ELECTROMECHANICAL ACTUATOR (EMA) ADVANCED TECHNOLOGIES FOR FLIGHT CONTROLS

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Abstract

In the frame of Sagem Research & Technology (R&T) programs related to new Flight Control Systems (FCS) for commercial aircrafts , an Electro Mechanical Actuator (EMA) developed and produced by Sagem (SAFRAN Group) flew for the first time in January 2011 ,as a primary flight control for an aileron application . Since then , 114 flight hours have been accumulated.

With this new type of actuator, in the scope of the preparation of future more electrical aircrafts, the use of the EMA technologies for the flight control systems is an important potential enabler. Thus, aircraft manufacturers will eventually be able to replace all or part of the hydraulic systems that activate flight controls with lighter and simpler electrical systems, offering the required reliability.
The paper deals with the development of this type of actuator from the definition up to various tests campaigns. It is focused on advanced technologies used in the Sagem's EMA that permits a highly integrated design, making it small enough to be installed in the reduced space of the wing, as well as several patented innovations. It will also offer a very long service life, to meet one of the main challenges facing tomorrow's jetliners.

"More electric" aircraft are lighter and more energy-efficient than conventional aircraft, enabling them to reduce fuel consumption and therefore the total cost of ownership as well as environmental impact.

Based on the success of these first flight hours testing, the design of a "more electric" wing should be possible in the next coming years, including EMA's for the primary and secondary actuators flight controls, in a nearly production-standard configuration. Nevertheless, Electro Hydrostatic Actuator (EHA) and Hydraulic Actuator (HA) technologies are making improvement, at the same time, and these technologies must also be considered for future programs, according to the type of aircraft to be equipped.
This paper mainly describes the two posters that are presented by Sagem during this ICAS 2012 International Congress.

1 Future goals for a more electric aircraft

The more electric aircraft will represent in the coming years major challenges for the aerospace community. Economical (mainly due to ever increasing price of fuel) and environmental (like fuel burn particles rejection or use of pollutant hydraulic fluids) such constraints impose a need for more electrification and energy optimization in the embedded systems of the aircraft. Thus as a main consequence, their complexity is growing rapidly and simultaneously.

Electrical systems, compared to equivalent hydraulic ones, show high gains in safety, reconfiguration and maintenance. Nevertheless, at present stage, they still demonstrate a bigger mass and less reliability. So, one of our main goal is to work in priority on these two key design drivers, without forgetting cost aspects.

1.1 Electrification of Embedded Systems

One of the main lever to reduce the fuel consumption at aircraft level is the efficiency increase of actuation systems .Today, they are mainly supplied through hydraulic circuits, of which pumps are driven by the engines, and also by pneumatic circuits taking the pressurised air from the engines as well. Those various circuits supply permanently some power and moreover they have quite poor efficiency ratio; this is conducting to some large energy loss.
Replacing those circuits by new electrical networks permit to increase considerably the aircraft systems efficiency, and as a consequence to diminish fuel consumption at engine level, mainly if it is possible to integrate “power on demand” strategies at electrical systems level.
On the other hand, flexibility, easy to install and possible self-monitoring of electrical systems permit to target important gains about acquisition and exploitation costs.

1.2 Electrical Systems main challenges

Electrical systems implies three main challenges :

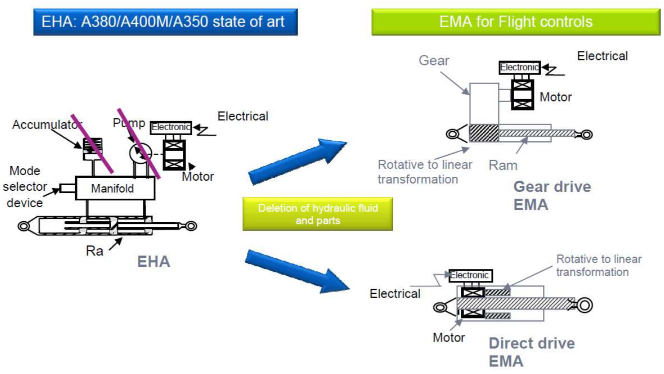
- the demonstration of their maturity and reliability in harsh environment.
- the optimization of their mass.
- their safety and types of failures, with an aim to reconfiguration enhancement.

