures. One approach to better accomplish standardization objectives has been the establishment of co-development programs, such as the VHSIC Avionics Modular Processor program, in which the french and United States Governments have initiated the development of interoperable digital processing modules. However, conflicts in timing between development efforts and schedules for production and deployment of aircraft platforms has resulted in limited use of such modules in major aircraft programs. Several models for NATO standardization organizations will be discussed which could address this problem and achieve significantly higher levels of interoperability in operational NATO equipment.

INTRODUCTION

Good morning, distinguished visitors to the AGARD Lecture Series. Thank you for inviting me to present the industrial point of view on this important issue.

The previous speakers provided a comprehensive historical review of avionics architecture, software, and hardware standardization. The afternoon speakers will address avionics technology and needs beyond 2000. I feel that the implications of interoperability and standardization for the industrial base is appropriately placed at this point in the schedule because the electronics industrial base, which clearly impacts on avionics, is the link between where we are today and where we will go tomorrow.

Before addressing the specifics of my subject, I will present my view of the electronics environment in today's world. Unlike some technologies which are driven by the military market, and others which are driven by the commercial market, the electronics technology is driven by both the military and commercial marketplace. That is, electronics is a shared technology. Military developed electronics have flowed to the commercial market, and we see more and more commercially developed electronics flowing to defense applications.

Electronics is also characterized by rapid growth and change. This is obvious to all of you who work in the industry. This rapid growth and change significantly impacts on the the industrial base as well as the customer base, especially relative to attempts to define and implement standards.

Finally, electronics is very big business, an expen business, and a very competitive business.

IMPLICATIONS OF INTEROPERABILITY AND STANDARDIZATION

For the purpose of this paper, I will focus on avionics standardization in the simplest of terms, rather than the global definitions of standardization and interoperability. My reason for doing this is to avoid the economic and political implications that surround both macro-level issues and to concentrate on the micro-level issues of standardized avionics. More specifically, I will begin by discussing what a standard is and who sets the de facto standard in the broadest sense. I will then proceed into the .. cations of standardization as it applies to avionics.

If I were to ask this group to define a standard and identify the body which sets the standard, I am sure that we would have a lively discussion. From my perspective in industry, I will state simply that the standard is that which is accepted by the competitive marketplace, and that the customer base establishes the de facto standards. In essence, the standard evolves through acceptance of a product by the consumer.

For example, let us look at the personal computer market. The Personal Computer (PC) is the standard because of its overwhelming market share. Although there are other personal computers in the marketplace, the majority tend to be PC clones, with Macintosh being the notable exception. The fundamental reason is economics, both for the customer and the manufacturers of PC compatible hardware, software applications, and compilers.

Because Personal Computers dominated the market initially and provided a lucrative business opportunity for other sectors of the electronics industry, vast amounts of capital were invested in supporting software, compilers and peripheral hardware. If your hardware or software was not compatible with the Personal Computer standard, you were required to develop the interface necessary in order to market your innovation.

Like hardware standardization, software also evolves through acceptance and use in the market. For example, the COBOL computer language accounts for 85% of all software applications in the world, followed by "C" language which has a 7% share, and all remaining languages a mere 8% of the world market. Again, the market established the de facto standard.

F-16 AVIONICS

The avionics business is very similar to the personnel computer business. In terms of a standard, the F-16 has become the PC of modern day fighter aircraft simply because it has gained customer acceptance and has been fielded in relatively large quantities throughout the world. Consequently, the F-16 avionics have evolved as the avionics standard for the US and many of its allies.

A network of personal computers, or general purpose processors, is very much like aircraft avionics which is fundamentally a network of integrated and custom designed processors (computers) linked to a variety of sensors or weapons systems.

Initial performance specifications developed for PCs were based on market surveys and analyses of perceived customer needs; the process used by the USAF was, in many ways, very similar. Laboratories developed specifications based upon the perceived needs of using commands based upon surveys and analyses of threat capabilities.

The result was a system architecture that focused on the integration of avionics sub-systems through the use of a set of specifications for a "Bus" and "Central Processing Unit." That is, the specifications focused on the interfaces between systems. So long as the subsystems were compatible with the Bus and CPU specifications, the design of the sub-systems was constrained only by performance requirements. The advantage of this architecture, based on interface specifications between subsystems, was that incremental improvements or additions to the avionics suites could be integrated without a total redesign of the avionics system.

Standardization in the F-16 program centered on the 1553 Bus and the 1750 CPU. The Avionics Subsystems simply had to meet these interface requirements.

LH AND ATF AVIONICS

In the ATF (now the F-22) and LH (now the RAH-66 Comanche) programs, a modular avionics architecture will be used. Rather than focusing on a standard interface between subsystems, the standard interface will be the backplane between data and signal processing modules. Module designs for data processing will use the INTEL 80960 32-Bit CPU, and Ada software.

Despite having standard specifications, we still have not "standardized" modular avionics in the LH and ATF. The "standardization" evolution is progressing, however, now that the contracts for the Lockheed YF-22 and the Boeing-Sikorsky Comanche were awarded. The Intel 80960 CPU will be the standard avionics processor in both systems and Ada will be the standard language. Had the Northrop YF-23 been selected for the ATF, the MIPS CPU would have been used and this opportunity for standardization across platforms would have disappeared. Through chance rather than design, a level of standardization will be achieved for the peripheral compiler.

With regard to the backplane, or the use of common modules in the RAH-66 Comanche and F-22, the issues are still being worked. A significant opportunity for the use of common modules in both systems lies ahead of us. Although both programs were originally intended to have identical specifications for the modular processors that were developed through the JIAWG and MASA, development of the modular processors is being done by different electronics companies and may have differences in implementation details that make them non-identical.

The fundamental fact is that standard specifications do not necessarily lead to interoperable equipment. Unless the avionics and avionics integration were being accomplished by the same company, and cost, schedule, operating system and performance supported standardization between both systems, complete and total standardization would probably not be achieved.

TIMING

Major aircraft programs influence avionics standardization more than do STANAGS or standardization studies. The reason is that the aircraft program will take advantage of the state-of-the-art electronic technologies during the development period. In turn, the standards evolve for that generation of aircraft. Without a vehicle (aircraft) to standardize to, a set of specifications will not make the transition from paper to hardware.

Take for example the current multi-national ASAAC (Allied Standard Avionics Architecture Council). The purpose of the Council is to develop a standard avionics architecture. The resulting product will not be ready for the F-22, EFA, and the RAFALE programs which are already in development. In fact, industry is pressing forward with the F-22, EFA, and RAFALE avionics architectures. Ultimately, whatever document emerges from ASAAC, will be of little immediate application, unless there is a major avionics upgrade to these aircraft. In all likelihood, the ASAAC results would be used as a point of departure for future program specific requirements.

The standardization issue at the national level in the US is less complex than that at the international level, however, the outcome is generally the same; we fall short of ambitious objectives. Ideally, the JIAWG should have established an avionics architecture standard for the LH, ATF, and ATA. In reality, it could not. The program cost, schedule, and performance were and will continue to be the over-riding factors. Standard Avionics will likely be relegated to a second or third tier consideration in program decisions.

The industrial perspective is quite simple; meet the cost, schedule and performance requirements first and foremost. Standardization will evolve, to whatever extent is practicable during FSD and be fixed during production.

MODULAR AVIONICS

One research program in the US which has had a profound effect on the current generation of avionics which will be used in the RAH-66 Comanche and F- 22 programs and, as well, in the F-16 Mid Life Update program is the USAF VHSIC Avionics Modular Processor (VAMP). This research and development effort focused on a processing requirement several orders of magnitude greater than the previous generation of avionics. The architecture was driven by the electronic advancements in a variety of sensor systems and weapons systems that demanded vastly more powerful processing that could integrate the data in real time.

In the early 1980's, the data and signal processing requirements for the new generation of integrated sensor and weapons system requirements were addressed in a coordinated research plan. Concurrently, JIAWG and MASA monitored and directed the research to make the most advantageous use of electronics developments in both the commercial and military communities

The architecture envisioned the use of a High Speed Fiber Optic Data Bus for transfer of raw data in the 50MHz range, massively parallel array processors for signal data in the range of 500–750 MOPS, the instantaneous transfer of processed signal data to a digital processor, SEM-E modules, and higher speed 32 bit RISC processors, integrated into a single modular avionics processor.

The basic research on modular avionics was very successful. The product of the US effort was a modular data processor that in [illegible] 750A CPU Module, a 1553 Data Bus Module. The research was extended to the international community via cooperative development projects with France and Germany. The French VAMP program addressed the integration of a Non-Volatile Memory Module, and a 32 Bit 68020-based CPU processing module. The German VAMP program will incorporate display [illegible]s. In each element of the program, valuable insights were gained by both the military and industrial participants.

These insights laid the groundwork for the RAH-66 Comanche and F-22 program specifications for full scale development. Without the concurrent R&D effort and full participation by both government and industry, the avionics packages envisioned for the RAH-66 Comanche and F-22 would not have progressed to this point.

MILITARY - INDUSTRIAL COOPERATION

Key to the military avionics standardization process in todays electronic environment is military-industrial cooperation beginning during the basic research phase of avionics concept development and continuing through Full Scale Development. This cooperation should be accomplished at both the national and international level on a continuing basis if it serves no other purpose than to establish a baseline of departure for potential cooperative programs.

As I discussed earlier, the RAH-66 Comanche and F-22 avionics specifications were greatly influenced by the success of the modular avionics research program as well as the JIAWG and MASA efforts in the US. The US military and US industry were positioned to take full advantage of the lessons learned in the research effort and apply them in a relatively short time to the FSD programs. Program cost, schedule and technical risk were reduced to an acceptable level.

At the international level, ASAAC provides the same opportunity for future avionics programs if their work is tied to cooperative research. However, some major obstacles must be overcome before ASAAC can achieve mutually acceptable results for all participants.

The US is in a position to offer a baseline for future avionics architectures but there appears to be an unwillingness of the European participants to accept the US JIAWG and MASA products as a point of departure. Lacking an agreement on the US work as a point of departure, the US would get no return on any investment that requires a return to basic studies that have already been completed . The reluctance of the European participants, on the other hand, to accept the US baseline is understandable since their military needs and their industrial investments may not be satisfied by the US baseline.

The timing for ASAAC may simply not be in the best interest of all participants in the absence of a major international program to which the results could be applied. Nonetheless, a mutual understanding of the leading edge electronics technology by both the military and industrial participants is needed to establish a baseline technological approach. To this end, in the absence of a multi-national program, NATO should establish an entity that would maintain an up-to-date set of avionics electronics specifications.

The principal issue to be decided is whether or not an organization dedicated to the maintenance of an up-to-date set of baseline avionics electronics specifications is of value. Once this issue is decided, the type of organization and funding sources, either government, industry, or private, or any combination thereof, can be addressed. The full range of standardization organizations exists today, from those staffed and funded by the government to those which are non-profit foundations supported by grants from industry.

SOME MODELS FOR STANDARDIZATION

As you are well aware, a standardization organization or multiple standardization organizations for everything from soup to nuts exist. If a standard does not exist, someone will eventually fill the void. These organizations come in all sizes and shapes. My purpose is simply to identify a few different types of organizations which influence standards in the commercial and military electronics arena that could be used as a model for future military avionics requirements in the international arena. These organizations include, but are certainly not limited to the following:

Acronautical Radio, Incorporated (ARINC) – A private corporation that coordinates Communications and Avionics Standards among the airlines and the airframe manufacturers. Much of this work is accomplished through open forums on avionics specifications, aircraft installation provisions, and standards for test equipment.

Airlines Electronic Engineering Committee (AEEC) – A special organization within ARINC which is fully funded by the airframe manufacturers. It is the focal point for the commercial airframe manufacturers and avionics equipment designers, the Federal Aviation Administration, and the international aviation community to develop the next generation avionic guidance and specifications for commercial modular avionics.

Open Software Foundation (OSF) – OSF is incorporated as a non-profit, industry supported research and development organization.This international organization was created to define specifications, develop leadership software, and make available an open, portable software environment. The foundation complements the work of various worldwide software organizations, and will provide implementations consistent with those standards.

Next Generation Computer Resources (NGCR) – The US Navy, under the auspices of the NGCR, has established a Project Support Environment Standards Working Group (PSESWG). The purpose of this US Navy funded joint industry/US Navy working group is to establish interface, protocol and service standards for mandatory use in future US Navy systems developments The specific objective is to select/define a set of industry-based standards to form an "open" framework for project support environment tools, user interfaces, database management systems, which will be applied in the development and maintenance of future US Navy programs.

These are but a few organizations which are focusing on the next generation of hardware and software for electronic systems. The common thread between these organizations is an attempt to establish a comprehensive baseline with respect to state-of-the-art, evolving technologies, in the electronics world.

CONCLUSION

The concepts and ideal of interoperability and standardization are fully appreciated and embraced at the national resource level. The reality of standardized avionics does not approach the grand concepts. Philosophically, however, we should not abandon these concepts, otherwise total chaos would reign. As imperfect as the process and as elusive as the goals may be, any movement toward that goal is commendable and worth the effort.

The degree to which standardization is achieved is a function of products accepted by the customer. Without a product and a customer, standards exist only on paper. This is the case in both the commercial and military market.

Standards in the commercial processor market are evolutionary and guaranteed to be de facto standards. In the military market, standard specifications, are provided, however, they in themselves do not guarantee a standard product. Two competitors designing a piece of hardware to the same specification will undoubtedly produce noncompatible components. One would assume that since the RAH-66 Comanche and F-22 avionics interface specifications were identical, modules would be interchangeable, but this is not assured to be the case. Despite the efforts of JIAWG and MASA, agreement on a CPU could not be reached prior to contractor selection. Through chance, the winning contractors both selected the INTEL CPU, and degrees of standardization will be achieved through the use of a common compiler.

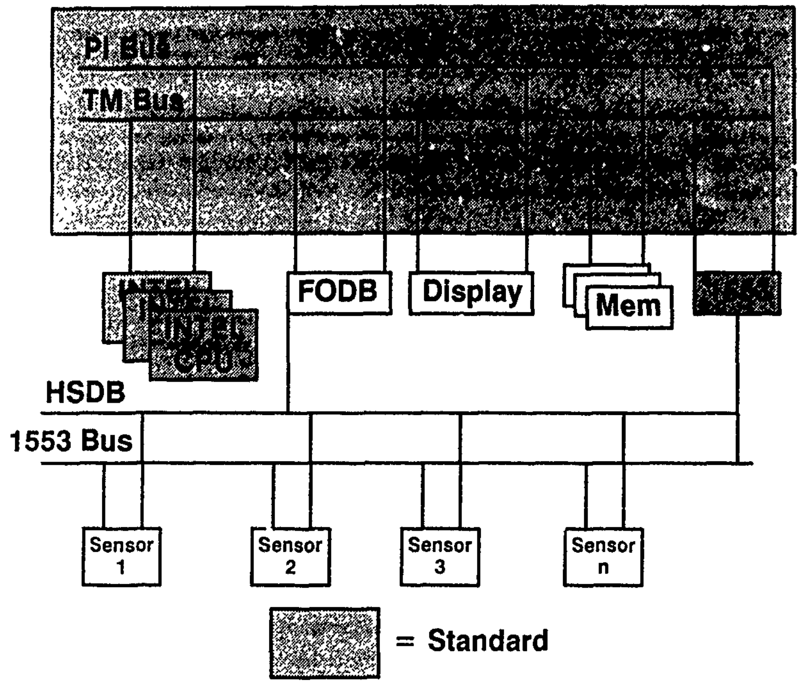
In the environment where program cost, performance and schedule dominate the decision process, and standardization is a second or third tier consideration, total standardization will not likely be achieved on the national level. Internationally, where operational requirements must be harmonized before a development and production decision, and national political and economic considerations are also dominant, the achievement of international standardization becomes even more difficult.

The greatest opportunity for international standardization in military avionics will come from government sponsored ASAAC – like activities when a target airframe is identified and a cooperative development is initiated. Again, however, the standardization will be limited to that particular aircraft. The aircraft market is so small and developments so separated by time and growing requirements that total standardization amongst the total fleet of aircraft is unreasonable to expect.

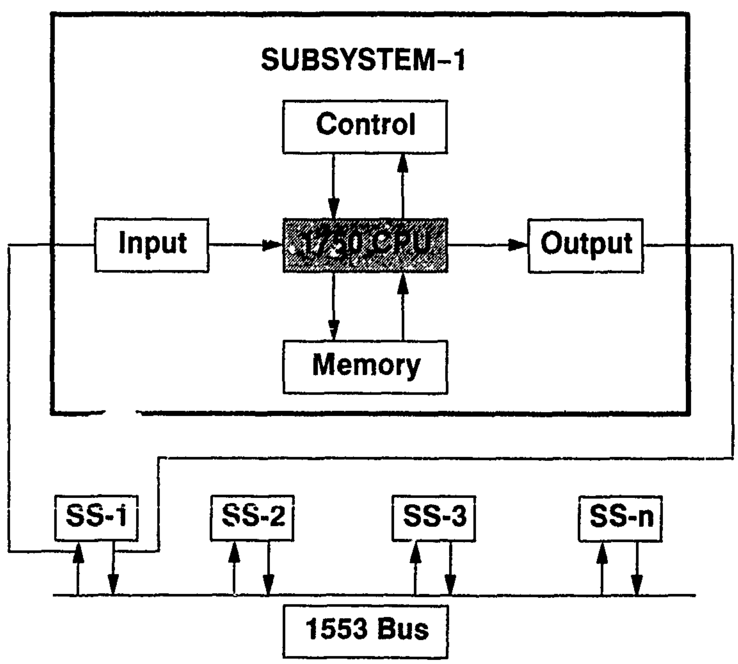
Industry, on the other hand should not realistically expect their respective governments to maintain updated specifications for electronics . I suggest that government and industry, on both the national and international levels, should pursue the establishment of an organization to maintain electronics standards for avionics that could be applied to military avionics. In the absence of an international co-development program, this is the most logical and supportable alternative. The information could be used by the military as an information baseline for developing military specifications that will lead to the greatest degree of industrial standardization.

In closing, the implications of interoperability and standardization for industries involved in the avionics business is still driven by the military organization. We will build to whatever standard the customer desires, provided that the opportunity to make a profit is presented. In order to be in a position to win the business, we must stay abreast of the state-of-the- art design, engineering, and manufacturing processes of the electronics industry and provide a competitively priced, quality product that meets cost, schedule and performance requirements. The latter are the most important standards for long term survival.

RAH-66 and F-22 Architecture



F-16 Architecture



AVIONICS TECHNOLOGY BEYOND 2000

by
L. McFawn and D. R. Morgan
Wright Laboratory
Avionics Directorate, WL/AA
Wright-Patterson AFB OH 45433-6543
U.S.A.

SUMMARY

If current trends continue, military avionics will face a very difficult situation at the turn of the century. This situation is predicted despite impressive strides made in avionics performance, reduced weight per function, reduced cost per function, and a steady improvement in hardware reliability over the past 20 years.

We want and need affordable performance with little or no support required. However, the projected avionics performance improvements needed for increased situation awareness and automation, the escalating costs of software and sensors, and the manpower and ground facility support limitations imposed by austere base operation are currently incompatible. If we are unable to achieve a reasonably balanced affordability/availability/performance capability triad, there will be no other option than to substantially reduce either the number of weapon systems or their war-fighting capability.

The basic architectural framework and modular avionics strategy (viz., PAVE PILLAR) needed to achieve this triad will soon be in place. Most of the needed enabling technologies are under development. The next step will be to carefully exploit, integrate, and validate these technologies in bold, innovative ways. Dramatic changes will be needed in the way we integrate and share sensor functions; in the way we develop and support software; and in the design environments we use. Some of these changes will induce "culture shock" and will not be welcomed at first. However, the authors believe that the improvements needed in future avionics cannot be realized by evolutionary methods.

1. CHALLENGES FOR EARLY 21ST CENTURY AVIONICS

This section contains the authors' opinions of the projected factors that will fundamentally impact future avionics systems and the implications of these factors.

The Need to Improve Performance

It is reasonable to project that stealth will become a primary design consideration for mar. new airborne military systems. Achieving avionics stealth while providing sufficient data to inform the aircrew of threat, terrain, and targeting information implies the following:

a. Electronic Support Measures (ESM) and Infrared Search and Track (IRST) passive sensors will be increasingly important on-board sources of information for air-to-air missions; use of Forward Looking Infrared (FLIR), laser radar (LADAR), stored terrain data, and power managed radars will be the primary on-board sensors for air-to-ground missions.

b. Externally derived data (bistatically developed, from Joint Tactical Information Distribution System, etc.) will need to be integrated to complement on-board sensors. Additionally, flight-wide to force-wide exchange/coordination of data will become much more important.

c. Active sensors will still be required, but they will be designed with low probability of intercept characteristics. They will be invoked and controlled through automated means to complement passively derived data. Sensor control strategies will be extremely complex with parameters such as signal strength, dwell time, and beam/null steering being carefully controlled.

d. Significantly enhanced automating aids will be required. Use of artificial intelligence and neural network technologies will be needed to routinely aid pilot decision aiding. Automatic target recognition for both ground and air targets will become mandatory.

e. Data from on-board/off-board passive sources, integrated sources, and active sources will need to be fused and coordinated as a function of dynamic mission situations. On-board actively derived data from radar, communication/navigation/identification (CNI), and electronic warfare (EW) will need to be integrated.

Achieving these capabilities will require significant advances in sensors and sensor signal processing. We will need to put the equivalent of teraop (10^{12} operations) super computers into future avionics.

The Need for Lower Avionics Costs

Achieving stealthy situation awareness from an airborne platform could conceivably become so complex and costly as to prohibit its widespread use. The software complexity alone could overwhelm us. Consider the massive costs and difficulty being experienced today for "simple" software; and then consider how we will ever design, develop, and debug real-time artificial intelligence (AI)-based software that simultaneously controls, fuses, and reconfigures such a complex system across diverse systems. When one considers the enormity of the cost and effort of developing and supporting the software across several aircraft having complex sensor systems, it becomes apparent that fundamentally and dramatically new, more efficient means of designing, developing, and supporting software will be mandatory.

Figure 1 shows the historical increase in on-board programmable memory and processor speed in military aircraft. Signal processing requirements for next-generation fighter aircraft will reach approximately 10-20 billion operations per second (BOPS) with a need for 100-200 MBytes of memory (Ref 1). Obviously, when the aforementioned sensor processing and automation processing capabilities are considered, even more dramatic speeds (e.g., 1000 BOPS) are expected soon after the turn of the century.

Figure 2 shows how the cost of software required to fill Air Force needs is steadily growing (Ref 2). For a modern fighter, we can expect to spend $1.5B to develop the code and $3-4B to support it over the weapon's life cycle. Although our efficiency in developing real-time software is improving at 3-4% per year, the demand is growing at about 12% per year. We are falling behind, and the job is becoming harder.

Figure 3 shows the dramatic shift from hardware-based solutions to software-based solutions (Ref 3). Despite the immense costs and manpower shortfall brought on by real-time avionics software, its ability to permit flexibility and ease of growth to respond to the threat still remains a lower cost alternative to hardware-based solutions.

Avionics hardware costs have also been escalating in response to performance and system adaptability needs. Figure 4 shows the historical trend in avionics cost as a percentage of weapon system flyaway cost. It has been estimated that hardware sparing, repair, and maintenance costs can be four to five times as much as the flyaway cost.

What are the primary cost, reliability, weight, power, and volume drivers for avionics hardware? Although the answer to this question cannot be obtained unless the exact configuration of the aircraft is known, general trend information is revealing.

As an example, it is highly informative to compare the relative cost, weight, volume, electrical power, and reliability of avionics for a conceptual multipurpose (air-to-air and air-to-ground) fighter using today's technology. Figure 5 (Ref 4) shows the above breakdown for sensors (multifunction integrated radar, EW, CNI, FLIR, terrain map), Integrated Core Processing (ICP) (data and signal processing), along with stores processing, vehicle management system (VMS), system mass memory, and displays and controls.

Note the sheer dominance of sensors in all categories. This should not be surprising when one considers the function of avionics is to sense or recall stored information of the entire outside world, provide information for presentation to the aircrew, and provide information to the stores and vehicle control systems. It is precisely this outside world, requiring improved sensing, which has become so extremely complex and difficult (e.g., numerical superiority of threats, stealth, robust electronic intelligence, desire for cooperative/internetted operation with friendlies, the desire to operate in adverse weather and at low altitudes, etc.). Data and signal processor hardware and software, controls/displays, and avionic architectures simply "operate" on the fundamental sensor data, reformatting, storing, transporting, processing, and displaying it. And, potentially compounding the sensor cost and complexity situation around the turn of the century will be the onset of advanced sensors and algorithms with dramatic new capabilities. Interflight data will be exchanged automatically with regularity; bistatic radar operation, where the emitter is in a sanctuary location, will become a commonplace tactic; ground targets will be automatically recognized, using on-board Synthetic Aperture Radar, laser radar (LADAR), and FLIR. Some sensor components will be housed on Unmanned Aerial Vehicles having offensive and defensive missions.

Sensor cost will be the fundamental driver in determining what performance capability we will achieve (afford) in the early 21st century for military aircraft. It must be driven down; and associated sensor weight, volume, and electrical power must be controlled. The same concepts of commonality, modularity, standardization, and sharing that have dramatically reduced the cost-per-performance ratio for the ICP portion of the avionics system must be applied to the sensor portion. Solutions are on the horizon. Both radio frequency (RF) and electro-optical (EO) apertures can be shared if the results of current day research and development (R&D) programs are exploited (e.g., radar/ESM/CNI, FLIR/IRST); a common, modular family of supercomputer quality preprocessors and signal processors is becoming a reality, modular RF receivers appear promising, work on a sensor network architecture that enables the switching and data distribution of sensor data has begun, and design efforts for integrated sensor systems are underway. As shown in Figure 4, the steadily growing (almost straight line) percentage flyaway cost of avionics for fighter aircraft (12% for the F-4 in 1960 to about 35% for new fighter aircraft) must be halted. Integrated sensor systems, to be described later, hold out the greatest promise of stabilizing this trend, assuming software cost trends can be also stabilized.

The Need for Improved Avionics Availability

The projected support environment for Air Force avionics around the year 2000 will force fundamental changes in electronics design, packaging, and cooling. The "Air Force Reliability and Maintainability (R&M) 2000" report portrays an immensely challenging situation for the avionics support community (Ref 5). The report emphasizes the need to plan for austere support conditions, dramatically improve avionics reliability, simplify maintainability, and reduce flight-line personnel, thereby reducing dependencies on the supply pipeline.

The authors believe that the "R&M 2000" scenario implies that the following characteristics are needed for 21st century avionics: (1) we must extend the use of modular electronics across a wide spectrum of avionics applications; (2) the number of different module types must be kept to a minimum to allow a full complement of spares to be carried on a small ground-based vehicle; (3) pervasive use of built in test/system integrated test with AI programs is needed, along with more extensive use of fault tolerance; (4) the concept of deferred or scheduled maintenance for avionics will need to be implemented, where graceful degradation concepts are built into virtually every module; and (5) advanced packaging and cooling technologies must be implemented to improve reliability.

The High Reliability Fighter (HRF) Concept Investigation undertaken by ASD/XR describes the reliability levels we may be able to achieve at the start of the 21st century. This study developed a baseline aircraft for comparison purposes consisting of the composite of 50 or so of the most reliable subsystems in the inventory (4.35 hours mean time between failure [MTBF] for the entire weapon system). By applying the reliability enhancements projected in airframes, engines, and avionics, the HRF was projected as having a 40 hour serial MTBF, with the avionics system MTBF at around 186 hours (compared with 12.6 hours baseline composite). By using redundancy, mean time between critical failure (MTBCF) figures of 150 hours were projected for the weapon system (Ref 6).

Challenge

The preceding discussions highlight the formidable challenge of simultaneously improving performance, lowering cost, and improving the availability of future military avionics. The remainder of the paper offers projected solutions in three broad areas: (1) avionics architecture, including the technology enabling "infrastructure" of processing, packaging and cooling, networks and switching circuitry, and the concept of integrated sensor systems; (2) avionics software; and (3) avionics design environments.

2. AVIONICS ARCHITECTURE

Trends

Figure 6 shows a portrayal of the federated architecture being flown in a vast majority of today's U.S. military aircraft. Sensors, processors, and displays are usually stand-alone "black box entities." Physical integration is achieved by STANAG 3838 (MIL STD 1553B) data bus(ses), with information integration provided by the crew which assimulates and interprets display information. Data processing has been generally standardized (e.g., MIL STD 1750A, 16-bit computers for USAF aircraft), with JOVIAL (again for the USAF) being the common software language. Separate sensors have their own chain of apertures, transmitters, receivers, preprocessors, signal processors, and sometimes, displays. Multifunction displays are frequently used. System control is provided by a close-coupling between crew (switch activation) and a real-time, centrally located operating system resident in a standard data processor. Reconfiguration due to a bus failure is employed.

This federated architecture stems from pioneering work accomplished by the Wright Laboratory Avionics Directorate's Digital Avionics Information System program and has been highly successful. However, system limitations are being observed for highly complex avionics suites. These limitations include:

a. inadequate bus bandwidth (1 megabit per second [MBPS]), resulting in several buses being required;

b. lack of robustness in operating system control for complex subsystems that need bus control to accomplish data servicing;

c. highly limited fault tolerance capability;

d. limited standardization;

e. dependence on intermediate shops at air base to affect repairs, thereby incurring added hundreds of millions of dollars of cost over the avionics life cycle.

The Integrated Avionics Architecture shown in Figure 7 solves many of the limitations and forms the baseline architecture as we enter the 21st century. This architecture was developed by the Wright Laboratory Avionics Directorate and is being employed on the Advanced Tactical Fighter (F-22) and the RAH-66 (LH) helicopter. One extremely important aspect of this architecture is the appearance of integrated functional subsystems--viz., the integration of CNI functions and EW functions to affect tighter control and sharing of resources, the appearance of a Vehicle Management System (VMS) (the integration of flight, propulsion, electrical, and utilities control), and an integrated stores management system. With the exception of high bandwidth sensor signals, data and control information is exchanged over the interconnect network under control of core processing. Because VMS is safety-of-flight critical and stores are safety critical, each integrated functional system has its own control resources and can reject data received from the interconnect network. In order to accommodate high bandwidth signals between processing centers and the cockpit or sensors, a High Speed Data Bus (HSDB) "Interconnect Network" has been added (a linear token passing distributed protocol operating over a 50 MBPS fiber optic link). Graphics-based, synthesized displays provide improved situation awareness. Separate sensors send digitized, high data rate, preprocessor signals (e.g., 800 MBPS) through point-point (see Data Net block on Figure 7) fiber optic links to the "Core Processing" which includes both signal and data processing. This architecture framework can be described as "open" in that it does not preclude the use of other networks or configuration approaches within the various functionally integrated systems. For example, STANAG 3838 can be used within the VMS, and MIL STD 1760 can be used within the stores system. And, although the core processing is implemented through a controlled family of standard form, fit, and function modules (which are replaceable at the flight time with no intermediate shop repair required), "black boxes" could be used for the VMS system. Further, if a network of STANAG 3838 (MIL STD 1553B) based avionics boxes were to be used, the designer simply uses a HSDB/1553B input/output (I/O) module, which is one member of the standard family of digital modules. Standard modules include I/O, power supplies, network switching, sensor interface, global memory, 16 bit and 32 bit data processing, and floating point processing for virtually any data or signal processing function. A limited number of custom modules are needed for EW and CNI signal processing.

