ASTIB: A RESEARCH PROGRAMME ON INNOVATIVE ELECTRO-MECHANICAL ACTUATORS AND IRON BIRD WITHIN THE CLEAN SKY 2 RESEARCH INITIATIVE

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Abstract

This paper presents an overview of ASTIB, a research program within the Clean Sky 2 initiative, that is focused on contributing to generate technological advancements to be implemented in a future Green Regional Aircraft (GRA); its main objectives are to support the improvement of the Technological Readiness Level up to above TRL 5 for a number of significant electrical equipments that are being considered of critical importance for the future GRA. This will help supporting industrial application decisions for future deployments of GRA.

The ASTIB is a multi-year programme that kicked off in October 2015 and is developing as planned toward its final objectives. This paper outlines objectives, organization, methodologies and progress of the project.

1 THE SCENARIO

Reducing the power consumption and thus the fuel burn is a major target for the next generation of aircraft. Two technological areas that can contribute to the power saving are wing load alleviation and electrical actuation. Load alleviation is a technique for redistributing aircraft loads encountered during flight with the purpose of reducing the wing root bending moment, hence allowing a lighter wing design with a resulting weight saving, reduction of the needed propulsive power. Electrical actuation can contribute to the reduction of the non-propulsive power because electromechanical actuators, when compared to the hydraulic actuators, rely on a power less subject to losses and lighter to distribute, besides presenting higher reliability and maintainability with a lower life-cycle cost.

Load alleviation (LA) and electrical actuation are two technological areas that have been widely addressed in the past years. A number of wing alleviation load systems have been proposed based on continuous non-conventional control of primary and secondary flight control surfaces, while technological progresses in electromechanical actuators (EMA) for flight control surfaces have been pursued in several research programmes.

Over the last years, several industrial programmes initiated the concept of a More Electric Aircraft. The aero-equipment industry has in particular launched several studies and developments on more electrical actuation with Electro Hydrostatic Actuators (EHA) and started to introduce EMA for auxiliary equipments. This has provided incremental approaches to address hydraulic circuits issues with Power-by-Wire technologies (A320, B777 and Falcon 7X), introduction of the 2-hydraulic/2-electric (2H/2E) power distribution architecture where flight controls are powered in backup mode by EHA using a local hydraulic reservoir (A380, A350XWB) and use of EMAs for some systems (spoilers, brakes and engine starters).

Several collaborative research and development projects also started to develop the All-Electric Aircraft. The POA FP5 and the MOET FP6 projects have demonstrated on specific systems the effectiveness of electrical actuation. More recently, Actuation2015 FP7 was focused on developing standardised modular EMA technologies with the development of standard components and supporting design and validation tools. EMA systems are consequently viewed as the best candidate for the aircraft of the future (i.e. the All- Electric Aircraft) when considering they are:

- Less complex because of the absence of hydraulic system
- Better suited to long term storage since there is no leak potential
- Energy saving with respect to hydraulic systems
- Installation and maintenance is easier (no filtration, no bleeding)
- Power distribution and management easier (power transmitted without mass transfer)

But, compared to hydraulic actuators or EHAs, technological barriers still persist for a wide adoption of EMA especially when considering these issues:

- Envelope constraints created by the adoption of thin wings and associated flight control surfaces
- Sensitivity to certain single point of failures that can lead to mechanical jams, resulting in a reluctance to adopt EMAs for flight safety critical applications as solutions are heavy and costly (redundancy, fail safe behaviour, etc.), thus creating difficulties for adoption and certification and impacts on costs
- Need to optimise the electrical distribution and heat rejection within the aircraft

Moreover, application of EMAs for continuous control of flight control surfaces requires a thorough optimisation effort in terms of architecture, design, materials and sensors in order to come up with a product which can be certified for the next generation of aircraft.

