4.1 Final publishable summary report of the FutureWings Project

Executive summary of the project

The FutureWings project aimed at the theoretical study, and at the preliminary experimental validation, of a small scale model of a wing structure having the capability of changing its shape through the use of a new type of hybrid materials, based on the implementation of layers of piezo-electric fibres into laminates of composite materials.

The project developed according the following steps that are perfectly correlated to the planned work packages of the project:

(1) Study of the state of the art concerning the use of piezo-electric components devoted to force the shape of beams or other type of structural elements typically adopted in the field of aerospace engineering (WP1)

(2) Initial definition of the requirements for the implementation of the electronic control system necessary for the activation of sets of Macro Fibre Composite components (MFC) (WP1)

(3) Analytical study of the Future-Wing concept: a thin walled beam whose shape can be controlled by means of piezo-electric actuators (different configurations of this type of beams have been numerically studied to define the geometry that has been assumed to produce a small scale model of the so called Future-Wing Unit). The numerical procedures to simulate an hybrid structure have been defined and verified. Two distinct geometry of specimens made up of hybrid material (composite material & MFCs components) has been studied and designed: torsion specimens and bending specimens (WP2, WP3).

(4) The specimens made up of hybrid composite active material has been manufactured and tested. The specimens undergone active bending and torsion deformation and the measurements of the displacements have been executed adopting laser sensors. Subsequently, the experimental data have been used to verify the robustness of the numerical technique necessary for simulating the Future-Wing Unit (WP4).

(5) Starting from the technical information collected thank to the modelling and testing of the hybrid specimens, the numerical analysis and the design of the Future-Wing have been implemented. Great efforts have been devoted to the implementation of numerical models which have allowed the simulation of a piezo-actvated structure under the effect of aerodynamic loads. Fluid Structure Interaction analyses have been implemented to carry out the analyses. Thank to the results of these numerical campaign the design and the manufacturing of the Future Wing Unit have been executed (WP5).

(6) A specific and novel control system of the MFC actuators has been studied and developed within the project. In particular a multiple channel high voltage amplifier has been designed and manufactured. This product allows to control simultaneously of a large number of MFC actuators also in a dynamic mode. Moreover a dedicated digital apparatus has been acquired and assembled for the execution of the tests on the morphing wing section (WP6).

(7) Static deformation tests has been planned and executed on the Future Wing Unit (the wing section profile of the unit is symmetric): for this unit both the leading edge and the trailing edge can be activated. Some measurements of the displacements have been executed and the results compared with a good level of satisfaction with the analytical data (WP7).

(8) A very important task of the project has concerned the development of a numerical model of a the so called Future-Wing Aircraft that is an aircraft with morphing aerodynamic surface (the wings for example). The aeroelastic model of such type of aircraft has been developed and its performances have been compared with those of a conventional aircraft (a reference aircraft has been used in the study). Typical aeromechanical manoeuvres have been simulated for both the aircraft models. Moreover a flight simulator has been implemented to verify the aeromechanical behaviour of the futuristic aircraft concept.

(9) In the development of the project young engineering students have been involved and the project itself has represented a very important educational training. The dissemination activities have been principally

devoted to show the results obtained at the end of the project through the participation to technical meetings (WP9).

Summary description of project context and objectives

The present project proposal was born starting from a very simple concept:

THINK OF AN AIRPLANE AS A GREAT BODY WITH ITS END STRUCTURES (WINGS, HORIZONTAL TAIL SURFACES, VERTICAL TAIL SURFACES, CANARD SURFACES) THAT COULD HAVE THE POSSIBILITY TO CHANGE THEIR SHAPE AS THEY HAD INTERNAL NERVE ENDINGS AND MUSCLES

In this sense, an interesting alternative to the use of high velocity control surfaces of an aircraft could be represented by "self shaping aerodynamics surfaces", i.e. the wing-box of the aerodynamic surfaces are conceived as **"beams" that can be elastically deformed on command along their entire length** and that can be actively managed during aircraft maneuvers in order to obtain the required aerodynamic forces distribution.

Such performances of the primary structures of an airplane can be obtained through the application of the composite hybrid materials in which some layers are manufactured with new generation piezoelectric fibers that can be drowned and trigged by relatively low voltage.

More in particular, the deformed shape of the supporting structure of a Future-Wing will be obtained exciting active piezo-electric layers in a quasi-static manner, and that gives us the possibility to use a low electric power level: In fact, within the project activities, one of the partners has developed a new model of Macro Fiber Composite (MFC) patch working at a reduced level of voltage. Moreover also an implementation of the combined sensor-actuator functions has been executed within the project.

A small scale model of Future Wing has been manufactured in the second period of the project: it has been realized through a specific design activity, based on the experience done testing ad hoc specimens of the hybrid material and setting up non-linear calculation models, which have started in the first period. Mechanical deformation tests on this model has been carried out to verify the technical feasibility of the FutureWings concept on the basis of available piezo-components technology.

At the same time, a large part of the scientific efforts has been devoted to the theoretical study of the aeroelastic behaviour of an innovative aircraft based on the FutureWings concept, that is an aeroplane without high velocity control surfaces on wings (ailerons). A numerical model of a complete piezo-wing aircraft has been set up and a steady-roll maneuver has been simulated. Moreover two three-dimensional models of wings have been analyzed by FSI method (coupled Structural + Piezo-Electric + CFD analyses) and compared.

One of the partners, on the basis of the deformation results obtained carrying out two dimensional Fluid Structure Interaction analyses on piezo-wing sections, has set up a tool which allow the construction in a real time of the geometry of a morphing wing that can be used for manipulating in a very easy manner three-dimensional structural grids and three-dimensional aerodynamic grids.

Another important task regarded the implementation of a flight simulator for the Future Wing Aircraft. The mathematics of the flight simulator has been developed on the basis of the aeromechanical data extracted by previous aeroelastic analyses; a graphical tool has been implemented to reproduce typical maneuvers of the aircraft.

The entire project was divided into 10 Work Packages and 23 Tasks having the following planned objectives (which have converged into the single more above mentioned goal of the Project that is the feasibility study of a morphing wing based on the use of piezo-electric actuators):

Obj. N.1: Characteristics relevant to the utilization of PiezoElectric Fibres Laminae into "active structures". Measure of the structural characteristics (static, dynamic, effects of temperature). Are the laminae with PE fibres embeddable within laminates of composite material rather than simply be glued as MFC? Identification of future research to be done to improve their performance.

Correlated activities: dedicated hybrid specimens have been designed and manufactured. The measurements of the structural characteristics of these specimens have been carried out and these results have been used as reference for the design of the Future Wing Unit

Obj. N. 2: Utilization limits of the with PiezoElectric Fibres Laminae as structural active components.
Which deformations imposed by the laminae with PE fibres are necessary to obtain the aerodynamic control of a wing? How many laminae of PE are necessary to produce such deformations? Is this number realistically applicable?

Correlated activities: experimental and numerical activities provided the technical limit (max applicable deformations) of available MFC patches. Anyway, the partner that supply the piezo-patches has suggested the use of a new type of single crystal piezo-fibers which can guarantee very high deformation levels with respect to standard MFC patches.

Obj. N.3: Comparison between the structural behaviour of a Future Wing and a Conventional Wing.
What are the structural differences between a wing with embedded PE Fibres Laminae compared to a conventional wing (deformability, weight, simplifications, complexity)? What are the differences in their aeroelastic behaviour?

Correlated activities: the models of the two wing has been constructed and analyzed adopting the Fluid Structure Interaction technique. Very complex analyses have been carried out and the comparison of the two wing has been executed (a roll maneuver has been simulated).

Obj. N.4: Development of new calculation techniques specific to the purpose.
Development of analytical models for the calculation of active modular wing structures (Future-Wing Unit). Development of a computer code for the optimization of the active structure (balance between the lay-up of passive carbon-fibres layers in the structure and the distribution of the minimum number of active PE layers to get the aerodynamic forces consistent with the structural strength).

Correlated activities: the numerical methodology adopted to reach the Objective N. 3 has been first adopted to study two-dimensional wing sections (a section with a flap and a section piezo-activated). This preliminary activity allowed the construction of the complex three-dimensional model of the piezo-wing.

Obj. N.5: Integrability of Piezo Electric Fibres Laminae as structural active system in a wing.
What are the technical limits (number and typologies of wire connections, insulation's problems), drive (voltage, power) and control (software) that might prevent the installation and the use of a large number of PE Fibres Laminae in a wing structure?

Correlated activities: two distinct units of the Future Wing has been studied: a torsion unit and a variable camber unit. The variable camber unit has been designed and manufactured adopting the same methodology used for the hybrid specimens fabrication. A multi-channel high voltage amplifier has been designed and manufactured to control the Future Wing Unit. This unit has been tested with success under the applied voltage loads.

Obj. N.6: Feasibility and limits of the Future Wings Airplane concept.
To which extent the presence of PiezoElectric Fibres Laminae affect the mechanical response of the structure? What is the expected level of deformation that active elements can produce inside a structure? What are the technological limits to increase the performance of hybrid composite laminates having embedded PiezoElectric Fibres Laminae, and what still needs to be done to overcome such limits?

Correlated activities: the available technology allows the realization of a morphing wing that shows similar characteristics of a conventional wing (equipped with an aileron surface) under specific limits (deflection angle of the standard aileron surface ranging between 5-8 degrees). Within the aim of a Level 0 project it seems realistic that an improvement of the performances of piezo-electric materials in the next decades will provide an industrial implementation of the Future Wing concept.

Preliminary conclusions

Obj. N.1: The hybrid specimens made of composite substrate material (carbon fiber type and glass fiber type) provides good performances both in bending and in torsion. The possibility to insert the MFC patches as inner layers of a hybrid composite structure has not been followed and implemented because the deformation efficiency of the piezo-composite thin walled structures increase with the distance of the active layer with respect to the neutral plane of the wall.

Moreover a very interesting and novel technological experience has been implemented and developed within the project concerning the possibility to reduce the voltage level used at present to control the MFC patches (this last topic represents an example of results exploitation of the FW project in view of application of the low-medium voltage MFC patches in other branches of the engineering and in other branches of the industrial market).

