CONFERENCE "17 ICAS CONGRESS"

NEW AVIONICS ARCHITECTURE CONCEPT FOR COMMERCIAL AIRCRAFT

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Summary

Avionics on commercial aircraft have until now been implemented with "Line Replaceable Units" concept with consequent high non-recurring development cart for aircraft manufacturer and high operating cost for airlines.

A new concept based on utilisation of standard modules with common frame design has been developped.

This presentation covers the key elements of this new concept on which AEROSPATIALE has launched a full development and research program with the objective to be ready for application on an aircraft launched in 1992.

The new concept is aimed to reduction of the total cost of ownership of avionics i.e. : initial development cost then maintenance cost. It must also provide more flexibility to add or modify system functions through onboard software loading.

1. Introduction

1.1. History

Avionics on commercial aircraft have evolved in complexity and technology over time, but until now, have been implemented with "Line Replaceable Units" concepts. Each unit was dedicated to one specific function or with increased electronic function to a set of closely related functions.

This situation which is illustrated by Figure 1 has induced parallel developments of several parts of equipment such as interface units, power supplies, processors and also software modules.

Moreover, these software modules have to be coded using low level languages to be able to cope with the stringent constraint of this embedded equipment.

This results in high Line Replaceable Units cost with consequent high non-recurring development and cost for aircraft manufacturer and high operating cost for airliners.

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- For iso-functions, the volumes of digital electronics is devided by two every five years
  AFCS : A310 = 134 Litres — A320 = 63 Litres — A340 = 31 Litres
- The total volume of digital electronics has a tendency to increase with time
  A310 = 745 Litres — A320 = 760 Litres — A340 = 830 Litres
- The number of digital equipement has increased
  A310 = 77 — A320 = 102 — A340 = 115
- Volume of on-board software
  A310 = 4 M Bytes — A320 = 10 M Bytes — A340 = 20 M bytes
- Number of digital links
  A310 = 136 — A320 = 253 — A340 = 368
- On-board calculation power
  A310 = 60 Mips — A320 = 160 Mips — A340 = 250 Mips

Figure 1

1.2. Integrated modular avionics concept

To reduce, the total cost (i.e. initial development cost plus operating cost) during the life of the aircraft, a new concept is being studied and largely discussed in the System and Architecture Interface sub-committee of the AEEC (Airline Electronic Engineering Committee).

The new concept is based on a modular system with common Frame design, common Fault tolerance processing, software partitionning, redundant power supplies and a flexible modular I/O. This results in an avionics system which can perform a number of functions simultaneously. High-throughput microprocessors, the Ada programming language, the ARINC 629 multi-transmitter data bus and efficient low voltage power supplies (LVPS) are the key components and technologies necessary to design, develop and integrate this type of advanced avionics architecture.

An avionics architecture which is defined according to the IMA concept, is an architecture having a few avionics cabinets containing standard Line Replaceable Modules (LRMs) for processing and sensors, actuators, control panel and displays interconnected through ARINC 629 data buses.

Each cabinet has data and signal processing capabilities to support several avionics functions software, memory, modular I/O, ARINC 629 terminals and dual low voltage power supplies. Each of the avionic functions included in the IMA concept should have a specification that defines all of the requirements for that particular function.

All the LRMs communicate with the core processing module via an intra-cabinet backplane data bus. This one can be duplicated for the reliability. In one cabinet, it is possible to have one or more core processing modules.

A complete independance between hardware and software will be provided by a standardized executive software.

Figure 2 gives an overview of the organization of one cabinet.

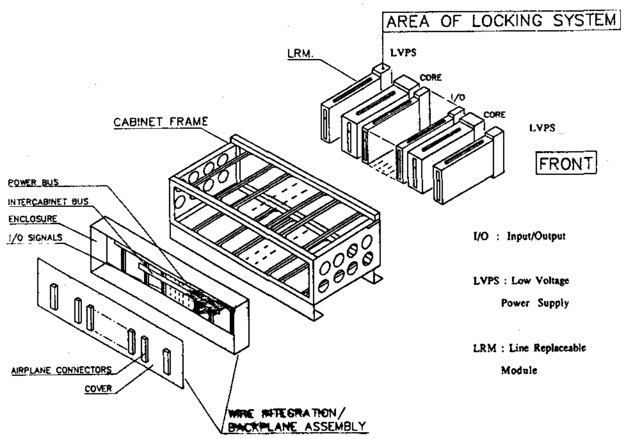

Figure 2

2 . AEROSPATIALE approach

2.1 . Objective

The new concept is very promising and AEROSPATIALE has already implemented such an application partially with the FMGC (Flight Management and Guidance Computer) for the A320, which is itself near a cabinet. Beyond this application, it has been decided to launch a development and research program with the objective to be ready for application on one A/C launched in 1992. This program covers the key elements which will be successively described.

