ALTERNATIVE ENERGY BASED SYSTEMS FOR ADVANCED UAV: THE "SAVE" PROJECT

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Abstract

SAvE (Systems for UAV Alternative Energy) is a research project funded by Piemonte Regional Government and assigned to Politecnico di Torino in sharing with Alenia Aeronautica. Aim of the project is the study of new, more efficient, more effective and more environment-friendly on board systems for advanced Unmanned Aerial Vehicles (UAV).

MALE (Medium Altitude Long Endurance) and HALE (High Altitude Long Endurance) UAVs are particularly critical from the energy consumption point of view, because of their need of flying continuously, for many hours, or days too, at high altitude. So new efficient solutions have be elaborated for Propulsive Power and for Secondary Power Systems.

To reach the Project global goal, SAvE activities will be focused on the verification of the feasibility of innovative Power Systems, able to be installed in a reference HALE UAV and to allow correct running of proper components.

1 Introduction

SAvE (Systems for UAV Alternative Energy) is a research project funded by Piemonte Regional Government and assigned to Politecnico di Torino in sharing with Alenia Aeronautica. Aim of the project is the study of new, more efficient, more effective and more environmentally friendly on board systems for future advanced Unmanned Aerial Vehicles (UAV). Fig.1 synthesises Partners, topics and goals of the research project.

It has to be remembered that Alenia Aeronautica is an aeronautical industry on the cutting edge of research about Unmanned Aerial Vehicles. Fig. 2 and Fig. 3 show two technological demonstrators recently developed by Alenia Aeronautica and tested in flight: the first, called "Sky-X", is jet powered and devoted to future development of "Unmanned Combat Aerial Vehicles" (UCAVs); the second is the "Sky-Y" and is a demonstrator of future UAVs, both MALE (Medium Altitude Long Endurance) and HALE (High Altitude Long Endurance).

Politecnico di Torino too is strongly involved in UAV topics [1], in particular in close cooperation with Alenia Aeronautica.

Future UAVs (both MALE and HALE), that Alenia plans to develop in the next future, are particularly critical from the energetic point of view, because they have to match the requirements of flying continuously, for many hours, or days too, at high altitude. So new efficient solutions must be elaborated for "Propulsive Power" and for "Secondary Power", i.e. power to be spent on board to allow a correct feed of several users. The two Power Systems are strictly connected, because the engine is usually the source of both Propulsion and Secondary Power, but the Secondary Power must also be available on ground, when the engine does not work and, more relevantly, in emergency mode, if the engine has to be cut off during flight. This last requirement is highly critical for MALE and HALE UAVs in civilian utilisation because of the necessity of controlling aircraft without propulsion (please remember that the descent from operational altitude could take a lot of time) to allow an emergency landing, or, at least, to reach terrain far from people or infrastructures.

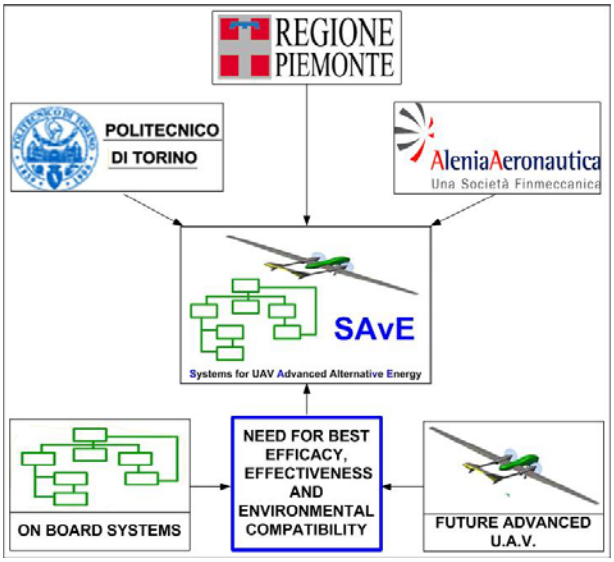

Fig. 1. Partners, topics and goals of "SAvE" research program

Fig. 2. Alenia Aeronautica "Sky-X"

Fig. 3. Alenia Aeronautica "Sky-Y"

The above discussed characteristics, together with the feature of being environmentally friendly are fully applicable to future UAVs envisaged for civilian utilisation. As far as this topic is concerned, it is important to remember that other initiatives are under discussion and one in particular, under the Piemonte Region umbrella, will address Advanced Land Monitoring System in which a central role is played by a future HALE UAV that will benefit from the results of SAvE.