Obj. N. 2: Thank to the deep aeroelastic studies carried out on two-dimensional wing sections, on the two three-dimensional half-wings and on to a complete aeroelastic numerical model of the Future Wing aircraft the limit of the present technology has been defined (as an example a roll manoeuvre has been simulated in a satisfactory manner with 5 deg deflection of the aileron surface of the reference aircraft). Also the take-off conditions of the reference airplane and of the future wing airplane have been analyzed: in this case the practical conclusions indicate that piezo-materials with increased performances of 400% are required to obtain similar performances of the reference aircraft. On the other hand a research carried out within the project indicate that new types of piezo single-cristal fibers already exist on the market having deformations capability four time the present piezo fibers used to manufacture the MFC patches. In this sense, a new research branch can be developed also thanks to the exploitation of the FutureWings project results.

Obj. N. 3: The comparison between a Future Wing and a Conventional Wing has been carried out with high level of reliability (by using FSI methodologies). The modelled Future Wing shows very good structural behaviour (similar deformation level both at the sea level and at the cruise altitude). The mass of the Future Wing is similar to the examined traditional reference wing. The static aeroelastic behaviour of the Future Wing is reliable. Very complex analyses have been implemented to control the piezo-material effects and to carry out at the same time the fluid dynamic analyses on the deformed wing. Further studies are required to define the dynamic aeroelastic response of such a wing. As a general result it can be said that the Future Wing structure must be conceived in a complete new manner with respect a traditional wing structure configuration: in particular “transition zones” with high deformation capability are required.

Obj. N.4: As said above, in the project 3D fluid structure interaction analyses have been carried out including the voltage control of the piezo-patches materials. A particular strategy has been implemented to simulate directly the voltage loads on the piezo-elements. Three-dimensional models of the active layers have been constructed referring to the real thickness of the MFC piezo-patches (that is 0.3 mm): this fact has represented a challenge in the development of the numerical activities on the 3D piezo-wing in the second period of the project.

Obj. N.5: The analyses and the experimental activities developed in the project highlight the completely new approach required to design, to manufacture and to control of a Future Wing structure. The wiring technique represents a challenge for a real structure. Also the connecting methods of the piezo-patches represents a complex technology problem. The electronic system for to control in a multi-channel way the piezo-patches has been developed properly and at the end of the project the possibility to implement high voltage micro-amplifiers has been highlighted: by using these type of amplifier it is not necessary to have wires along all the structure with very high voltages running, on the contrary, final amplification step occurs directly in a micro-amp embedded in the layout of each piezo-patch. This new type of integrated patches have been preliminary studied and designed. This is another example of exploitation of the project results.

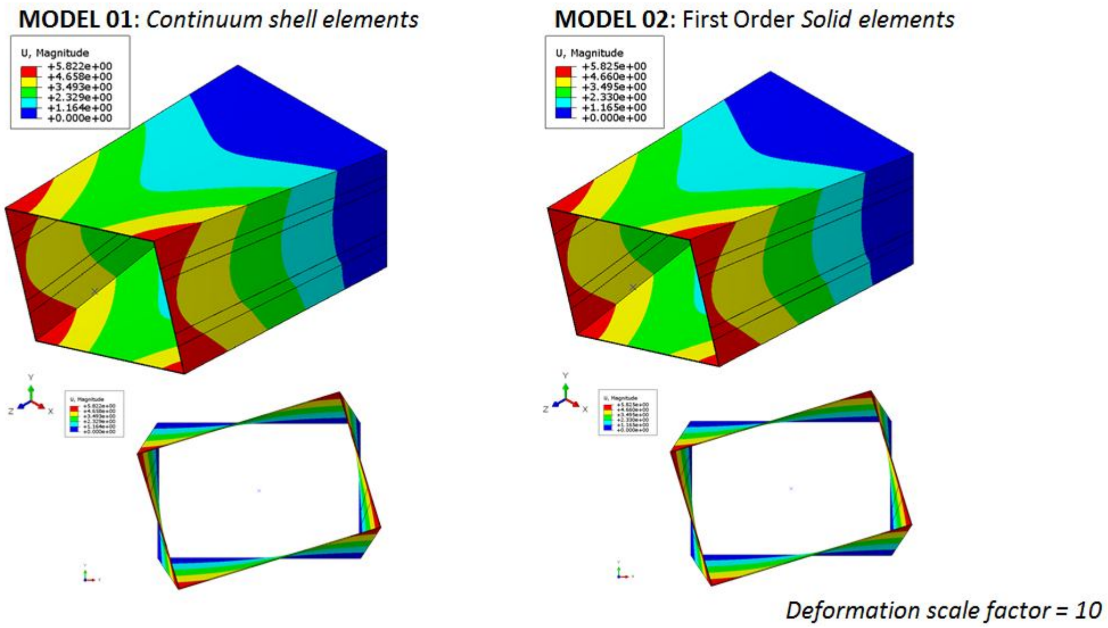
Obj. N.6: As anticipated in the discussion of Objective N. 2, at present the simulation of a complete Future Wing aircraft has shown that to obtain similar aeromechanical performances of the reference aircraft (at the take-off conditions) the mechanical characteristics of the piezo-patches should increase by about a factor of 4. This represents a limit with respect the present piezo-material technology level, but as said, new materials having very high strain capabilities and very high fracture toughness will be available on the market in the very near future.

Description of the main S & T results/foregrounds

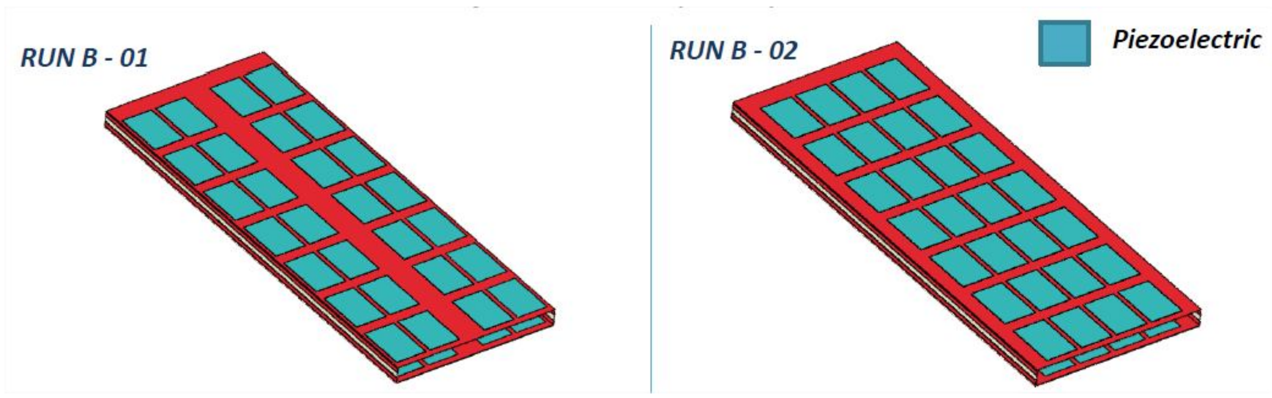
<u>Geometry of piezo-morphing structures and hybrid specimens behaviour</u>

Looking at the first part of the Project, a theoretical model based on the classical elementary theory of the thin walled structures (lumped parameters model) has been developed; the warping constraint effects have been evaluated by means of the standard method of the elasticity equations. Part of a master thesis has been dedicated to this activity.

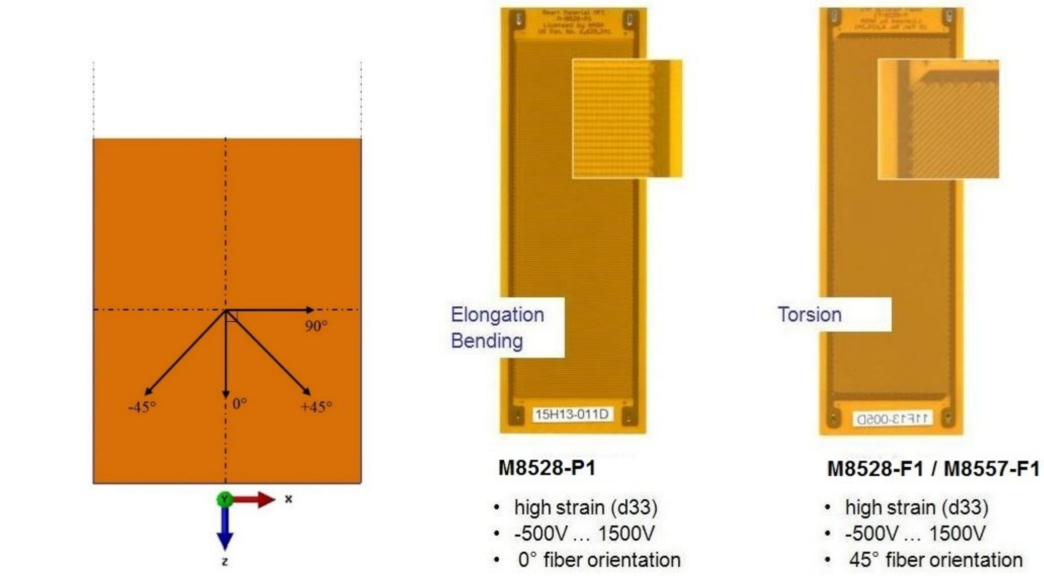
At the same time a very important amount of work has been dedicated to the simulation of realistic hybrid specimens made of composite materials and MFC patches. Bending and torsion specimens have been studied in detail for several weeks by means of non-linear FE analyses. At the end of this analysis, detailed drawings of the specimens have been prepared in order to proceed with the manufacturing and testing phases.



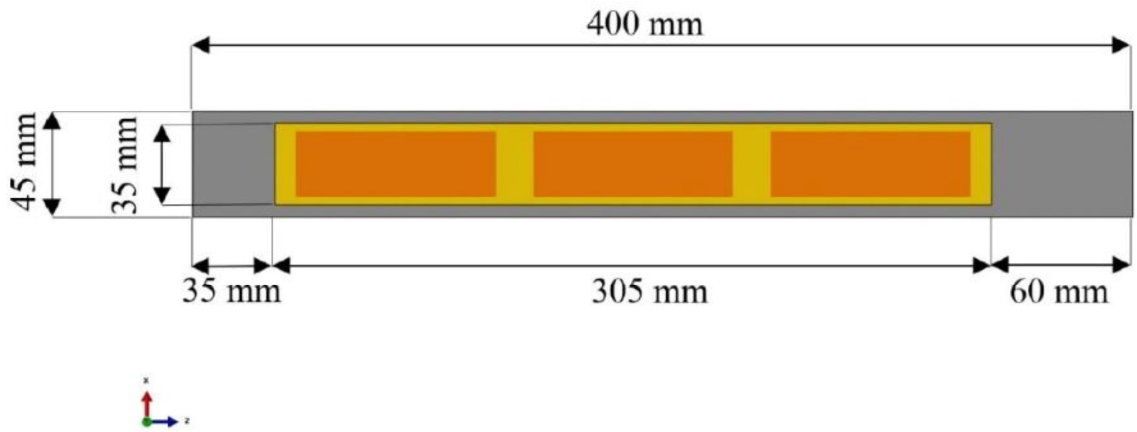
Displacement contours for 2 models of a thin walled activated beam (examples of FE results).



