HYBRIA

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Project acronym
HYBRIA

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Hybrid laminates. Industrialization for aircraft nose fuselage.

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FINAL PUBLISHABLE SUMMARY REPORT

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From March 15th 2012 to March 14th 2014

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LIST OF ACRONYMS

AFP	Automatic Fiber Placement
ATL	Automatic Tape Lay-up
BAI	Bendind After Impact
BVID	Barely Visual Impact Damage
CAD	Computer Assisted Design
CAI	Compression After Impact
CfP	Call for Proposal
CFRP	Carbon Fibre Reinforced Plastic
CS	Clean Sky
DVI	Detailed Visual Inspection
FP	Framework Programme
FRF	Frequency Response Function
GRA	Green Regional Aircraft
GVI	General Visual Inspection
IADP	Innovative Aircraft Demonstrator Platforms
JTI	Joint Technology Initiative
NDT	Non Destructive Technique
SHM	Structural Health Monitoring
STL	Sound Transmission Loss
UD	Unidirectional
VID	Visual Impact Damage
WP	Work Package

4.1 Final publishable summary report

4.1.1 Executive summary

HYBRIA Project entitled “Hybrid laminates. Industrialization for aircraft nose fuselage.” is a FP7 project of 24 months, which has begun on March 2012, the 15th and has ended on March 2014, the 14th. The project is related to the CfP of Clean Sky: SP1- JTI-CS-2011-03 and it is being developed in the frame of the Green Regional Aircraft programme with activity code: JTI-CS-2011-03-GRA-01-039. HYBRIA consortium is composed of only one single partner; FIDAMC, whose facilities are located in Getafe (Spain).

The use of layered composites in aircraft fuselage structural components offers the opportunity to embed interleaved layers of different materials in the skin laminates so that additional performances may be added while maintaining the structural efficiency. The presence of layers of damping materials inside the composite laminate normally results in an important reduction of mechanical properties. The goal is to design composite laminates with integrated acoustic insulation without compromising the mechanical performance of the composite structure.

After the materials screening/selection and architectures/mechanical studies carried out within the former COMPASS project, the aim of HYBRIA project is to develop hybrid structures by means of industrial manufacturing processes. During the project, three curved stiffened panels representative of the GRA cockpit fuselage were produced: hybrid skin fuselage with co-cured stringers of different shape section. Several manufacturing trials were carried out during the production of the demonstrators with the intention to validate innovative manufacturing concepts that will be implemented in the whole GRA cockpit production. NDT as well as dimensional analysis of the demonstrators were performed in order to assess the quality of the specimens produced.

HYBRIA Project supports the development of a strong European expertise in both innovative materials development and composites materials process which propels European citizens at the edge of innovation and expertise in these fields: this will guarantee to maintain high added value parts manufactured in Europe, ensuring an effective competitiveness.

4.1.2 Summary description of project context and objectives

Integration of acoustic damping function in a single material system will permit enhancing the structural behavior and diminish overall structural weight by reducing redundancies between subsystems and functions. To meet the objectives of the project, work has been split up into four main work packages which related purposes are described hereafter.

First stage of the project was dedicated to explore potential issues regarding the large scale manufacturing of hybrid panels with acoustic material insertion. Objective of WP1 was to complete the materials and configurations screening previously carried out in COMPASS project which allows selecting the hybrid skin architecture, definition of the manufacturing process and CAD model generation. Additionally, flat panels were produced for being tested subsequently within WP4.

WP2 was devoted to tooling design and manufacturing. The tooling basically consisted of two tools for the hot-forming of the stringers and a male PEAU for both integration and curing phases. Additionally, two types of innovative caul-plates were manufactured by FIDAMC in order to study the effect of different stiffness of the caul-plates on the aerodynamic surface of the specimen among other aspects.

The objective of WP3 was to validate, by means of the manufacturing of three curved stiffened panels representative of the GRA cockpit fuselage, different manufacturing concepts that will be implemented in the whole GRA cockpit production. Several manufacturing trials were carried out during the production of the demonstrators. Within this WP, NDT as well as dimensional analysis of the demonstrators were performed in order to assess the quality of the specimens produced.

Finally, objective of WP4 was to complement the material properties data base from COMPASS project, carrying out vibro-acoustic, erosion, BAI, buckling and low energy impact tests. Acoustic-vibration tests will be carried out in order to produce experimental data against which damping theoretical model will be compared to. Additional mechanical testing, necessary to complement the investigation in those multifunctional configurations explored, was accomplished within this WP as well.

