Contenido

1 EXECUTIVE SUMMARY

This section will be edited by the Commission as such. The length of this part should not exceed 40 pages. This report should address a wide audience, including the general public. This summary report has to be updated at the end of each reporting period.
Please provide an executive summary. The length of this part cannot exceed 1 page.

Traditional aircraft structures use Aluminium stiffened panels for fuselage, wing and tail plane skins. In recent years, as composite materials become more prevalent in modern aircraft structures, stiffened skin panels are made of composite materials instead of Aluminium due to its light weigh and therefore its fuel consumption reduction.

Composites materials traditionally require expensive and polluting manufacturing techniques that shadow the possible advantages of these theoretically greener kinds of materials. Due to these composite materials' limitations, new methodologies are intended to solve the named problems.

In the present project, comparison between different Liquid Resin Infusion manufacturing processes (oneshot stringer and panel infusion vs. bonded stringer over infusion panel) has been done in the common playground of structural testing. Two geometrically similar wing skin panel coupons were manufactured and tested for quantifying their performance. Moreover, a third panel with different geometry but same manufacturing technique was tested as well.

Transducers and instrumentation in Structural Testing is a wide field in which several measurement techniques can be applied for every magnitude to measure. These options have different advantages and disadvantages, which leads to an unknown most convenient or feasible option to employ.

Thus, further comparison for conventional (Contact measures, Extensometry, etc.) and new measurement techniques (Digital Image Correlation, Optical Fiber, etc.) is needed in order to classify and organize the most appropriate and efficient option for the every project.

The ACID project explored and analyzed these topics on the frame of the project. Tasks done on this project has a double value:

> First, perform an evaluation of the manufacturing techniques that are the trend in the present aeronautical materials. Failure Load and mode are the keypoints for comparing. This knowledge will settle these novel manufacturing techniques and its results and will lead to further material and processes development.
>
> Second, to realize a benchmarking for the measurement devices that has applicability in the Aeronautical Structural Testing. Cross comparison will prove the most convenient system for the study case and will give an assessment for the deviations of the readings. Advantages and disadvantages for the measurements are highlighted.

2 PROJECT CONTEXT AND MAIN OBJECTIVES

Please provide a summary description of the **project context** and the **main objectives.** The length of this part cannot exceed 4 pages.

Stiffened panels are required in structures, which can be obtained by different processes. They can be made by attaching stiffeners to a thin panel or by producing integrally stiffened panels. An innovating manufacturing process based on Liquid Resin Infusion (LRI) can be employed for obtaining integrally stiffened panels. It is based on molding a dry NCF (Non Crimp Fabric) pre-form of Carbon fiber plies, which is bonded by a one-shot injection process to high stiffness, pre-cured pre-preg T-section stiffeners. This method presents benefits like lower costs in machining and assembly operations.

The structural behavior of integrally stiffened panels is normally better than those panels with attached stiffeners, but the difference is difficult to quantify by analysis and is dependant on the manufacturing technology. Specially, the major interest is to clarify the structural behavior of the panels, and especially their critical mode of failure.

The immediate solution could be to carry on comparative structural tests on different coupons molded by different manufacturing methods, but it must be taken into account that habitually employed strain and stress measuring systems are limited to specific pre-defined points or have limited resolution. As the manufacturing process and materials are expensive, and last a long term, few coupons are available. Therefore, carefully combined measurement systems must be employed to obtain as much information as possible during the test, and also recurrent information is desirable to correlate results obtained by different sources.

As an answer to this scenario, the ACID project is intended to explore and analyze some of the previous factors, trying to study comparatively the mechanical properties and behavior of different panels obtained by different manufacturing process.

To achieve this goal, a testing matrix was accomplished, based on 3 LRI coupons. Two of them are panels with attached stiffeners and the other one an integrally stiffened panel. It is expected that the results obtained in the tests help to clarify the panels' behavior and allow comparing the mechanical advantages versus economic benefits of the manufacturing processes.

Main objectives of the project can be described as follows:

1. Carry on large scale structural tests for obtaining ultimate properties and failure modes of components manufactured by different processes.
2. Measure strain and stress information during the test in a recurrent manner to combine and correlate the obtained signals which define the structural behavior of the panels throughout the test.
3. Analyze the obtained results, establishing a comparison between the behaviors of panels with attached stiffeners and integrally stiffened panels.
4. Analyze the obtained results, establishing a qualitative comparison between the mechanical advantages versus economic benefits of the manufacturing processes.

In order to fulfill these objectives, a careful work plan was established, divided in a series of work packages, WP. The interrelation of these WPs as well as the main partners involved in each of them is shown in Image 1.