In the frame of the more electric aircraft, and to cope with these challenges, the SAFRAN/Sagem ‘SMART WINGS’ project is intending to develop all the necessary technological bricks to achieve the next steps of electrification.
The increase of the flight controls electrification of the wings, like ailerons, spoilers, high lift and trimmable horizontal stabilisation systems, will represent an important contributor to this evolution.

2 Which flight controls technologies for future aircrafts ?

2.1 The state of the art : HA,EHA,EMA

The state of the art relatively to actuation of aircraft flight controls is mainly using Hydraulic Actuators (HA) and/or more recently using Electro-Hydrostatic Actuators (EHA) as back-up, which generates locally some hydraulic power from an electrical source. These mixed solutions can be seen on more recent aircraft generation, like A380 or G650.
The introduction of electrical actuation solution is the new tendency. In few applications, Electromechanical Actuators (EMA) have been implemented, mainly for the so-called secondary flight controls, like flaps and slats, and more recently for a spoiler surface, on the B787.
The figure hereafter summarizes future technological evolutions of the state of the art relatively to more electrical actuators.

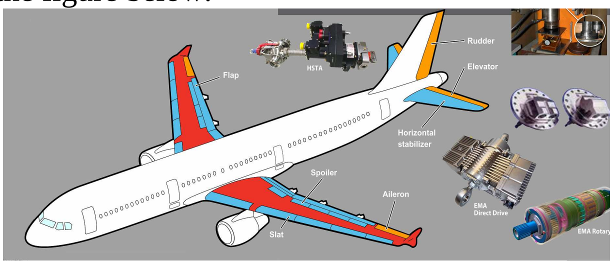


For Sagem, in order to choose adequate technologies regarding optimized wings surfaces control, we have taken the major hypothesis that all technologies will cooperate, EHA and EMA, for front line as for back-up actuation systems. Moreover some type of aircraft will still retains HA solution as the most suitable technology.

At the moment, a large part of potential solutions under development is concentrated on a ‘point to point ‘replacement of hydraulic equipments (servo-command) by electromechanical actuators. This approach doesn’t permit a real optimisation at aircraft level and the introduction of real benefits for future electrical architectures (in particular the reconfiguration and ‘power on demand’ requirements).

2.2 The SAFRAN/Sagem ‘SMART WINGS’ project

This project intends to propose an optimum solution for a complete flexible and thin wing using mainly electrical technologies, and assuming that the aircraft is still having conventional surfaces to control, as shown in the figure below.



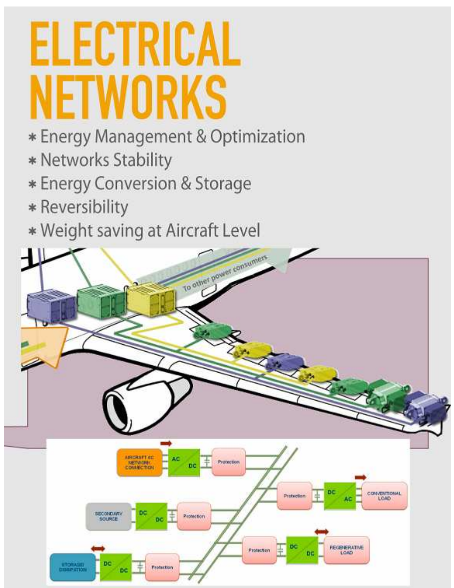
Both primary and secondary actuators are considered, as well as high lift and trimmable horizontal stabilisation systems.
One of our major goal concerns a high integration of Drive & Control electronics, whatever the type of actuator is, either EMA or EHA. Another key design driver is concerning our capability to integrate dedicated sensors and electrical motors in such actuators, with an aim to reduce mass and volume, to respect the environmental constraints of future thin and flexible wings.
Our ‘Smart Wings’ concept will cope with systems architectures, permitting to achieve safety goals and aircraft certification.
Actuation, energy distribution, complete health monitoring solutions, will permit an optimal control of such future wings that will have more and more carbon fibre elements, at structural level.
The main objectives of this program are the following :