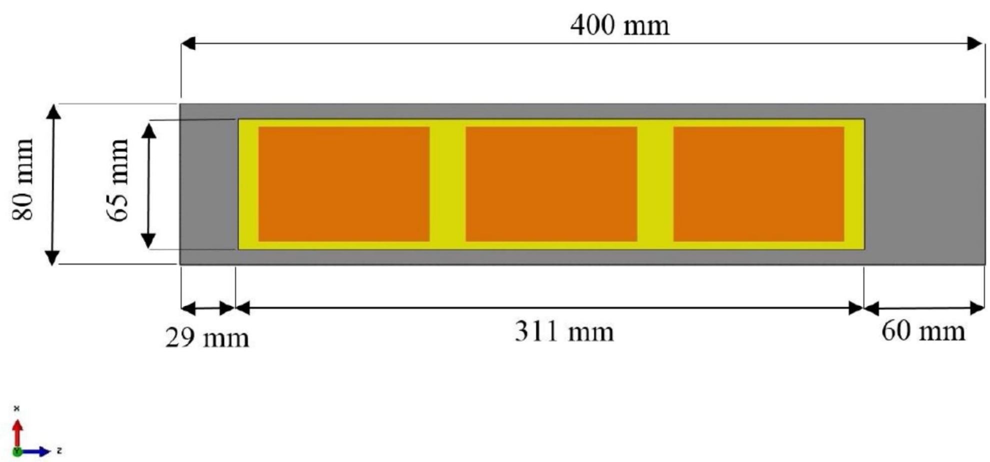
Study of a realistic distribution of piezoelectric patches applied to a thin walled beam undergoing torsion



MFC types and fiber orientation



Layout and dimensions of a bending specimen

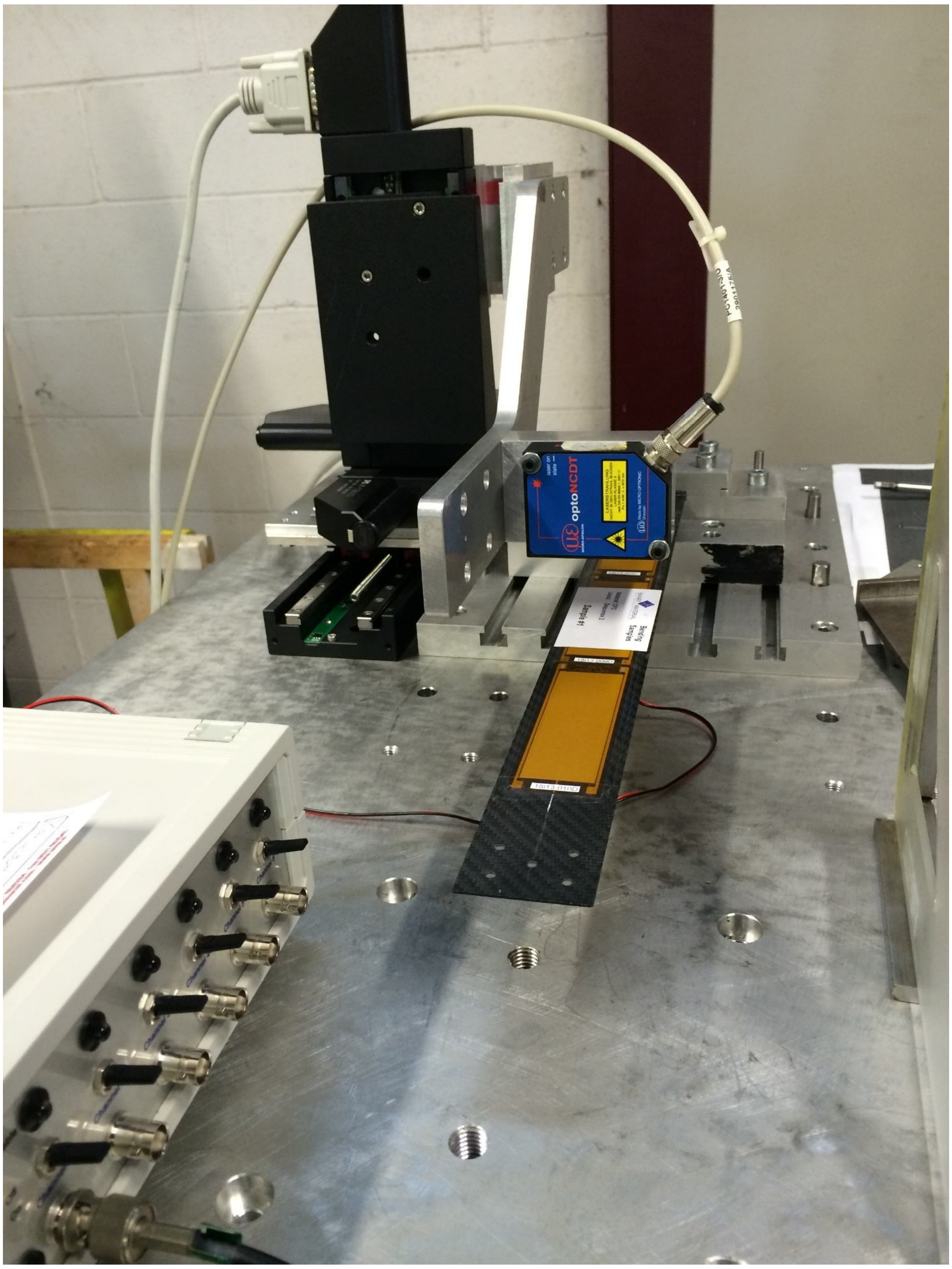


Layout and dimensions of a torsion specimen

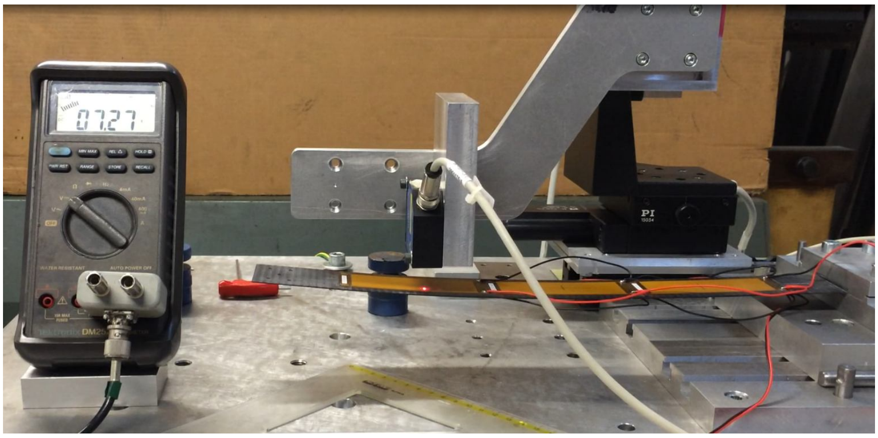
A set of little specimens have been used for measuring the elastic characteristics of the orthotropic substrates material used for the hybrid specimens.

The hybrid specimens have been manufactured in two different typologies: carbon/epoxy substrates and glass/epoxy substrates. The piezoelectric actuators made with MFC patches have been glued on both sides of the substrates. The possibility of a co-curing technique was evaluated, but due to the uncertainty of the final thicknesses and the stiffness characteristic of the specimens, it was decided not to use it.

The mechanical components of the test equipment have been produced, in particular a system of three linear slides controlled by computer has been realized and assembled. This slides allowed the positioning of the laser sensors that have been used to measure the initial deformation of the hybrid specimens, and the deformations induced by the piezo-electric actuators during the tests. A preliminary and novel version of a High Voltage Amplifier with 6 independent channels has been manufactured to the purpose.



Test of a bending specimen: the high voltage six-channel amplifier is visible on the left of the figure

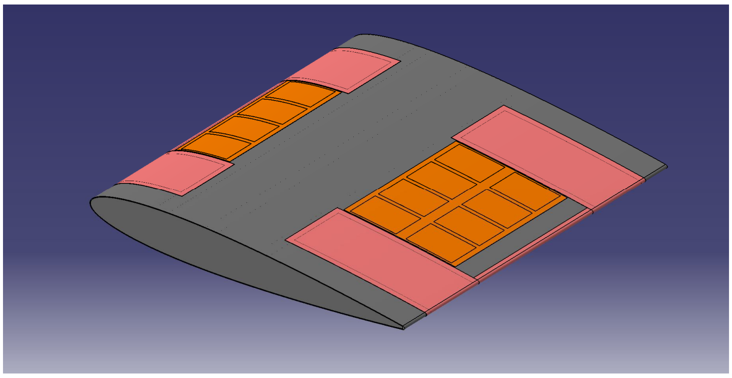


Test of a bending specimen (measurements of the displacements)

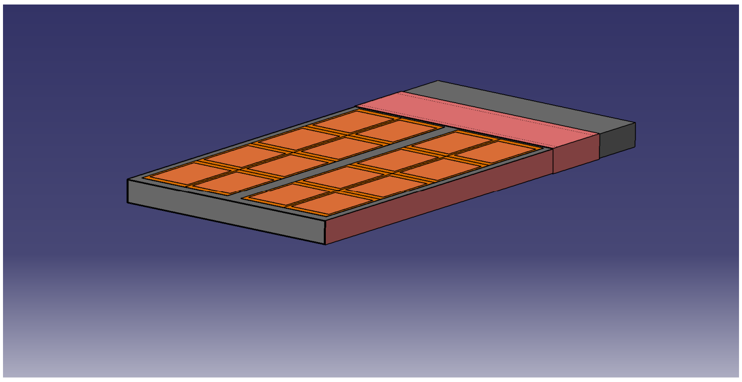
Deformation tests of the hybrid specimens have been carried out: the comparison between experimental and numerical results shows a very good agreement, confirming the validity of the numerical models developed in the first part of the Project. The results of this activity have been presented at an international workshop held in Aachen (Germany).