Referring to Figure 8, we see how the family of common modules are "mixed and matched" to create processing clusters for signal and data processing, along with pooled spares for purposes of reconfiguration in the event of module failure during flight. This process requires the extensive use of chip-level built-in-test and an operating system capable of reconfiguring to a desired state. An Ada-based operating system and application programs are used. The form, fit, and function of all digital and support modules, associated connectors, backplane buses and switches, and method of cooling is governed by a Tri-Service organization called the Joint Integrated Avionics Working Group (JIAWG) to ensure high-volume, low-cost module use through force-wide deployment.

From a family of roughly 20 different modules (including power supplies and input/output modules), virtually any signal of data processing function can be implemented, possibly using a total of 200-300 modules. Modules are edge cooled through a conduction heat exchange from the module center plate and the ribs (top and bottom) located in the rack. The working fluid is pumped through cavities in the rack to enable easy flight-line replacement. A typical module weighs about 0.75 kg, is approximately 15x15x1.5 cm in dimension, and has an approximate reliability of 10,000 hrs MTBF. Currently, 32 bit data processor modules operate at 20 million instructions per second and a Floating Point Processing Element module operates at 125-150 million FLOPS using Very Large Scale Integration technology. A module generating 40-50 watts can be cooled to around 80 degrees junction temperature. Intermodule communication is supported by robust data network and switch traffic across a 24-28 layer backplane (controlled by the JIAWG organization). Figure 9 shows a Common Signal Processor. Overall network control resides with a Data Processing Module which is connected to a dual Parallel Interface bus (backplane bus, 25 Megawords/sec) or to a Testing/Maintenance backplane bus which supports testing on a noninterference basis. High speed digitized sensor data enters the processing complex through a Sensor Interface module, is routed through the backplane to Data Flow Network, parallel switch modules (32 bit data path, 25 MHz clock for 800 megabit/sec), to Global Memory modules for buffering and on to Processing Element modules for floating point processing.

Before departing this architecture, note that Radio Frequency (RF) and Intermediate Frequency (IF) modules for a given function (e.g., CNI) could be placed within the same enclosure (with backplane modifications) if desired. However, it is fundamental to note that although this architecture supports growth, redundancy, reconfigurability, communications security, and data fusion, it is primarily a digitally-based system. It is the product of the most advanced technology deployable this decade.

21st Century Avionics Architecture

The question can now be asked ... "how can we improve on this architecture?" The previous discussion on challenges for 21st century avionics reveals that, if possible, sensor cost, weight, volume, and power need to be attacked, further reliability improvements need to be made, and a feasible, cost-effective means of achieving "supercomputer" quality digital processing must be implemented. We will need to enhance the baseline digital integrated avionics architecture while extending it into the sensors. The strategy remains the same: continue with the use of a common, modular, standard family of modules (be they RF or digital) to reduce cost and supportability problems; share functions wherever possible to reduce weight, volume, and, hence, cost; exploit and integrate advanced packaging, cooling, and interconnect technologies to reduce weight and volume and improve reliability; establish a means to achieve fault tolerant system operation to reduce weight, volume, electrical power and cost, and improve system availability. An integrated sensor architecture is needed.

The above question now becomes a series of questions ... "What do we need to improve? With what technologies? What are the needed architectural constructs? Can we simply add on to the PAVE PILLAR architecture or must we substantially depart from it? Are there evolutionary steps which must be taken? Are we clever enough to overcome software complexity problems? Will cultural resistance to functional integration be a more powerful retardant than the technology? How does a design team architect such a system? What will happen to classical boundaries between CNI, radar, or EW; to offensive and defensive avionics; to RF and EO avionics?" The following discussion hopefully will provide insight into these issues.

Figure 10 outlines the basic requirements that must be embodied in this advanced architecture. The PAVE PACE program, currently underway at Wright Laboratory, has begun the process to embody these requirements initially into a design and ultimately, into a system demonstration. Figure 11 shows the resulting top-level system block diagram and the highlights of the approach being taken. Note the fundamental precept of building onto the PAVE PILLAR concept to permit cost effective preplanned product improvement upgrades as well as application to new aircraft weapon systems. In comparing this architecture with Figure 7 (PAVE PILLAR), the most obvious difference is the introduction of the integrated RF and EO sensor systems. As we will see, there will also be significant upgrades to the data network and the core processing. Note also that future avionics systems can be viewed as consisting of six major categories: RF, EO, core processing, cockpit, vehicle management processing (flight, propulsion, and utility control), and stores processing. The following discussion outlines the basic characteristics of this 21st century architecture.

Integrated Core Processing

The Integrated Core Processing functional area accomplishes signal, data, and a majority of digital preprocessing functions using a standard family of highly advanced digital modules.

During 2000-2010 application, it is predicted that silicon-based digital circuits (e.g., BICMOS) will still be the dominant technology, with circuit feature size of 0.5 microns and a clock rate of 100-150 MHz being commonly used. Multi-chip packaging (MCP) will be required to avoid the speed slowdown encountered by printed wiring boards (e.g., a factor of 4 speedup is possible). Here, bare chips will be closely arrayed on silicon substrates, with interchip communication accomplished by balanced transmission lines a few microns wide. Wafer scale integration and superconductivity are not currently projected to be used except for highly specialized applications. It is projected that by a 1998 proven technology availability date, the following performance should be achieved per module: General Purpose Processing Element: 450 MIPS; Floating Point Processing Element: 2400 MFLOPS; System Mass Memory: 144 Mbytes; Photonic Switch Module: 64 x 64 optical cross-bar switch.

MCPs will form the building block for future digital avionics. An MCP can be imagined to contain 40-50 chips, is 5 times more efficient in packaging density, consumes 5-50 watts, measures 2.5 to 10 cm on a side, and has a reliability in excess of 100,000 hrs MTBF. They are a possible throwaway item at the depot.

Figure 12 shows the concept of how members of a MCP family are "mixed and matched" to create a family of standard modules. Such a module is shown in Figure 13. Note that because of extremely dense MCP packaging and high circuit clock rate, modules will require improved cooling since 100-200 watts heat generation per module is forecast. Liquid flow-through cooling, where the fluid in the rack is pumped through a heat exchanger within the hollow centerplate of the module, will be used. This technology has been tested for ruggedness and is capable of removing 200 watts with a junction temperature of 83°C. Note, also (Figure 13), that optical interconnects will be commonly used to affect sensor/module and module/module data interchange. Such interconnects are needed to permit high speed (2 Gigabit/sec) switched data to be processed, creating the need for an optical switching module, a photonic backplane, and photonic I/O circuitry on each module. Figure 14 shows a conceptual portrayal of how various modules would communicate through the switch controller. Such a photonic backplane configuration, operating at 1 Gigabit/sec is being developed by the Wright Laboratory Avionics Directorate. Substantial size reductions of the laser transmitter will have to be made before this design is implemented in practice, although it is expected to be available by 1995.

Cockpit/Pilot Vehicle Interface (PVI)

Reduction of crew workload while providing situation awareness of the threat, targets, friendlies, weather terrain, and obstacles will remain the PVI challenge for early 21st century avionics designers. Figure 15 illustrates an advanced PVI concept with these capabilities. An integrated helmet mounted display/sight will provide a graphical, "virtual" world for situation awareness and off-boresight target acquisition and weapon release. Large head-down displays, using full color liquid crystal display and robust graphics technologies will be used to present "BIG PICTURE" situation awareness. Information from several sensor sources, whether on-board, from within the flight, or external to the flight, will be fused for improved graphical imagery presentation targeting or track file prediction. Artificial intelligence technology will be used for automatic display modeling and for real-time route planning, and will provide crew recommendations for tactics and system reconfiguration in the event of hardware failure. In addition, speech recognition is expected to find utility in this time frame. However, the most significant automation impact is expected to occur with automatic target recognition. This technology is being vigorously pursued at the Wright Laboratory Avionics Directorate and is expected to find partial use before the end of this decade (e.g., target cueing) and be fully operational by 2005-2010. The vast majority of graphical, fusion, and automation processing will occur in the integrated mission processor complex. Communication to the cockpit (panel and Helmet Mounted Display) will be accomplished over a fiber-optic, switched network.

Vehicle Management System (VMS)

Early 21st century fighter aircraft are expected to utilize highly maneuverable fly-by-wire flight controls, as well as thrust vectoring, all aimed at achieving extreme maneuverability.

Advanced VMS designs are expected to incorporate an integrated suite of sensors, effectors, and processors that control the state of the vehicle. This suite will include: (1) flight control resources such as control surfaces; vehicle reference sensors such as accelerometers, rate gyros, angle of attack, and airspeed indicators; (2) utility management functions such as electrical power control, lighting, nose wheel steering, and environmental control system; (3) propulsion control (both engine, thrust deflectors, and inlet control; (4) controls (e.g., throttle, stick, rudder pedals) and displays (e.g., attitude direction indicator, angle of attack indicator) (see Figure 16). An integrated, bus-structured triply-redundant set of vehicle management processor clusters will be used to meet safety-of-flight (the probability of loss of control for the vehicle should be less than $1x10^{-6}$, the probability of mission abort less than $1x10^{-3}$). Such a highly fault tolerant system must detect, isolate, and recover from faults in less than 30 milliseconds. Although a modular approach will be used to promote ease of maintenance and supportability improvements, the question of the degree of commonality with mission processing modules is still under investigation. Although power supply and switch modules could be used, most memories on the VMS should be "burned-in" read only memories (with battery backup) to protect against electrical transients. However, many of the previously described MCPs can be used.

Because the integrated data network traffic is under 1 Megabit/sec, debate continues on the need to use a high speed data bus for commonality reasons (50 Megabit/sec) or a DOD MIL-STD 1773 bus (the fiber optic version of STANAG 3838).

A significant issue is the extent of VMS/Core Processing integration. It is expected that shared inertial sensors (for flight control and for inertial navigation) will become commonplace for cost reasons. Because of the close weapon system coupling that is occurring with the VMS in the areas of terrain following/avoidance, weapons control, automatic, air-air trajectory control, and the powerful new control capabilities that an integrated VMS provides (e.g., high angle of attack gunnery during air-air combat, rapid nose pointing), debate continues as to whether system control, trajectory steering, display management, stores control, etc. should reside on the mission processing or VMS areas. The authors believe that generic boundaries of mission processing, stores management, cockpit, sensors, and VMS will exist on early 21st century avionics. However, there will be close information coupling across a system of data networks contained within each functional area. Safety (e.g., inadvertent stores release) and safety-of-flight (e.g., unrecoverable angle of attack) will dominate VMS and stores system architectural partitioning. Each safety-related functional area will request data services from the integrated core processing area, and will then ensure its acceptability before use.

Integrated Sensor Systems

Having briefly described the core processing, cockpit, and VMS systems, the integrated RF and

EO systems, projected to be available in the 2005-2010 time frame, will now be discussed.

The advent of microwave and millimeter integrated circuit (MMIC) technologies, opto-electronics and high speed digital circuitry will allow us to re-look at the way RF electronics are designed, developed, and integrated. Several questions come to mind: (1) are there ways in which we can reduce weight, volume, power, and cost through functional sharing of hardware building blocks? (2) does it make sense to attempt to reuse these building blocks across diverse weapon systems? (3) what type of new integrating architecture is needed?

In answering these questions, one must acknowledge that RF systems differ greatly from digital systems in the following, fundamental ways. RF systems are multi-dimensional in bandwidth, dynamic range, and phase and as such, they have been implemented as point-designed, custom functions within EW, CNI, or radar functions. As a result, one RF system component is often dependent on another (e.g., multi-stage amplifier circuits located across the sensor system). If we are to separate unique, point designed equipment from common hardware, we must be able to "contain" unique requirements closer to the aperture and develop a "standard I/O" interface that will allow common modules to be used. RF equipment, because of its uniqueness, has not enjoyed the "infrastructure" of the digital industry relative to common manufacturing techniques, chips, etc. The RF industry often has to "roll their own", building onto what worked before. As a result, learning curve experience and reliability is difficult to achieve with low volume production and high non-recurring expenses.

Based on the above considerations, it would appear that commonly shared receiver modules may be the most attractive area for RF standardization. For example, EW receiver modules, each responsible for a specific frequency band, could be time shared across various EW apertures on an aircraft (the radar receiver function may be a candidate for sharing under specific conditions). Similarly, CNI receiver modules can be time shared across the 20MHz-2GHz spectrum. These modules would hopefully find standardized use across various aircraft types.

Using such receiver modules in such a manner requires a very low noise network that switches the intermediate frequency signal to the appropriate receivers/processor modules. Further, this switched network must support multifunction apertures which are expected to be available by the 21st century.

RF modules will fall into two classes: a set which can be shared/duplicated across functions within and across aircraft, and a set that is unique to a sensor function, but which can be used on several other aircraft types.

The type of "sensor architecture" needed will be determined by several factors. For example, we will need to determine the extent of modularity and fault tolerance needed to achieve improved availability, where digital signal conversion is best accomplished, where advanced signal fusion should best occur and the degree to which multifunction apertures will be available. These issues are, in turn, related to hardware "front-end" and receiver technology availability and the resulting complexity and amount of the software needed to control the system.

Figure 17 shows the basic concept behind an integrated RF system design. First, note the use of shared RF apertures across classical RF functions. A recent PAVE PACE study accomplished by McDonnell Douglas Corporation estimated that a total of 13 antennas (five basic types) will provide all the CNI/EW/radar functions, replacing 25-35 different antennas normally found on tactical aircraft. Here it is assumed the RF band of operation extends from 30 MHz to 18000 MHz, with growth provisions for higher frequencies. Both multi-arm and active phased array antennas will be used. Broadband matrix switches, beamforming networks, and built-in-test circuitry will be used in the aperture electronics, along with MMIC technology used for phase shifters, switches, and low noise amplifiers.

Studies to date indicate that only four frequency converter types, each implemented in standard flow-through modules, are needed to cover the entire RF band (see Figure 18). The output of each converter is a standard IF frequency where a common IF switch module is used to direct the signals to various standard receiver modules (six types needed). In this way, various shared apertures can be switched to frequency converters

(RF interconnect), and frequency converter modules can be switched to various receiver modules (common IF switch), a fault tolerant, shared family of resources will be employed to dramatically reduce cost, weight, and volume. For the entire integrated RF design, a total of approximately 105 standard modules, 21 of which are common to core processing, will be needed (see Figure 19).

Few opportunities for sharing EO sensors appear to exist relative to the RF domain. However, significant cost savings will occur if a common IRST/FLIR aperture is used, along with common modular preprocessors and integrated core processing. Figure 20 shows a general configuration of such an integrated EO system.

PAVE PACE studies to date reveal that significant weight, volume, and cost savings can be achieved by the use of common, modular avionics in both RF and EO sensors, along with the sharing of aperture and receiver electronics. Preliminary analysis shows that for the RF system, 65% of the acquisition cost can be saved by the use of standard modules alone, compared with a non-integrated, non-modular RF design.

The table below summarizes the results of the McDonnell Douglas PAVE PACE study.

	INTEGRATED RF SYSTEM[1] (1998 TECHNOLOGY AVAILABILITY)	FEDERATED RF[1] (CURRENT R&D TECHNOLOGY)
RELIABILITY (HOURS)	441	158
COST (1990, U.S DOLLARS)	1 8M	7.2M
POWER (KILOWATTS)	31	35
WEIGHT (LBS)	450	940
VOLUME (FT^3)	5.4	11 5

	INTEGRATED EO SYSTEM[2]	FEDERATED EO SYSTEM[2]
RELIABILITY (HOURS)	424	92
COST (1990, U.S. DOLLARS)	1 9M	4.5M
POWER (KILOWATTS)	4	7.6
WEIGHT (LBS)	540	854
VOLUME (FT^3)	6.5	18 1

1 RF system consists of full function CNI, multifunction radar, and ESM/electronic countermeasure (ECM) system.

2. EO system consists of Navigation FLIR, targeting FLIR, IRST, infrared missile warning (IRMW), laser warning, laser illuminator.

Figure 21 shows the significant differences between the use of federated and integrated sensors for fighter aircraft of the early 21st century. One observation is clear: integrated sensor systems implemented with a family of modules will be the most dominant change in avionics during this period.

3. 21ST CENTURY AVIONICS SOFTWARE

Functional Partitioning

Figure 22 shows the six principal application centers that constitute the software architecture for future tactical aircraft. Each functional block shown has been defined to: reduce duplicative functions, enable a modular software framework, reduce data latencies, allow for growth, and enable flight safety and system security related functions to be segregated from the rest of the system. Note that a complex, internetted set of smaller software modules exists within each "major" module shown.

The Integrated Core Processing "meta-function" is partitioned into a set of artificial intelligence-based software modules that enables mission planning, tactical planning, situation assessment, and P.., reflecting the need to assist the pilot in complex, time-compressed missions. Further, an integrated data base is postulated. It permits a coherent integration of previously federated data bases dealing with knowledge bases, electronic combat, weapons data, maintenance data, terrain, navigation waypoints, etc. This approach will bring much needed discipline and commonality to an area which has seen tremendous proliferation.

Figure 22 also shows a more fundamental change in avionics that is expected; viz., the classical partitioning of sensors into offensive and defensive categories has disappeared. One can no longer find top-level "radar" or "CNI" modules, but rather, an "Integrated RF module". A new culture will be needed; new ways to organize, to design, to communicate are needed. Designers must become more function oriented, instead of sensor oriented. For example, the range and angle to target functions classically provided by radar, ESM, and IRST are now viewed as coming from an RF and an EO system.

Figure 22 also shows the estimated magnitude of the flow of digitized data between functional modules. Figure 23 shows a general configuration of how digitized sensor data, data flowing between data and signal processors, and digitized video data is routed through very high speed optical network switches. Most of these identical switches will be dual redundant for fault tolerance.

This network will consist of an optical cross-bar switch of approximately 64x64 size and will operate as serial links around 2.5 Gigabits per second, and packaged within a standard line replaceable module. Note that this network is also used to distribute data across a photonic backplane that houses the array of standard modules performing pre-processing, signal, and data processing. With the advent of high speed, compact photonics packaging, it is expected that the use of metal circuits to carry signals between subsystems and across backplanes will be replaced by photonic circuits built from fiber cable and optical waveguides. Also, the future of most bus-oriented circuitry (photonic or not) appears to be limited because of the significant strides projected for semiconductor-based optical switches (i.e., complex protocols and bottlenecks occurring with buses are avoided with switched networks).

Software - The Future is Uncertain

The above discussion assumes that needed real-time software can be, and will be, developed to support the early 21st century avionics systems. Figures 1, 2, and 3 clearly showed the magnitude of software growth through the 1990s. It is expected that this growth will only escalate during the early 21st century.

Currently, the U.S. Department of Defense, which went from a $20 billion software expenditure during 1988 to a $34 billion expenditure in 1990, has more lines of software code on order in 1990 than has been written for existing systems (Ref 7). Software development programs, whether military, commercial, or consumer based are rarely on time and within budget. There is a substantial shortfall of trained software personnel (a 12% demand growth versus a 4% supply growth per year). We make the vast percentage of mistakes during the conceptual design stage. For avionics, a million lines of code requiring hundreds of people working for 3-5 years, must run in real time, and is expected to contain zero errors. And then twice that cost and effort will be spent debugging, changing, and upgrading that software over the life cycle of the weapon system. Clearly, a crisis condition exists in the design, development, and support of software. These problems are further compounded when the avionics requirements of real-time operation and flight criticality are added. We are currently approaching a cross road where the question must be asked ... "are we capable of designing the software needed to implement the integration concepts enabled by advanced hardware? Can we afford the software?"

A significant effort is underway to "solve" the "software problem". Fundamentally, it must be turned into an engineering discipline rather than a "black art". New tools and procedures will be required; a new development and support process is needed.

The software process has often been divided into several life cycle phases as evidenced by many life cycle models. These phases often include requirements analysis, specification, design, code, test, integration, deployment, and post-deployment support. Of these phases, post-deployment support or maintenance makes up over 66% of the cost of the software. Therefore, it has often been addressed separately. However, this post-deployment support is finally being recognized as simply an extension of the development cycle. Many have recognized that the current waterfall life cycle of DoD STD 2167A (Figure 24) is in fact insufficient to address complex software systems. Each phase of the life cycle cannot be completely determined before beginning the next phase. This approach introduces a paradox: one cannot really understand the problem until the software is complete; however, you cannot write the software until you understand the problem. This is the reason many experts in the field are beginning to suggest a spiral or cyclic life cycle model (Figure 25). This model consists of specify a little, design a little, code a little, test a little, and repeat. This method is also known as prototyping. The process is repeated until the desired detail and functionality is obtained. In this way of thinking, post-deployment support is only another set of cycles of the basic development cycle. The emphasis on software management for future avionics systems should center around improving this basic development cycle (Ref 2).

The keystone to improving productivity and quality of software is software reuse in the most general sense. Software reuse relates to not reinventing the wheel at each step in the software life cycle. Reuse strikes at the heart of the "not invented here" syndrome. The reuse concept has been used within computer science for decades. The concept is simple. When faced with more and more lines of code to write, one simply abstracts the language one uses so that fewer lines of code need to be written. This can be seen in the development of higher order languages (HOL) in the late 1960s and 1970s. Faced with writing massive amounts of assembly code, computer scientists came up with a higher level of abstraction in HOL such as FORTRAN to reduce the amount of code needed to be written. Then with the development of very efficient compilers, HOL programmers were able to write one line of HOL code that was translated into several lines of assembly language. This same principle was used in the development of fourth-generation languages in the business community. Another form of reuse has existed for years. In the scientific and mathematical community, mathematical and statistical packages have been extensively reused successfully for years. The challenge then is to develop a strategy for injecting reuse into the real-time avionics software development environment to reduce the cost of avionics software through increased productivity and improved quality.

Unfortunately, the solution to increasing the amount of reuse only partially requires a technical solution. The other portion of the solution involves changes in culture, management, and acquisition practices. Both the technical and non-technical issues have been spelled out in numerous reports. The real solution will involve bringing technical solutions from other domains to bear while considering the unique features of avionics, and experimenting with innovative acquisition and management practices.

The technical solution has to involve a coordinated attack along several fronts. First, reuse has to be embedded in the software practices and methods along the entire life cycle. This includes introduction of reuse into specification and design as well as code and test. To do this, the tools and methods in a software environment have to be able to support reuse. Second, a level of abstraction appropriate to avionics or other subdomains within avionics needs to be agreed upon. This will enable the level and types of reuse to be defined and allow languages to be defined to capture this reuse. This will then allow "compilers" or translators to be developed to make the proper transformations. Note that this does not mean the elimination of the Ada standard anymore than the introduction of FORTRAN spelled the end of assembly language. These higher level avionics language abstractions will be built on Ada. Third, a method to catalog and retrieve the reusable components needs to be implemented. This methodology requires the mix of database techniques, artificial intelligence, and software engineering principles. And finally, this whole process must be instrumented to measure not only the productivity, but to improve the quality and confidence in reused components. Metrics can be developed to track the quality of reused components to give the designer some confidence in the quality of the component. Also, reusable components could make formal verification with correctness proofs a viable alternative. Proofs could be performed on reusable components once and then reused with complete assurance over and over.

The management and acquisition issues associated with software reuse will probably be more difficult to tackle than the technical issues involved. A change in culture will have to occur within the software development community. The "not invented here" syndrome will have to be overcome. Acquisition practices will need to change to create incentives for software reuse. Software reuse involves a heavy up-front investment to save cost later in the life cycle and in other related projects. This investment cannot be justified in today's acquisition environment of cost-plus or fixed fee contracts. The idea of royalties may need to be investigated for reusable components. This will promote the development of quality reusable components, since developers will get paid based on the number of times a component gets reused. And finally, the legal issues of responsibility need to be addressed. This could perhaps be the greatest difficulty in reusing components across the avionics industry.

Once a software development process is established, an integrated set of Computer Automated Software Engineering (CASE) tools will be needed. The following discussion of CASE tools is adapted from Harris and Jackson (Ref 8).

Avionics CASE Tools

Of the more than 200 CASE tool vendors today, most have focused on only a small portion of the total system development process as mandated by MIL-STD-2167A. Most tools stress requirements analysis and design specifications. In general, each tool has its own data base and internal interfaces that are usually incompatible with other tools.

There is a need to emphasize those tools necessary to maintain software throughout its lifetime, plus tools critical to avionics software development. Table 1 lists representative CASE tools that need to be integrated.

TOOLS THAT ARE NEEDED

- Requirements
  - Rapid Prototyping
  - Analysis/Trade-Offs/ Conflicts
  - Tracing
- Design
  - Structured/Object Oriented
  - Selection of Reusable Components
  - Analysis/Impact
  - Reverse-Engineering
- Code
  - Semi-Automatic from Design
  - Smart Editor
- Initial Test
  - Automated Test Case Generation
  - Automated Unit Test
  - Automated CSCI Test
  - Test Analysis
- Real-time Testing
  - Interface to Test Equipment
  - Automated Testing
- Configuration Management
  - Transparent
  - Process Status Monitoring
- Information
  - Automated Documentation
  - Tied to the Software
  - On line easy access
  - Access to all information

Table 1. Representative CASE Tools That Need to be Integrated

Avionics software and hardware are often developed concurrently. MIL-STD-2167A even assumes this concurrency. Consequently, there is a need for tools that permit integrated system modeling (hardware and software). Some CASE vendors have recognized this by teaming with hardware simulation vendors to produce this joint capability. This, however, is not typical.

As a complement to hardware development, traditional software engineering is based on top-down, functional decomposition of software requirements in order to arrive at computer software configuration units. These units represent testable code. More recent software design methodologies, however, are embracing concepts of software reusability and adaptability for their products. CASE has not yet addressed this latter approach.

As technologies advance and integrated avionics become a reality, there is a need for tools that permit development plus lifetime support of new architectures that implement integrated systems. These tools should cover both initial and post-development cycles, and support both hardware and software simulations.

There is a need for CASE to provide "instantaneous" documentation methods. Using multi-media technologies, it should be possible for documentation to be a natural part of the design process, rather than an appendage that occurs near the end of a milestone.

Tools that provide "automatic" code generation and that draw from reusable software libraries are needed for large software-intensive programs. Many current tools make claims for code generation, however, in most cases, only the "shell" for code structure is provided. While this is a step towards automatic coding, the ultimate CASE tool would produce compilable code based on an object-oriented design methodology.

Most methodologies implemented by CASE tools supporting Ada define only high-level declarations for the language, and lack capabilities that define package specifications, package bodies, generic units, and limited private types.

CASE tools should support planners, managers, analysts, designers, engineers, programmers, and system maintainers. There is no current comprehensive tool that serves all of these masters, although some purport to. The problem collectively for CASE is that there are no standards for interfacing tools or data bases, so that individual tools effectively and efficiently complement one another. This has forced nonuniformity in software engineering environments and the products they produced.

An Implementation Issue

A major problem of implementing CASE in many situations is that of cost. The total CASE implementation cost for a technical staff of 200 has been estimated to be $6.5 million over a 5-year period. Companies must demonstrate, or have a high level of confidence, that this magnitude of investment will pay off. This is probably one reason for many "pilot" projects using CASE. Documented results so far show no productivity gains for six months to a year after the tools are introduced. Instead, losses have been cited during the learning period. Many software development groups do not practice software engineering methods, which are themselves a rather new discipline; and transition to these methods is not immediate. By trair.' and tradition, software creation has been an individual endeavor. Team-programming is typically not learned until programmers leave school and enter large corporations where the corporate culture dictates it.

Usual cost categories to implement CASE for the first time are: (1) workstations ($10K to $20K per person); (2) the CASE tools themselves ($5K to $50K); (3) customization to integrate with the current software engineering environment (estimated to be at least 20% of total cost); and (4) training costs (this should include "lost productivity" costs while learning).

An Ideal Avionics Development Tool Set

An ideal CASE toolset environment for avionics systems development would have most, if not all, of the following attributes:

1. A single user-interface for all of the individual tools of the set. This would provide all users a "window" into their world that satisfies their needs and minimizes training for the organization.

2. A common data base that provides universal integrated knowledge to all users.

3. A "windowing" scheme that allows each different type of user (planner, analyst, designer, engineer, programmer, tester, manager) to use the tool set from different point of view.

4. The capability to implement "real-time" documentation.

5. The capability to maintain traceability among elements of requirements, design, coding, integration of software and hardware, system testing, validation and verification.

6. Provision for all levels of avionics system development: unit testing, dynamic testing, and system-integration testing.

7. Local area network and workstation implementation for expansion or tailoring to given needs.

The ideal avionics CASE system should provide functional support for a life cycle software process including these nine functions: (1) the ability to create graphical system requirements and design specifications; (2) the ability to check, analyze, and cross reference system information; (3) management of an integrated data base/repository for software reuse and for storing, managing, and reporting project management information; (4) the ability to build software prototypes and simulate system performance; (5) capability to generate code and accompanying documentation; (6) the enforcement of standards and procedures; (7) testing, validation, and verification of software; (8) interfaces to outside data dictionaries and data bases; and (9) a capability to re-engineer existing software. The Avionics Directorate of Wright Laboratory is supporting efforts that are contributing to achieving these ends.

4. FUTURE AVIONIC SYSTEM DESIGN ENVIRONMENT

Avionic system design is becoming more and more complex. Avionics systems have become more than several people can cope with. A lesson learned from many previous systems is that the more that can be dealt with in the early part of design, the least costly changes are in the later stages of the life cycle. Therefore, it is necessary to recognize problems associated with reliability, maintainability, manufacturability, and security, along with normal hardware and software issues as early as possible in the system life cycle. The system life cycle also needs to be traceable from the system requirements all the way through to implementation. This is necessary so that intelligent tradeoffs can be made when system requirements change. The size and complexity of the system design problem, therefore, seems to point to a concurrent, automated design environment where many factors can be traded by various people and maintained throughout the system life cycle.

This problem is very similar to the software development process. The problem can only be understood as you approach the solution and the solution can only be attained when you understand the problem. Therefore, this process requires the ability to rapidly prototype the avionics system and simulate alternatives. A set of tools and models are needed to represent the system and test out alternatives early in the design process. These tools would encompass requirements capture tools, requirements analysis tools, design tools, reliability models, cost models, and functional simulators. The data from these tools must be compatible with each other as well as software and hardware automated tools and methods.

5. CONCLUSIONS

Military avionics in the early 21st century must be cost contained at approximately 30% of the (fighter) weapon system flyaway cost. Aside from cost, availability will likely be the next most important characteristic for avionics in order to support austere basing and reduction of personnel. At the same time, revolutionary capabilities in achieving unparalleled performance, stealth, and automation improvements through advanced sensor and AI technologies will become a reality shortly after the turn of the century. RF beams will be pointed selectively in real time; ground targets will be recognized automatically; aircrews will be provided machine-generated expert assistance for mission planning and tactics; intra and internetted flights of aircraft will automatically receive and transmit battle management information.

The issue during the 1990s is to determine whether low cost and availability is necessarily contradictory to achieving needed performance. If this seeming paradox is not resolved, less capable weapon systems or a few, highly capable aircraft will result.

The technology infrastructure for a powerful new avionic system is being developed and should be mature for transition before the year 2000 (e.g., MMIC-based RF circuits, multi-chip packaging, flow through cooling, parallel processing, switched photonic networks, multifunction RF transmitters, automatic target recognition algorithms, high resolution EO sensors, etc.).

It appears that reduced hardware cost, increased performance, and improved availability can be simultaneously achieved through the use of sensor integration and "supercomputer" exploitation, with advanced packaging and cooling technologies playing an important role. The use of a small family of both RF and digital line-replaceable modules will be mandatory for cost containment, along with the use of multifunction apertures. In general, most of the resources across the sensor systems will need to be shared to achieve weight, volume, and cost constraints, as well as fault tolerance.

