KEY ENABLERS FOR POWER OPTIMIZED AIRCRAFT

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1 ABSTRACT

The purpose of this paper is to show what aspects should be jointly addressed and optimized in order to reach the very stringent requirements driving the power-optimized aircraft within its systems area.

This article describes the current 'more electrical aircraft' status, the need for a new approach highlighting three major aspects, and initial method implementation and results.

2 CONTEXT

Civilian aeronautics industry is facing a very stringent challenge in order to reach the Air Transport environmental footprint requirement that was set for the 2020 horizon.

As an example the ACARE *(Advisory Council for Aeronautics Research in Europe)* objectives are a 50% CO_2 and a 80% NOx emissions reduction for that above-mentioned time horizon.

All aircraft aspects are therefore impacted by such a green revolution, from aerodynamics to propulsion, encompassing avionics aspects (optimized trajectories) as well as aircraft systems among which power systems have a potential significant direct or indirect impact on the global result. In fact, considering the overall challenge at aircraft level, all directions have to be explored and worked out.

After a quick overview of current 'more electrical aircraft' research results, we will propose another global approach and examine what type of benefits could be induced.

3 THE MORE ELECTRICAL AIRCRAFT ISSUE

In order to satisfy such stringent environmental requirements within the A/C power systems area, the more electrical A/C global research and industrial effort has followed initially a stovepipe approach, in electrifying existing pneumatic or hydraulic power functions or equipment.

Today the current statement of such approach is that results are, at best, marginal with regards to the main aircraft driving parameters i.e. mass and fuel burnt, although depending of the aircraft global size (mass, range, etc...)

As an example, one can refer to MOET *(More Open Electrical Technologies)* study, where comparing, at aircraft level, optimized legacy power systems (electrical, pneumatic and. hydraulic power) versus a more electrical power systems architecture for a single aisle commercial transport aircraft, leads to unsatisfactory results.

This "electrifying existing pneumatic or hydraulic power systems" approach, where the driving direction is technology breakthrough and local optimization, shows its limits.

Historical industrial context matching with the legacy aircraft systems architecture and ATA structure creates a stovepipe global approach with few ‘trans’ systems or ‘trans’ ATA vision.

4 THE POWER OPTIMIZED AIRCRAFT APPROACH

4.1 WHAT IS AT STAKE ?

Ever since aircrafts flew, optimization started : First, aircraft characteristics directly linked to primary flight performances (Mass, Drag, Lift, Handling Qualities) were improved ; then economical performance was introduced (Operating Costs) in the “local” design compromises; Nowadays, environmental issues, as well as more efficient (technical and economical) flying vehicles demand, lead to introduce new ways of addressing the challenge.

Further improvement is required from “more electrical aircraft” towards “power optimized A/C” approach, in order to demonstrate that power nature evolution is definitely promising yet requires in depth system and technology approach to demonstrate a competitive position as compared to improved legacy solutions.

The power optimized A/C approach needs to address simultaneously 3 aspects, that jointly allow to perform, among others, a leverage onto the systems non functional performances (mass, reliability, safety...) and ease the ability to ‘escape’ from legacy architecture solutions:

- Architecture
- Technology
- Engineering Tools

The approach is then consolidated through the use of physical mock-ups, both at technology and system levels (This experimental phase is out of the scope this paper).

4.2 ARCHITECTURE

Architecture is a key to bring a new vision in a domain that has been a long term step by step local optimization approach within stove pipe, ‘rigid’ functional or physical areas. Yet while opening these areas, one has to address all non functional system performances that were underlying in the legacy architecture choices (power nature segregation for safety, …); this brings an additional fold in engineering complexity.

A key architectural enabler is incremental certification capability. In fact, in the power optimized A/C, research and development will absorb significant amount of investments to explore such a breakthrough; there will be significant evolutions in the domain (much more that in the legacy very matured vision) that must not jeopardize or reset the initial developments. Architecture is the way to reach such capability to implement all necessary evolutions step after step.

Furthermore, Architecture has to address power management. A preliminary analysis shows that A/C systems can be classified in permanent and intermittent power users, therefore allowing to sequentially provide proper power to the requiring functions. Such a capability entitles to install less power generation or conversion, while keeping all airworthiness requirements. Thus, it is through Energy flows management that the architecture can bring such a mass reduction capability and aim for a better competitiveness for the airlines.

A first consequence in the electrical domain of such an approach is the share of power conversion which will drive the power flows towards different types of loads that are sequentially operated; a second consequence is the need to bring together industrial competencies that know how to process power to their own loads on this above-mentioned shared power processor.

The architecture answer to this issue is to design an Integrated Modular Power Electronics system that allows any load provider to master the overall power control function without jeopardizing its know how, while keeping its overall function responsibility: this is a similar approach as Integrated Modular Avionics. As a consequence, the power conversion system is composed of modules that are interlaced or operate in stand-alone when coupled with loads.