Small scale model of the Future Wing Unit

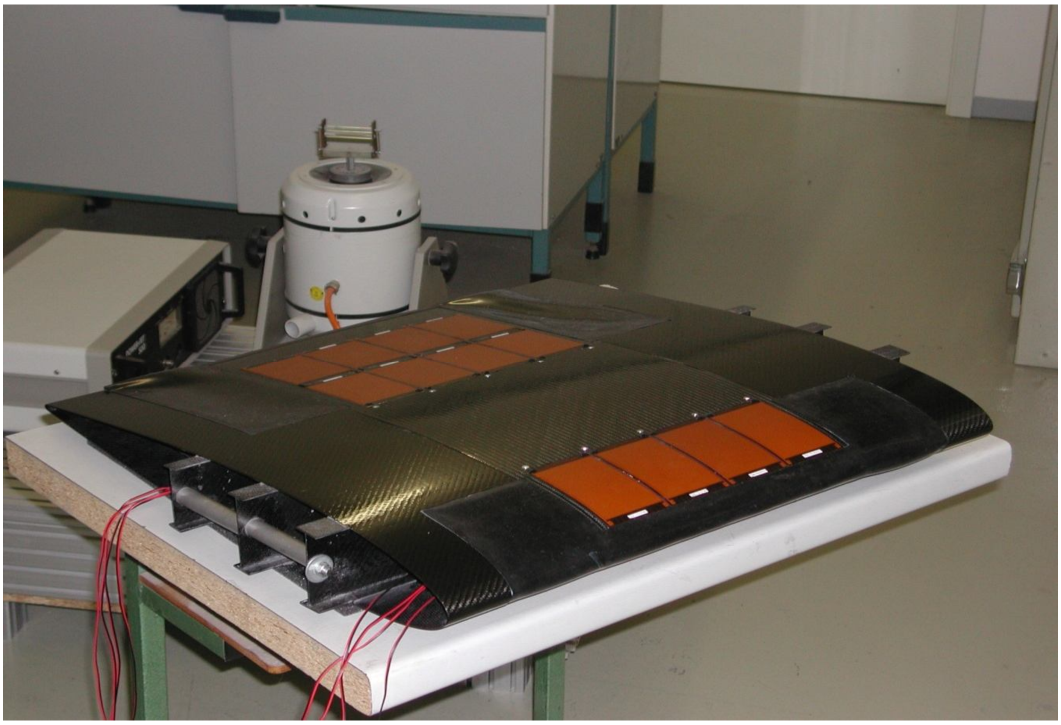
A small scale model of Future Wing has been studied manufactured in the second period of the project: it has been realized through a specific design activity, based on the experience done testing ad hoc specimens of the hybrid material and setting up non-linear calculation models, which have started in the first period. Mechanical deformation tests on this model has been carried out to verify the technical feasibility of the FutureWings concept on the basis of available piezo-components technology.



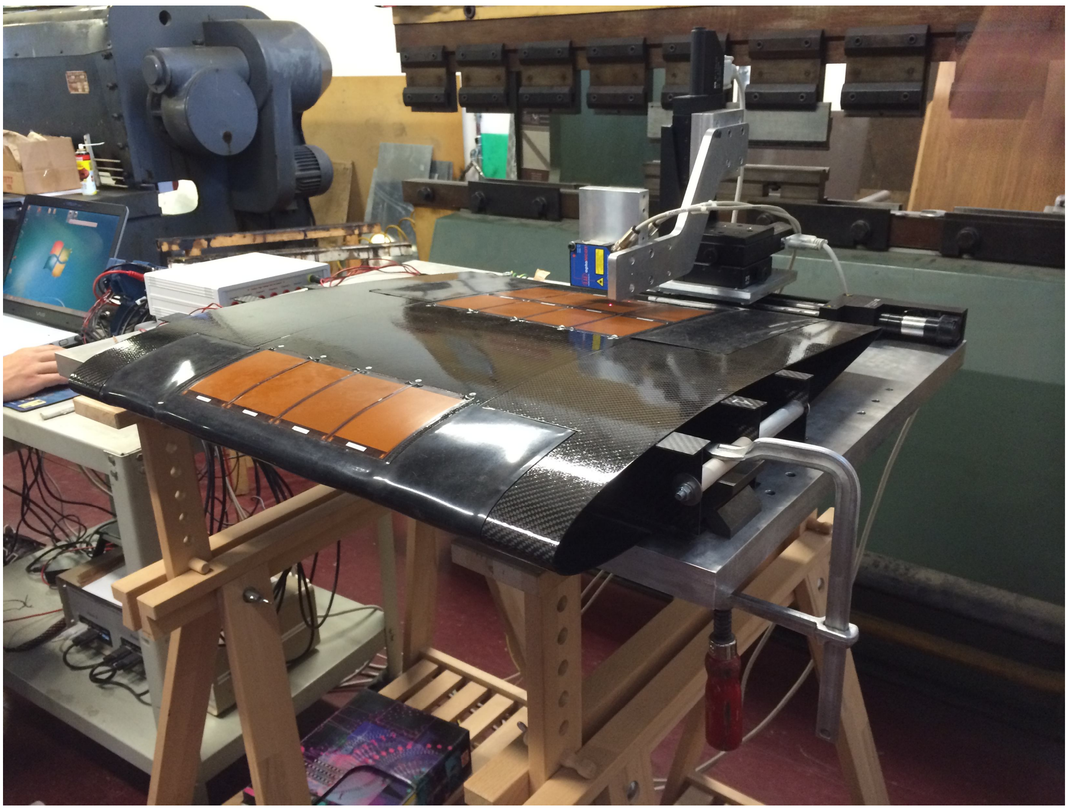
Global view of the FW-UNIT-1 (variable camber unit)



Global view of the FW-UNIT-2 (torsion unit)



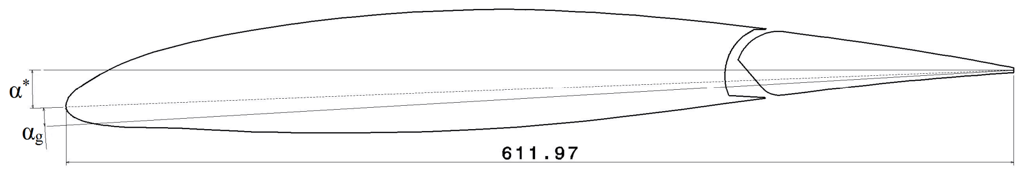
Future Wing Unit 1 – view of the assembled unit



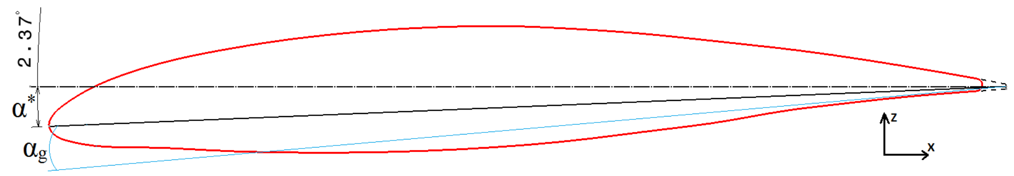
The FW-UNIT-1 on the test bench during a deformation test

Aeroelastic analyses of the Future-Wing

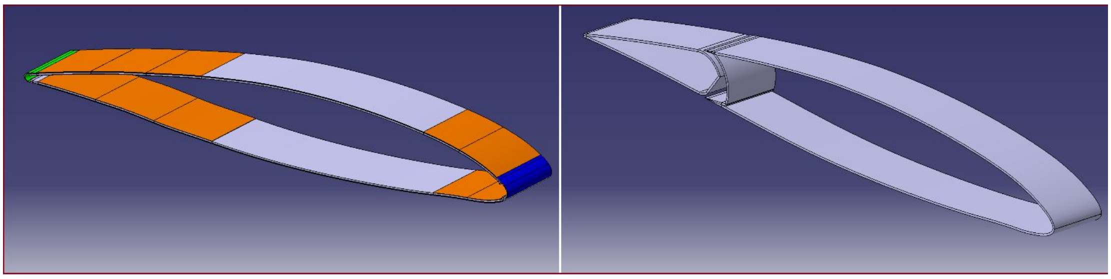
A numerical technique has been set up for the simulation of combined structural, piezo-electric, and aerodynamic analyses. This technique has been applied first to two-dimensional models (a reference wing section with a flap and a morphing wing section activated with hybrid piezo-electric structured layers).