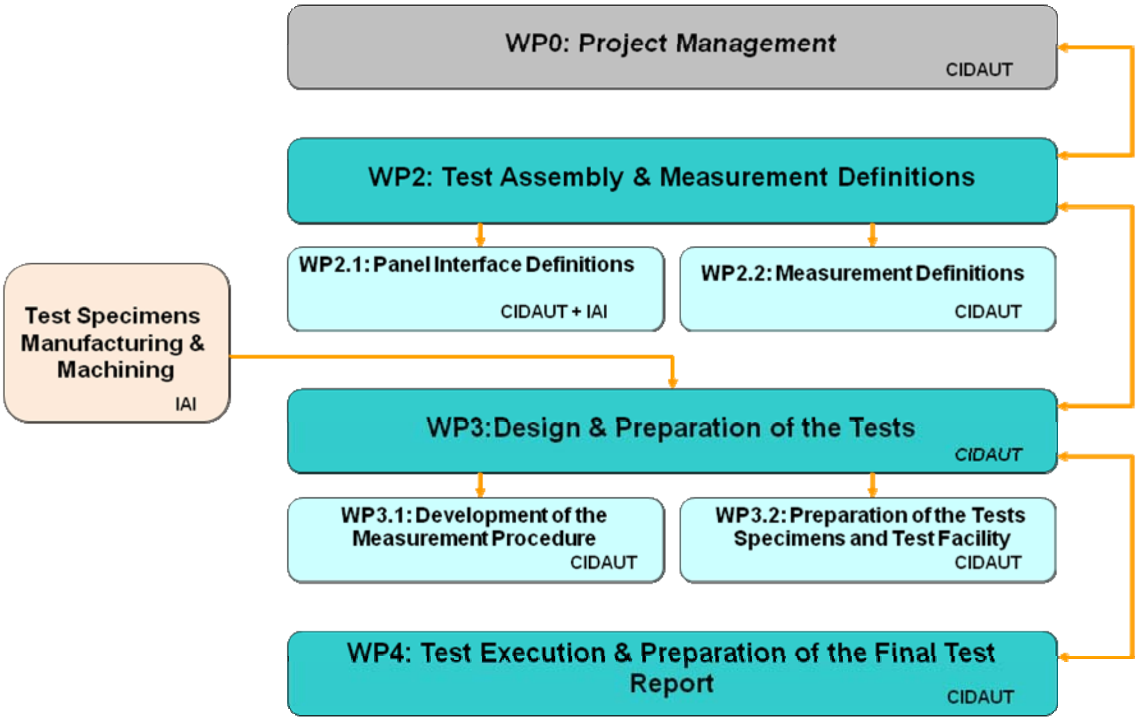

Image 1 Scheme of the project

3 RESULTS

Please provide a description of the main S & T results/foregrounds. The length of this part cannot exceed 25 pages.

The tests will validate the structural analysis methods used in the design of the panels, and also the applicability of the manufacturing process to the panels structural application.

3.1 TEST SPECIMENS

Three composite stiffened test specimens were tested. They represented two different wing skin panel configurations. Mechanical requirements for these kinds of structural components imply the use of stiffeners joined to the skin panel, in order to confine out-of-plane buckling to a specific area.

- First panel, with 3 stringers, was tested up to ultimate compression stress.
- Second panel, similar to the first one but obtained by a different manufacturing process, was also tested up to ultimate compression stress.
- Third panel, with 2 stringers and a simulated man-hole, was tested in moderate compression and then up to ultimate tensile stress.

The aim of the tests was to verify if new manufacturing methodologies LRI (Liquid Resin Infusion) offers as good results as the traditional pre impregnated method but with the associated advantages, such as energy and money saving and time economy; together with a less contaminant manufacturing process.
Test specimens were supplied manufactured and machined by IAI, adapting their contact areas with the defined tooling.
General CAD images of these skin panel specimens are given bellow.

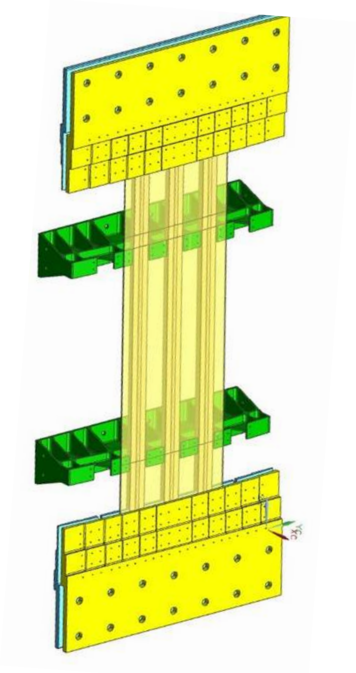	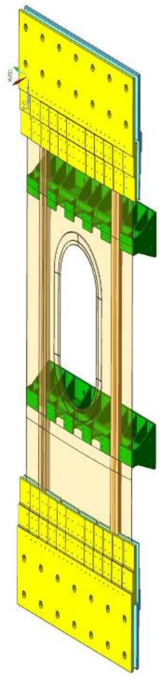
Specimens 1 & 2 geometry	Specimen 3 geometry

Image 2: Specimens geometry

3.2 TEST GENERAL DESCRIPTION

3.2.1 Test Loads and Test machine

Basically the tests consisted on loading axially the different test specimens under two different load profiles: Compression up to ultimate load and a moderate compression and ultimate tensile combination effort.

Although all loads were done in a quasi-static pace, loading was controlled in displacement rate mode which usually gives a safer control mode against abrupt force variations.

A number of stops during loading modes were set, to let some devices acquiring test data (others work in a continuum acquisition).

A MTS (Model: 311.41) Universal servo-hydraulic system 2.5MN was employed for these tests. It has the following capabilities:

- Force Capacity: +/- 2,5 MN
- Displacement stroke: +/- 75 mm
- Dynamic system (from quasi-static up to 20Hz)

Two Hydraulic Powers Units with a combined flow of 1.200l/min were employed for hydraulic supply.

3.2.2 Test Tooling

In the wing structure real application, in addition to the stiffeners, ribs provided additional support to the panels. They were intended to control buckling effects.

