Abstract
Since twenty years the rapid increase of micro electronics performance according to Moore’s Law pushed the respective customer demand for more and smarter functionality on modern Aircraft (A/C) systems. In order to keep the volume, weight, power consumption and cost of avionic within reasonable limits the classical concept: one function = one avionic controller can finally not be maintained. Concepts are due to get multiple software (SW) functions of different origin and criticality level to be integrated on single avionic controller devices. This is the step to “Integrated Modular Avionics (IMA)”. The first IMA solution was introduced 1995 on the Boeing 777. It was the “A/C Information Management System (AIMS)” from Honeywell, a backplane based modularized “cabinet”. The AIMS Cabinet integrated several flight guidance, data recording and maintenance applications. After several years of in service experience the new avionic concept proved to be at least one order of magnitude more reliable than conventional embedded controllers. Today the IMA cabinet technology is state of the art on different A/C programs.

In Europe Airbus together with THALES-DIEHL took a further step in the development of an Open IMA technology standard on the A380 program. The features of “open” IMA go beyond the initial approach of AIMS by Honeywell in terms of applying open avionic and commercial communication standards as well as sharing knowledge between the IMA platform provider and the airframer on the technical features of the standardized computing resources.

In order to achieve this, the proprietary cabinet solutions were abandoned and substituted by general purpose ARINC 600 Standard avionic controllers, labeled CPIOM (Core Processing & IO Module), which are applied to both cockpit and utility functions, i.e. quite across all A/C system domains. Further, an “A/C Full DupleX (AFDX)” switched Ethernet communication network was provided which connects all controller devices of the A/C. Ethernet switches and CPIOM are designed according to the common aeronautic ARINC 600 standards and thus, are open to all potential avionic manufacturers. Additionally Airbus and THALES-DIEHL developed the necessary processes, methods and tools that support the new Open IMA technology.

The presentation will give a survey on the state of the art of the A380 IMA concept in terms of technical aspects and with a strong focus on the methodical features of this technology (configuration, incremental qualification, tools, industrial roles & responsibilities, liabilities etc.). Finally – derived from the Lessons learnt – a roadmap towards further needs and targets and the respective technology will be given.
1 INTRODUCTION

A strong pull for more and more computer centred information processing on board aircraft is driven by high demands on safety, dependability, and handling quality subject to stringent economic constraints. For this reason we find Moore’s Law (i.e. the doubling of micro electronic performance every 18\textsuperscript{th} months) quite exactly ruling on avionic system design since more than 35 years. The exponential increase of the performance does not only apply to memory capacity, which host the application software (SW) code and the respective processing power for getting it executed. The demand for more data communication especially drives the number of signal interfaces between the systems into quantities which were beyond imagination some years ago. Thus, complexity becomes the issue (Fig. 1).

Up to the 90ies avionic system design followed the “federated architecture” principle: “one function - one computer”. This approach finally met its natural limit when the weight and volume of the “black boxes” hit the envelope restrictions of the aircraft. And, another burden became obvious: the huge number of different “black boxes” charged the balances of the airlines with significant maintenance costs for world wide computer spare provisioning and handling. In order to shrink volume, weight and costs the aerospace industry developed concepts to integrate multiple SW functions of different origin and criticality level on single computing devices. This indeed showed the desired effect on weight and volume reduction however, not on the expenses. The high level of function integration forced fault propagation and in-transparent functional interference, which turned the reliability of the “black boxes” down and created severe industrial liability issues. Troubleshooting and modifications became significant cost drivers.

Multiple function integration on one computer requires specific provisions on the operating system. Middleware has to be implemented that keep the different SW functions virtually apart, separate it from the HW and provide services for more sophisticated built in fault diagnostic. However, these provisions are quite expensive

Figure 1 – Installed function SW and signal interfaces on board commercial A/C
to develop. For the amortization of these “extra cost for integration” standardization is mandatory. Controller HW and SW are designed as multipurpose devices in order to get them spread over many A/C system function domains and A/C programs.

The first step into this direction was taken by Honeywell, 1995 with the concept of Integrated Modular Avionic (IMA), Fig. 2. It featured the decomposition of the avionic devices into its basic functional elements: Processing, I/O, Power Supply and Gateway. These functions were allocated to distinct modules (CPM = core processing module, IOM = I/O module, PSM = power supply module, GWM = gateway module). Physically the modules were assembled within a cabinet frame. The communication between the modules provided a highly failure tolerant time triggered back plane bus (SAFE BUS™). The back plane bus protocol and the module operating system middleware provided certified services for strong SW/SW partitioning, HW/SW segregation, and failure monitoring. This IMA controller concept first was applied on the Boeing 777 aircraft for cockpit functions (AIMS = Aircraft Information Management System). It turned out to achieve reliability figures and “No Fault Found (NFF)” rates that were up to one order of magnitude higher than comparable devices the aeronautical industry used before.