2 SAvE Research Program Context

The HALE UAV, envisaged in order to make future implementation of this Advanced Land Monitoring System possible, is perfectly fitted with the characteristics that can be considered for future products. Consequently SAvE program has been structured and planned in order to explore and compare alternative and innovative configurations for on board systems of such future UAVs. Focusing the attention on the Secondary Power System, the traditional solution is the one based on engine(s) that, in addition to provide propulsion, feed secondary power by mechanically driven electric generators and hydraulic pumps. In case of gas turbine engines, the secondary power is fed by air energy, or simply heat, directly derived by the engine core. By now a well established trend is the substitution of hydraulic users by electrical ones, which might thus lead to the connection of only electrical generators to the engine. The well known "all electric" philosophy implies also the elimination of the bleed air and the adoption of an electric engine's starting system. Quite obliged consequences are the need of having high voltage DC generated and of avoiding brushes.

Please note that, in the case of HALE aircraft, reciprocating engines are very attractive, because of their better performances at high altitude, thanks to the fact of being supercharged and because of their reduced specific fuel consumption. In particular Alenia Aeronautica believes that a very interesting opportunity will be given by reciprocating supercharged "diesel" cycle engines. The reasons are reported hereafter:

– this kind of engine can be easily supercharged in order to give enough power at very high altitude as requested;
– the specific fuel consumption is low and this cope very well with the long endurance required;
– the fuel could be the same normally used for turboprop and turbojet engines;

– the power to weight ratio has been greatly improved for this kind of engines even in the automotive context; so these engines will be automotive derivative, with considerable development cost and risk reduction.

It is relevant to recall that the "Sky-Y" technology demonstrator aircraft is now flying with an automotive derived supercharged diesel engine.