2.2 . Architecture

As concerns the aircraft systems, there are different types of functions which can be classed in the following groups :

- Flight control/Navigation,
- Communications,
- Ancillary systems (Electrical power, Air conditioning, Hydraulic power),
- Engine control.

2.2.1 . Implementation on today technology

Safety and availability objectives are associated with each type of function. This is reflected by specific implementations for the onboard computers, such as :

- Computers with two independent processing channels,
- Software and hardware dissymilarity for these processing channels,
- Redundancy ensured by several computers.

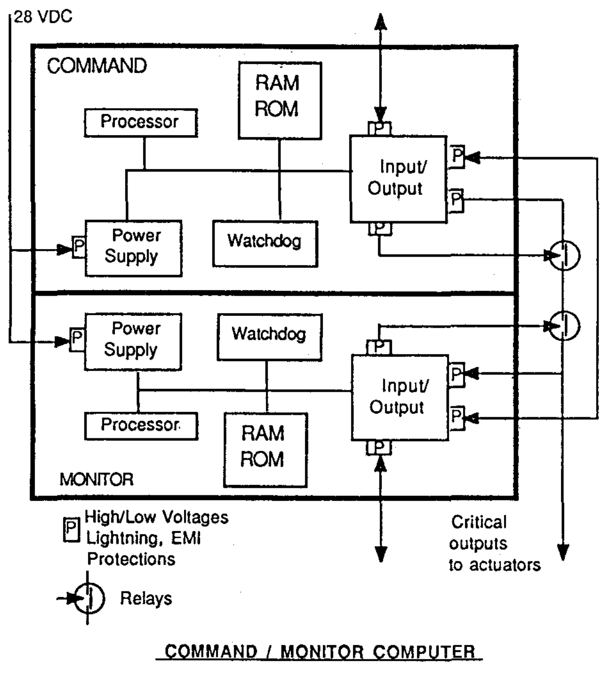

Figure 1

These implementation principles permit very stringent safety requirements to be met (relevant to transmission of erroneous outputs) by placing the computer in a reliable status subsequent to failure. The function concerned is then ensured (availability requirements) by the redundant computer(s). In the Airbus A320 Fly-By-Wire Controls, two types of computers are used : the ELACs (Elevator and Aileron Computers) and the SECs (Spoiler and Elevator Computers). These computers were designed and produced by different equipement manufacturers for design and manufacture fault-tolerance reasons. Also, two ELACs and three SECs give the necesssary availability for the function during complete aircraft flying time.

Let us take an other example, the Airbus A320 Autopilot :

This system is built around 2 different computers ; the FMGC (Flight Management and Guidance Computer) and the FAC (Flight Augmentation Computer) and two control units ; the FCU (Flight Control Unit) and the MCDU (Multi purpose Control and Display Unit). Data processing uses information provided by a group of sensors and generates the commands for :

- Guidance
- Thrust control
- Flight Envelope computation
- Navigation
- Performance

Then it provides :

- Display inside the cockpit through Display Management Computers
- Surface control through fly-by-wire computers
- Engine control through FADEC computers

The information which is generated is associated with different safety requirements which result in different architecture implementations :

- Some fonctions, as AFS cruise, flight management, require a reasonable failure rate $< 10^{-4}$ to 10^{-5} per hour.

  They are implemented with a single channel.

- Other functions require extremely improbable failure rate $< 10^{-9}$ per hour in order to avoid any undetected failures.

  They are implemented with dual channels.

- Moreover, system availability is demanded under 100 feet for all weather landing : Function loss probability is 10^{-9}.

  The Auto Flight System has then a dual-dual implementation to meet safety requirements :

- Integrity : control and monitoring channels used to avoid undetected failure which might result in surface runaways. These two channels have their own hardware resources. In the same way, software comes from different designs and languages for the two channels.

- Availability : today hardware reliability leads to duplicating AFS computers with automatic change over to meet the availability requirements in critical flight phases.

Moreover, critical guidance commands are computed from inertial sensor data. To reach the probability of 10^{-9} for undetected surface runaways, implementation of IRS (Inertial Reference System) and ADS (Air Data System) is thus made by three independant data processing sources.