The use of integrated sensor systems in the era beyond 2000 is viewed as the most significant change that will occur because of significant cost, weight, and volume savings. In addition, such a system enables more efficient emission control for stealthy operation and allows the sensor system designer to more easily fuse sensor data. However, a significant cultural change will need to be affected to accept and adapt to this concept. Sensor engineers will need to be retrained to broaden their knowledge base, and avionics organizations will need to be dramatically altered.

System and software engineers will be forced to undergo similar changes as the result of sensor integration and the fighter coupling of mission, sensor, flight, propulsion, and weapon stores processing.

The widespread use of modular avionics and the concept of a flexible, open architecture will promote multinational, participatory development of future avionics.

A significant, but not unsurmountable difficulty to be overcome is software cost. Integration and performance both imply complex software and large amounts of it. It is conceivable that a high performance early 21st century fighter might need 20-30 million lines of code for its operational flight program, support software, and mission planning software. If the current productivity of approximately 10 verified and validated lines of code per day is not improved, thousands of qualified programmers would be required, making the entire venture unweildy and prohibitive in cost.

Hence, much of the future progress to be made in avionics lies with the progress made in improving software productivity and the use of highly integrated sensor and system concepts. There is room for cautious optimism because of the significant effort being made in integrated tool development and the focus towards software reuse, and the strides in RF and photonic circuitry.

6. REFERENCES

(1) Lt. Col. M. Borky, USAF, ASD/YF, "Advanced Tactical Fighter Overview", 1990 NAECON Conference, Dayton, Ohio, USA, May 1990.

(2) R Morgan and D. Shakley, USAF, WL/AAAS, "New Directions in System Avionics", USAF, WRDC/AAAS, Tenth Annual IEEE/AESS Symposium, Dayton, Ohio, USA, 29 Nov 1989.

(3) R. Harris, USAF, WL/AAAF, "Support Technologies for Avionics Operational Flight Programs", 1991 NAECON Conference, Dayton, Ohio, USA, May 1991.

(4) McDonnell-Douglas Corporation, St. Louis, Missouri, USA, "PAVE PACE System Definition" Contract with U.S. Air Force, 1991.

(5) USAF R&M 2000 Action Plan, Vol II, 1989.

(6) H.A. King et al, Northrop Corp., "High Reliability Fighter Concept Investigation", Vol II, Feb 1988.

(7) A. Marsh, Government Executive Magazine, May 1990, pp. 62-63.

(8) R. Harris and O. Jackson, "Software Engineering Tools for Avionics Embedded Computer Resources", 1991 NAECON Conference, Dayton, Ohio, USA, May 1991.

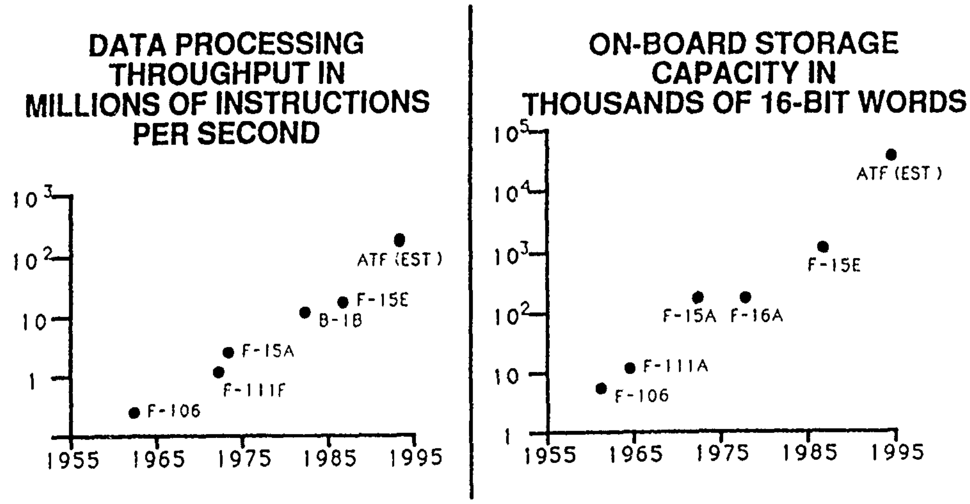


Figure 1

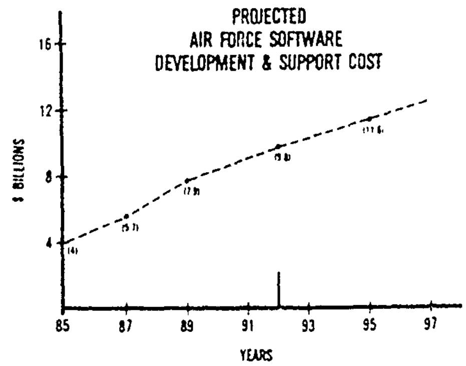


Figure 2

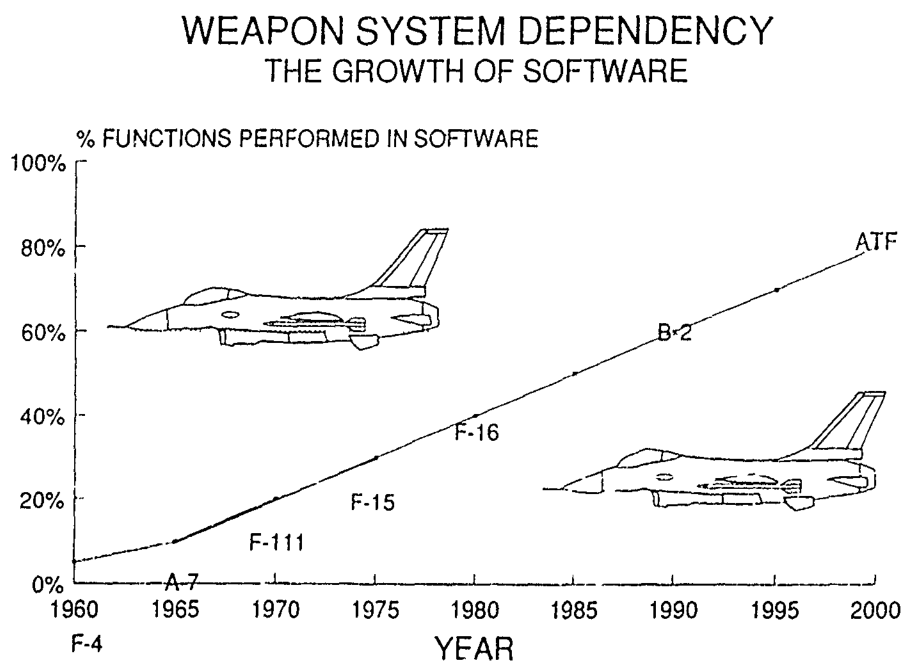
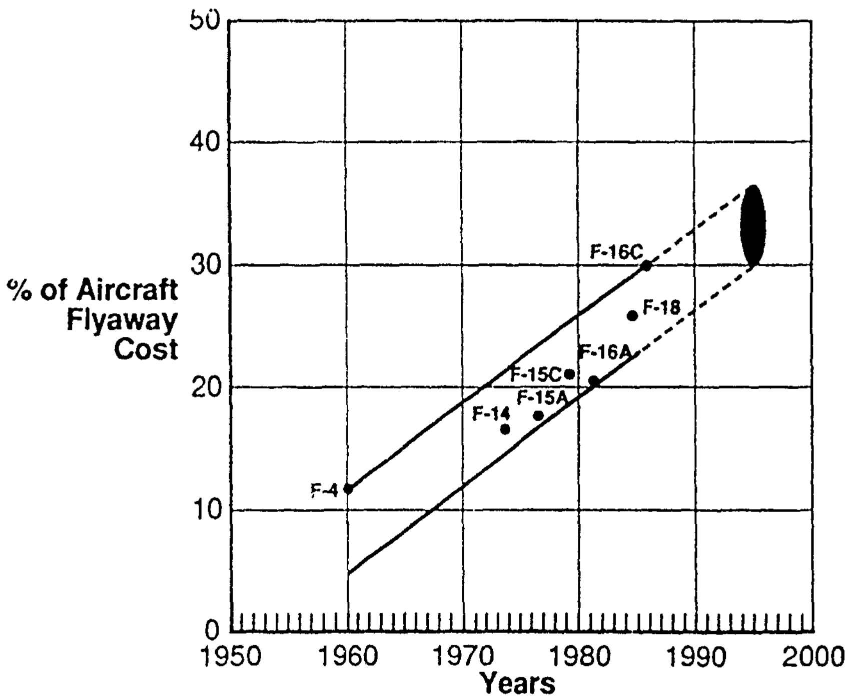


Figure 3



From "Avionics Acquisition, Trends and Future Challenges."
R. B. Longbrake, ASD/ENA

Figure 4

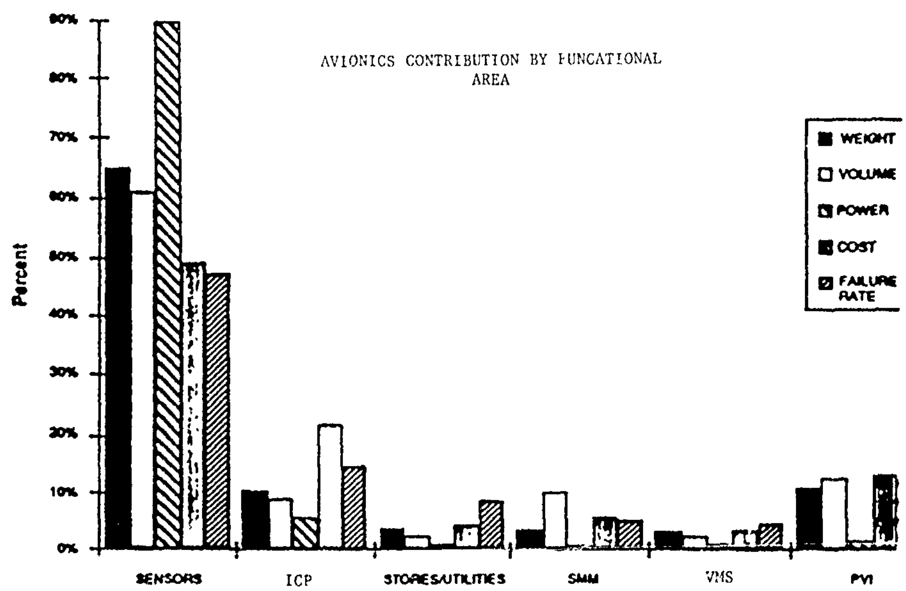


Figure 5

FEDERATED AVIONICS ARCHITECTURE

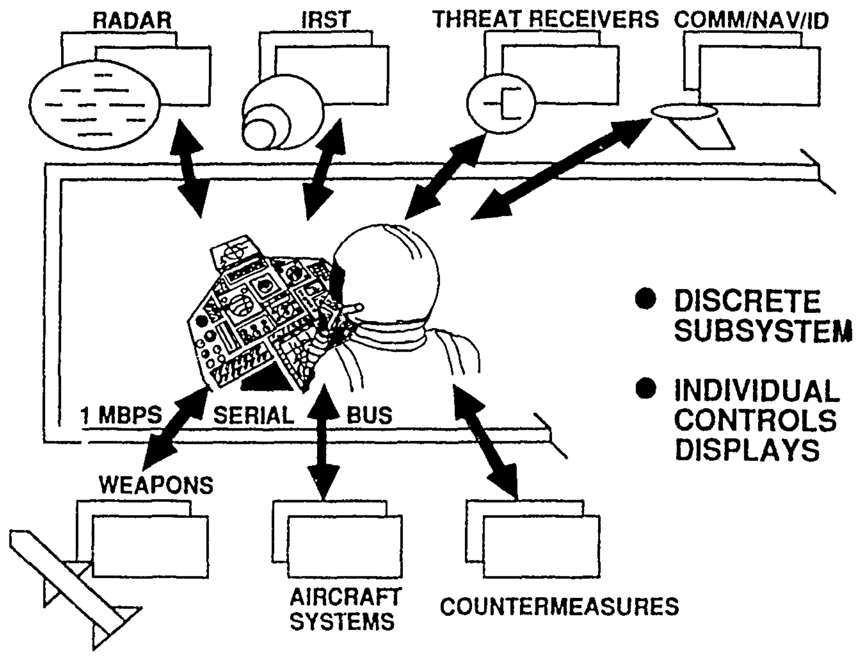


Figure 6

INTEGRATED AVIONICS ARCHITECTURE

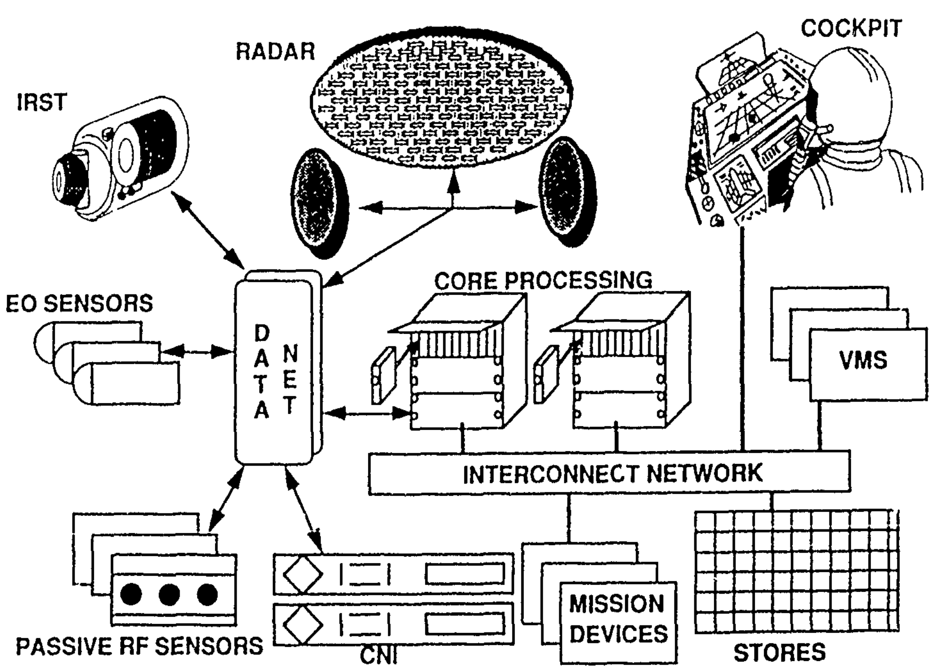


Figure 7

MODULE ALLOCATION

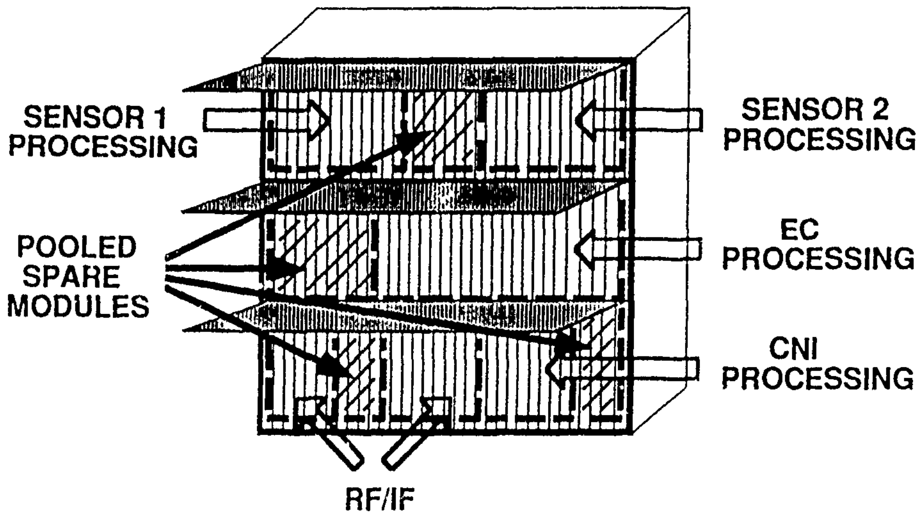
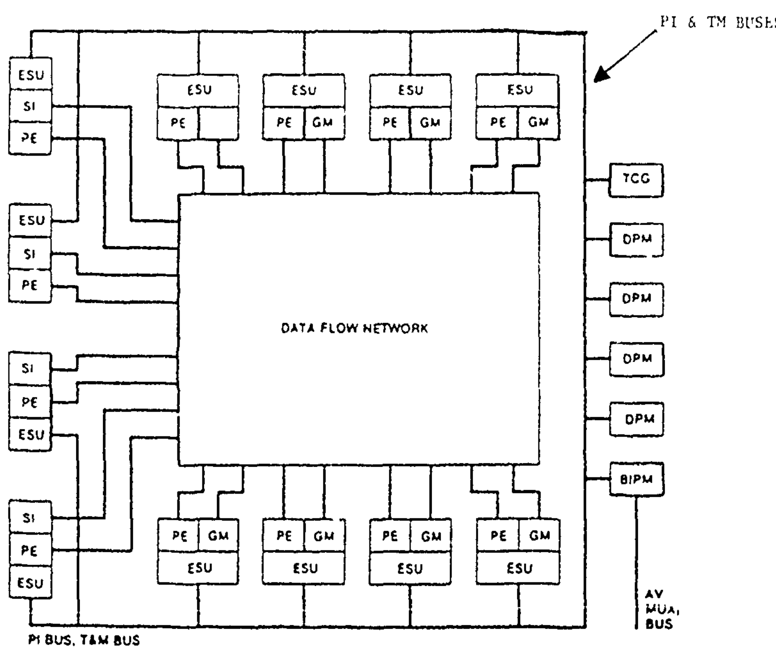


Figure 8

GENERIC RADAR CSP CONFIGURATION



PE = Floating Point Processing Element
GM = Global Memory
SI = Sensor Interface
ESU = Element Supervisor Unit
TCG = Timing Control Generator
DPM = Data Processor Module
BIPM = Bus Interface/Processor Module

Figure 9

AVIONIC REQUIREMENTS FOR THE 21st CENTURY
TOTAL SYSTEM EFFECTIVENESS

System Requirement	Implementation Driver	Enabling Technology Needs
o Cost	30% of Aircraft Cost Software Development Cost Reduced Life-Cycle-Cost	Common Modules Object Oriented SW Resource Sharing
o Availability	Austere Basing 30 Day War Fighting Capability 5-10X Improvement in MTBCF	Fault Tolerance Integrated Diagnostics Reconfiguration High Rel. Devices
o Performance	LO Threat, Threat Capabilities 4π Situational Awareness Information Fusion,Sensor Integration Machine Intelligence, Pilot Aiding	Parallel Processing Supercomputing Photonic Networking MIMIC-Sensor Integ. AI/ ES & Algorithms
o Extensibility	FORCE-WIDE DEPLOYMENT FOR ADVANCED. AIRCRAFT	Common Modules JIAWG Networks & Standards Technology Insertion

Figure 10

PAVE PACE HIGH-LEVEL ARCHITECTURE

Begin with a Pave Pillar/JIAWG Baseline Architecture, Integrate Enabling Technologies to Reduce Cost, Improve Availability, Performance, and Extensibility

- Extend the Pave Pillar Concept
  - Integrated RF/EO
  - VMS, Stores
- Enhance Core Avionics
  - SuperComputing
  - Networking
  - Operating System
- Expand Avionics Systems Capabilities
  - Pilot Aiding
  - Cooperative Tactics
  - Advanced Weapons
- Introduce System Integration Methodologies
  - Concurrent Engineering

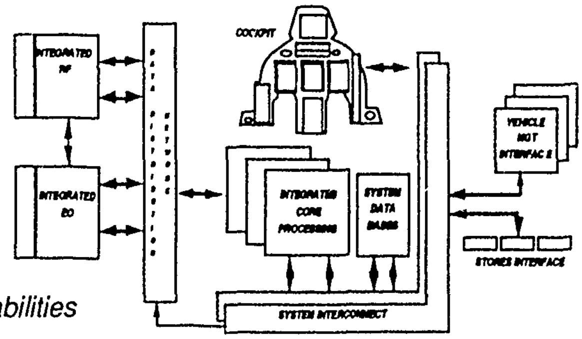
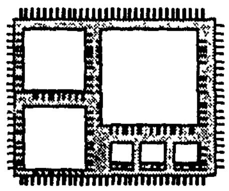


Figure 11

INTEGRATED CORE PROCESSING BUILDING BLOCKS



MULTI-CHIP PACKAGE (MCP)

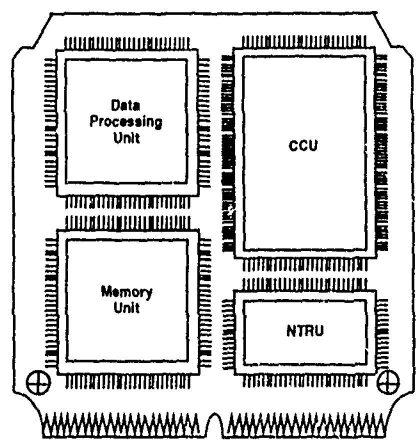
MCP FAMILY

- COMMON CONTROL UNIT (CCU)
- NETWORK XMIT/RECEIVE
- MEMORY UNIT
- DATA PROCESSING UNIT
- SIGNAL PROCESSING UNIT
- DATA PROC/COPROCESSOR
- NON-VOLATIVE MEMORY

MODULE FAMILY

- GENERAL PURPOSE PROCESSING ELEMENT (GPPE)
- FLOATING POINT PROCESSING ELEMENT (FPPE)
- SORT ENHANCE P.E (FOR EC) (SEPE)
- SYSTEM MASS MEMORY (SMMM)
- PHOTONIC SWITCH MODULE (PSWM)
- PHOTONIC SWITCH CONTROL MODULE
- POWER SUPPLY MODULE