4.1.3 Description of the main S&T results/foregrounds

4.1.3.1 Manufacturing trials, complementary testing and specimen design

A total of six extra monolithic flat hybrid panels (1650mmx600mm) were manufactured within this task for being subjected to vibro-acoustic tests, among others, in WP4. One or two damping layers were inserted in the CFRP laminates. Acoustic materials selected for this work were SMACWRAP and Kraiburg products. Furthermore, two geometries of acoustic insert were explored: acoustic material in a continuous layer and located at specific areas by means of homogeneously distributed patches (see Figure 1).

CFRP laminate was laid up by means of ATL for the six panels with carbon-epoxy UD tape. The acoustic damping material was positioned by hand directly in contact to the prepreg without using adhesive. All panels were cured with vacuum bag in autoclave cycle. Manufacturing of the panels was satisfactory with the exception of the panel with double layer of SMAC patches, in which air bubbles were trapped between the patches. This panel was manufactured again modifying slightly the laminate configuration, producing successfully an element with double acoustic damping layer. NDT inspection revealed that, for some configurations, the acoustic material insertion causes a distortion in the ultrasonic signal response. Some coupons were afterwards extracted for being dedicated to complementary testing in WP4.

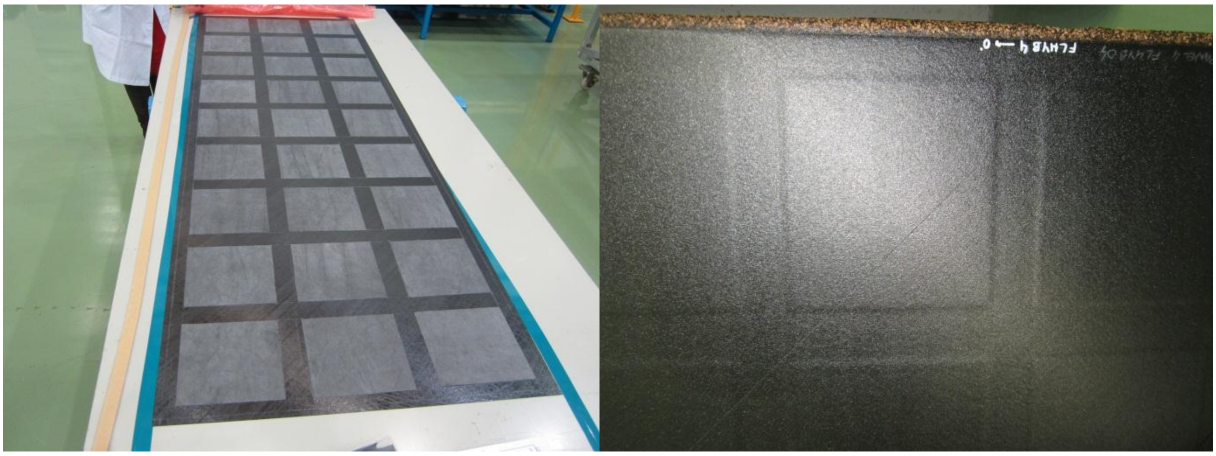

Figure 1. Left) acoustic material patches positioned on the CFRP laminate; right) detail of a hybrid laminate with insertion of double layer of damping material embedded

For the manufacturing trials, an area of the GRA cockpit fuselage was selected as demonstrator. The final geometry turns out to be a double-curvature surface stiffened panel. The design corresponds to a specific area of the GRA IADP cockpit, one of the most critical parts from the manufacturing point of view. Reasons behind the selection of this particular area of the concerned fuselage are mainly related to its double curvature and because it combines two different stiffeners (see Figure 2). Basically, the manufacturing process selected consisted in a co-curing of skin and stringers in a male tool in autoclave cycle. The skin is laid-up with AFP machine while Ω and T stringers are hand and ATL laid-up respectively.

