FLIGHT-EMA (e-Rudder)

Advanced Flight control system – Design Development and Manufacturing of an Electro Mechanical Actuator with associated Electronic Control Unit and dedicated Test Bench

State of the art – Background

The use of electrical Power On Demand systems in place of hydraulic systems are becoming the norm in all new aircrafts developments. The continuing need to reduce overall fuel burn on the aircraft leads to the use of more electrically powered systems.

Current aircrafts rely on one or several hydraulic systems to provide the hydraulic power required to operate the different con-sumers installed throughout the A/C. These systems go from utility consumers, such as the landing gear, cargo doors, etc… to primary and secondary flight control surfaces.

In an attempt to reduce weight and cost -by diminishing fuel consumption-, improve environmental impact –reducing use of hydraulic fluids and lowering fuel burnt particles-, and to some extent increase safety and reliability, A/C designs are leaning towards the "All Electric Aircraft (AEA)" concept. Although, this concept may seem feasible nowadays, AEA major challenges need to be overcome:

· Safety and reliability: prove electrical systems maturity and assure the operation in the event of any possible failure.
· Mass and Volume optimization: miniaturizing devices such as IC, gears or motors.
· Harsh environment including:

- Thermal constraints: as there is no fluid which could be used as a natural refrigerator, need to evacuate heat through other methods arise.
- High Vibrations.
- EMI / EMC: adequate electrical protections are necessary to protect electronic circuits.

The benefits of the electric A/C are clear and some applications are being already targeted with the introduction of electric motors as a replacement to hydraulic ones or even the removal of a complete hydraulic system. Such achievement has recently been accomplished in A380 and A350 aircrafts with 2 electric 2 hydraulic circuits architecture (2H2E).

The absence of hydraulics also greatly reduces costs and simplifies maintenance activities [1]. Diminution of operating costs will be patent in the forthcoming years as these A/Cs operate on a regular basis. The objective in a midterm is to eliminate another hydraulic circuit (1H2E) using the remaining one for landing gear and some primary flight control actuation until the AEA is achieved in a long-term horizon.

Despite all the improvements achieved to date, the industry is still reluctant to rely exclusively on electrical actuators on critical flight surfaces. In the example for the A380, only the rudders have all the actuators powered by electricity, but just as a backup solution, being the main source of energy still hydraulic (EBHA).

Electro-Hydrostatic Actuation (EHA) is the current state of the art for electrical flight control systems in operation. EHA are used as passive actuators until servo-control becomes inoperative or there is a loss on the hydraulic circuit. Electromechanical Actu-ators (EMAs) have already been implemented for some secondary flight surfaces like flaps or slats in A350 and A380.

An EMA consists of the association of a mechanical assembly (comprised by mechanical components and an electric motor) and an Electric Control Unit (ECU) for power and control management.

The EMA concept is similar to EHA but uses a gearbox to connect the motor and actuator rod instead of hydraulics. Therefore, main advantage of EMAs compared to EHA is the simplicity due to the reduction of necessary components (essentially hydraulics) with the consequent increase in reliability and weight savings

Electric redundancy requirement could lead to a configuration of two motors and an ECU, which needs also a double power supply redundancy in order to segregate completely the electric failure mode. For high load applications, as a primary flight control actuation system, this electric redundancy has a heavy weight penalty in the EMA and therefore a single electric motor is considered a reasonable option if a separated emergency extension procedure can be included.

Objectives

The FLIGHT-EMA project objective is to design, develop, manufacture, tune and validate an innovative and smart Electro-Mechanical Flight Control system primary Actuator focused towards the study and validation of a future oil less Power by Wire aircraft. FLIGHT-EMA (E-RUDDER) actuator is based on a modular and efficient approach that integrate easily exchangeable electric and mechanical components with sensors and control strategies that will allow automatic and autonomous safety control.

Volume, mass, electrical consumption, power to mass ratio, reliability, durability and safety are concepts that will drive the development. The FLIGHT-EMA system will be tested and validated at several stages: Virtual validation at model level and finally actual experimental validations of the complete system through both on-ground and in-flight test campaigns.

These sequential and complementary validations assure thus a reliable, safe and efficient performance of the prototype and provide data for a deep concept evaluation.

Description of work

During the whole duration of the project CESA have been managing the consortium and relationship with Alenia by means of teleconferences as well as internal meetings.

FLIGHT-EMA system (EMA, ECU, Test Benches) was tested and validated at several stages: Virtual validation at model level and finally experimental validations of the complete system through both on-ground and in-flight test campaigns.