Fixture conditions were designed for representing the real assembly of the component within the wing, reproducing the real boundary conditions. Stiffeners are the longitudinal structure along the wing and the ribs are in a perpendicular orientation. This way, the testing fixture configuration worked close to the real state of the wing structure in real flight, with compression and tensile efforts over the skin panels, provoked by lifting effect of the cantilevered wing.

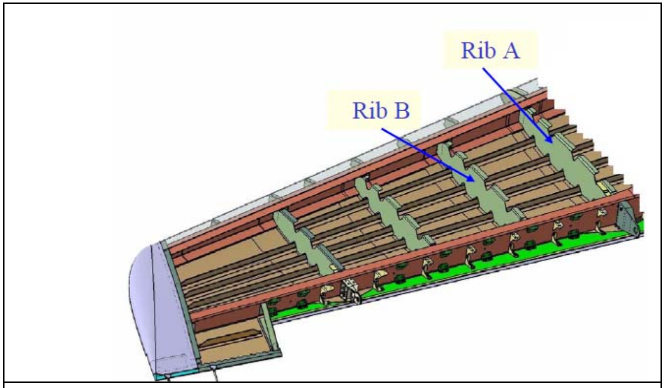

Image 3: Wing Structure

In order to be more representative, the interface between tooling and specimen (the jig that transmits the efforts to the specimens from the test machine) was carefully designed and mechanized to be properly adapted to the wing panels shape.

The final design was designed following the CAD (provided by the manufacturer IAI) to assure a perfect contact to the test specimens and CIDAUT completed it with the necessary interface up to the test machine actuator. So, the specimen was attached to the tooling by means of the same kind of joints used in real case. The interface between the end of the specimen assembly and the test machine was developed so boundary conditions represented the real environment of skin panel specimen. The final design withstand the required load conditions respected the geometry of the specimens.

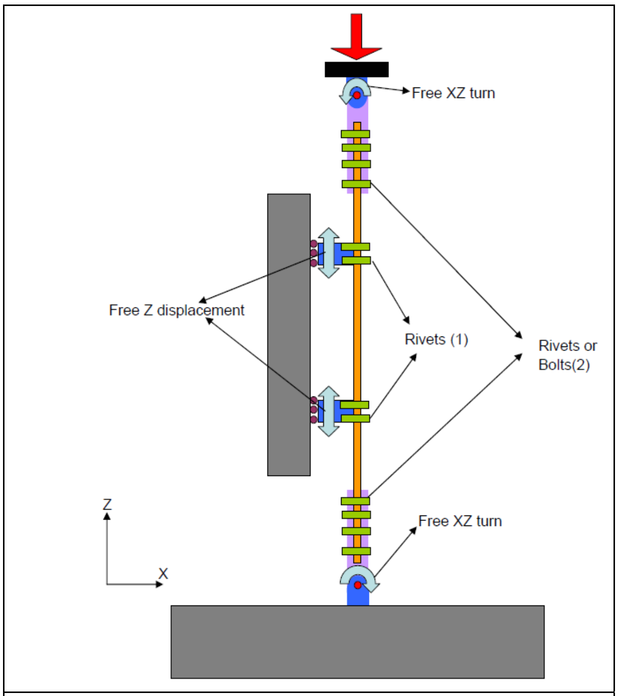

Image 4: Schematic Boundary Conditions

3.2.3 Instrumentation and Acquisition devices

Combined measurement systems were employed to obtain as much information as possible during the test, and also recurrent information to correlate results obtained by different sources.

The Testing system includes two sensors that usually use as a feedback signal which are also used as external measurement sources. These are a load cell to measure the applied external force, and a LVDT (Linear Variable Differential Transformer) sensor to measure the applied external displacement.

The LVDT is embedded in the Machine Actuator and the load cell fixed to it as part of the loading chain.

Specimens' instrumentation is divided into two parts. The first one could be named "Conventional measurement system" and the second one the "Advanced measurement system"

Conventional measurement system was based on extensometry (strain gauges and rosettes) and displacement transductors (potentiometers). Both of them are contact and discrete measurement devices.

- Extensometry: Strain gauges and rosettes were bonded on certain locations along the component's surface to measure its flat tensional state. Its output signals are the axial strain, in case of strain gauges, and the individual strains in three directions for rosettes, so combining them principal strain values and directions on the singular instrumented point can be calculated.

  The stronger point of this measurement system is the resolution of measurement. Because of the contact between the surface and the gauges, even the smaller strains can be measured with accuracy.
  Each specimen was instrumented with 24 rosettes, 45 strain gauges and 12 potentiometers, as it can be seen on next image.