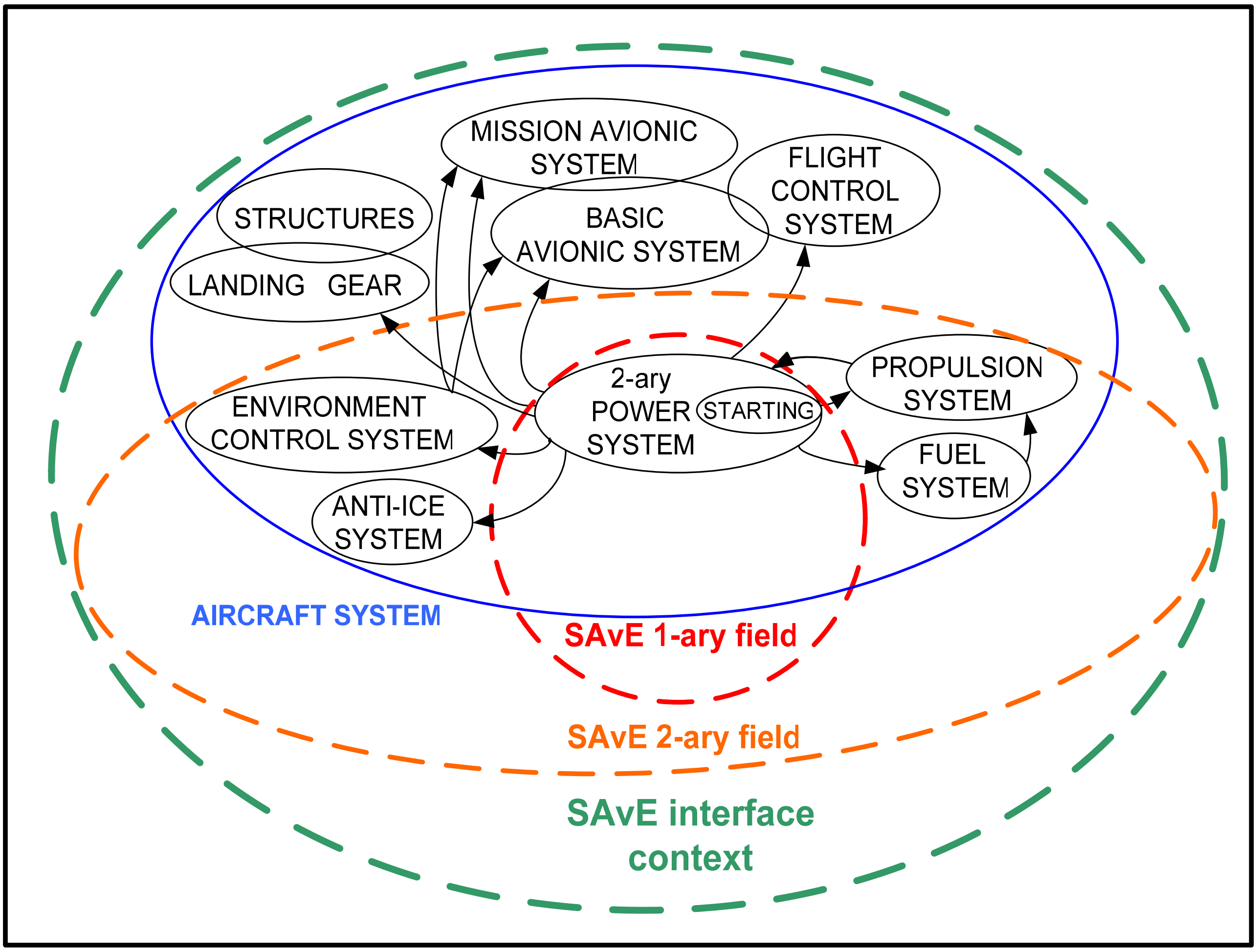

Fig. 5. Main field of study of SAvE, 2-ary field of interest and interface context

Within the scope of SAvE it has been decided, as Fig. 5 shows, to study mainly the Secondary Power System, with the only assumption of the "all electric" choices [2]. The Secondary Power System will thus be the primary field of research of SAvE project. Propulsion System, Fuel System, Anti-Ice and Environment Control System will be also considered, because their close connection with the Secondary Power System could suggest changes of their configuration, changes that will be considered and evaluated. The kind of engines will not be the object of investigation, but their relevant characteristics will have great influence in the work.