Information is either voted with elimination of the faulty source or items of information are compared in pairs. This structure prevents any surface runaway due to a faulty source. In the event of a second failure occurence, it prevents surfaces from being affected thanks to auto-elimination of the system.

2.2.2 . Implementation in IMA concept

The same level of integrity is requested for the IMA concept, it is thus necessary to have the same level of safety as the one provided today by segregated independent sources. This will be achieved through high level monitoring of the communication network made up of ARINC 629 buses.

But an architecture with only one type of bus per side does not allow the safety and availability aims to be met for avionics systems. There is a common point between the three ADC and IRS data processing ; sensor information has not to be transmitted through the same physical support : Interference may result in total loss of the AFS.

It thus appears that each cabinet must be connected with at least two different types of ARINC 629 buses to provide two segregated physical supports for sensor information acquisition.

Integrity requirements lead to keeping control and monitoring channels with dissymmetrical software and separate hardware.

There are always two dual computers to meet availability requirements.

One solution of architecture could be for the AFS :

- 4 cabinets for AFS.

Command channel for computer 1	in cabinet	1 side	1
Monitoring -----------------------	1 -----------	2	1
Command channel for computer 2	in cabinet	1 side	2
Monitoring -----------------------	2 -----------	2	2

- 3 buses for the 3 ADIRS.

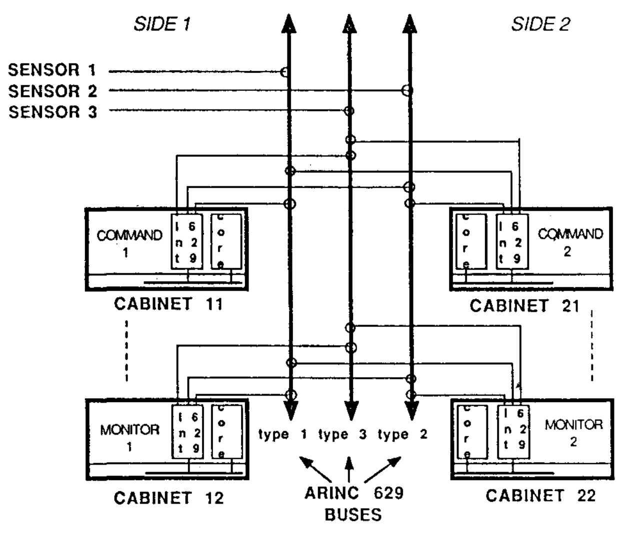

Figure 2

This architecture raises following problems which will have to be solved.

1) There is one bus for one sensor. Moreover, each cabinet receives data from the 3 buses : Then, if one bus or one sensor is lost, cabinets continue to receive data from 2 sensors via 2 segregated physical supports.

2) There is no segregation between side 1 and side 2 of the aircraft as is the case today : as each cabinet is connected to the 3 buses, a high level of confidence is resquested for bus interface units.

3) There is separate hardware for command and monitor channels. Taking this point into account, the Command and Monitor channels for the same side could be gathered in the same cabinet.

4) There is total dissymmetrical software for command and monitor channels if two dissymmetrical executive software units exist : one for cores 11 and 21 ; an other for cores 21 and 22.

5) Availability is provided by a change over towards the two redundant cabinets as today.

In an IMA context, all the aircraft functions share the hardware resources such as the communication buses and the processing and power supply modules and, in part, the Inputs/Outputs. This means :

- Possible grouping of the functions must be analyzed with respect to various criteria such as data exchanged, required computing time, etc.,

- That the operating reliability of the onboard system must be approved as the failure of one item can affect several functions.

2.3 . Data communications

2.3.1 . Inter-equipment bus

2.3.1.1 . Main characteristics

The single-transmitter multiple-receiver (15 to 20) ARINC 429 bus is used today to meet the inter-equipment communication requirements. The increasing complexity of the digital functions tends to make this low-speed bus obsolete. It is also unsuitable for file transfers.

In order to solve this problem, aircraft and equipment manufacturers are working together to define a new network-oriented communication media : the ARINC 629 bus.

Its main characteristics are :

- multiplexed multiple-access serial bus, type CSMA-CA (collision avoidance protocol : prevents access conflicts),

- asynchronous operation,

- 2 Mbit/s flow rate,

- physical layer : current or optical (under study) coupling,

- max. length : 100 m,

- up to 120 subscribers.

The messages transiting on the bus are structured as follows :

- 20-bit words with :

  • 3 synchro bits,
  • 16 data bits,
  • 1 parity bit.