STANDARD MODULE



GPPE MODULE

Figure 12

ADVANCED PROCESSOR MODULE

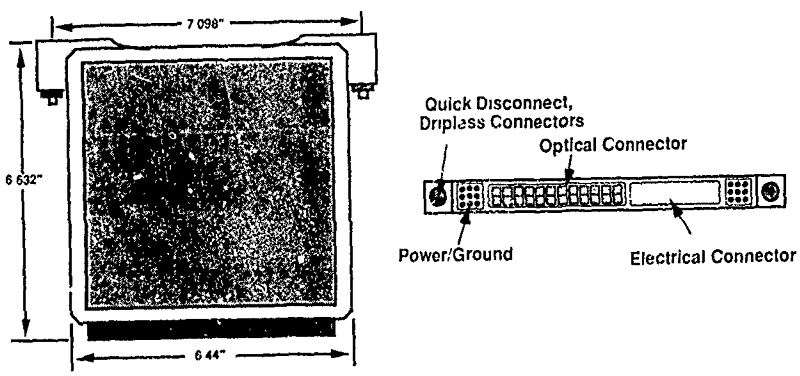


Figure 13

FUTURE BACKPLANE NETWORK

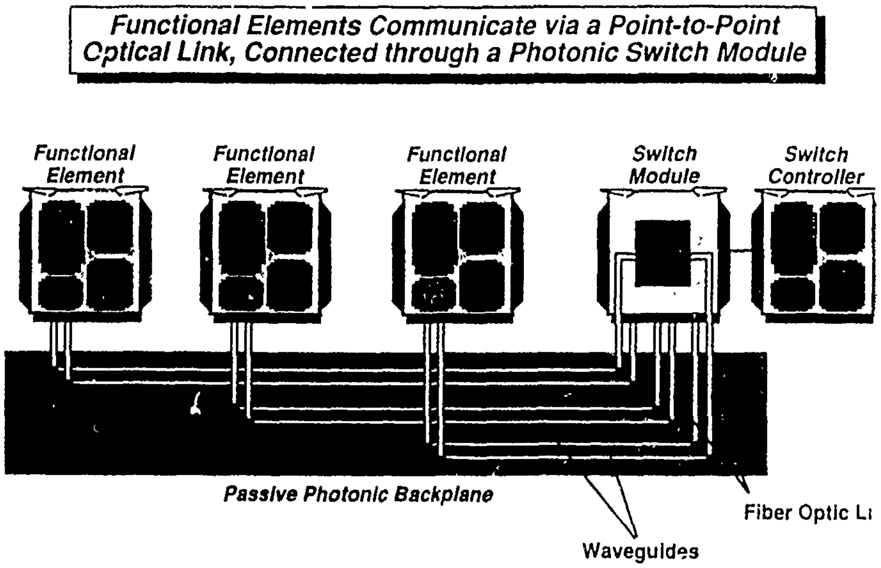


Figure 14A

COMPARISON OF IMPACT OF DIGITAL TECHNOLOGY/PACKAGING TECHNOLOGIES

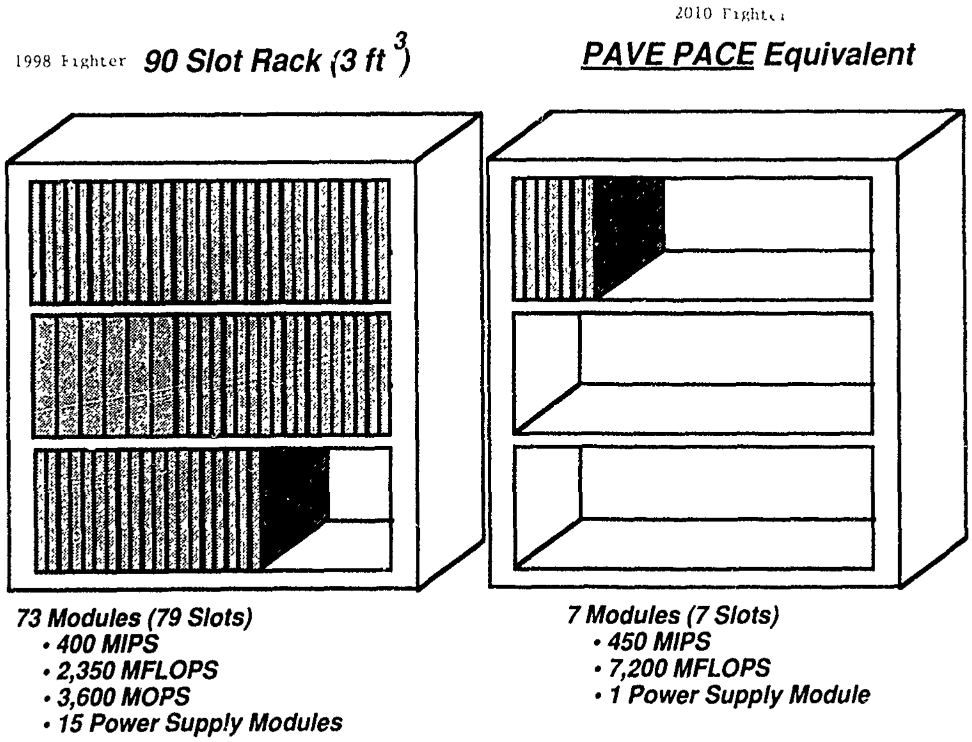


Figure 14B

ADVANCED PVI CONCEPT

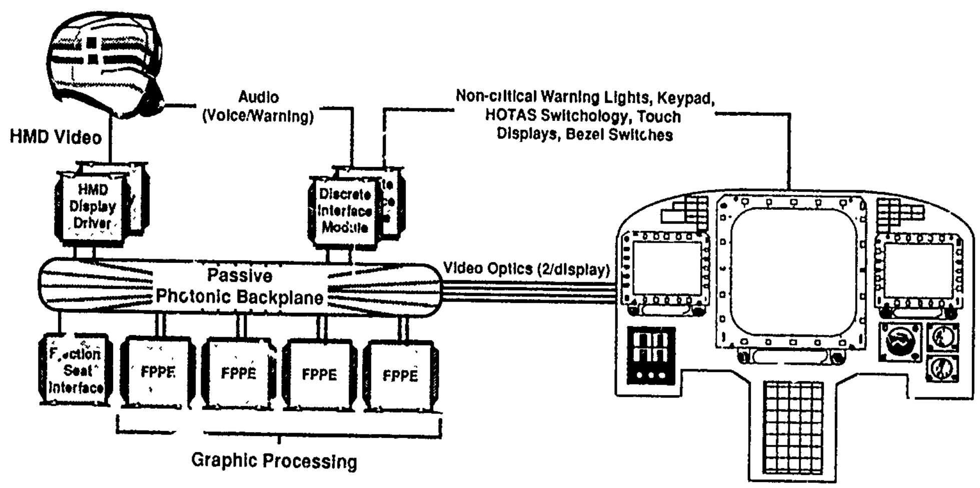


Figure 15

INTEGRATED VMS SYSTEM

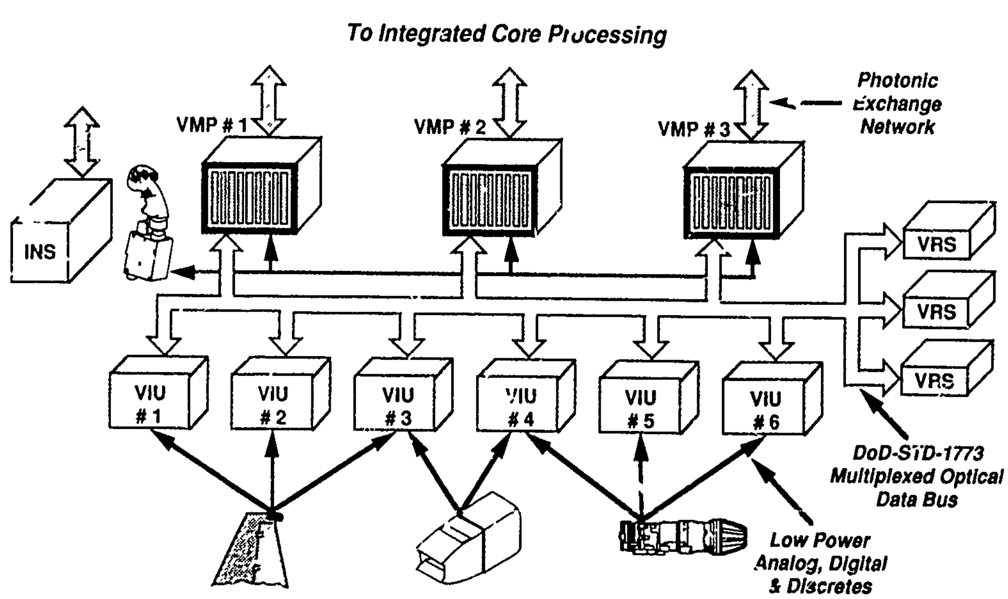


Figure 16

INTEGRATED RF SYSTEM CONCEPT

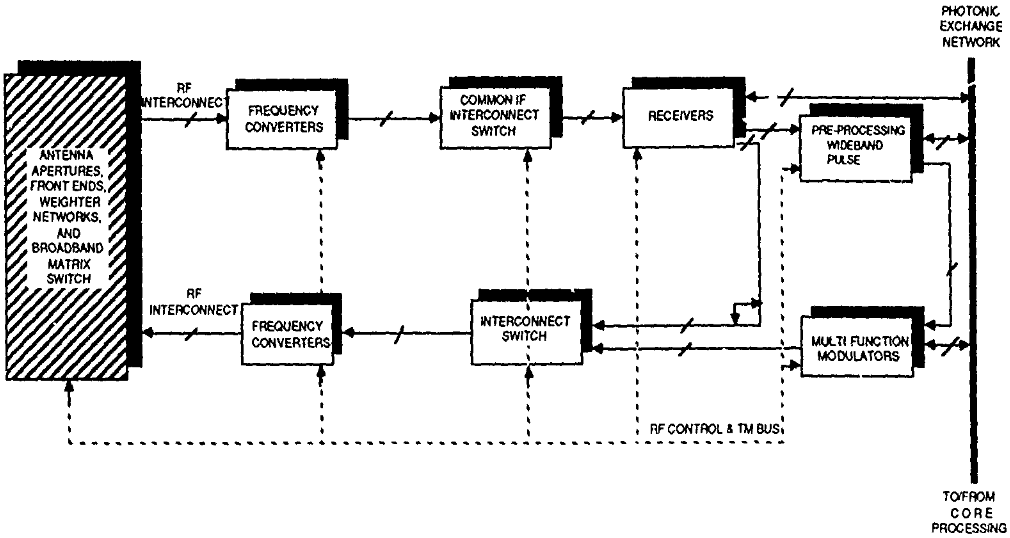


Figure 17

INTEGRATED RF RECEIVER

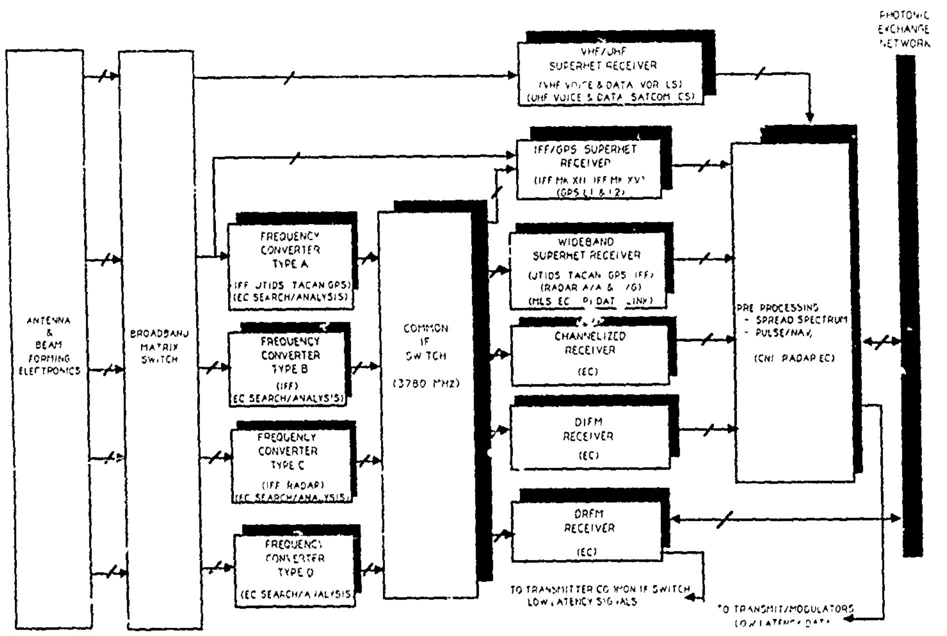


Figure 18

MODULAR DESIGN FOR INTEGRATED RF SYSTEM

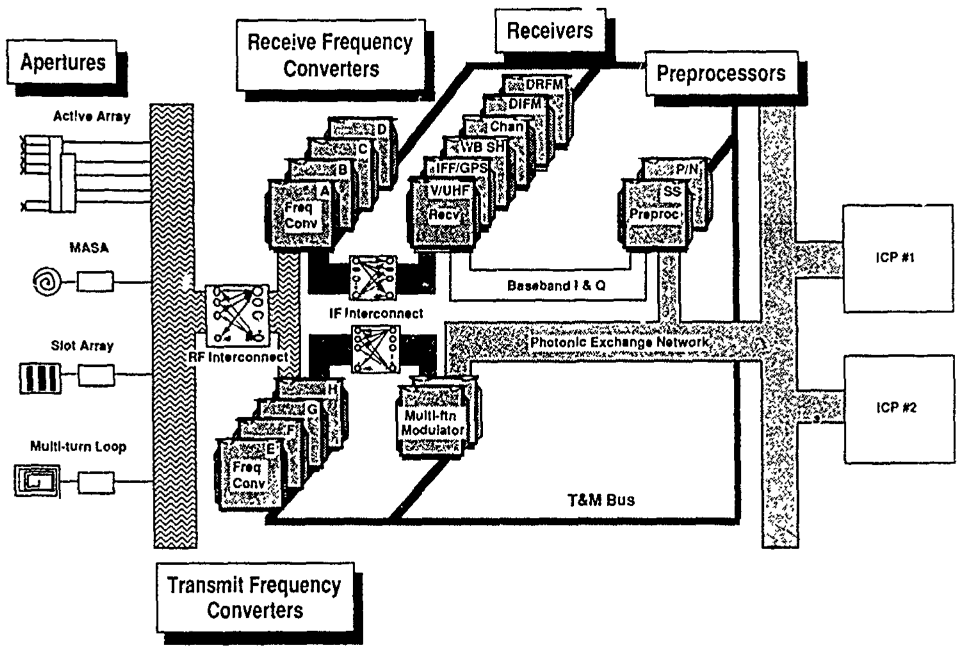


Figure 19

INTEGRATED EO SYSTEM

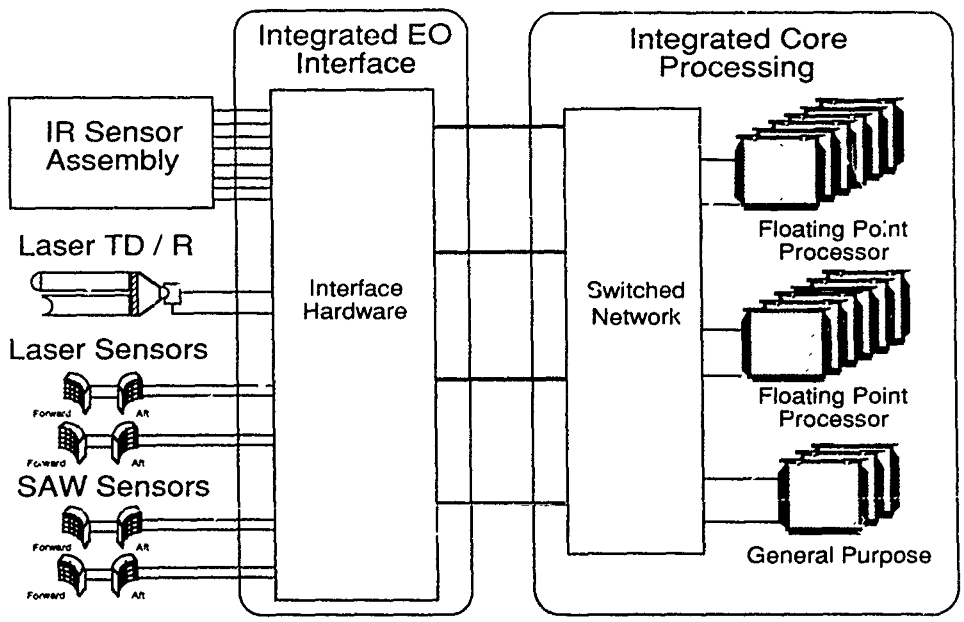


Figure 20

COMPARISON OF AVIONIC PARAMETERS

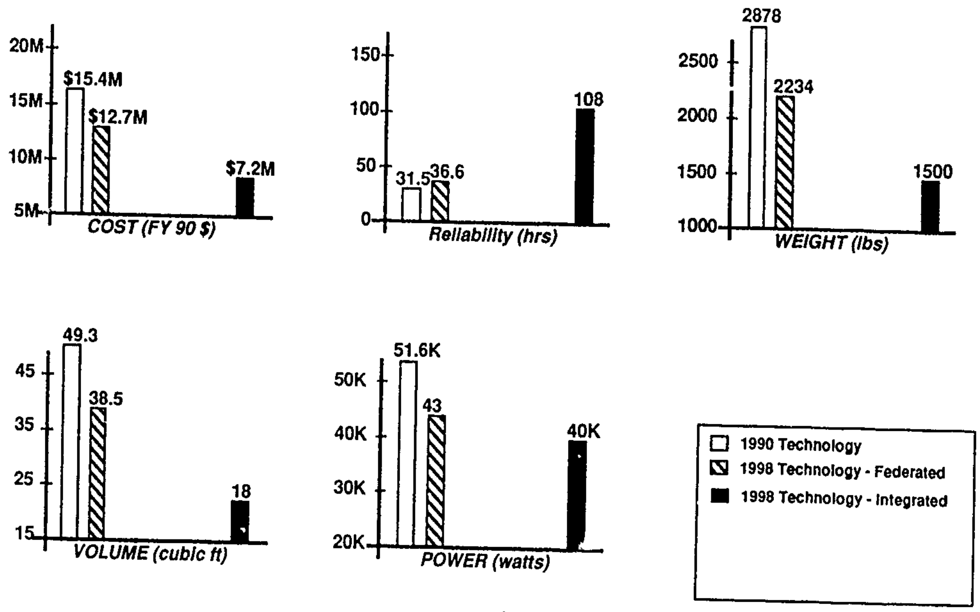


Figure 21

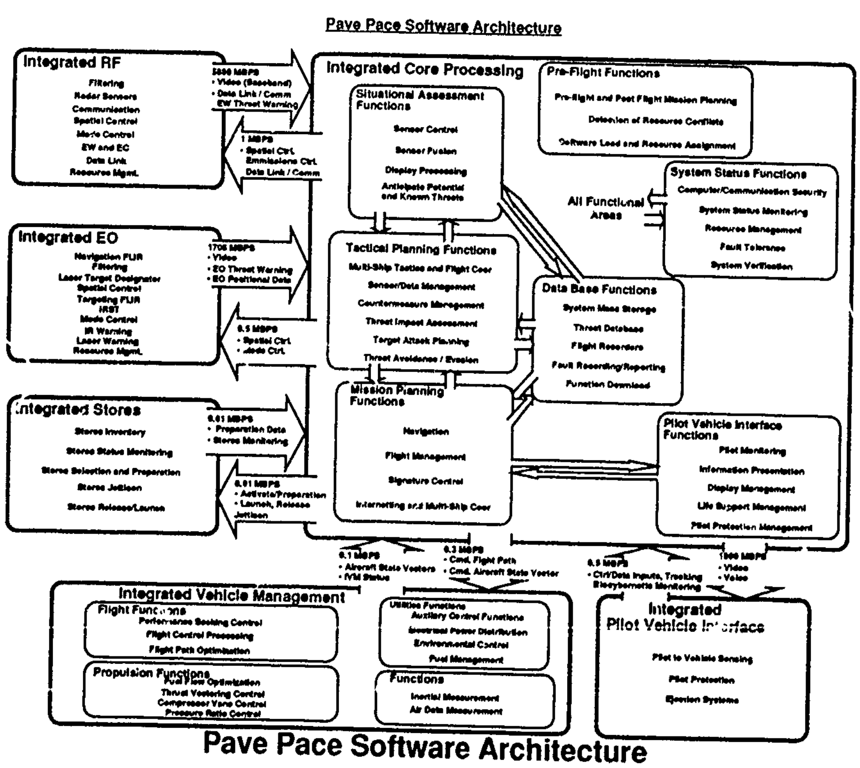


Figure 22

VERY HIGH SPEED OPTICAL NETWORKS (VHSON)

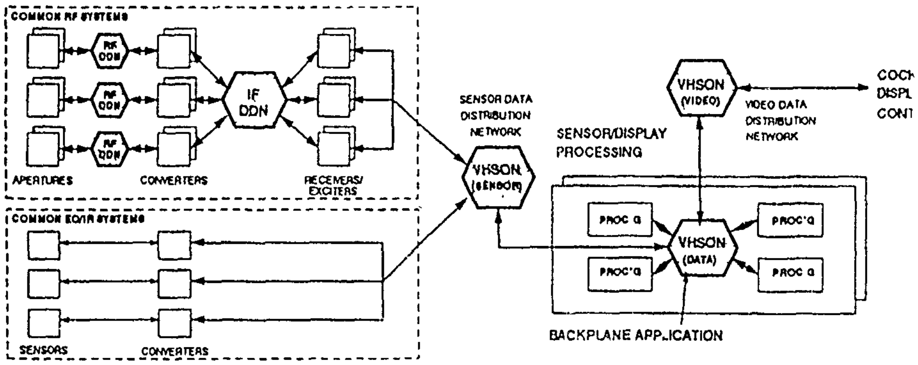
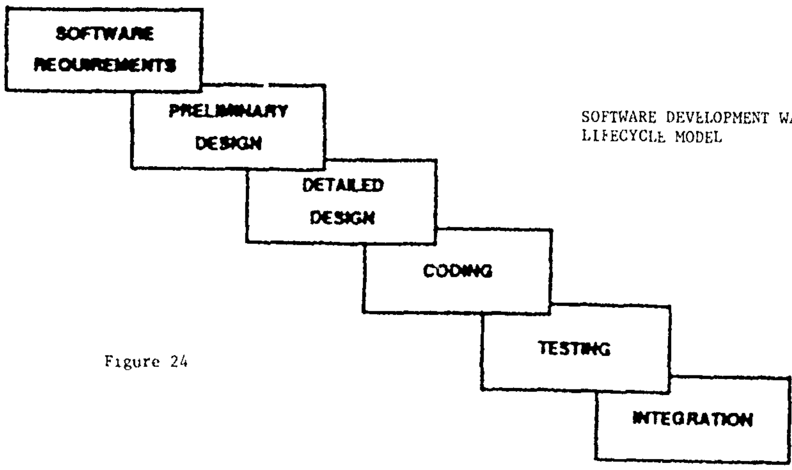
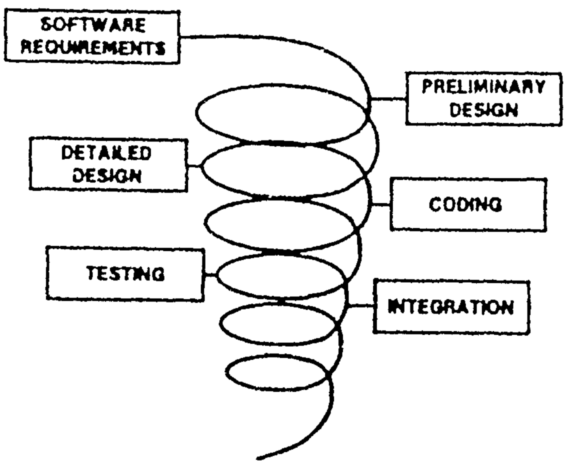


Figure 23



SOFTWARE DEVELOPMENT WATERFALL LIFECYCLE MODEL

Figure 24



SOFTWARE DEVELOPMENT SPIRAL LIFECYCLE MODEL

Figure 25

SELECTIVE BIBLIOGRAPHY

This bibliography with abstracts was prepared to support AGARD Lecture Series No. 176 by the Scientific and Technical Information Program of the U.S. National Aeronautics and Space Administration, Washington, D.C., in consultation with the Lecture Series Director, Dr. Gary L. Ludwig, Wright Patterson Air Force Base, Ohio.

UTTL Impact of fault-tolerant avionics on life-cycle costs
AUTH A/SCHOR, ANDREI L. B/LEONG, FRANK J., C/BABCOCK, PHILIP S., IV PAA C/(Charles Stark Draper Laboratory, Inc Cambridge, MA) IN NAECON 89; Proceedings of the IEEE National Aerospace and Electronics Conference Dayton OH May 22-26, 1989 Volume 4 (A90-30676 12-01) New York Institute of Electrical and Electronics Engineers Inc 1989, p 1893-1899
ABS The authors examine the effects of a fault-tolerant implementation of a mission-critical avionics function on aircraft life-cycle costs A triplex redundant architecture is contrasted with a simplex implementation of the same function The cost analysis used in this study accounts for the major contributors to the cost of ownership It is shown that an increased mission readiness and a high function reliability during the mission combine to provide a much higher overall mission success level and consequently a significant cost advantage for the fault-tolerant architecture A fault-tolerant implementation of an avionics function can significantly reduce life-cycle costs by reducing the number of additional aircraft required to achieve desired levels of mission readiness and success The high fault coverage inherent in such an implementation increases the probability of mission success by reducing the probability of undetected faults prior to the start of the mission and mitigating the effects of faults during the mission 89/00/00 90A30805

UTTL Demonstration of Avionics Module Exchangeability via Simulation (DAMES) program overview
AUTH A/STRAUSS, JACK B/PORTELLI BILL, C/OSETH, TODD PAA A/(USAF, Aeronautical Systems Div , Wright-Patterson AFB OH) C/(ZYCAD Corp Mount Olive, NJ) IN NAECON 89 Proceedings of the IEEE National Aerospace and Electronics Conference, Dayton OH, May 22-26 1989 Volume 2 (A90-30576 12-01) New York, Institute of Electrical and Electronics Engineers Inc 1989, p 660-667
ABS The Joint Integrated Avionics Working Group (JIAWG) organization strategy and program planning to achieve commonality in the concurrent development of advanced tactical weapon systems in each of the three services is discussed The completeness, adequacy, and technical issues in the area of avionics specifications and systems are especially complex A history of the significant JIAWG events in addressing these common concerns that led to the DAMES program is discussed The contribution of the DAMES tasks strategy and gate-level system simulation methodology contributions to the efficient design, manufacture cost reduction, and risk reduction of the advanced avionics for triservice weapons systems are detailed 89/00/00 90A30725

UTTL A test and maintenance architecture demonstrated on SEM-E modules for fiber optic networks
AUTH A/JENSEN, CURTIS A B/CORLEY JACK H PAA B/(Harris Corp , Government Aerospace Systems Div , Melbourne FL) IN AUTOTESTCON '89 - IEEE International Automatic Testing Conference Philadelphia, PA Sept 25-28 1989 Conference Record (A90-28310 11-66) New York Institute of Electrical and Electronics Engineers Inc , 1989 p 255-260
ABS The authors describe a general-purpose test and maintenance architecture for electronic subsystems and its demonstration in several avionics SEM-E modules for fiber-optic networking of the Advanced Tactical Fighter A-12, and other modern aircraft The results of applying this test and maintenance architecture are delineated in terms of payoff, penalty, and problems encountered Industry efforts needed to eliminate some of the problems encountered are discussed 89/00/00 90A28342

UTTL An operational perspective of potential benefits of microwave landing systems
AUTH A/BARRER, JOHN N , B/SINHA AGAM N PAA B/(Mitre Corp McLean, VA) (National Convention of Aerospace Engineers, 3rd, New Delhi, India, Feb 26 27 1988) Institution of Engineers (India) Journal, Aerospace Engineering Division (ISSN 0257-3423) vol 69, Sept 1988-Mar 1989, p 16-21
ABS The operational requirements of the ground systems avionics and air traffic control procedures that are needed to derive the maximum operational benefits from an MLS are summarized MLS applications are described including reductions in route length, arrival and departure noise exposure, airspace conflicts Also consideration is given to improving airport capacity, operational restrictions due to ILS siting problems, and rotorcraft applications 89/03/00 90A23242

UTTL RISC lifting off in avionics
AUTH A/WONG, JAMES M. H PAA A/(Sanders Associates Inc Nashua, NH) IN AIAA Computers in Aerospace Conference, 7th, Monterey, CA, Oct 3-5, 1989, Technical Papers Part 1 (A90-10476 01-59) Washington, DC, American Institute of Aeronautics and Astronautics, 1989, p 45-51
ABS The philosophy behind the use of the reduced instruction set computer (RISC) in avionics is addressed, and the merits of RISC versus the complex instruction set computer (CISC) are examined The different RISC architectures are examined using as illustrations the designs taken from various vendors Cost aspects and technology trends are briefly considered
RPT# AIAA PAPER 89-2967 89/00/00 90A10483

UTTL Radio Technical Commission for Aeronautics Annual Assembly Meeting and Technical Symposium, Washington, DC, Nov 28-30, 1988 Proceedings
AUTH A/JAGO JOANN C PAA A/(Radio Technical Commission for Aeronautics Washington DC) Meeting and Symposium sponsored by the Radio Technical Commission for Aeronautics Washington, DC Radio Technical Commission for Aeronautics, 1988, 288 p No individual items are abstracted in this volume
ABS Technological and standardization problems in the development of communication avionics are examined in reviews and reports Particular attention is given to ICAO planning for future aeronautical communication standards digital voice communication techniques, communication systems for next generation commercial aircraft extending data communication to oceanic routes, RTCA mode-S data-link standardization AEEC satellite-systems standardization air communication using Inmarsat and FAA support for future air-ground digital communication Also included is a panel discussion presenting user perspectives on aeronautical telecommunication Diagrams drawings, and tables of numerical data are provided 88/00/00 89A45875

UTTL The equipment scene
AUTH A/WESTON, J L PAA A/(Smiths Industries Aerospace and Defence Systems Co London, England) IN Civil avionics - The future international scene Proceedings of the Symposium London England Mar 17 1988 (A89-24851 08-06) London Royal Aeronautical Society 1988 p 65-80
ABS A comprehensive evaluation is made of design imperatives in state-of-the-art flight control equipment, which increasingly exploits digital/intelligent and fly-by wire technologies The goals of these development efforts encompass in addition to superior accuracy and response time performance greater system integration higher reliability, lower weight, diminished power requirements, and lower costs Attention is given to development and economic trends in computer RAMs gate arrays, and memory densities as well as to the design of active-matrix liquid-crystal displays and their matrix pixel configuration Features of the software development cycle for flight control systems are also noted 88/00/00 89A24855

UTTL Setting the scene - The operator's viewpoint
AUTH A/FEATHERSTONE, D H PAA A/(Aeronautical Radio Inc Annapolis, MD) IN Civil avionics - The future international scene Proceedings of the Symposium London England Mar 17 1988 (A89-24851 08 06) London Royal Aeronautical Society 1988 p 1-10
ABS After an evaluation of the ways in which technological advancements in electronics can be exploited for economic gain in the airline industry attention is given to such emerging technologies as the Microwave Landing System, the Mode S upgrade of the Secondary Surveillance Radar S stem, and the Airborne Collision Avoidance System The Airlines Electronic Engineering Committee anticipates that these systems will operate in parallel with existing ones for some time, allowing airlines to train with, and then transition to, the new systems as economics permit 88/00/00 89A24852

UTTL Comparison of FAA DO-178A and DOD-STD-2167A approaches to software certification
AUTH A/DEWALT MICHAEL P PAA A/(FAA Seattle WA) AIAA Digital Systems Conference, 8th, San Jose CA Oct 17-20, 1988 8 p
ABS There are two popular standards for developing avionics software The standard used for commercial aircraft is RTCA/DO-178A, Software Considerations in Airborne Systems and Equipment Certification whereas military environment uses DOD-STD-2167A Military Standard Defense System Software Development This paper compares these two standards and demonstrates that with some minor additional documentation changes software developed under the military standard DOD-STD-2167A could be compatible with certification requirements imposed by the Federal Aviation Administration through RTCA/DO-178A for commercial aircraft
RPT# AIAA PAPER 88-4044 88/10/00 89A19864

UTTL Standardization implications - An air logistics command perspective
AUTH A/ILIFF RICHARD J PAA A/(USAF, Wright-Patterson AFB, OH) AIAA, Digital Systems Conference 8th, San Jose CA Oct 17-20 1988 5 p
ABS The effect of various hardware and software standardization initiatives on the logistics command is examined In particular attention is given to the Modular Avionics System Architecture program, the concept of line replaceable modules and problems associated with the implementation of this concept, standardization in satellites and software standards It is noted that the end results of moving to standards is sometimes a higher front end cost due to the logistics infrastructure development because of the need to support new technologies which make the standard possible In the long run however, the life cycle cost will be improved
RPT# AIAA PAPER 88-3857 88/10/00 89A19859

UTTL Reliability and maintainability in modern avionics equipment - A user's point of view
AUTH A/KENNIS, FRANS J IN ICAS Congress, 16th Jerusalem Israel, Aug 28-Sept 2, 1988, Proceedings Volume 2 (A89-13501 03-05) Washington DC, American Institute of Aeronautics and Astronautics, Inc , 1988 p 1677-1682

ABS The point of view of the user (i e Belgian Air Force) concerning the reliability and maintainability of modern avionics equipment in tactical fighter aircrafts is presented Past experiences by the Belgian Air Force on aircrafts such as the F-84F, F-104G and Mirage III are highlighted Maintainability problems related to the F-16 are analyzed, causes of lack of maintainability are indicated and recommendations are made for improving maintainability A special analysis addresses the F-16 reliability improvement warranty (RIW) A new approach is presented for a RIW contract which more evenly distributes the burdens and risks between the contractor and the government 88/00/00 89A13671

UTTL Economical technology application in commercial transport design
AUTH A/DRAKE, MICHAEL L PAA A/(Boeing Commercial Airplane Co , Seattle WA) SAWE Annual Conference 46th, Seattle WA May 18-20 1987 16 p
ABS An evaluation is made of the development status and applicability to state-of-the-art medium-range transport aircraft of technologies that may improve airline operating cost The aircraft in question are of B757 class Attention is given to factors figuring in direct operating costs the cost effects of Al-Li alloy and advanced composite structures' introduction, the operational advantages of such systems as electronic engine controls and fly-by-wire control for relaxed static stability flight characteristics, and the effect on operating economics of airport delays that may be precluded through improved technologies' application
RPT# SAWE PAPER 1798 87/05/00 88A53796

UTTL Reliability and life cycle cost of military aircraft - The vital link I - The context
AUTH A/DANIEL D W PAA A/(Ministry of Defence Procurement Executive London, England) IN Reliability '87 Proceedings of the Sixth Conference Birmingham, England Apr 14-16, 1987 Volume 1 (A88-428L1 17-38) London, Institute of Quality Assurance 1987 p 38/3/1 to 3B/3/4
ABS The initiatives of the Ministry of Defence (MOD) and industry's response to the provision of models and methods for the evaluation of system cost-effectiveness from the earliest stages of development are examined Particular attention is given to the relationship between improved reliability on the one hand and lower costs and improved operational performance on the other It is shown why evaluation tools are urgently required, and a strategic framework for their development is provided 87/00/00 88A42864

UTTL VHSIC interoperability standards and design for test rules Their impact on weapon system support concepts
AUTH A/MCDERMOTT, JON T PAA A/(Honeywell, Inc Minneapolis, MN) IN AUTOTESTCON '87 Proceedings of the International Automatic Testing Conference San Francisco, CA, Nov 3-5 1987 (A88-36528 14-59) New York, Institute of Electrical and Electronics Engineers Inc 1987 p 245-249
ABS Two recent developments in microelectronics have the potential to significantly change the way weapon systems are supported They are the development of buses to be used for control and data information flow between subsystem maintenance controllers, module maintenance controllers, and individual elements (chips) of a module, and the inclusion of testable building blocks in CAD databases along with rules that govern their use When applied to weapon-systems design these two concepts can be combined to give an onboard hierarchical maintenance and diagnostic capability that could significantly change weapon-system support concepts The author discusses these concepts and their relation to weapon-system support and future automatic test systems 87/00/00 88A36560

UTTL Application of an integrated interconnection system in helicopter wiring
AUTH A/GOHMAN RICHARD W PAA A/(McDonnell Douglas Helicopter Co Mesa, AZ) AHS Annual Forum, 43rd, Saint Louis MO May 18-20 1987 Paper 11 p
ABS A representative integrated interconnection system (I2S) wiring design was prepared for the AH-64A helicopter and compared to the existing wiring design to quantify the production cost savings and the technical risks involved in the design concept Experiments in EMI/EMC performance and fabrication of a test harness were combined with the analytical evaluation effort The conclusions drawn from this study indicated that the I2S is not effective as a concept to design replacements for existing harness assemblies, but it does present sufficient production cost saving in a new wiring design effort to be seriously considered in the design trade evaluation 87/05/00 88A22800

UTTL Improving avionics acquisition and support from conceptualization through operations
AUTH A/GEBMAN JEAN B/SHULMAN HY PAA B/(Rand Corp Santa Monica CA) IN Avionics in conceptual system planning Proceedings of the Eighth Annual IEEE Symposium Dayton OH Dec 3 1986 (A88-16912 05-66) New York, Institute of Electrical and Electronics Engineers, Inc , 1986, p 69-76
ABS The problem of the supportability of avionics equipment is examined with emphasis on an approach to acquisition and support that begins with the concept formulation stage and follows through the equipment's full life of service The basis for such an approach is summarized, and a broad strategy for enhancing avionics supportability is formulated Some tradeoffs are proposed which should be made at the concept formulation stage to further enhance the benefits of the strategy for improving avionics supportability 86/00/00 88A16919

UTTL The design agent process as a strategy for future avionics competition enhancement and quality assurance
AUTH A/DELANEY WILLIAM J PAA A/(Charles Stark Draper Laboratory Inc , Cambridge MA) IN Avionics in conceptual system planning, Proceedings of the Eighth Annual IEEE Symposium, Dayton, OH, Dec 3, 1986 (A88-16912 05-66) New York, Institute of Electrical and Electronics Engineers Inc 1986, p 53-58
ABS The design agent concept of acquisition management is examined with particular reference to future avionics acquisition requirements The activities, responsibilities, and competition enhancing benefits of the design agent approach to acquisition management are discussed and illustrated by several different application examples It is claimed that the design agent's ability to uniquely establish and control multiple contractors for competition enhancement purposes has direct relevance to the need for improved acquisition strategies on select 6 3 programs 86/00/00 88A16918

UTTL The avionics acquisition process beyond the year 2000
AUTH A/LAVOIE, R P B/CULP A M IN Avionics in conceptual system planning, Proceedings of the Eighth Annual IEEE Symposium Dayton OH Dec 3 1986 (A88-16912 05-66) New York, Institute of Electrical and Electronics Engineers Inc , 1986, p 45-49
ABS The current weapon system acquisition and support process is examined with emphasis on problems related to the useful life of microelectronic component technology requirements changes and technology obsolescence The need for changes in the present acquisition process is emphasized and it is shown that a good solution should accept the reality of long development programs and adjust the process to deal with rapidly developing technology requirements changes, and obsolescence The critical elements of the solution are long-term planning, sustained investment for improving systems, managed change and incremental transfer of system responsibility 86/00/00 88A16917

UTTL Avionics in conceptual system planning Proceedings of the Eighth Annual IEEE Symposium Dayton OH, Dec 3 1986 Symposium sponsored by IEEE New York Institute of Electrical and Electronics Engineers, Inc 1986 92 p For individual items see A88-16913 to A88-16920
ABS The papers presented in this volume deal with various aspects of the problem of integrating avionics into total system design during the concept formulation stage with particular attention given to impacts upon definition of requirements future avionics concepts, tradeoffs between the vehicle propulsion and avionics integration of supportability into the design and acquisition strategies Papers are included on system architecture design and tools for a distributed avionics system the design agent process as a strategy for future avionics competition enhancement and quality assurance the avionics acquisition process beyond the year 2000, and electromagnetic compatibility modeling for future avionics systems 86/00/00 88A16912

UTTL Reliability maintainability and testability of RAF equipment
AUTH A/IZZARD J , B/MILLOY P D G PAA B/(RAF London, England) IN Cost-effective avionic and weapon systems Proceedings of the Spring Convention London, England May 14 15, 1986 (A87 48051 21-83) London, Royal Aeronautical Society, 1987 p 9 1-9 10
ABS The RAF's institutional view of cost-effectiveness in avionics and weapons systems emphasizes life cycle costs (LCCs) rather than acquisition costs Reliability maintainability and testability are held to be critical to the achievement of cost effectiveness, and are invested in to the requisite degree before a piece of equipment is allowed to enter service Attention is presently given to LCC costing practices the operational costs of equipment unreliability USAF experience with reliability and maintainability, testability design provisions and built-in test technology capability projections 87/00/00 87A48060