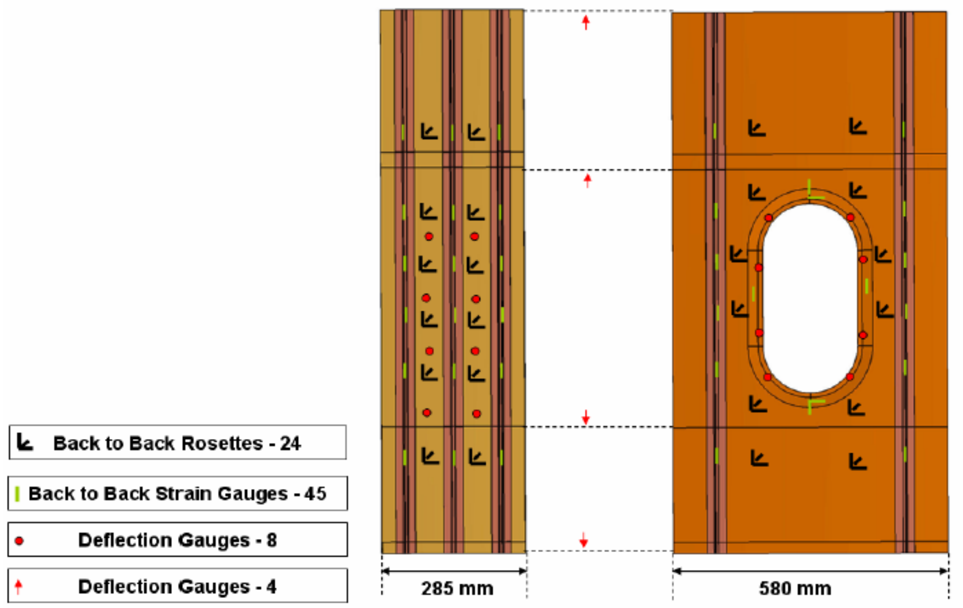

Image 5: Conventional measurement system distribution

- Linear Potentiometers: The reading of potentiometers is displacement measurement. They are contact sensors, as the strain gauges. A wire in contact with the specimen surface detects panel out-of-plane displacements along the wire axis.

The device that recorded conventional measurements system readings was the HBM MGC PLUS +Catman one.

Advanced Measurement System was based on DIC systems (Digital Image Correlation) and Optic strain measurement. These advanced systems, supplies new capabilities over the Conventional systems lack.

Their benefits of these methods are, first of all, continuing measurements (Linearly continuum in case of Optic fibre, and 2D or 3D continuum, in case of Photogrametry). Additionally, Photogrametry is a non contact measurement system.

Digital Image Correlation systems are a non contact 3D deformation measurement with which it can be calculated and analyzed the shape and the flat strains of the component by means of analyzing video images of two cameras. These complex system optimal results are, however, conditioned to a correct procedure of positioning, illuminating, painting and calibrating previous processes.

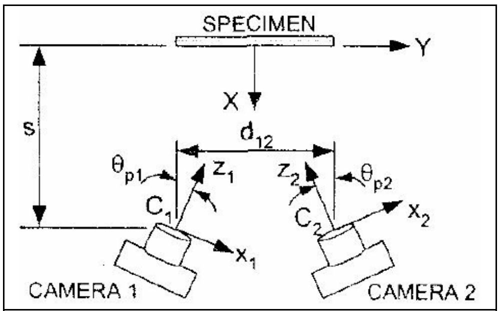

Image 6: Camera positioning scheme

For providing the DIC from patterns, a spray paint is applied over the interest surface of the panels prior testing.

The testing zone of interest was located on the outer surface of the panel (surface without the stringers). It covered up to the lateral stabilizers and was centered on geometrical centre of the panels. Around 750mm long (considering 650mm between lateral stabilizers) and the width of each panel was recorded.

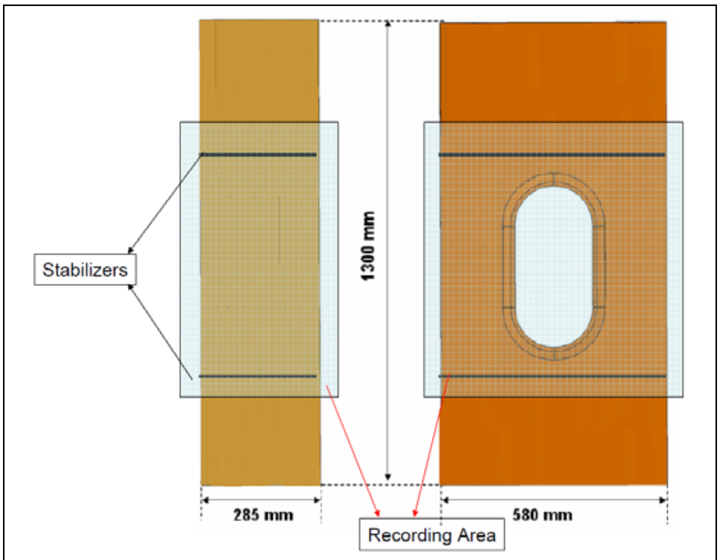

Image 7: Recording areas

Once the volume of interest was defined, and the specimen prepared, several images from the back side of the specimens were taken by two Photron High Speed Cameras (opposite side of the images above). These cameras' speed capability is up to 5.400 fps at full resolution / 500.000 fps at reduced resolution.

By analyzing the recordings with technical Aramis software, the displacement and position measurements of any point of the recorded area can be obtained as an output. This is possible by compounding both simultaneous images to generate a 3D model from certain instant of the record. Once this is done, this 3D surface can be compared with the one in the instant later and then, measure the movement of the painted patterns in the surface. Namely, the shape of the surface at any moment of the test can be obtained when both cameras record at the same time.

Synchronization between conventional and advanced measurements was assured with a trigger that launched the test and also started the acquisition (including the video recording).