- these words are transmitted in word strings with a max. length of 257 words comprising :

  • a label word (string identification),
  • up to 256 data words.

Two types of access protocols (MAC : Medium Access Control) have been defined for the 629 :

- the BP (Basic Protocol), designed by BOEING and already validated, source of the 629 standard. This protocol enables operation either in periodic mode or in aperiodic mode. For this, BOEING has developed a Communication Controller (Terminal) operating in the BP mode : the DATAC.

- The CP (Combined Protocol) defined by Airbus Industrie : much more flexible than the BP as it allows transfer of both periodic and aperiodic data on the same bus.

At present, only the BP is validated. The work performed by Aerospatiale on the CP concerns the validation of the protocol and, also, the manufacture (in partnership with Sextant Avionique) of a 629 interface integrating the first four layers (Physical, Datalink, network and transport) of the OSI model for the 629.

This interface will be a standard circuit common to all bus subscribers (see Figure 3 : the interface is, here connected to the bus by current coupling). It therefore manages the transmission and the reception of the information relevant to each subscriber.

The items of equipment connected to the ARINC 629 bus are :

- the smart actuators and sensors,
- specific equipment,
- cabinets.

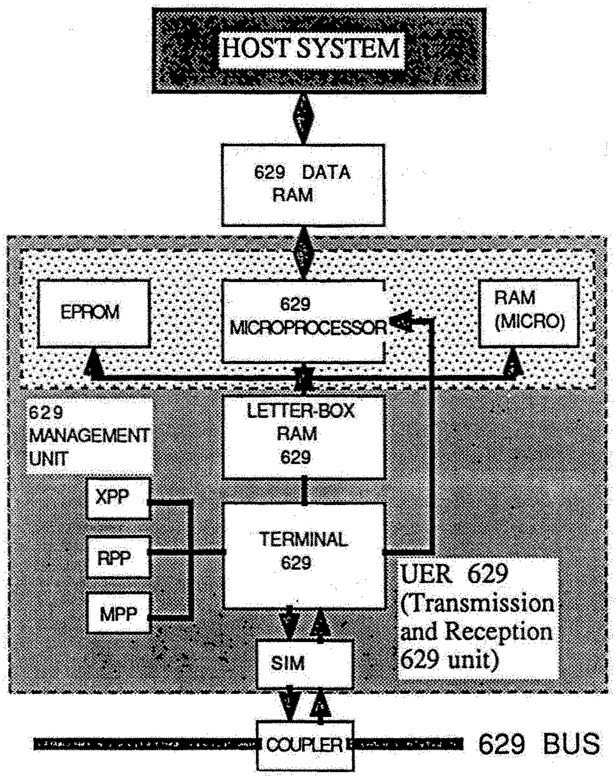

Figure 3 - 629 INTERFACE ARCHITECTURE

629 interface is dedicated to all Input/Ouput operations between Host System and the other systems via the 629 ARINC bus.

It is composed of two parts :

- A 629 "Terminal" Unit, supporting the OSI Model "Physical" layer, "MAC" Sublayer (Medium Access Control) and a part of the "LLC" (Logical Link Control: Frames assembling) sublayer.

  The "TERMINAL" is an Specific Integrated Circuit, performing and directing all of the above operations.

  XPP, RPP, MPP are EEPROMs allowing the Terminal configuration (Transmitted and Received labels,...).

  The SIM (Serial Interface Module) is a modulator (transforming Manchester Encoding to Doublets Encoding and vice versa).

  The letter Box RAM is the Memory Interface to the 629 Management Unit.

- A 629 Management Unit, supporting OSI layers 2 to 4 (Datalink (LLC) to Transport). It is essentially composed by a microprocessor and its environment.

<u>2.3.1.2 . Safety-Reliability aspect of the 629</u>

The requirements given for the various avionic functions are naturally passed on to the 629 interface.

These requirements concern :

a) fault detection

b) loss of 629 interface - loss of 629 bus.

On the basis of an architecture of the type mentioned above, with three current coupled 629 buses, we obtain stringent requirements for the 629 interface :

a) The most stringent requirement for this interface is the high degree of error detection that it must provide. We have previously seen that certain critical functions must have a reliability of 10^{-9} (for example, sending of AP orders must have a reliability (non-detected errors) of 10^{-9}/h).

This implies the implementation of a certain number of checks in the 629 interface :

- error detector codes for memory transferts (RAMs, customization memories, etc...),

- Control/Monitoring type structure: the 629 terminal, for example, integrates a high number of monitoring functions (in particular, on transmission, the data is looped to the acceptance channel for optimum control).

b) The "loss of bus" or "loss of 629 interface" aspect is also to be taken into account.