EMA technologies were not considered mature enough in 2007 (TRL too low) to be part of the CLEAN SKY Systems for Green Operations (SGO) programme. Recent advances in several features of EMAs and the results achieved in Actuation 2015 FP7 programme encourage a re-evaluation of EMA technology for aircraft flight critical applications, ranging from actuation of primary flight control and load alleviation surfaces to actuation of the landing gear.

The promising perspectives of load alleviation / load control technologies as well as electrical actuation for flight control surfaces and landing gear need to be thoroughly investigated and verified in order to gain the necessary confidence and maturity level for moving to their implementation in a flying demonstrator. This requires:

- Development of suitable prototype components integrating the innovative features capable of making electrical actuation an accepted proposition for future flight controls and landing gears

- Design and construction of an integration test rig (Iron Bird) allowing verification and validation of:
  - Enhanced electrical power distribution & load management technology
  - Electrical landing gear technology
  - Flight control system technology

  The iron bird will enable integration and testing of the new technologies in a relevant environment and support the permit-to-fly achievement for the demo flight configuration of the R-IADP Flight Test Bed#1. The iron bird incorporates advanced features such as: real-time generation and control of the actuators loads, injection of degradations in the equipments components, assessment of the merits of a health management system in a representative environment.

It is worth to note that ASTIB is oriented to a new turboprop for regional aircraft use, and that this type of aircraft presently in service do not have boosted flight control actuators (either hydraulic or electromechanical) due to the lower actuation forces with respect to larger aircraft. This offers the opportunity to freely explore different alternatives without being somehow biased by the existing solutions.

2 FRAMEWORK AND CONSORTIUM

2.1 Framework

ASTIB: Development of **A**dvanced **S**ystems **T**echnologies and hardware/software for the flight simulator and **I**ron **B**ird ground demonstrators for regional aircraft is a research programme within Clean Sky 2 framework which falls in the Green Regional Aircraft research line and addresses the topics JTI-CS2-CPW-REG-01-01. The project integration within the Clean Sky 2 programme is shown in Figure 1.

ASTIB is a contributor to the Regional Aircraft Innovative Aircraft Demonstration Platform (IADP) and interfaces with the following IADP Work Packages:

WP 0: Management with the Sub-Work Package: 0.7.2 ASTIB management

WP 2: Technologies Development with the Sub-Work Packages: 2.2.3 Health monitoring, 2.3.2 Electrical landing gear system, 2.4 Innovative flight control system

WP 3: Demonstrations with Sub-Work package 3.4 Iron bird

2.2 The Consortium

To achieve the objectives defined in the above referenced Clean Sky 2 call, the ASTIB Consortium was drawn up to gather a critical mass of expertise in a wide range of skills (equipment suppliers, testing facilities suppliers, experts in flight mechanics, flight control systems, prognostics and health management, modeling and simulation, software developers). The ASTIB Consortium, that acts as a Core Partner in the Green Regional Aircraft IADP, gathers 6 partners which include:

- ⇨ A major supplier of electromechanical actuators for aeronautical applications (Umbra Group)
- ⇨ An internationally recognized supplier of landing gears (Magnaghi Aerospace)
- ⇨ A leading provider of complex test facilities for aerospace applications (CERTIA)
- ⇨ Two main academic institutions (Politecnico di Torino and INSA), both internationally recognized for the quality of their scientific work in the fields of flight mechanics, flight

control systems, more electrical actuation, prognostics and health management, modeling and simulation, software development

⇨ A company with a wide experience in managing international research and development programmes (Viola Consulting)

Such complementary set of competences creates a leveraging effect for the project, providing the best confidence that its ambitious objectives are met and that hurdles that might be encountered during the project development are successfully overcome. The specific competences brought in by each partner of the Consortium hence make up the individual bricks that are being assembled in a coherent organization representative of technological R&D development: from early specification and definition, to design, modeling and simulation, manufacturing, assembling, test facilities development and construction, testing.

ASTIB draws on the experience gained by four partners of the Consortium (CERTIA, INSA, Politecnico di Torino and Umbra) from the participation to several past R&D projects.