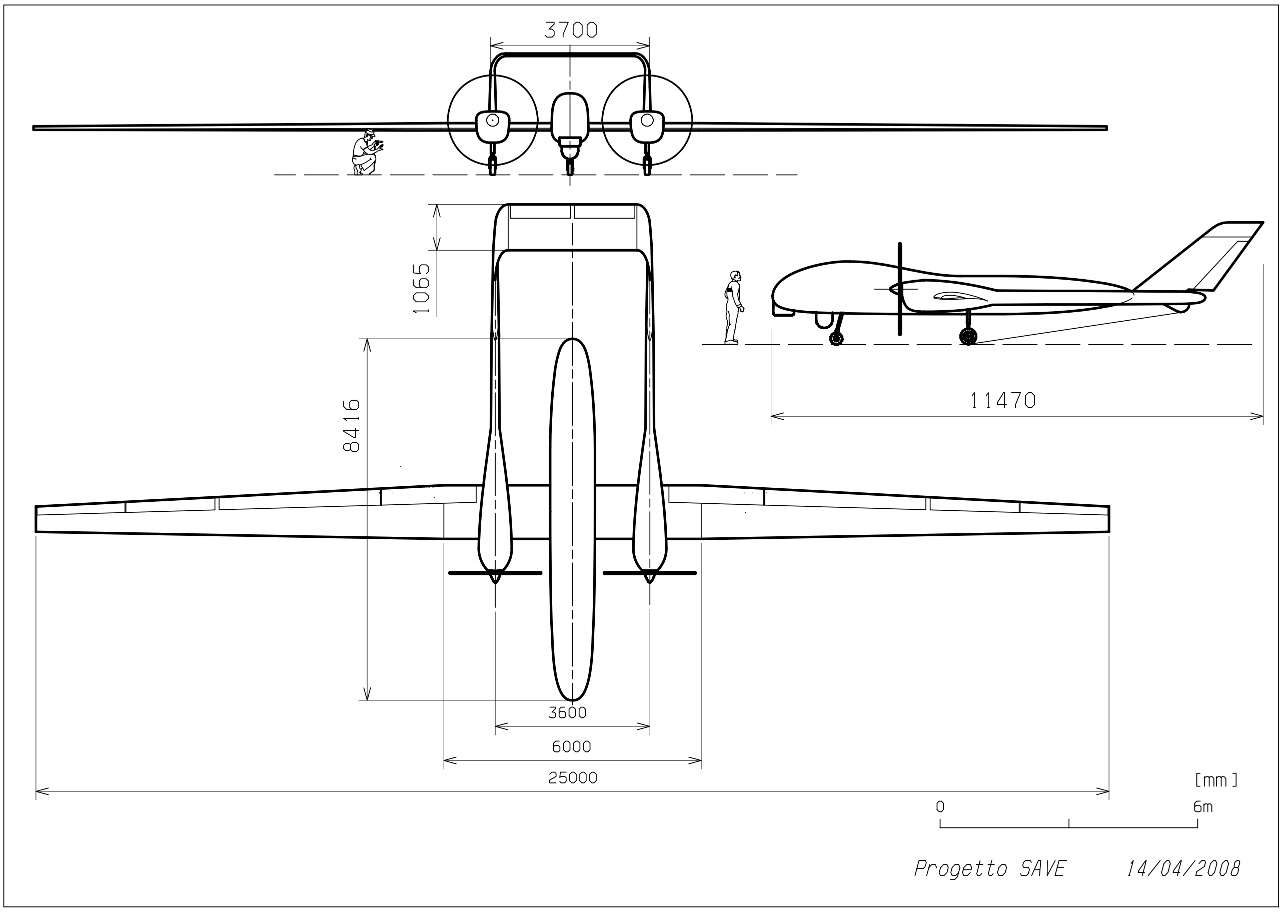

Fig. 6. SAvE reference aircraft; 3 view drawing

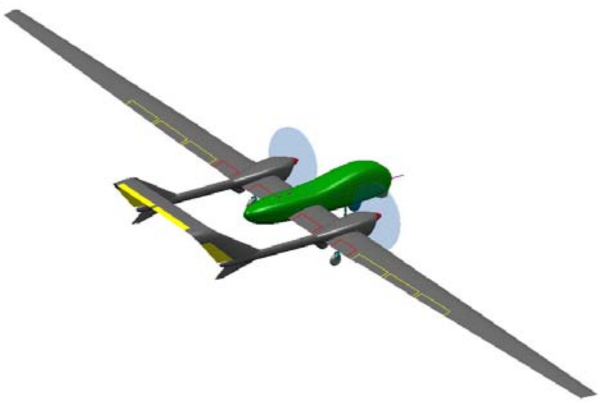
Fig. 7. SAvE reference aircraft; 3-D model

Finally it has to be remembered that the Aircraft Configuration, the Structural Layout, the Landing Gear, the Avionic System (both basic and mission) and the Flight Control System (this one obviously based on electrical powered actuators) will not be studied within the SAvE program, but they will represent the interface context for the other systems, thus being a source of requirements and boundaries.

For a better comprehension of such SAvE interface context please see in Fig. 6 and Fig. 7 (respectively the 3-view drawing and the 3-D model) the aircraft configuration that will be considered in the research program. Main technical data of the aircraft are reported in Table 1. We have already discussed the innovative choice of diesel engines for future MALE-HALE UAVs of Alenia Aeronautica; in particular, the SAvE reference aircraft will be powered by two 2400 cc Diesel (automotive derivative) illustrated in Fig. 8. In order to understand why reciprocating engines are considered an ideal choice for MALE-HALE UAVs, Fig. 9 shows the power available also at very high altitude thanks to the fact of being supercharged.

3 Alternative solutions for subsystems configuration

During the preparation phase of SAvE project proposal and the start up phase of the activity an intensive team work has been directed, other than in a systematic documentation effort, towards two well defined areas: a) the definition of a SAvE reference aircraft, its systems (1-ary and 2-ary SAvE field of interest) and the requirements document, b) the conception of alternative solutions of such on board systems configurations.

Dimensions	
Length:	11.47 m
Wing Span:	25.00 m
Wing Area:	25.00 sqm
Aspect Ratio:	25
Weights	
O.E.W.:	2213 kg
Fuel Weight:	1200 kg
M.T.O.G.W.:	3763 kg
Performances	
Endurance:	30 h
Radius:	2500 NM
Operational Altitude, Z:	14000 m
Time of climb:	1,5 h
Cruise speed:	200 KTAS
TO and Landing lengths:	1800 m
Power	
2 x 230 HP (Z $\leq$ 10000 m)	
Payload	
– Sensor EO/IR.	
– Radar: SAR radar.	
– Datalink NBDL-LOS (Narrow Band Data Link-Line Of Sight) / WBDL-LOS (Wide Band Data Link-Line Of Sight).	
– Datalink WBDL-SAT (Wide Band Data Link – Satellite).	
– Electrical Power needed : about 5 kW.	

Table 1. Main technical data

3.1 Systems Specification

A document containing the general requirements and specifications has been written down by a Joint Team Politecnico-Alenia Aeronautica. While the top level requirements, i.e. those requirements which refer to the aircraft and its mission, are strictly connected to the industrial perspectives and to the contexts in which the future MALE and HALE UAVs will operate, the systems requirements, pertaining to the SAvE project, have been agreed upon by the Joint Team on the basis of the following considerations:

a. functionalities and coherence with the SAvE reference aircraft, its mission profile and consequently its avionics, the flight control and the propulsion system;

b. the safety levels that have to be pursued in accordance with the envisaged employment of the aircraft also in the civil field and in the national territory;

c. environmental compatibility, pursued through the reduction of emissions and consumptions and through the consideration of environmentally friendly alternatives (for instance the adoption of only "natural" fluids for the cooling system);