- maintain an equivalent level of safety and performance
- diminish the total mass ,at aircraft level
- increase the availability of functionalities, even add some new ones
- simplify maintenance operations
- optimize ownership total cost

In order to achieve all these goals, federating various technologies, many challenges will have to be faced, at three levels such as, system, equipment and technology.

2.2.1 System level

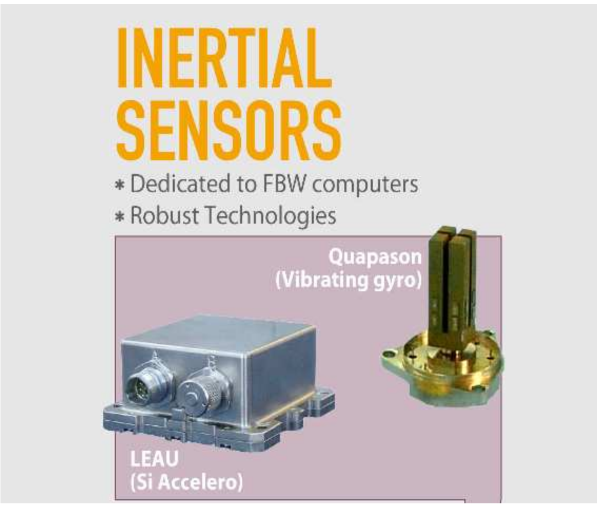
Electrical architectures, mainly electrical ones, will imply a new system approach at aircraft level, taking into account availability and maintainability more and more stringent requirements.
New control modes, new distributed actuation solutions or mutualisation of power electronics for instance, are emerging.
At the same time, certification constraints and systems validation are going to evolve, thanks to the aircraft electrification increase.
The figure below shows an example of a possible topology for future electrical networks.



Several challenges must be tackled:

- safety ,reliability and dispatch requirements improvement
- EMI/EMC new composite wings and structures
- Wings network ,sensors and actuators
- Reversible DC network stability and performance
- installed power reduction and aircraft wiring optimization
- data and power coupling on field busses

An other type of innovation level should appear with the generalization of dedicated inertial sensors usage due to more sophisticated Fly By Wire (FBW) control laws, with the wings flexibility increase.

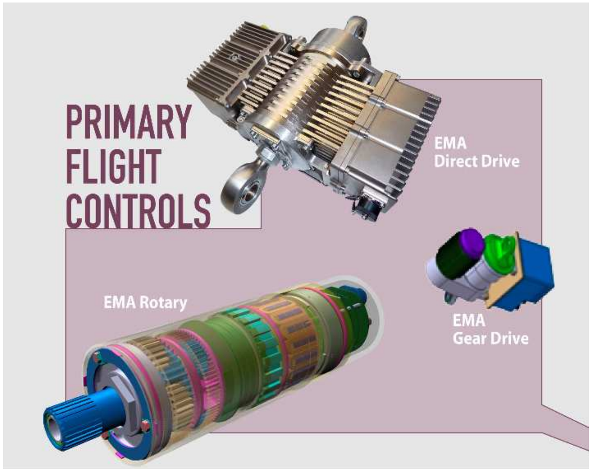


Such equipments encompassing robust Sagem inertial technologies appeared more than ten years ago on few large civil aircrafts, and will probably be generalized for future programmes with new wings type development. They are dedicated to specific algorithms within FBW embedded computers.

