1. Final Publishable Summary Report

1.1 Executive Summary

EVITA (Non-Destructive EValuation, Inspection and Testing of Primary Aeronautical Composite Structures Using Phase Contrast X-Ray Imaging) aims at bringing Grating-based Phase Contrast X-ray imaging technology to Non-Destructive Evaluation and Inspection of primary and/or complex aeronautical composite structures, during the design, manufacturing assembly, repair and re-use procedures and processes of key components.

Based on the review of the design, manufacture, assembly and repair procedures applicable in Aeronautical components made of composite materials, a Grating-based Phase Contrast X-Ray imaging demonstrator was developed to inspect large composite components with the following goals:

- increase the level of detectability of defects in composite structures,
- reduce the amount of defects that, up to now, were very difficult or impossible to be detected using industrial standard inspection methods (e.g. ultrasound-based methods),
- increase the level of Non-Destructive Testing (NDT) process reliability for safety critical composite structures.

Following the initial development process, selection and manufacturing of composite specimens with actual and/or artificially induced flaws were performed in parallel with the design and development of the demonstrator. It is important to mention that a very significant part of the effort in the project was devoted to this task, including subtasks such as mechanical design, gratings design and manufacturing, control and image modules development and final assembly and characterisation of the demonstrator.

Then an exhaustive and extensive testing and measurements campaign took place, using the proposed innovative methodology in order to validate and benchmark it against industrial standard NDT methods. Once the tests campaign was finished, a set of parameters to compare and evaluated the results was defined, concluding that the EVITA demonstrator allows the detection of defects that up to now were very difficult or impossible to detect with industrial standard methods.

Finally, taking advantage of the inputs from the industrial partners with a vast experience in the whole chain of aircraft production and operations, a roadmap for the development and subsequent certification of a more performant stationary Phase Contrast X-Ray Imaging prototype was defined.

The introduction of this innovative methodology is expected to provide the aeronautical industry with a reliable and detailed insight of the integrity of thin and thick composite structures as well as of complex geometry ones, such as integrated closed boxes and sandwiches. By increasing the level of detectability of defects in composite structures, as well as by detecting defects invisible to standard non-destructive testing technologies, the novel method will play a major role during the full life cycle of composite components, reducing the inspection cost during the whole lifecycle.

Consequently, EVITA developments will enable the industry to improve manufacturing and assembly procedures and to reduce requirements for extensive mechanical testing campaigns. The prompt and automatized detection of defects in single components, both before and after assembly, will reduce the number of replacements at a later stage, thus improving the production process and the lifetime of components. Moreover, the new method will improve the localization of defects during maintenance allowing for efficient and reliable repair operations and minimising the aircraft downtime. The combination of the aforementioned achievements will lead to a direct reduction of the aircraft development and operational costs.

Finally it is expected that the proposed novel non-destructive methodology will help achieve the goals of reduction of aircraft weight, through enabling reduction of defects threshold accepted in primary composite structures, thus resulting in the application of lower safety factors in the design of composite components. The subsequent decrease in fuel consumption will contribute both to the reduction of aircraft operational cost and to the emission of greenhouse gases in the atmosphere.

1.2 Project Context and Objectives

1.2.1 Project Context

The new Boing Dreamliner as well as the Airbus A350 are being fabricated of composites for 50% or more of their primary structural weight. Figure 1Figure 1: Percentage of composite in new aircraft shows the percentage of composite and other materials in these two aircrafts. A steep rise is visible for the last ten years and it is expected that this trend will continue for the next years and involve all segments of the aircraft industry from private jets to long-distance carriers via helicopters and drones as underlined for private jets in Figure 2. The detection and tracking of defects during production, assembly and maintenance of composite parts is therefore becoming more and more important.

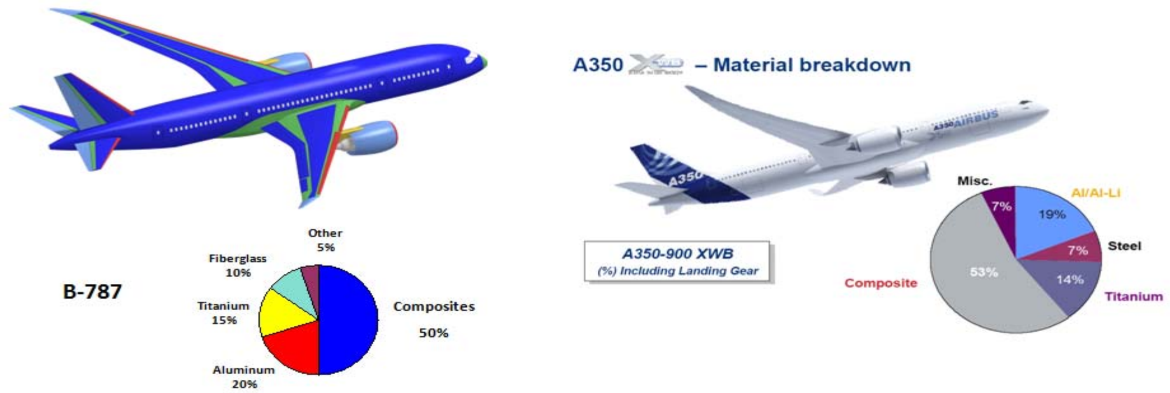


Figure 1: Percentage of composite in new aircrafts

The next twenty years will see introduction of large commercial aircraft having more than 55 % of composite structures.

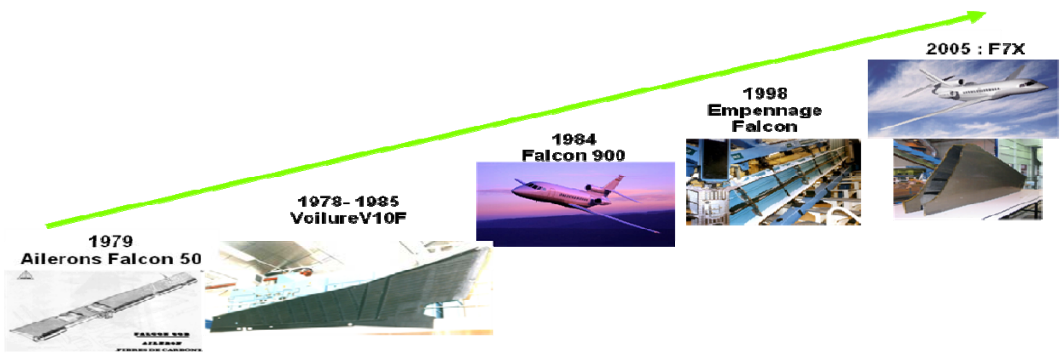


Figure 2: Evolution of the use of composite structures in the civil jets Falcon

This growing use of composite material is driving the concept of lean manufacturing currently developed amongst aircraft manufacturers, which leads to very strong demands on new testing and quality assurance concepts to enable and support the developments, and which would also have to take into account the "Green testing" aspects and increased automation.

The detection and tracking of defects, which covers the whole Life Cycle like testing, manufacturing, assembly and maintenance of composite parts, is therefore more and more important. On one hand NDT/NDI issues arise more specifically from the continuous development of new manufacturing and assembly technologies for composite materials as well as from the introduction of new resins, advanced textiles and resin fibre systems, thus leading to new specific defects on top of those already found with conventional manufacturing technologies. On the other hand the growing complexity of subassembly groups containing composite parts increases the challenge of early detection of unacceptable flaws before the detection becomes either impossible or rework causes excessive production costs. It is thus of paramount importance to install quality inspection methods sensitive to micrometre defects also deep within the structure and not only the surface, at every component level prior to following assembly steps.

All through the life cycle of aerostructures made of complex composite materials, Aerospace Original Equipment Manufacturers (OEM) need innovative, cost-effective and fast non-destructive inspection (NDI) technologies. The actual NDI techniques (dye penetrant, eddy current technique, thermography, shearography, tap testing, conventional x-ray, immersion or water-jet Ultrasonic or gel-coupled contact Ultrasonic) have major limitations in terms of resolution and sensitivity, infrastructure needed, inspection speed, flexibility and flow detection capability.

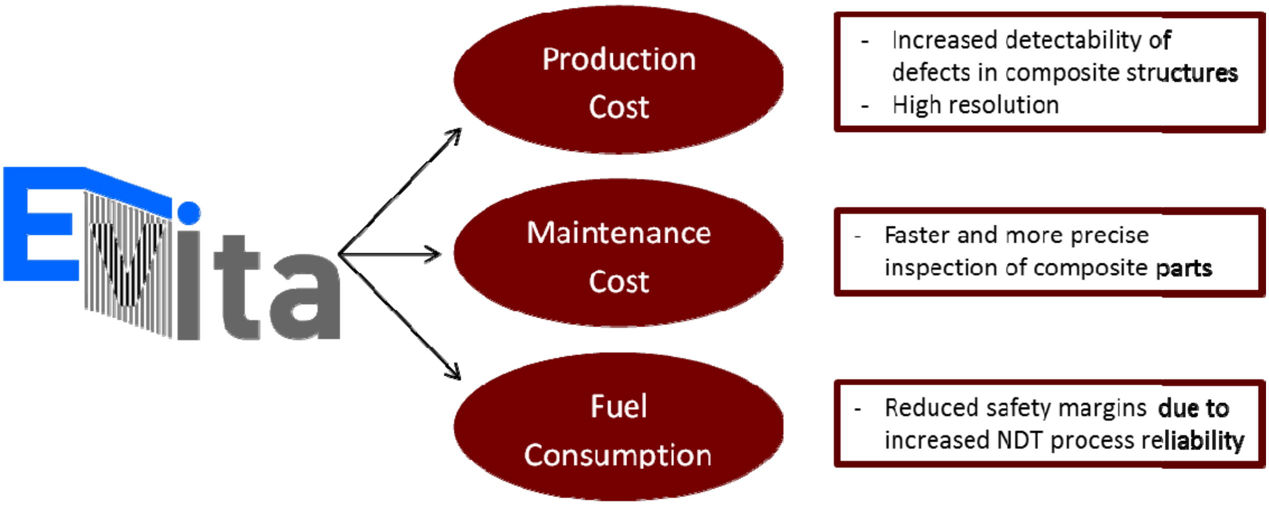
Current composite testing is nearly completely based on Ultrasonic (UT) inspection which is the most versatile and diffused NDI method, and essentially with wet-coupled ultrasonic testing which were adapted from metallic inspection procedures. In production, whatever aircraft or helicopter manufacturer (Boeing, Airbus, Embraer, Bombardier, Airbus Helicopter, Dassault Aviation,…) fast and expensive multi-channel inspection machines with over 128 parallel transducers as well as phased array transducers and electronics are commonly used. This approach has been almost sufficient up to now as it works only on smooth profile or circularly symmetric shapes using bubbler or water jet techniques (examples are panels for the stabilisers on Airbus aircraft, the rear pressure bulk head of the new A380 or helicopter panels).

On top of those issues, one of the major drawbacks with conventional ultrasonic testing is the evaluation time of the data especially for laminate structures (data evaluation is still done completely manually by qualified personnel). This causes high costs for inspection because of two reasons. First the whole inspection (including evaluation) is rather time consuming (up to several weeks per panel) and, secondly, online production is not possible which complicates the manufacturing process and limits the throughput by a variety of bottlenecks. This situation currently leads to manual inspection which is the most expensive item in the quality assurance, therefore cycle costs can be extremely high.

Several methods have emerged in the past essentially on both sides of the Atlantic Ocean; some have been fully funded through national and European projects (SYSTEMATIC (FR), INDET, INDUCE, CANDIA, FANTOM, DOTNAC, MAAXIMUS) in order to increase flexibility, speed of inspection by increasing the coverage, such as Infrared Thermography, Shearography, Terahertz-based technologies or other optical techniques. These methods are however restricted to some niche applications, such as sandwich structures, maintenance (impact detection and repair patches assessment), in general parts that must not be wetted such as those manufactured for aerospace systems, rockets and satellites. Despite improvements and commercially available systems they cannot beat ultrasonic techniques for most of the composite material applications. Although Ultrasonic inspection remains the reference standard complying with relatively fine and quantitative assessment of material quality, it has two major limitations, the first one in terms of resolution and sensitivity when the thickness of the part increase beyond 30 mm, which is nevertheless well above the limits of Infrared Thermography, and Shearography, typically 3mm, and the second one when the geometry of the part becomes complex.

The goal of the EVITA project is to tackle these different issues through the development of an appropriate lean and novel NDT/NDI method, to push back these boundaries and enable the non-destructive evaluation and testing of fibre reinforced polymers down to the micrometre level. The proposed technology development based on Phased Contrast Imaging X-Ray (PCI X-ray) will help reduce the safety margins for composites and therefore to significantly reduce structural weight. This will be possible due to detailed and highly reliable knowledge of the internal damage status of primary structural elements. Available deep volume inspection tools will allow the producer to specify tight flaw density thresholds which are a prerequisite to introduce structural weight reductions. Current safety margins are not only resulting from experience with metallic structures, but also limited to the performance of the established NDT tools developed for conductive components.