The loss of a 629 bus may occur following, for example, break of a cable or line misadaptation ; but can also be caused by permanent contamination of the bus by one of the connected interfaces (babbling).

The probability of such contamination must be reduced. Here, the tolerances are governed by the architecture selected and the requirements of the critical functions (as loss of a function may be caused by loss of its connections with the exterior, in this case, the 629). The use of redundant buses enables a reduction in the requirements relevant to the 629 interface "loss" aspect.

The safety-reliability objectives for the 629 channel are, therefore, taken into account in the specifications, then in the design of the 629 interface. On this subject, Aerospatiale are collaborating with Sextant avionique to develop a 629 terminal (ASIC) integrating the Combined Protocol.

Also, Aerospatiale are studying, in collaboration with CERT, a 96-subscriber optical network which can take the 629 access protocol (CP).

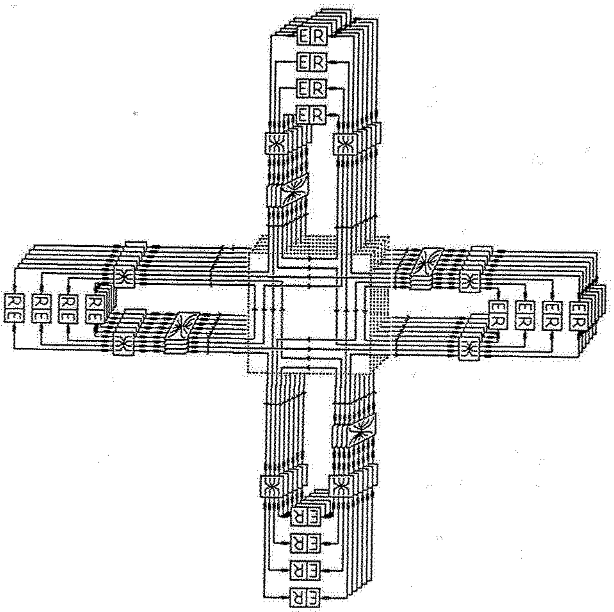

Figure 4

Architecture for a typical 96-terminal network (4 branches and 6 layers).

R = reception channel, T = transmission channel

Each network enables the interconnection of up 96 units : Each unit includes a transmission channel and a reception channel (on transmission, the transmission channel is looped to the reception channel).

The two types of couplers (couplers 4*4 and 6*6) enable, when a terminal transmits on a fibre, distribution of the signal to all other terminals.

The 629 CP can, therefore, be implanted on this type of network.

The architecture of this network also offers high performances which allow, unlike the other optical networks proposed, a high number of subscribers. It facilitates the implementation of a fault-tolerant avionics architecture (reconfigurations easily achievable in case of failure).

2.3.2 . Backplane bus

The backplane bus enables communications between the modules on a given cabinet. The need is new as the current computers are equipped, for inter-card dialogue, with micro-extension buses where the processing card is the master.

With an IMA, we can have up to 32 subscribers on the bus.

Several modules can request control of the bus :

- the core modules, if there are several,

- the Input/Output modules with minimum intelligence to preprocess the data.

The applications integrated into a given core module use the bus in the following cases :

- dialogue with the inter-cabinet ARINC 629 bus,

- dialogue with the I/O modules for reception or transmission of data related to the application.

Dialogue with analog or discrete data (feedback loops, real-time information) require a more frequent refresh rate than exchanges on the ARINC 629 bus in order to make the data route delays negligible when compared with the processing cycles. All acquisitions and transmissions are performed totally asynchronously with respect to the application sequencing. The bus must permit transmission of periodic data, for most exchanges and aperiodic data, for file transfer or messages. The throughput required is estimated at one 16-bit megaword per second.

Data integrity must be observed with a high transmission error detection level.

The PI bus, at present under study, meets these requirements. The specification is validated and, today, prototype components are available on the market.

Its capacity is 12.5 16-bit megawords per second. It is of the parallel, multimaster type with detection (2 bits) and error correction (1 bit) possibilities. Its limitations lie in the fact that maximum utilization length is 60 cm but especially in the fact that it requires 72 connection pins which is penalizing for cabinet reliability.

A serial optical bus is also being studied on a longer term basis. The expected advantages are a throughput of 200 megabits per second and immunity to electromagnetic interference.