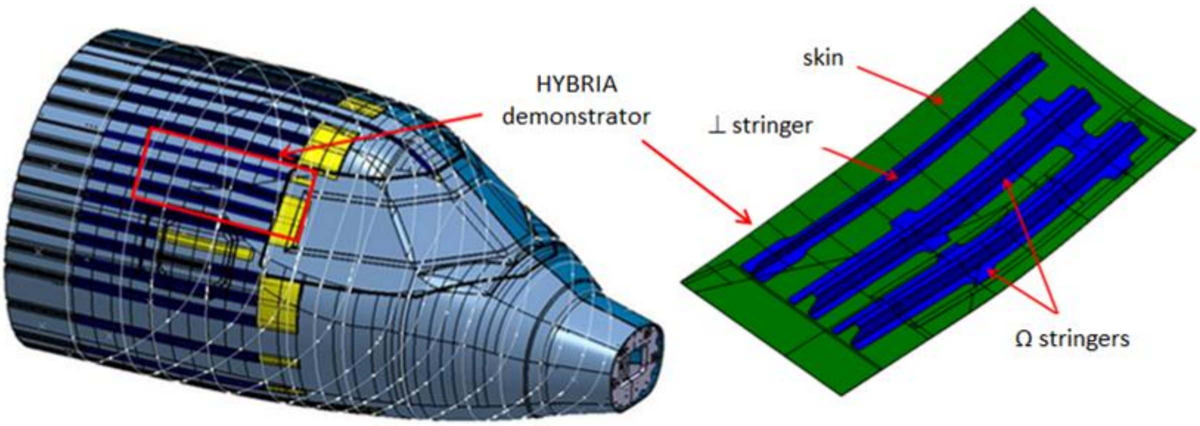

Figure 2. Left) selected area of the GRA IADP cockpit for the manufacturing tests; right) general view (from inside of the cockpit) of the HYBRIA demonstrator 3D model

4.1.3.2 Tooling design

As agreed in the Negotiation Report, the Topic Manager provided the CAD models as well as the main tooling in order to employ most part of the project budget in manufacturing and mechanical/acoustic-vibration tests. The tooling basically consisted of two tools for the hot-forming of the stringers and a male PEAU for both integration and curing phases (see Figure 3).

Figure 3. Left) Hot-forming tool for Ω stringers; mid) integration-curing tool; right) hot-forming tool for T stringer

Additionally, two types of innovative caul-plates were designed and manufactured by FIDAMC in order to study the effect of different stiffness of the caul-plates on the aerodynamic surface of the specimen among other aspects. One set of caul-plates was developed in collaboration with Airbus, it is made of CFRP prepreg and it is vacuum-tight, so that it will allow to partially remove the vacuum bag that currently is used in autoclave curing cycles, which would involve costs reductions coming from both operation time and ancillary material savings. On the other hand, the second set of caul-plates is elastomeric, mainly made of rubber. This configuration could offer the opportunity to manufacture flat parts and afterwards, to adapt these elastomeric caul-plates to the required geometry, which would imply cost savings derived from the tooling (see Figure 4).

Figure 4. Left) Manufacturing of elastomeric caul plate; right) elastomeric caul-plate as-cured

4.1.3.3 Demonstrator manufacturing

Several manufacturability tests were accomplished during the production of the three HYBRIA demonstrators in order to predict further issues during the manufacturing of the full scale GRA cockpit demonstrator. Most relevant manufacturing aspects explored were:

- Acoustic material positioning over a double curvature surface. Acoustic material embedded in a continuous single layer and by means of double layer of patches shimmed with slit tape.
- Automatic slit tape lay-up of the skin with AFP over acoustic material (see Figure 5).
- Optic fibre sensors integration for SHM: sensors embedded in stringers and skin (see Figure 6).
- Automatic support-less lay-up of skin over Ω stringers without using reaction mandrels by enabling a software tool. Reason behind this lay-up strategy is to reduce the manufacturing time as well as simplify the tooling, which involves cost savings.
- Different caul plates configurations and improved interfaces for minimizing the print left on the surface of the specimen.
- Feasibility of demoulding simulating a 360° section.

As a work methodology, all lessons learnt during the production of each demonstrator were implemented in subsequent executions. The production of these specimens demonstrated the feasibility of the insertion of acoustic material within a CFRP structural element (among other aspects) by means of industrial manufacturing process.