After EMA and Test Benches set-up, tuning and qualification campaign in Tecnalia, MDU and CESA facilities, the Consortium priority was to perform all validation and qualification tests in order to comply with Copper-Bird and Flight demonstrator time windows available, in close collaboration with the Topic Manager, Labinal and ATR personnel.

Once the integration of the In-Flight Test bench Assembly had been correctly checked, final In-Flight testing took place on March 7th 2016. It consisted of a batch of tests performed in the ATR72-600 aircraft during more than one month of work and on-site support. FLIGHT-EMA In-Flight Test bench assembly was tested integrated in the aircraft. Performances when supplied and commanded by the aircraft electric supply was successfully demonstrated.

EMA with On-Ground Test Bench performances were validated at Copper-Bird installations at Labinal Power Systems facilities in Paris.

These sequential and complementary validations assures a reliable, safe and efficient performance of the demonstrator and provide data for a deep concept evaluation.

The actuator implements three different control modes commanded by the ECU: Active, Damping and Antijamming mode. Active mode controls the actuator in position according to the demand from FCC, Flight Control Computer, having internal close loops as position, speed, current and flux-weakening

When ECU sets the operation of EMA to Damping mode, actuator is not controlled in position close loop any more. Therefore, actuator is controlled to act as a damper in which a force close loop is controlled as a function of the speed imposed by the rest of actuators installed in aerodynamic surface. This mode of operation is possible thanks to the reversible capability of actuator with a low backdrive force tested in a wide range of speeds. In this way, motor/generator is able to impose the force required to avoid any flattering of aerodynamic surface or to extend the Landing gear with a limited speed. During these operations, electrical energy is generated in actuator. This power is managed internally to control the HVDC (High Voltage Direct Current Bus) including the constant frequency control and the redistribution of power flow.

Last mode of operation is the antijamming scenario. In case of EMA for Rudder, the antijamming system allows disconnecting the actuator from the Rudder surface in case of a non-recoverable failure in actuator keeping the control by the other actuators installed in architecture working in Active mode.

In order to design an EMA/ECU device for safety-critical applications, the commonly used solution is the device redundancy. However, in high load application, the electric redundancy has a heavy weight penalty in the EMA. To solve this issue without compromising the safety, a single electric motor with a separated emergency actuations approach has been adopted.

A static test bench based on a spring load equivalent to the real one was also used for a preliminary adjustment of the main parameters of control without influence of the dynamics and inertias.

Flight control EMA requires a complex control based on the three internal loops included in ECU, current, speed, position, flux weakening and inertia compensation. Therefore, a dynamic test bench was used with servo loading actuator to control the force profile according to the kinematic and inertias of the real Rudder application. This test bench was used to fix the parameters related to inertia and flux weakening.

Results reveal the real effects of main parameters of system as inertia, backlash, frictions, death bands, precision and resolutions in the curves of speed and current. A careful study of these effects have been done in order to optimize the current consumptions avoiding peaks of current that can constraint the performance of the EMA and also the characteristics of the power flow from power supply

The very demanding requirements needed a huge number of tuning and validation tests, being a big effort from both technical and managerial point of view. It included parameters control tuning with no load, sinusoidal, trapezoidal and constant load, at different amplitudes and speed, with the aim to validate control stability, performances, limits, frequency response and load actuator effectiveness. Demonstration campaign also included Anti-jamming system, Vibration test, EMI/EMC, voltage spikes, and other environmental conditions for airborne equipment according to aeronautical standards.

Results

a) Timeline & main milestones

The project had a total duration of 40 month. The complete specifications were agree between the consortium and Alenia by month 10. The Preliminary design review took place on month 11 and the final design review on month 21. The EMA with the In-Flight test Bench delivery took place on Jan-16 (M34) to ATR for in-light test campaign. The On-Ground system delivery took place on April 2016 (M37) and the consortium gave all requested on-site support at Labinal Power Systems facilities in Paris.

b) Environmental benefits

The technologies presented will open the door to high performance, environment friendly and economic aircraft operation by better exploiting available weight reduction potentials of new design philosophies without compromising the existing, high aerospace safety requirements. These technologies are also enabling contributions to sustain or even improve safety of aircraft operation by means of more affordable and efficient integrated sensing / actuating technologies. FLIGHT-EMA project will contribute to achieve the objectives of reducing the aircraft operational cost and reducing the environmental impact by providing manufacturing capabilities to fabricate metallic system and equipment components and structures. IATA figures show that if an aircraft reduces its weight by 100 kg, it will save four kg of fuel in each flying hour, and that every kilogram of fuel saved reduces CO_2 emissions by 3 to 3.3 kg, that is, 0,12kg CO_2 emissions are produced per kg of weight of the aircraft and flying hour.

c) Maturity of works performed

Main characteristics for FLIGHT-EMA actuator is a linear actuator with inverted ballscrew architecture with an anti-jamming system located inside screw able to disconnect the actuator from the surface avoiding in this way, any possible mechanical single failure (even screw jamming) assuring the manouver of the flight control by means of a second actuator in parallel. Its dedicated electronics (ECU) is connected to a DC power supply network at 270VDC for normal extension/retraction operation. ECU also includes the necessary electronics to control the BLDC motor and to manage the auxiliary 28V BLDC motor that
Picture, Illustration
controls anti-jamming electromechanical system allowing always Gear extension.