Airbus, in parallel took the same approach in order to prepare the avionic design of the A380 but went further on three properties:

1. Airbus abandoned the proprietary cabinet and module standard of Honeywell and selected the open ARINC 600 norm for the avionic modules.
2. The back plane bus was replaced by a 100Mbit Full DupleX (AFDX) switched Ethernet network according to the commercial open standard to which all types of avionic devices can be attached to, and
3. The IMA modules were applied to all types of aircraft functions i.e. cockpit and utility systems.

According to these principles Airbus labelled its concept the “Open IMA” (Fig. 3). One main consequence of the Airbus approach is that the modules and the communication devices might be procured from third party avionic suppliers according to the specification owned by Airbus. The aim is to develop a market for the open IMA standard in order to control the costs by competition.

Figure 3 – The “Open IMA” network on the A380

2 THE IMA DEVELOPMENT PROCESSES, METHODS AND TOOLS

The goal is to get the majority of the aircraft system functions operated on standardized IMA controllers being linked to the Aircraft Data Communication Network (ADCN) based on the Aeronautical Full DupleX (100Mbit AFDX) switched Ethernet technology. For this purpose Airbus has to modify the conventional development processes, methods and responsibilities. The IMA / system development and integration procedure is split between
In a first step Airbus specifies the basic features of the IMA modules according to the IMA ARINC standards 600, 615 and 653. This covers the module packaging, the API services, the monitoring, data loading etc. Then Airbus collects and merges the specific requirements of the different system functions, which shall be processed by IMA modules. This concerns special signal types, processing cycles, memory use, EMC, etc. to be added to the basic module specification. Based on this specification the avionic module manufacturer develops the respective standardized multi purpose IMA modules (CPIOM = Core Processing & I/O Module). In parallel system specifications are issued to the system manufacturers who are obliged to use those standard CPIOM controllers within their system design.

This requires that the system suppliers have to be provided with a very detailed description of the CPIOM. This is the “Module User Guide”, a manual, which precisely explains the CPIOM design features and how it must be operated.
Additional refinement iterations are executed between the system suppliers and the module manufacturer in the frame of “requirement capturing workshops” under the governance of Airbus in order to complete the module design and to promote a mutual understanding (Fig. 4 top).

When the system suppliers start the function development a complete tool chain is delivered to them, which supports their development process. The tool chain provides SW configuration tools, SW linkers and loaders and module emulation devices. These tools enable the system manufacturers to debug and verify the SW of their functions in the very early stage of the development cycle even if the physical CPIOMs are not yet available (desktop validation). The efficiency of this approach can be quantified from the fact that on the A380 the system function qualification on IMA modules was achieved up to one year earlier than with conventional controller design.

When the IMA modules are ready Airbus provides the necessary quantity of them to each system manufacturer who run their application on a CPIOM. On site the different system suppliers perform their local single function integration and system qualification. The modules are pre-configured by Airbus according to the final integration condition on the aircraft when several functions from different system suppliers will have to be processed on the module. This is the process of “**incremental qualification**” which means that each system manufacturer only gets its own function integrated to the module without being obliged to consider the presence of any function from other system vendors, which will be integrated to the same module afterwards (Fig. 4 center). The **incremental qualification** approach is supported by the strong partitioning property of the IMA modules. The validity of this property has to be verified and demonstrated by the CPIOM manufacturer according to the Airbus CPIOM specification. Because of the novelty of the technology Airbus double checks the partitioning features again after Module delivery. For this purpose a specific test suite is applied to the modules, which proves that the different SW partitions on a CPIOM cannot interfere under any condition. The tests must comply with the demands of the aircraft certification process. The verification of the partitioning mechanisms is worth the effort because it enables Airbus to integrate the module with several pre-qualified functions from different system suppliers on the aircraft without the obligation to re-qualify the system functions after final integration – the functions will not interfere.

The open IMA concept puts Airbus into the position of the IMA system integrator. The development responsibility for the single systems and their functions remains at the system manufacturers. The avionic module supplier provides Airbus with “empty” IMA modules. Airbus, in turn, integrates those empty CPIOM with the AFDX-Ethernet-ADCN on the aircraft in order to establish the basic computing resource for different system functions (**Fig. 4 bottom**).

Before the system functions can be processed on the IMA Network Airbus has to generate appropriate configuration files for the ADCN communication and for the CPIOM operation.