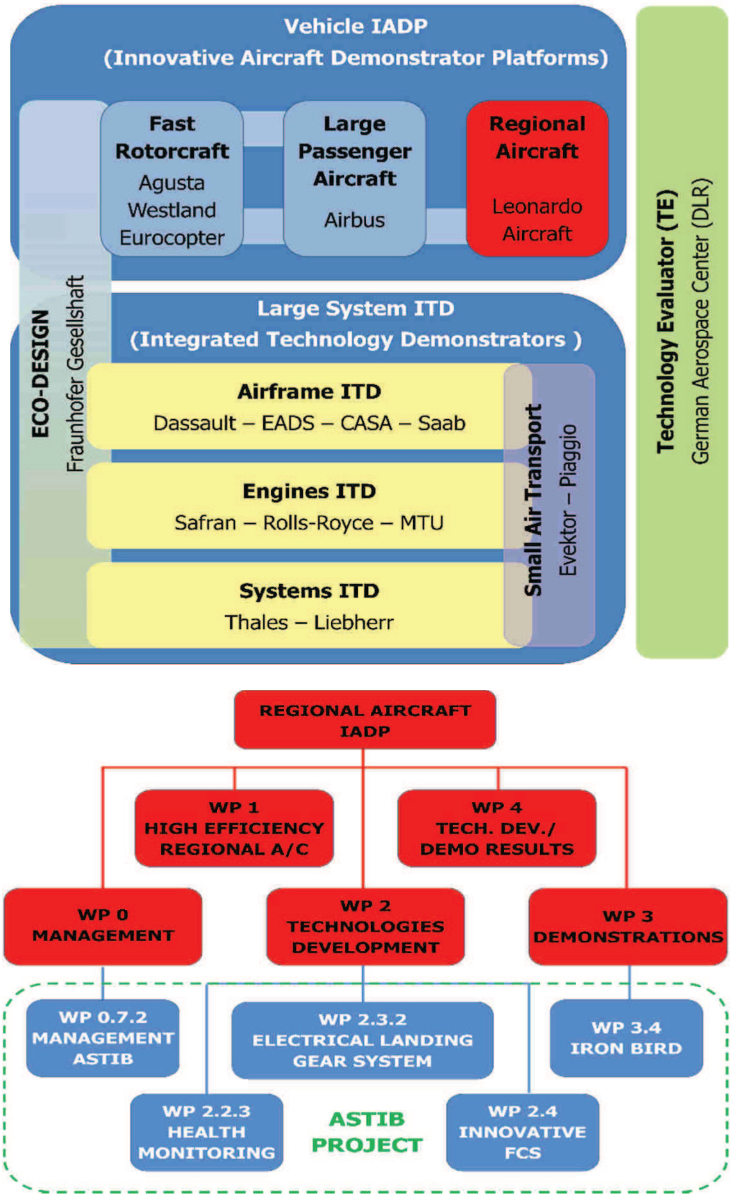

Figure 1: ASTIB project integration in Clean Sky 2

3 FOCUS AND OBJECTIVES

3.1 Focus

As stated in Section 1, the adoption of electrical equipments for flight critical applications in future aircrafts is motivated by a number of economic and environmental considerations. However, the actual implementation of such equipments requires that several breakthroughs are achieved to meet envelope, cost and safety barriers that currently prevent the introduction of a full electrical architecture. For this reason, new aircraft are still relying on hydraulic actuation for primary flight control surfaces and landing gear. It must then be emphasized that new aircrafts developed by newcomers (Avic, Irkut, etc.) tend to be cost competitive by using equipment of proven technologies produced in low-cost countries. A need is thus perceived by the European aviation community in moving towards new technologies able to offer a more efficient, more environmental friendly and more reliable product that will thus be competitive versus the corresponding products based on old technology offered by the competitors.

ASTIB fundamental concept is focused to fully supporting this objective by developing flight representative electromechanical actuators for primary flight control surfaces and for landing gear, effective prognostics and health management algorithms, specific simulation software and a multi-functional integration, verification and validation test rig that will permit the execution of tests in flight representative conditions.