Fig. 8. Diesel engine

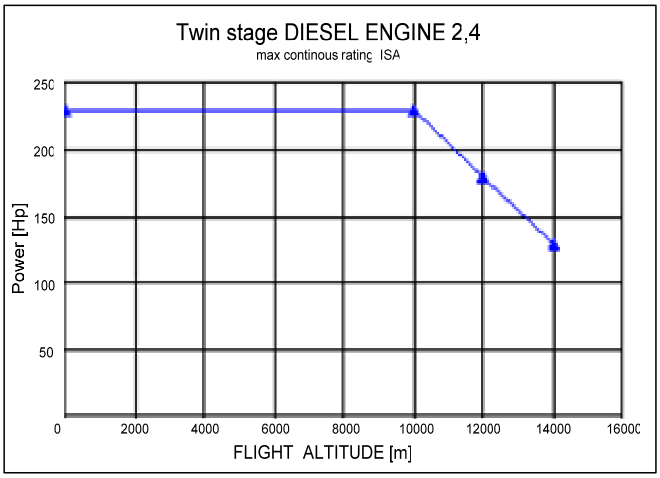

Fig.9. Supercharged Diesel Engine Power available vs. Flight Height

GENERAL REQUIREMENTS	SYSTEMS REQUIREMENTS
– The SAvE aircraft shall be designed to perform a design-reference mission (see Table 1). – The SAvE aircraft shall be able to operate beyond line of sight. – The SAvE aircraft shall have a nominal radius of 100 NM. – The SAvE aircraft shall be capable of an endurance, at optimum condition, up to 30 hours. – The SAvE aircraft shall be able to patrol the mission area for no less than 15 hours. – The maximum service ceiling shall be no less than 14000 m – The SAvE aircraft shall be able to takeoff and land in no more than 1800 m. – The SAvE aircraft shall be able to takeoff and land autonomously. – The SAvE aircraft shall be able to achieve a maximum operating velocity (VMO) of at least 200 KCAS. – The time of climb to achieve the maximum service ceiling shall be no more than 1,5 hours. – The SAvE Aircraft shall be designed with a cumulative probability to loose the system of $5*10^{-6}$. per flight hour or less. – The combination of all catastrophic failure conditions is characterised by an occurrence of $5*10^{-7}$ per flight hour or less. – The SAvE Aircraft will be provided with a “Safe Flight Termination” mode. – The SAvE aircraft structure shall be designed applying as a guideline the criteria contained into the EASA CS-23 Standard. – All the relevant requirements and assumptions for loads and structural design shall be considered in the design activity. These requirements shall define: ▪ design masses; ▪ design flight configurations; ▪ design flight envelop; ▪ manoeuvre loads criteria; ▪ gust loads criteria; ▪ ground loads criteria; ▪ miscellaneous loads criteria; ▪ flutter and aeroelastic requirements. Basic requirements are reported as follows: ▪ Limit loads are the maximum loads expected in service (design loads). Loads are limit loads. ▪ The structure shall be able to support limit loads without permanent deformations. ▪ Structural deformations shall not interfere with safe operation of the airplane, at any load up to limit load. ▪ Ultimate loads are limit loads multiplied by prescribed factors of safety (Ultimate Load Factor). ▪ The factors of safety (Ultimate Load Factor) shall be TBD, unless stated otherwise in the *Structural Design Criteria*. – Safety shall be considered both as loss of critical functions and from the point of view of installation, requiring a “Safety Zonal Analysis”. – The accessibility to an area/item shall be in relation to the frequency of the need to gain access to the area/item. The Aircraft shall have an in-flight failure detection capability (CBIT and/or Visual) covering the safety critical failures.	**Electrical Power Generation System** – The secondary power shall be totally electric. – Both dc and ac electric power shall be available on board the aircraft. – Dc electrical power shall be 270 Vdc or 28 Vdc. – Flight controls will be fed by dc. – The maximum continuous rating power requested in normal flight conditions shall be 6000 W + ECS (Environmental Control System) + Anti-Ice (TBC) without Payload.. – The maximum continuous rating power requested in Safe Flight Termination mode shall be TBD W + Anti-Ice (TBC). – An independent source shall be related with every engines. – Every source of electric power shall be able to perform mission completion. – An independent stand-by source shall guarantee the Safe Flight Termination. This source cannot be a RAT not to interfere with descent performances. – Batteries and possible Fuel Cell shall have a safe installation. – The Electric Power Generation System shall provide autonomous engine starting. – For ground operations external electrical power connections shall be provided for every kind of electrical power available on board. – All Electrical Power Generation System regulations shall be observed. **Anti-Ice System** – The SAvE aircraft shall be adequately protected by ice during normal flight. – The ice protection shall be available during descent in Safe Flight Termination mode too. – The Anti-Ice System safety level shall be consistent with Safe Flight Termination mode safety level. **Environmental Control System, ECS** – The ECS shall be provided for Avionics cooling needs. – The ECS shall not be functional critical. – Fluids utilized by ECS shall be environmentally friendly. **Fuel System** – The fuel shall be either the normal TAG fuel or Diesel fuel. – The fuel shut off valve, controlled by the GCS, shall also enable the emergency shutdown. – A safety switch device, located on the airframe, shall allow the emergency activation of the fuel shut off valve. – The fuel system shall have integral tanks or self-sealing tanks. – The defueling sequence shall minimise structural loads. – A low level switch(es) shall detect the residual amount of TBD% of the total fuel capacity. – Ground servicing of fuel shall be through a single point receptacle. – The emergency defueling system will be provided. – The emergency defueling system shall be related to Safe Flight Termination mode. – A vent device shall allow the correct fuel vent. – All Fuel System regulations shall be observed **Anti-Fire System** – The SAvE aircraft shall be adequately protected against fire, in particular inside engine’s nacelles.