UTTL Modular ICNIA packaging technology
AUTH A/PORADISH, FRANK PAA A/(Texas Instruments Inc Avionics Systems Div McKinney) IN Digital Avionics Systems Conference, 7th, Fort Worth TX, Oct 13-16 1986 Proceedings (A87-31451 13-01) New York Institute of Electrical and Electronics Engineers Inc 1986 p 753-756
ABS Significant size weight power and reliability improvements can be achieved in next generation avionics by the modular integration of similar functions into a fault tolerant reconfigurable architecture The Integrated Communication Navigation Identification Avionics program (ICNIA) is accomplishing this task with a combination of modular circuit designs using VHSIC technology improved packaging designs incorporating surface mount component technology, and a modular two-level maintenance support concept for reduced life cycle cost This article concentrates on the modular packaging technology of the digital processor subsystem 86/00/00 87A21546

UTTL F/A-18 Hornet Reliability development testing - An update
AUTH A/ROSGER W R PAA A/(McDonnell Aircraft Co , Saint Louis MO) IN Institute of Environmental Sciences Annual Technical Meeting 32nd Dallas and Fort Worth TX, May 6-8 1986 Proceedings (A87-26026 10-38) Mount Prospect, IL, Institute of Environmental Sciences 1986, p 86-92
ABS The characteristics of the Operational Mission Environments (OMEs) used to accelerate the identification of failure modes and provide corrective action early in the Reliability Development Test (RDT) program of the F/A-18 Hornet are discussed Different OMEs are needed for the develoment test, burn-in, and All Equipment test because of the different results expected The operationally realistic environments and test acceleration generated more failures than traditional reliability testing, and half-life vibration, 750 hours vibration simulation, and high thermal rate cycling were all up-front tests 86/00/00 87A26035

UTTL An expert system for the configuration of aircraft modular VSCF generator systems
AUTH A/HO T -L B/BAYLES, R A , C/SIEGER E R PAA C/(Westinghouse Electric Corp , Baltimore, MD) IN NAECON 1986, Proceedings of the National Aerospace and Electronics Conference Dayton OH May 19-23 1986 Volume 1 (A87-16726 05-01) New York, Institute of Electrical and Electronics Engineers, 1986, p 304-311
ABS The modular VSCF (Variable Speed Constant Frequency) electrical systems are designed using the latest technology and modular design techniques The system is separated into standard modules to reduce the manufacturing cost and improve the product quality and services This tool is an expert system which automatically configures the modules required for a particular application The automatic configuration expert system is a rule-based synthesis system whose domain encompasses the matrix of standard modules The configuration system is built by using a rule-based expert system development tool OPS5, in a VAX 11/750 computer It has the domain-specific knowledge necessary to configure the generators embedded in its rule-base and exhibits expertise to place the modules in the proper arrangement based on customer specifications and design criteria 86/00/00 87A16755

UTTL LAMPS MK III - A 'New Look' success story
AUTH A/GOOD T M PAA A/(IBM Corp Federal Systems Div , Owego, NY) IN 1986 Annual Reliability and Maintainability Symposium, Las Vegas, NV January 28-30, 1986 Proceedings (A87-15401 04 38) New York, Institute of Electrical and Electronics Engineers, Inc , 1986 p 151 155
ABS The reliability enhancement elements incorporated into the LAMPS MK III development program are described New elements included conservative derating criteria to ensure that a 20-yr service life would be available from 99 percent of the 30 000 components of the integrated system Other program elements are parts selection and a test analyze, and fix program A reliability estimate for the SH-60B helicopter exceeded the reliabilities of other current systems by a factor of 2 5 86/00/00 87A15415

UTTL Air Force standardizing avionics
AUTH A/MONAHAN, G , JR PAA A/(USAF, Office of the Deputy Chief of Staff for Research, Development and Acquisition, Washington, DC) Defense Electronics (ISSN 0278-3479) vol 17 Aug 1985 p 120-122, 125, 126, 128, 130
ABS Taking a multilevel approach towards the standardization of avionics - in components circuit boards, black boxes, hardware and software - the USAF is seeking to reduce costs, increase interoperability and make room for the technology of the future Breakthroughs in computer and electronics technologies have enabled hardware standardization on the highest level the line-replaceable unit standardizing the form fit and function (F3) of such units promises significant savings in support and development costs Software, applicability architecture organizational structure implementation, current advances and future directions are topics covered 85/08/00 85A44074

UTTL The relationship between an advanced avionic system architecture and the elimination of the need for an Avionics Intermediate Shop (AIS)
AUTH A/ABRAHAM S J PAA A/(General Dynamics Corp , Fort Worth, TX) IN AUTOTESTCON '83 Proceedings of the Conference Fort Worth, TX November 1-3, 1983 (A85-26776 11-59) New York, Institute of Electrical and Electronics Engineers, Inc 1983, p 206-211
ABS While Avionics Intermediate Shops (AISs) have in the past been required for military aircraft, the emerging VLSI/VHSIC technology has given rise to the possibility of novel well partitioned avionics system architectures that obviate the high spare parts costs that formerly prompted and justified the existence of an AIS Future avionics may therefore be adequately and economically supported by a two-level maintenance system Algebraic generalizations are presented for the analysis of the spares costs implications of alternative design partitioning schemes for future avionics 83/00/00 85A26804

UTTL Trends in digital engine control - Integration of propulsion control with flight control and avionic systems in future military and commercial aircraft
AUTH A/ECCLES, E S PAA A/(Dowty & Smith Industries Controls Ltd , Cheltenham, Glos , England) IN Design and advanced concepts of avionics/weapons system integration; Proceedings of the Symposium, London, England April 3 4 1984 (A85-21456 08-01) London Royal Aeronautical Society 1984, 9 p Research supported by the Ministry of Defence of England
ABS This paper discusses future trends in engine control and addresses the integration of flight control and propulsion control both in commercial and in future advanced military aircraft Such aircraft may employ sustained supersonic cruise and maneuvering flight thrust vectoring and extensive variable geometry features The paper outlines the factors which force the integration of systems the benefits hoped for and the status of current work It discusses the effects of integration on inter-system and inter-organizational interfaces and the methods and technologies needed to achieve the ends being sought within anticipated timescales 84/00/00 85A21466

UTTL Man-machine integration
AUTH A/ROE, G PAA A/(British Aerospace, PLC, Brough, N Humberside, England) IN Design and advanced concepts of avionics/weapons system integration, Proceedings of the Symposium, London, England, April 3, 4 1984 (A85-21456 08-01) London, Royal Aeronautical Society 1984, 9 p
ABS Attention is given to British studies addressing questions of pilot cockpit task optimization, and the overall system architecture required to meet the operational requirements imposed for next-generation tactical combat aircraft in the sphere of communications The Tactical Combat Aircraft Avionics Demonstrator Rig is devoted to the investigation of such issues as total system integration, interface standardization, effective subsystem intercommunication system degradation amelioration, and improved maintenance procedures The architecture under development has a multibus hierarchy and implements data transmission standard 1553B for subsystem-to-subsystem and bus-to-bus communication Emphasis is given to the influence of pilot needs on system design and implementation 84/00/00 85A21463

UTTL Integrated communications - A designers view
AUTH A/BRIERLEY, W E PAA A/(Marconi Avionics, Ltd , Airadio Products Div , Basildon, Essex England) IN Design and advanced concepts of avionics/weapons system integration Proceedings of the Symposium, London, England April 3 4 1984 (A85-21456 08-01) London, Royal Aeronautical Society, 1984, 7 p
ABS An integrated aircraft communications system should ensure high confidence levels for all phases of a task or mission, allow effective operation at the lowest possible crew workload, and be cost-effective with respect to equipment size weight power demand, reliability and maintainability It is noted that while the technology for control and display system integration is available the techniques required in common communication signal processing remain to be developed Attention is given to the unique integration problems encountered in the man/machine interface of control and display systems, the acquisition and/or transmission of communication intelligence and signal processing 84/00/00 85A21462

UTTL High density modular avionics packaging
AUTH A/PORADISH, F PAA A/(Texas Instruments Inc Dallas, TX) IN Digital Avionics Systems Conference, 6th Baltimore MD, December 3-6, 1984, Proceedings (A85-17801 06-01) New York American Institute of Aeronautics and Astronautics, 1984, p 634-640
ABS Requirements and design configurations for high density modular avionics packaging are examined, with particular attention given to new hardware trends, the design of high-density standard modules (HDSM's), and HDSM requirements The discussion of the HDSM's covers thermal management, system testability, power supply and performance specifications The general design of an integrated HDSM demonstration system currently under construction is briefly described and some test data are presented
RPT# AIAA PAPER 84-2749 84/00/00 85A17898

UTTL A standard computer bus for MIL-STD-1750A avionics computers
AUTH A/PENN, D , B/LEVY, S , C/LOKER, E PAA B/(Israel Aircraft Industries, Ltd Tel Aviv Israel), C/(Elbit Computers, Ltd , Haifa, Israel) IN Digital Avionics Systems Conference 6th, Baltimore, MD, December 3-6, 1984 Proceedings (A85-17801 06-01) New York, American Institute of Aeronautics and Astronautics, 1984, p 393-398
ABS While MIL-STD-1750A describes an instruction set architecture (ISA), the application of this ISA requires the usage of a data and address bus system which permits efficient communication between the cpu, memory, and application oriented input/output devices The data and address bus system design and implementation is influenced by the design of the cpu and main memory since these two devices, in general, are the main users of the bus system The Lavi avionics system utilizes a standardized data and address bus system (called L-BUS) for use in the MIL-STD-1750A computers which are embedded in the various components of the avionics system The L-BUS is described and is proposed as a potential standard bus for MIL-STD-1750A implementations
RPT# AIAA PAPER 84-2679 84/00/00 85A17360

UTTL F404 new standards for fighter aircraft engines
AUTH A/RIEMER, B A , B/POWEL S F , IV PAA B/(General

Electric Co , Lynn, MA) IN International Council of the Aeronautical Sciences, Congress, 14th, Toulouse, France September 9-14 1984, Proceedings Volume 1 (A84-44926 22-01) New York, American Institute of Aeronautics and Astronautics 1984, p 476-482

ABS Design features, performance capabilities and applications of the F404 jet engine are described The F404 supplies 16-22 klb thrust, is 159 in long and 35 in in diameter and has a pressure ratio of 25 1 The engine includes wide chord, low aspect ratio fan blades enhanced aerodynamics and a high stall margin Early usage has revealed an unrestricted throttle movement throughout the performance envelope, a 3 25 sec interval from idle to full power, high inlet distortion tolerance, reliable air starts and dependable afterburner light The digital controls are built into two ceramic modules which permit easy installation of redundancy Testing has surpassed 500 hr in the F-20 and will be initiated in the F/A-18 Other potential applications are in the MAS39, the A 6 the ACX demonstrator and the X-29 84/00/00 84A44981

UTTL Digital electronic flight decks - The outlook for commercial aviation

AUTH A/CLAY, C W PAA A/(Boeing Commercial Airplane Co Seattle, WA) (Institute of Electrical and Electronics Engineers, Annual Symposium, 5th, Dayton OH, Nov 30 1983) IEEE Transactions on Aerospace and Electronic Systems (ISSN 0018-9251), vol AES-20, May 1984, p 221-226

ABS Digital avionics are increasingly able to reduce overall commercial airliner costs through their great reliability and flexibility of operation Attention is presently given to the development of modular control units for fly-by-wire and power-by-wire directional controls and engine throttle controls as well as the design features of a network of multisystem digital data buses which can be developed to manage the complex interchange of data among interrelated digital systems throughout an aircraft 84/05/00 84A36907

UTTL Thermal characteristics of standardized Air Force avionic enclosures

AUTH A/FRANKLIN J L , B/LEONARD, C F PAA B/(Boeing Aerospace Co , Seattle WA) AIAA, SAE, ASME, AIChE and ASMA Intersociety Conference on Environmental Systems, 13th San Francisco, CA July 11-13, 19 3 11 p

ABS To resolve the question of avionic enclosure energy dissipation limits and develop thermal design data on MIL-STD-XXX style enclosures, a series of thermal analyses, the majority of which were performed steady-state were carried out using an updated version of the ENCLOS thermal analysis program Results based on the use of ceramic chip carriers from both initial and updated analyses and test results are presented Using data collected on the heat exchanger card, and clamp conductances, together with device conductances, plots of junction temperature versus power enclosure power dissipation were constructed Properly constructed size 2 8 MCU standard enclosures may operate at power levels of watt/cu in without incurring excessive junction temperatures To achieve the same power densities, size 9-12 MCU enclosures with side-mounted heat exchangers require high conductance circuit cards and card clamps

RPT# SAE PAPER 831103 83/07/00 84A29038

UTTL Avionics standardization - Do's and dont's

AUTH A/RICKER, R K PAA A/(USAF Wright-Patterson AFB OH) IN Digital Avionics Systems Conference, 5th Seattle WA October 31-November 3 1983, Proceedings (A84-26701 11-06) New York Institute of Electrical and Electronics Engineers, 1983, p 23 1 1-23 1 5

ABS The paper covers a broad range of lessons learned in the last decade of avionics standardization activities within the Air Force It covers technical and management considerations and traces a number of projects from idealistic goals to the reality of implementation The hardware area will address criteria for selection, the specification, finding the customers balancing market realism against the promises of advocacy, and the necessity for end-to-end planning Specific examples with mini-case histories of UHF radios, TACANs, INSs altimeters air data computers, data recorders, etc will be used to illustrate points Current interface standards such as MIL STD 1553 and 1760 will be examined relative to their evolution and acceptance The issue of validation and continued maintenance and support will be covered The software standards of MIL STD 1589 and 1750 will be treated in a similar manner The importance of a clear waiver process and the value of broad based user groups will be highlighted The question of what level of support services that need to be provided off line to insure acceptance will be addressed 83/00/00 84A26803

UTTL Fault tolerant flight control avionics integration using MIL-STD-1553B

AUTH A/MCSHARRY M E PAA A/(Boeing Military Airplane Co Seattle, WA) IN Digital Avionics Systems Conference, 5th Seattle, WA, October 31-November 3, 1983, Proceedings (A84-26701 11-06) New York Institute of Electrical and Electronics Engineers 1983 p 11 1 1-11 1 8

ABS While the design of integrated systems using distributed processing, hierarchical architectures, and data bases, provides the greatest independence and immunity from fault propagation compromises that tend to more tightly couple integrated system components may be needed in order to satisfy performance requirements Attention is presently given to the MIL-STD-1553B integrated system data bus which is marginally capable of satisfying the data transfer requirements for both flight control and mission avionics and whose mission avionics functions must be implemented with a higher level of redundancy if the mission functions affect flight safety Redundancy can be attained through hardware replication as well as analysis 83/00/00 84A26744

UTTL The missing link for advanced avionics systems executives

AUTH A/LEEPER, K R PAA A/(Boeing Military Airplane Co , Advanced Airplane Branch, Seattle, WA) IN Digital Avionics Systems Conference, 5th, Seattle, WA October 31-November 3, 1983, Proceedings (A84-26701 11-06) New York Institute of Electrical and Electronics Engineers, 1983 p 2 6 1-2 6 6

ABS An avionics system executive was developed with the aid of the Digital Avionics Information System (DAIS) program This executive was coded mostly in high-order language with hardware interfaces in machine code However, it was found that the DAIS executive was more complex than necessary for many applications It was, therefore, decided to eliminate asynchronous operations from the executive As a result of this decision the Single Processor Synchronous Executive (SPSE) was obtained Developments with respect to a further evolution of standards continued, however, and revisions appeared which were not included in the DAIS evolution The present investigation is concerned with the efforts of an American aerospace company to update the SPSE to MIL-STD-1750A and MIL-STD-1589B It is pointed out that the 1750A SPSE represents the missing link in the evolution of the avionics executive of yesterday to the advanced executive of tomorrow 83/00/00 84A26704

UTTL EME susceptibility testing of aircraft

AUTH A/CLARK, D E , B/HEATHER, F W PAA A/(Georgia Institute of Technology, Atlanta GA), B/(U S Navy Naval Air Test Center, Patuxent River MD) IN NAECON 1983, Proceedings of the National Aerospace and Electronics Conference, Dayton OH May 17-19, 1983 Volume 1 (A84-16526 05-01) New York, Institute of Electrical and Electronics Engineers, 1983 p 158-161

ABS The Naval Air Test Center, Patuxent River Maryland, has the task of conducting tests and evaluations on naval aircraft to assure compliance with EME (electromagnetic environment) susceptibility specifications The NATC is developing a facility called the Electromagnetic Environmental Generation System (EMEGS) to perform the system-level susceptibility tests This paper describes the EMEGS facility and its supporting instrumentation and examines the engineering aspects of upgrading the EMEGS 83/00/00 84A16540

UTTL Role of standards with integrated control

AUTH A/GADBOIS, R G PAA A/(Lear Siegler, Inc Astronics Div Dayton OH) IN American Control Conference 1st Arlington VA, June 14-16, 1982, Proceedings Volume 2 (A83-37076 17-63) New York, Institute of Electrical and Electronics Engineers, 1982, p 588 589

ABS The effect of standardization on the application of integrated control technology to military aircraft is discussed in terms of a latent conflict between the cost benefits of standardized systems and those attainable by implementing new technologies unaccounted for by the standards The signal-interface standard MIL-STD-1553 while beneficial for connecting avionic systems that need to interact, is found to be potentially inefficient for self-contained packages (such as those being developed for integrated flight and propulsion control), and less reliable for components requiring the exchange of very few signals Architecture standards referring to instruction sets and high-order languages need to be applied pragmatically focusing on form, fit, and function computer-aid programs allowing access in natural English may be able to achieve the benefit goals of a standardized high-order language 82/00/00 83A37104

UTTL Benefits of mission profile testing

AUTH A/WAGNER, J F , III B/BURKHARD, A H PAA A/(USAF, Aeronautical Systems Div Wright-Patterson AFB OH), B/(USAF Flight Dynamics Laboratory, Wright-Patterson AFB, OH) IN Environmental stress impact and environmental engineering methods Proceedings of the Twenty-seventh Annual Technical Meeting on Emerging Environmental Solutions for the Eighties Los Angeles CA May 5-7 1981 Volume 1 (A83-31476 13-38) Mt Prospect, IL Institute of Environmental Sciences, 1981, p 26-31

ABS Tangible and intangible benefits of combined environment reliability testing (CERT) are described in terms of the perspective of the acquisitor logistician and user of avionics equipment Both cost saving benefits and operational effectiveness impacts are discussed When used as a test-analyze-fix growth test program in the acquisition process, CERT benefits all the decision makers in the equipment's life cycle This benefit is obtained without significant adverse impact on performance as measured against established performance factors used by decision makers Total acquistion cost comparisons are shown 81/00/00 83A31481

UTTL Jovial language control procedures with a view toward Ada

AUTH A/KNOOP, P A , B/EVANS, B R PAA B/(USAF, Wright-Patterson AFB, OH) In NAECON 1982 Proceedings of the National Aerospace and Electronics Conference Dayton, OH May 18-20 1982 Volume 2 (A83-11083 01 01) New York, Institute of Electrical and Electronics

Engineers, Inc , 1982, p 953-960

ABS JOVIAL is the interim standard language for Air Force avionics embedded computers until Ada becomes available The JOVIAL Language Control Facility (LCF) has developed and fine-tuned the procedures of language control and defined them using a formal modeling technique The resulting models promote tight administration of the control function by exposing the details of all tasks and forcing attention to their interrelationships They also provide a basis for reconfiguring proven Air Force language control functions for Ada, and the ICF has dentified some important considerations in accomplishing this The Air Force's transition to Ada has a high probability of success because of their experience with JOVIAL, their systematic evolution and fine-tuning of language control procedures, and the extensibility of these procedures to encompass Ada 82/00/00 83A11198

UTTL Integrated CNI avionics logistics considerations

AUTH A/HARRIS, R L., B/MCMANUS J C PAA A/(USAF Avionics Laboratory, Wright-Patterson AFB, OH), B/(USAF Human Resources Laboratory, Wright-Patterson AFB OH) In NAECON 1982 Proceedings of the National Aerospace and Electronics Conference, Dayton OH, May 18-20, 1982 Volume 2 (A83-11083 01-01) New York, Institute of Electrical and Electronics Engineers, Inc 1982, p 643-650

ABS The Integrated Communication Navigation Identification Avionics (ICNIA) program is an advanced development program which includes logistics support criteria into its conceptual design and system definition Some key logistics considerations of ICNIA are discussed including the integration of a number of avionic systems, the development of specifications for an Integrated CNI Evaluator and a series of logistics analysis studies Advanced and new technologies employed in ICNIA will make possible a reduction of the number of systems through the development of a single integrable reconfigurable system These features lead to expectations of major savings in volume, weight, and life cycle costs, as well as an improvement in system readiness 82/00/00 83A11157

UTTL ICNIA - Lessons learned on sensor integration

AUTH A/HAMME, D L PAA A/(USAF, Wright Aeronautical Laboratories, Wright-Patterson AFB, OH) In NAECON 1982, Proceedings of the National Aerospace and Electronics Conference, Dayton, OH, May 18-20, 1982 Volume 1 (A83-11083 01-01) New York, Institute of Electrical and Electronics Engineers, Inc , 1982 p 93-97

ABS Integration, at several levels, appears to be a fruitful concept for addressing avionics problems at both macroscopic and microscopic levels This paper addresses some of the necessary attributes of system integration efforts and associated problems in winning acceptance of integration concepts from a management viewpoint It is illustrated by reference to the Integrated Communication Navigation Identification Avionics (ICNIA) program which is traced from its initial concept through approval to become one of the first Air Force programs with the primary objective of functionally integrating a subset of sensor avionics The discussion covers lessons learned from proposing and defending the philosophy of integration which ultimately resulted in this major advanced development program within the Avionics Laboratory It offers an insight into syste and technology challenges for the coming decade 82/00/00 83A11096

UTTL F/A-18 Hornet reliability challenge - Status report

AUTH A/RICKETTS, M P PAA A/(McDonnell Aircraft Co , St Louis, MO) In Annual Reliability and Maintainability Symposium, Los Angeles, CA, January 26-28, 1982 Proceedings (A82-42176 21-38) New York, Institute of Electrical and Electronics Engineers, 1982, p 491-496

ABS A development status report is given for the F/A-18 Hornet Reliability Program, in which an attempt is made to give reliability criteria the same design emphasis as weight performance and cost Among the established reliability assurance techniques applied are periodic status assessments for each subsystem manager, failure mode and effects analyses, an approved parts list, selective use of Sneak Circuit Analysis, and a closed loop evaluation and reporting system which reports and tracks all equipment failures. The F/A-18's 3 7-hour mean flight time between failures (MFTBF) requirement was tested in 50 Reliability Demonstration flights, and an 8 4-hour MFTBF was demonstrated The F/A-18 incorporates such high inherent reliability design components as solid state avionics improved avionics cooling, a fixed-geometry engine air inlet, simpler hydraulics, and the highly simplified F404 engine 82/00/00 82A42229

UTTL R/M/LCC effects of commercial off-the-shelf equipment

AUTH A/MACDIARMID, P. R , B/PETTINATO, A. D C/JOHNSON, B G PAA B/(USAF, Rome Air Development Center, Griffiss AFB, NY), C/(Rockwell International Corp Cedar Rapids, IA) In Annual Reliability and Maintainability Symposium, Los Angeles, CA, January 26-28, 1982, Proceedings (A82-42176 21-38) New York, Institute of Electrical and Electronics Engineers, 1982, p 40-46

ABS This paper addresses the effects of using commercial off-the-shelf equipment in military environments Comparisons are made of military vs commercial reliability approaches and an analytical approach for choosing the most appropriate acquisition strategy is presented Life cycle cost comparisons are made of commercial off-the-shelf equipment vs similar militarized equipment in military environments Examples are presented of assessing risks under varying applications and choosing the best acquisition strategy 82/00/00 82A42181

UTTL Simple vs sophisticated TacAir avionics II - Soviet TacAir avionics technology

AUTH A/BUSSERT, J Military Electronics/Countermeasures, vol 8, Mar 1982 p 56-62

ABS An historical study is presented of Soviet tactical aircraft avionics developments, encompassing radars, ECM ordnance communications and cockpit instrumentation It is noted that (1) there has been a marked shift since 1970 from interceptor to ground support aircraft development and production, (2) that ostensibly obsolete electronics such as the MiG-25 vacuum tube-based Foxfire radar may exploit low vulnerability and exceptionally high power levels and (3) that the simplicity of Soviet avionics design imposes a lower acquisition and maintenance cost burden while increasing reliability and the trainability of crews It is suggested that the Soviet study of F-14 Phoenix missile systems since the Iranian revolution has been instrumental in the development of a MiG-25 two-seat variant with anti-cruise missile look down/shoot down capability 82/03/00 82A28397

UTTL The modular ATE

AUTH A/LEVY, E I PAA A/(Eastern Air Lines, Inc Miami FL) In AUTOTESTCON '80, International Automatic Testing Conference, Washington, DC November 2-5, 1980 Proceedings (A82-27876 12-59) New York, Institute of Electrical and Electronics Engineers, Inc , 1980 p 51-53

ABS The Eastern Air Lines concept of modular ATE is presented, with attention given to both hardware and software aspects Existing maintenance philosophies and the classical ATE are reviewed to show why present concepts are no longer cost effective Potential problems of the modular ATE concept are examined, and the need for further standardization and close industry cooperation is discussed 80/00/00 82A27886

UTTL Airline ATE requirements

AUTH A/HARMON, H E PAA A/(American Airlines, Inc , Dallas TX) In AUTOTESTCON '80, International Automatic Testing Conference, Washington, DC November 2-5 1980, Proceedings (A82-27876 12-59) New York, Institute of Electrical and Electronics Engineers, Inc , 1980 p 43-46

ABS The general requirements of airline ATE (automatic test equipment) are reviewed, and attention is given to dedicated modular general-purpose and circuit card ATE It is noted that maintenance of all-digital avionics will require the full utilization of standardized instrument techniques and the ATLAS test language to accomplish cost effective testing and repair And it is recommended that airlines effectively communicate these test equipment requirements to the suppliers of future avionics equipment 80/00/00 82A27884

UTTL The use of dynamic mock-ups in the design of advanced systems

AUTH A/GRAVELY, M L B/HITCHCOCK, L PAA A/(USAF Flight Dynamics Laboratory, Wright-Patterson AFB, OH) B/(U S Naval Material Command, Naval Air Development Center, Warminster PA) In Human Factors Society, Annual Meeting 24th, Los Angeles, CA, October 13-17, 1980, Proceedings (A82-22901 09-54) Santa Monica, CA Human Factors Society, Inc 1980, p 5-8

ABS The advantages of using dynamic mock-ups in advanced system design are discussed in terms of the USAF's Digital Avionic Information System (DAIS) Program and the Navy's Advanced Integrated Display System (AIDS) Cockpit Development Program Experienced pilots are employed to judge the acceptability of slide projector displays for radar low-light level television, and alphanumeric and vector graphic formats Cost effectiveness is achieved by lowering software costs, minimizing time in constructing the mock-up, and high reliability-low maintenance features The cockpit layout is set up once the required tasks and the number of multifunction controls are known, and variations on the instrumentation set-up are tested repeatedly The AIDS concept allows remote location of a slide projector for closed circuit television display of various instrument configurations in different situations, and selected displays are chosen for full scale simulation 80/00/00 82A22902

UTTL Very high speed integrated circuits Into the second generation II - Entering Phase 1

AUTH A/MARTIN, J PAA A/(National Semiconductor Corp , Santa Clara, CA) Military Electronics/Countermeasures, vol 8, Jan 1982 p 60-63, 65, 66

ABS The intended applications of the Very High Speed Integrated Circuits (VHSIC) chips and technologies fall into four basic categories These categories are related to current operational systems which could be improved through VHSIC technologies without change in performance, the addition of new performance features to existing systems, planned upgrades of existing systems through the use of VHSIC technologies and new systems which could not be developed without the use of VHSIC technology Attention is given to system design evolution, aspects of technology insertion, advantages related to standardization, applications related to the development of the next generation Advance Tactical Fighter aircraft, the improvement of reliability, and technology transfer issues 82/01/00 82A21848

UTTL Trends in maintainability and reliability of avionics systems with particular reference to DCAD Technical Publication 1/77
AUTH A/LOY, A F PAA A/(Ministry of Defence /Procurement Executive/, London England) IEE Proceedings, Part F - Communications, Radar and Signal Processing, vol 128, pt F, no 7 Dec 1981, p 433-439
ABS The procurement situation with respect to reliability and maintainability (R&M); prior to the DCAD Technical Publication 1/77 (1978) is reviewed first The general contents of the document and the translation of the document's principles into a form suitable for contracts are then discussed Application of the publication is outlined and an indication is given of the direction R&M activity should proceed in order to meet the challenges of future systems Particular attention is given to the reliability parameter which has presented a more serious problem during the design, development and production phases 81/12/00 82A16561

UTTL Balancing readiness and life-cycle cost objectives in avionics acquisition
AUTH A/CALVO, A B B/KRONENFELD J E PAA B/(Analytic Sciences Corp , Reading, MA) In NAECON 1981 Proceedings of the National Aerospace and Electronics Conference, Dayton, OH May 19-21, 1981 Volume 2 (A82-14676 04-01) New York, Institute of Electrical and Electronics Engineers Inc 1981, p 891-897
ABS Life-cycle cost/readiness analysis methods and issues emerging in studies conducted at TASC are discussed in order to establish a balance between life-cycle cost requirements during peacetime conditions and operational readiness needs in wartime employment Specific areas which provide a basis for the design team are reviewed, including assessment of logistic support impacts the identification of principle system design parameters and exploration of tradeoffs on investment options In addition, recommendations on incorporating the analysis efforts in the systems acquisition planning process are offered 81/00/00 82A14785

UTTL Reusable avionics executive software
AUTH A/BOUSLEY, R F PAA A/(Boeing Military Airplane Co , Seattle, WA) In NAECON 1981 Proceedings of the National Aerospace and Electronics Conference Dayton OH, May 19-21, 1981 Volume 1 (A82-14676 04 01) New York, Institute of Electrical and Electronics Engineers Inc 1981, p 31-36
ABS Forecasts indicate that avionics architecture will evolve from single multiplex to hierarchical multiple multiplex architectures The USAF DIAS program is developing a common modular reusable executive computer program in order to minimize the cost of executive software in future avionics systems The key to the concept of a modular reusable executive is the definition of the functional modules within the executive and a rigidly enforced interface between the functional modules An executive for an avionics application consists of two major functions (1) a bus control for interacting to a data transfer medium and for controlling this medium and (2) a local control for executive functions which are local to the processing element A proposed hierarchical avionics architecture, and the executive configuration and functional module are illustrated 81/00/00 82A14681

UTTL Software documentation - The lifeline of computer programs
AUTH A/KING, S H B/POTTS B H PAA A/(General Dynamics Corp , Fort Worth TX) B/(BHP Development Co Redwood City, CA) In Digital Avionics Systems Conference 4th, St Louis MO November 17-19, 1981 Collection of Technical Papers (A82-13451 03-04) New York American Institute of Aeronautics and Astronautics, 1981 p 181-187
ABS Guidelines for determining software documentation needs and methods of implementation are presented Topics discussed include the purposes of software documentation, documentation types and scope, the use of software documentation for management control, and a recommended documentation procedure It is emphasized that good documentation provides the means for successful software integration in present and future aircraft
RPT# AIAA 81-2255 81/00/00 82A13476

UTTL MIL-STD 1750 chip set Possible designs
AUTH A/LYNN H C B/MOORE R K PAA B/(General Dynamics Corp , Fort Worth TX) In Digital Avionics Systems Conference, 4th, St Louis MO November 17-19, 1981 Collection of Technical Papers (A82-13451 03-04) New York American Institute of Aeronautics and Astronautics, 1981, p 168 172
ABS The development of a MIL-STD-1750A compliant microprocessor chip set for use in digital avionics systems is presented Design constraints are identified and a logical partitioning of the chip set is defined Signal interfaces are proposed, and potential physical configurations for the chip set are presented The cost of miniaturization is found to be high, although with user discretion in implementing the instruction set architecture features while providing as much capability as possible, a MIL-STD-1750A compliant microprocessor chip set with wide user acceptance can be produced
RPT# AIAA 81-2253 81/00/00 82A13474

