Final Report
Please note that the contents of the Final Report can be found in the attachment.

4.1 Final publishable summary report

Executive Summary

It is well known that aircrafts' safety is of great importance, resulting to thorough inspections of all aircraft components for possible defects /flaws, both during the assembly and in-service life stages. Part of the maintenance procedures implies the structural integrity inspection through the aid of Non Destructive Testing (NDT) techniques, aiming to detect structural defects in damaged or flaw components and prevent a catastrophic failure by substituting or repairing them. Airworthiness authorities casually refer these inspections as "Checks" categorised in a scale from A to D Checks (see Table 1). Structural inspection and component removal for detailed inspection are actions that take place mainly in C and D Checks. The main disadvantage of these Checks is that they require a lot of time and they can only be performed in large hangars or into appropriate modulated spaces where NDT facilities can be accommodated. Nowadays, more and more aircraft primary structures are fabricated from composite materials, which are designed with respect to Damage Tolerance (DT) principles. Nevertheless, aircraft composite components are not assessed under DT principles simultaneously with NDT procedures in structural inspections, so far, but separately. Thus the combination of an advanced NDT technique with DT principles in a single inspection system will provide efficiency, time and cost saving in aircraft's maintenance composite structure.

Table 1. Frequency, Man-hours and overall time required for each maintenance check

	Period of time	**Man-hours**	**Time for completing the Check**
A Check	500-800 flight hours	20	Overnight
B Check	4-6 months	150	1-3 days
C Check	15-21 months	Up to 6000	1-2 weeks
D Check	5-6 years	Up to 40000	Up to 3months

Consequently, the TRACE-IT project was aimed at developing a field implementable system combining the capabilities of an advanced Non Destructive Inspection (NDI) technique, a flexible manipulating device for automated inspections and a novel methodology for incorporating NDT data into DT assessment. In particular, high sensitivity ultrasonic Phased Array (PA) technology accompanied with a sophisticated defect detection software were developed to manually and/or automatically (through the aid of the manipulator) inspect composite aircraft structures and to detect small size flaws. Selected results from the PA inspection are used as inputs to perform online or semi-online DT assessment of damaged composite components. The assessment is processed through the aid of advanced numerical Finite Element Methods (FEM) in a computer. Eventually, the results from the PA technique as well as the results from the DT analysis after processing are available to the inspector in a simple Graphical User Interface (GUI).

Summary description of project context and objectives

Maintenance expenditure usually represents approximately 20% of the overall operating cost of which 70% is labour and only 30% is materials. A single visit of an aircraft for a D Check costs from 850,000 to 1,500,000 Euros, while the required time for full structural inspection varies from 1 to 3 months. This high cost has a major impact to older aircrafts because their maintenance cost in comparison to their value is the reason why occasionally these aircrafts are being phased out from a particular airline's fleet upon reaching their next D Check. Apart from the need of reducing the time and cost for aircraft maintenance, always there is a need for efficient and reliable damage inspection and operational evaluation of aircrafts. The result of an undetected flaw due to inefficient inspection may lead to its catastrophic failure and eventually to aircraft loss. Nowadays, engineers design aircrafts to withstand a certain amount of damage without causing concern. This is the concept of DT, which is officially introduced mainly to aircraft design within the framework of the aeronautical regulation by the Federal Aviation Regulation (FAR) and Jet Airworthiness Requirements (JAR). However, during maintenance procedure components are not assessed under DT principles. The components are examined separately through the aid of NDT procedures.

Based on the aforesaid the main objective of the TRACE-IT project was the development of an inspection system that will be able to provide a feedback regarding the applied DT principles for composite aircraft structural design simultaneously with the inspection routine. The DT evaluation of composite components, during maintenance, will give the opportunity to maintenance managers and engineers to re-assess the inspection interval frequency. The TRACE-IT system is comprised by two parts: a qualified PA method attached to a mobile manipulating system, and a DT assessment technique processed on a computer. The results from the PA technique are used as inputs to perform a DT numerical analysis for the inspected component. However, in order for this system to be fully implemented in a 'real-world' setting and in order to accomplish the above general objective, the following main tasks were addressed during the TRACE-IT project:

i) Selection of an appropriate PAUT technique for maximizing defect detection and assessment capabilities. For that purpose, numerical parametric studies were implemented studying the effectiveness of different PAUT methods.

ii) Development of an adequate PA technique for the manual and automated inspection of planar and slightly complex composite surfaces. Based on the findings derived through the numerical calculations, a linear phased array probe was selected and a PAUT control software application was created.

iii) Design and development of a device for efficiently manipulating the PA probe. A lightweight device able to inspect flat and low radius curved surfaces as well as able to move in vertical and upside down positions, was manufactured.