Optical Fiber Distributed Sensing technology is capable to measure strains throughout an optical wire (as a strain gauges does in a point), by means of measuring reflections of a light beam through a glass fiber wire. The physical principle is based on the emission of a narrow pulse of light through the optical fiber and listen the reflection. That reflection is affected by changes in strains or temperatures of the wire. These changes make the spectral shift to be different and then, it can be measured and scaled.

Main benefit of this new technology is that no drift by the effect of time is observed in the reading as in traditional strain gauges, and that can be considered continuous within a line, since the wire can carry high density of measuring points along its length. Contrary, the low rate acquisition needed to get a good measurement, restricts its application to static cases.

Six loops of wire, distributed in 3 different heights mirroring respect stringer axis were used in each stringer of the panel. Thus, 2 or 3 optical wires depending on the panel, one per stringer, allow a fully measure of the stringer's strain

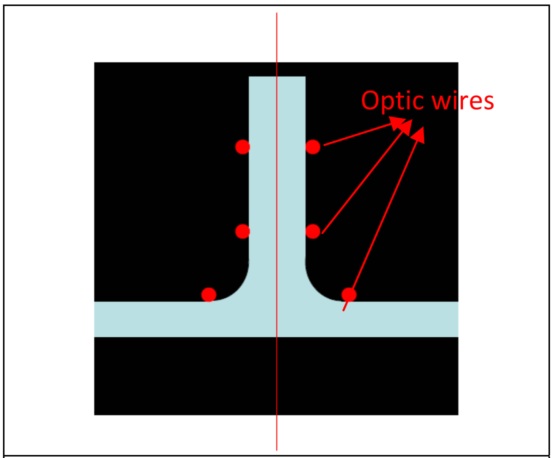

Image 8: Optic Fibre distribution example

3.3 TESTING TOOLS

The tooling design was divided into three different parts clearly different, since they were intended for different tasks:

- Clamping: introduction of the loads into the panels were carried out through this tooling. These parts surround the panel's ends and they had been designed to adapt perfectly to the surface shape of the specimens by CAM machining. These parts were sent to IAI partner, which manufactured the panels, for checking possible deviations.
- Ribs: Compression loads over thin parts leads to buckling effects, causing instabilities in the named way of out of plane movements. In order to stabilize out of plane movements, a representative tooling of the ribs present in real wing inner structure was designed and manufactured by CAM machining.
- Auxiliary tooling: To assure the correct final assembly of the specimens both to the ribs and to the testing system, a tooling solution had been implemented. This special tooling was designed by CIDAUT with two different purposes: fixing the specimens in a unique position for drilling the holes where to attach the ribs, and as interface to assembly the specimen to the testing system, respecting the pre-defined boundary conditions. Eventually, it allowed aligning and assembling the other parts of the jig set in a controlled relative position and by means of this, the panel could be correctly placed and finally mechanized.

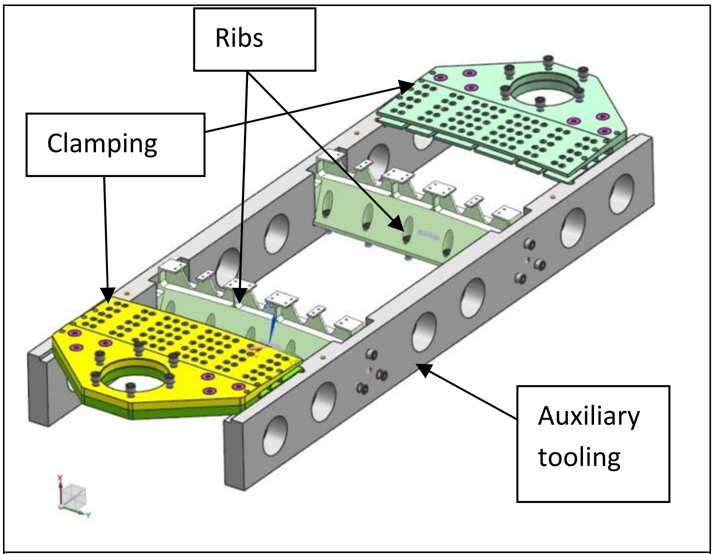

Image 9: Complete assembly

3.4 SPECIMENS PREPARATION

The final adaptation of the panels to the tooling and the holes drilling were done by IAI (correction of thickness deviation and holes drilling). Panels were received in late October and November.

After its reception, the instrumentation process started with strain gauges installation according to Image 5, for being the greatest time consumer. This instrumentation covered the light sanding, cleaning, and surface preparation, in addition to positioning, bonding and protecting processes.

Due to the high quantity of gauges and rosettes of the panels, wiring and connection processes required a carefully installation and codification, essential for avoiding measuring mistakes. The high density of instrumentation to be applied on the prototypes had required a wise planning method. It was developed carefully to guarantee precision on other measuring devices, such as DIC or Optic Fiber.

Final panels' aspect and extensometry instrumentation and its distribution are shown in the following image.

