1. Publishable summary

1.1 Project context and objectives

The “System for Green Operations” (SGO) is one of the six Integrated Technology Demonstrators of the CleanSky program. The main driver of SGO is represented by an eco-compatible design, aiming at reducing CO2 production and at optimizing aircraft energy management – see **Fig. 1**.

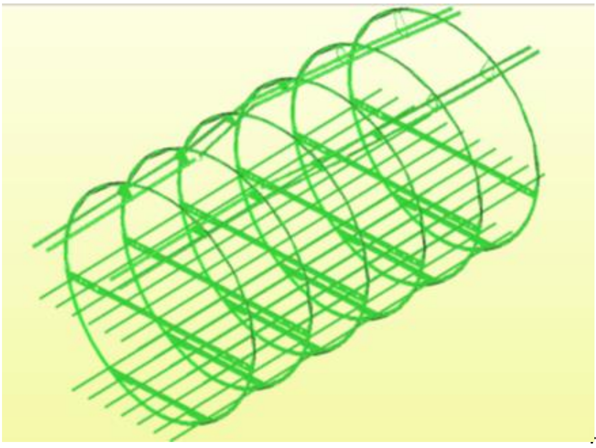
Fig. 1– SGO ITD main drivers and goals

Work package 2.3.3 “Optimized Electrical Wiring Interconnection System for More Electric Aircraft & More Composite Aircraft”, led by Safran Labinal (SEnS) will address very ambitious challenges for Electrical Wiring Interconnection System (EWIS) for future Aircraft.

The metallic bodies of “standard” aircrafts are commonly used as conductive electrical pathways for the return of direct and alternating currents, faults currents, lightning currents and also other functions related to voltage differentials, electrostatic charge draining, electromagnetic shielding etc. Such a procedure is not applicable in composite aircrafts because their bodies don’t assure the necessary conductivity, and a dedicated conductive electrical pathway (currently named “current return network”, hereafter referred as ALEEN, ALmost Equipotential Electrical Network) has to be integrated into the aircraft body.

Such networks can be practically realized in several different ways and can therefore have several features, e.g.:

a. It can be a network of interconnected longitudinal and lateral paths extending for the whole aircraft fuselage. Parallel and non-parallel paths can occur.
b. The paths may be made of wires, strips or also extruded metal sheets. Copper, aluminium and other types of conductive metals can be used.
c. The paths shall be fastened to the structure of the aircraft.



d. In case part of the aircraft structure is made of metal (e.g. structural beams, cages, rails to fix passengers seats, or also a whole sub-part of the aircraft like the nose) the current return network may be intentionally connected to such structures, which for this reason, become part of the return network.
e. The different parts of the network can be connected together by electrical joints (rivets, bolts and other connecting strategies).

Apart the implementation details it is obvious that not only the network can never be an ideal ground but also that worse performance than those currently obtained on metal aircraft may be expected. Therefore it is of interest to evaluate the effects the network has on connected electrical systems such as EWIS and more in general to estimate how it works with respect to each required function (e.g. return of direct and alternating currents, faults currents, lightning currents…).

In this frame, not only the compatibility of the critical/essential electrical and electronic systems with respect to indirect effects of lightning has to be assured[4], but also the aircraft-structure, the ALEEN, the cable-harness configuration and the cable-harness protection must be considered as a whole in order to optimize the overall wiring design and therefore to avoid over-dimensioning which could lead to undesired mass increase.

The **ARROW** project aims at developing a numerical methodology and a CAE tool (hereafter referred as "**ALEEN-L Modelling Tool**") suited to model user defined cable-harness configurations installed aboard an aircraft made of composite and conductive materials, equipped with an Almost Equipotential Electrical Network.
In particular the **ALEEN-L Tool** has to be suited to evaluate the $V_{oc}(t)$ and $I_{sc}(t)$ waveforms (V_{oc}=Open Circuit voltage; I_{sc}=Short Circuit current) at equipment loads, induced by lightning strikes on the aircraft, in order to allow the verification of their compatibility with the design and qualification values.

The tool is able to:

a) provide fully 3D modelling capability (detailed shape of the aircraft/ALEEN parts, 3D shapes etc.).
b) consider the composite parts of the aircraft, characterized by finite conductivity. In particular the Tool must be able to accurately model complex engineered materials (e.g. expanded foils on CFRP layers) in terms of impedance, skin and proximity effects. Characterization of the materials in terms of measured Surface Impedance must be allowed.
c) accept measured data as partial characterization of ALEEN and cable-bundle sub-parts[5] (because some parts are impossible or too costly to model);
d) manage the effect of the electrical connections among parts of the equipotential network (ALEEN) and of the aircraft.
e) accurately manage small elements in the frame of big models (for example the whole aircraft or the main part of it). Some other requirements about the modelling accuracy shall be derived considering the scope of **ALEEN-L** (e.g. maximum acceptable uncertainty about V_{oc} and I_{sc}).
f) accurately work in the very low frequency region (i.e. in the quasi-static region), where the well-known "low-frequency breakdown" makes a large number of numerical solvers ill-conditioned.

[4] i.e, the systems must continue to assure the functionalities for which they have been installed during and after lightning strikes

[5] In some cases is impossible or too difficult to only refer to modeling. A typical example is a "bonding screw". For such cases it is important to have the possibility to include in the numerical model of the aircraft some measured data (e.g. the contact resistance of the bonding), when properly de-embedded.