All ASTIB activities are specifically focused on application to a regional aircraft; however, the project results could be exploited advantageously in other aircraft types.

3.2 Objectives

In order to support the improvement of the TRL up to above 5 for a number of significant electrical equipments of the future GRA ASTIB will develop:

- Innovative electromechanical actuators for flight control surfaces aimed at wing load control
- Electrically actuated main and nose landing gears
- Reliable prognostics and health management functions for the electromechanical actuators
- An advanced multi-functional integration, verification and validation test rig ("Iron Bird") provided of intelligent control, allowing testing of new flight control system architectures aimed at wing load alleviation / load control, virtual flight execution, real-time loading and faults injection, thereby allowing a comprehensive technological assessment the flight control system and of its electromechanical flight control actuators, aircraft electrical equipment and electrically actuated nose and main landing gears

As for ***electromechanical actuation***, ASTIB detailed objectives are:

- **Reduce envelope** and **weight,** and **improve reliability** by:
  - ⇨ Developing new actuators architectures with reduced number of components and new design suitable for installation in thin wings
  - ⇨ Developing robust control laws
  - ⇨ Introducing new materials
  - ⇨ Demonstrating the feasibility of electrically actuated landing gears
- **Increase safety margins** by:
  - ⇨ Developing prognostics and health monitoring techniques able to detect degradations, predict their evolutions and estimate when, under continuing usage, they will evolve into failures

- **Increase the confidence level** by:
  - ⇨ Exploring new control strategies for the electromechanical actuators allowing to optimise the dynamic response and to minimise the disturbances following a failure
  - ⇨ Developing high-fidelity, physics based, models and real-time models enabling the execution of hardware-in-the-loop and software-in-the-loop tests, therefore allowing assessment of the flight control system behaviour over the entire flight envelope under normal and simulated fault conditions

As for the ***Iron Bird***, ASTIB detailed objectives are:

- **Design, development and construction of a specific infrastructure** able to:
  - ⇨ Allow testing of new flight control system architectures aimed at wing load alleviation / load control
  - ⇨ Accept the installation of the electrical power distribution system and the associated electrical loads
  - ⇨ Reproduce the aircraft installation of the electrical landing gear system
  - ⇨ Reproduce the aircraft installation of flight control surfaces with their electromechanical actuators
  - ⇨ Install programmable load banks simulating aircraft electrical loads to complete the global aircraft electrical system simulation.
- Implement a **simplified aircraft model** into a simulation module capable to verify the systems behaviour in a simulated flight condition by allowing:
  - ⇨ Simulation of the aircraft flight mechanics and real time computation of the aerodynamic loads
  - ⇨ Simulation of the sensors
  - ⇨ Simplified aeroelastic model of the aircraft
  - ⇨ Ability to connect the iron bird directly with an aircraft cockpit with its controls
  - ⇨ Interfacing with the flight control computer
- Implement **real-time generation of aerodynamic loads** acting on the flight control surfaces
- Implement **real-time models** of the flight control actuators
- Enable **faults simulation** in the components under test
- Support the **testing activities** for electrical landing gear, electrical power distribution and flight control systems by allow to conduct tests with actual and virtual (real-time models) hardware; this will provide the possibility of easily exploring the merits of different architectures of the flight control system
- Provide a platform suitable for future installation of other components of the flight control system

4 ELECTRO-MECHANICAL ACTUATION

4.1 Electrical landing gear

Electro-mechanical actuators (EMAs) and electronic control units (ECUs) are being developed to extend, retract and lock a prototype test item of the main and nose landing gears. The rig will reproduce weight, inertia and stroke of the real system and will be fully representative with respect to the electro-mechanical actuation.

The development process and the complementary activities (e.g. high-fidelity and real-time mathematical models) are similar to those the flight controls and are outlined in next section.