2.2.2 *Equipment level*

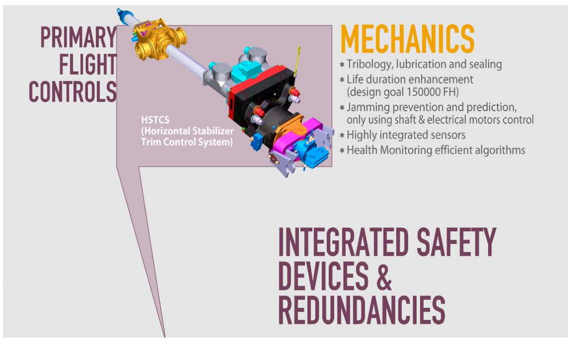
Electrical equipments and in particular electromechanical ones, introduce new types of failure modes, like the electronics ones, mechanical jamming, effort limitation, non natural damping …

In general these failure modes are quite different from what can be seen on hydraulic actuators.



The design and development of the above types of EMA's leads to many challenges such as:

- high integration of motor, bearings and roller /ball screws
- very long life lubrication in severe environment
- load measurement and control functions
- optimized thermal dimensioning
- standards software /hardware concepts
- embedded compact power electronics
- health monitoring of all critical parts

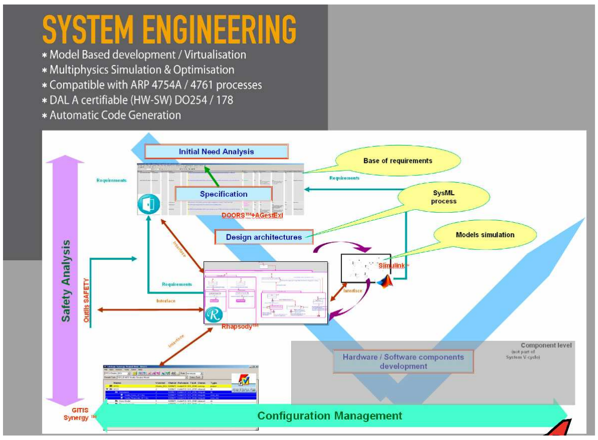


2.2.3 Technology and Methodology level

The solutions being implemented need important technological steps in all domains, in order to achieve life duration and reliability strong requirements, so that safety goals and certification can be obtained. Thus, mechanical elements, sensors, electrical motors, power drive and control electronics must be considered.

The developments of such aeronautical systems of which functional and operational complexity are increasing, as well as ever more ambitious performances criteria linked to key design drivers (mass, volume, reliability, cost and time to market…), lead us to define innovative System Engineering processes, through instrumented methods supported by commercial tools and in parallel specific R&T research are also necessary to be successful in this field.

The figure below, dedicated to System Engineering for Flight Controls, summarizes the Sagem approach to this end, which is more detailed in chapter 3 of this paper.

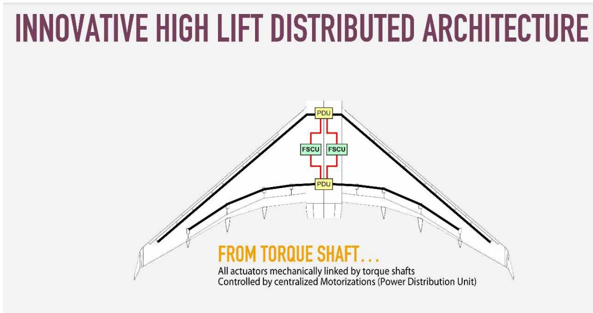


The associated workshop must be compatible with ARP 4754A and 4761 guidelines requirements, dedicated to highly complex embedded systems, which are used by certification and regulation agencies.