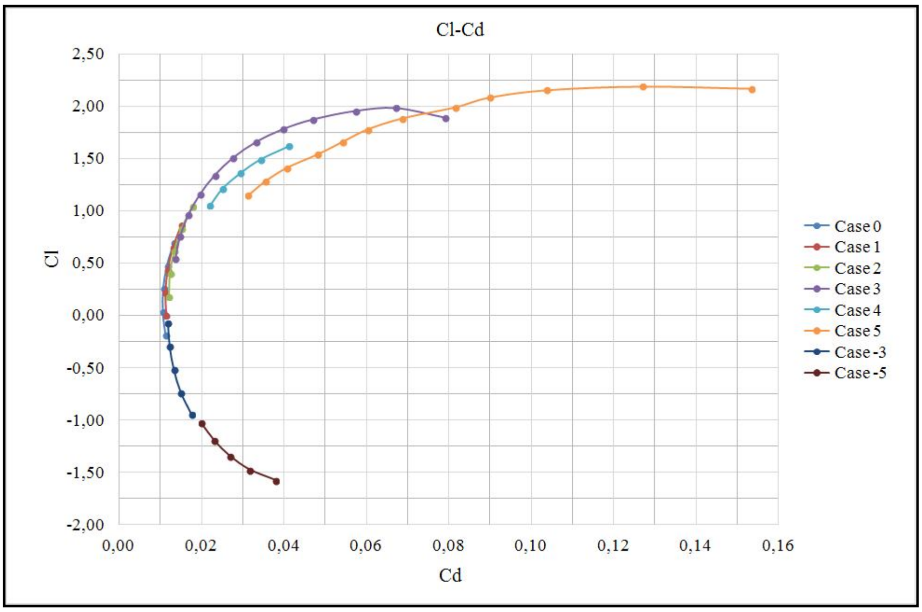
Sketch of the reference profile of the wing section equipped with an aileron



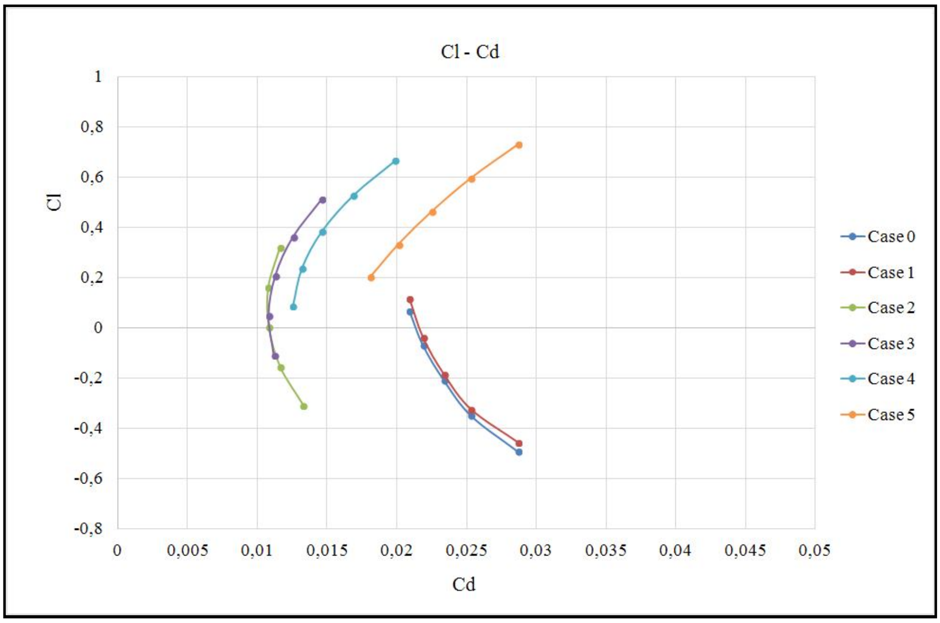
Sketch of the reference profile of the wing section equipped with piezo-patches



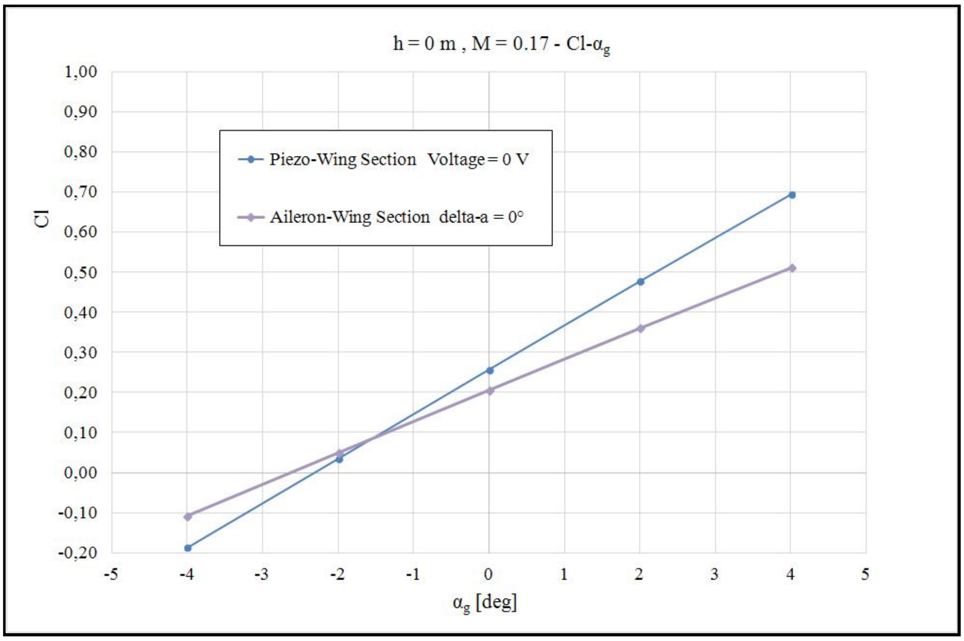
Sketch of models used for the aeroelastic comparison of reference wing sections



Drag polar curves for the piezo-wing section (h = 0 m, M = 0.17) – different voltage loads cases



Drag polar curves for reference aileron-wing section (h = 0 m, M = 0.17) – different aileron angles

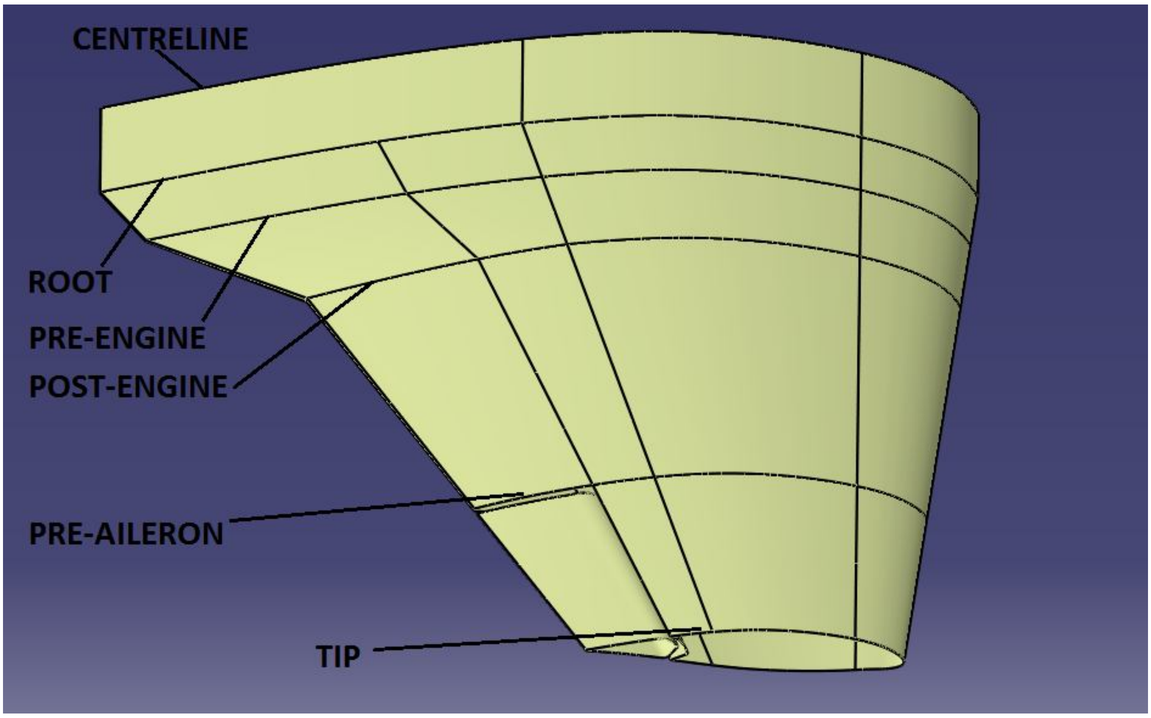


A comparison of Cl-αg curves for the examined wing sections (h = 0 m, M = 0.17)

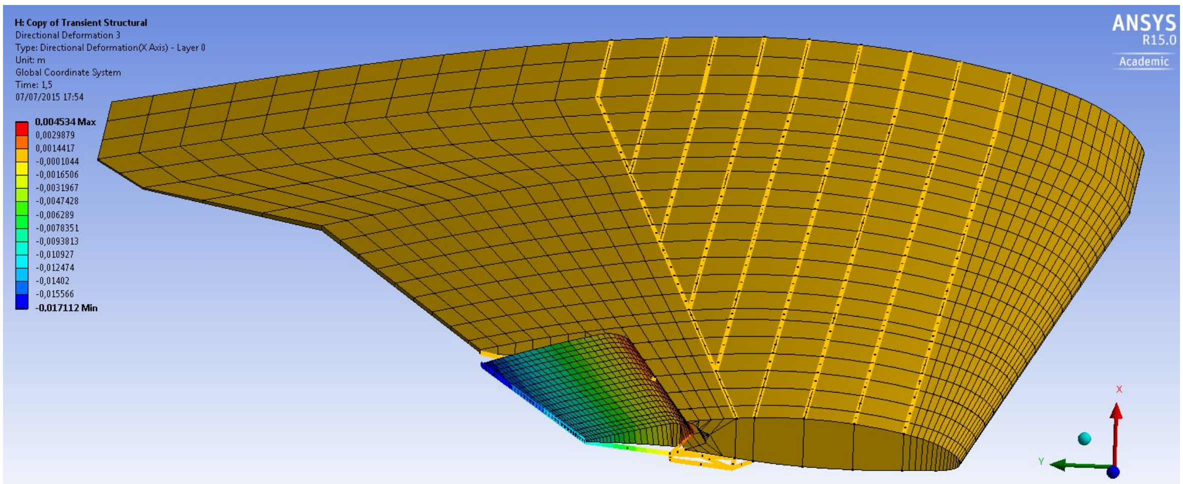
For little values of the rotation angle of the aileron the drag polar of the two wing section are quite similar, but in general it has been demonstrated that the piezo-wing section is more efficient from an aerodynamic point of view. The smooth geometry of a piezo-section provide better aerodynamic performances.

Two three-dimensional models of wings have been analyzed by FSI method (coupled Structural + Piezo-Electric + CFD analyses) and compared. From the aerodynamic point of view, a piezo-wing is more efficient with respect to a standard wing. The results of this activity have been presented at an international workshop held in Manchester (Great Britain).