The ADCN configuration mainly concerns the address tables of the Ethernet switches, the data frame size, its transmission rate and the required bandwidth of the Virtual Links (VL). The VL feature communication lines which the signals take along the network. They can be considered as virtual wires, which transmit data according the ARINC429 standard protocol across the AFDX switches and cables. Adding new or changing subscribers to the ADCN only means to establish a new VL between the
transmitting and the receiving device. This makes the configuration and the modification of the avionic architecture quite flexible.

The configuration of the CPIOM concerns the allocation of memory space, signal ports and processing cycle times to the different application SW partitions. The configuration data is laid down in configuration table files, which are loaded on the CPIOM in order to get the operating system perform as required by the different SW applications, which run on the module.

After completion of the local system function qualification the system suppliers provide their respective application SW partitions to Airbus. Airbus assorts and collates these files according to the individual IMA system configuration, which depends on the actual serial production number (MSN) of the aircraft and adds the respective configuration tables. Application SW partitions plus configuration table files make up the final SW load that is delivered to the final assembly line where it is loaded up to the empty CPIOMs on the aircraft under production. As an interface between Airbus IMA SW integration facility and the final assembly line - for the hand over of the “final SW loads” - a protected database – the “SW Ground Repository, SGR” is installed (Fig. 4 bottom).

Application SW and configuration files always constitute a tight entity, which must not be confused or mistaken for safety reasons. This is why the application SW loads and the respective configuration files are processed through a validated tool chain that automatically performs the version management based upon qualified Product Data Management (PDM) tools (Fig. 5).

Figure 5 – IMA development tool chain

3 PRESENT STATUS OF IMA DEVELOPMENT

Not long ago the A380 after having passed all her Flight Tests gained the Type Certificate (TC) from EASA and FAA. She is now ready to enter service soon. The
TC includes the approval that the new IMA technology and the equivalently new processes and means being applied to show compliance with the safety objectives have been considered valid by the authorities. In detail this applies to the following items:

1. the CPIOM basic features for incremental function integration like strong partitioning, fault monitoring, HW/SW segregation etc.,
2. the configuration tables for the ADCN and CPIOM,
3. the respective system validation and verification at the system supplier’s facilities,
4. the compilation of the different application SW partitions and the respective configuration tables for the final CPIOM SW load. The validity of the final SW load and the respective configuration table for each individual fully integrated CPIOM has been approved in the frame of distinct IMA bench tests for the “bare” module, the “configured” module and the “integrated” module,
5. the transmission of the final CPIOM SW load to the final assembly line through the SGR,
6. the on board SW loading of the empty CPIOM,
7. the correct operation and configuration of the fully integrated IMA /AFDX network in context with the connected aircraft systems in the frame of ground tests and a more than one year flight test campaign which successfully accomplished the IMA verification and validation process.

By passing the a. m. steps the AFDX and IMA avionic network was experienced as a very mature system that needed only minor modifications and ran stable virtually from the first day when operated on the aircraft. Constantly remaining in the table of the 10 most fault free systems indicates the quality of the IMA components, the underlying topology and of the respective development tools and processes.

4 LESSONS LEARNT

The handling of the IMA devices, the understanding of their technical features and behavior, the management of the new three lateral IMA industrial processes (the “IMA-Triangle”) and interfaces had successfully performed within a worldwide network of distributed stakeholders. Considering the ratio of local and remote assistance Airbus had to provide to the respective stakeholders we can conclude that the manuals and tools, which support the development are already in a quite satisfying condition so that fairly remote development processes of the “IMA-Triangle” were feasible. Due to the stringent guiding of the IMA development plan and the early availability of network and module emulators the system function integration to the IMA CPIOM was achieved between six to twelve months earlier than on classical controller devices.

The Virtual Link (VL) concept of the ADCN turned out to be a very flexible means for the handling of modification and extension of communication requests. Whereas in the past new wires had to be physically installed on the aircraft the activity is now reduced to the definition of a new VL, which simply means to enter a new address and some data frame transmission parameters to the configuration table of the network.

IMA modules were equipped with in depth fault monitoring, instrumentation services and Built In Test (BIT) facilities at a very early stage of function integration.
These provisions could be used for debugging and trouble shooting at system and aircraft integration, which saves time and cost for additional test installation.

In order to fit the IMA CPIOM to the collective function requirements of the users (i.e. the system manufacturers) background knowledge has to be exchanged between the system vendors and the IMA supplier. For this purpose Airbus has organized “requirement capturing workshops” which proved to be an efficient means for getting a comprehensive view on the necessary provisions that have to be implemented on the IMA devices in order to meet the functional application demands of the users.