2.3 New concepts for High Lift systems

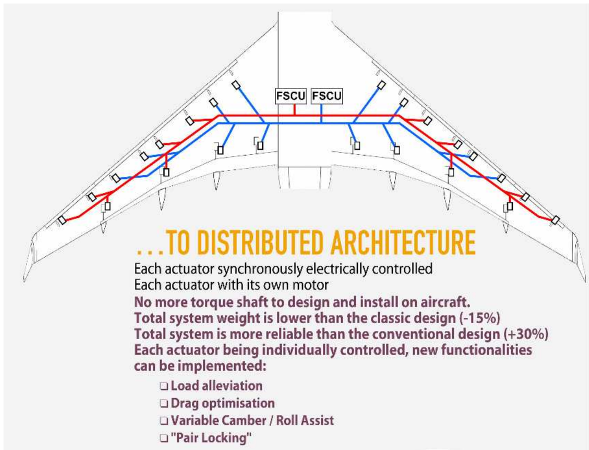
Future aircraft programs will rely on always more increasing electrification of their systems. In the field of secondary actuation systems, two main axes are investigated by Sagem R&T within the Avionics Division:

- innovative architecture with independent electrical synchronization of all surfaces, through dedicated EMA's distributed control.
- classical architecture with mechanical synchronization, but with the introduction of a 'more electric' Centralized Power Drive Unit .

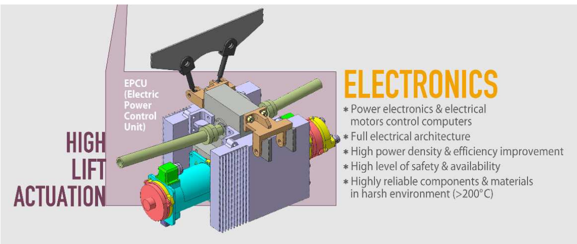


The figure above shows current High Lift system architecture on any aircraft.

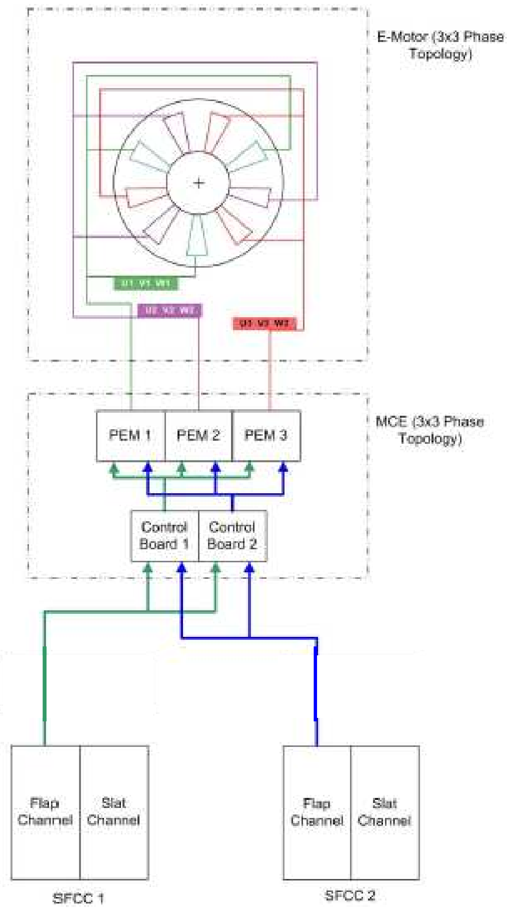
The two figures below are presenting what a future system could be. New flight controls functionalities are also being investigated.



On the electronics side, very important improvements in reliability and miniaturization are being developed.