1.2.2 EVITA Main Objectives



The main objectives of **EVITA** are:

- To provide an important corner-stone to fully exploit the potential of composite materials for aircraft manufacturing and repair. A fast and reliable detection of defects in these materials will enable and enables optimized designs and therefore allow for a significant weight reduction, leading to a more cost efficient manufacturing of green aircrafts.
- To develop an optimal solution to tackle the remaining and new NDT issues in the composite material life cycle in terms of defect detection capabilities, integration in the lean manufacturing concept, and replacement of aged NDI installations inspections getting less compatible with the environmental constraints (REACH).
- More specifically, to provide concrete specification limits on detectability of deep volume structural defects like cracks, porosity, voids, fibre wrinkles, delaminations, disbonds, inclusions, and the like in composite materials for aeronautic assembly groups with the means of phase contrast X-ray imaging.
- To build a dedicated phase contrast X-Ray imaging demonstrator. Optimised operational parameters for different composite materials, for thin and thick samples or for sandwich structures were established and an extensive series of test-sample measurements were performed to explore the limits of this methodology.
- To perform benchmarking measurements with established NDT tools in order to compare the results of the test campaign with the EVITA demonstrator.
- Reduction of the mechanical dynamic stress compliance verification in the non-recurrent engineering design phase of aircraft development. The same applies to the development of repair procedures.
- Finally, roadmaps towards stationary and mobile applications of phase contrast X-ray imaging in aircraft development, manufacturing and maintenance/repair, including certification requirements,

were performed allowing to estimate the time and costing to market and serving as bases for the subsequent development of industrial stationary prototypes.

1.2.3 Specific Objectives

The main specific objectives corresponding to the various building blocks and expected contributions of the partners are listed below.

The project was divided into three technical workpackages,

- The goal of the first workpackage was to identify components and procedures covering the lifecycle of Aircraft parts and structures, testing, manufacturing, assembly and repair, for which phase contrast x-ray imaging is potentially beneficial. Different kind of defects like cracks, fibre wrinkles, mis-orientated plies, porosity, voids, inclusions, delaminations, disbonds, resin rich or resin light areas were assessed at different stages of the manufacturing and repair processes with respect to their detectability by phase contrast x-ray imaging. This was mostly done by the industrial partners DASSAV and GMI. Detailed simulations of the phase contrast image formation, done by CSEM, supported this assessment. Based on this knowledge, a design trade-off between different system parameters was made and a concept with specifications for the PCI demonstrator was laid out.
- The objective of the second workpackage was to design, manufacture, assemble and characterise a demonstrator matching the specifications and concept defined in WP1. This activity mainly involved CSEM, with support from UNIMAN, NTUA and GMI for image processing and control and acquisition software developments. Much effort was spent for the planning and commissioning of the grating interferometer, in particular for the design and manufacturing of the gratings, which conforms the most innovative part of the project.
- The third workpackage delivered the experimental proof that the objectives set in WP1 were met. Measurements of selected samples (manufactured by GMI and UNIMAN, and DASSAV providing real samples) were performed with the EVITA system with the purpose to compare them with the traditional non-destructive technique and hence provide conclusions on the detectability of the different defect types and applicability of the EVITA system to different components types.
- Selected results of these technical activities were presented, during the execution of the project at conferences and workshops. Furthermore, a project webpage was set up and constantly updated to inform the interested community about the status of the project.

1.2.4 Ultimate Goal

The ultimate goal of this project was to provide a novel, lean, green NDT/NDI method for composite materials covering the whole Life Cycle and solving the major drawbacks of conventional NDT methods such as ultrasonic, infrared thermography and conventional X-rays. More specifically, on one hand, the novel method eases the inspection of thick laminates or parts with complex geometry and allows for the detection of new types of defects occurring with the last implemented manufacturing technologies such as RTM and LRI. On the other hand, it aims at reducing the inspection and evaluation times, during manufacturing, assembly, repair and re-use of composite components.

1.3 Description of the Main Scientific and Technical Results and Foregrounds

The project EVITA aimed at bringing Grating-based Phase Contrast X-ray imaging technology to Non-Destructive Evaluation and Inspection of primary and/or complex aeronautical composite structures, during the design, manufacturing and assembly processes, as well as during the repair and re-use procedure of key components.

A summary of the work performed to design and manufacture the EVITA demonstrator and its competitive advantage with regards to the standard industrial NDT methods is summarise below.

1.3.1 Technical Specifications and Concept Development of the Phase Contrast X-Ray Imaging System

1.3.1.1 Study of the Composite Structures Life Cycle Procedures

In order to define the technical specifications and the concept design of the XPCI demonstrator, it was necessary to perform a thorough examination of the CFRP design, manufacturing, assembly and repair procedures in terms of:

- Existing standard NDT methods for inspection of composite structures in an industrial environment. Table 1 shows those selected for the benchmarking:

System	Principle of Operation	Reference
Laser Ultrasonics system (LUT)	A laser impact on the material generates ultrasonic waves by thermoelasticity. Detection in pulsed-echo or reflection mode (one sided technique) is obtained through laser interferometry.	Lockheed Martin (USA), ParSystems (USA), Bossa Nova (USA) , Tecnar (CN), Tecnatom (SP), IMI (CN)
Through Transmission Ultrasonic (water jet systems)	A water jet guides the ultrasonic waves into the part which are picked up on the opposite side by a front facing water jet. Arrangement of several water jets to increase the speed of inspection fixed on a 12 to 15 axes gantry or robotic plate-form.	GE IT (USA), Matec (USA), Intelligent NDT (DE), Tecnatom (SP), AREVA (FR), Midas NDT (UK)
Through Transmission Ultrasounds (Air Coupled Ultrasonic System)	Specific transducers enable the transmission of ultrasonic waves in the part. The technique is used only in through transmission due to its lack of sensitivity. Arrangement of several transducers is possible to increase the speed of inspection; they are fixed on a 12 to 15 axes gantry or robotic plate-form.	QMI (USA), Starman (CZ), Doctor Hillger (DE)
Pulse Echo Ultrasonic (Phased Array systems)	Set-up of Phase array ultrasonic transducers (from 64 to 256 elements per unit) which are translated in contact or not to the part with liquid coupling by a multi-axes gantry	Intelligent NDT (DE), Tecnatom (SP), AREVA (FR), Olympus (USA)

Laser Shearography	In shearography, the part being tested is illuminated by an expanding laser beam, and its image is taken with an image-shearing camera. Two images are taken. One image is made of the part in the undeformed state, and a second image is made after deformation. The processed image produces a fringe pattern that depicts the gradient of the surface displacements due to the deformation generated by the subsurface defects.	LTI (USA), Steinbichler (DE), Dantec (DE)
Active Infra-Red Thermography	Heat waves are applied on to a part and an infrared camera monitors the temperature contrast variations with time between sound and defected areas as a function of the thermal resistance of the defect.	FLIR (USA), Thermal Wave Imaging (USA), Thermo-Sensorik (DE)

Table 1: Standard NDT methods for inspection of composite structures in an industrial environment

- Definition of composite components “target group” (dimensions, materials, geometrical characteristics etc.) that were considered within EVITA:
    - Class 1 (vital): primary structural components (beams, frames, etc)
    - Class 2 (major): other structural components (stringers, skins, moving surfaces, doors etc.)

  Table 2**Error! Reference source not found.** shows the manufacturing methods and the kinds of components / samples that were examined during the project.

Classification	**Manufacturing Method**				
	Conventional (hand) lay-up of prepregs	**Automatic lay-up of prepregs**	**Tailored Fiber Placement**	**Liquid Resin Infusion**	**Resin Transfer Molding**
Class 1	Yes	Yes	Yes	Yes	Yes
Class 2	Yes	Yes	Yes	Yes	Yes

Table 2: Cases examined in the project EVITA according to the components classification in terms of criticality and manufacturing method

- Typical flaws and damages associated with composite materials and structures during their whole life-cycle:
    - Delamination between layers of the composite structure,
    - Porosity,
    - Foreign objects,
    - Cracks,
    - Wrong number of plies (part usually out of shape),
    - Wrong ply orientation (part usually out of shape),
    - Overlap,
    - Gap between plies,
    - Resin rich and poor areas,
    - Cut fibers,
    - Wavy fibers,

- Wrong resin ratio (type b),
- Insufficient or over curing (type b),
- Inhomogeneous loading of specific inclusions.
- Debonding between skin and adhesive film,
- Debonding between adhesive film and substrate (core or component)

- Other general requirements such as:
  - Safety requirements
  - Repair application environment
  - Accessibility
  - Personnel training assumptions
  - Equipment MMI requirements
  - Vibration of the environment

Figure 3 shows the Falcon series horizontal stabilizer spar. This part is a class 2 and it is manufactured using the method "Resin Transfer Molding" (RTM).

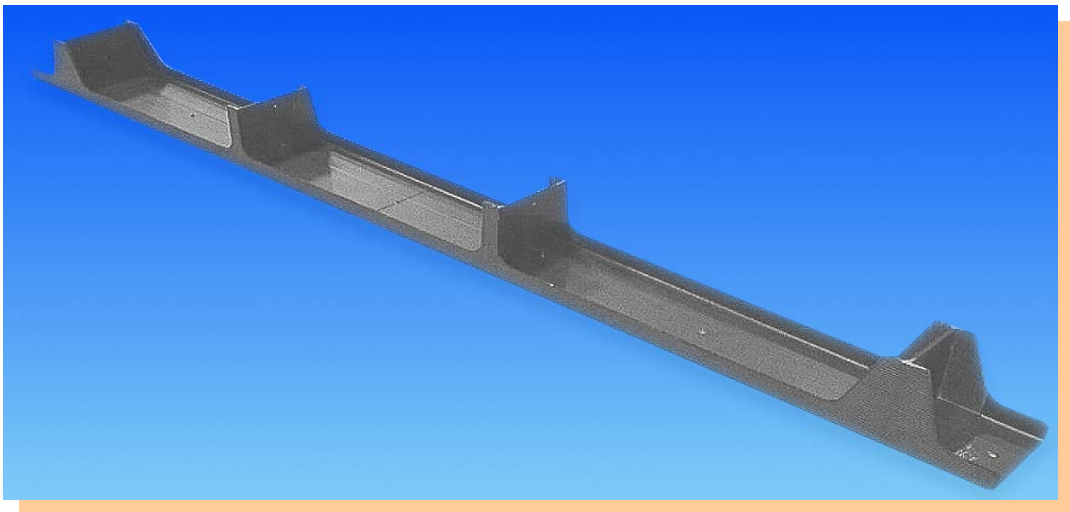


Figure 3: Falcon series horizontal stabiliser spar (confidential)

After the analysis above, it was decided which samples to produce (i.e. material, component size and thickness) to test the capability of the EVITA XPCI methodology in comparison to currently available NDT techniques.

Table 3 shows the reference defect sample variables which were examined in order to validate the XPCI technique:

Ref Number	Monolithic CFRP Laminates	Variables to Examine
1	Delamination between layers	Defect Size, Effect of Sample Thickness
2	Porosity	% Porosity, Effect of Sample Thickness
3	Foreign Objects	Nature of Foreign Object, Defect Size, Effect of Sample Thickness
4	Cracks	Defect Size, Effect of Sample Thickness
5	Resin Rich and Resin Poor Areas (Overlaps/Gaps)	Defect Size, Effect of Sample Thickness
6	Cut Fibers	Defect Size, Effect of Sample Thickness
7	Wavy Fibers	Defect Size and Orientation, Effect of Sample Thickness
	Sandwich Structure - Flaws in the Bonding Layer	
8	Bond Line Defects (Debonding, Disbonding and Seperation)	Defect Size (length, thickness), Effect of Sample Thickness
9	Foreign Inclusion at the Bond Line	Nature of Foreign Inclusion, Defect Size, Effect of Sample Thickness
	Flaws in the Honeycomb or Foam	
10	Crushed Core / Torn Up Core	Nature of Core Material, Size of Defect, Thickness of Sample
11	Crack in the Foam Core	Nature of Core Material, Size of Defect
12	Debonding of the Honeycomb Cell Wall	Size of Defect, Thickness of Sample
13	Lack of Filling of Cells	Nature of Core Material, Defect Size, Effect of Sample Thickness
14	Foreign Inclusion in the Core Material	Nature of Core Material and Foreign Inclusion, Defect Size, Effect of Sample Thickness
	Hybrid Structures	
15	Bond Line Defects	Defect Size, Effect of Sample Thickness and Material Combination
16	Composite Repair of Metallic Crack	Defect Size, Effect of Sample Thickness and Material Combination

Table 3: Reference defect sample variables which were examined in order to validate the XPCI technique:

1.3.1.2 Technical Specifications of the XPCI Demonstrator

The design specifications and the architecture of the new XPCI system and associated methodology were defined, taking into consideration the corresponding performance requirements and constraints. To fix the initial specifications and architecture, a Preliminary Design Review (PDR) took place in which the consortium discussed on the new device specifications. New inputs from the partners as well as from the Advisory Board were also taken into account to define the definitive set of specifications.

The specification of the XPCI system have been broken down in the following parts:

- Safety procedures
- System architecture
- Active hardware
- Supporting hardware
- Software
- Operational procedures (other than safety)

It should be underlined that each part of the specifications should not be considered alone, but in conjunction with the other parts, as the overall system wa evaluated as one entity.