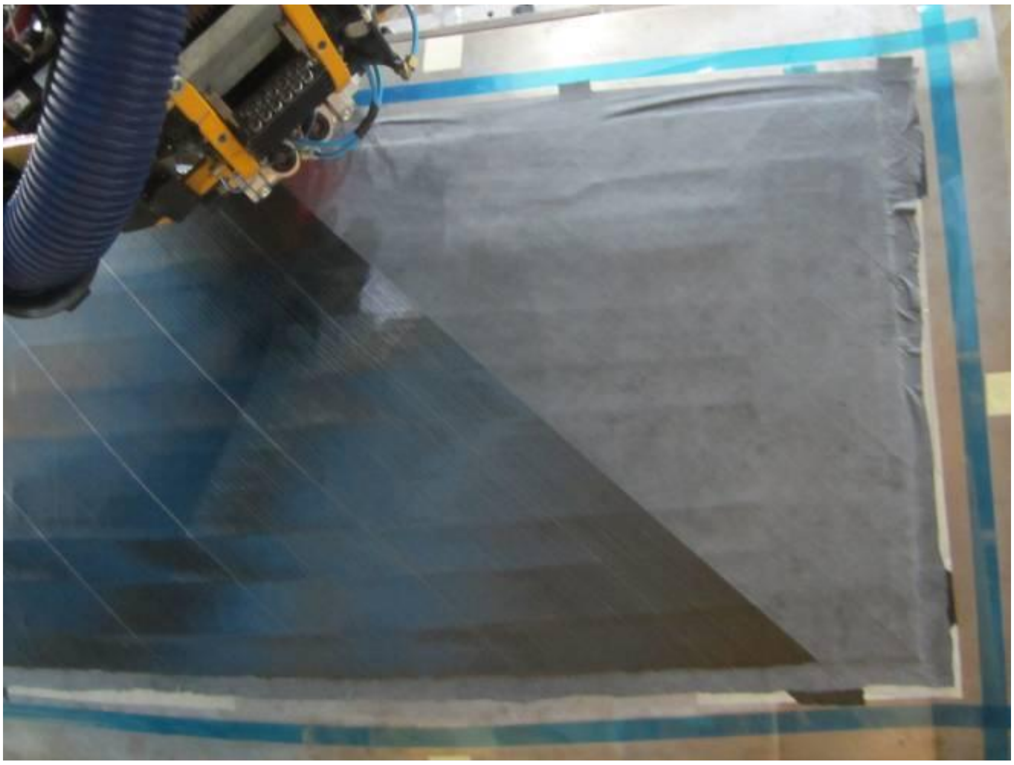

Figure 5. Automatic slit tape positioning over acoustic material

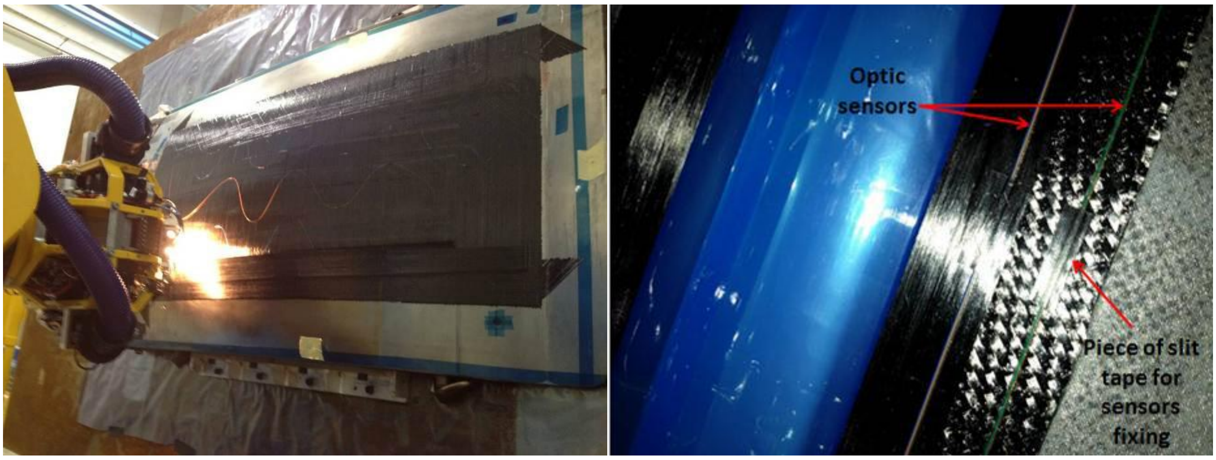

Figure 6. Left) automatic slit tape positioning over optic sensors integrated in the skin, right) positioning of optic sensors in the feet of stringers

Demonstrators were NDT inspected by means of pulse-echo technique (using both semiautomatic and/or manual procedures) according to AIRBUS procedures. No relevant indications were reported. However, demonstrator with double layer of acoustic material, showed 6-9dB of ultrasonic signal attenuation which does not meet AIRBUS standards (<6dB) are difficult to determine because the demonstrator has a bronze mesh on surface while the reference standard (specifically manufactured for this inspection) has not. Moreover, visual observation of the outer surface of the demonstrator revealed areas of the bronze mesh with lack of resin. This fact, together with the metallic protection absence on the reference standard could explain the attenuation reported. Figure 7 presents inner side of one of the HYBRIA demonstrators produced as-demoulded.