2.4 . Basic software

One of the basic principles of the IMA concept is the sharing of a given processing resource by several aircraft functions. Therefore, several application software packages, possibly produced by different equipment manufacturers, must be integrated and executed on a given microprocessor.

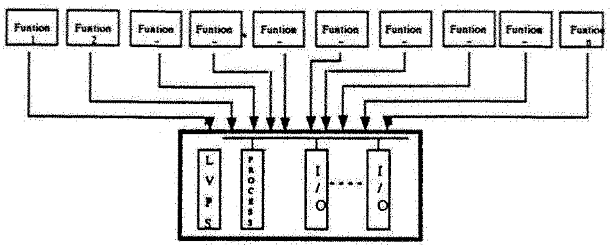

Figure 6

The basic software offering the interfaces and services required for these application software packages must be standardized for the following reasons :

- In the IMA concept, we want that the different applications are completely independent of the hardware components (core module, micro-computer, links of communication) in order to be integrated on any cabinet.

- We want also that the applications are independent of their development environment (compiler and associated tools).

The executive environment software must provide a standard interface for :

- communication between applications,

- access to the I/O resources,

- access to the Runtime environment.

Only the implementation of the executive software will be dependent of the architecture of cabinet.

Two kinds of needs are defined :

The first is that the executive software must include interfaces with its environment. The different types of interfaces are following :

- an interface to access to the hardware resources,

- an interface to communicate with any application,

- an interface with the host computer for the software loading,

- an interface with the host computer for the debugging system.

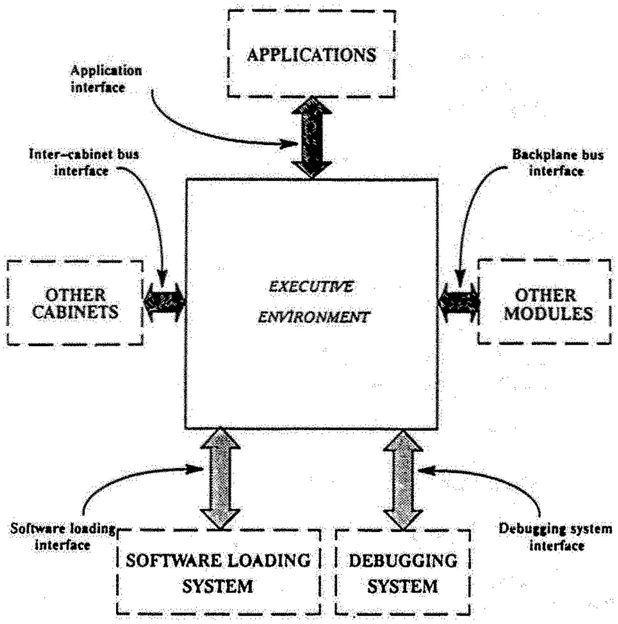

Figure 7

The second is that it must provide a set of functions as following :

• the management of the applications execution,

• the maintainability of the cabinet,

• the initialisation of the cabinet,

• the management of the fault.

Moreover, ADA language is strongly recommended for the IMA application software implementation. As a matter of fact, firstly, the ADA language has been developped, which takes all the aspects of the software into account and authorizes, for example, the access to low level resources (such as interrupt, bits), while remaining a high level programming language with all the positive aspects that this implies (modularity, abstraction,...). There is no doubt that in a few years, ADA will become the common standardized programming language for avionics embedded equipment, because it brings better productivity, code quality and maintainability. It will therefore cut down avionics software life cycle cost.

The evolution towards ADA is already underway with the ARINC document ; "ARINC 613 guidance for using the ADA programming language for avionic systems" and with a few equipment for the Airbus A340 which will use ADA.

2.5 . Airplane configuration

2.5.1 . Requirements

The software related to a function is not frozen. New versions developed by the equipment manufacturers must be easy to install on the aircraft.

At present, the software is stored :

- in PROM for the software programs which change little,

- in memory modules which plug into the units.

The use of a PROM requires, on each change of version, removal and opening of the unit in order to replace the modified PROMs.

Memory modules enable new versions to be installed without the need to open the units. However, the unit concerned by the modifications must be located in the avionics compartment.

This configuration management principle appears unsuitable for the IMA concept where :

- an application is split over several modules and a module can support several applications,

- certain tables, permitting dialogue between applications or used for the management of data at input/output module level, are shared by several applications,

- the hardware is standardized.

In particular, the IMA concept aims in standardizing the cabinet modules. The software packages are thus independent from the hardware with the application code and all the parameter tables required for their operation (I/O, executive, etc...).