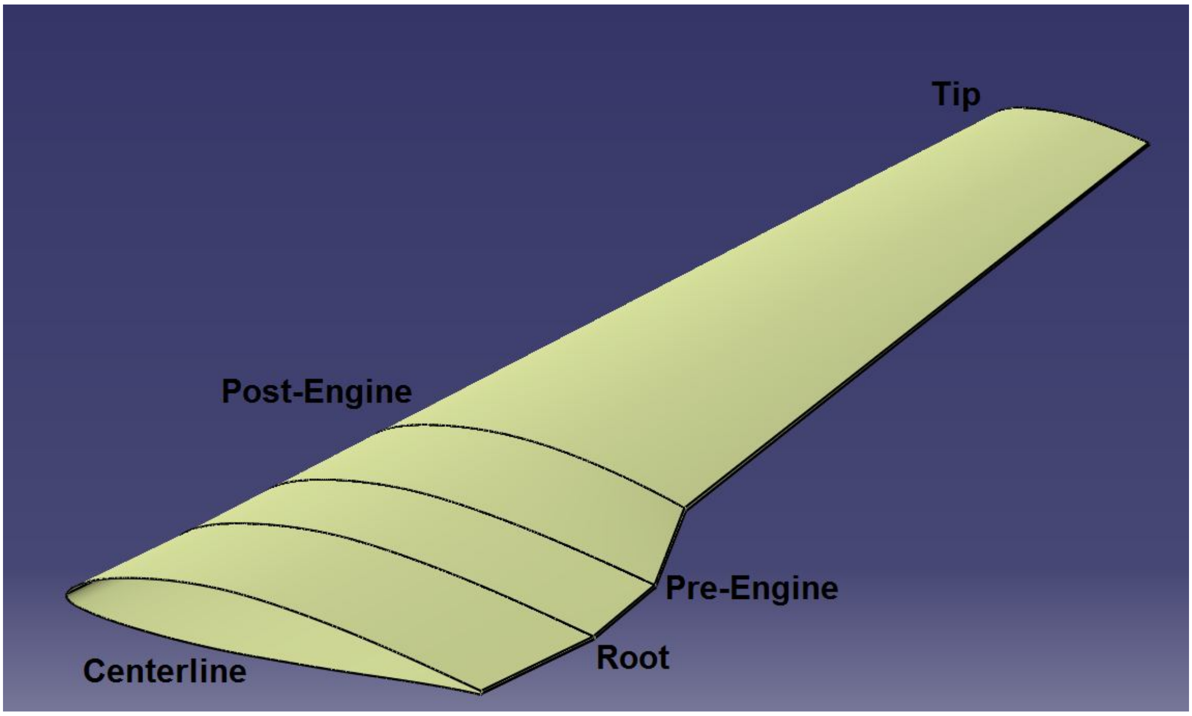
A large part of the scientific efforts has been devoted to the theoretical study of the aeroelastic behaviour of an innovative aircraft based on the FutureWings concept, that is an aeroplane without high velocity control surfaces on wings (ailerons). A numerical model of a complete piezo-wing aircraft has been set up and a steady-roll maneuver has been simulated.



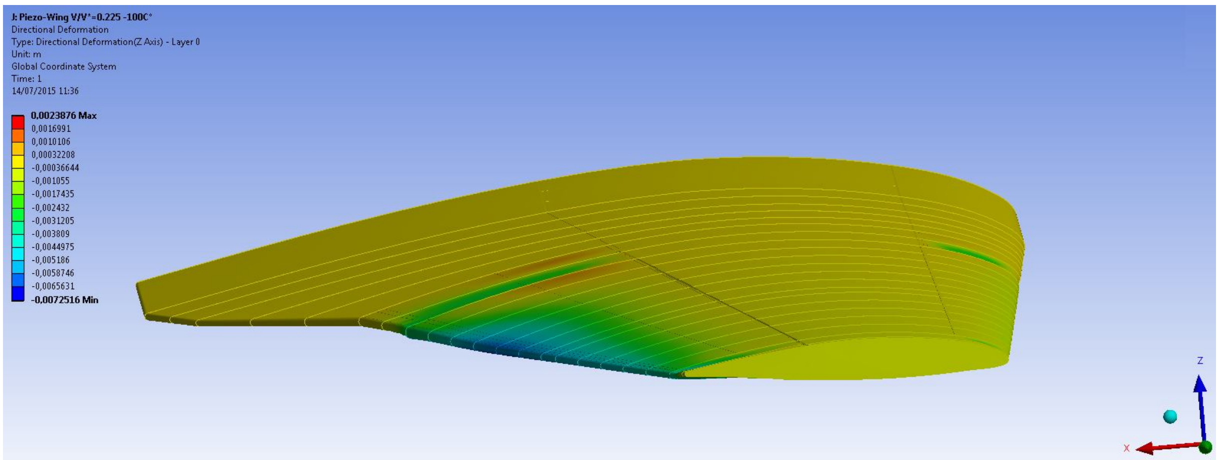
Sketch of the basic geometry of the 3D aileron-wing



Downward rotation of aileron surface = 5°



Sketch of the geometry of the 3D piezo-wing



Deformed shape of the piezo-wing model (voltage + thermal pre-strain of the transition regions)

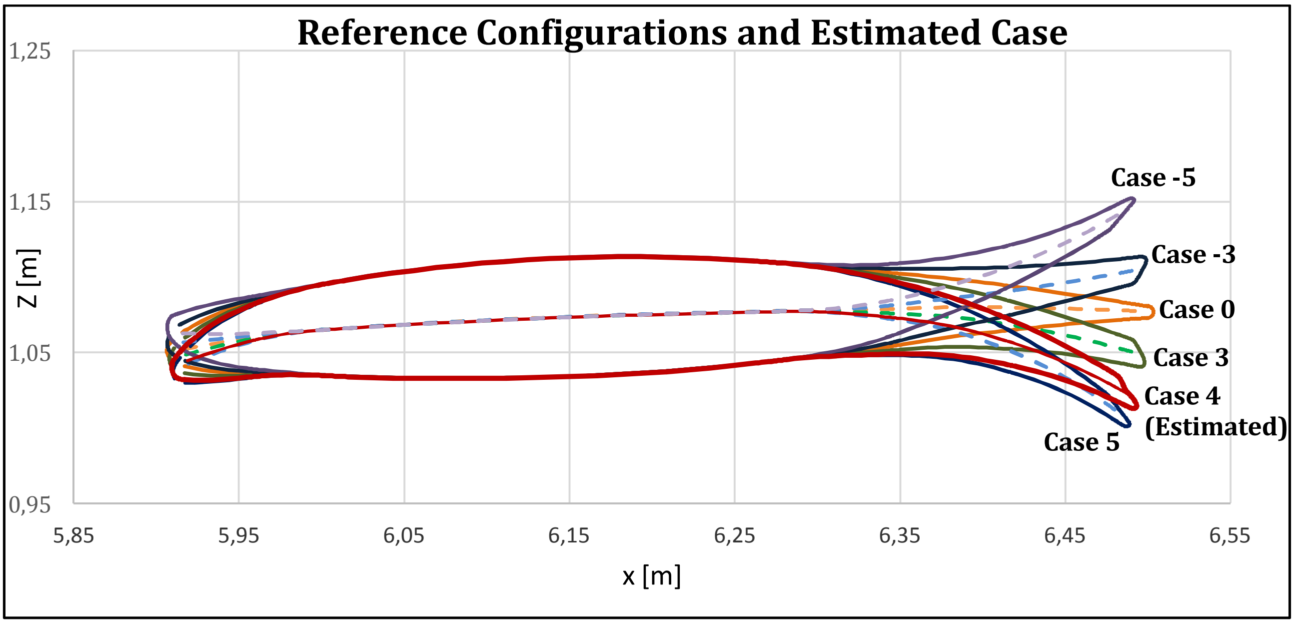
The aeroelastic analyses performed adopting the models of the two wings reveal that the available technology of the MFC actuators allow to obtain a morphing piezo-wing that produce a steady roll moment similar to that provided by little deflection of the aileron (about 5-8 degrees).

The study has demonstrated that adopting a new type of piezo-fibers (single crystal fibers with higher elongation performances) a piezo-wing can reach the aeroelastic characteristic of a conventional wing.

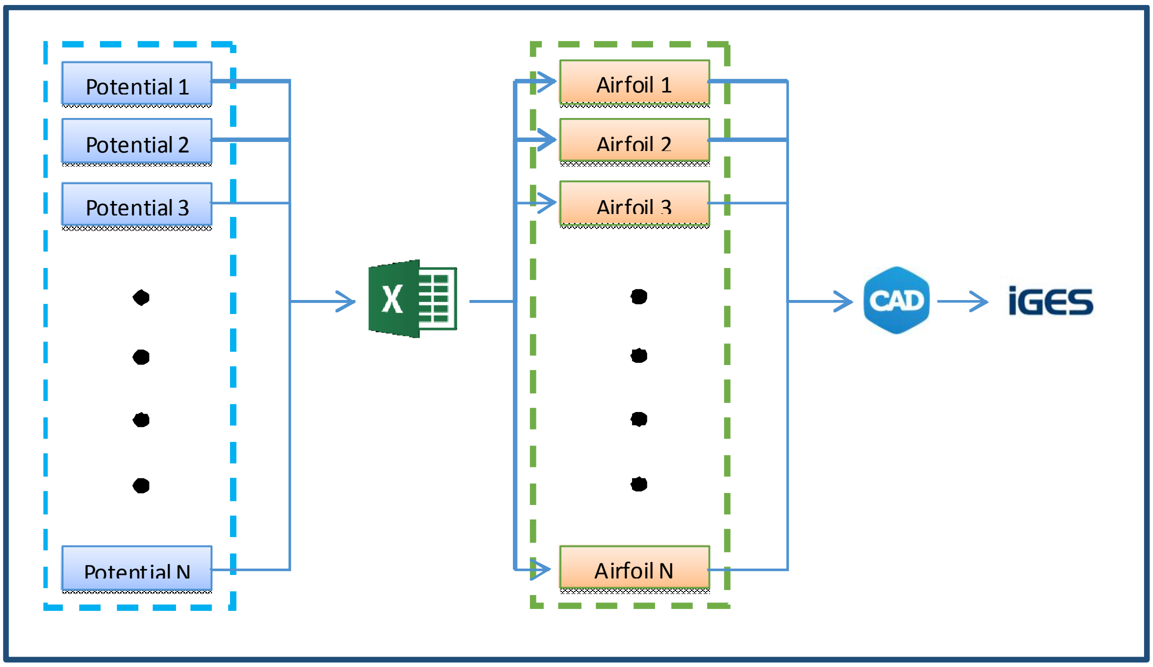
Computer aided inventive design

A parametric tool has been developed in a first version to update in a real time the geometry of future wing under the effect of electric loads, gravity loads and aerodynamic loads.