The dedicated test bench is able to apply a programmable counter load on a linear actuator by means of a hydraulic actuator ensuring steady loads in high dynamic load curves, as well as in static load applications.

Taking into account the activities and results obtained, the Technology Readiness Level (TRL) achieved within the project is TRL5 with only some performances tests pending. A demonstrator has been developed and manufactured, and the different components (EMA and ECU) were integrated and tested in a simulated environment. A dedicated test bench has been developed to test performance and operational conditions of the system. Part of tests for TRL 6 has also been partially achieved through functional and environmental testing and in-flight activities described.

Image 1. Flight-EMA demonstrator assembled for the first time

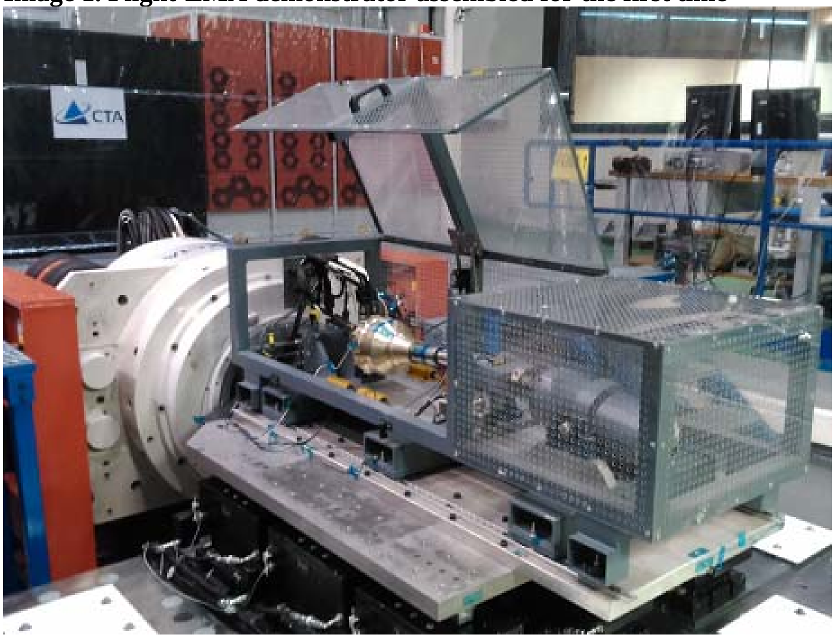

Image 2. Flight-EMA demonstrator and In-Flight test bench performing vibration test

Image 3. Flight-EMA and In-Flight TB performing validation test in the ATR aircraft cabin

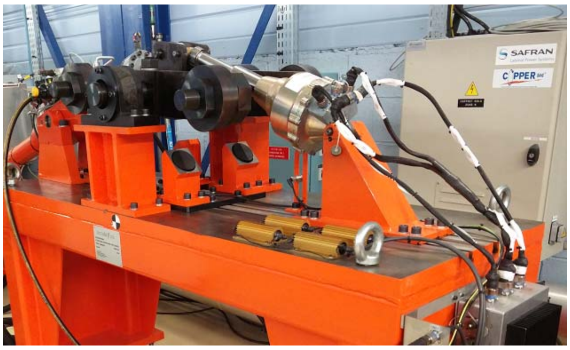

Image 4. Flight-EMA and On-Ground TB performing validation test in Copper-Bird installation at LBS facilities

Project Summary

Acronym: **FLIGHT-EMA (e-Rudder)**

Name of proposal: **Advanced Flight control system – Design Development and Manufacturing of an Electro Mechanical Actuator with associated Electronic Control Unit and dedicated Test Bench**

Technical domain:

Involved ITD: **Green Regional Aircraft (GRA)**

Grant Agreement: **323318**

Instrument: **Clean Sky JU**

Total Cost: **1,151,041.00 €**

Clean Sky contribution: **730,613.50 €**

Call: **JTI-CS-2012-1-GRA-03-009**

Starting date: **07/03/2013**

Ending date: **06/07/2016**

Duration: **40 month**

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Participating members: **CESA; Tecnalia; MDU**