4.2 Electro-mechanical actuators for load alleviation – load control flight control surfaces

ASTIB develops EMAs for controlling the positions of flight control surfaces dedicated to perform wing load alleviation and control. This creates stringent requirements in terms of envelope and weight that are being addressed by evaluating the merits of new design, new components and new technologies able to lead increased power density of the EMA and higher safe operating temperature for both the EMA and its controlling electronics (ECU). The development process is going through the following steps:

- For the EMA
  - ⇨ Definition of the EMA architecture and components
  - ⇨ Sizing of the components and their integration
  - ⇨ Functional, thermal and stress, and reliability analyses
- For the ECU
  - ⇨ Definition of HW architecture and components
  - ⇨ SW functionalities
  - ⇨ HW schematics
  - ⇨ Thermal and reliability analyses
- Manufacturing of components and assembly
- EMA and ECU acceptance tests

In parallel, control laws are being defined for performance improvement over the present state-of-art control strategies. In particular, non-linear control laws are studied for the EMAs for best exploiting their characteristics, and ways are defined to make the control laws energy optimized (providing required dynamics without exciting unnecessary dynamics) also making them robust and resilient to the parametric uncertainties encountered in flight and over the life time.

High-fidelity mathematical models are being developed of multi-physics type aimed at providing a precise mathematical description of the dynamic behaviour of the EMAs components. This task covers the following activities:

- Define the physical characteristics of the components
- Define the minimum necessary:
  - Coverage of physical effects
  - Parameter set per equipment/component and parameterization method
  - Coverage of failure modes and way of implementation/ dynamic triggering of faults
- Selection of the most convenient type of equations solver
- Allow the possibility of inject degradations and faults and simulating the resulting behaviour of the flight control system
- Verify the models numerical stability
- Define the model fidelity requirements to obtain meaningful and computationally efficient state-space representations from the multi-physics models

In addition, real-time models are built to allow execution of the hardware-in-the-loop tests.

5 PROGNOSTICS AND HEALTH MANAGEMENT

ASTIB tasks are to develop the structure of a reasoning and prognostic system that will accept and fuse the features vectors from the EMAs to generate the current diagnostic state, disambiguate among possible different origins of the fault indication and predict the evolution of a fault and the remaining useful life from physics based and data driven algorithms.

Algorithm development will be split between those functions that need to operate in real-time and those that operate in non real-time (e.g. trending and prognostics) and can be implemented on a ground based analysis tool.

A summary of the tasks definition is the following:

- Identify the significant features that can be extracted from all sensors data to detect faults at their early initiation stage and enable the required level of prognostic and health and usage monitoring to be achieved
- Identify the methodology for collecting data from which the significant features can be derived: which data can be continuously collected in flight and which data should be collected on ground by injecting appropriately selected stimuli
- Define suitable condition indexes providing a mathematically definable indication of the fault; the extracted features vector will be one of the essential inputs to the prognostic and health monitoring algorithms
- Design and development of reasoning algorithms for inferencing uncertainty information from EMA diagnostics
- Design and development of prognostic algorithms that are able to learn from laboratory accelerated aging test and online adapt to real operating conditions
- Develop online prognostics approaches for real time application as the EMA is monitored and the data are streaming into a processor for fault detection and failure prognostics
- Develop prognostics and decision support tools for predictive maintenance

The following Figure 2 shows how Prognostics and Health management is being addressed.