Last but not least, architecture has to be jointly thought along with technology it is using in order to create a mutual improvement. ‘Electrification’ only approach partly fails because architecture is not deeply addressed along with Technology.

4.3 TECHNOLOGY INCLUDING POWER PROCESSING

Power density, whatever the system, is a key driver. Power material and components such as SiC and GaN allow new power density values; integrating electrically and thermally such components in a Power Electronics board is a key know-how in order to take full advantage of such new components.

Local Power heat extractor is therefore a key technology for power electronics

Increasing power leads to voltage increase to keep manageable current level; all components involved in power distribution (including power management) are technology enablers for high power flows.

High Voltage Energy storage, both in terms of amount of stored energy and power input or output capability is a critical technology driver for safety, power transients and management.

Power control algorithms are keys for several aspects: power converter filters mass optimization, EMC standards fulfillment.

Mastering high power electronics designs for severe environmental conditions (non pressurized areas, etc…) is also a key to bring flexibility to aircraft designers when installing these new equipments in the airframe.

Reliable design in power electronics is a must to satisfy aircraft dispatch requirements to reach competitive operating costs.

4.4 ENGINEERING TOOLS AND METHODS

As seen earlier, addressing the system optimization in a wide area leads to deeply re-assess the non-functional requirements; a tooled-up approach which includes an overall ‘multi-view’ / ‘multi-dimension’ capability is an enabler for such approach.

A ‘Multi-view’ engineering tools stands on an architecture meta-model that manages attributes describing the functional and non functional characteristics of the components that constitute the studied architecture.

A given ‘point of view’ will consist in assessing an architecture with regards to criteria, therefore allow comparison between solutions.

Semantic-based approach is needed to ‘early’ investigate, with the proper level of abstraction, non-functional requirements such as safety, involving power related failure propagation algorithms.

The overall process consists in an usual functional analysis, followed by less traditional logical architecture based on components which characteristics are mastered at technology engineering level. Several ‘multi-view’ analyses are performed at logical level before projection in a physical architecture.

Logical architecture means a proper functional and non-functional abstraction at components level, taking into account only physical constraints that have an influence on functional and non-functional architecture requirements.

Functional system integration and early validation tools, as well as global assessment tools are mandatory to demonstrate architecture and technology concept maturity, and to allow comparison between potential solutions.

Within the wide new power area, generating standards (high voltage network,..) can also be considered as a way to allow proper feasible systems architecture thus allowing a flow-down allocation of system requirements to each and every sub-system.

The ‘power optimized A/C’ Systems approach is to be driven by 3 figures of merit that can be used to assess its global ‘value’ at aircraft level :

- Power Processed / Mass, which relates to efficiency and Power/thermal efficient integration
- Dispatch rate at aircraft level / Equipment Recurring Cost, which highlights both reliability and redundancy optimization
- System Reliability / Non Recurring Cost, which indicates proper reliability oriented design method

5 CURRENT RESULTS ASSOCIATED WITH THE POWER OPTIMIZED AIRCRAFT APPROACH

The overall approach was started in Thales mid-2008.

The following summarizes main results reached after this first 2 years of Research.

5.1 ARCHITECTURE

Architecture work is supported by Thales MELODY-ADVANCE Tool.

As stated earlier, initial Architecture work was dedicated to traditional external and internal functional analysis within a power global perimeter (electrical power generation, pneumatic power generation, main engines and APU start functions, electrical networks, air related functions, cooling functions - hydraulic power was excluded in these early stages of the study) , which functional details may vary depending on the functional knowledge. Successive refinements of the functional knowledge within the architecture is part of the capability offered by the tool, as long as modeling limitations are mastered inside the model.

A set of components was built in order to start the architectures implementation. Thus legacy architecture, more electrical logical architecture and power optimized logical architecture can be implemented.

At logical architecture level, first synthesis between functional and non functional requirements led to optimizing the power processing module power throughput, the number of modules required to both satisfy the safety and dispatch requirements, the power contactors requirement.

Architecture is being extended with partners in order to expand the global power perimeter knowledge and coverage that should further improve the mass and fuel savings that are expected from a ‘trans-ATA’ power optimized A/C approach. A global Power management function is also identified and designed to allow enhanced operations within the power perimeter and thus between the already mentioned power modules .

5.2 ELECTRICAL POWER PROCESSING TECHNOLOGY

As stated earlier, maturing a robust, open and efficient Power Conversion Module in order to deliver the proper power waveform to the loads is key to implement a multi-function power architecture.

The module capabilities must cover various types of motors, various AC networks.

Thales has developed an architecture module based on ‘independent’ building blocks that allow to mature, through a multi-year road map, the various technical challenges associated with the multi-function architecture:

- Module usage domain (type of motors)
- Modules interlace
- Modules reconfiguration (failure)
- Sensor and sensorless load control
- Open Control Command module to generate the power waveform for each and every module/load coupling (IMA like approach)
- Filters

Globally the module has reached a Technology Readiness Level (NASA scale) of 4.