Table 4 summarises the main specifications of the XPCI demonstrator:

Rqmt ID	Requirement Text
	General requirements
RQ 1	*The EVITA demonstrator wa equipped with a full shielding cabinet made out of lead and lead glass.* <u>*Dimensional specifications*</u> - *Inside volume sufficient to accommodate sample up to $1\times1\times0.5$ m^2* - *Cabinet material lead or lead glass* - *Wall thickness>1mm (depending on the X-ray source)*

RQ 2	*The EVITA demonstrator was designed to accommodate the following specifications* *- Distance L_{SD} between Source Unit and Detector Unit: 0.8 – 1.2m* *- Distance H_M between Π-arm and central axis: 0.3 – 0.5m*
	X-ray Source Unit
RQ 3	*EVITA uses an X-ray design energy between 30 and 50 kilo electron-volts (keV).*
	X-ray Detector Unit
RQ 4	*The EVITA demonstrator implemented the Full Field Imaging Mode. The Scanning Imaging Mode (Type 1) was not implemented in the frame of this project for budgetary reasons.*
RQ 5	*The EVITA demonstrator achieved a field of view of 200×150mm² with a pixel size of 75 micrometres.*

Table 4: Main specification of the XPCI demonstrator

1.3.1.3 XPCI System Concept

Based on the technical specifications of the demonstrator, the XPCI system concept was defined and divided into functional modules. The requirements were analysed and a concept was developed for each module. In particular, the system parameters were optimized thanks to numerical simulations.

This system concept defined the guidelines to use for the detailed design of the system.

The XPCI demonstrator consists of the grating interferometer (GI), the sample manipulation module (SMM), the Control Module (CM) and the Image Processing Module (IPM). The Figure 4 shows the XPCI system modules:

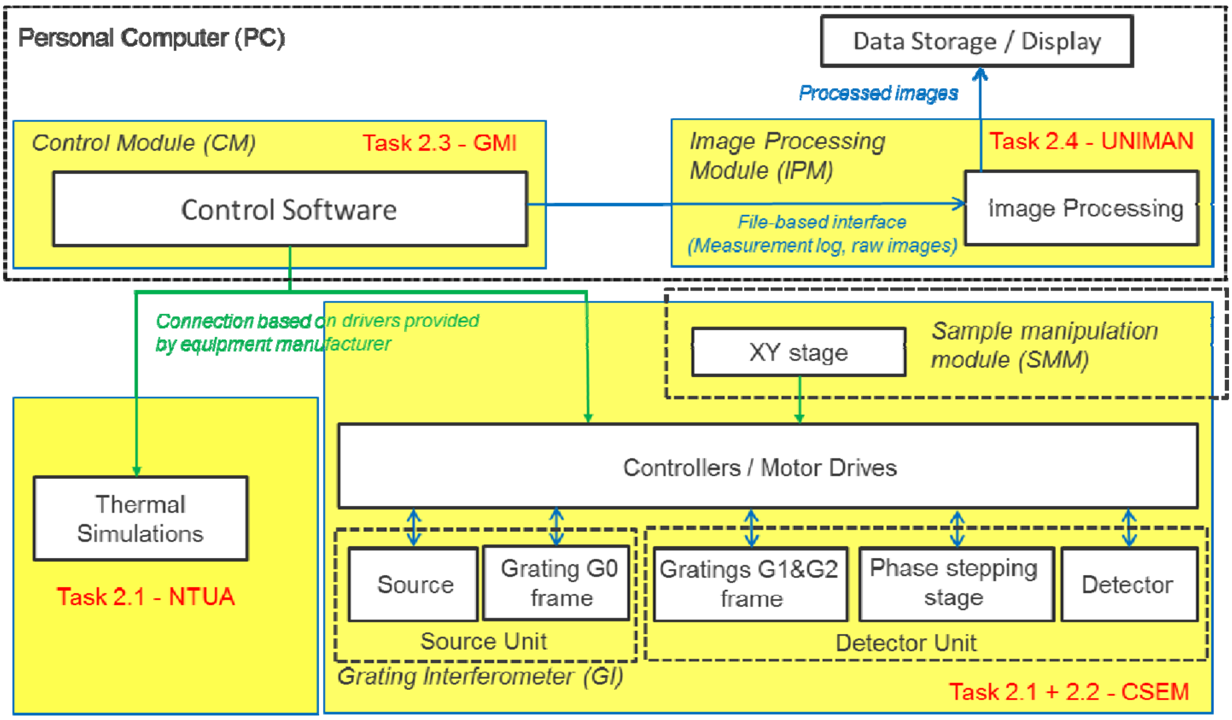


Figure 4: XPCI system modules

The testing and validation process will enable comparison of the defect detection capability of the XPCI process and state of the art industrial NDT processes for aerospace composite materials. Reference samples containing defects typically produced during manufacturing, repair and usage of monolithic composites, sandwich structures and hybrids have been proposed to test the capability of the XPCI process.

The system concept was evaluated against the needs from the aeronautic industry in order to find the best-possible system parameters for the XPCI demonstrator. During the CDR an optimal trade-off between the relevance of the defect types, the performance of the system for each defect type and the technical complexity (cost-driving factor) of the built demonstrator was performed.

1.3.1.4 Summary of the Results

- A thorough examination of the CFRP design, manufacturing, assembly and repair procedures was performed in order to define the standard NDT systems that are usually used, the target group components (class 1 and class 2) and the typical flaws and damages associated with composite materials and structures.
- The technical specifications of the XPCI demonstrator and the system concept were successfully defined.
- The test and validation plan was successfully defined and a first set of flaws was agreed by the partners
- A trade-off between the relevance of the defect types, the performance of the system for each defect type and the technical complexity (cost-driving factor) of the built demonstrator was performed

1.3.2 Detailed Design and Development of the XPCI Demonstrator

The design and development of the XPCI demonstrator was performed following the defined technical specifications and system concept.

1.3.2.1 Detailed Design of the XPCI System

The detailed design of the XPCI demonstrator was performed. This included the selection of the off-the-shelf hardware components and the mechanical design of a customized rig to mount the individual components. The design followed the defined system concept defined and ensured sufficient stability and accuracy for the degrees of freedom required for the alignment and operation of the XPCI demonstrator. A CAD model representing the demonstrator in its final form was drawn. The model was used to perform thermal simulations and study the behaviour of the demonstrator in presence of temperature drifts.

The XPCI demonstrator has been divided into two sub-units: the source unit (SU) and detector unit (DU), which were assembled together using a supporting structure called the Π-arm. The different sub-units are shown in Figure 5, where the Sample Manipulation Module was added for completeness even if it is not part of the Grating Interferometer and is independent mechanically.

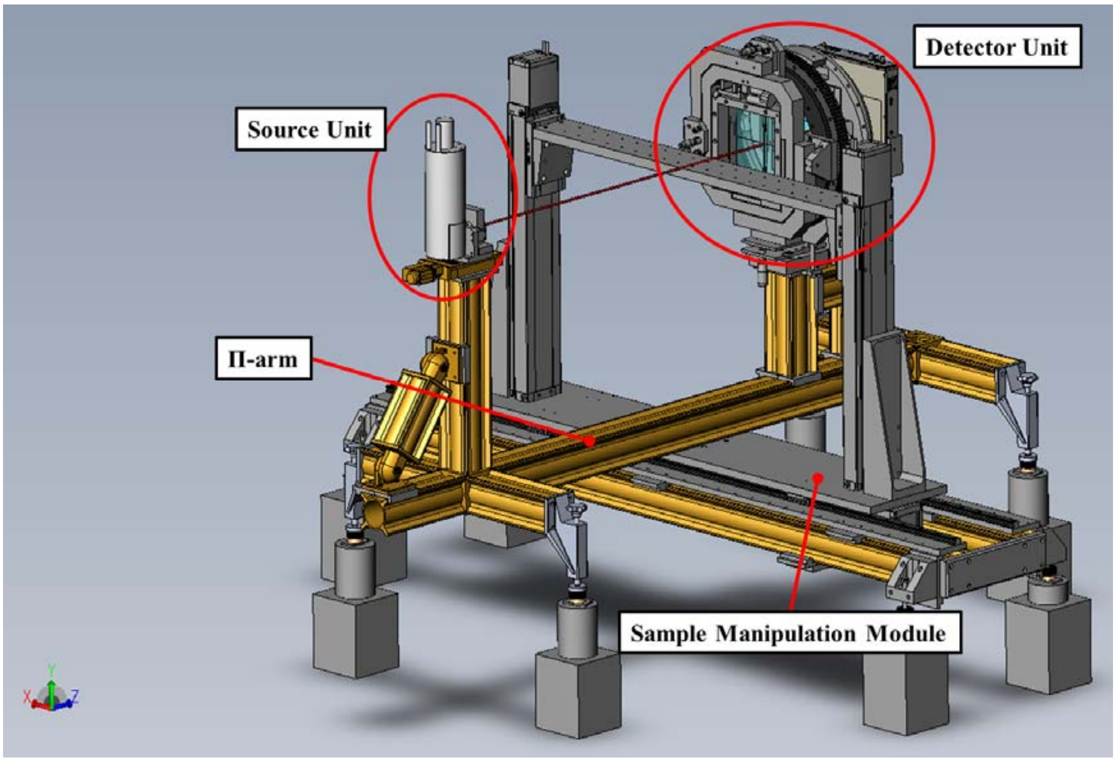


Figure 5 : Isometric view of the CAD model of the XPCI demonstrator, including the Sample Manipulation Module and the Grating Interferometer. The latter is divided into Source Unit, Detector Unit and Π-arm

- The source unit consisted of the assembly of the X-ray tube and the source grating G0 and contains three motorized axes.
- The detector unit consisted of the electro-mechanical structure holding the gratings G1 and G2 as well as the detector holder. Both sub-units are mechanically decoupled. The detector DEX2315 from Dexela Limited is mounted onto a tilt-tip table M-37 from Newport, which allows the adjustment of the three rotational degrees of freedom.
- Special attention has to be taken to the grating holder, which was designed to hold the four grating together, one of the most innovative parts of this project together with the gratings themselves. Figure 6 shows an isometric view of the grating holder CAD model.

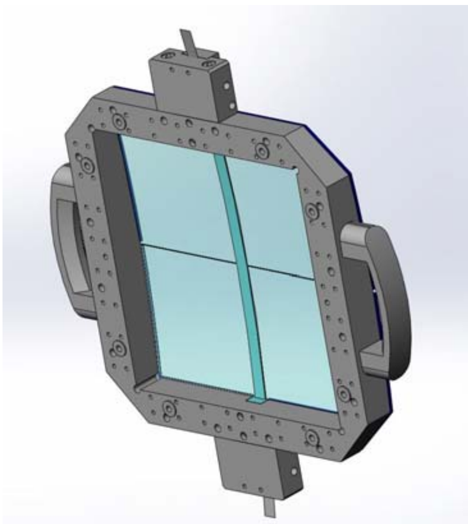


Figure 6: Grating Holder

The architecture of the Control Module (CM) and Image Processing Module (IPM) was defined, taking into account the selected hardware components and the interface between CM and IPM.

Finally the design of the X-ray shielding was performed in collaboration with the supplier.

1.3.2.2 Gratings Design, Manufacturing and Testing

The gratings specifications were frozen during the definition of the system concept and subsequent design trade-off. This included the choice of the periodicity and depth of all X-ray gratings, the size and the geometry of the gratings. It is important to note that **the quality of the gratings determines the accuracy and precision of the whole XPCI demonstrato**r.

The fabrication of the gratings was achieved using the expertise of CSEM in micro-fabrication processes of such gratings. The quality control of the gratings was ensured by regular inspection of the grating at different steps of their production using conventional methods such as confocal microscopy and scanning electron microscopy.

Some iteration was required in order to optimize the process parameters of the grating specifications. The XPCI laboratory setup existing at CSEM in Zurich was used as a feedback on the quality of the gratings.

The processes for the fabrication of the gratings G0, G1 and G2 are explained below:

- G0: the fabrication of the G0 gratings was performed in four main steps, on 100 mm diameter silicon wafers:
  1. Photolithography
  2. Vertical etching of the silicon
  3. Filling of the gratings with gold
  4. Dicing of the wafer

  The dimensions and the performance of the G0 grating were reached according to the specifications.