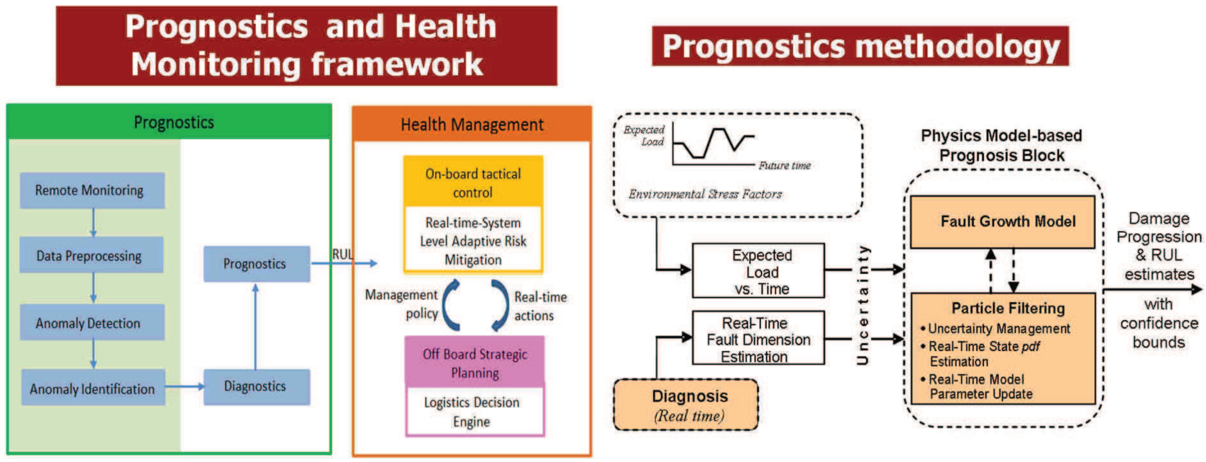

Figure 2: Prognostics and Health Management concept diagram

6 IRON BIRD

The iron bird is used to verify and validate the functionality and performances of significant equipment of the flight control system, of the landing gear and of electrical equipment and their integration with other systems (e.g. power system); it is developed for permitting verification of these equipments also under simulated failure conditions, thereby supporting the aircraft integration and certification process.

The iron bird is designed to strictly reproduce the aircraft installation of the electrical landing gear system, of load alleviation / load control surfaces and aileron. Its structure is also suitable to accept future installation of other wing control surfaces.

The iron bird structure offers a platform for installation of generators, alternators, power converters and relevant control unit reproducing the electrical power generation network of the regional aircraft, as well as the installation of programmable load banks simulating aircraft electrical loads in order to complete the global aircraft electrical system simulation.

Significant features of the iron bird are outlined hereunder.

The iron bird is organized around a ***skeleton*** making up the support structure for the main systems and components which comprise the iron bird rig. The skeleton consists of a welded steel platform providing support for separate modules accommodating the aircraft flight controls and landing gear, and for the aircraft electrical equipment. The flight control actuators and their simulated aerodynamic surfaces are installed within their own dedicated structural modules mounted at the appropriate location on the platform. Each structural module consists of a steel framework and provides mounting for a ***loading actuator*** designed to apply the required load to the relevant aircraft actuator.

Loads on the flight control actuators are generated by an innovative ***force control system*** consisting of actively controlled hydraulic loading actuators using a non-linear, adaptive force control law. As the tests will be run simulating flight routines, the loading actuators will produce flight control surface loading appropriate to the flight conditions and type of handling set. The load control system will be able to reproduce loads induced in real flight from gusts and turbulence. Loading will be constantly varied to match each phase of a flight based on the output from the aerodynamic and other software models contained within the Flight Mechanics Simulation Computer (FMSC).

The ***FMSC*** implements the aircraft model allowing to verify the real equipment behaviour in a simulated real-time flight condition. The FMSC includes:

- Simulation of the aircraft flight mechanics
- Simulation of the sensors (air data sensors, inertial sensors and accelerometers)
- Real-time computation of the aerodynamic load and the wing disturbance
- Simplified aeroelastic model of the aircraft

The iron bird skeleton reproduces a wing and a portion of fuselage. In order to enhance the verification and validation possibilities, the equipment on the other wing is simulated by a ***Simulated Wing Module*** which contains real-time models of the actuators running in parallel to the physical actuators installed in the real wing. Moreover, real-time models are developed to simulate the behaviour of flight control actuators, and relevant flight control surfaces, that are not physically present, such as elevator and rudder.