1.2 Work performed and the main results

Work performed during the first period of the project implementation (M1 – M12) is described here below.

The scope of the work was reviewed and the requirements of the entire activity assessed. In particular the modelling methodology was analysed and assessed both for the basic modelling methodology (Task 2.1) and the advanced modelling methodology (Task 2.2).
After the requirement specification at system level, the detailed assessment of the specific development activities was assessed, in details:

- the detailed requirements and relevant test plan (for elementary tests) for the upgrades of the 3D modellers (Task 3.1);
- the detailed requirements and relevant test plan for the development of the CHAPL module, that represents the harness input data processor (Task 4.1)
- the detailed requirements and relevant test plan (for elementary tests) for the upgrades of CRIPTE (Task 5.1)
- the detailed requirements and relevant test plan for the development of the ALEEN-L tool (Task 6.1)
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The following activities are presently on going:

- The detailed test plan for the system validation w.r.t. the SGO WP leader mock-up measurement; this activity is going to be finalized (Task 7.1)
- The development activities for the upgrade of 3D solvers (Task 3.2) and CRIPTE solver (Task 5.2)
- The CHAPL tool development (Task 4.2); also this activity is going to be finalized
- The development activities relevant to the ALEEN-L tool integration (Task 6.2 – Task 6.3)

The web site of the project has been created and is on-line (Task 8.3). Concerning the dissemination activities (Task 8.4), a paper titled *A Hierarchical Fast Solver for EFIE-MoM Analysis of Multiscale Structures at Very Low Frequencies* was published on the IEEE Transactions on Antennas and Propagation. The paper *Investigation of Split-Potentials Low Frequency Stabilization of Kernel-Independent Low-Rank Compressive Solvers* was presented at EuCAP 2014
The following dissemination events have been planned for the next period:

1. AMEREM Conference 2014 – presentation of the paper
A. Mori, M. Bandinelli, G. Sammarone, J.P. Parmantier, S. Bertuol, I. Junqua, F. Vipiana, M. A. Echeverri Bautista, G. Antonini, D. Romano, J. Genoulaz, T. Lebreton, "*The ARROW Project. Modelling of Lightning Indirect Effects on Composite Aircraft equipped with Current Return Networks*", accepted for presentation at Amerem 2014, Albuquerque, New Mexico.

2. International Symposium on EMC 2014 - presentation of the paper
D. Romano, G. Antonini, M. Bandinelli, A. Mori, "*Broadband full-wave frequency domain PEEC solver using effective scaling and preconditioning for SIPI models*", accepted for presentation at 2014 International Symposium on EMC, August 2014, Raleigh, North Carolina.

3. EMC Europe 2014 – presentation of the tutorial
M. Bandinelli, A. Mori, G. Antonini, D. Romano, "*Application of PEEC formulation to analysis of electrical networks in aircraft*", in *Proc. of EMCEurope 2014,* September 2014, Goteborg, Sweden.

1.3 Expected final results and their potential impact and use

The work in ARROW will provide numerical models for the electromagnetic analysis of the structure constituting an aircraft and of the cable harnesses installed on it, with particular reference to lightning excitations. Such numerical models will be implemented and organized in a CAE tool suitable to evaluate the open circuit voltages and the short circuit currents (and other electromagnetic quantities) induced by lightning strikes on the aircraft, allowing the compliance of a particular design.

Impacts of ARROW project are expected both in the more general frames of "*airplane security improvement*" and "*environmental aspect*" and with regard to important *technical aspects*.
The impacts on "*environmental aspects*" and "*airplane security*" are related to the fact that composite aircrafts are considered. As known, the application of composite materials allows several benefits with respect to the usage of "standard" metallic structures, mainly in terms of maintenance cost and fuel consumption reduction. On the contrary composite materials have worse electrical and electromagnetic performance because of their lower conductivity (which means higher induced voltages, lower shielding effectiveness etc.), so augmenting the vulnerability of the electrical/electronic systems to both internal (intra and inter systems) and external threats (lightning, HIRF etc.).
ALEEN concept has been identified as an innovative mean to control and reduce such kind of problems, but it is worth noting that also innovative tools are needed to support aircraft manufacturers in the analysis, design and verification of such a complex 3D element, which moreover strongly interacts with the whole aircraft.
ARROW project will provide such a support, in form of a validated CAE industrial tool properly interfaced to CAD design procedures. More in particular the following advantages are expected through ARROW:

- higher confidence in the design solution (risks reduction) of More Electrical Aircraft combined with full composite aircrafts;
- reduced design cost and "time to market", allowing for "virtual prototyping of the whole aircraft configuration and therefore allowing reduced bread-boarding activities;
- reduced cost related to certification, allowing a minor number of certification tests by reducing the number of configurations to be tested at aircraft level and helping a better design of the test-plan.

The technical aspects involved in ARROW will impact the European competitiveness not only at aircraft industry level, but also the:

- ships and naval industry (: "below deck" analysis and design)
- critical infrastructures protection against pulse and CW threats (for example: Intentional Electro-Magnetic Interference, IEMI)

A project public website was put up having the following address: **http://arrowproject.univaq.it/**

Fig. 2 – The ARROW web site home page