Image 10: Three Stringers Strain Gauges Distribution

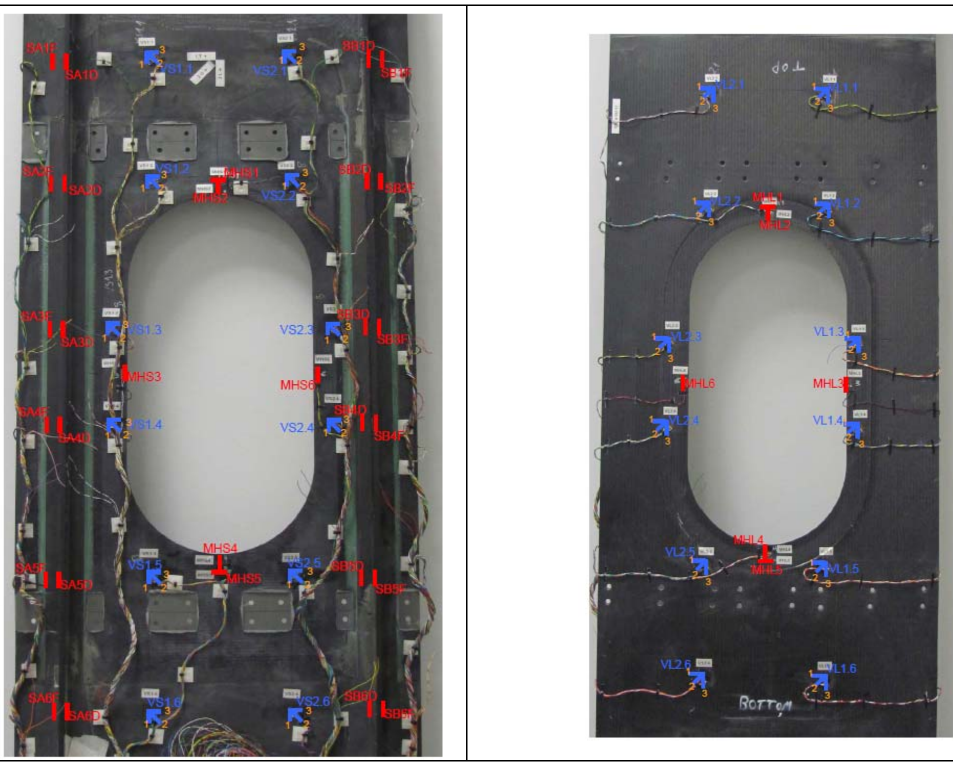

Image 11: Manhole Strain Gauges Distribution

Once strain gauges installation had been done, optical fiber was bonded to the stringers. This was a delicate process, due to the fragility of the thin optical wires.

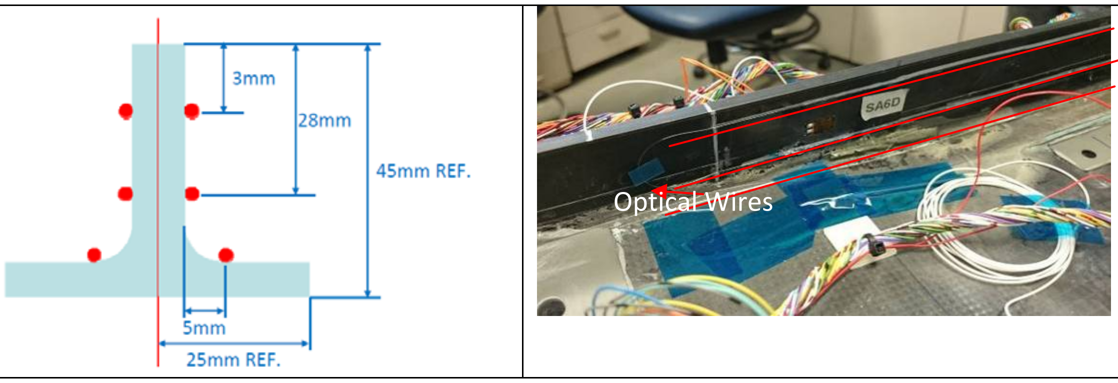

Image 12: Stringer Optical Fiber Marking

3.5 FINAL TEST SET UP

The final assembly of each test specimen into test machine was done once the specimen was fully instrumented, and the panels tested one after another. Final test set-up is shown in Image 13.