5.3 ENGINEERING TOOLS AND METHODS

A Thales developed system engineering tool called MELODY-ADVANCE is used for the overall engineering process. This first 2 years phase was dedicated to specify and build the multi-view application layer that allow to assess the various architecture solutions.

The following highlights 2 major achievements in the development of viewpoints:

- "3D" viewpoint
- Failure propagation viewpoint

3D Viewpoint

Coupling of "2D" logical architecture (from the MELODY ADVANCE Tool) with an aircraft global 3D digital mockup (from 3DS CATIA Tool) allows to validate various architectural choices without the need to perform a formal physical projection of the logical architecture.

In fact, physical constraints that can be extracted from the 3D digital mockup help validating functional choices. For instance, the impedance of the wirings that feed the various loads will affect the performance of a passive converter. Getting an early estimated value of the cable characteristics into the 3D digital mockup will be fed into the architecture tool leading to a decision of whether a passive converter fulfills the function or if an active converter is required.

This coupling requires developing interfaces between both tools in order to allow this "3D" viewpoint.

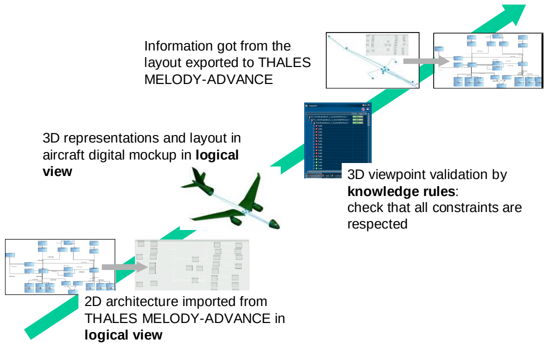


Figure 1 : Early validation of Architecture = the "3D" viewpoint approach

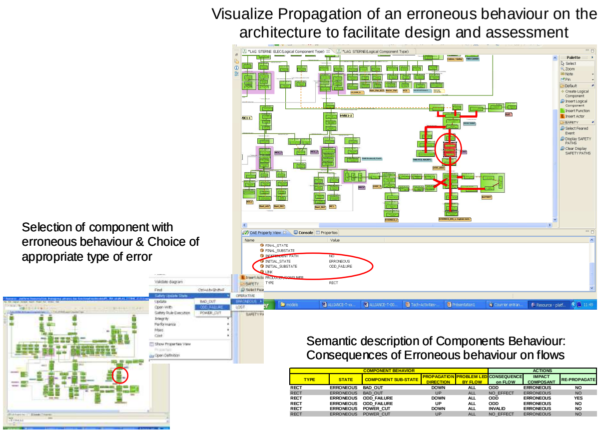
Failure Propagation Viewpoint

In order to evaluate, in a Top Down approach, the safety requirements of an architecture, a specific failure propagation was developed.

This assessment is based on semantic-based algorithms that process the operating status of each logical component (which describes the possible types of failure) to propagate any failure conditions that the system may encounter.

Safety rules extracted from certification rules are used as criteria which are considered as targets by the algorithms.

If inability to satisfy a criteria is identified, failure propagation inhibition mechanisms, including monitoring, have to be introduced in the architecture.



COMPONENT BEHAVIOR					ACTIONS		
TYPE	STATE	COMPONENT SUB-STATE	PROPAGATION DIRECTION	PROBLEM LED BY FLOW	CONSEQUENCE on FLOW	IMPACT COMPOSANT	RE-PROPAGATE
RECT	ERRONEOUS	BAD_OUT	DOWN	ALL	ODD	ERRONEOUS	NO
RECT	ERRONEOUS	BAD_OUT	UP	ALL	NO_EFFECT	ERRONEOUS	NO
RECT	ERRONEOUS	ODD_FAILURE	DOWN	ALL	ODD	ERRONEOUS	YES
RECT	ERRONEOUS	ODD_FAILURE	UP	ALL	ODD	ERRONEOUS	NO
RECT	ERRONEOUS	POWER_CUT	DOWN	ALL	INVALID	ERRONEOUS	NO
RECT	ERRONEOUS	POWER_CUT	UP	ALL	NO_EFFECT	ERRONEOUS	NO

Figure 2 : safety point of view, using semantic-based failure propagation

6 CONCLUSIONS

The “power optimized aircraft” approach started 2 years ago in Thales allowing to set up tools, architecture study and initial technology development. The method allows the identification of new architectures when looking for non ‘electrification type solutions’.

Partnership will allow in future further significant improvements, by encompassing a larger perimeter of the power system area, thus opening room for an other breakthrough, which is the power management function.

7 GLOSSARY

ACARE : Advisory Council for Aeronautics Research in Europe
IMA : Integrated Modular Avionics
IMPE : Integrated Modular Power Electronics
APU : Auxiliary Power Unit
MOET : More Open Electrical Technologies
TRL : Technology Readiness Level

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