2.5.2 . Uploading

Uploading offers the flexibility required for module configuration. It is used to :

- initialize all cabinets when aircraft is first set into service,

- reupload certain modules after removal,

- reconfigure the aircraft following changes in application software. Only a few modules are uploaded.

Uploading must not have any effect on the application software.

There are two stages in the uploading operation :

a) The generation of the data to be uploaded

This data concerns :

- the application software,

- the data (tables or codes) required for these applications,

- parameterizing fo standard I/O modules.

In addition to the data to be remote loaded, the configuration contains information which allows the hardware architecture to which this software configuration is adapted to be identified (type and position of the module).

- The position of each module

b) Module parameterizing on the basis of this data, (their transfer requires a safe protocol and strict checks). This is the downloading operation itself.

All this data is generated by a ground tool i.e. the configuration generation system. The code which is generated is stored on a simple support : an optical disk.

The software volume to be uploaded is estimated to be 5 Mega bytes per cabinet for 10 cabinets in the aircraft, i.e.: a total volume of 50 Mega bytes.

Uploading uses the aircraft communication network. It is connected to the ARINC 629 bus to allow direct access to the cabinets.

It uses the backplane bus to communicate with the Modules.

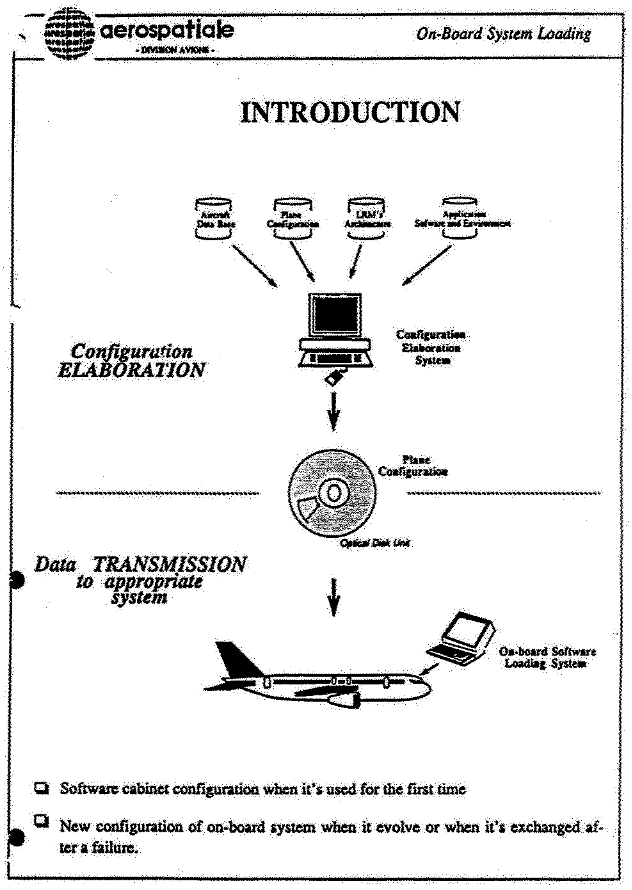

Figure 8

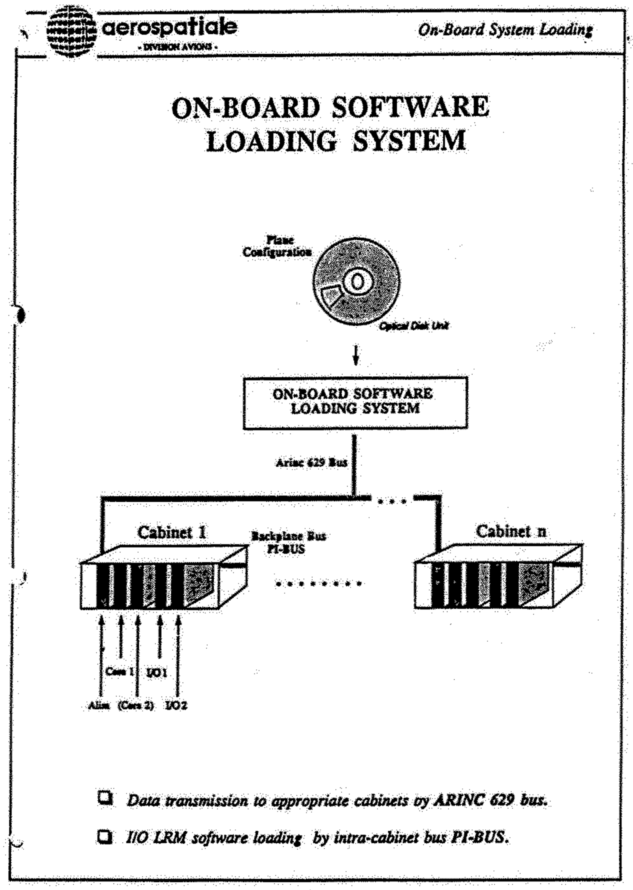

Figure 9

2.6. Next studies

The use of integrated modular avionics on future aircraft implies prior analysis, assessment and validation of a high number of elements entering into this concept.

