1 Publishable summary

Project context and objectives

The All-Electric Aircraft is a major target for the next generation of aircrafts and helicopters to lower consumption of non-propulsive power and thus fuel burn.

The aim of ACTUATION2015 is to develop and validate standardised, modular and pooled EMA for the first time for all airframe systems (flight control, high lift, main landing gear, nose wheel steering, door locks, thrust reversers) and all types of airframes (business, regional and large aircraft and helicopters).

The ACTUATION2015 **detailed objectives are to:**

- **Reduce the overall Life Cycle Cost** (LCC) (development, acquisition, certification, maintenance, operation) by:
    - Providing standardised families of EMA modules usable in different types of applications and, when feasible, sharable between different applications
    - Designing and producing EMAs from off-the-shelf standardised modules using standardised design and validation methods and tools
    - Addressing all types of aircraft systems and aircraft applications – from helicopters to large aircraft
    - Standardising and reducing number of qualification and re-qualification tests
- **Reduce weight and improve the reliability** by
    - Introducing new materials, (e.g. SiC for electronics, magnetised composites for motors, etc.)
    - Introducing new architectures (e.g. Hybrid Power Device – HPD – used in a significant manner and applied on power drive – reducing the number of components)
    - Enabling the full electric architecture at aircraft level
    - Resources sharing and optimising actuation architectures (e.g. power generation shared between transient actuators)
- **Increase safety margins** by
    - Developing health monitoring techniques to predict failures
    - Implementing fault tolerant systems and architecture to guaranteeing safety, thus reducing complex, bulky, expensive and heavy solutions such as jam free actuators,
- **Mature the technology** (passing from TRL3 to TRL5 in the project) for industrial application decision in 2016/17 and deployment for the next generation of short/medium range single aisle aircraft by 2020

As a result, ACTUATION2015 will contribute to European leadership in electric actuation standardisation.