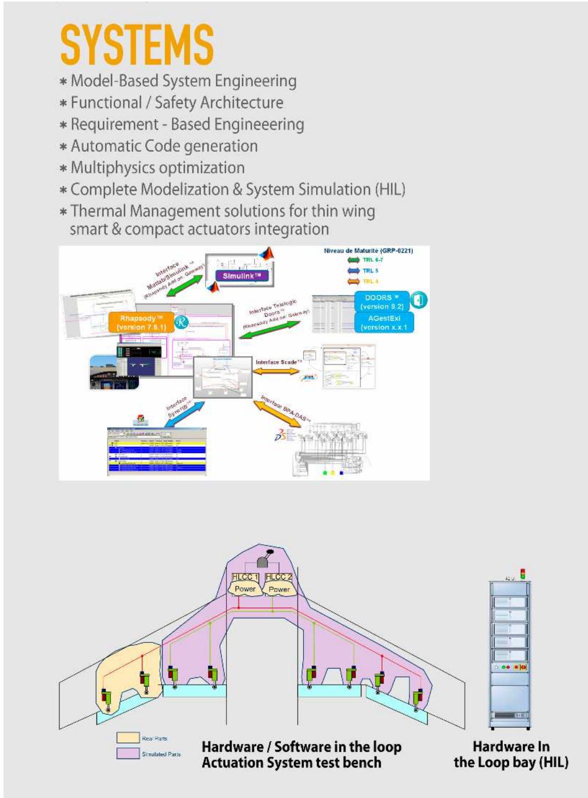
About electrical motors topology, very stringent safety and reliability requirements are permitted, thanks to the electrification, optimizing at the same time system mass and volume, and easiness in installing and maintaining it at aircraft level.



The figure above shows what a Sagem High Lift Power Drive Unit new electrical architecture could be.

3 A System Engineering Workshop dedicated to Flight Control Systems

The figure here after summarizes the main functionalities of the Sagem FCS workshop.



3.1 General

3.1.1 Scope

In the frame of more electric aircraft, especially in the flight control systems domain, it is mandatory to acquire competences in terms of methodology and system/software/hardware techniques, in order to answer efficiently to customers requirements, as well during Request For Proposal as during the whole development of any aircraft program.

The final goal is to define and validate a “System and Safety Engineering Workshop “ that permits to specify, design, simulate any Flight Control System architectures and to interface these outputs directly with other physical models, like thermal, mechanical vibrations, EMI/EMC environmental conditions…, to ease and accelerate the global design of the FCS itself, and simultaneously through a complete virtualization process to increase the maturity of the equipments that form the final system.

3.1.2 Main functionalities

Two main axes have been considered:

- the Requirement Based Engineering (RBE) ,with the following goals :
  - ➢ Use a formalization of the requirement (through models).
  - ➢ Use these models to build and justify the description of the solution and finally define/justify the system architecture.
  - ➢ Take into account the certification aspect.
- the Design, with the following goals:
  - ➢ Introduce model transformation techniques that take all requirements into account during analysis.
  - ➢ Propose a method (and associated tools) to build an architecture of models with a multi-views approach
  - ➢ Manage these models under configuration, including the usage context.
  - ➢ Integrate the dysfunctional analysis, with links to functional and physical architectures.

3.1.3 Hardware/Software In the Loop

Concerning verification and validation tools, a Flight Control System Integration Bench has been developed, using Hardware and Software In the Loop (H/S IL) architecture principle .It permits to test the system model either totally virtually, or by replacing the simulated parts with real equipments, including their real time embedded software, or their equivalent emulated software.

Associated test means permit to adjust models according to the observed behavior of the system/equipment under verification/validation.

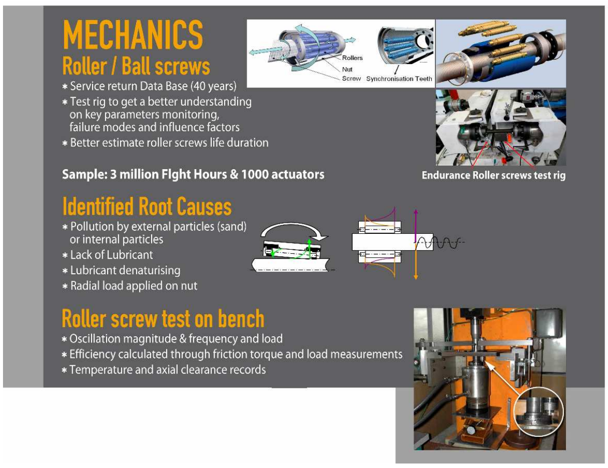
A dedicated Man Machine Interface has been developed to give access to all these functionalities of this very complex but powerful Flight Control System Bench.