Table 2. System Specifications.

d. energetic efficiency pursued also through weights reduction and through the optimization of the various systems interfaces.

Fig. 10 shows the logical process which, on the basis of above cited considerations, has led to the definition of the systems specifications. Starting from these specifications, different innovative systems solutions, alternative to the more traditional ones, have been developed (considering in particular the electric power generation [1]). These innovative solutions will be then analyzed more into the details, in order to verify their feasibility and their effectiveness.

Systems requirements and specifications are thus the drivers of the SAvE project, as they direct the research towards innovative solutions, taking into account practical aspects of a realistic scenario in order to individuate the best systems configuration for a near term development.

The outputs of the requirements document are summarised in Table 2.

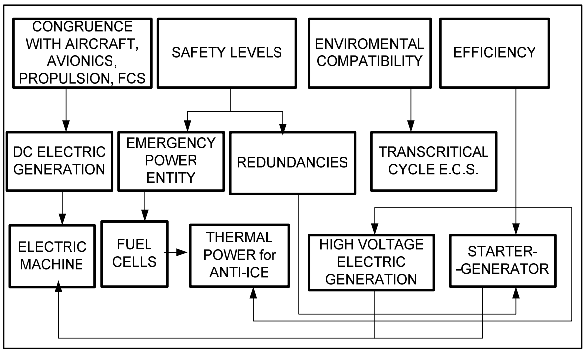

Fig. 10. Logical process followed for systems requirements definition.

3.2 Alternative concepts for Systems configurations

On the basis of the Systems Requirements the Joint Team has started its second activity, i.e. the definition of a certain number of different concepts for the configuration of those systems that are the main subject of the SAvE research program. The logic procedure, that has guided this activity, is characterized by successive steps. The first one consists in identifying which technological solutions in the various fields of the SAvE systems have to be taken into account for a possible future utilization. The result of this analysis is reported in Table 3, where possible choices between alternative solutions are listed. It is clear that the identification and the assessment of the technological aspects and their related alternative solutions, shown in Table 3, have stemmed from an intense activity of documentation, study and testing, run in parallel to the Joint Team activities mainly by academic research groups of three different Departments of the Politecnico di Torino, in particular the Department of Aerospace Engineering, the Department of Electric Engineering and the Department of Chemical Engineering.

Technology element	Alternatives
Electric Generation	28 Vdc vs HVdc (270 V)
Starter	Only Starter vs Starter/Gen
Starter/Generator	Alone vs Starter/Gen +Gener.
Electric Machine kind	Brushless vs Switched Reluctance
Power Storage	Batteries vs batteries + Fuel Cells
Fuel Cells H2	Stored vs by Reforming
E.C.S.	Traditional vs Transcritical
Anti-Ice	Utilising F.Cells Thermal Power or not

Table3. Alternatives considered.

It is quite obvious that, taking into account two alternative solutions for each technological element and considering all acceptable combinations between them, there are many tens of possible global configurations for the SAvE systems.

Some examples of these combinations of different alternatives are illustrated schematically in Fig. 11, 12, 13 and 14.

In particular, Fig. 11 shows a configuration, which has been named “traditional”, because it is characterized by the most traditional choices for all technological aspects listed in Table 3. This configuration has been considered as the reference configuration for all the others that are going to be elaborated. In fact at the moment the Joint Team is considering a few tens of configurations. The most promising of these configurations will be chosen and then, later on during the research program, will be fully developed.