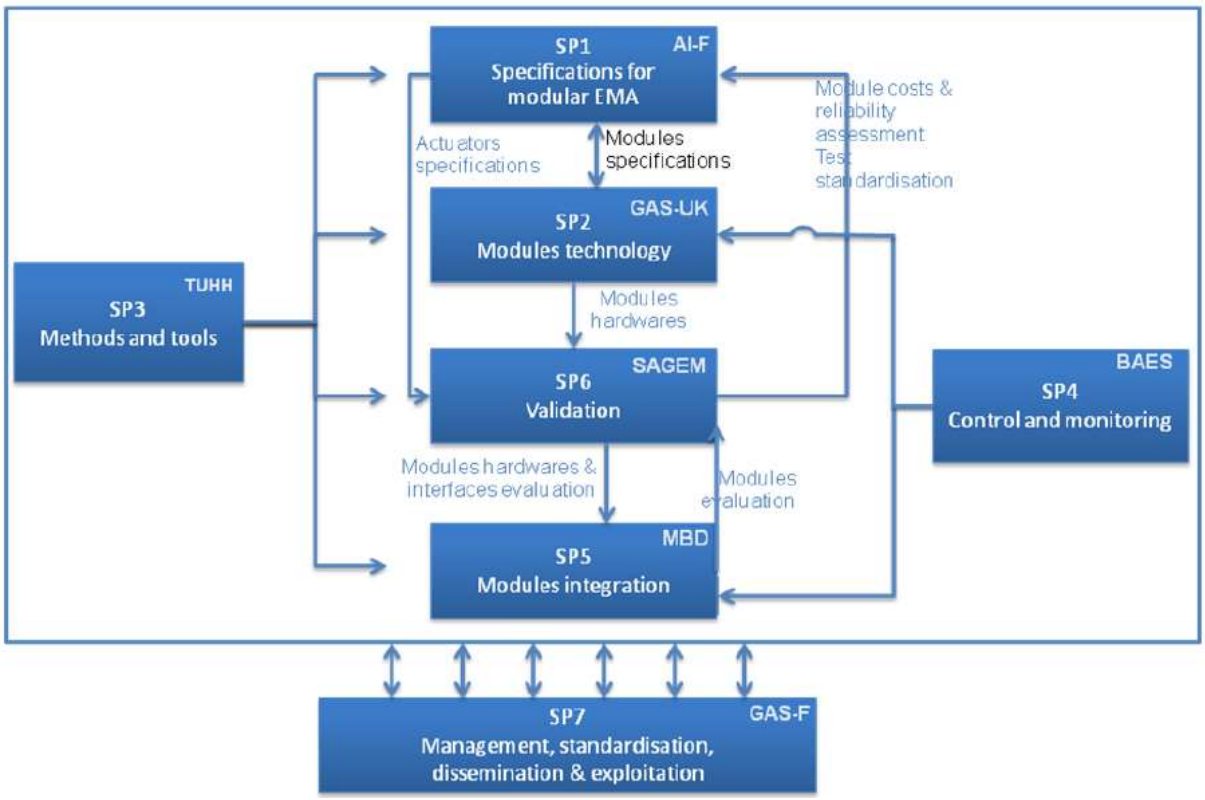

Figure 1: Overall ACTUATION2015 structure

1.1. SP1: Specifications for modular EMA

The first step of SP1 was addressing with airframers the standard template definition to capture the electrical Actuators sizing requirements for the complete system's family PFCS, HLS, LGS, TR/CD. The template has been iterated and completed all along the actuation sizing period with partners during the second year of the project. The final template with the associate requirements definition is now frozen.

The second step was to define with partners a standard template to capture the Components requirements for the targeted modules: Power Drive Electronics (Power Core Module, Control and Monitoring Module), Motors, Mechanics (Screw, Reducer, Gearbox, Sensors). The template has been as well iterated and completed all along the components sizing period with partners. The final template with the associate requirements definition for components is now frozen.

Actuation requirements are captured by Airframers for the full aircraft range and compiled on the standard template. The actuators requirements have been revised and optimized following actuator design phase with partners. Electrical actuator sizing sensitivity to airframer requirements has been identified with each supplier. This has allowed airframer requirements optimisation / adaptation for keeping the EMA design as simple as possible. The development of improved EMA modelling tools and design rules developed by partners has supported this iterative process for requirements and design optimisation (Actuator and System). The requirements are now frozen.

Actuators modular topologies traded and down-selected to provide the appropriate solution at aircraft level have been detailed and confirmed during the second year. All the actuator topologies are frozen.

Power Drive Electronics standardization is a major enabler for the full electrical aircraft competitiveness in terms of Cost and Reliability. This is the most complex equipment of the electrical actuation. The PDE modular architecture has been studied in detail and optimized with partners all along the second year. The following modularity and standardized interfaces is now frozen:

- Standard Power Drive Electronics modular architecture (PDE)
- Standard Power Core Module (PCM)
- Standard Control & Monitoring Module (CMM)

- Standard Internal Standardized Supply Interface (ISSI)
- Standard Sensors interfaces
- Standard Solenoid command
- Standard Protocol for Inverter Control Over LVDS
- Standard Basic Software (Operation System) to support Airframer & Supplier software applications

Motor module with standardized interfaces has been detailed and optimized with partners all along the second year. The mechanical and electrical interfaces of the standard motors are detailed in the associated module specification.

Mechanical modules studies have addressed both the Linear and Rotary actuators. Standardized parameters have been consolidated along the second year. A typical leverage targeted for the screw standardization is to cover a large range of applications with the same screw diameter, lead, nut and rollers. The mechanical part of electrical actuation is the most adherent to each application and the standardization is more limited as compared with Electronics and Motor. Gearbox standard sensors and standard interface with the motor have been defined and frozen in the specifications.

Actuator standard sensors have been traded and consolidated with partners all along the second year. The sensors type and characteristics for Motor, Mechanics, Power Drive Electronics and Application are now frozen.