Figure 7. View of the inner side of HYBRIA demonstrator

Dimensional inspection was carried out for all specimens. Thickness was checked in the three demonstrators. Points belonging to both skin and stringers were measured. Most of the sampled points fit reasonably well within the tolerance limits, established in ±7% of the nominal values. There is no indication remarkable with the exception of thickness measured in web and/or head of stringers of third demonstrator, which are very close to the upper tolerance limit. Aerodynamic surface of the third demonstrator was measured in order to assess whether asymmetric lay-up areas of the concerned configuration causes a geometrical distortion of the element. Second demonstrator was studied as well with the intention to compare both acoustic configurations (continuous simple layer and double acoustic layer in patches) and their deviations against theoretical surface. In view of the measured values, both demonstrators seem to be slightly closed in their contour in comparison against the 3D model.

4.1.3.4 Testing

Acoustic-damping characterization

Acoustic-damping performance of the configurations explored was assessed by means of two types of tests: sound transmission loss factor measurements carried out in a double partition room and dynamic characterization for quantifying the modal damping of the panels through vibrational testing. Monolithic not-stiffened flat panels (manufactured within the WP1) where subjected to STL tests in a double partition room according to UNE-EN-ISO-140-3 standard. Transmission loss factor of each panel was measured at diffuse incidence at different acoustic signal frequencies, from 125Hz to 4000Hz.

Vibrational tests were carried out in order to quantify the modal damping of each configuration explored. Both flat panels produced within WP1 and curved demonstrators manufactured during WP3 were subjected to vibrational tests. The intention was to measure as accurately as possible the FRF in order to perform correlation analysis. The broadband tested was 1024Hz with a spectral resolution of 0.25Hz. Regarding boundary conditions, special care was taken in order to prevent the supporting device from influencing the results (see Figure 8).

Figure 8. Left) Dynamic test set-up; right) detail of accelerometer bonded to the specimen

The concerned results will be used to feed and correlate theoretical damping models. A first evaluation revealed that constrain layers improve the damping performance, which decreases as well the noise radiation.

Complementary testing

Erosion tests were carried out in a second test campaign complementary to the first one performed in the frame of COMPASS project on coupons with insertion of acoustic material. Since results obtained from first test campaign were not conclusive, the aim of these tests was to corroborate that the acoustic material does not negatively affect the behavior of the hybrid laminate against a blasting media. From results of these complementary erosion tests it is concluded that the insertion of SMAC layer in the CFRP laminate does not negatively affect the behavior of the global laminate against erosive particles but it offers an improvement of the erosion protection. Elastomeric layer seems to behave as a barrier against erosive particles since it slows down the damage growth through the hybrid laminate. Figure 9 shows a hybrid coupon subjected to erosion test.

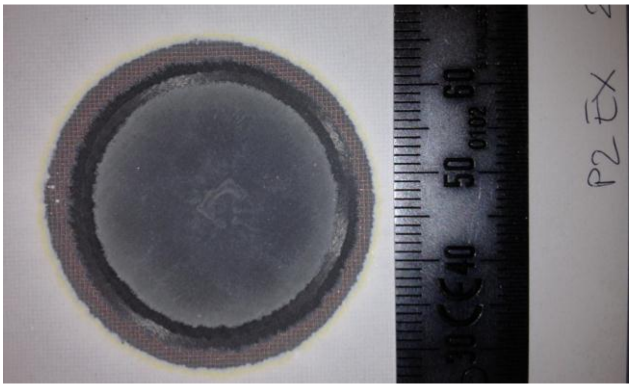

Figure 9. Coupon with acoustic insertion exposed during 2 minutes to media blasting

BAI tests were completed. The objective of these tests was to derive the bending after impact strength allowable of the most typical laminate configuration the skin of the GRA fuselage cockpit is made of. Left side of Figure 10 shows the test set up while right side of that figure presents a detail of a tested coupon. Despite of the inherent difficulty of testing thin laminates in a 4 points bending set-up due to the non-linear performance of the phenomena, the test campaign was carried out, after some set-up adjustments, successfully. Coupons were tested with the tool face in the tensile side. Energy impact selected for BAI coupons was consistent with that used for previous CAI coupons tested in the frame of COMPASS project.