4 EMA's at Sagem , a concentration of technologies

EMA technology, in order to enter a product development phase, implies to evaluate and extend the EMA life duration. Four main topics likely to influence this major requirement are:

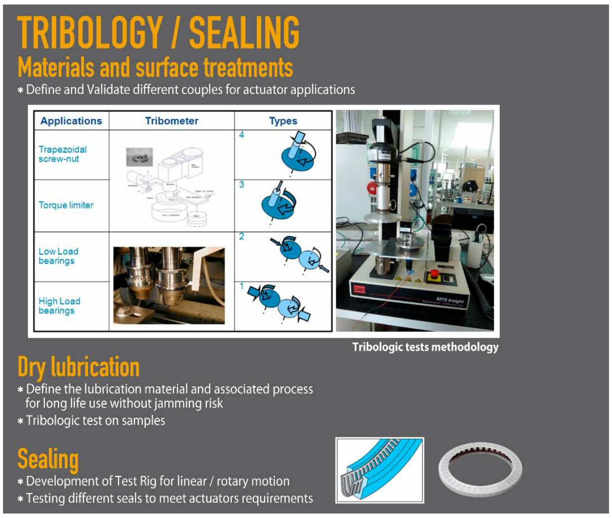
- roller/ball screw endurance characterization,
- steel and surface treatment,
- lubrication,
- dynamic sealing.

4.1 Mechanics



Mechanical transmission life duration (Ball or Roller Screw) is a key driver for the EMA life duration itself .In this context, Sagem has developed a dedicated test bench in order to test different configurations of screws (satellite roller screws, ball screws…). The purpose of this experiment is to perform accelerated ageing test to evaluate screw life potential and to study their degradation modes in order to contribute to EMA Health Monitoring (HM) algorithms improvement.

4.2 Tribology /Sealing



In order to optimize steel and heat treatment process with respect to EMA mechanical parts tribological constraints, Sagem is leading a dedicated National study related to steel and surface treatment selection.

The change of actuation power alimentation technology from hydraulic to electric gives an opportunity to suppress "liquid" lubrication (grease/oil). Dry lubricated actuator could allow a weight decrease and less maintenance activities.

Dynamic sealing experimental campaign aims at testing various solutions under environmental conditions as close as possible to aircraft environment (temperature range, pressure range, icing , etc…).This is a way to anticipate potential sealing issues before prototype testing .

4.3 Electronics

The electronic part of an EMA is one of the main component to be optimized with respect to reliability and mass.

This is necessary to achieve the right level of such key design drivers to make electromechanical technology competitive enough, regarding the hydraulic one.

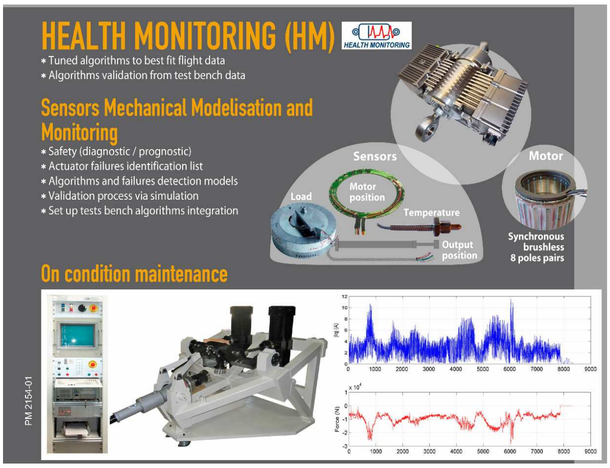
To drive the power demand from EMA's, the main criteria is the ratio KW/Kg (Kilowatt per Kilogram), that will increase in the coming years, thanks to usage of new materials, and at the same time to innovate on thermal solution, at EMA level .

On the control side, the aim is to miniaturize electronics as far as possible, and at the same time to be able to implement new software functionalities to control electrical motors and to increase the resources needed for achieving Health Monitoring objectives, like memories and data processing throughput.