The Actuator pre-sizing phase has required appropriate modelling tools and design rules to be created. The EMA technology is new and there was no complete process and tools available off the shelf when starting the project. This was a major challenge regarding SP1 objectives and schedule. These models and tools have been completed and/or built by partners for the EMA sizing. Design iterations have been performed along the second year to reach the required level of confidence on components sizing.

The Module families have been defined as a priority for the middle range applications (short range and regional aircraft) to specify accurately the modules where hardware is developed within the project. Power core ranges, control and monitoring avionics capacities, motor characteristics, screw, gearbox for middle range applications have been defined. The end parts of the A/C families (e.g. Large aircraft, Business) will be closed as soon as the detailed design phase is closed for the demonstrators.

Modules specifications consolidations and modules preliminary design have been performed during this second year based on every other week iteration with SP2 partners for both requirements and design validation. The number of bi-lateral reviews increases in combinatorial fashion due to same reviews to be performed with each supplier for each product at component and actuator level. The following modules Specifications are now frozen with the associated modules preliminary design (iterative process):

Modules specifications SP1 ⇔	***Modules preliminary designs SP1***
• PCM [Power Core Module]	Safran, GAS
• CMM [Control & Monitoring Module]	Safran, GAS
• Flight control PDE [Power Drive Electronics]	Safran, GAS
• Braking PDE [Power Drive Electronics]	MBD
• OS [Operating System]	Safran, GAS
• Motor [Aileron, Spoiler]	GAS, SAGEM
• Screw [Aileron, Rudder, Elevator]	GAS / Rollvis & SKF
• Gearbox [Spoiler]	Liebherr, SAGEM

Modular actuators specifications refinement and validation for actuator demonstrators have been performed through actuator preliminary design pre-validation reviews during this second year. Process based on every other week iteration with SP1/SP5 partners. The following actuators Specifications are now frozen with the associated actuators preliminary design (iterative process):

Actuator specifications SP1 *(demonstrators)* ⇔	***Actuator preliminary designs SP1***
• Aileron linear actuator	GAS-F
• Spoiler rotary actuator	SAGEM
• High lift ePCU	GAS-UK

- Braking MBD
- Rotor linear actuator SENER

SP1 second year results and status can be summarized as follows:

- Complete process convergence.
- Major progress on EMA key areas by airframers and partners.
- Amount of studies and results beyond the DoW.
- Numerous players Airframers and Partners. SP1 coordination workload completely underestimated.
- Competition but all partners in constructive position.
- Complex challenging process turned in 24 months under pressure without time loss.
- The outcome is dense, innovative and promising for the electrical aircraft.
- Players fully involved for PDR phase.
- Activity in line with the proposed revised schedule

The next steps will be to close all the PDR, to finalise the Operating System standardisation, to follow the modules and actuators detailed design, to perform the CDR, to finalise the definition of modules families for Large aircraft and business, to follow the Lubrication standardization workshops, to perform actuators virtual integration within aircraft, to support the modules standardization process with WP7 in consistency with the modules specifications.

1.2. SP2: Technology modules

SP2 will develop the required technology to meet the cost, reliability and weight project key targets. SP2 addresses technology works related to hardware EMA (electro-mechanical actuator) modules including: mechanics, motor architecture, composite materials, mechatronics, new sensors, power electronics, while applying the standardisation process.

Furthermore, SP2 will design and manufacture three types of modules (motor, power electronics, and mechanics) to be used for integration in SP5 (Modules Integration) and testing in SP6 (Validation).

The inter linkages of SP2 with other SPs and its WPs are presented in Figure 2 below:

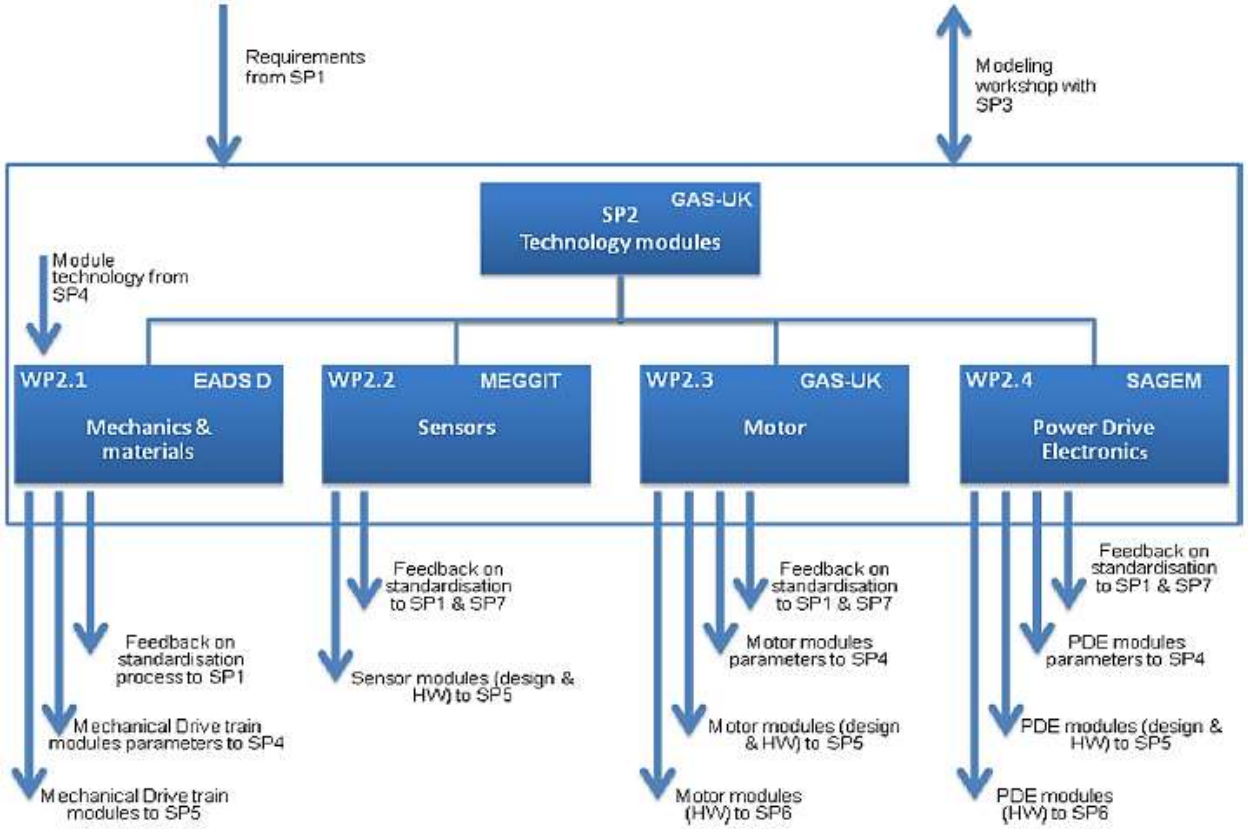

Figure 2: SP2 diagram

1.3. SP3: Method and tools

A key step in the preliminary design process of electromechanical actuators is the development of suitable design methods and tools that allow for early design phase optimization in terms of safety, performance, weight and maintenance costs among others. In the scope of SP3 the most relevant preliminary design issues are addressed with focus on the harmonization and optimization of existing methods and tools with standardised interfaces. The partners are contributing to enhance the capabilities of Europe's aerospace research field and industry with improved methods, standard component libraries, standards for interface-modelling, categories for evaluation of critical components as well as an effective chain of tools for qualification.

The preliminary design approach being considered in ACTUATION2015 and thus SP3 incorporates dedicated tools for modelling systems of multiple physical domains with focus on electromechanical actuators. Modelling activities include mechanical, electrical and control schemes, as well as thermal aspects. Of equal importance is the conception of appropriate tools to perform detailed safety and reliability analyses. This constitutes a fundamental part in the model-based tool chain of the preliminary design process. The safety and reliability tools are to cover the development of new concepts for degradation analyses through the compilation of knowledge about the behaviour of EMAs. System identification techniques that take into account the variability of inputs, parameters and confidence levels shall help to characterize the lack of reliability information or inexact observations. To complement this approach, a reliability uncertainty method is being developed which should deliver confidence levels for calculated system and subsystem failure rates.