A ***cabin dummy*** provided with pilot controls and image generator allows the execution of pilot-in-the-loop tests. Pilot commands are sent to a Flight Control Computer (FCC) that is provided by Leonardo Aircraft, while the images on the visual screen are generated from signals coming from the FMSC.

Suitable hardware and software are provided in the iron bird for test automation, acquisition, recording and monitoring functions and subsystem/interface simulation, specifically related to electrical distribution, landing gear and flight control system tested architectures. The data acquisition system provides the means of measuring and recording all physical parameters necessary on the rig throughout its operational life. It is designed with the capability of measuring signals from many different kinds of sensors, to record information and it is capable to read all the FMSC data.

Hydraulic fluid power is used to drive the loading actuators; it is provided by a dedicated hydraulic power supply. The iron bird is equipped with a heat exchanger to reject into a water cooling system the heat generated by the different components during its operation.

A final innovative feature of the iron bird will be the ***Health Management System Module*** which is developed to perform the following functions:

- Implement the prognostics and health management functions that are developed in the project
- Allow injection of simulated degradations and their progression to verify the merits of the PHM algorithms

The iron bird will be located at Leonardo Aircraft facilities in Pomigliano d'Arco.

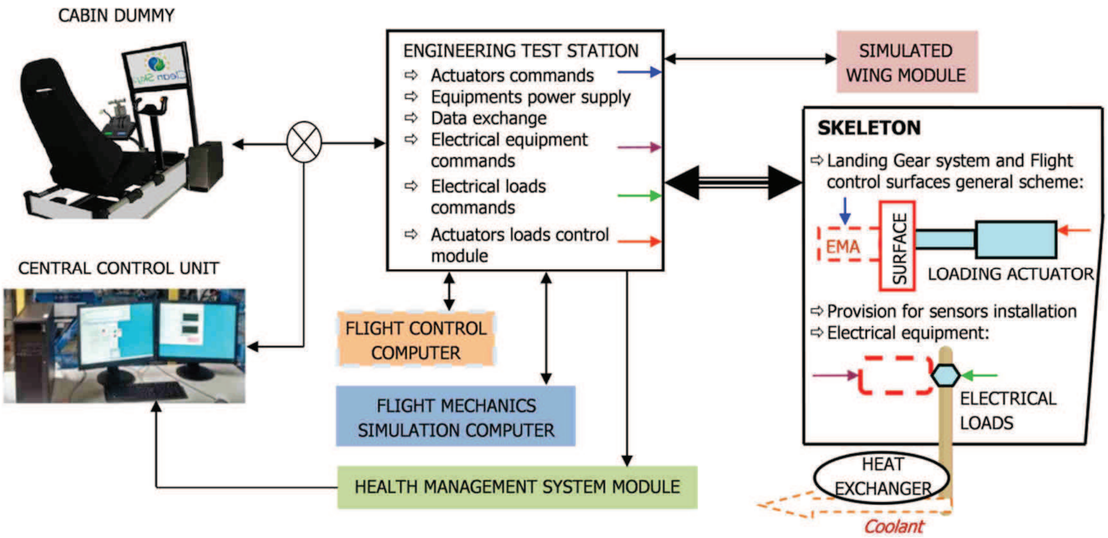

Figure 3: Iron Bird concept diagram

7 CONCLUSIONS

It is expected that the body of knowledge acquired in ASTIB, the foreseen validation of the project results and the market position of the involved stakeholders will provide an innovation potential, so as to:

- Contribute to the development of flight worthy EMAs
- Facilitate the implementation of a prognostic and health management system for the entire aircraft flight control system, compatible with an overall aircraft and fleet level solution.
- Exploit the capabilities of the new iron bird for enabling a reduction of the time-to-market, inclusive of a reduction of the certification time, by enhancing the flexibility of the tests

The ASTIB project is now in its second year of a multi-year programme in which most of the activities will be performed in the first four years.

8 REFERENCES

[1] Clean Sky 2 Proposed Technical Programme, 31st July 2013
[2] ASTIB public web site: www.astib-cs2.eu