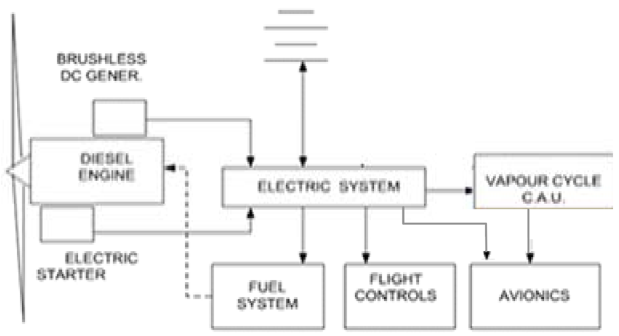

Fig. 11. Traditional Configuration.

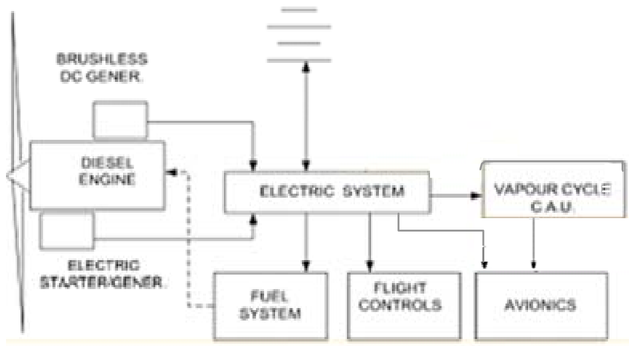

Fig. 12. With Starter/Gen + Generator

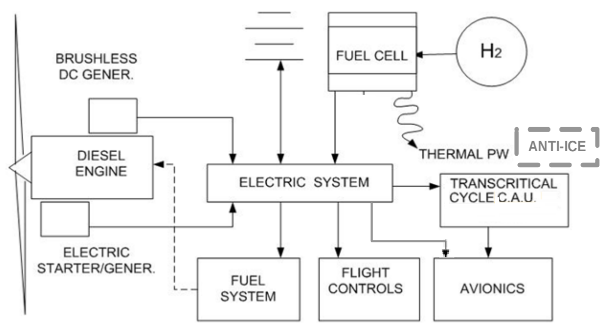

Fig. 13. Fuel Cells with H2 stored

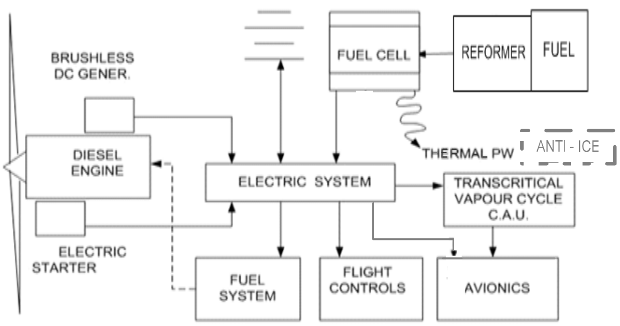

Fig.14. Fuel Cell with Reforming

4 Further activities

Next activities will focus on the complete definition and development of the most interesting systems configurations, where all systems are fully integrated.

Fig. 15 shows the general schedule of the whole SAvE Program, where it is possible to see the classic design approach: after the definition of alternative configurations and their preliminary sizing, both functional and physical simulation models can be developed. The former will be useful to better understand the technical performance of the systems, while the latter will be fundamental to estimate the mass properties of the systems and to proceed with the installation studies and, consequently, to evaluate R.A.M.S. [3] and costs characteristics.

It is worth noting that the Digital Mock Up (see an example in Fig. 16) is extremely useful to perform R.A.M.S. analyses [4].

As far as the functional simulation models are concerned, it has to be remembered that, apart from being useful for the sizing and the verification of the systems design, as shown in Fig. 15, the systems functional simulation models will be combined with simulation models, designed by the Alenia Aeronautica Team, of the scenario, the aircraft, the avionics and the flight control system to constitute a global integrated simulation environment, which will allow to verify and validate the final solutions at the end of the project.

Getting back again to Fig. 15, it can be noted that, apart from the activities of the above mentioned Joint Team, there are other contemporary research activities of the Alenia Aeronautica Team and of the Politecnico di Torino Teams, which, as a matter of fact, have started before the planned "Go-Ahead".

These activities can be summarized as follows:

a. documentation, elaboration of the mission profile and thus of the SAvE aircraft concept, the definition of the propulsion, flight controls and avionics systems, the development of the simulation models of those systems and the integration of all models in the global integrated simulation environment (Joint Team);

b. documentation, thorough analysis and experimental investigation of the technological aspects and, where necessary, support of the Joint Team in the development of the SAvE systems simulation models (Politecnico di Torino).