To close the loop of the preliminary design process, a virtual integration platform at system and aircraft level is being developed by the partners of SP3. When finished, it should allow evaluating component models with respect to dynamic requirements, local reconfiguration and interfaces to the power distribution system. Additionally it will provide an environment to analyse system to system interactions. As a result the notion of conducting virtual qualification tests should be at reach. Thereupon, much work is being dedicated to pave the way for virtual qualification and certification through the definition of a modular process as an alternative to subsystem qualification in order to ease the integration of virtual testing into the process.

1.4. SP4: Control and Monitoring

SP4 is made up of three separate work packages: WP41 “Prognostics and Health and Usage Monitoring”’ WP42 “Advanced Control and Monitoring” and WP43 “Regenerated Power Management”. WPs 41 and 42 were both kicked off at the beginning of Year 1 but the start of WP43 was delayed to the start of Year 2.

The work in WP41 has progressed steadily throughout Year 2 albeit progress has been somewhat slower than hoped for. During the year three physical meetings and a number of WebEx meetings have been held to review progress and to plan the future activities. A number of reports were written and approved during this period. Some of these were deliverables and these addressed: the software sizing estimate for the PHM functions, standardised methods for EMA Usage Monitoring and standardised methods for EMA Anomaly Detection. A number of other reports were also generated during the year; these reports were internal to the WP and captured the results of work carried out by individual partners.

WP42 is concerned with looking at advanced control and monitoring techniques that can be applied to the ACTUATION2015 EMAs. The companies that participate in this WP are a sub-set of those who participate in WP41 – for this reason the WP42 meetings have been held jointly with the WP41 meetings to minimise the travel and organisational effort required. The partners within WP42 have looked at a variety of different control and monitoring ideas, techniques and solutions that can be used to enhance the performance, improve the reliability and/or aid failure identification. The candidate solutions that have been identified have been evaluated using a model of a linear aileron EMA actuator that was developed by GAS-F and/or models developed by the individual partners.

WP43 is concerned with the management of power that can be regenerated by an EMA as part of its normal operation. EMAs have four quadrants of operation and will consume power when operated in two of these quadrants and will generate power when operated in the other two. The power that is generated by an EMA can be managed local to each EMA or it can be placed onto the EMAs power supply. Managing regenerated power local to each EMA has the disadvantage of adding functionality and thereby volume and cost. For ACTUATION 2105 a decision was made at the start of the programme to allow the EMAs to place any regenerated back on the supply buses; this is easy do because the EMAs are powered from a DC (±270V) bus. Allowing the re-generated energy to be placed onto the power supply is not in itself a solution. The regenerated energy will cause the bus voltage to rise, possibly outside of allowable limits. Hence a means of managing the voltage levels on these buses is still needed.

1.5. SP5: Modules integration

Based on SP1 requirements, SP5 will make actuator level integration of the different standard modules developed in SP2, using Methods & Tools provided by SP3, and Health Monitoring Algorithms developed in SP4. Ultimately SP5 will feed back results of analysis to SP6 for overall assessment.

SP5 will address the handling of the integration of:

- Single module reference for different actuator applications (identify common requirements to be used for module design to get effective multi-actuator integration).
- Double source modules on the same actuator.

A global coordination has been organized, via periodic progress meeting, to ensure the coherence of the work being performed by the different partners within SP5 and make sure that the module specification is elaborated in accordance to actuator needs.

WP52 & WP53 have not progressed as scheduled mainly because the progress of the design of the demonstrators is dependent upon the final architecture trade-offs from SP1 (WP16). The module design and specification in SP2 require the family of modules to be defined as an output of WP16 (task delayed).

Nevertheless, the pre-sizing work performed in WP16 of SP1 has developed tools and produced results that anticipate the work of SP5.