  The Figure 7 shows an example of the achieved geometry of the G0 grating lines after vertical etching (step 2):

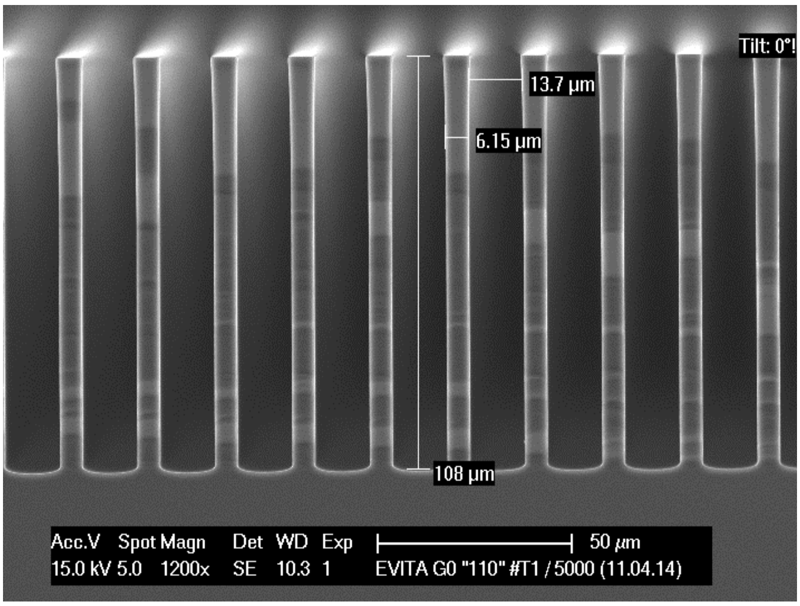


Figure 7: Cross section of G0 wafer after vertical etching of silicon

- G1: the fabrication of the G1 gratings was performed in four main steps, on 150 mm diameter silicon wafers:

1. Photolithography
2. Vertical etching of the silicon
3. Thinning to 200 µm + H1
4. Dicing of the wafer

After the vertical etching (step 2), the silicon line width was measured on 5 points on each wafer in the scanning electron microscope. An example of a measurement is shown in the Figure 8:

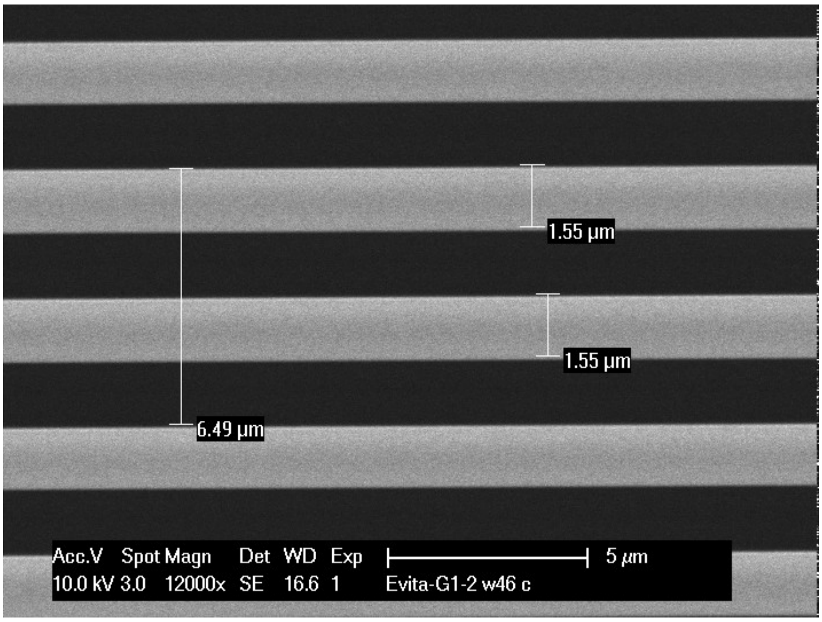


Figure 8: Silicon line width measurement on G1

The measured main dimensional parameters grating height H_0, silicon width W and duty cycle DC_0 of the chosen designs were deemed acceptably within specification.

- G2: the fabrication of the G2 gratings was performed in five main steps, on 150 mm diameter silicon wafers:
  1. Photolithography
  2. Vertical etching of the silicon
  3. Gold electroplating
  4. Thinning to 200 µm + H2
  5. Dicing of the wafer

  This has been the most critical fabrication process, and severe technical difficulties were encountered that have led to large delays with respect to the project plan and overpassed the budget. Despite extensive efforts put up by CSEM, these difficulties could not be fully solved in the frame of the project. These difficulties can be summarise as follows:

  - The adhesion of the Au layer to the substrate was difficult to ensure reliably. After extensive efforts, a solution could be found to this problem with a proper surface pre-treatment.
  - The grating lines of these high aspect ratio structures have a tendency to collapse (stick) during wet chemical process steps. The narrow and deep topographic structures make processing, characterization and troubleshooting unusually difficult. At present this problem could not be solved in the frame of the project.

  Four G2 gratings with the dimensions according to the specifications would have been needed to reach a field of view of 200x200 in the XPCI demonstrator. Only one was of the high quality requested (dead area < 1%), which implies a field of view of 100, implying more exposure time to make a measurement.

1.3.2.3 Hardware and Software Acquisition and Development

Hardware commissioning: the designed mechanical parts were subcontracted to third parties and to the mechanical workshop of CSEM. Commercial components like the X-Ray detector, X-Ray source, piezoactuators and their controllers, etc. were analysed. Proposals were requested to several suppliers for each component of the demonstrator and the most suitable one in terms of quality and price was ordered.

The control and acquisition software was programmed following the designed architecture (see subchapter 1.3.2.1) allowing the acquisition of XPCI images under the modalities defined during the CDR and in the system concept.

The basic architecture of the control software consists of two main pillars: the alignment mode and the imaging mode. In the diagram of Figure 9 the architecture and the flow of the GUI is presented. Following a top to bottom and left to right logic the user is invited to follow the following workflow:

- Manual or Automatic Alignment (Relative alignment of G0, G1 and G2)
- Acquisition of Calibration Images (Dark Field and Flat Phase stepping)
- Acquisition of Measurement Images (Phase stepping acquisitions of measurement images)

The control features and the functions of the EVITA control software, developed to integrate all the functionalities of the active components of the XPCI system and provide a “close to commercial” control and acquisition tool were successfully developed.

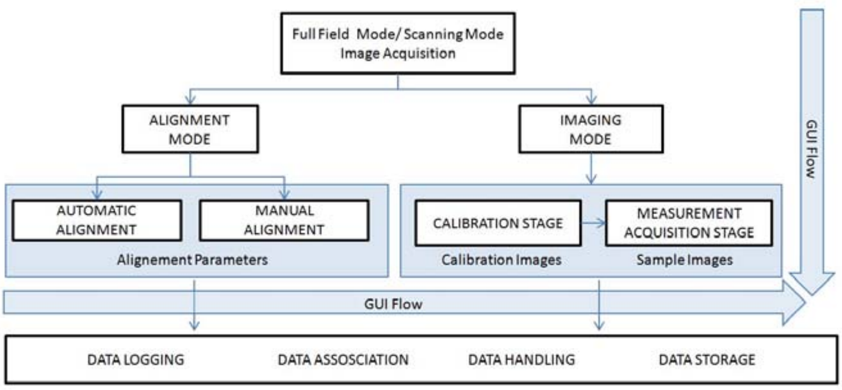


Figure 9: Software architecture diagram

Due to the large amount of data generated by the XPCI system when performing inspections, a detailed data structure was created in the data server (see Figure 10).

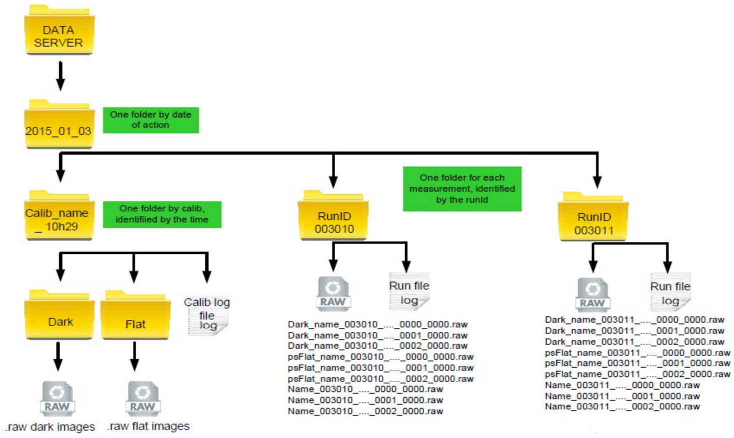


Figure 10: Structure of the data in the data server

1.3.2.4 Image Processing Module

Image processing algorithms were developed, whose purpose was triple:

- Image reconstruction: it aims at analyzing the raw data in order to separate the different contrast mechanisms and reconstruct three different images: the absorption, the refraction and the scattering images
- Artefact correction. The following artefacts corrections were performed:
  - Defective pixels / regions
  - Grating non-uniform response (fixed pattern)
  - Moiré fringes
  - Stitching artifacts
  - Noise reduction
- Defect detection and image fusion

  Figure 11 shows and example of defective pixels:

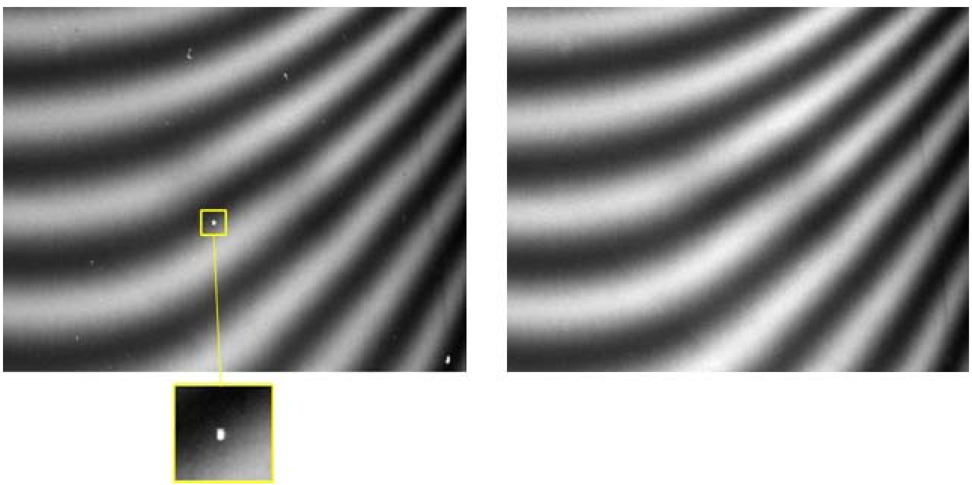


Figure 11: Original image with defective pixels (left) and the corrected image after detecting and removing the defective pixels (right)

- Defect correction and image fusion: the optimization of the detectability and identification of the defects were made using image processing and image fusion. Image fusion is particularly useful when the defects are observed in two or more images.

1.3.2.5 System Assembly and Characterisation

The assembly of the XPCI demonstrator took place using the components developed in the subchapters 1.3.2.2, 1.3.2.3 and 1.3.2.4. Then the demonstrator was characterized and a user manual was written for future use of the methodology.

The way to show the successful assembly of the demonstrator is through pictures:

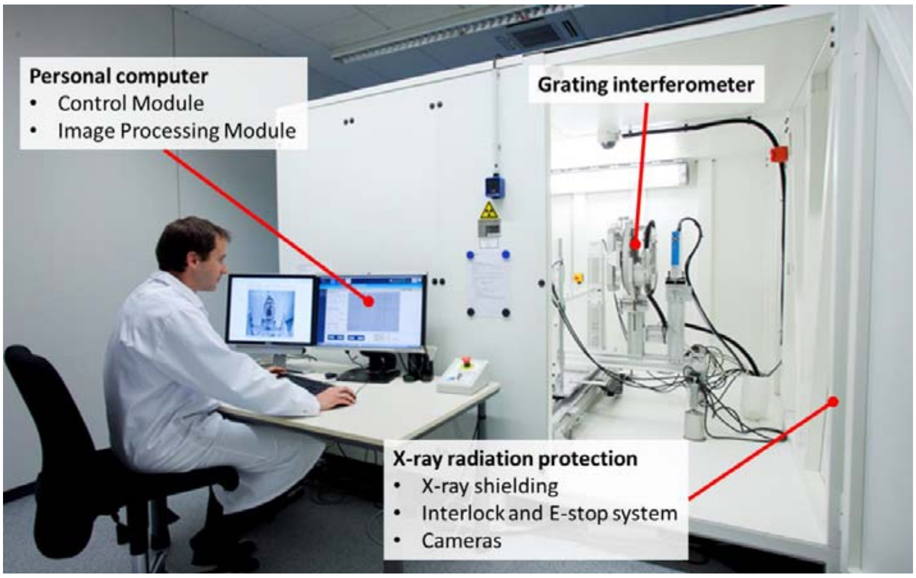


Figure 12: Picture of the PCI demonstrator at CSEM Alpnach giving an overview of the different components such as the control computer, the x-ray radiation protection system and the grating

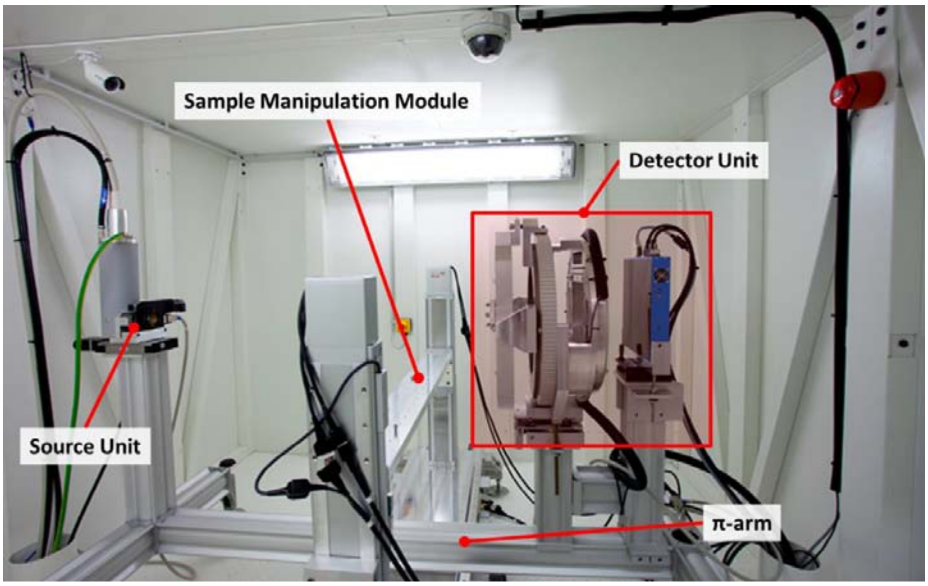


Figure 13: Picture of the grating interferometer and its components

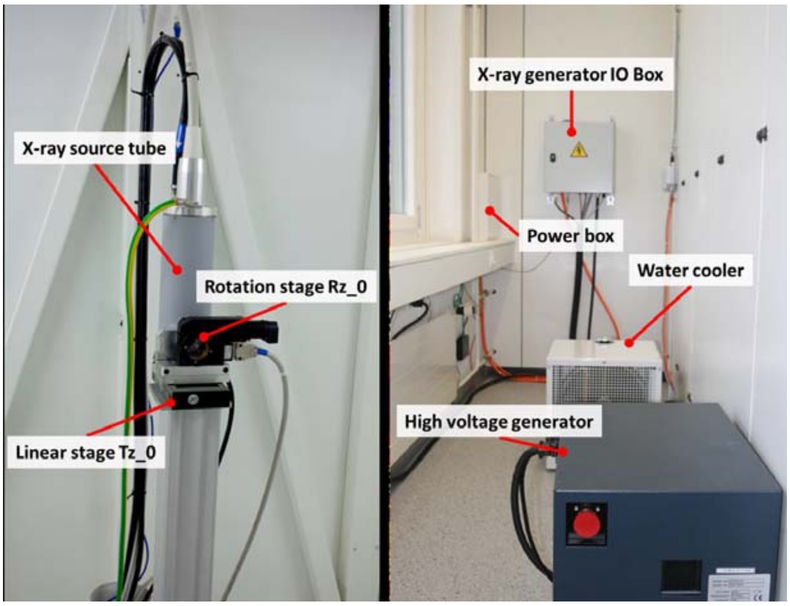


Figure 14: Picture of the source unit (left) and the X-ray generator infrastructure (right)