More generally all electronic components, by using new materials, must be able to perform against harsh environmental conditions, under severe vibrations and with temperature above 200°C.
Simultaneously a high reliability must be targeted, in order to achieve stringent safety and availability goals, at system level.

5 Electro Mechanical Actuator Health Monitoring

The emergence of EMA technology paves the way for a new maintenance philosophy based on failure anticipation. The aim of Health Monitoring algorithms is to detect actuator degradation, before it leads to an actuator failure. When EMA degradation is detected by Health Monitoring functions, Airlines maintenance teams can plan unscheduled interruption to repair or replace the EMA in appropriate facilities, at a chosen time, with the minimum impact on aircraft commercial operations. The Health Monitoring functions are designed to avoid the failures that could ground the aircraft, such as actuator jamming or loss of actuator damping (depending on the actuator function in the flight control system). This function will enhance aircraft operational reliability.



Health Monitoring algorithms are capable of Detection (monitored parameter has departed its normal operating envelope), Diagnosis (identify, localize and determine severity) and Prognosis (reliably and accurately forecast operational time to end of useful life).
Health Monitoring is based on real measures and estimations through models. A large amount of data must be then processed to support all functions belonging to this new field of research, which is getting more and more important for future aircrafts systems.

6 Conclusion

In the perspective of the More Electric Aircraft, the 2017 future challenge will be to test more electrical wings, with Ailerons, Spoilers, High-Lift and Trimmable Horizontal Stabilizer, all of them being mainly controlled with smart EMA's concept, close to a serial definition. This approach will become a reality thanks to the SAFRAN/Sagem 'SMART WINGS' federative project.

A positive achievement will be the result of a methodological and multidisciplinary teamwork approach, requiring many skills and know-how. It will be done to optimize the global aircraft system architecture and to deeply integrate all cutting edge technologies used in EMA technologies – power & control electronics, critical software, electrical motor, sensors, innovative materials, etc …

The technical goal of any actuator development is to design and validate solutions which enable good reliability and safety, at system level, while permitting weight savings, better availability of embedded systems and maintenance tasks reduction at aircraft level.

According to SAFRAN/Sagem, the EMA technology is a strong potential candidate to reach all these objectives.

In a first phase, the EMA technology for a Primary Flight Control was proposed and the target was to evaluate it on an aircraft's aileron, in flight, meaning that a good level of maturity has been achieved (Technology Readiness Level (TRL) 6, at equipment level).

The 'SMART WINGS ' program will enable the integration and the validation of solutions thanks to all the technologies being investigated in the R&T activities of Sagem and SAFRAN Group . The maturity level necessary to go into a flight tests phase will be achieved (TRL6) around year 2017.

Reconsidering the whole Flight Control System architecture has an impact on its weight, reliability and cost. The main trade off aims at evaluating and comparing innovative architectures.

In a near future, Aerospace industry will require EMA standardization and cost reduction. In order to tackle those challenges, SAFRAN/Sagem has joined the ACTUATION 2015 European program late November 2011 .

Today, a reference on the "linear EMA technology for an aileron primary flight control" has been established with success and confirmed by a first flight tests phase. Several lessons learned have been collected during its development phase by Sagem.

This permitted to build and to reinforce SAFRAN/Sagem on-going and next research programs in the frame of the More Electric Aircraft. The next EMA generation for FCS will be developed through the future technical platform CORAC-GENOME National program, which has started recently .

References

[1] Derrien JC* , Senegas D* ,Todeschi M** and Tieys P**.. *EMA Aileron COVADIS Development.* ATC404, SAE AeroTech, Sagem*-Airbus**, Toulouse-France 21st October 2011.

[2] Derrien JC* ,Todeschi M** and Tieys P**.. *EMA COVADIS Development.* 5th International Conference on Recent advances in Aerospace Actuation Systems and Components (R3ASC'12) , Sagem*-Airbus**, Toulouse-France 14th June 2012.

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