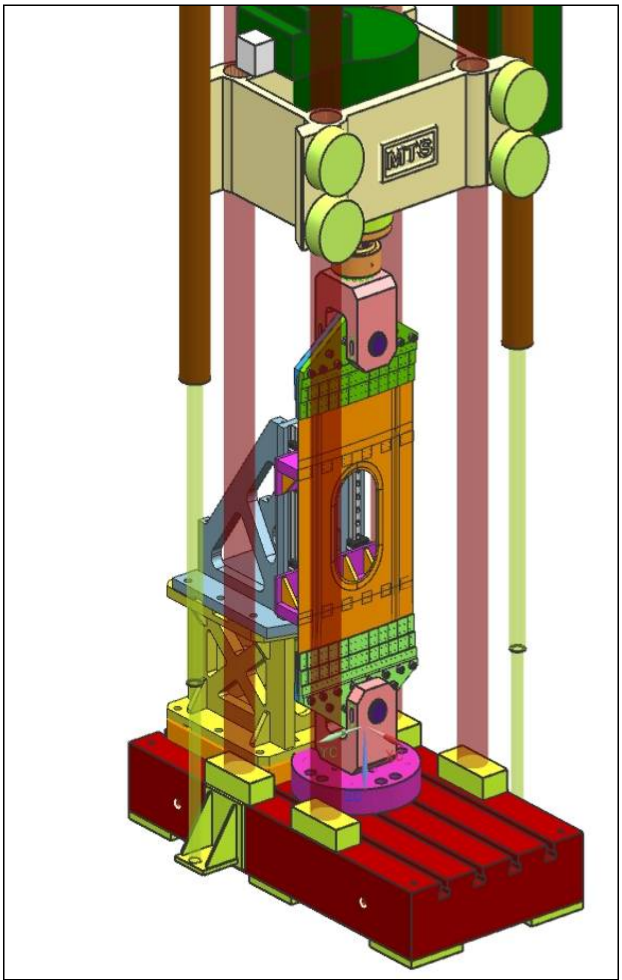

Image 13: Test machine Specimen assembly

After assembling the specimen to the testing system, linear potentiometers were installed in the inner surface in horizontal direction for measuring the out-of-plane displacements of the panel. Their position was achieved by means of a light structure intended to hold them during the test. This structure was joined to the ribs, and therefore its axial displacement (tensile or compression) was permitted.

Image 14: Inner face Potentiometers

Also, more potentiometers were placed at the side of the panel and controlled transversal movements.

Finally DIC device was prepared to record the test. Several parameters were adjusted to set up correctly the measurement, as distances to the test panel or between cameras and their angle, and so the optical objectives focal distances. Also, a calibration process, recommended by the DIC software supplier was done. This procedure provides to the system with a file that gives meaning to the images that are recorded later and thus makes the 3D analysis possible.

The final set up for DIC measurements is shown in the following picture.

Image 15: DIC system

The outer surface of the panel was painted with black mate paint for ridding off the possible bright of the images that could spoil the analysis in the shining areas. After drying time, a white paint spotted lay was applied on the recording area.

3.6 TESTS RESULTS

Once the test set-up is completed, the test could be carried on. Several steps were done in each of them for permitting quasi-static measurements for measurement devices which require it. Tests sequence was the following one:

- First test: specimen corresponding to the Conventional LRI process manufacturing methodology was compressed up to failure. The obtained Compression Ultimate Stress was 720kN. The panel failed in the central area between ribs.

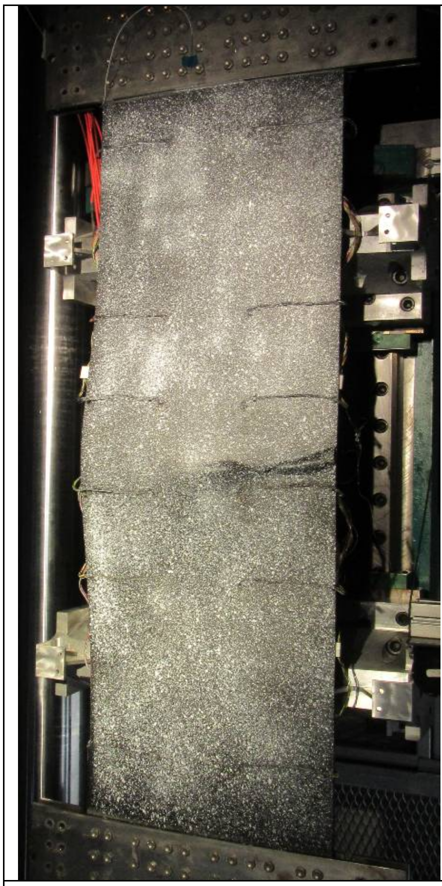

Image 16: Conventional Panel

- Second test: specimen corresponding to the Innovative One Shot LRI process manufacturing methodology was compressed up to failure. The obtained Compression Ultimate Stress was 730kN. The panel failed in its upper area above the upper rib.

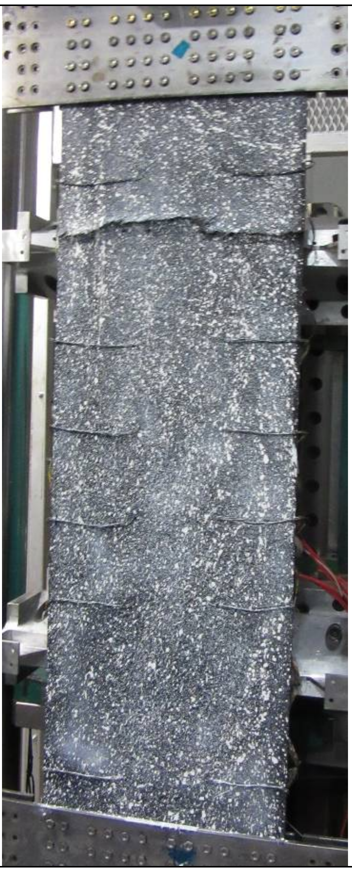

Image 17: OneShot Infusion Panel

- Third test: specimen corresponding to the Conventional LRI process manufacturing methodology with manhole geometry was moderately compressed up to 170kN and then tested in tensile up to failure. The obtained Tensile Ultimate Stress was 950kN.