The next studies can be classed into three main categories :

- system aspects,
- hardware aspects,
- software aspects.

2.6.1. System aspects

The following are taken into account in the new architecture studies :

- operational requirements,
- possession costs,
- system requirements, in particular, the maintainability, testability, reliability, safety and availability requirements.

An analysis and a definition of the system functional architecture will be made from the previous work, the objective being to define the requirements relevant to the exchanges between the various system functions, the availability of these functions and the associated architecture.

The technical solutions will be recorded then followed by an analysis and choice recommendations to meet the requirements defined above in relation to the following fields :

- processing unit,
- power supply,
- system bus,
- backplane bus.

Among these technical solutions, fault-tolerance will be studied with its various applications levels : cabinets, modules for electronic bays, and in parallel with it for sensors.

2.6.2 . Hardware aspects

2.6.2.1 . Core module (processing unit)

The general system architecture studies described in 2.6.1 will enable us to obtain the core module characteristics relevant to :

- performance/calculation capacity,
- memory capacity,
- internal architecture (task sharing between the module CPU and the input/output-dedicated microcontrollers).

The following will be studied within this framework :

- several types of processors (CISC, RISC or transputers),
- several architectures : in particular a fault-tolerant architecture.

2.6.2.2 . Power supplies

Modular avionics requires the definition and standardization of the cabinet backplane supply voltage distribution. Studies will be made to select the best breakdown for the various conversion and filtering stages requiring this power supply.

2.6.2.3 . Other modules

To reap the best benefits from modular avionics the constituent modules must be as generic as possible to obtain a number of resources common to all functions.

However, in certain cases, specific modules must be studied for special signal processing operations (for example radio-navigation modules) or to generate messages with specific structures, such as image generators for CRTs.

2.6.2.4 . System bus

The 629 bus has been retained by the ARINC committee to replace the 429 bus on the new generation aircraft (> 1995). Assessment benches for this new type of bus must be installed together with the software tools to acquire, as rapidly as possible, know-how on the use of this bus.

2.6.2.5 . Backplane bus

In the new integrated modular avionics, there are specific requirements for a backplane bus, these are :

- high throughput bit rate for reducing the staleness of data exchanged between applications,
- fault containment, high reliability and supporting fault-tolerant architectures,
- multimaster capability for supporting modularity and flexibility.

2.6.2.6 . Optronics

New fiber optic architectures and components will be reviewed, designed and assessed to permit reliable transmissions (EMI protection) at data rates significantly higher than in present aircraft in order to cover future requirements with expansion potential.

Application of these new technologies could also be applicable to inter-equipment data links and the backplane bus inside the new avionics cabinet.

2.6.3 . Software aspects

In the software field, the new studies will carry on from the studies already in progress for the national and European markets. They concern :

- basic executive software specifications and associated services adapted to suit the various types of envisioned hardware targets with standardization of the interface with the application software written in ADA,
- definition of the architecture software modules enabling portability and reuse.

3 . Conclusion

The new concept which has been presented is aimed at reduction of the total cost of ownership of avionics.

The benefits for the airframe manufacturer will be :

- reduced development cost,
- reduced wiring,
- more flexible architecture,
- ability to add or modify system functions through onboard software loading.

The benefit for the airline will be operating cost reduction through better maintenability.

First benefit will be the reduction of different spare part to be stored in each shop. The fault tolerance concept which is studied may also provide the possibility to replace the "on condition" maintenance actions by scheduled maintenace.

In addition to these benefits, an important effort is also made to improve the high cost induced by the numerous injustified removals of avionics equipment. To achieve this objective, in addition to the study of the new concept and fault tolerance mecanism, the following points are also considered.

- EMC improvement

- power supply with reduction of transients
- improved monitoring (BITE effectiveness)
- dynamic behaviour assessment
- asynchronism control
- connector minimization
- thermal aspects

and, of course, adequate software engineering and assurance quality control.