For all the EMA hardware prototypes (Aileron actuators, MLG retract actuator, Helicopter Secondary Flight Control actuator & High Lift actuator) and virtual integration WP16 results are:

- Actuator architecture closed to be finalised,

- CAD design and mechanical analysis has started.

For all the applications, one of the main technical difficulties encountered in WP16 is actuator space envelope. A/C integration constraints are strong & available spaces dedicated to actuators are very small.

1.6. SP6: Validation

SP6 will standardise test means and procedures, validating modular application performances by running standardised tests using the modules developed in SP2 (Technology modules).

Besides, SP6 will assess some of the project end results (cost, reliability, weight, level of modularity) and prepare certification.

SP6 is divided into four WPs:

- WP61 Modular test bench
- WP62 Modules evaluation
- WP63 Modularity technology
- WP64 Qualification and certifiability assessment

The inter-linkages of the SP6 with other SPs and its WPs is presented in Figure 3 below:

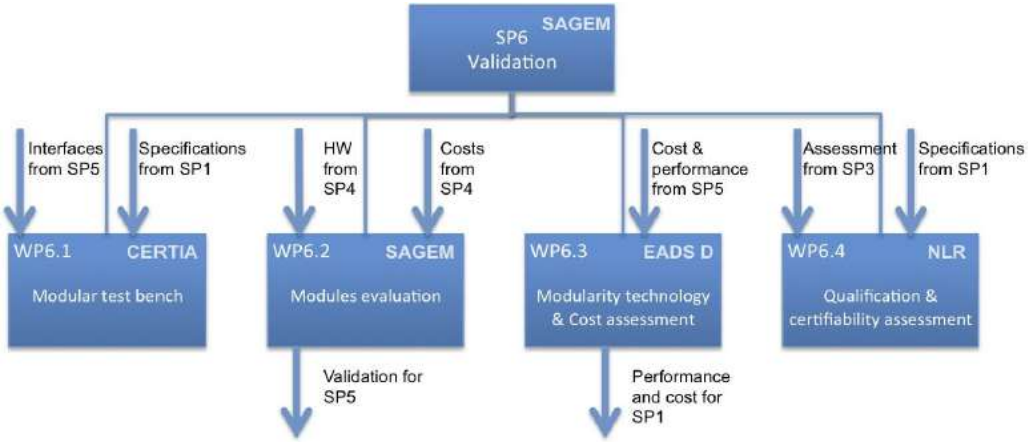

Figure 3: SP6 diagram

1.7. Expected final results and their potential impact and use

Building on POA and MOET results, ACTUATION2015 will deliver:

- Standards and modular EMA products, tools and methods ready to use with the output of CLEAN SKY SGO, making available the technology needed to develop the All-Electric Aircraft
- New mature actuation technologies (TRL 5 modules):
  - Improved sensor technologies
  - New control and power management techniques
  - Standardised and enhanced Health and Usage Monitoring
  - Mechatronics solutions applicable to aircraft environmental conditions
- Common standards and Shop Replaceable Units (SRU) or Line Replaceable Units (LRU):
  - Motors, sensors, Power Drive Electronics (PDE), power drive systems
- Communality and scalability in qualification process, providing credit for certification:
  - Qualification methods
  - Data base on components technologies and processes

Three types of standard modules – PDE, Motors and Mechanics – used to build several actuator systems will be jointly specified and then developed to validate:

- The concept of modular standard component applicable to several actuator systems (primary and secondary flight control, high lift, landing gear, thrust reverser and cargo doors), scalable for application to different types of systems and aircraft (from helicopters to business and regional aircraft up to large commercial aircraft)
- Low cost and mature actuation technology for several actuator systems starting with landing gear (the most costly system) and flight control – the core of the systems aircraft architecture
- The overall weight, operational reliability, installation and maintenance benefit at a global level of electrical actuation solution

This will result in the creation of **standardised modules hardware families, interfaces and software environment** enabling the development and production of modular EMA technologies.

Project logo

Figure 4: Project logo

Project public website: www.actuation2015.eu

Figure 5: Website home page