A preliminary implementation of a flight simulator of a Future-Wing Aircraft has been performed.



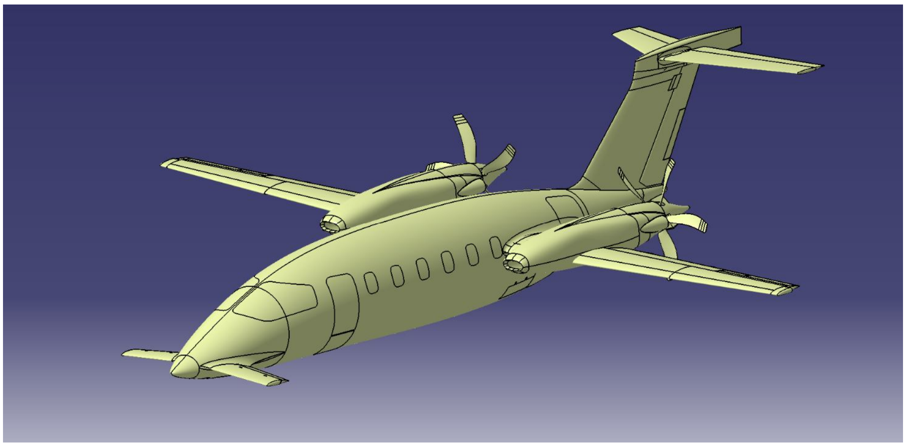
Estimated deformation with very high potential loads (primitive geometries)



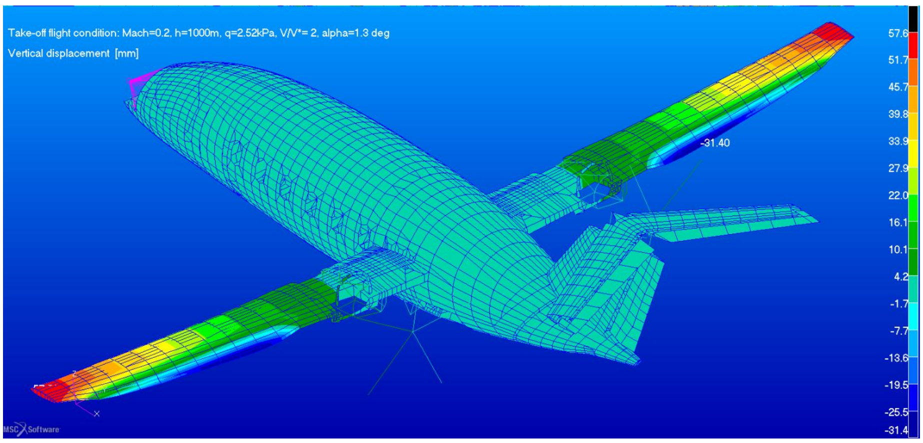
Process workflow for the definition of a morphing geometry (based on aeroelastic results)

The flight simulator: Future-Wing aircraft within with the deformed left half-wing (“aileron” down)

At the end of the Project, it can be stated that the aero-elastic and aeromechanical characteristics of an aircraft based on the Future-Wing concept are similar to the characteristics of a standard configuration aircraft. The research developed within the project provides important indication for developing high performance piezo-electric materials based on the use of single crystal piezo-fibers. Moreover, on the basis of the experiences acquired within the project, from a structure point of view, the design and manufacturing of a Future Wing aircraft does not show particular criticalities. The Future Wings project will participate to the international aeronautics event Aerodays 2015 in London (Great Britain).



CAD model of the Piaggio P180 assumed as the reference aircraft



The Future-Wing aircraft at takeoff: M=0.2, h=1000 m (increased morphing loads).

Scientific and technological contribution in the market of new materials

The FutureWings project has signed a significant step ahead in the knowledge of Piezo Electric Fibres Laminae behaviour. In fact, it has allowed an improvement in the knowledge and products development of new MFC patches having the possibility to work with lower values of the applied voltage, moreover the project has allowed the implementation of sensors application based on the MFC technology and the possibility to reduce the dimension of the high voltage amplifier. This last technology will allow the possibility to amplify the voltage directly on the patches support: doing this the high voltage current will not traverse (in a complex wiring system) the morphing structure reducing in a very strong manner any problems related to electrical shorts.

The improvement of the technological know-how produced by the project, has provided an important contribution to the companies involved, and a potential strong increase in the possibilities of application of smart materials not only in the aerospace industry but also in the mechanical and civil engineering.

As far as aeronautical applications are concerned, it is too early to draw complete conclusions, nevertheless from the initial knowledge developed in the Project, it seems that structural applications of Piezo Electric Fibres Laminae shall be accompanied by the development of more performing materials, even if the possibility of positioning self deforming structures starting from the wing tip, play a positive role in reducing manoeuvre loads and necessary deformations.

The large efforts devoted to the simulation of a piezo-wing and to the simulation of a complete aircraft equipped with piezo-wings has demonstrated that the available technology allows (at least from a static point of view) the possibility to execute rolling maneuvers characterized of little deflection angles of the aileron surface deflection. Anyway the structural behavior of such a wing seems to be perfectly comparable with that of a conventional passive wing.

As expected at the end of the project the small scale Future-Wing model, principally conceived and used for the experimental part of the research, will be a powerful tool for demonstrations during the dissemination activities of the project results. In fact has been planned the participation of the project to the event Aerodays 2015, moreover seminars activities dedicated to young engineering students have been planned.

Work opportunities for the young engineers involved in the research has been much increased at the end of the project being the covered subject of actual and increasing interest from the industrial point of view and thank also to the experimental study and to the theoretical study carried out on the hybrid specimens, on a three-dimensional morphing wing, and on the Future Wing Unit (which contains the technology of the composite material and the technology of MFC components).

A an example in the activity of the coordinator partner, during the project 1 post graduated young engineer and 4 MS students have been employed. The project has represented a very good opportunity for the professional training of these young people. Moreover two Post-Doc engineer has been involved directly in the project: they worked directly as researchers with high level of autonomy.

As described above, the following practical results have been obtained within the technology of piezo-electric actuator:

(1) a new type of piezo-patch has been studied and manufactured (with low-medium voltage capability)

(2) a new model of micro high amplifier card has been studied and produced that can be directly integrated in the production of a piezo-patch

(3) a market research revealed that exists a new type of single crystal fibres having piezo characteristics but with higher performances (these fibres have an elongation capability that is 4 time that of the present piezoelectric fibres)

(4) the model of a multiple channel high voltage amplifier has been implemented withi the project

Main results achieved during the first period of the project:

- Composite material characterization (elastic modules)
- Design and manufacturing of the Hybrid specimens
- Design and manufacturing of the testing apparatus
- Tests of the hybrid specimens
- Validation of the finite element models (comparison of numerical and experimental data)
- Deep study of geometries to use for the design of a Future Wing Unit module
- Study and manufacturing of the multi-channels High Voltage Amplifier
- Preliminary implementation of aeroelastic analyses of a Future-Wing Aircraft
- Preliminary implementation of the flight simulator of a Future-Wing Aircraft

Main results achieved during the second period of the project:

- Preliminary models for fluid structure interaction analyses of morphing wing sections
- Reliable numerical procedures for analyzing a Future Wing Unit
- Design of two distinct Future Wing units
- Detailed design and drawings of the Future Wing Unit 1 (curvature's change)
- Manufacturing of the Future Wing Unit 1
- Reliable procedures for analyzing a reference wing section and a morphing one
- Preliminary results on the aerodynamic performances of a morphing wing section
- 3D models for FSI analyses of a reference wing (with aileron)
- 3D models for FSI analyses of a morphing wing (with piezo-patches)
- Aeromechanical performances of the morphing wing *vs* the reference wing
- Aeroelastic model of a complete Future Wing Aircraft
- Aeromechanical performances of the FW Aircraft *vs* the reference Aircraft
- Basic procedures for a real time control of the geometry of a morphing wing
- Flight mechanics model of the FW Aircraft (Implementation of a Flight Simulator)
- Set up of the multi-channel electronic control system (High Voltage capabilities)
- Deformation tests of the Future Wing Unit 1
- Final validation of design and manufacturing technologies of a piezo-wing section

Potential strategic impact of the FutureWings project

As mentioned, the project moves starting from the idea of thinking to an airplane as a great body with its end structures that could have the possibility to change their shape as they had internal nerve endings and muscles: the nerves will be represented by a thin wiring grid connected to an electronic control system (both developed within the Project), while the muscles will be represented by the composite active layers based on the MFC concept and that, within the Project, will be embedded in the whole composite structure of a small scale model of a wing-box.

It is a fact that the development of such "self shaping structures" will have a wide field of applications and **a huge impact in many Engineering fields in the coming decades**, nevertheless this matter is actually at a quite embryonic level, and the decisive step forward offered by the "Future-Wings" Project will have a **major catalytic effect on some international research activities related to this type of structures**, and in particular this is valid for some breakthrough and emerging technologies that are in a state of latent growth in the European Community area.

For instance, Smart Material GmbH (Partner 3) has developed a first example of "living tissue", the so called Macro Fibers Composite (MFC), that will allow us to start with the Project, but technological applications such as those described in this project proposal at present do not exist. The experimental phase of the research certainly had margin of risks, but at the end of the project it offers a great opportunity to grow: it is now the right time to groped an important jump forward in this specific field. In fact, thank to the FutureWings project, the SMG researchers have studied and developed a new product, ready for the market: the multiple channel high voltage amplifier. Moreover a new type of MFC actuators has been implemented working with lower value of voltage and the possibility to reduce the dimension of the amplifier open a very interesting field of industrial application of new piezo-electric actuators (the Voltage will be amplified directly on the support structure of the MFCs).

Also, the software that has be developed, in a preliminary form, by iChrome (Partner 4) within the project, and that in its preliminary version is strictly necessary to adapt in a real time the geometry of a morphing wing numerical model, will offer to the market highly specialized computing software devoted to adapt easily and in a very fast way the shapes of the basic elements of modern numerical structural models. The software can be used during the phase of conceptual design and preliminary development of a really complex machine (an airplane as a whole), having the possibility to control in a active way all the decision phases of this basic design activity, by taking into account a great number of design parameters, generating a great number of preliminary configurations of the aircraft (by selecting a certain numbers of control nodes the geometry of the external surface of the aircraft model can change in very fast manner). In other words the Future-Wing project will allow to fix the bases to develop an intelligent software that will act as a bridge between more and more heavy multi-disciplinary numerical analyses and the proper design phase of the entire architecture of an aircraft, taking into account as an example, already in the preliminary design, the manufacturing and logistics requirements.