UTTL Avionics component standardization - The key to maintainability
AUTH A/MARTIN J PAA A/(National Semiconductor Corp Santa Clara CA) In Digital Avionics Systems Conference 4th, St Louis MO November 17-19 1981, Collection of Technical Papers (A82-13451 03-04) New York American Institute of Aeronautics and Astronautics, 1981, p 163-167
ABS The issue of maintability of avionics components is discussed with particular reference to problems currently seen within the logistical support system Particular attention is given to nonstandard specifications, proliferation of part numbers, the problem of product obsolescence and the problem of diminishing manufacturing sources It is shown that standardization is essential for the long-term viability of the defense structure
RPT# AIAA 81-2252 81/00/00 82A13473

UTTL Variable speed constant frequency /VSCF/ electrical system cuts cost of ownership
AUTH A/HILDEBRANT, R V B/VANNOCKER, R C PAA B/(General Electric Co Aircraft Equipment Div , Binghamton, NY) In Intersociety Energy Conversion Engineering Conference 16th Atlanta, GA, August 9-14, 1981 Proceedings Volume 1 (A82 11701 02-44) New York, American Society of Mechanical Engineers 1981, p 130-135
ABS The methodology employed in the development of the electrical generating system for the F/A-18 aircraft is considered This system was the first production application in which the cycloconverter electronics were packaged with the generator and mounted directly to the accessory gearbox Being the first production system of this type a detailed and comprehensive analysis and evaluation program was undertaken to provide assurance that the design could operate with a high degree of reliability in this generally hostile environment A primary maintainability design objective was related to the design and the selection of parts and materials which would last for the life of the unit without scheduled maintenance Attention is given to maintenance cost experience and life cycle costs 81/00/00 82A11719

UTTL Closed loop environmental control systems for fighter aircraft
AUTH A/TSUJIKAWA, G S B/RAJPAUL V K PAA B/(Boeing Military Airplane Co , Seattle, WA) American Society of Mechanical Engineers, Intersociety Conference on Environmental Systems, San Francisco CA, July 13-15 1981, 6 p USAF-sponsored research
ABS A favorable thermal environment for aircraft avionics implemented in an energy efficient manner is an important factor in reducing aircraft life cycle costs through improved avionic reliability This paper discusses the application of closed loop environmental control systems (CECS) to a tactical mission aircraft The specific objective was to determine CECS configurations which would provide significant savings in fuel consumption and life cycle costs while maintaining stable low temperature clean and dry environment for avionics equipment Preliminary designs were developed for a positive displacement rotary vaned air cycle machine system hybrid air/vapor cycle system centrifugal Freon compressor vapor cycle system and a turbo-machinery air cycle machine system System characteristics, details of design performance and life cycle cost data were compared with an existing open loop air cycle system The study showed that closed loop system configurations and close avionic temperature control resulted in substantial life cycle cost savings
RPT# ASME PAPER 81-ENAS-2 81/07/00 82A10890

UTTL Aircraft/avionics environmental integration program
AUTH A/HERMES P B/WAFFORD J PAA B/(USAF Aeronautical Systems Div , Wright-Patterson AFB, OH) In Life cycle problems and environmental technology, Proceedings of the Twenty-sixth Annual Technical Meeting Philadelphia PA, May 12-14, 1980 (A81-46476 22-38) Mt Prospect, IL, Institute of Environmental Sciences 1980 p 23-27
ABS Activities of USAF/Aeronautical Systems Division related to aircraft/avionics environmental integration are reviewed with emphasis on specifications and standards being developed to assist in acquiring equipments and systems in a cost effective manner The primary purposes of these documents are (1) to introduce new analyses and tradeoff studies in the early development phases, (2) to provide a contractual basis for informal activities previously accomplished by the contractors, and (3) to replace or supplement universal requirements with engineering approaches tailored to specific applications 80/00/00 81A46480

UTTL Avionics thermal integration for the Boeing 767 airplane
AUTH A/SLACK, R L , B/LLOYD A J P PAA B/(Boeing Commercial Airplane Co , Renton, WA) In Life cycle problems and environmental technology, Proceedings of the Twenty-sixth Annual Technical Meeting Philadelphia PA May 12-14, 1980 (A81-46476 22-38) Mt Prospect IL, Institute of Environmental Sciences 1980 p 11-18
ABS With reference to Boeing aircraft B-747 and B-767 methods used to improve avionic reliability and reduce maintenance costs by lowering component operating temperatures are discussed Attention is given to the following cooling concepts (1) avionic cooling air exhausted overboard after cooling avionics, (2) avionic cooling air recooled using ram air, (3) avionic cooling air recooled using air conditioning system and (4) avionic cooling air recooled using skin heat exchange A prototype avionic cooling system for the B-767 which employs a skin heat exchanger is presented 80/00/00 81A46478

UTTL DAIS controls and displays - A systems approach to avionics subsystem integration
AUTH A/BROWN G W B/GARCHER J D PAA B/(USAF, Avionics Laboratory, Wright-Patterson AFB Ohio) In NAECON 1980 Proceedings of the National Aerospace and Electronics Conference Dayton Ohio, May 20-22 1980 Volume 3 (A81-30226 12-04) New York Institute of Electrical and Electronics Engineers Inc 1980, p 1057-1064
ABS The increasing complexity of U S Air Force aircraft mission requirements and the necessity for reducing avionic life cycle costs require a total systems approach to future avionic subsystem integration The Digital Avionics Information System Controls and Displays (C/D) is an integrated subsystem that utilizes specific pilot control procedures and common communication techniques to accomplish virtually all avionic functions with the same pilot C/D hardware This paper discusses the system design approach needed during avionics development process to achieve an integrated C/D subsystem Emphasis is placed on interaction between pilot procedures mission operations, and C/D subsystem and related interfaces The reconfiguration capabilities, the ease of incorporating new avionic functions and other benefits derived from common C/D hardware are also addressed Finally critical issues facing C/D such as pilot workload acceptance by the avionic community of new control and display techniques, degree of display device complexity and C/D areas amenable to standardization are examined 80/00/00 81A30336

UTTL Tailoring software logic to the needs of the pilot - A software designer's nightmare
AUTH A/MURRAY J B/REISING J PAA A/(System Consultants Inc Dayton, Ohio) B/(USAF Flight Dynamics Laboratory Wright-Patterson AFB Ohio) In NAECON 1980 Proceedings of the National Aerospace and Electronics Conference Dayton Ohio, May 20-22, 1980 Volume 3 (A81-30226 12-04) New York Institute of Electrical and Electronics Engineers Inc 1980 p 1052-1056
ABS Digital avionics and multifunction displays and controls are being incorporated into aircraft of the Air Force, Navy and Army with increasingly greater frequency One of the key aspects in their acceptance and usefulness is the design of the software so that it supports the needs of the user, specifically, the pilot By tailoring the software such that display formats and multifunction control logic are custom-designed to appropriate mission phases, a reduction in pilot workload is accomplished A series of studies have been conducted examining this reduction in pilot workload by employing Tailored Multifunction Control Logic versus standard Branching Control Logic A significant improvement in pilot performance has resulted from the use of Tailored Logic However, in an era of ever increasing software costs, the benefits to the pilot need to be weighed against the costs of implementing this tailored software 80/00/00 81A30335

UTTL An analysis of the common Multi-Mode Radar Program using the Standardization Evaluation Program
AUTH A/THOMAS J L B/JOLDA J G PAA B/(USAF Wright-Patterson AFB, Ohio) In NAECON 1980, Proceedings of the National Aerospace and Electronics Conference, Dayton, Ohio, May 20-22 1980 Volume 2 (A81-30226 12-04) New York Institute of Electrical and Electronics Engineers, Inc 1980, p 839-845
ABS The cost impact of standardization as applied to Air Force avionic systems is discussed in this paper Several life cycle cost estimates were made on the ASD Common Multi-Mode Radar Program using the Standardization Evaluation Program (STEP) model Costs for development operation, and support of a common (standard) radar system are compared with like costs estimated for using individually developed radar systems across applicable aircraft STEP estimates project life cycle costs of unique radar systems to be twice those of a common radar system Results are discussed in terms of STEP runs and ASD costing estimates, and STEP model use is described 80/00/00 81A30318

UTTL Automated Requirements Development System
AUTH A/HAZLE, M B/GLENN J S PAA B/(Mitre Corp Bedford, Mass) In NAECON 1980 Proceedings of the National Aerospace and Electronics Conference Dayton Ohio May 20-22, 1980 Volume 1 (A81-30226 12-04) New York, Institute of Electrical and Electronics Engineers Inc 1980, p 435-439
ABS The Automated Requirements Development System (ARDS) is a set of software tools supporting requirements for the development activities of the Air Force Electronics System Division (ESD) program office for large weapons systems The activities are specification generation, review, revision and analysis and requirements tracing ARDS functional capabilities include document generation and maintenance, comment management, document analysis and remote tool interface ARDS data include outlines standard paragraphs standard terms and definitions checklists, guidelines, and specification samples 80/00/00 81A30276

UTTL Using microprocessors in fault monitoring of aircraft electronics
AUTH A/MAYBANKS, A PAA A/(Ultra Electronic Controls Ltd , London, England) American Society of Mechanical Engineers, Gas Turbine Conference and Products Show Houston Tex , Mar 9-12, 1981, 5 p
ABS The Ultra Electronic Controls Fault Identification Module as used in the Electronic Engine Control Unit (ECU) for the Olympus 593 engines of the Concorde Supersonic Transport Aircraft is discussed This is based on a CMOS microprocessor for low power consumption and enables the module to be applied to existing units without redesign of power supplies The module examines the outputs of existing fault monitoring circuits and compares these with software-defined reference levels It then determines from this and other signals taken from the ECU safety consolidation circuits the engine control subsystem which is at fault This module has been in service for close to one year now and the impact on rapid and accurate fault diagnosis, elimination of premature ECU removals and thus reduction of cost ownership of the ECU is discussed
RPT# ASME PAPER 81 GT 138 81/03/00 81A30040

UTTL Avionic architectural standardization - Logistic support perspective
AUTH A/MASON R C B/PARRIOTT L D PAA B/(TRW Defense and Space Systems Group, Redondo Beach, Calif) In Standardization in military avionics systems architecture Proceedings of the Seminar, Dayton Ohio November 28 1979 (A81-13167 03-04) New York Institute of Electrical and Electronics Engineers, Inc , 1979, p 27-34
ABS The advent of digital technology, specifically embedded computer systems (ECS) has provided the impetus for rapid growth in the sophistication and complexity of airborne information processing functions Along with the growth in avionic systems sophistication, there has been a corresponding increase in their costs and a proliferation of unique computer-embedded avionic systems and subsystems This influx of embedded computer systems has introduced a new approach to the management and support of avionics systems at air logistics centers This paper will describe this avionic support approach This paper takes a closer look at the problem created by the rapid influx of embedded computer systems each with their unique architectures for current and planned ECS support systems and then reflects on several lessons learned and discusses where both avionic architectural standards and support facility standards can help reduce the proliferation of support systems 79/00/00 81A13171

UTTL Cost analyses for avionics acquisition
AUTH A/TOOHEY, E F B/CALVO A B PAA B/(Analytic Sciences Corp Reading Mass) In Annual Reliability and Maintainability Symposium San Francisco Calif January 22-24 1980 Proceedings (A80-40301 16-38) New York, Institute of Electrical and Electronics Engineers Inc , 1980 p 85-90
ABS The paper reports on the types of cost reliability and maintenance tradeoff studies of cost analyses required for formulating an effective acquisition strategy Sample study results are provided, and a description of how study results are used to focus on critical issues in the acquisition program is provided The reliability is found to be a central factor but its ultimate effect on support costs is determined by other influences such as the structure and efficiency of the logistic support system, attention must be directed early in the development cycle to identifying support cost drivers within a framework which accomodates the actual equipment use and support conditions Once the drivers are identified, cost control procedures in the form of warranties and verification testing which focus on the principal areas of concern can be integrated into the acquisition plan 80/00/00 80A40311

UTTL Avionics and controls technology trends
AUTH A/SMYTH, R K PAA A/(Milco International, Inc Huntington Beach Calif) American Institute of Aeronautics and Astronautics, International Meeting and Technical Display on Global Technology 2000 Baltimore Md May 6-8, 1980, 13 p
ABS The trends which will define the state of the art in the year 2000 for aeronautics avionics and controls are emerging in 1980 The prospective of the last three decades of avionics and controls developments coupled with the current technological progress in very large scale integration (VLSI) microelectronic circuits provide the basis for the projection of technology trends for the year 2000 The paper reviews the trends in broadly applicable technologies as they will impact the aeronautic vehicle specific technologies during the next two decades
RPT# AIAA PAPER 80-0919 80/05/00 80A32889

UTTL Issues in avionics standardization
AUTH A/RICKER, R K PAA A/(USAF, Aeronautical Systems Div Wright-Patterson AFB Ohio) In Challenge of the '80s, Proceedings of the Third Digital Avionics Systems Conference Fort Worth Tex , November 6-8, 1979 (A80-32417 12 06) New York, Institute of Electrical and Electronics Engineers, Inc , 1979, p 240-243
ABS The paper defines criteria for the selection of avionics standardization factors which take into account the forces which determine the productivity of standardization These factors include technological maturity and architectural suitability, the maturity factor deals with a subsystem where the majority of elements are in a three-year cycle of 'order of magnitude' performance requirements, size reduction, or mechanization changes In such cases standardization is not feasible, if the subsystem is architecturally interdependent with other subsystems with complex interfaces and a high degree of software standardization is much more difficult than in a stand-alone subsystem with simple interfa . 79/00/00 80A32430

UTTL A comparison of computer architectures for the NASA demonstration advanced avionics system

AUTH A/SEACORD C L , B/BAILEY, D G , C/LARSON, J C PAA C/(Honeywell, Inc , Avionics Div Minneapolis Minn) CORP Honeywell Inc Minneapolis MN In Challenge of the '80s Proceedings of the Third Digital Avionics Systems Conference, Fort Worth, Tex , November 6 8 1979 (A80-32417 12-06) New York Institute of Electrical and Electronics Engineers, Inc , 1979, p 51-57

ABS The paper compares computer architectures for the NASA demonstration advanced avionics system Two computer architectures are described with an unusual approach to fault tolerance a single spare processor can correct for faults in any of the distributed processors by taking on the role of a failed module It was shown the system must be used from a functional point of view to properly apply redundancy and achieve fault tolerance and ultra reliability Data are presented on complexity and mission failure probability which show that the revised version offers equivalent mission reliability at lower cost as measured by hardware and software complexity 79/00/00 80A32427

UTTL Single chip custom LSI microcomputers for avionics applications

AUTH A/KANTOWSKI, J W PAA A/(Bendix Corp Avionics Div Fort Lauderdale, Fla) In Challenge of the '80s Proceedings of the Third Digital Avionics Systems Conference Fort Worth Tex November 6-8 1979 (A80-32417 12 06) New York, Institute of Electrical and Electronics Engineers, Inc , 1979 p 32-36

ABS The paper discusses a single chip custom LSI microcomputer with flexible architecture and a variable instruction set This device was developed as an alternative to a full custom LSI and its associated long lead time high development cost and difficulties in incorporating changes The microcomputer contains all the computer elements similar to MOSTEK 3870 it is much more efficient, the hardwired logic can be included on the chip and its costs are cheaper than standard system implementations Software development can take place on existing systems using macroinstructions and can be fully debugged in its application system using a simulator board 79/00/00 80A32423

UTTL Advanced avionic architectures for the 1980's - A software view

AUTH A/MORGAN L F PAA A/(Lockheed California Co Burbank Calif) In Challenge of the '80s Proceedings of the Third Digital Avionics Systems Conference Fort Worth, Tex November 6-8 1979 (A80-32417 12-06) New York Institute of Electrical and Electronics Engineers Inc 1979 p 13-18

ABS The paper examines advanced avionics architectures including 'distributed' and 'hierarchal' with a centralized multiprocessor system at the apex It was shown that the concept of distributed computers in avionics has been carried too far and that the eventual impact of cheap-reliable digital hardware in avionics software will be the use of larger numbers of CP and memory elements in dedicated and shared hierarchal architectures The all digital character and requirements for future avionics architectures will lead to a fly-before-specify policy using an early total system-simulation approach systems development 79/00/00 80A32420

UTTL WELS - An international approach to range instrumentation support

AUTH A/LUSTINA W P PAA A/(RCA Missile and Surface Radar Div , Moorestown, N J) RCA Engineer vol 25, Feb -Mar 1980 p 41-46

ABS It is noted that reliable on-demand operation of precision tracking radars is a key element in supporting critical missions on today's test ranges Such radars are located at various sites around the world which complicates the problem of keeping them operational The paper describes an interagency approach to the problem, the Worldwide Engineering and Logistics Support (WELS) Program Attention is given to the scope and operation of the program, including the diversity of range user requirements and the engineering/technical assistance and logistics support needed 80/03/00 80A31249

UTTL ATE system acquisition for E-3A sentry /AWACS/

AUTH A/DUNCAN R D P , B/WILSON, J H , C/SCHELLENBACH R R PAA A/(USAF Electronic Systems Div , Bedford Mass), B/(USAF Warner Robins Air Logistics Center Robins AFB Ga), C/(Support System Associates, Inc Burlington Mass) In AUTOTESTCON '79 Proceedings of the International Automatic Testing Conference, Minneapolis, Minn September 19-21, 1979 (A80-29991 11-59) New York, Institute of Electrical and Electronics Engineers, Inc 1979, p 365-369

ABS The paper describes the systems engineering and management decisions for the support of the organic depot maintenance operation of the E-3A Sentry Aircraft in order to provide cost effective acquisition of ATE, a listing is given of the alternatives and considerations required to form an overall picture of the technical capability and total ownership cost of a particular ATE system Special attention is given to ATE useful life requirements, efficiencies and personnel skill level The methodology employed in support of the E-3A mission avionics is considered 79/00/00 80A30033

UTTL F/A-18 Automatic Test Equipment

AUTH A/MAJOR T J PAA A/(U S Naval Air Systems Command, Washington, D C) In AUTOTESTCON '79, Proceedings of the International Automatic Testing Conference, Minneapolis, Minn , September 19-21, 1979 (A80-29991 11-59) New York, Institute of Electrical and Electronics Engineers, Inc , 1979 p 317-319

ABS The development of the F/A-18 Automatic Test Equipment is discussed Attention is given to areas in which cost reduction techniques and lessons learned from past ATE programs have been implemented Areas covered include the F/A-18A ILASS, the need for the ATE to be ship, shore and USMC van compatible, systems monitoring, confidence testing performance testing, and station maintenance and repair Also covered are the Radar Test Station (RTS) and the benefits of the colorgraphic display, which include the possibility for operator corrective action improved operator efficiency reduced paper documentation currency of documentation and automatic test generation 79/00/00 80A30028

UTTL System EMC - Tendencies of a worldwide standardization and cooperation

AUTH A/RODE R PAA A/(Messerschmitt-Boelkow-Blohm GmbH, Munich West Germany) In Electromagnetic compatibility 1979 Proceedings of the Third Symposium and Technical Exhibition Rotterdam, Netherlands May 1-3 1979 (A80-27753 10-32) Zurich, Eidgenoessische Technische Hochschule Zuerich, 1979 p 485-490

ABS The paper deals with the tendencies in worldwide EMC standardization and cooperation Emphasis is placed on standardization of test methods including system analyses, system integration, prototype and production systems EMC problems in an international airport and military aircraft are outlined 79/00/00 80A27784

UTTL An integrated multi-system approach to the support of digital avionics

AUTH A/BABIAK, N J , B/PARRIOTT, L D , JR PAA A/(USAF, Logistics Command, Wright-Patterson AFB, Ohio), B/(TRW Defense and Space Systems Group, Redondo Beach, Calif) In NAECON 1979, Proceedings of the National Aerospace and Electronics Conference Dayton, Ohio May 15-17 1979 Volume 2 (A79-48590 21-01) New York, Institute of Electrical and Electronics Engineers, Inc 1979 p 644-649

ABS The paper examines existing avionic support facility configurations with respect to intended as well as realized support capabilities A standard approach to the integration of digital avionics support facilities is discussed noting that responsive mission support and reduced life cycle costs may result The classic component capabilities of the USAF's Avionics Integration Support Facility (AISF) are examined for dynamic simulation avionics test and integration, offline computation and flight test The advantages and disadvantages of the present AISF approach are discussed noting the expense of the single system approach Attention is given to the first building block in the standardized AISF approach called the Dynamic Simulation system and an analysis of the three core elements, including the simulation processor, is presented 79/00/00 79A48647

UTTL Potential effects of standardization on avionics software life-cycle cost

AUTH A/SCHANE R N , B/WILLIAMS J R , C/YACHOWSKY M F PAA B/(Logicon Inc , Dayton, Ohio), C/(USAF, Aeronautical Systems Div , Wright-Patterson AFB, Ohio) In NAECON 1979 Proceedings of the National Aerospace and Electronics Conference Dayton, Ohio May 15-17 1979 Volume 2 (A79-48590 21-01) New York, Institute of Electrical and Electronics Engineers, Inc 1979, p 558-567

ABS Quantitative models are developed to evaluate the potential effects of standardization on avionics software life cycle cost Four candidate standardization areas are investigated computer-language standardization standard cross-training of maintenance personnel standard GFE support hardware and software, and standard interfaces Standardization-cost-savings models are defined relative to the baseline cost of a hypothetical non-standardized avionics system The baseline system is defined to include nine subsystems each with an embedded computer and an operational flight program (OFP) Life-cycle costs of the baseline system are computed using a detailed rule of-thumb model constructed as a composite of current cost data and models from the literature 79/00/00 79A48637

UTTL Avionics computer software operation and support cost estimation

AUTH A/FERENS D V , B/HARRIS, R L PAA B/(USAF, Avionics Laboratory Wright-Patterson AFB, Ohio) In NAECON 1979 Proceedings of the National Aerospace and Electronics Conference, Dayton Ohio, May 15-17, 1979 Volume 1 (A79-48590 21-01) New York Institute of Electrical and Electronics Engineers, Inc , 1979, p 296-300

ABS This paper describes many current models and methods available for predicting computer software operational and support costs and discusses the limitations of available models and methods as useful tools This paper also discusses in detail the Air Force Avionics Laboratory's current effort to develop a model that will help the engineer or cost analyst accurately predict operational and support costs of avionics systems computer software being maintained at Air Force Air Logistics Centers 79/00/00 79A48620

UTTL RTCA standards - Improved specs and regulations
AUTH A/FUCHS W C PAA A/(Radio Technical Commission for Aeronautics Washington, D C) In Annual Reliability and Maintainability Symposium, Washington, D C January 23-25 1979 Proceedings (A79-39876 16-38) New York Institute of Electrical and Electronics Engineers 1979, p 381-383
ABS The Radio Technical Commission for Aeronautics (RTCA) develops minimum performance standards for avionics and telecommunications These standards have been employed as specifications by manufacturers and have also served as the basis for government regulation of the aviation industry Subjects under consideration by RTCA committees during 1978 included ground proximity warning equipment, emergency locator transmitters, airborne Omega receivers future civil aviation frequency spectrum requirements and the role of mean-time-before-failure data in specifying safety standards 79/00/00 79A39919

UTTL Life cycle costing of simulated vs actual equipment for intermediate maintenance training
AUTH A/EGGEMEIER F T B/KLEIN, G A PAA B/(USAF Human Resources Laboratory, Wright-Patterson AFB, Ohio) In Human Factors Society Annual Meeting, 22nd, Detroit Mich , October 16-19 1978 Proceedings (A79-18201 05-54) Santa Monica, Calif Human Factors Society Inc 1978, p 267-271
ABS Initial results are presented of a two-phase effort to develop life cycle cost (LCC) estimates of training equipment for F-16 avionics intermediate station maintenance personnel This initial phase was a preliminary analysis of major cost factors differentiating simulated and actual test equipment It was conducted to provide an early estimate of the cost of a training simulator and to decide if a more detailed LCC study was warranted Total estimated 15 year costs for simulated equipment trainers were approximately 50% less than comparable estimates for actual equipment trainers 78/00/00 79A18217

UTTL CITS - Tomorrow's test system today
AUTH A/DERBYSHIRE, K PAA A/(Rockwell International Corp Los Angeles, Calif) In Industry/Joint Services Automatic Test Conference and Workshop on Advanced Test Technology Management, Acquisition Support San Diego, Calif April 3-7 1978, Proceedings (A79-16426 04 38) Washington, D C National Security Industrial Association, 1978, p 112 114
ABS The Central Integrated Test System (CITS) developed for the B-1 aircraft, allows the B-1 to meet the requirements of self-sufficiency and flight hours to maintenance of an advanced aircraft CITS continuously monitors all aircraft subsystems in flight and on the ground, and performs fault isolation to the LRU level Maintenance is accomplished through the use of CITS-supplied failure data and system operation is verified through the use of CITS active ground tests 78/00/00 79A16431

UTTL Advanced technology impact upon ATE self test
AUTH A/YOUNG W PAA A/(Bendix Corp Test Systems Div Teterboro N J) In AUTOTESTCON '77, Symposium Hyannis, Mass , November 2-4 1977 Record (A79-12301 02-33) New York, Institute of Electrical and Electronics Engineers, Inc , 1977 p 72-77
ABS The paper examines the opportunities afforded to ATE self-test by the use of microprocessors and LSI Current self-test concepts are briefly examined in terms of inherent ambiguities testability, and the need for accessory test equipment The concept of using intelligent instruments along with compact diagnostic module testers within the framework of a large ATE system is treated as a viable cost-effective approach to current ATE self-test problems 77/00/00 79A12306

UTTL Support systems for advanced military electronics
AUTH A/KENNEY, J W PAA A/(General Dynamics Corp Fort Worth, Tex) In AUTOTESTCON '77 Symposium, Hyannis Mass November 2-4 1977, Record (A79-12301 02-33) New York, Institute of Electrical and Electronics Engineers, Inc , 1977 p 64-71
ABS The paper examines some of the ways in which support systems are likely to change to keep in step with new avionics approaches It is found that those factors which will probably have the greatest influence on ATE support systems are improved reliability, total digital designs, standardization of processors, software and systems operation monitoring, and on-station SRU (Shop Replaceable Unit) operations Of lesser importance are concepts such as dynamic reconfiguration and redundancy 77/00/00 79A12305

UTTL An analytical method of defining low life cycle cost avionics
AUTH A/BLOXON, W D , B/KENNEDY, C D PAA A/(Boeing Wichita Co , Wichita Kan), B/(USAF Aeronautical Systems Div Wright-Patterson AFB, Ohio) In NAECON '78, Proceedings of the National Aerospace and Electronics Conference Dayton Ohio May 16-18 1978 Volume 3 (A78-49851 22-04) New York, Institute of Electrical and Electronics Engineers, Inc , 1978 p 1222-1224
ABS The present study provides a basis for defining a modernized strategic avionics system to meet the improved performance and reduced operation and maintenance costs to support strategic operational requirements in the 1980s The analysis shows that a dramatic cost effectiveness improvement can be achieved over the baseline and that current technology will support the guide requirements for life cycle cost and performance In order to meet SAC's requirements the following features are necessary improved radar resolution, high jamming resistant terrain following radar good radar performance in weather radar image freeze, Class I inertial system, low altitude penetration, and redundancy for mission success 78/00/00 78A49990

UTTL Life cycle testing for avionics development
AUTH A/HANCOCK, R N PAA A/(Vought Corp , Dallas, Tex) In NAECON '77 Proceedings of the National Aerospace and Electronics Conference, Dayton, Ohio, May 17-19 1977 (A78-15551 04-33) New York, Institute of Electrical and Electronics Engineers, Inc , 1977, p 46-53
ABS The paper reviews recent DOD avionics reliability improvement activities in developing the roles of laboratory and flight testing, with emphasis on the importance of the integrated test plan and involvement of all affected engineering disciplines The status of DOD test standards revisions is discussed and a general assessment is made of the effect of these revisions on test procedures, facilities and costs It is found necessary to use various degrees of life cycle event and environmental simulation when testing at the various systems levels from piece parts to total system 77/00/00 78A15557

UTTL Future aerospace digital signal processing concepts
AUTH A/HSUEH S F , B/VOJIR W , C/BURKHARDT, P PAA C/(Grumman Aerospace Corp Bethpage N Y) In Computers in Aerospace Conference, Los Angeles Calif October 31-November 2 1977, Collection of Technical Papers (A78-12651 02-59) New York, American Institute of Aeronautics and Astronautics, Inc 1977 p 75-81
ABS The paper attempts to outline likely requirements for signal processing in avionics in the future (up to 1985 and beyond) and to indicate some of the considerations that will influence the design and performance of future signal processing machines Emphasis is placed on currently successful techniques which should be exploited for multipurpose applications, and on the fact that a multipurpose programmable signal processor is needed which meets the full diversity of major avionics applications Functional modularity and software commonality are recommended as areas of standardization which will allow for growth in device technology and theoretical developments
RPT# AIAA 77-1389 77/00/00 78A12661

UTTL A new avionics thermal control concept
AUTH A/TOKEN, K H PAA A/(McDonnell Aircraft Co St Louis, Mo) ASME SAE, AIAA ASMA, and AIChE, Intersociety Conference on Environmental Systems 7th, San Francisco, Calif July 11-14, 1977, ASME 10 p
ABS The use of more efficient thermal control techiinques for cooling avionic systems on fighter aircraft can reduce avionic failure rates and aircraft weight penalties due to cooling systems Thus, significant economic benefits in initial aircraft purchase cost and in reduced cost of ownership may be possible in addition to increasing the dependability of increasingly important avionic systems This paper describes a heat pipe-liquid cooling concept for avionic system cooling which exhibits higher thermal efficiency than currently used cooling techniques The new heat pipe cooling concept allows higher temperature coolants to maintain avionic components at lower operating temperature, thereby increasing avionic reliability and reducing aircraft weight penalties incurred by the cooling system Key technical developments required for the implementation of the new cooling technique are identified Measured thermal performance for small heat pipes which were developed for the new cooling system are presented
RPT# ASME PAPER 77-ENAS-14 77/07/00 77A46855

UTTL Avionic power supplies - Integrity aspects
AUTH A/BRITNELL C PAA A/(Civil Aviation Authority, London England) In Symposium on Avionics versus Electrics - Who Should Determine Future Power Supplies, London England March 15, 1977 Proceedings (A77-38458 17-07) London, Royal Aeronautical Society 1977 14 p
ABS Present-day airworthiness regulations are considered sufficient to facilitate the certification of the great majority of new and projected avionic systems and their electrical power supplies However, additional requirements appear to be needed to allow the certification of those new types of high integrity system which are required throughout flight and where a common mode fault affecting either the system hardware or software would have hazardous consequences The solution is likely to be a procedural one, involving the careful development and rigorous application of new requirements written in terms of essential design features and procedures 77/00/00 77A38463

UTTL The Electronically Agile Radar's 'balanced design', and its importance to life cycle cost
AUTH A/MUKAI, D M , B/ATKINSON, P E PAA A/(USAF Avionics Laboratory, Wright-Patterson AFB, Ohio), B/(Westinghouse Defense and Electronic Systems Center Baltimore, Md) In NAECON '76, Proceedings of the National Aerospace and Electronics Conference, Dayton, Ohio, May 18-20, 1976 (A77-37352 17-33) New York Institute of Electrical and Electronics Engineers, Inc , 1976, p 379-386