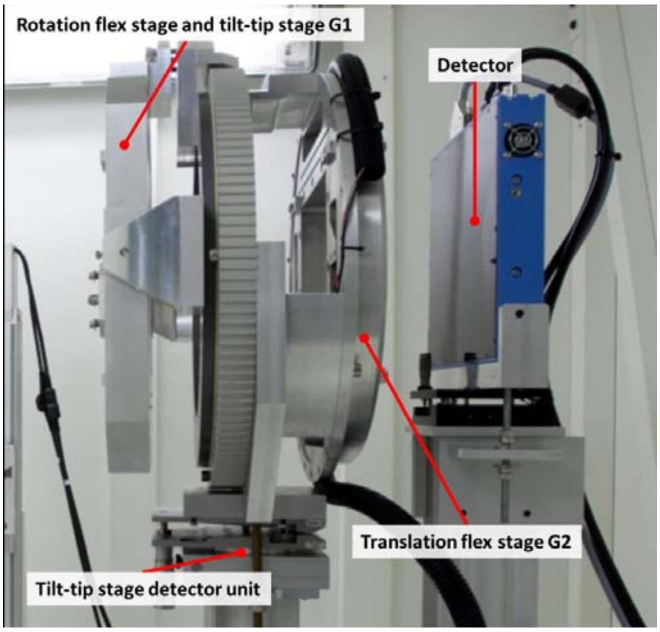


Figure 15: Side view of the detector unit

1.3.2.6 Summary of the Results

- The demonstrator was successfully designed.
- A CAD model representing the demonstrator in its final form was drawn. The model was used to perform thermal simulations and study the behaviour of the demonstrator in presence of temperature drifts
- The manufactured and tested gratings G0 and G1 reached the dimensions according to the specifications.

- The manufacturing of the gratings G2 encountered severe problems, leading to only one very high quality G2 grating following the specifications. This implies a field of view of 100x100 instead of 200x200.
- As a result of these technical problems, more man/months as well as more consumables than initially planned were needed, overpassing the budget allocated to this task.
- The hardware commissioning was done satisfactory in the timeframe and all the parts were successfully assembled in the demonstrator.
- The control and acquisition software was successfully developed. Even new features not defined in the DoW but making easier the whole control and acquisition process were developed.
- The development of the image processing module for the image reconstruction, artefact correction and defect detection and image fusion was successfully finished and included in the "control and acquisition" software.
- The fact that part of this task was developed in parallel with the task 3.3 "XPCI measurements" help improve the algorithms every time new tests were performed.
- The EVITA demonstrator was successfully assembled and characterised.
- A user manual was written to allow future users to use the demonstrator. It is not intended to interpret the results of the tests.

1.3.3 Proof-of-Concept

1.3.3.1 Selection and Production of Samples

According to the Test and Validation Plan requirements and after a long discussion during the Critical Design Review, the appropriate number of composite specimens with real and artificial flaws (calibration specimens etc.) was decided and manufactured. In a similar manner, specific representative CFRP components were used, in order to assess at larger scale the efficiency of the new NDT method.

The size and shape of these defects was checked with X-ray tomography to ensure that the manufacturing processes are producing the required defects.

Several set of samples were produced:

- **Calibration samples**. As part of the initial testing process, samples of varying thickness were examined to understand the limits of operation of the XPCI technique. A range of calibration samples was produced for this purpose. On this basis, the calibration samples produced are shown on Table 5 and Table 6 :

Sample	Sample Type	Manufacturing	Approximate	Responsible Partner
CAL M1	Monolithic Laminate	RTM	4	DASSAV
CAL M2	Monolithic Laminate	RTM	10	DASSAV
CAL M3	Monolithic Laminate	RTM	20	DASSAV
CAL M4	Monolithic Laminate	RTM	30	DASSAV

Table 5: List of monolithic laminate calibration samples produced for the EVITA project

Sample	Sample Type	Core Type	Approximate	Partner responsible
CAL S1	Sandwich	Nomex	10	DASSAV
CAL S2	Sandwich	Nomex	100	DASSAV
CAL S3	Sandwich	Al Honeycomb	10	DASSAV
CAL S4	Sandwich	Al Honeycomb	100	DASSAV
CAL S5	Sandwich	Foam	10	DASSAV
CAL S6	Sandwich	Foam	100	DASSAV

Table 6: List of sandwich structure calibration samples produced for the EVITA project

- **Defect free baseline samples**. Baseline samples were produced which are defect free when measured by industrial NDT techniques. Defect free examples need to be available for examination for both monolithic laminate and sandwich structures after manufacturing, but also after a composite repair process.
- **Defect containing reference samples**. In order to test the capability of the PCI technique, manufacturing routes were developed which produced controlled defect containing samples in a repeatable manner. In addition, destructive and non-destructive methods were used to confirm the presence of defects of a certain size and shape before these samples can be used to test the capability of the PCI technique.

Table 7 shows the complete range of defect reference samples produced for the EVITA project together with the partner responsible for production of the defects.

Table 8 shows the defect and sample variables which needed to be examined for each defect type as part of the validation of the PCI technique.

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		Possible Process Step Responsible for Defect			
		Manufacture	Repair/Assembly	Usage	Partner Responsible for Reference Sample Manufacture
Ref No.	Monolithic CFRP Laminates				
1	Delamination between layers	o	x		NTUA/GMI
2	Porosity	x	o		UMA
3	Foreign Objects	x	o		UMA
4	Cracks			x	UMA
5	Resin Rich and Resin Poor Areas (Overlaps/Gaps)	x	o		UMA
6	Cut Fibers	x	o		UMA
7	Wavy Fibers	x	o		UMA
	Sandwich Structure - Flaws in the Bonding Layer				
8	Bond Line Defects (Debonding, Disbonding and Separation)	o	x	o	NTUA/GMI
9	Foreign Inclusion at the Bond Line	x	o		DASSAV
	Flaws in the Honeycomb or Foam				
10	Crushed Core / Torn Up Core	o	o	x	DASSAV
11	Crack in the Foam Core	x	o	o	DASSAV
12	Debonding of the Honeycomb Cell Wall	x		o	DASSAV
13	Lack of Filling of Cells	x		o	DASSAV
14	Foreign Inclusion in the Core Material	x	o		DASSAV
	Hybrid Structures				
15	Bond Line Defects	o	x		NTUA/GMI
16	Composite Repair of Metallic Crack		x		NTUA/GMI

Table 7: Defect reference samples produced during the project

		Variables to Examine
Ref Number	Monolithic CFRP Laminates	
1	**Delamination between layers**	Defect Size, Effect of Sample Thickness
2	**Porosity**	% Porosity, Effect of Sample Thickness
3	**Foreign Objects**	Nature of Foreign Object, Defect Size, Effect of Sample Thickness
4	**Cracks**	Defect Size, Effect of Sample Thickness
5	**Resin Rich and Resin Poor Areas (Overlaps/Gaps)**	Defect Size, Effect of Sample Thickness
6	**Cut Fibers**	Defect Size, Effect of Sample Thickness
7	**Wavy Fibers**	Defect Size and Orientation, Effect of Sample Thickness
	Sandwich Structure - Flaws in the Bonding Layer	
8	**Bond Line Defects (Debonding, Disbonding and Seperation)**	Defect Size (length, thickness), Effect of Sample Thickness
9	**Foreign Inclusion at the Bond Line**	Nature of Foreign Inclusion, Defect Size, Effect of Sample Thickness
	Flaws in the Honeycomb or Foam	
10	**Crushed Core / Torn Up Core**	Nature of Core Material, Size of Defect, Thickness of Sample
11	**Crack in the Foam Core**	Nature of Core Material, Size of Defect
12	**Debonding of the Honeycomb Cell Wall**	Size of Defect, Thickness of Sample
13	**Lack of Filling of Cells**	Nature of Core Material, Defect Size, Effect of Sample Thickness
14	**Foreign Inclusion in the Core Material**	Nature of Core Material and Foreign Inclusion, Defect Size, Effect of Sample Thickness
	Hybrid Structures	
15	**Bond Line Defects**	Defect Size, Effect of Sample Thickness and Material Combination
16	**Composite Repair of Metallic Crack**	Defect Size, Effect of Sample Thickness and Material Combination

Table 8: The reference defect sample variables which needed to be examined in order to validate the XPCI technique.

1.3.3.2 Benchmarking Measurements

Measurements were performed with the traditional non-destructive techniques in order to compare with the EVITA system and provide conclusions on the detectability of the different defect types and applicability of the EVITA demonstrator to different components types.

Inspections methods used during the benchmarking measurements:

1. **Ultrasound.** Ultrasonic testing (UT) is the most widely used NDI method for the composites testing. On microscopically homogeneous materials (i.e. non-composite) it is commonly used in the frequency range 2kHz to 20 MHz. With composite materials the testing range is significantly reduced because of the increase attenuation, so the operating frequency limit is usually 10 MHz or less.
2. **Pulse Echo Ultrasonic A-Scan**. The Pulse echo straight beam, longitudinal wave technique is used widely for the detection of disbonds, delamination and porosity in fabricated materials.
3. **Phase Array (PA)**. A phased array system is normally based around a specialized ultrasonic transducer that contains many individual elements (in this experiment 64 element) that can be pulsed separately in a programmed pattern.
4. **Pulse Phased Thermography (PPT)**. In a PPT system, a rapid heat pulse is applied to the surface of a component via two or more flash lamps and the subsequent thermal decay from the surface monitored using a high spatial and temperature resolution infrared camera. A defect provides resistance to propagation of the thermal wave, which is reflected back to the surface to be observed as artefacts in the surface temperatures of the inspected component. The time a defect becomes visible is dependent upon the material properties and depth below the surface.

Table 9 shows the list of samples that were tested:

Sample ID	Category	Materials	Comments	
137186-3	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thin (4mm)	foreign objects
137186-9	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thick (20mm)	foreign objects
137186-4	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thin (4mm)	out of plane wrinkles
137186-10	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thick (20mm)	out of plane wrinkles
137186-5	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thin (4mm)	resin rich/resin poor
137186-11	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thick (20mm)	resin rich/resin poor
137186-6	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thin (4mm)	cut fibres
137186-12	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thick (20mm)	cut fibres
137186-7	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thin (4mm)	in-plane-wave
137186-8	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thick (20mm)	in-plane-wave
137186-13	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thin (4mm)	porosity <2%
137186-14	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thick (20mm)	porosity <2%
137186-15	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thin (4mm)	porosity 2 to 5%
137186-16	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thick (20mm)	porosity 2 to 5%
137186-17	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thin (4mm)	porosity > 5%
137186-18	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thick (20mm)	porosity > 5%
137186-2	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thin (4mm)	cracks
137186-19	coupon with artifical defect	Monolithic, Epoxy-carbon prepreg layup	thick (20mm)	cracks
P15_47	repair	Monolithic, Epoxy-carbon prepreg layup		bad quality patch with porosity + inclusions
P15_48	repair	Monolithic, Epoxy-carbon prepreg layup		Teflon inclusions
P15_49	repair	Monolithic, Epoxy-carbon prepreg layup		stepped panel 12 plies, 6 removed plies
P15_50	repair	Sandwich - NOMEX	complex	repair patch + teflon disbonding + magnetorestrictive wirgs + porosity
P15_51	manufacturing	Monolithic with spare and foam	complex	trailing edge of the leading edge slat A350

Table 9: List of samples

Evaluation of the coupon samples

Table 10 and Table 11 summarize the results obtained in terms of the detectability of the different manufactured defects using the following colour code:

Good prospects	Some prospects	Poor prospects

Thin sample (4 mm):