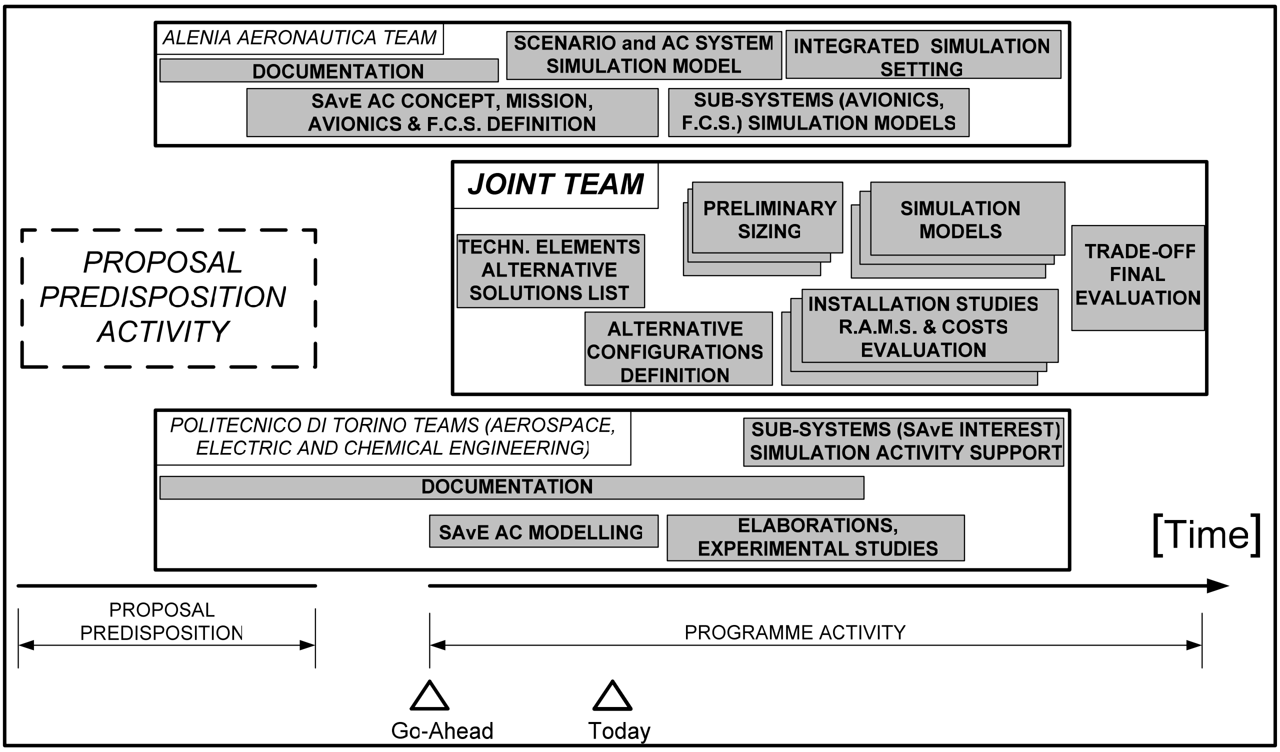

Fig. 15. SAvE program schedule

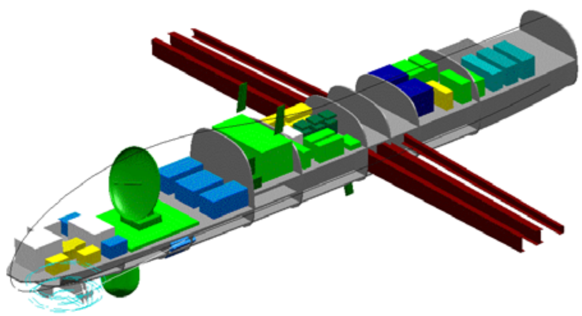

Fig. 16. Example of Digital Mock-Up at Conceptual Level.

Eventually, talking about the Joint Team, whose main activities have already been described, it is worth noting that it represents also a new type of organization, which can be called "Technological Incubator" as it is an integrated environment, located inside the Industry (in our case Alenia Aeronautica), where about ten people (one third coming from the Industry itself and two thirds coming from the University) will work together side by side. Apart from the important exchange of skills, competences and information, the expected advantage is above all the professional growth of young researchers and PhD students, which will be fundamental either if they will then work in Industries or if they will work in Universities. Last thing to be said about the Joint Team is that this new type of organization could be tested during the SAvE program and then successfully used also in other future applications.

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