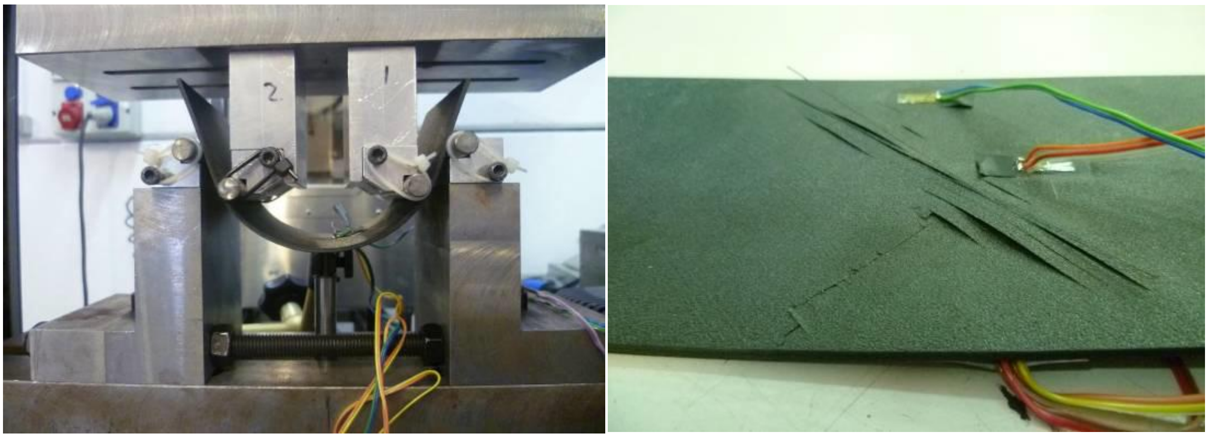

Figure 10. Left) Testing (4 points bending) of non-impacted coupon; right) failure mode detail of an impacted tested coupon

Buckling tests were performed according to the test plan. The objective of these tests was to explore the effect of the acoustic layer and the retention plies on the skin local buckling allowable and post-buckling behaviour. The no-growth of impact damages due to repeated loading was also investigated.

Low energy impact tests were carried out. The objective of these tests was to determine the BVID and VID impact damage thresholds, just after the impacts and after relaxation, for a fuselage skin typical laminate. The intention was to obtain the energy threshold corresponding to detectable damages by GVI and DVI limited to 35J.

4.1.4 Potential impact and the main dissemination activities and exploitation of results

Regarding acoustics, future aircraft generation has highly demanding requirements to produce designs that will be increasingly more attractive for airlines and comfortable for passengers. The fact that next generation fuselages will have an important amount of composite materials offers the opportunity to reduce engine and aerodynamic noise, as well as vibration transmission to the interior of the aircraft using acoustic multifunctional lay up. The most common method to minimize noise and vibration propagation to the interior of the cabin in current aircraft is the use of add-on parts that contribute to partially reduce noise and vibration levels. However, many add-on parts are required and this leads to high material costs, high labour costs and increased weight of the aircraft.

HYBRIA project has demonstrated the feasibility of acoustic material insertion within a CFRP structure by means of industrial manufacturing process without significant decreasing of properties. Therefore, assembly operations are simplified as well as overall structure weight is reduced. Moreover, HYBRIA project has proposed manufacturing processes which allow tooling simplification as well as reduction of ancillary materials consumption for the production of composite structures.

Development of new hybrid fuselage configuration, together with one-shot process which allow co-curing hybrid skin, is a key enabling technology for achieving a reduction in weight and processing time, which will involve a notably reduction of consumption and manufacturing costs respectively.

Spread of use of multifunctional materials in aircraft fuselages will result in:

- Reduction of engine and aerodynamic noise in the aircraft cabin.
- Reduction of vibration transmission to the interior of the aircraft.
- Less assembly steps in the production process.
- Less labour costs related to these assembly steps
- Less use of bolts and rivets: diminution of aircraft parts weight
- Lower fuel consumption due to diminution of aircraft parts weight and reduction of industrial production steps (less energy required as less parts produced separately).
- Energy savings and decrease of material scraps derived from the tooling simplification and the reduction of the ancillary materials consumption during the manufacturing of CFRP structures.

Globally, impacts on society will be:

- Diminution of manufacturing costs and easier and cheaper maintainability: airlines operations savings will benefit all the stakeholders.
- Diminution of time production.
- Lower carbon emission, which is in line with European policy objectives in the frame of Clean Sky programme.

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