Even if in the project development the numerical models of wings and the numerical models of the Future-Wing Aircraft have been developed following standard methodology: in fact the software developed by iChrome has reached a first stage of implementation. But numerical the work done to simulate the aeroelastic behaviour of a morphing wing (with a fixed geometry, that is only one configuration of the wing has been studied) adopting piezo-electric actuators has been very expensive from human resources point of view. This fact justify the implementation of a software that allows an efficient and robust manipulation of complex structural models.

In this sense **the development times and costs of new complex machines, as it is an aircraft, will be strongly reduced** and the development phase of a new aircraft will be very similar to what happens today in the automotive sector, for a new car model. A direct consequence of this fact will result in a reinforcement of the European aerospace industry capability to compete and to maintain a leading position in the global market of aerospace products.

The same thing could happen in the field of space engineering: the design of complex and expensive machines for space exploration programs or to put in place interplanetary missions would be easier and so less expensive.

The previous considerations allow us to realize easily what could be the impact of the FutureWings Project methodologies and results both in the education fields (pre-university and university education, applied research fields, etc …) and in the industrial field.

Limiting the view only to the fields of interest of the partners involved in the project, the following concrete results can be highlighted:

1. An improvement in the knowledge and products development in the field of new materials (hybrid composite materials). The FutureWings project will contribute to the development of a European area of technological excellence in the market of new materials, that is one of sectors with the strongest potential economical development in the world in the decades to come. The increase of know-how and the technological problems solving that will be faced in the actuation of the WPs of the project will provide the increase in the personnel resources engaged by the companies involved and a strong increase in the possibility of the applications of smart materials not only in the aerospace industry but also in the mechanical and civil engineering. Work opportunities for a lot of young engineers, high-level technical staff, skilled workers and, at the same time, applied research opportunities will be much more increased at the end of the project. In fact, as an example, the experience done in the research group of the Project Coordinator (University of Pisa) has allowed a very efficient educational training for 4 students in Aerospace Engineering and offered the possibility to increase the personal know how of two Post Doc researchers.
2. As said, a further development of a multi-disciplinary optimization software can lead to the development of new and very efficient methods (fast and flexible) for designing complex and highly integrated engineering systems, structures and machines. Also in this case the development of a technological excellence in the market of computerized and integrated products design will be assessed also thanks to FutureWings project. From a practical point of view the increase of the know-how of iChrome has been very important.

With reference to the requirements specified in the Work Programme we will try to summarize in the following the peculiar answers given by the proposed research.

New fundamental knowledge:

- mathematical model of the airplane Flight Mechanics describing the behavior of an airplane which can fly without using any traditional high velocity control surface (no ailerons, no rudder, no horizontal tail control surfaces), but that can deform its aerodynamic surfaces (wings, tail) according to the flight requirements; the aeromechanical model of the Future Wing Airca=raft has been developed and implemented in a flight simulator;
- robust theoretical models describing the behavior of active hybrid composites material upon deformation commands; a deep finite element research has been executed to simulate composite structure activated by means of MFC patches; the integration of the piezo-electric behavior with the structural deformation and the aerodynamic loads has been implemented in a very robust manner; very complex numerical analyses have been carried out with a very good level of success;
- numerical models of a Future-Wings aircraft configuration and first assessments about its airworthiness characteristics; the aeroelastic model of the Future Wing Aircraft has been implemented within a conventional commercial code; also in this case the methodology used to simulate the morphing wings of the aircraft has been implemented with a very good level of success; a comparison of numerical data with aeromechanical industrial realistic data has been possible and physical limits of the present technology have been defined and measured;
- fundamental knowledge concerning the behaviour of active hybrid composites materials, based on tests carried out on specimens and on a small scale model of a wing; the planned campaign of measures included static and dynamic tests and experimental simulation of the failure of one or more active

elements in the small scale model. Within the project only static tests have been executed, anyway the dynamic control of the MFC actuators inserted on the Future wing Unit (the small scale model of a morphing wing section) will be realized within a short time.

Emerging technologies:

- radically new application of advanced MFC elements;
- development of an integrated and efficient system necessary to realize the power supply of the piezo-electric fibers embedded in the hybrid composite material layers; the know-how acquired by SMG allows to reduce risks of shorts in the piezo-structure;
- development of the electronic control system of a structure made of hybrid composite materials; SMG has developed a new product (the multiple channel HV amplifier)
- early development of a new flexible and efficient design software aimed to lay the basis for a Computer Aided Inventive Design.

Radical new concepts with strong innovation potential:

- the project offers a radical new concept of an aircraft, in which the conventional mobile aerodynamic surfaces are replaced by self shaping aerodynamic surfaces (wings, tail). For this type of aircraft the change of pressure distribution necessary to carry out classical flight maneuvers will be obtained by changing the shape (torsion and bending deformation components will be controlled) of the primary aerodynamics surfaces, thanks to the use of the active electronic control of the hybrid material with which the primary structures of the aircraft are built. As said the present technology can’t allow the implementation of this concepts in a very short time, but there is the possibility to use single crystal piezo-electric fibers with higher actuation performances; the study and development of more efficient MFC products based on the use of high-deformation piezo-fibres can be possible.

Expected impact and step change in aeronautics:

- the use of smart material to realize artificial “living tissues” allow to think to an aircraft which will be controlled, at least during classical high velocity flight condition, by changing the shape of its aerodynamics primary surfaces. In this way all the internal plants, that nowadays are necessary to govern the attitude and the movement of the control surfaces during the flight operations of aircrafts, will be eliminated with a great weight saving and fuel saving, an important reduction emissions of pollutant gases, an improvement in the mass distribution (improvement of the aircraft aeroelastic behavior), a reduction of risks related to the use of these plants and a reduction of costs relevant to the manufacturing and the maintainability of these plants.

Expected impact and step change in other engineering fields:

- the concept of replacing “mobile parts” with “parts deformable on command” has really a very wide range of applications: the FutureWings project aims to provide a tremendous step forward in the application of these technologies of the future. As an example, in the field of large wind turbine engineering the application of the FutureWings concept will allow to change the shape of more and more large blades and to adapt, in a continuous and controlled way, the blades geometry to obtain the optimal aerodynamic loads distribution from the energy production point of view and at the same time reducing the value of stresses in the blades. Moreover, the possibility of adapting at least the shape of only the blades tip, during different work condition, will allow to reduce the noise production of large wind turbine due to vortex shedding. In the field of robotics engineering or in the field of biomedical engineering the development of more and more efficient “living tissues” will allow to design very complex and efficient mechanical limbs that in a future could be directly controlled by electrical impulses of human central nervous system.

Main dissemination activities of the FutureWings Project

The dissemination of the project results has developed producing two scientific publications by attending international workshop organized by the European Aerospace Science Network (University of Aachen - October 2014, University of Manchester - September 2015).

Scientific seminars will be organized at the end of the project involving students of the University of Pisa. The results available at the end and during the project will be object of publication on wide diffusion scientific journals. At the end of the first period a paper has been submitted for the publication on "International Journal of Aircraft Engineering and Aerospace Technology". A Project Public Website has been set up to facilitate the activity of dissemination.

Additionally, partners websites offers the possibility to present major project results. This offers the chance that researches and future users from other fields of applications all over the world can be informed, supported and trained with the new piezoelectric elements developed within the project. Again, this will become a multiplier effect for the transfer of project results into new innovative applications.

It is intention of the partners, to use the Future-Wing scaled model, which is necessary for the experimental part of the research, as a powerful mean of dissemination of project results. The Future Wing model will be rearranged after Project end, and it will be available to show to public the new technology during fairs and exhibitions. The FutureWings Project will participate at the Aerodays 2015 event in London (October 2015).

From the specific educational point of view, the development of the project and the dissemination of the relevant results will represent a strong opportunity of promoting studies on the modeling and on the industrial application of the hybrid composite materials.

A flyer that describes the main project activities and that shows in a pictorial manner the project results has been prepared.

Exploitation of the FutureWings Project results

In view of the complementarity in their interests, the partners intend to have further collaborations beyond project end.

SMG and iChrome are strongly confident on the short term exploitation possibilities of Project results, because during the Project they had a realistic opportunity to improve their core business products (MFC components and Simulation SW respectively), and they will consequently try to open new work opportunity in their specific fields.

It can anticipate that the following items could have important industrial applications.

In particular:

- more advanced piezoelectric elements embedded in denser grids (lower voltages) – **SMG**

  Based on the results of the experimental studies with different MFC electrode layouts SMG will start working on final design issues for first low voltage MFC prototypes until end of 2015. In 2016 final evaluation tests are planned and after they were passed successfully SMG will start to promote the low voltage MFC during appropriate exhibitions and road shows within the 2nd half of 2016.
- multiple channel high voltage amplifier – **SMG**

  This module will be shown on the company next road show, the Oceans MTS/IEEE at the beginning of October 2015 in Washington, DC.
- high voltage amplifier of reduced dimensions – **SMG**

  SMG did some initial tests with novel μ-sized high voltage amplifier modules. Based on this tests it is planned to add this HV amplifiers directly piggy-backed to the MFC to create a new type of MFC actuator with integrated HV power source. For this it is planned to do the design and evaluation test phases within 2016 and the promotion of this new product at the beginning of 2017.
- software for the computer aided inventive design based on the advanced morphing methodology, exploiting software packages already developed by **iChrome**

  With suitable financial investments in 2016 new development activities will be carried out to improve the capability of the software. The preparation of specific project proposals can be a way to obtain funds and to involve industrial companies in the application of the proposed methodology.

- development of a torsion thin walled beam with an internal robust supporting structure - **University of Pisa**

  The self-morphing torsion beam model will be used the study the implementation of movable aerodynamic surfaces. In 2016 new research activities will be carried out involving young engineers to demonstrate the feasibility of the torsion beam concept. With suitable financial investments a demonstrator will be manufactured and tested. The preparation of new project proposals can be a way to obtain funds to involve industrial companies in the application of the proposed methodology.