Type of defect		size	Water jet	PA	X-Ray CT	IR-Thermo-graphy	Double through transmission	A-Scan
Foreign Object	Steel	20x20 mm	Good	Good	Good	Poor	Good	Good
		12x12 mm	Good	Good	Good	Poor	Good	Good
		6x6 mm	Good	Good	Good	Poor	Good	Good
	Aluminium	20x20 mm	Good	Good	Good	Poor	Some	Good
		12x12 mm	Good	Good	Good	Poor	Some	Good
		6x6 mm	Some	Good	Good	Poor	Some	Good
	ETFE	20x20 mm	Poor	Good	Poor	Poor	Poor	Good
		12x12 mm	Poor	Good	Poor	Poor	Poor	Good
		6x6 mm	Poor	Good	Poor	Poor	Poor	Good
	PTFE	20x20 mm	Poor	Good	Poor	Poor	Poor	Good
		12x12 mm	Poor	Good	Poor	Poor	Poor	Good
		6x6 mm	Poor	Good	Poor	Poor	Poor	Good
Resin rich and poor area	4 mm gap + 2 fibre tows in each of the 2 mid-plane plies		Poor	Good	Poor	Poor	Poor	Poor
	2 mm gap + 2 fibre tows in each of the 2 mid-plane plies		Poor	Good	Poor	Poor	Some	Poor
	4 mm gap in each of the 2 mid-plane plies		Poor	Good	Poor	Poor	Poor	Poor
	2 mm gap in each of the 2 mid-plane plies		Poor	Good	Poor	Poor	Good	Poor
Out-of-plane wrinkle			Good	Good	Poor	Poor	Good	Poor
Fibre misalignment			Poor	Poor	Poor	Poor	Poor	Poor
Cut fibre	1 mm		Poor	Good	Poor	Poor	Poor	Some
	2 mm		Poor	Good	Poor	Poor	Good	Some
	4 mm		Poor	Good	Poor	Poor	Good	Some
	8 mm		Poor	Good	Poor	Poor	Good	Some
Porosity	P<2%		Good	Good	Poor	Poor	Some	Some
	2%<P<5%		Good	Good	Poor	Poor	Good	Some
	P>5mm		Good	Good	Poor	diffusivity (Good)	Good	Some
Cracks			Poor	Poor	Poor	Poor	Poor	Poor

Table 10: Results of the evaluation of the detectability of different defects as investigated using the coupon samples 4 mm thick

Thick samples (20 mm):

Type of defect		size	Water jet	PA	X-Ray CT	IR-Thermo-graphy	Double through transmission	A-Scan
Foreign Object	Steel	20x20 mm	Green	Green	Green	Red	Green	Green
		12x12 mm	Green	Green	Green	Red	Green	Green
		6x6 mm	Green	Green	Green	Red	Green	Green
	Aluminium	20x20 mm	Red	Green	Green	Red	Red	Green
		12x12 mm	Red	Green	Green	Red	Red	Green
		6x6 mm	Red	Green	Green	Red	Red	Green
	ETFE	20x20 mm	Red	Green	Red	Red	Red	Green
		12x12 mm	Red	Green	Red	Red	Red	Green
		6x6 mm	Red	Green	Red	Red	Red	Green
	PTFE	20x20 mm	Red	Green	Red	Red	Red	Green
		12x12 mm	Red	Green	Red	Red	Red	Green
		6x6 mm	Red	Green	Red	Red	Red	Green
Resin rich and poor area	4 mm gap + 2 fibre tows in each of the 2 mid-plane plies		Red	Green	Red	Red	Red	Red
	2 mm gap + 2 fibre tows in each of the 2 mid-plane plies		Red	Green	Red	Red	Orange	Red
	4 mm gap in each of the 2 mid-plane plies		Red	Red	Red	Red	Red	Red
	2 mm gap in each of the 2 mid-plane plies		Red	Red	Red	Red	Orange	Red
Out-of-plane wrinkle			Red	Red	Red	Red	Orange	Red
Fibre misalignment			Red	Red	Red	Red	Red	Red
Cut fibre	1 mm		Red	Red	Red	Red	Red	Red
	2 mm		Red	Red	Red	Red	Red	Red
	4 mm		Red	Green	Red	Red	Red	Red
	8 mm		Red	Green	Red	Red	Red	Red
Porosity	P<2%		Green	Green	Red	Red	Red	Red
	2%<P<5%		Green	Green	Red	Red	Red	Red
	P>5mm		Green	Green	Red	Red	Red	Red
Cracks			Red	Red	Red	Red	Red	Red

Table 11: Results of the evaluation of the detectability of different defects as investigated using the coupon samples 20 mm thick

1.3.3.3 XPCI Measurements

The measurements were performed with the EVITA system and provided conclusions on the detectability of the different defect types and applicability of the EVITA system to different components types.

The samples were screened using the Full Field Imaging mode and the stitching functionality.

Table 9 shows the list of tested samples.

Evaluation of the coupon samples

Table 12 summarizes the results obtained in terms of the detectability of the different manufactured defects using the following colour code:

Good prospects **Some prospects** **Poor prospects**

Type of defect		**size**	**Thin sample (4mm)**	**Thick sample (20mm)**
Foreign Object	Steel	20x20 mm		
		12x12 mm		
		6x6 mm		
	Aluminium	20x20 mm		weak signal
		12x12 mm		weak signal
		6x6 mm		weak signal
	ETFE	20x20 mm		
		12x12 mm		
		6x6 mm		
	PTFE	20x20 mm		
		12x12 mm		
		6x6 mm		
Resin rich and poor area	4 mm gap + 2 fibre tows in each of the 2 mid-plane plies			
	2 mm gap + 2 fibre tows in each of the 2 mid-plane plies			
	4 mm gap in each of the 2 mid-plane plies			
	2 mm gap in each of the 2 mid-plane plies			
Out-of-plane wrinkle				weak signal
Fibre misalignment				
Cut fibre	1 mm			
	2 mm			
	4 mm			weak signal
	8 mm			weak signal
Porosity	P<2%			
	2%<P<5%			
	P>5mm			
Cracks				indirect only

Table 12: Results of the evaluation of the detectability of different defects as investigated using the coupon samples

1.3.3.4 Evaluation of the Results

The results of the test campaign of the same samples with the benchmarking methodologies and with EVITA and their comparison can be summarized in Table 13:

NDT Method / **Parameters**	*Water jets (Transmission)*	*DTT (Double Through Transmission)*	*A SCAN*	*PAUT (Phased Array in Reflection mode)*	*X-Ray CT (X-ray Tomography)*	*PCI (Phase Contrast Imaging)*	*IRT - Thermography*	*ST - Shearography*	*THz*
Set-up	*Transmission Reflection*	*Transmission Reflection*	*Transmission Reflection*	*Transmission Reflection*	*Transmission*	*Transmission*	*Transmission Reflection*	*Reflection*	*Transmission Reflection* Tomography
Contrast Mechanism	Absorption Reflection at interfaces	Absorption Reflection at interfaces	Absorption Reflection at interfaces	Absorption Reflection at interfaces	Absorption	Absorption Scattering Refraction	Air gaps (Thermal resistance) block the heat diffusion	Mechanical deformation of the surface layer	Reflection at interfaces
Sensitivity	All types of materials	All types of materials	All types of materials	All types of materials	All types of materials High Z number	All types of materials Light materials	All types of materials	All types of materials	Only for dielectric material
Calibration time			30s			15s			
Set-up time (1)	10mn	10 mn	>1mn	>1mn	30s	60s	>1mn (2)	>1mn (2)	30s
Inspection /scanning time (1)	5 m²/h	5 m²/h	0.5 m²/h	30 m²/h	<1 m²/h	5 - 30m²/h	60 m²/h	60 m²/h	0.1 m²/h
Exploitation time (1 &3)									

NDT Method	*Water jets (Transmission)*	*DTT (Double Through Transm*	*A SCAN*	*PAUT (Phased Array in Reflecti*	*X-Ray CT*	*PCI (Phase Contrast Imaging)*	*IRT - Thermography*	*ST - Shearography*	*THz*
Limitation to complex shape	Limited to skin for sandwiches or stiffened box	Limited to flat parts	Limited to skin for sandwiches or stiffened box	Limited to skin for sandwiches or stiffened box		Limited in the case of overlapping structures			
Detectability					Function of resolution				
Resolution	> 2mm	>2mm	>1mm	>1mm	>0.1mm	> 0.1mm	>5mm	>5mm	>5mm
Penetration depth in CFRP	> 50mm	< 50mm	< 50mm	< 50mm	> 50mm	> 30mm	3mm to 4mm	3mm to 4mm	> 50mm
Contact or contactless	Contact-free – Liquid coupling	Contact-free – Liquid coupling	Contact –Liquid coupling	Contact –Liquid coupling	Contact-free	Contact-free	Contact-free	Contact-free	Contact-free
Safety requirements	No	No	No	No	Standard X-ray radiation protection requirements	Standard X-ray radiation protection requirements DIN 54113-3:2005_04	No	No	No
Portable vs stationary	Flexible on site, transportable	Stationary	*Flexible on site, transportable*	*Flexible on site, transportable*	Stationary	Stationary	Flexible on site, transportable	Flexible on site, transportable	Stationary
Full field vs point to point	Translation Index 1 to 3mm	Translation Index 1 to 60mm	Translation Index 2 to 2mm	Translation Index 1 to 60mm	Translation Index 100 to 300 mm / 0.1 to	Translation Index 100 to 130mm	Translation Index 100 to 300 mm	Translation Index 200x300 mm	Translation Index 1 to 3mm

NDT Method	*Water jets (Trans mission)*	*DTT (Double Throug h Transm*	*A SCAN*	*PAUT (Phased Array in Reflecti*	*X-Ray CT*	*PCI (Phase Contrast Imaging)*	*IRT - Thermogr aphy*	*ST - Shearogr aphy*	*THz*
					1°				
Need of a qualified technician?	*UT Level 1*	*UT Level 1*	*UT Level 1*	*UT Level 1*	*RT level 1*	*RT level 1*	*IRT level 1*	*ST Level 1*	-
Recurring vs non-recurring costs	*Average / High*	*Average / High*	*Low / Low*	*Low / Average*	*Negligible / Very High*	*Negligible / High*	*Negligible / Average*	*Negligible / Average*	*Negligible / High*
Sensitivity to external/ environmental conditions (e.g. vibration, temperature, dust,...)	Water temperature	Water temperature	Dust	Dust	Vibration, temperature	Vibration, temperature	Temperature	Dust	
Surface preparation	*No - Cleaning*	No - Cleaning	No - Cleaning	No - Cleaning	*No - Cleaning*	*No - Cleaning*	Mat coating (black preferably)	White coating	*No - Cleaning*
Limitation	Materials that can be wetted	Materials that can be immersed	Materials that can be immersed	Materials that can be immersed	Defects that have a low contrast with substrate	Defects that have a low contrast with substrate and delamination	Limited to cooperative surfaces, otherwise requires paint if possible	Limited to rigid parts and to defects that have an effect on the surface layer *but rigid*	Limited to non conducting materials

Table 13: Comparison of EVITA measurements with the benchmarking ones

(1) Order of magnitude for a one m² flat panel
(2) These methods might require surface preparation, black paint for Infrared Thermography and white paint for Shearography.
(3) The exploitation time depends on the analysis time which is very much dependent on the soundness of the inspected part, the more the number of indications to analyze the larger the analysis time.

1.3.3.5 Roadmap for a Portable / Stationary XPCI Prototype

XPCI can be considered as an upgrade of existing X-ray digital installations and future ones at the manufacturing stage, particularly computed tomography (CT) systems (foreseen for complex geometry composite parts) and those inspected by Neutron radiography, to which XPCI would bring optimal inspection performances together with Dual energy or Multiple energy Digital radiography.

The combination of these three technologies, not yet at the same TRL level but compatible, appears ideal to deal with most inspection cases both at the manufacturing and maintenance stages.

Future development of the technology:

- Complementary imaging mode development and validation

  In EVITA, the Full Field Imaging Mode (FFIM) has been developed and implemented. Another mode of XPCI imaging called Scanning Imaging Mode (SIM) was not in the scope of this project. Its development should decrease considerably the cost of the technology (detector and grating cost).

- Potential concepts

  Four ways can be foreseen: stationary system, transportable system, Kit for existing X-Ray Digital Radiography installations and all in one installation.

  All in one concept:

  In order to fulfill the detection requirements in terms of defect detection by X-rays, to be able to replace entirely the currently used ultrasonic inspection without the necessity to mix the two methods, it appears that an ideal system would be based on a tomographic system implemented with the different XPCI subgroups (SH, G0, G1 and G2) and with a multi-energy X-ray detector or a dual energy procedure. This concept “all in one” seems feasible and should be the governing idea of the road map. In effect, these three X-ray techniques are quite complementary for the inspection of composite materials and structures:

  - X-ray tomography enables a volume inspection necessary for complex geometry parts and structures enhancing the detection of most types of defects, however limited toward porosity assessment and low contrast of similar materials (foreign inclusions such as ETFE, PTF tape, paper tape, peel ply material,...),
  - Phase contrast imaging is best at porosity assessment and defect types which provide diffraction such as cracks from impact damages, fiber misalignment, out of plane wrinkles, cut fiber, volumic foreign inclusions.
  - Multi-energy or dual energy X-ray Imaging is best at porosity assessment and low contact of similar materials (foreign inclusions such as ETFE, PTF tape, paper tape, peel ply material,...).

  This concept seems feasible, even with existing installations which can be upgraded with either one or two of the missing techniques.

- Safety requirements

  The standard X-ray radiation protection requirements are governed by the power of the X-ray generator. The X-PCI demonstrator has been enclosed in a cabinet complying to the German Standard DIN 54113-3:2005_04.

- Need of a qualified technician

  The qualification levels for X-rays (RT level 1, 2 and 3) should apply to this method which does not introduce specificities requiring a different qualification. However, a specific training be required to set up the system.