Expecting ambiguous failure cases, and as an instrument to handle the successive “finger-pointing” situations, Airbus has established an arbitration board, which constitutes system-, avionic- and aircraft experts who investigate the situation in order to find the root cause and to agree on a reasonable and economic solution. It can be stated, that up to now no such “ambiguous” failure case had been experienced that might have justified the activation of the arbitration board.

At the present instant Airbus does not experience any issues with the split liabilities of the IMA process where the responsibility for the proper operation of the system function is shared between the system manufacturer, the avionic CPIOM provider and the IMA network integrator. The present Airbus contracts, which concern the “IMA-Triangle”, provide the clauses, which cover the liability subject. However, only in service experience will bring the evidence that the provisions taken so far are adequate. Revision of the contracts concerning legal issues will be one major task of the IMA arbitration board.

5 NEXT STEPS

There are some items, which need further development:

The allocation of the various system functions and SW partitions to the different CPIOM within the ADCN is still a manual process at design time. With increase of the IMA integration level on future A/C programs, the IMA development tool chain needs completion at the front end by a provision that supports the allocation of SW functions and communication needs to the available IMA / ADCN resources in order to automatically satisfy all relevant performance indices for cost, safety, availability etc. subject to pre-defined optimization criteria. Airbus presently is going to develop such facility.

The quality of the results when using such IMA configuration optimizer significantly depends on the flexibility of the IMA modules. Therefore it is reasonable to remove the analog signal interfaces from the CPIOM and make it a pure digital CPM in order to get it independent from its location within the ADCN. The analog signals can be shifted to smart units, Remote Data Concentrators (RDC) or Remote Electronic Units (REU), linked by serial data buses and Gateway Modules to the ADCN. Power distribution boxes (PDB) or solid state power contactors (SSPC) within the central electric power system may serve as the respective switching devices. This step definitely will impact the overall system architecture on aircraft level as can be seen from comparison of Fig. 6 and 7. This obviously indicates how the IMA approach drives the system design and function breakdown all across the aircraft. The IMA network optimizer therefore has to cover or at least support those indirect effects on the overall system architecture on aircraft level as well.
**Figure 6** – Present embedded system architecture based on CPIOM solution

**Figure 7** – Example for a “more federated” IMA architecture

When in the frame of the iterative function allocation process the IMA network and the aircraft systems shall be handled as an entity this task will be facilitated if IMA
items like API middleware, monitoring functions or data bus standards may be used within proprietary system computers and smart electronic devices as well. Therefore one future topic will be to check the portability of IMA SW, HW and middleware standards and their application within the frame of proprietary system controller devices.

Parallel to the aeronautic IMA development other fields of embedded system application like tele-communication or automotive industry have developed some own products, which partly have already achieved the state of extended commercial of the shelf (COTS) standards. Especially the open COTS operating systems from Wind River Systems, Green Hills Software, OSE, and Lynux Works have gained a considerable maturity status that makes them interesting for the application on highly dependable and safety critical computing devices. The same applies for Middleware in the field of system and component failure diagnostic where especially the automotive industry follows and promising trail from a tooling and commercial point of view. Another item, which attracts the attention of the aeronautic IMA community concerns the highly dependable data bus protocol products like TTP or FlexRay which find quite broad resonance in different fields of application. The wide spread industrial acceptance of the a. m. COTS standards will lead to stable and mature products with a well balanced price/performance ratio. The basic idea of the “Open IMA” concept relies on the broad application of COTS products to which the stakeholders of the IMA technology have free access. On the other hand it is obvious that big COTS standards are much less under the rule of an Aircraft manufacturer than own or aeronautical specifications. Therefore Airbus has to consider how COTS standard products, which we cannot drive directly will impact the life cycle of the aircraft systems. In this context a reasonable approach may be to consider common interests and procedures between the telecom, the automotive and the aeronautic industry in order to gain more dominance on the specification of big standards and profit from common experience and strategies.

6 CONCLUSION

It was shown how the avionic architectures and devices developed from purely proprietary products to a highly integrated, modularized general purpose avionic network based on open standards. The reasons, which impelled the IMA technology, were explained and the necessary features and provisions of an IMA network were detailed. It was shown how the IMA solution affects the industrial processes and the way in which they were implemented on the A380. The present state of the art of the IMA solution and its respective processes, means and tools were outlined. From a comparison of the achievements and lessons learnt versus the future targets of the IMA approach a reasonable road map of the future steps in order to exploit the inherent potential of the IMA solution on future aircraft programs were derived. Finally it is worth stating that presently Airbus stays ahead worldwide with its capability to manage the tri-angular IMA development and integration process (avionic manufacturer – airframer – system supplier) within an industrial environment on aircraft program level.