ABS The Electronically Agile Radar (EAR) is being designed to be compatible with the B-1 B 52 or FB-111 weapons systems It was decided to use an EAR design philosophy which balanced overall requirements such as performance reliability maintainability nuclear survivability/vulnerability, and cost in such a way as to minimize the overall EAR life cycle cost The objective of this balanced design concept is the elimination of the tendency of one requirement to drive the radar design to an unacceptable cost 76/00/00 77A37402

UTTL Increasing system reliability with BITE
AUTH A/PLICE, W A PAA A/(Honeywell Inc St Louis Park Minn) In NAECON '76 Proceedings of the National Aerospace and Electronics Conference, Dayton, Ohio May 18-20 1976 (A77-37352 17-33) New York Institute of Electrical and Electronics Engineers Inc , 1976 p 208-214
ABS The paper reviews the basic concepts of onboard testing of avionics with Built-In-Test Equipment (BITE) and considers the effects of onboard test capability on system reliability A central onboard test system concept is discussed and an adaptive modeling concept is introduced which offers potential for increased testing capability at reduced cost in a computer-based avionics system 76/00/00 77A37380

UTTL SEM - Building block for optimized avionics cost
AUTH A/STALEY, W W PAA A/(Westinghouse Defense and Electronic Systems Center, Baltimore, Md) In NAECON '76, Proceedings of the National Aerospace and Electronics Conference Dayton Ohio, May 18-20 1976 (A77-37352 17-33) New York Institute of Electrical and Electronics Engineers Inc 1976 p 51-57
ABS The objectives of the program to develop a Standard Electronic Module (SEM) for avionics are to reduce acquisition and maintenance costs and to improve reliability and availability of replacement parts Attention is given to whether standardization is practical in avionics applications and what should the standardization be It is concluded that there are no technical obstacles for a succesful SEM once proper incentives are provided 76/00/00 77A37359

UTTL A marketplace approach to military avionics standardization
AUTH A/SMITH, C N D PAA A/(Arinc Research Corp Annapolis Md) In NAECON '76 Proceedings of the National Aerospace and Electronics Conference Dayton Ohio, May 18-20 1976 (A77-37352 17-33) New York Institute of Electrical and Electronics Engineers Inc 1976 p 33-41
ABS This paper explores the commercial practices widely used toda by the airlines industry to develop effective avionics specifications and high-quality hardware Principal among these practices is the Airlines Electronic Engineering Committee's open forum process, the use of form fit, and function specifications the use of marketplace forces the application of warranties and data exchange within the Avionics Maintenance Conference It describes some of the major elements of these practices and explores their potential impact on competition profit reliability, maintainability and life-cycle costs The possible application of commercial avionics acquisition processes to the military environment is reviewed 76/00/00 77A37358

UTTL The reliability and costs of RAF avionic equipment
AUTH A/DOUTY, P A PAA A/(RAF London, England) In Symposium on Equipment and Systems Design for Minimum Cost of Ownership, London, England March 16, 1976 Proceedings (A77-22751 08-83) London, Royal Aeronautical Society 1976 13 p , Discussion, p A1-A10
ABS Reliability and maintainability requirements as related to the ownership costs of RAF avionic equipment are discussed Particular attention is given to cost savings from improved reliability of aircraft to savings from improved reliability in avionic systems, and to maintainability actions to reduce cost It is suggested to reduce the increasing dominance of maintenance costs, which would result in freeing funds for the continued purchase of new equipment 76/00/00 77A22752

UTTL EMP hardening of aircraft by closing the points-of-entry
AUTH A/MORGAN, G E PAA A/(Rockwell International Corp , Anaheim, Calif) In International Symposium on Electromagnetic Compatibility, San Antonio, Tex October 7-9, 1975, Record (A77-15401 04-33) New York, Institute of Electrical and Electronics Engineers Inc 1975, p 3AIId1-3AIId8
ABS EMP (electromagnetic pulse) couples radio frequency energy into aircraft cables by a series of interactions with the total system In a series of trade studies it was concluded that to harden the C-130 aircraft against EMP, it would be most cost effective to begin by closing the points of entry into the fuselage It was indicated that this would provide the greatest benefit in improving hardness with the least effect on cost, weight, reliability, and maintainability A detailed investigation was begun to identify all the points of entry on the C-130, and to devise ways to close them This paper presents preliminary results of this investigation 76/00/00 77A15408

UTTL A critique on third generation ATE experience
AUTH A/WILLIAMSON, P H PAA A/(General Dynamics Corp Electronics Div , San Diego Calif) In Automatic Support Systems Symposium for Advanced Maintainability Westbury, N Y October 28-30, 1975 Conference Record (A76-45601 23-02) New York, Institute of Electrical and Electronics Engineers, Inc 1975 p 223-226
ABS A third generation ATE the Hybrid Automatic Test System (HATS) is based on the use of universal stimulus/measurement techniques and minicomputer software to reduce the amount of station hardware, the use of a programmable interface to reduce the number and complexity of adapters required, and the use of an English-like programming language which permits on-line program generation and debug The experience with nine HATS currently used for Test Program Set (TPS) development shows that the on-station time required to debug a program has been appreciably reduced by on-line programming and that interactive programming has reduced the development costs of TPS The problem of an excessive relay failure rate during HATS development was solved by developing a dynamic screening test for relays and providing self-test software to isolate the failed relay 75/00/00 76A45631

UTTL Techniques for achieving low cost strapdown navigation
AUTH A/GILMORE, J P B/MCKERN R A C/MUSOFF H PAA C/(Charles Stark Draper Laboratory Inc , Cambridge Mass) In INTERCON 75 International Convention and Exposition, New York, N Y , April 8-10, 1975, Conference Record (A76-11826 02-33) New York Institute of Electrical and Electronics Engineers, Inc , 1975 p 35/3-4 35/3
ABS Accurate, reliable and less vulnerable radio navigation systems (GPS, OMEGA DME and LORAN) have been forecast for the early 1980s This radio navigation capability permits a reformation of the INS implementation requirements from those of stand-alone navigation to that of high-bandwidth aiding of the radio navigator Use of low cost strapdown technology in this application area becomes very attractive Modularity concepts in both hardware and software are presented as a basis for achieving such a low cost goal This paper presents a detailed system concept showing how to implement a strapdown system in the high-bandwidth aiding problem and how to integrate all of the conventional inertial-avionics subsystems into a unified strapdown system 75/00/00 76A11842

UTTL Maintainability payoffs during weapon-system test - The value of appropriate testing
AUTH A/NELSON, J R PAA A/(Rand Corp Washington, D C) In Annual Reliability and Maintainability Symposium Washington D C January 28-30 1975 Proceedings (A75-44202 22-38) New York Institute of Electrical and Electronics Engineers, Inc 1975, p 26-29
ABS A summary of lessons learned from a decade of experience in examining developmental and operational field tests of aircraft weapon systems is presented An approach to reconcile design-to-cost and life-cycle cost in the context of maintainability payoffs during weapon-system test is discussed 75/00/00 75A44204

UTTL Lessons learned through a MIL-STD-1553 time division multiplex bus
AUTH A/BOOSE E F PAA A/(Mitre Corp Bedford, Mass) In NAECON '75, Proceedings of the National Aerospace and Electronics Conference, Dayton, Ohio June 10-12, 1975 (A75-37623 18-01) New York Institute of Electrical and Electronics Engineers, Inc , 1975 p 634-641
ABS An experimental time division multiplex bus designed and built in accordance with the MIL-STD 1553 standard is described It consists of a controller bus controller interface unit transmission medium, and two remote terminals A new design feature is the use of a microprocessor for timing and control functions in one of the remote terminals The discussion covers the spectrum of the signals found on the bus, transmission medium characteristics, the partitioning of a remote terminal the microprocessor in the subsystem interface unit signal conditioning at the subsystem interface, and candidate areas for further investigation 75/00/00 75A37705

UTTL Reliability and the cost of ownership
AUTH A/PROCKTOR, I H PAA A/(British Airways, Ltd , Luton Airport, Beds , England) In Symposium on the Application of Electrical Control to Aircraft Propulsion Systems, London, England, February 20, 21 1974, Proceedings (A74-43201 22-28) London Royal Aeronautical Society, 1974 8 p
ABS The present work discusses in general terms some of the problems arising in the maintenance of aircraft and suggests guidelines for the disciplines of reliability and maintenance control After certification of aircraft it is vital that feedback of operators experience and modes of failure should continue This demands an adequate system of recording analyzing, and reducing information to data Route faults location must be expeditious, and diagnosis within the capability of the average maintenance man Because of the many interfaces of components and systems, system interrogation is required rather than checks on individual boxes 74/00/00 74A43208

UTTL The role of electronic displays in future avionic systems
AUTH A/MCKINLAY W H B/BRAID J M C/MATTHEWS, M A V PAA C/(Ferranti Ltd , Hollinwood Lancs , England) In The future of electronic displays, Proceedings of the Joint Symposium, London, England February 23, 1972 (A72-32631 15-02) London, Royal Aeronautical Society 1972 13 p
ABS Discussion of the state of art, and of present and future trends in electronic displays, and assessment of their expansion potential in avionics systems An effort is made to achieve a perspective in which electronic display technology is related to other technologies which have a bearing on its adoption in real systems Special attention is given to computer driven displays, or displays used in systems based on digital data exchange 72/00/00 72A32635

UTTL Acquisition and recording an AMX A/C Aeritalia experience and present trends
AUTH A/CATTUNAR S CORP Aeritalia S p A Turin (Italy) CSS (Flight Test Development) Presented at the European Telemetry Conference Aix-en Provence, France 1987
ABS Experimentation with the BUS 1553 B as the active link for all avionic navigation and armament equipment in an AMX prototype A03 aircraft is described The system allows for acquisition of 256 parameters from transducer and analog sources Two different acquisition techniques through a PCM (pulse code modulation) acquisition system and directly on a magnetic tape recorder are used The results of the experimentation helped in developing a unit allowing for considerable savings in track usage
RPT# ETN-89-95217 87/00/00 90N12598

UTTL The B-1B central integrated test system expert parameter system
AUTH A/MONTGOMERY, GERARD J CORP Air Force Wright Aeronautical Labs , Wright-Patterson AFB OH In Colorado Univ , Proceedings of the Air Force Workshop on Artificial Intelligence Applications for Integrated Diagnostics p 388-393 (SEE N89-14740 06-63)
ABS The B-1B Central Integrated Test System (CITS) provides a comprehensive on aircraft diagnostic capability and records approximately 19,600 parameters The B-1B CITS Expert Parameter System (CEPS) is an initiative to improve B1B diagnostic capabilities by applying expert system and data analysis techniques to the in-flight recorded data The manner in which CEPS enhances B-1B on and off aircraft diagnostic capabilities and reduces false alarm, can not duplicate and re-test okay accurrences will be presented The CEPS capabilities will be discussed and an overview of the accomplishments and status of the CEPS program will be given This paper will illustrate the applicability of the B-1B CEPS concepts to other existing and future weapon systems The ability to reduce future weapon system built-in test requirements through the use of on-aircraft expert systems will be discussed along with the need for a ground based diagnostic system 87/07/00 89N14763

UTTL Design for interoperability (interchangeability)
AUTH A/KONOMOS, GEORGE CORP Air Force Wright Aeronautical Labs Wright-Patterson AFB OH In AGARD, The Design, Development and Testing of Complex Avionics Systems 5 p (SEE N88-23767 17-06)
ABS Interoperability of the various elements used in a system is the design property which allows the intermixing of elements from various sources (manufactures) without any impact on the performance of the system or the operational hardware Here, the line replaceable module approach is discussed This is a new approach to avionics where a processor module is a 6 inch by 6 inch plug-in board with processing power many times higher than that of older line replaceable units 87/12/00 88N23789

UTTL Development and testing of a predictive methodology for optimization of man-machine interface in future avionics systems
AUTH A/PARKS, ROGER E CORP Textron Bell Helicopter Fort Worth, TX CSS (Advanced Human Factors System Design) In AGARD, The Design, Development and Testing of Complex Avionics Systems 9 p (SEE N88-23767 17-06)
ABS The trend toward increasing complexity and cost in emerging avionics systems driven by requirements for increased functional capability has created a need for a predictive analytical methodology which accurately forecasts system performance early in the design process, and treats the human operator and the equipment as a fully integrated man-machine system A methodology that meets these needs has been developed and validated by Bell Helicopter Textron The process is being used to provide early, accurate avionics system characterization, thereby reducing design costs 87/12/00 88N23780

UTTL A structured approach to weapon system design
AUTH A/MALLEY H M B/JEWELL N T , C/SMITH R A C CORP British Aerospace Aircraft Group Preston (England) CSS (Military Aircraft Div) In AGARD, The Design Development and Testing of Complex Avionics Systems 12 p (SEE N88-23767 17-06)
ABS A structured approach to the design of highly integrated weapon systems of the future is described The approach was used in the design of the avionics system for the UK Experimental Aircraft Program (EAP) demonstrator aircraft Brief descriptions are given of the EAP systems, the main systems design tools used, the activities carried out during the systems design process and the management and control procedures adopted A series of observations highlighting some of the findings of the project and providing pointers to the design of future weapon systems is given 87/12/00 88N23773

UTTL Avionics acquisition trends and future approaches
AUTH A/LONGBRAKE RONALD B CORP Aeronautical Systems Div Wright-Patterson AFB, OH CSS (Directorate of Avionics Engineering) In AGARD Flight Vehicle Development Time and Cost Reduction 11 p (SEE N88-20173 12-81)
ABS The current and future direction of the U S Air Force avionics is discussed While the paper discusses primarily tactical aircraft avionics the findings and conclusions are applicable across USAF systems The paper covers the acquisition methodology the background and trends of avionics and future approaches The basic influences are operational needs, availability survivability, available technology cost and schedules The challenge is to provide effective avionics in a budget constrained world To accomplish this requires emphasis on providing performance to counter the threat, flexibility for diverse use and basing, cost and schedule realism, and systems capable of being upgraded through planned growth as the threat changes It has been shown that the 5 to 10 percent improvements in performance can increase the cost 20 to 50 percent therefore, sufficient and not best performance should be the goal While initial acquisition cost is of concern, life cycle cost is even more important To keep life cycle costs down and have an effective system during combat, maintenance concepts need serious attention To accomplish these objectives the discrete avionics systems of the past must be replaced with integrated avionics responsive to crew needs increasing threats and fiscal constraints Future needs will cause continued increases in avionics cost The use of new technologies new avionics system integration and architecture techniques use of common hardware modular and reusable software and improving the environment in which the avionics must operate can control the life cycle cost of avionics while meeting needs of future systems 87/09/00 88N20184

UTTL An evaluation of perceptions of form fit function (F3) standardization on the Standard Inertial Navigation Unit (STD INU) program
AUTH A/ROSENSTEEL, THOMAS E CORP Air Force Inst of Tech Wright-Patterson AFB, OH CSS (School of Systems and Logistics)
ABS This study compared perceptions on F3 standardization by the Avionics Standardization Acquisition community and the User Avionics Standardization Acquisition community focusing on the STD INU Program and the subset of the two acquisition communities which worked with the STD INU Program A survey addressed perceptions on the effect of F3 standardization on acquisition costs logistics support costs mission availability the inertial industrial base new technology insertion reliability and achieving Program Management Directive objectives, the costs and benefits of F3 standardization and whether or not the benefits outweighed the costs, etc The most often mentioned benefits were reduced logistics support costs increased force readiness and reduced acquisition costs The most often mentioned costs were constant configuration changes, increased integration costs and numerous aircraft interface requirements About half the survey participants recommended standardizing at a lower level i e , modular standardization for both the ring laser gyro and the next generation STD INU Programs
RPT# AD-A188955 AFIT/GSM/LSY/87D-1 87/12/00 88N19446

UTTL Supportability in aircraft systems through technology and acquisition strategy applications
AUTH A/HALEY, DEBRA L CORP Air Force Inst of Tech Wright-Patterson AFB, OH CSS (School of Systems and Logistics)
ABS The importance of high reliability systems in the national defense strategy of force multiplier is paramount Currently, the Air Force has adopted Reliability and Maintainability (R&M) 2000 as a management policy to achieve high reliabilities However there are few methods being implemented which can improve the measures of reliability One method used with success by satellite systems is the use of expensive but highly reliable class S electronic parts as opposed to the class B parts used in avionics and ground electronic systems A method for determining the improvement of systems' Mean Time Between Failure (MTBF) was developed Additionally the impact of improved system MTBF along with higher acquisition costs as a result of using class S parts was analyzed in a life cycle cost model Results obtained in this research indicate that class S parts have the potential of significantly increase MTBF while actually lowering life cycle costs Recommendations for follow-on research are given
RPT# AD-A186465 AFIT/GLM/LSM/87S-30 87/09/00 88N15759

UTTL Design principles and practices for implementation of MIL STD-1760 in aircraft and stores
AUTH A/LAUTNER, D E , B/MAREK, A J , C/DRUM W M D/FERNANDEZ R R CORP LTV Missiles and Electronics Group Dallas TX CSS (Missiles Div)
ABS The trends in weapon system designs (aircraft and stores) has resulted in a growing concern over the general proliferation of aircraft-to-store electrical interfacing requirements and the resulting high cost to achieve interoperability between aircraft and stores MIL-STD-1760 was prepared to reduce the aircraft/store electrical integration problem by specifying a standard electrical interface between aircraft and stores The standard electrical interface is based on recognized trends in store management systems which use serial digital transmission for control, monitor, and release of stores

This report deals with the interoperability requirements as described in MIL-STD-1760 and is intended to be an aid to understanding and meeting the requirements for both current and future weapon systems In general this report provides the following (1) An overview of MIL STD 1760 requirements exclusions and future growth provisions (2) Detail design considerations applicable to the Aircraft Station Interface (ASI) (3) Detail design considerations applicable to the Mission Store Interface (MSI) (4) Aircraft/Store Physical Design Considerations (5) A commentary on the requirements in MIL-STD 1760

RPT# AD-A183724 REPT-3-52110 6R-128 87/06/00 88N10027

UTTL Aircraft electromagnetic compatibility

AUTH A/CLARKE CLIFTON A B/LARSEN, WILLIAM E PAA B/(Federal Aviation Administration Moffett Field Calif) CORP Boeing Commercial Airplane Co , Seattle, WA

ABS Illustrated are aircraft architecture electromagnetic interference environments electromagnetic compatibility protection techniques program specifications, tasks and verification and validation procedures The environment of 400 Hz power, electrical transients and radio frequency fields are portrayed and related to thresholds of avionics electronics Five layers of protection for avionics are defined Recognition is given to some present day electromagnetic compatibility weaknesses and issues which serve to reemphasize the importance of EMC verification of equipment and parts, and their ultimate EMC validation on the aircraft Proven standards of grounding, bonding shielding wiring and packaging are laid out to help provide a foundation for a comprehensive approach to successful future aircraft design and an understanding of cost effective EMC in an aircraft setting

RPT# NASA-CR-181051 NAS 1 26 181051 DOT/FAA/CT 86/40 D6-53840 87/06/00 87N23856

UTTL Some development trends in light ground attack aircraft

AUTH A/TONINI R B/AVAGNINA, G M C/LOJACONO E D/BRAGAGNOLO N PAA D/(Aeritalia S p A Caselle Torinese Italy) CORP Italian Air Staff Rome In AGARD Improvement of Combat Performance for Existing and Future Aircraft 16 p (SEE N87-22663 16-05)

ABS The development of a light bomber attack aircraft AM-X is discussed Specific design requirements and cost effectiveness, a mission effectiveness model effectiveness tradeoffs weapon systems and avionics are among the topics surveyed 86/12/00 87N22666

UTTL Avionics standardization Perceptions and recommendations

AUTH A/FURRU J A CORP Air Force Inst of Tech Wright Patterson AFB OH CSS (School of Systems and Logistics)

ABS This research effort reflects the perceptions and attitudes about avionics standardization by some members of the acquisition community All of the interviewees were knowledgeable on the subject of and many had extensive experience with avionics standardization They either were currently working or had previously worked with avionics standardization The analysis reflects some of the attitudes about the policies and procedures of avionics standardization and the role of the Deputy for Avionics Control in the process of standardization The analysis also includes recommended changes to the current process of standardizing avionics equipment The result of the research effort shows that the acquisition community has not accepted avionics standardization for a number of reasons

RPT# AD-A161709 AFIT/GSM/LSY/85S 11 85/09/00 86N20388

UTTL Navy should join the Air Force and Army program to develop an advanced integrated avionics system CORP General Accounting Office Washington, DC CSS (National Security and International Affairs Div)

ABS Modern technology should soon enable separate avionics systems in an aircraft to be consolidated into a single package to conserve space, save weight, and reduce costs The report points out the potential benefits of avionics consolidation and recommends the Navy join in a demonstration program now being conducted by the Air Force and Army to exploit such benefits

RPT# PB85-222503 GAO/NSIAD-85-94 B-215379 85/06/17 86N12224

UTTL Avionics and civil aircraft systems The present and the future

AUTH A/LABORIE J P CORP Societe Nationale Industrielle Aerospatiale Toulouse (France) CSS (Div Avion) Presented at GIFAS Semaine Aerospatiale Francaise de Conf Tech Madrid 12-15 Jun 1984

ABS The technological progress in the design of avionics systems from the Concorde to the Airbus family is described The weight reduction cost advantages and ease of maintenance obtained with numerical techniques and laser gyros are discussed The ergonomic advantages introduced with the extensive use of cathode ray displays are pointed out The design trends for the A310 and longer term evolution are examined

RPT# SNIAS [illegible] 85/02/16 [illegible]

UTTL Avionics data base

AUTH A/MCGOWAN, J , B/WON, D J , C/VAMETTEN, D CORP Applied Systems Inst Inc Washington DC

ABS This document is a compendium of data for U S commercial avionics equipment produced by 61 manufacturers It contains data for the Air Transport Association (ATA) Specification 100 categories of auto flight communications indicating and recording and navigation as well as for antennas and couplers For each piece of equipment the following information has been collected technical specification price technical standard order number, ATA Specification 100 code and manufacturer name address, and phone number In addition to this report the data is available in machine readable form compatible with the IBM personal computer with R base 4000 Data Base Management System

RPT# AD-A152415 FAA-APO-85-4 85/01/00 85N27863

UTTL Some aspects of how to design cost-effective flight control systems

AUTH A/BUTTER U B/BOTZLER L CORP Messerschmitt-Boelkow Blohm G m b H , Munich (Germany F R) CSS (Aircraft Div) In AGARD Cost Effective and Affordable Guidance and Control Systems 14 p (SEE N85-26638 16-01)

ABS The design of flight control systems for fighter aircraft is discussed with respect to areas which contribute to minimizing life-cycle costs As life cycle costs include all costs accumulating during the whole life of the system all phases from the design to in-service use are considered Any structural and technological design features that are introduced to save costs during system operation and maintenance require additional development effort Therefore the expected cost benefit has to be balanced against the development effort invested into the system to achieve a cost-effective design 85/02/00 85N26639

UTTL Reliability predictions for military avionics Royal Signals and Radar Establishment reliability prediction method no 250 CORP Royal Signals and Radar Establishment Malvern (England) CSS (Reliability and Environmental Engineering Section)

ABS A prediction model for military avionics applications 18 months after an equipment is first introduced, is presented Base component failure rates with maximum stress levels are presented Factors influencing avionics reliability are outlined

RPT# BR69221 77/09/00 85N22388

UTTL Standard Attitude Heading Reference System (SAHRS) full scale development program

AUTH A/BACHMAN, K L CORP Naval Air Development Center Warminster PA In AGARD Helicopter Guidance and Control Systems for Battlefield Support 12 p (SEE N85-16797 08-01)

ABS There is a recognized need within the military services for reliable low cost-of-ownership Attitude Heading Reference Systems (AHRS) capable of operating for extended periods without the need for calibration or regularly scheduled maintenance In recognition of this need the military services have embarked upon a joint service full scale engineering development program to provide a Standard Attitude Heading Reference System (SAHRS) utilizing strapdown technology for a multiplicity of rotary and fixed wing platforms System design concepts and performance characteristics are described Procurement and schedules are also discussed 84/08/00 85N16804

UTTL Design for Tactical Avionics Maintainability CORP Advisory Group for Aerospace Research and Development Neuilly-Sur-Seine (France) Conf held in Brussels, 7 10 May 1984 ANN Advanced methods and tools to support design for avionic maintainability and testability are discussed Both hardware and software design for maintainability issues and approaches are addressed For individual titles see N85-16732 through N85-16756

RPT# AGARD-CP-361 ISBN-92-835-0366-10 AD-A149199 84/10/00 85N16731

UTTL Increased joint avionics standardization could result in major economies and operational benefits CORP General Accounting Office Washington, DC CSS (National Security and International Affairs Div)

ABS This report discusses the Department of Defense's efforts to standardize tactical avionics subsystems and the need to provide better support for these activities The objective was to look at the progress made in standardizing core avionics subsystems by the Joint Services Review Committee for Avionics Components and Subsystems Top management commitment must be enhanced and funds must be allocated to projects expected to provide major cost-saving and operational benefits The GAO recommends to establish a management structure for standardization that includes a high-level sponsor accountable for supporting the JSRC programs through the budget process determine whether funds for fiscal year 1984 and subsequent years should be reprogrammed to ensure that joint standard avionics systems sponsored by JSRC are developed and available when needed to meet candidate aircraft installation schedules, and establish a dedicated budget line item for joint avionics programs The DOD agrees with the first two recommendations but does not agree with the last one

RPT# AD-A145730 AD-F300467 GAO/NSIAD 84-127 84/07/10 85N10945

UTTL Quantum leap in avionics

AUTH A/CANTRELL W E CORP General Dynamics/Fort Worth, TX Proc held in Dayton, Ohio, 30 Nov - 2 Dec 1982 In ASD Proc Papers of the 2nd AFSC Avionics Std Conf Vol 2 p 959-975 (SEE N84-31165 21-06)

ABS Current standardization levels in such programs as the F-16 are providing benefits of productivity and growth that have been significant in the success of that program The ever-increasing drive to performance, multi use systems and diverse weapons has heavily taxed current avionic resources In addition the data transfer requirement is complicated by the high speed data flow that modern computers both feed on an produce by multiple source-multiple destination video distribution requirement, the need to self-test the system to lower levels and the desire to dynamically reconfigure from a failure Fortunately the technology to achieve solutions to these new problems is evolving in the VHSIC and fiber optics programs so that it is possible to rearchitecture the system at the module level as opposed to the LRU level Module level standardization around a small number of types allows a large number of system level combinations while achieving economies of scale at the module level The usual objection to standardization that it freezes innovation is avoided by technology transparency provisions while at the same time the objection that standardization obsoletes the present is avoided by downward compatibility provisions Candidates for standardization in this approach include bus interfaces the system network modules and racks

RPT# AD P003584 82/11/00 84N31189

UTTL Standard avionics software The future strategy for cost-effective avionics

AUTH A/STRAUB, E C CORP Arinc Research Corp Annapolis MD Proc held in Dayton Ohio, 30 Nov - 2 Dec 1982 In ASD Proc Papers of the 2nd AFSC Avionics Std Conf Vol 2 p 927-945 (SEE N84-31165 21-06)

ABS This paper reports an ARINC Research Corporation's work in developing and evaluating software acquisition alternatives for the USAF's Multi-Mode Radar program (since renamed the Multi-Role Radar (MRR) Program) Although the paper reflects work accomplished for that program the approach taken could be used for any software-intensive avionics program where several aircraft are involved and for which most of the software and hardware might be common The work was sponsored by Air Force Systems Command's Deputy for Reconnaissance and Electronic Warfare, Aeronautical Systems Division (ASD/RW) The paper assesses the applicability of current radar technology and production programs to an MRR discusses guidance provided by existing and proposed policies Directives and Standards examines the operational cost schedule risk supportability and management aspects of three software development alternatives and addresses the use of the ASD/ACC software cost estimating model to analyze software development costs Software acquisition alternative results are presented

RP # AD-P003582 82/11/00 84N31187

UTTL Fiber optics for the future - wavelength division multiplexing

AUTH A/SPENCER J L CORP National Aeronautics and Space Administration Langley Research Center Hampton VA Proc held in Dayton, Ohio, 30 Nov - 2 Dec 1982 In ASD Proc Papers of the 2nd AFSC Avionics Std Conf Vol 2 p 871-888 (SEE N84-31165 21-06)

ABS Optical wavelength division multiplexing (WDM) systems with signals transmitted on different wavelengths through a single fiber can have increased information capacity and fault isolation properties over single wavelength optical systems This paper describes a typical WDM system The applicability of future standards to such a system are discussed Also, a state-of-the art survey of optical multimode components which could be used to implement the system are made The components to be surveyed are sources multiplexers and detectors Emphasis is given to the demultiplexer techniques which are the major developmental components in the WDM sys em

RPT# AD-P003579 82/11/00 84N31184

UTTL Proposed MIL-STD for avionics installation interfaces

AUTH A/SCHOPF G CORP Aeronautical Systems Div Wright-Patterson AFB OH Proc held in Dayton Ohio 30 Nov - 2 Dec 1982 In its Proc Papers of the 2nd AFSC Avionics Std Conf Vol 2 p 861-870 (SEE N84-31165 21-06)

ABS This paper describes the Military Standard (MIL-STD) now in development for avionics installation interface standardization Originally based upon the interface standard used by the commercial airlines, this new MIL-STD now extensively revised, is scheduled for coordination at the end of 1982 The background which led to the development of the standard includes on analysis of the benefits expected to result from its application, the relationship between this standard and other military standards, and the similarities between this standard and the commercial (ARINC 600) standard The open forum approach using maximum industry participation was used extensively over a two-year period to produce the document The technical highlights of the standard including weight and power dissipation limits, environmental requirements and LRU form factors are presented A new electrical connector, which also serves as a hold-down device, is a key element in the design approach Air Force plans for implementation of the standard are aimed primarily at new airframes and major avionics updates of existing airframes Also, those avionics subsystems being developed for multiple airframe application are prime candidates

RPT# AD-P003578 82/11/00 84N31183

UTTL Options and opportunities for standards A NATO/AGARD viewpoint

AUTH A/SHEPHERD, J T , B/URBAN, L J CORP Marconi Avionics Ltd Rochester (England) Proc held in Dayton Ohio, 30 Nov - 2 Dec 1982 In ASD Proc Papers of the 2nd AFSC Avionics Std Conf Vol 2 p 843-859 (SEE N84-31165 21-06)

ABS This paper presents a summary of the findings of AGARD Working Group 06 This working group was established to consider Distributed Micro Processor Application to Guidance & Control Systems The results of this study are presented in AGARD AR-178 One of the areas considered by the working group was option and opportunities for standards and it is this area that is being considered in this paper It should be emphasized that this document is not intended to suggest definitive standards or even to state categorically that any given standard should be developed Rather its intention is to focus attention upon the need for standards and to point out areas where opportunities exist for standardization As will be seen from the previous sections in this report there is a vast proliferation in hardware and software When systems are developed they often produce unique hardware and software such as operating systems, executives high level languages etc Since the life cycle of aircraft systems is at least twenty years from conception, it could be as much as thirty years after the initial design before the systems are finally phased out This makes it almost impossible to maintain avionic systems in the later parts of their life cycle

RPT# AD-P003577 82/11/00 84N31182

UTTL Concepts for LHX avionics

AUTH A/SMITH, R H CORP Army Aviation Center, Fort Rucker, AL Proc held in Dayton, Ohio 30 Nov - 2 Dec 1982 In ASD Proc Papers of the 2nd AFSC Avionics Std Conf Vol 2 p 815-819 (SEE N84-31165 21-06)