1.3.3.6 Summary of the Results

In terms of detectability:

- X-PCI fulfills most of the requirements, to an equivalent level with Phase Array Ultrasonic Pulse Echo (the reference technique for composite materials NDT, with less sensitivity for defects of lower contrast such as some foreign inclusions (ETFE and PTFE) and delamination but rather more sensitive to cracks and porosity which is a great advantage for maintenance in particular (ability to detail impact damages).
- These measurements demonstrate the ability of the EVITA system to determine micro-cracks and the porosity level in composite components.
- The EVITA system can be applied to monolithic samples of different thicknesses. The defect detectability decreases with the thickness – for a constant exposure time. Nevertheless, an image could be obtained even for composite thicknesses of up to 30mm.
- The metallic mesh present on the structure does not disturb the refraction and scattering images (no shadowing) while it may be relevant for the conventional X-ray image.
- The primer, paint or adhesive does not disturb the acquisition – except if these layers display a strong porosity. If the porosity of these layers is high, a background signal is created in the scattering image.
- Different sandwich core materials were investigated (metallic / NOMEX honeycomb and foam) and could be imaged. For the honeycomb core, a quasi-normal incidence of the X-ray is required if the skin needs to be inspected.
- Bent composite components (radius) can be inspected with the EVITA system. Different viewing angles may be required to optimize the detectability of defects in different regions.
- 3D shape can be imaged with the EVITA system. However, since no depth information is available with simple X-ray projections, the structure at the back and at the front of the image may overlap. From a single angle, it is not possible to say if the defect is located at the front of at the back. Nevertheless, multiple angles can be used to distinguish between different depths in the images.

Advantages and disadvantages of the XPCI demonstrator and methodology:

- Advantages: it's a contact free without coupling agent transmission technique with the related advantages of being more sensitive than others NDT method and having a higher penetration depth, thus allowing the inspection of thicker parts.
- Drawbacks: its lack of depth information, its stationary use and the safety requirements requiring a cabinet or bunker.
- The cost should be competitive by comparison with other methods thanks to low recurring costs despite a higher purchasing cost.

Way forward and roadmap:

- From a technological point of view, the implementation of the XPCI mode called Scanning Imaging Mode (in EVITA, the Full Field Imaging Mode (FFIM) was developed and implemented) would decrease considerably the cost of the technology (detector and grating cost).
- The concept "all in one" would help fulfill the detection requirements in terms of defect detection by X-rays and would be able to replace entirely the currently used ultrasonic inspection without the necessity to mix the two methods. An ideal system would be based on a tomographic system implemented with the different PCI subgroups (SH, G0, G1 and G2) and with a multi-energy X-ray detector or a dual energy procedure.

1.4 Expected Project Impact and Main Dissemination Activities

1.4.1 Expected Project Impact

1.4.1.1 Overview on Impact and Synergy beyond Aeronautics Industry

Economic growth around the world has led to a continuous increase of air-traffic numbers during the past decades. This increase is expected to continue at an even stronger pace for the next two decades. As the operating fleet grows, the costs and hazard exposure will also increase. Despite the recent difficulties faced by the industry, the market forecast over the next twenty years for commercial aircraft is expected to be of the order of €1.6 Trillion[1]. The Aerospace Market remains a highly competitive one and any aspect of commercial advantage must be sought. EVITA addresses a key element of competitive advantage for the industry, those of aircraft reliability during manufacturing, operation and maintenance costs.

The primary drivers for EVITA relate to safety, economic and societal issues. The application of the proposed advantages to the composite manufacturing and repair processes increases reliability during manufacturing (mainly assembly of composites operations), improve performance and minimise the time the aircraft needs to spend on the ground for repair. This will permit increase aircraft availability and lower maintenance costs to be incurred by the operating company. The increase in reliability will lead to a reduction in accidents, loss of life and associated compensation costs resulting from failure of critical aircraft structural components. EVITA will lead to a major change in the development of NDT for composite manufacturing and repair procedures, thereby strengthening the EU position within the global Aerospace Market, whilst maintaining the competitive advantage of the EU companies over its US and Japanese rivals.

Although the main scope of this project was to design tailored NDT solutions to achieve the cost reduction targets in manufacturing and operation for the European aeronautics industry, preliminary discussions with key players of the automotive industry clearly demonstrate potential synergies with the supply chain of these two markets as well. The growing use of lightweight CFRP components also in the automotive industry for similar motivation of reduction in fuel consumption and increased motor efficiency with lower power engines required for vehicles of significantly smaller total mass will demand improvements in NDT techniques adapted to these materials at even higher speed. New technologies will need to undergo early stage improvement cycles in the introduction phase, but in spite of different geometry and size of CFRP components used in aeronautics and automotive industries, the cost saving potential for the entire European economy is significantly greater than for the aeronautics industry alone.

Within the renewable energy sector, the rapidly growing adoption of wind energy, up to large scale deployment of off-shore windfarms in the coastal zones of the Nord Sea in Denmark, is to a large extent based on extensive use of ultralight weight CFRP components for the wind rotor blade designs. This industry, although not yet as mature as the automotive sector, is much more amenable to adoption of modern lightweight materials, and is growing at impressive rates. While the total amount of CFRP components is going to be smaller than in automotive industry, the requirements in dynamic impact stability monitoring in both design NDE and production NDT phases is of equal importance. The main impact in this market will be to a lesser extent saving in fuel (actually almost none, as operation under renewable energy is independent on fossil fuel) but in a potential increase in rotor blade efficiency due to significant reduction of weight and corresponding increase in sensitivity also to smaller wind strength. Pushing rotor blade designs to mechanical limits is not possible without advanced NDE and NDT tools detecting early onset of crack propagation and delamination under stress. Thus we expect very positive impact of the main results of this project related to advancement of NDE for CFRP components also for the wind energy industry. While early NDT instrumentation will need to be tailored to the needs of aeronautics industry, synergy impact to wind energy industry should result in straightforward manner and further add to positive economic added value of this research. It is planned that full industrialization of the results of the project, in terms of application of the new NDT methodology to various cases, could take place within five (5) years after the end of the project. Synergy transfer to other industries such as the automotive and wind energy sector have already started, in particular in

1 Airbus Industrie. Global Market Forecast – 2004-2023 – www.airbus.com.

the automotive industry, with overlap and further delay due to geometric and production process related adaptations.

1.4.1.2 Cost Savings as a Result of this Project

1.4.1.2.1.1 Reduced Production Costs

Non-destructive evaluation and inspecting techniques form an integral part of production and maintenance processes in the aeronautics industry. In particular, considering that quality control and production inspection activities weight up to 40% of the overall aircraft production costs, EVITA consortium expects that project results will enable a reduction of actual aircraft development costs of 10%. EVITA inspection systems will offer users lower non-recurring engineering costs, due to more accurate and faster inspection processes during aerospace product developments involving composite parts. Although these production costs are non-recurring in the total life cycle, they constitute a substantial potential for cost savings when advanced inspection tools dedicated to modern fibre composites become widely available.

1.4.1.2.1.2 Reduced Maintenance Costs

The inspection of aircraft is carried out during periods of maintenance activity. During this period the aircraft is decommissioned from service. For an Airbus A320 minor checks take place every 600 flight hours for the newly manufactured aircraft and every 500 flight hours for the older ones [2,3]. Medium planned maintenance normally takes place every 20 months for the new aircraft and every 15 months for the old ones. Major planned maintenance during which the aircraft is taken apart is carried out every 6 years for the new A320 and every 5 years for the old ones. Major planned maintenance can result in aircraft being taken out of service for well over 30 days. According to Airbus in the first 5 years of operation an A320 requires 564 man-hours in maintenance, for 10 years of operation 1,344 man-hours and for 12 years of operation 1,981 man-hours. The total average cost of maintenance for an A320 over a period 15 years is €5.2 million, a significant burden for the operating airline. Total maintenance costs for Europe amount to €615 million per year. According to Airbus Group, Dassault Aviation and Augusta Westland experience, aero-structures inspection cost represents an important part of the aircraft's life cycle cost (both during production and operation life), reaching five times of the ownership cost and 25% of direct operating cost (with an average of 10%). These high costs are justified on one hand by the high safety standard requested by the aerospace industry that requires frequent inspection cycles, on the other hand by the large use of manual inspection, caused by the lack of efficient automatic tools.

The successful implementation of the EVITA project development is expected to reduce this maintenance, repair and inspection costs significantly, through increase of repair reliability and reduction of time required for the performance of repairs.

Air transport and civil helicopter MRO represent 50% of a broader 140 B€ global MRO market (with military, business and general aviation), see Figure 16.

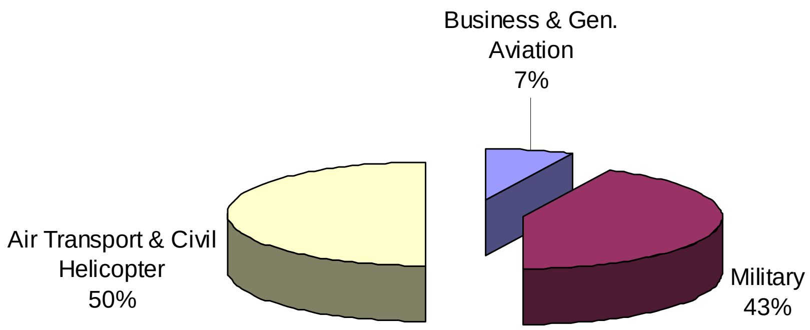

Figure 16: Global MRO Market Share expected by 2017

2 Trends in A320 Maintenance, Flight International, July/August 2005, p.38
3 Airbus A320 to benefit from lower maintenance costs, Aviation News, Dec./Jan.2005, p. 27

1.4.1.2.1.3 Maintenance Process Efficiency and Environmental Improvements

EVITA is expected to significantly reduce the operating costs through the overall aircraft life-cycle because the inspections, typically scheduled at regular flight-hour intervals, will be performed when aircraft is in service whilst maintaining high safety standards and they will be faster (suppression of operations related to the part immersion and drying that significantly slow down the preparation time), cheaper (no watering system large pools or tanks, pumping and filtering systems, expensive water squirters) and more accurate than the current or on-going development ones.

Within this framework a solution able to effectively reduce inspection time and efficiency would have a great impact on the whole aircraft and helicopter life-cycle, from production (reducing production time and increasing flaws detection at the earlier stage) to maintenance (reducing maintenance time and aircraft/helicopter safety) and disposal (permitting un-flawed parts reuse).

The EVITA consortium believes that the possibility to develop a totally green and fully automated NDI technique will allow a clean and faster testing and maintenance process of aircrafts, reducing environmental footprint of inspection throughout the whole life-cycle of the aircraft (from production to disposal). Taking as an example Dassault Aviation, out of the following number of referenced parts:

- 20,000 for the Falcon F900 and F2000,
- 20,000 for the Falcon F7X,
- 20,000 for the Rafale,

and taking into account that per aircraft:

- 500 parts are category 1 (100% liquid penetrant tested)
- 1,100 parts are category 2 (100% liquid penetrant tested)

that leads to about 15,000 parts which are liquid penetrant tested every month, these figures might be similar within the helicopter manufacturer and much higher, around 10 times within Airbus, not mentioning the jet engine manufacturers. As a matter of fact, one of the major subcontractors in France inspects around 2,500 parts a day working in 3 shifts. A modern liquid penetrant testing installation would cost around 2 M€, 2 to 4 times the cost of an installation able to perform one of the alternative methods proposed.

Actually liquid-coupled UT and dye penetrant inspections are used by aircraft manufacturers but they are not practical for large pieces, porous materials, water-sensitive composite structures and, moreover, they need complex plants to manage fluid circulation and purification. The XPCI technique does not require toxic chemicals and materials and thanks to its flexibility and configurability both composite structures and metallic materials can be effectively inspected (this last provided the emitted energy can be readjusted). EVITA offers the reduction of waste and consumables (no more films and water) because it is a non-contact inspection methodology.

The cost of ownership for EVITA inspection systems will be lower than existing water jet and immersion coupled inspection systems. This also implies that clean maintenance will be possible, and that the PCI X-Ray system will be more ecological than standard contact or water jets systems, which require gel or energy to be run properly.

1.4.1.2.1.4 Increased Flexibility of Complex Hybrid Components' Handling and Reduced Human Error

A recent analysis of Augusta Westland NDI Division stated that dry NDT/NDI technologies have a huge potential for non-destructive inspection of sandwich panels made of thin composite skin and honeycomb. The reason of that relies on the high risk of water ingress into the honeycomb cells; to reduce this risk all the parts shall be made water tight by temporary sealing the edges. Moreover for the inspection of helicopter composite blades, the problem is even more serious due to the fact that this type of parts, besides the problem of the risk of water in the sandwich trailing edge, are also made of a thick monolithic hollow spar that shall be filled of water for the ultrasound coupling. The time requested to be spent for the preparation of a full honeycomb sandwich panels to the total time for the inspection is estimate in 10 %, while the time requested for the preparation of a composite blade is about 20%. The possibility to inspect those parts without any use of water while maintaining the requested sensitivity is therefore an attractive prospect.

In summary, the following handling aspects are expected to receive significant cost benefits:

- Higher versatility of EVITA technology advanced equipment to aerospace OEMs for multiple inspection cases of large complex composite panels, which is currently not permitted with the actual existing NDT/NDI Systems, will allow real-time and optimum adaptation of the XPCI system to the tested structure, curved structures or pieces with variable thickness will be more easily tested.
- Cost reduction will be also achieved reducing the need of highly qualified personnel thanks to higher inspections precision.
- XPCI can comply easily with automated and robotic NDE, removing human operator handling error sources.
- Reduction of the time consumption for testing (especially for a field testing conditions) by at least a factor of ten (from 15 days to one), because EVITA technology does not need coupling gel or water jets, which considerably slow down the inspection of large complex structures.
- Reduction in wastage, due to fewer false calls, and better information on damage.
- Safer aerospace sector. Considering that 80% of aircraft failures are related to human mistakes during maintenance, higher automation levels offered by this technology together with a more accurate inspection reduce the need of operator's intervention.