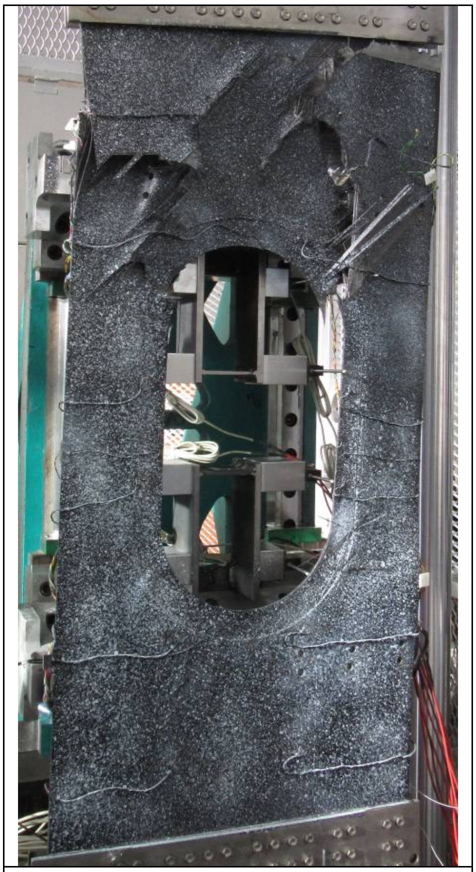

Image 18: Manhole Panel

As have been seen during the project, the comprehensive comparison performed over the similar geometry panels leads to the claim the novel composite manufacturing procedures performance is equivalent to the conventional ones.

The results shows that the behavior up to failure is similar in both specimens, without any major deviation in the acquired readings (Extensometry, Potentiometers, etc), and no detected damage occurred prior to final break, with similar Displacements and Stiffnesses. Their Load limit is in a sharp range.

Overall test conclusion indicates that despite the technology applied, the general mechanical response of the specimens is extremely similar.

About the second group of achievements, the ones related with the measurements methods, the test readings show a general good result, considering the repeatability of the data for the same magnitude and panel area.

Performance of the conventional measurement systems is largely proved and is one of the best advantages that balance the high cost and installation time needed. Their accuracy, stability and noise to signal ratio are outstanding. They will be then use to evaluate novel measurements systems. On the other hand, being discrete sensors, the information provided by these conventional methods is local.

Optical fiber, compared with uniaxial Strain Gauges of the stringers shows a good correlation. The expendables cost is low and the installation cost are average (although equipment is expensive), achieving a continuous reading with high accuracy and correlation against Strain Gauges. The good performance requires the fiber to be properly bonded and be kept in that condition throughout the test.

Signal quality of non contact DIC devices, is lower due to the higher noise. With a low cost of installation and expendables, but a higher hardware (videocameras) and software (ARAMIS) cost, the system performs good with some remarks. If the signal to be measured is high enough (e.g. out of plane movements) the noise will not cause a noticeable decrease of the reading quality and the correlation with potentiometers is close enough to conclude the DIC system response is good.

If the reading to be measured is low, for instance, the plane strains of the skin; the noise affects more deeply the reading. It has to be kept in mind that the window employed for the project is big enough to covers the dimensions of the specimens, but exactly because of that, is not possible to measure small distances (reaching ranges of microns) with enough precision.

To sum up, the benchmarking done in the project is a cross comparison that put light on the complex and wide options field of the measurement systems within the Aeronautical sector. The work done can be employed in the future Tests, as a shortcut for knowing the most suitable and convenience measurement method to apply, based in the study here written.

4 POTENTIAL IMPACT

Please provide a description of the **potential impact** (including the socioeconomic impact and the wider societal implications of the project so far) and the main dissemination activities and the exploitation of results. The length of this part cannot exceed 10 pages.

Impact

Advantages and disadvantages of the composite materials and its increasing importance on the Aeronautical sector have been deeply explained and can be understood from the perspective of fuel saving consumption on air transport. Additionally, the manufacturing techniques are expensive and dirty. Further research need to solve associated problems with these materials.

The structural tests done during the project over panels manufactured with conventional and novel techniques have meant a common playground in which assesses the mechanical performance of these techniques result.

This development on composite applications will mean the extension of the number of uses, out of the traditional industry fields increasing the beneficiaries of the innovative research. The use of novel methods leads to a settlement of these advantageous new techniques in any sector working with composites, or in new sectors suitable for acquiring benefits of these materials, such as Renewable Energies, Automotive, etc.

At the same time, this innovation can lead to new techniques and therefore a new push-forward the state of the art.

This forward development can be eased by the comparisons performed in the advanced measurement methods in the project. Numerous devices and technologies can be applied in the structural testing field, but a benchmarking of them, showing pros and cons of each of them is proved to be a powerful tool with a high applicability in the future.

Dissemination

Due to the highly technical results obtained as an outcome of the work and the confidentiality agreed in the project, dissemination activities will be restricted to the webpage of the CleanSky consortium.

The initial exploitation of the project results is the acquired know how within Cidaut. Although it will not lead to a patent, the knowledge will support future collaborations with new CleanSky projects.

Exploitation

First steps for the exploitation of the project outcomes have been accomplished within the Clean-sky framework and its transmission of information.

The understanding of the structural behavior of the advanced composite panels, gained by these tests by using novel measurement procedures, brings much closer the implementation of similar designs in commercial use, mainly in the aerospace industry.

Apart from the achievements for the composite manufacturers and their novel techniques data, the study performed in the project framework, and its large number of measuring technologies, means a deeply understanding of the characteristics of the measurement devices.

This knowledge has been transferred into the Structural testing laboratories, stands for the smart application of measurements and a cost reduction by means of installing the better technical solution for each technical challenge, clarifying the limitations of each system.

Comparison over the performed tests, means a direct short term benefit for CIDAUT, increasing know how and the applicability of the measurements systems available.

Please provide the public website address (if applicable), as well as relevant contact details.
www.cidaut.es