ABS LHX is the acronym for a family of light, highly capable aircraft intended for operational use in the airland battle well beyond the year 2000 They will be capable of operation in a wide variety of adverse environments on a very hostile battlefield (lasers and other directed energy weapons will be commonplace) Accordingly the conceptual designs being considered are very different from today's helicopters One major thrust is toward automation of crew duties, with a goal of achieving single pilot operation

RPT# AD-P003575 82/11/00 84N31180

UTTL Westinghouse uses USAF-developed standards

AUTH A/SHYMAN C S CORP Westinghouse Defense and Electronic Systems Center Baltimore, MD Proc held in Dayton, Ohio, 30 Nov - 2 Dec 1982 In ASD Proc Papers of the 2nd AFSC Avionics Std Conf Vol 2 p 753 765 (SEE N84-31165 21-06)

ABS Westinghouse has applied digital standards advantageously for the U S Air Force on its latest weapon systems At present Westinghouse is applying MIL-STD-1750A (ISA), MIL-STD-1589B (JOVIAL 73 HOL) and MIL-STD-1553B (multiplex busing) to three major programs B-1B Offensive Radar System Improved AN/APG-66 Radar for the F-16 and AFTI F-16 Electro-Optical Sensor/Tracker Westinghouse has gone one step further than the digital standards With U S Air Force encouragement Westinghouse has a program for maximum radar commonality among the B-1B ORS F-16C and the U S Army Sgt York DIVAD Gun System This paper will cover Westinghouse's approach toward managing the application of the military standards across multiple programs with different prime contractors and services Additionally, the method by which configuration control of standard module hardware (i e , rational standardization) maintained at Westinghouse will be discussed

RPT# AD-P003572 82/11/00 84N31177

UTTL Advanced cockpit-systems integration

AUTH A/ROE G CORP British Aerospace Public Ltd Co , Brough (England) CSS (Act Design Group) Proc held in Dayton, Ohio 30 Nov - 2 Dec 1982 In ASD Proc Papers of the 2nd AFSC Avionics Std Conf , Vol 2 p 695-717 (SEE N84-31165 21-06)

ABS The present paper describes two major complementary activities funded by the United Kingdom Ministry of Defense which are being undertaken at the Brough site of British Aerospace These studies are addressing the problem of pilots task optimization and the overall system architecture needed to meet the operational requirements of the next tactical combat aircraft These activities are the Advanced Cockpit Design Studies and the Tactical Combat Aircraft Avionic Demonstrator Rig The Advanced Cockpit Studies have been underway for some 6 years The scope of these studies has been extensive, covering escape system design, g' alleviation techniques, advance pilot and equipment cooling techniques, information and control task rationalization and the development of workload prediction and measurement techniques The studies have, after a number of iterations culminated in the development of a dynamic cockpit mockup The studies specifically related to the information and control task rationalization will be discussed in this paper in some detail The Tactical Combat Aircraft Avionic Demonstrator Rig is presently at the mid point of a 3-4 year evolutionary design program investigating such topics as total system integration, standardization of interfaces, effective sub-system inter communication, graceful degradation of the system and improved maintenance procedures The architecture being developed has a multi bus hierarchy and implements the data transmission standard 1553B for sub system to sub system and bus to bus communications

RPT# AD-P003569 82/11/00 84N31174

UTTL Integrated testing and maintenance technologies
AUTH A/DENNEY R C B/PARTRIDGE, M J , C/WILLIAMS, R B
CORP Boeing Aerospace Co Seattle WA
ABS Maintenance of weapon systems is becoming an increasingly important consideration in weapon system development because the cost of maintenance is a significant portion of the life cycle cost of the system The objective of the Integrated Testing and Maintenance Technologies effort is to define requirements for an onboard test system for the avionic suite planned for tactical fighters in the 1990's Problems with current onboard test systems were analyzed to determine where improvements could be made In addition, the anticipated avionic architecture and mission of the 1990's were evaluated to determine the impact on maintenance capability Requirements for the Integrated Testing and Maintenance System were developed and documented in a system specification Identified improvements over current systems include better filtering of intermittent failure reports better isolation of intermittent failures through the use of recorded data more extensive use of system level tests of mission operational data and a man-machine interface providing more information to the maintenance technician In addition, artificial intelligence applications were evaluated to determine where they might be effectively applied to ITM A design concept for a fault classification expert system was developed
RPT# AD-A138587 AFWAL-TR-83-1183 83/12/00 84N22528

UTTL Multibus Avionic Architecture Design Study (MAADS)
AUTH A/RICH, B A B/HALDEMAN D G , C/STAUTBERG J L D/WHALEN W P CORP TRW Defense and Space Systems Group Redondo Beach, CA
ABS The Multibus Avionic Architecture Design Study (MAADS) evaluated projected avionic requirements for tactical aircraft of the 1990s and defined an architectural approach and design example suitable for use as the baseline for the Avionic System Integration Demonstrator (ASID) System Definition project The architectural approach is multi bus in nature including MIL-STD-1553B bus a high speed bus, and a video bus System sizing and timing estimates are provided Areas for potential future standardization are identified
RPT# AD-A138226 AFWAL-TR 83-1141 83/10/00 84N21546

UTTL Automated data base implementation requirements for the avionics planning baseline, Army
AUTH A/SPERATO, M B/MEAD, R CORP Arinc Research Corp Annapolis, MD
ABS The U S Army Avionics Research and Development Activity intends to establish the use of the Avionics Planning Baseline-Army (APB-A) document as an important facet of the formal avionics planning process The APB-A was designed to maintain maximum compatibility in both form and content with similar avoinics planning documents published by the Air Force and the Navy This overall compatibility should facilitate the exchange of information among the three services for the identification of avionics standardization opportunities The first edition of the APB-A was the product of the collection and manual assembly of avionics planning data for current and future planned Army aircraft into a report format similar to that of the Air Force Avionics Planning Baseline and the Navy Avionics Planning Baseline This technical report addresses the requirements for implementing an automated version of the Army avionics data base compatible with existing Air Force and Navy data base architectures and capable of mechanizing the production of the APB-A The complete automated system will be documented in a future report
RPT# AD-A135259 REPT-2846-01-TR-3062 83/07/00 84N18103

UTTL USAF (United States Air Force) avionics master plan
CORP Department of the Air Force Washington, DC
ABS This is the fourth annual USAF Avionics Master Plan (AMP) It is prepared by the Deputy for Avionics Control as directed in AFR 800-28, Air Force Policy on Avionics Acquisition and Support The purpose of the plan is to serve as a guide to the avionics community, to focus resources and energies on common goals, and promulgate strategies to move toward the resolution of common problems Strong emphasis continues in the avionics program areas of tactical and strategic C3, electronic combat and target acquisition/recognition from the standpoint of improved near/mid term capability Programs supporting these areas are proceeding essentially as previously planned, with the exception of tactical C3 Significant changes are being planned in the approach to achieving jam resistant communications The alternative architecture to be selected (scheduled for review and approval in the near future) could impact the JTIDS and Mark XV IFF programs as well as SFFK TALK
RPT# AD-A125819 82/12/00 83N29205

UTTL Towards a veritable supervisor program for avionics software
AUTH A/BRACON, G CORP Electronique Serge Dassault, Saint Cloud (France) In AGARD Software for Avionics 14 p (SEE N83-22112 12-01)
ABS Experience acquired in the development of equipment and avionics software for the Mirage F1 and the Mirage 2000, led to the definition of a software overseer The AIGLE supervisor program is oriented toward considering methodologies and assists in developing, maintaining, and following the project It involves a group of complementary operational tools which use a central data base and can then divide the information The integration of official service and the comfort of man machine dialog permits improved productivity The essential characteristics of AIGLE is the automatic knowledge of quality control information and of project management This permits validation of production processes an indispensable element in software certification
83/01/00 83N22116

UTTL Advanced avionic systems for multimission applications volume 2
AUTH A/SMITH, L A B/BEHNEN, S W C/PRATT K D D/MCCALL M B E/BOUSLEY R F CORP Boeing Military Airplane Development, Seattle, WA
ABS This study produced system control procedures and executive software design specifications for three different information transfer systems (ITS) each designed to implement multimission aspects of an avionic system The stationary master is the best understood ITS and has multimission advantages if the applications software is designed for change The non-stationary master is an excellent candidate for a pod-oriented multimission application The contention access ITS is designed to be most flexible in terms of change, at the potential cost of higher initial integration checkout due to the asynchronous nature of the communication A second task was to design, develop and build a compact version of the DAIS executive that would function in a one processor system and support only synchronous bus communications This executive, called the Single Processor Synchronous Executive (SPSE) was tested and delivered to AFWAL The primary goals of this task were to build a functional executive that Maintains the DAIS executive-to-applications interface Communicates on a MIL-STD-1553A bus Is coded in J73/I Supports the avionic system load for an AMST or modern tactical fighter aircraft Uses DAIS support software (LINKS ALAP PALEFAC PALEFAC processor) and Requires substantially less memory than the baseline DAIS executive All goals were achieved
RPT# AD-A121794 AFWAL-TR-82-1076-VOL-2 82/10/00 83N19750

UTTL Development of avionics installation interface standards
AUTH A/BAILEY S B/SULLIVAN N , C/SAVISAAR A CORP Arinc Research Corp Annapolis MD
ABS This report summarizes ARINC Research Corporation's efforts under Air Force Contract F04606-79-G-0082 "Standard Rack-Mounted and Panel-Mounted Avionics Interface Concepts Analysis " The period of performance was 29 August 1980 through 15 June 1981 The technical areas addressed were the analysis and potential specification of rack mounted avionics cockpit mounted control panels, and panel-mounted instruments Contract tasks included conceptual studies of potential configurations of a Standard Avionics Integrated Control System (SAICS) The results of the SAICS analyses are reported separately in ARINC Research Publication 2258-02 1-2439 Cost Benefit and Failure Criticality Analyses of the Standard Avionics Integrated Control System (SAICS) Concept, June 1981 The concepts analysis project described herein continues a contractual effort initiated by the Air Force in 1979 to determine whether a comprehensive Packaging, Mounting, and Environmental (PME) avionics interface standard would benefit Air Force aircraft Comprehensive findings of that effort are documented in ARINC Research Publication 1753-01-1-2124, Standard Avionics Packaging Mounting and Cooling Baseline Study January 1980, which addresses the applicability of commercial airline avionics to military aircraft, the cost benefits associated with Air Force PME standards, and a possible implementation scenario with recommended activities and schedules
RPT# AD-A116852 REPT-2258-03-2-2477R 8 /08/00 83N11123

UTTL Integrated control of mechanical system for future combat aircraft
AUTH A/WILCOCK G W B/LANCASTER P A C/MOXEY C CORP Royal Aircraft Establishment Farnborough (England) , British Aerospace Aircraft Group, Warton (England) In AGARD Tactical Airborne Distributed Computing and Networks 16 p (SEE N82-17086 08-01)
ABS Various techniques for the application of digital control to aircraft utility systems were investigated It is shown that the prefered approach utilizes a number of distributed processors and terminals that interface with the utility components Analysis performed to data shows a weight saving of approximately 100 Kg (i e 50%) and a pilot workload reduction of the order of 4 1, may be achieved in a twin engine combat aircraft 81/10/00 82N17117

UTTL Techniques for interfacing multiplex systems
AUTH A/GROSS J P CORP SCI Systems Inc , Huntsville AL
ABS Data describing the characteristics of a number of aircraft multiplex systems were collected and compiled Although Air Force aircraft received priority, were consideration was also given to other military and commercial aircraft The F-16 B-52 OAS, YAH-64 F-18 F-15 and ARINC 575 systems were included MIL-STD-1553B was used as a baseline for comparison The compiled data was analyzed to determine points of incompatibility between these systems and a feasibility study was performed to assess possible techniques to be used in achieving bus compatibility A programmable interface module design philosophy is recommended which utilizes a distributed three-microprocessor arrangement to achieve

the desired interface compatibility The three-processor conept allows three independent software-controlled events to occur simultaneously thus providing an extremely high degree of flexibility both for existing systems and for future growth

RPT# AD-A101457 AFWAL-TR 80-1223 81/02/00 82N13135

UTTL A standard control display unit for multi-aircraft application

AUTH A/SWANSON, R L B/SCOUGTON, C R CORP Collins Radio Co Cedar Rapids, IA CSS (Government Avionics Div) In AGARD The Impact of New Guidance and Control Systems on Mil Aircraft Cockpit Design 10 p (SEE N82-13048 04-01)

ABS The need for standardization of military hardware is well documented both within the US DOD and NAT Standardization issues revolve mainly around interoperability logistics, and life-cycle cost advantages The issue of standardization and its suitability in the design of aircraft control/display units (CDU) is addressed Potential benefits, requirements, and remaining problems associated with standardization of avionics control displays are discussed Included is a discussion of a CDU that is currently being produced which has many of the features considered essential to the ultimate standard CDU 81/08/00 82N13054

UTTL Actual versus simulated equipment for aircraft maintenance training Cost implications of the incremental versus the unique device

AUTH A/VESTEWIG R F , B/EGGEMEIER, F T CORP Air Force Human Resources Lab , Brooks AFB, TX CSS (Logistics and Technical Training Div) Presented at the 23rd Ann Meeting of the Human Factors Soc , 1979

ABS Life cycle cost estimates were developed for use of simulated test equipment vs actual test equipment in a maintenance training program of the type used for current advanced fighter aircraft Previous life cycle cost comparisons had not explicitly considered the cost implications of procurement and support of a unique training device vs an incremental device This effort included the unique vs the incremental device factor Total estimated fifteen year costs for simulated equipment trainers were significantly lower than comparable estimates for actual equipment trainers The results indicate that the cost implications of a unique device vs an incremental device are important determinants of both acquisition and support cost estimates and should be considered fully in future life cycle costing efforts

RPT# AD-A102388 AFHRL-TP-81-17 81/07/00 81N31104

UTTL Airborne Systems software Acquisition Engineering Guidebook for application and use of the guidebooks (series overview)

AUTH A/PARRIOTT L CORP TRW Defense and Space Systems Group, Redondo Beach CA

ABS This guidebook serves as an introduction to the Airborne Systems Software Acquisition Engineering guidebook series which describes significant activities and events in the software acquisition life cycle of airborne embedded computer systems acquired within the framework of Air Force 800-series documents This guidebook contains a brief description of the other fifteen guidebooks and discusses the application and use of the various guidebooks during the acquisition of embedded weapon system software

RPT# AD-A100216 TRW-30323-6003-TU-00 ASD-TR-80-5028 80/10/00 81N28787

UTTL Airborne Systems Software Acquisition Engineering Guidebook for software cost analysis and estimating

AUTH A/WOLVERTON, R W CORP TRW Defense and Space Systems Group Redondo Beach CA

ABS This guidebook assists Air Force Program Office engineering and management personnel in costing embedded software for avionics applications A methodology for cost reporting and avoiding the '90 percent complete' syndrome is presented An annotated bibliography gives the author's personal view of source material relevant to avionics software costing using modern programming practices

RPT# AD-A100215 TRW-30323-6012-TU-00 ASD-TR-80-5025 80/09/00 81N28785

UTTL Predicting cost/reliability/maintainability of advanced general aviation avionics equipment

AUTH A/DAVIS M R , B/KAMINS M , C/MOOZ, W E CORP RAND Corp , Santa Monica, CA

ABS A methodology is provided for assisting NASA in estimating the cost reliability, and maintenance (CRM) requirements for general avionics equipment operating in the 1980's. Practical problems of predicting these factors are examined The usefulness and short comings of different approaches for modeling coast and reliability estimates are discussed together with special problems caused by the lack of historical data on the cost of maintaining general aviation avionics Suggestions are offered on how NASA might proceed in assessing cost reliability CRM implications in the absence of reliable generalized predictive models

RPT# NASA-CR-152149 RAND/WN-10233-NASA 78/06/00 81N19111

UTTL Summary of AGARD Lecture Series 100 Methodology for control of life cycle costs for avionics systems

AUTH A/GABELMAN, I J CORP Gabelman (Irving J) Technical Associates, Rome NY Lecture held in Bonn, 7-8 May, 1979 and in Athens 10-11 May 1979 In AGARD Design to Cost and Life Cycle Cost 8 p (SEE N81-11902 02-81)

ABS The continually increasing cost of avionics and weapons systems between aquisition and their lifetime operation are discussed Specific emphasis is given to the following elements of life cycle costs, parametric cost analysis, and life cycle cost methodology 80/07/00 81N11924

UTTL Design to life cycle costs interaction of engine and aircraft

AUTH A/JONES, E J CORP Ministry of Defence, London (England) In AGARD The Appl of Design to Cost and Life Cycle Cost to Aircraft Eng 15 p (SEE N80-31342 22-01)

ABS The distribution of life cycle costs for a typical combat aircraft between airframe avionics and engine is discussed Distribution of costs for the aircraft between development production initial support and operation and support is compared with the distribution for the engine The effect of fleet size and service life upon the life cycle costs are indicated The large commitment of life cycle costs early in the conceptual and feasibility phase of the program is indicated The choice of engine is an example of this early commitment The relative effect of the choice of single or twin engine installation of a derated engine or the use of an existing engine upon the engine life cycle costs and the interaction with aircraft costs is discussed The severe operating conditions for the engine of a combat aircraft are reviewed Reduced support costs are not expected to give a large fold return on extra engine development investment 80/05/00 80N31344

UTTL Standard avionics packaging mounting and cooling baseline study

AUTH A/BAILY S , B/JACKSON, A C/RUSSELL J D/SMITH C N D E/SULLIVAN N CORP Arinc Research Corp Annapolis MD

ABS This is the final report on a study concerning the development of an avionics packaging, mounting, and environmental (PME) standard and an associated cost-benefit analysis The report compares military and commercial airlines avionics generic standards to determine their technical and procedural differences and identifies the changes and waivers required when equipment built to the commercial airlines standards are procured by the USAF It also compares the functional and physical characteristics of certain military and commercial avionics equipments and assesses the degree of utility of current commercial equipments for use in USAF aircraft The opinions of aircraft and avionics manufacturers concerning a military avionics PME standard and their suggestions as to what the standard's scope an applicability should be are reported Alternative avionics cooling procedures and technologies and the concept of employing a separate environmental control system dedicated to avionics cooling are reviewed A life-cycle cost payback model that addresses the impact of PME standardization on the cost of avionics systems in USAF aircraft is described The results of exercising the model are reported The significant tasks and scheduling for the next phases of avionics PME development leading to the definition and acceptance of a military avionics PME standard, are presented

RPT# AD-A082166 REPT-1753-01-1-2124 80/01/00 80N24312

UTTL Reliability management of the avionic system of a military strike aircraft

AUTH A/WHITE, A P , B/PAVIER J D CORP Elliott-Automation Space and Advanced Military Systems Ltd , Camberley (England) In AGARD Avionics Reliability Its Tech and Related Disciplines 13 p (SEE N80-19519 10-38)

ABS The system management techniques to achieve the reliability requirements for the avionic system of the Panavia Tornado aircraft are described The method of apportionment of these requirements to each of the constituent parts of the system is explained The aims of effectiveness and experience to date of reliability demonstrations are outlined 79/10/00 80N19546

UTTL Military adaption of a commercial VOR/ILS airborne radio with a reliability improvement warranty

AUTH A/FEDER E I B/NIEMOLLER, D L PAA B/(Bendix Corp Fort Lauderdale, Fla) CORP Army Avionics Research and Development Activity Fort Monmouth, NJ In AGARD Avionics Reliability, Its Tech and Related Disciplines 8 p (SEE N80-19519 10-38)

ABS Low cost, small lightweight airborne navigation receivers were acquired and reconfigured to meet U S Army aircraft specifications The contract includes a clause requiring the manufacturer to assume responsibility for the field reliability and repair of each receiver for a minimum of four years If successfully implemented, the reliability improvement warranty should increase reliability, availability, and maintainability and reduce the overall equipment life cycle costs 79/10/00 80N19540

UTTL Impacts of technologies selected on the reliability, and operational availability of equipments Cost considerations

AUTH A/GIRARD, J M , B/GIRAUD M CORP Electronique Marcel Dassault Saint Cloud (France) In AGARD Avionics Reliability, Its Tech and Related Disciplines 17 p (SEE N80-19519 10-38)

ABS A single criterion, V, is proposed to allow manufacturers to evaluate the merits of technological variants once an equipment baseline version is designed and quoted The V factor is computed for an airborne digital computer, a Doppler navigational radar, and a search and rescue beacon, each considered in three different versions 79/10/00 80N19536

UTTL A method for designing multiprocessor architectures for avionics functions

AUTH A/ALEONARD, C , B/DEMOMENT A C/ROMAND, P , D/GILLON, J , E/LEMAITRE, J F PAA D/(CERT Toulouse, France) F/(CERT, Toulouse France) CORP Societe Crouzet, Valence (France) In AGARD Advan in Guidance and Control Systems Using Digital Tech 7 p (SEE N80-14017 05-01)

ABS A digital technique is given for the design of high performance automatic systems The evolution of digital techniques presents the automatist with the problem of the total design of a control system It means going beyond algorithmic synthesis from the beginning, to take into account all the functional and operational aspects Thus it is possible to optimize the control system according to three important criteria regard for the desired operating performances, the total cost, and the very important matter of operational safety (reliability, security, maintainability, and availability) 79/08/00 80N14021

UTTL Avionics standardization potential analysis

AUTH A/GATES, R K B/SHIPP, R F CORP Analytic Sciences Corp Reading, MA

ABS The objective of the Avionics Standardization Potential Analysis program is to develop a general methodology for evaluating the benefits accruing from the use of standard equipment across future USAF avionics systems The methodology has been developed using navigation avionics as being representative of avionics in general, in a study of standardization potential across navigation systems (SPANS) The methodology covers the process of establishing future avionics systems requirements through mission analysis, identification of available equipment for the design of mission-responsive avionics suites, evaluation of future quantitative demands for avionics equipment, synthesis of mission-capable avionics systems collection of relevant cost and reliability data and evaluation of standardization options using a computer-based Standardization Evaluation Program (STEP)

RPT# AD-A066138 TASC-TR-1059-3 AFAL-TR-78-168 78/11/30 79N23958

UTTL Modular Avionics Packaging (MAP) CORP General Electric Co Utica, NY CSS (Aircraft Equipment Div)

ABS In considering Modular Avionics Packaging, the objective of the General Electric study program was to develop an avionics equipment packaging concept, compatible with MIL-E-5400 and applicable to multiplatform avionics requirements stretching into the 1990's Specific elements evaluated were Standard Avionics Module (SAM) requirements and concepts integrated racks and WRA requirements and concepts, and airframe interface considerations The V/STOL Type A platform was used as the driving requirement in performing trade-off studies Key design objectives and constraints included the following Minimizing installed avionics weight and volume Mechanical simplicity, Significant improvement in Reliability and Maintainability, Eliminating single-point failure modes, Direct access to Weapons Replaceable Modules (WPM), Modules capable of being conduction-cooled Significant improvement in thermal performance, and Improved testability at all hardware levels

RPT# AD-A059637 77/11/30 79N14093

UTTL The Avionics Laboratory Predictive Operations and Support (ALPOS) cost model volume 3

AUTH A/TUREK, J P , B/WIENECKE E L III, C/FELTUS E E CORP Westinghouse Electric Corp , Hunt Valley, MD

ABS Recent DOD experience shows that a prime factor in the evaluation of alternative weapon systems for performing a particular mission is Life Cycle Cost (LCC) Since 70% of the system LCC is determined by the end of the conceptual phase, it is important that techniques to predict LCC be available during that phase Since system definition is not complete enough in this phase to perform detailed analysis using accounting models, the major tool which can be used is parametric estimating models This report describes a model which relates the available design parameters to LCC via various cost estimating relationships (CERs) This document is Volume 3 of the Final Report which describes the consolidated data base utilized to develop the Avionics Laboratory Predictive Operations and Support (ALPOS) cost model The Air Force Program Monitor was Lt Thomas T James, Jr (AFAL/AAA-3), System Evaluation Group, Avionic Systems Engineering Branch

RPT# AD-A059354 AFAL-TR-78 49-VOL-3 78/04/00 79N14091

UTTL Report on Modular Avionic Packaging (MAP) industry briefing and response

AUTH A/KIDWELL, J R CORP Naval Avionics Center, Indianapolis, IN

ABS This report provides information related to a modular avionic packaging (MAP) concept presented to industry on 9 May 1978 at the Naval Avionics Center Indianapolis Indiana In attendance at this meeting were 78 representatives of different divisions of 33 companies As major suppliers of avionics to the Navy comments provided by these companies were anticipated to be very useful in the further development of packaging approaches for future avionics This report contains the responses provided by industry Although the companies responding are identified by name for reference, a reasonable attempt has been made to render the comments anonymous by removing company names and product references The comments have been grouped into categories and summarized, however, no attempt has been made in this report to resolve areas of conflicting opinion given by different companies It is not intended to imply that the Navy or this Center endorses agrees, or disagrees in any manner with the comments provided by industry

RPT# AD-A059193 NAC-TR-2240 78/08/09 79N13039

UTTL The feasibility of estimating avionics support costs early in the acquisition cycle Volume 2 Appendixes

AUTH A/MORGAN, J D , B/FULLER, A B CORP Institute for Defense Analyses, Arlington, VA CSS (Cost Analysis Group)

ABS This paper reports on research to determine the feasibility of developing methods to estimate early in the system acquisition cycle the potential support cost inputs of alternative avionics components envisioned for Air Force and Navy fighter aircraft Support costs are defined as those costs incurred at the organizational intermediate and depot levels to maintain avionics equipment and the costs of avionics spares and repair parts support Volume 2 is a compilation of appendixes containing additional material to support the basic report, including summary evaluations of forty eight key documents encountered in the literature search

RPT# AD-A053486 AD-E500026 P-1292-VOL-2 IDA/HQ-77-19873 77/09/00 78N28093

UTTL General aviation avionics equipment maintenance

AUTH A/PARKER, C D , B/TOMMERDAHL J B CORP Research Triangle Inst Research Triangle Park, NC

ABS Maintenance of general aviation avionics equipment was investigated with emphasis on single engine and light twin engine general aviation aircraft Factors considered include the regulatory agencies avionics manufacturers, avionics repair stations the statistical character of the general aviation community and owners and operators The maintenance, environment and performance, repair costs, and reliability of avionics were defined It is concluded that a significant economic stratification is reflected in the maintenance problems encountered, that careful attention to installations and use practices can have a very positive impact on maintenance problems and that new technologies and a general growth in general aviation will impact maintenance

RPT# NASA-CR-145342 RTI-1464-00-00F 78/05/00 78N24132

UTTL Preliminary candidate advanced avionics system for general aviation

AUTH A/MCCALLA, T M , B/GRISMORE F L C/GREATLINE S E D/BIRKHEAD L M CORP University of Southern Illinois Carbondale

ABS An integrated avionics system design was carried out to the level which indicates subsystem function and the methods of overall system integration Sufficient detail was included to allow identification of possible system component technologies and to perform reliability modularity maintainability, cost and risk analysis upon the system design Retrofit to older aircraft, availability of this system to the single engine two place aircraft, was considered

RPT# NASA-CR-152025 77/07/00 78N10060

UTTL Avionics maintenance study

AUTH A/OWENS, P R B/STJOHN, M R , C/LAMB, F D CORP Air Force Avionics Lab Wright-Patterson AFB OH

ABS Avionics maintenance has become a major contributor to the life cycle cost of weapons systems and this study was undertaken to gain insight into factors contributing to the cost of avionics maintenance To become familiar with the procedures employed and operating conditions encountered in the operational Air Force, a team from the Air Force Avionics Laboratory visited several avionics maintenance squadrons, along with depot organizations at Air Logistics Centers Through interviews with both supervisors and maintenance technicians at these organizations, a familiarization with the working level procedures was acquired Similarities and differences in procedures, personnel, test equipment, complaints and equipment supported at installations under different major commands were noted A wide range of avionics from old, tube type equipment through the latest solid state equipment just being introduced into the inventory was considered in the selection of organizations to be visited Difficulties in obtaining replacement parts and dissatisfaction with test equipment were found to be the problems most often voiced by maintenance personnel To persons from a laboratory environment, the age of some equipment still in use was shocking and the necessity for designing avionics to provide reliable service for 15 to 20 years was strongly realized The need for early consideration of ATE requirements to insure rapid cost-effective fault isolation in new avionics design is emphasized as one conclusion to the study

RPT# AD-A042568 AFAL-TR-77-90 77/06/00 78N10003

UTTL Use of commercial off-the-shelf equipment in military aircraft

AUTH A/SCOTT D L CORP Defense Systems Management School, Fort Belvoir, VA

ABS The goals of the project were to identify and evaluate the

documents controlling the performance environmental testing and reliability testing of commercial avionics equipment, and to compare these procedures with conventional military practice, and to analyze and highlight those factors which impact the decision of an acquisition program manager who is considering the use of commercial equipment in military aircraft
RPT# AD-A033818 76/05/00 77N23103

UTTL A lessons-learned study of an Airborne UHF radio program
AUTH A/MEDLIN, K A CORP Air Force Inst of Tech, Wright-Patterson AFB, OH CSS (School of Engineering)
ABS A study was made on the evolution of the major subsystem program Of primary concern was the manner in which a program is initiated the changes which it undergoes and the reason for the changes The intent of the study was to extract lessons learned which might be of benefit to others in subsystem program management The study was accomplished by reviewing program data and interviewing key participants This data was reviewed through an hypothesized framework of initial attempts regrouping nature and direction solicitation, evaluation and award of a subsystem program This study has shown the difficulty in establishing a basis of action for a subsystem program, the subjective nature of requirements the difficulty in building competition and openhandedness into a program, and the complexity of a program even when it is a subsystem In addition, it was shown that the hypothesized framework was realistic in reviewing the evolution of a subsystem program
RPT# AD-A021264 GSM/SM/75S-6 75/09/00 76N29473

UTTL Models and methodology for life cycle cost and test and evaluation analysis
AUTH A/ANDERSON, R H, B/DIXON T E, C/COUCH, R F, JR D/NEWHART, W H JR CORP Office of the Assistant for Study Support, Kirtland AFB, NM
ABS This report documents various models and methodology which were developed during the course of some analytical studies on life cycle cost and test and evaluation These studies were conducted by the Office of the Assistant for Study Support (OAS) at the request of DCS/Development Plans Headquarters AFSC The objectives of the study were to Investigate the present methods of subsystem reliability specification and identify limitations associated with these methods investigate new and innovative techniques for subsystem reliability management and identify benefits to be derived in terms of higher performance/lower costs, and, develop models and methodology applicable to life cycle cost and test and evaluation analyses (Modified author abstract)
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14. Abstract

There is a growing need to develop flexible/robust avionics to meet ever changing mission needs of the operational forces. Such needs may conflict with other characteristics required such as standardisation, increased reliability, durability and integrity. Weapon system costs and associated avionics costs continue to increase while military budgets continue to shrink due to changing world conditions. Thus it is even more important to intelligently resolve these often conflicting forces driving development efforts.

These evolving trends, conflicts and challenges will be examined in this Lecture Series with a view to enhancing dialogue, understanding and improved planning.

This Lecture Series, sponsored by the Avionics Panel of AGARD, has been implemented by the Consultant and Exchange Programme.

AGARD Lecture Series 176 Advisory Group for Aerospace Research and Development, NATO THE CONFLICTING FORCES DRIVING FUTURE AVIONICS ACQUISITION Published September 1991 210 pages There is a growing need to develop flexible/robust avionics to meet ever changing mission needs of the operational forces. Such needs may conflict with other characteristics required such as standardisation, increased reliability, durability and integrity. Weapon system costs and associated avionics costs continue to increase while military budgets continue to shrink due to changing world P.T.O.	AGARD-LS-176 Avionics Reliability — electronics Air force procurement Air force operations Budgeting Defense Budgets

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