1.4.1.2.1.5 Total Economic Impact of EVITA on the Aerospace Composite Repair Industry

As already mentioned, the impact of EVITA on the aerospace composite repair is considerable. An estimation is shown in Table 14 for a period of 4 to 5 years after project completion.

Contributory factor	**Sales, service or savings in World**	**Sales, service or savings in EU**
Cumulative profits from sales of newly developed equipment and associated methodology	Estimated to be €12M	€3.0M
Savings generated as a result of this project due to increase of reliability and mechanical performance of repairs, reduction in spending on maintenance by airlines and higher aircraft availability	Approximately €25M	Approximately €8,3M
TOTAL	**€37M**	**€11.3M**

Table 14: Total impact of project (per annum) on the aerospace composite repair industry 4 to 5 years after project completion

1.4.1.3 Contribution to Community Social Objectives

EVITA will assist in the development of high technology SMEs and RTDs, where job opportunities will be developed for the industrialization and series production of the projects results, contributing to the renown of European technology and inducing future related research developments. EVITA ambition is to provide a technology that can be industrialized and applied on aircraft production and maintenance within the next five (5) years, while promoted to the worldwide market through composite manufacturers and repair stations. It deals with a subject, the advanced composite material NDT techniques, which is a challenging issue between Europe and USA.

1.4.1.3.1.1 Employment Prospects and Level of Skills in the EU

The European aerospace industry directly employs some 429 thousand people whilst the second tier suppliers employ a further 500 thousand people. European industry has taken bold steps to use an increasing amount of advanced aerospace materials in their aircraft structures. Consequently, their aircrafts have on average considerably more advanced light-weight materials than US suppliers such as Boeing, making European aircraft significantly lighter than US manufactured aircraft of similar seat capacity. This gives European aircraft manufacturers a considerable competitive advantage over US manufacturers. This advantage is threatened by a loss of confidence in the use of advanced light-weight materials following recent air disasters caused by undetected defects or poor repair techniques in such components. EVITA can restore confidence in the use of advanced aerospace materials, in particular in the detection of porosity and micro-cracks by developing more confident, efficient and easier to apply methodologies and associated NDT equipment. This will result in safeguarding and increasing the employment prospects in the European aerospace industry.

1.4.1.3.1.2 Life Extension of Aircraft

EVITA delivers a new methodology to improve safety and operational capability of aircraft, leading to an increase in operational life. The countries of former Eastern Europe have aged aircraft fleets, which include 30-35 year old aircraft. In the absence of efficient repair solutions for their composite parts, these ageing aircraft may need to be decommissioned in the near future, to meet EU safety standards. This will seriously affect the East European airlines that are currently struggling to be competitive and survive in the global market. The EU predicts strong growth in the market which could be exploited by airlines that increase the operational life of their aircraft, whilst meeting EU safety standards, leading to significantly better returns on investment and profitability. EVITA may contribute to European wide sustainability and growth, particularly enhancing employment prospects in the new Member States.

1.4.1.3.1.3 Level of Skills in EU

EVITA will lead to an improvement in the level of skills for European citizens, as it will implement new NDT technology with more automated application. This greater level of sophistication represents **a step change over current technology**, which is based on less efficient methods.

1.4.1.3.1.4 Environmental Impact

Through enabling the extension of the economic life of aircraft components made of composite materials, greening of aircraft fabrication and maintenance is achieved, thus helping in reduction of the environmental impact of aviation.

EVITA eases the Digital Radioscopy and helps to speed up the swop between silver X-ray films (more and more difficult to get in appropriate sizes) to digital imaging, not needing chemical processes. This exploitation should spread in the different manufacturing plants and maintenance sites thus reducing their waste to make these plants “greener”. It should also speed up the replacement of old NDI/NDT ultrasonic and X-ray radiography installations, suppressing respectively water consumption and chemical waste, both aspects for Liquid Penetrant Testing replacement.

1.4.1.3.1.5 Contribution to Standards

Currently, the authorizing bodies conclude their requirement specifications from past experience mainly gained in the design and production of metallic components. This leads to mechanical load specifications of maximum static and dynamic loads until permanent damage occurs. In case of metallic components this is indicated by onset of creep deformations. Modern CFRP composite materials do not display such creep flow behaviour, however they may be loaded to much higher stress levels without permanent damage, while they break catastrophically in overload. These catastrophic failures in turn may be triggered by crack propagation and resulting breakage not detected in their microscopic defect initial state by established NDT methods. Thus advanced NDT techniques are desperately needed for two different reasons, obviously for motivation to reduce the safety factors based on lower defect detection levels, and maybe less obvious but equally important, to enable the authorizing safety bodies of the aeronautics industry to enforce best suited advanced NDT methodologies that fully exploit the potential of these modern materials in both cost and fuel consumption reduction targets. This goal may only be reached if the NDT safety norms on dynamic load are specified in different manner for CFRP than for metallic components, also referring to advanced inspection procedures based on phase contrast X-Ray imaging.

The EVITA will establishes first-in-world XPCI NDE capability, confirmed by the EVITA industrial partners (Dassault Aviation and GMI Aero) and by several members of the EVITA Advisory Board (GKN Aerospace, Airbus IW, RUAG, Alenia and EASA).

Considering the normative scenario, worldwide civil aviation agencies such as FAA and EASA reviewed their directives regarding the non-destructive testing technologies applied to in-service inspection activities of aeronautic components: e.g. EN 4179 ("Qualification and approval of personnel for non-destructive testing"), NAS 410, FAR 43 are some of the directives modified in order to consider the new developments in non-destructive inspection field. EASA Part 66 Regulation is being considered in order to take into account the novel proposed methodology for the identification of flaws (M6 – 6.3.1 "Detection of defects/deterioration in composite and non-metallic material", and M7 – 7.14.1 "Inspection Methods").

For the standardization issue, the development of a reference characterization and calibration procedure is also fundamental because it would allow full traceability of the measured parametre, which is important for application in aeronautics.

1.4.2 Main Dissemination Activities

During the whole duration of the project, many activities to disseminate the project and the XPCI technology and demonstrator took place.

Some of them were planned and other happened during the execution of the project, when interested organisations and media learned this methodology could detect defects that were very difficult or impossible to detect with standard industrial methods.

GMI Aero and NTUA, two of the EVITA partners participated simultaneously in the "Composites repair monitoring and validation - Dissemination of innovations and latest achievements to key players of the aeronautical industry – AEROPLAN" Coordination and Support Project (FP7-AAT-2011-RTD-1 (CSA-SA), Project No 285089).

In the frame of this project several dissemination activities took place, including the preparation of a book of abstracts and presentations to specific target groups, together with a website devoted to this project, namely www.aeroplanproject.eu. Given the existence of partners which are simultaneously linked to both projects, the EVITA innovations and project progress were integrated within the AEROPLAN dissemination tools.

Table 15 shows the dissemination activities carried out during the whole project:

O.	Type of activities[4]	Main leader	Title	Date	Place	Type of Audience	Countries Addressed
1.	Press release	CSEM	Non-Destructive Inspection of Micro-Defects in Composite Aeronautical Structures Helps Make Greener and More Reliable Aircraft	08/03/2013	Neuchâtel (CH)	Scientific community, (higher education research), industry, civil society, medias	CH, FR, DE, AT, UK, SP, GR, IT
2.	Conference presentation	CSEM	Non-Destructive Testing and Evaluation of Composites by means of Phase Contrast X-ray Imaging	12/03/2013	JEC Europe 2013, Paris (FR)	Scientific community, (higher education research), industry, civil society, medias	CH, FR, DE, AT, UK, SP, GR, IT
3.	Poster in an exhibition	CSEM	Phase Contrast X-Ray Imaging: excellent sensitivity to macroscopic and microscopic defects	12/03/2013	JEC Europe 2013, Paris (FR)	Scientific community, (higher education research), industry, civil society,	CH, FR, DE, AT, UK, SP, GR, IT
4.	Articles published in	CSEM	Le premier helicoptère Suisse prendra son	05/09/2013	L'Express,	Civil society,	CH

[4] Conference presentation, workshop presentation, web based project information, press release, flyer distribution, articles published in press, videos, media briefings, presentations in other events, exhibitions, thesis, interviews, films, TV clips, poster display, Other.

	the press		envol en 2014		Neuchâtel (CH)	medias	
5.	Conference presentation	CSEM	Dark field X-ray imaging for materials characterization	16/09/2013	Frontiers in Optical, Murten (CH)	Scientific community, (higher education research), indu	CH, DE, AU, FR, UK, SP
6.	Poster in a conference	CSEM	Non-Destructive evaluation, inspection and testing of primary aeronautical composite structures using phase contrast Y-ray imaging	10/10/2013	3rd International EASN Association Workshop on Aerostructures, POLIMI (IT)	Scientific community, (higher education research), industry, civil society, medias	CH, FR, DE, AT, UK, SP, GR, IT
7.	Conference presentation	CSEM	Phase Contrast X-ray Imaging: An Advanced Inspection Solution to Detect Micro-Defects in Polymers and Composite Materials	10/10/2013	3rd International EASN Association Workshop on Aerostructures, POLIMI (IT)	Scientific community, (higher education research), industry, civil society, medias	CH, FR, DE, AT, UK, SP, GR, IT
8.	Conference presentation and	CSEM	Zerstörungsfreie Prüfungen mit der Phasenkontrast-X-Ray Technologie	15/10/2013	Deutsch-Schweizer Photonenmesstag	Scientific community, (higher education research), industry	CH, DE, AU
9.	Conference presentation		Laminate fibre structure characterisation by orientation-selective X-ray grating interferometry	25/03/2014	iCT Wels (AU)	Scientific community, (higher education research), industry	AU, CH, DE

10.	Exhibition presentation	CSEM	Non-Destructive evaluation, inspection and testing of primary aeronautical composite structures using phase contrast Y-ray imaging	04/11/2014	VISION, world leading trade fair for machine vision, Stuttgart (DE)	Scientific community, (higher education research), industry, civil society, medias	CH, FR, DE, AT, UK, SP, GR, IT
11.	Flyers	CSEM	Non-destructive inspection for tomorrow's aircraft	19/02/2015	Alpnach (CH)	Scientific community, (higher education research), industry, civil society, medias	CH, FR, DE, AT, UK, SP, GR, IT
12.	Poster in an exhibition	GMI	Non-Destructive evaluation, inspection and testing of primary aeronautical composite structures using phase contrast Y-ray imaging	10/03/2015	JEC Europe 2015, Paris (FR)	Scientific community, (higher education research), industry, civil society, medias	CH, FR, DE, AT, UK, SP, GR, IT
13.	Exhibition	GMI	Portes ouvertes GMI (EVITA live demonstration)	15/06/2015	Paris (FR)	Industry	FR
14.	Articles published in the press	CSEM	Better Inspections Will Mean Lighter, More Fuel-Efficient Aircraft	17/07/2015	Aviation Week & Space Technology, MRO Edition (US)	Industry, civil society	US, FR, SP, DE, UK, CA
15.	Video	CSEM	EVITA project: how to test a composite	03/08/2015	Alpnach (CH)	Scientific community, (higher	CH, FR, DE, AT,

			structure			education research), industry, civil society, medias	UK, SP, GR, IT
16.	Conference presentation	CSEM	EVITA Proof-of-Concept	02/09/2015	5th International EASN Association Workshop on Aerostructures, University of Manchester (UK)	Scientific community, (higher education research), industry, civil society, medias	CH, FR, DE, AT, UK, SP, GR, IT
17.	Conference presentation	CSEM	Non-Destructive Evaluation and Inspection of Primary Aeronautical Composite Structures Using Phase Contrast X-Ray Imaging	16/11/2015	7th NDT Symposium on NDT in Aerospace, Bremen (DE)	Scientific community, (higher education research), industry	CH, FR, DE, AT, UK, SP, IT

Table 15: EVITA dissemination activities

1.5 Project Web Site and Relevant Contact Details

The project web site is www.evita-project.eu.

Table 16 shows the EVITA relevant contact details:

	Name	Position within the organisation	E-mail address
CSEM	Ana Maria Madrigal (coordinator)	Head of Aerospace Programme	anamaria.madrigal@csem.ch
	Vincent Revol	Project Manager	vincent.revol@csem.ch
GMI	Roland Chemama	CEO	roland.chemama@gmi-aero.com
	Konstantinos Kitsianos	R&D engineer	konstantinos.kitsianos@gmi-aero.com
NTUA	Georges Tsamasphyros	Professor at the Faculty of Physical Science and Applied Mathematics, section Mechanics	tsamasph@mail.ntua.gr
	Georges Kanderakis	Researcher	gkandera@central.ntua.gr
DASSAV	Hervé Tretout	Head of the NDE laboratory	herve.tretout@dassault-aviation.com
UNIMAN	Philip Withers	Professor of Material Science at the school of Materials	p.j.withers@manchester.ac.uk
	Matthieu Gresil	Lecturer of composite materials, NDT/SHM at the school of Materials	matthieu.gresil@manchester.ac.uk

Table 16: EVITA relevant contact details