iv) Development of a spatial positioning system, capable of tracking the position of the PA ultrasonic probe relative to the component under inspection. An encoding system was incorporated onto the manipulator able to measure the X-Y coordinates of the probe. Through appropriate cabling, the communication with the UT module for sharing the probe coordinates is possible.

v) Development of software for the processing of the PA imaging results, with capabilities of data conversion to suitable format for DT numerical analysis. An open source software application was used to process the raw UT data based on the threshold value method. Moreover, a Matlab routine was developed for data conversion, preparing the data to be used as inputs for the DT assessment.

vi) Code development for generating a numerical parametric model in commercial FE software. The code is written in the Parametric Design Language of the FE software allowing easy alternation of the inputs as well as control onto the FE model.

vii) Development of a user-friendly GUI allowing the simple operation of the TRACE-IT system. A software application was created providing the needed interconnection between the individual software applications developed for the manipulator control, the UT inspection control and the post-inspection analysis through the aid of Damage Tolerance technique. Options to control the storage of the different informative contents and a display area were also considered.

Description of main S & T results/foregrounds

In order to achieve the main scientific and technological objectives of the TRACE-IT project, the work activities have been organised into a number of districted Work Packages (WPs) and divided into research activities (WPs 1 to 5), demonstration (WP6), dissemination and exploitation (WP7) and management (WP8).

For the initial phase of the TRACE-IT project, the overall specifications of the TRACE-IT system were documented and the test cases that would be assessed were defined, after the advice from the two End Users (see D1.1). For testing throughout the whole span of the project, four different composite components applicable in the aerospace industry (with specified defects) were provided by HAI and ISQ. The defects included mainly artificial delaminations of different shape, dimensions and depth, as the presence of this defect mode was highlighted to be the most crucial for the adequacy of an aerospace composite component. Moreover, during the initial phase of the project, literature reviews were performed on the mechanical behavior of different composites (see D 1.2) and on the state-of-the-art NDT methods widely used in aerospace composites inspections (see D 1.3). In the former case, information was gained regarding specific loading conditions as well as failure mechanisms on composites, while the latter literature review summarised the main advantages and limitations of the current NDT techniques for composite inspections, information that can be used for relative comparison with the capabilities of the developed TRACE-IT inspection system. The above tasks led to the achievement of the first project's milestone, defining the specifications of the TRACE-IT system and the requirements of the TRACE-IT project.

The second milestone of the project concerned the study for the development of a suitable PA method for composites inspection. Different ultrasonic configurations were modeled (by NTUA), that would potentially be used from the automated inspection and analysis system of the project. Original plan for the TRACE-IT system was the use of phased arrays and FMC/TRF methods. Nevertheless alterations to the initial plan were performed as the above did not provide a step change improvement on defects imaging. For the purpose of the TRACE-IT system, the linear scan and the linear half step scan configurations were selected and proposed as the main screening tools (see D 2.1), while from the results produced after the completion of the TRF models, it was observed that even if better A-Scan results were retrieved in this case, this information was not that useful for the damage tolerance analysis (see D 2.2).

After the completion of the numerical parametric studies, the development of a PAUT inspection methodology (including hardware and software applications) was performed (see D 3.1) (by Dynawave). A linear phased array probe consisted of 128 elements was selected as the main scanning equipment, while for the implementation of manual inspections an encoded trolley was used having a wedge of 30 mm thickness (see D 3.2). Initial validation of the inspection equipment and methodology through the manual configuration showed that promising results regarding defect detection can be retrieved (see D 3.3). Nevertheless, large deviations regarding the sizing of defects were observed in some instances, which were expected to be overcome during the repeat of the automated procedure through the aid of the manipulator, as a greater degree of accuracy would be achieved. In other words, a drawback of the manual inspection mode, observed during the preliminary validation task, is the inability to perform high rate and accurate mapping scanning due to the man factor involved.

For the automated capability of the TRACE-IT inspection system, a manipulating device was designed and manufactured (by ISQ) (see D 4.1 and D 4.2). The prototype scanning system is consisted of three main parts: the main unit (scanner itself), the electronic control unit (responsible for controlling the electronic units assembled in the scanner), and the air control unit (responsible for the air /vacuum control). The main characteristics of the manipulating device are its lightweight construction and its ability to move-inspect flat and low radius curved surfaces as well as ability to move in vertical and upside down positions. The hardware device is accompanied of a software application, responsible for the scanner control, the position mapping and the communication with the UT module for sharing the probe coordinates (see D 4.3). The mapping and control software was developed with a set of specific capabilities to optimize the communications with the other modules and includes a Graphical User Interface (GUI) architecture to facilitate its operation at industrial level.

The last milestone (MS5), related to the project's research activities, dealt with the completion of the algorithms for the structural integrity evaluation using DT method and the development of the TRACE-IT control software. This work was primary performed by ARES, where initially a pattern recognition algorithm was developed for extracting defect characteristics such as defect location and size from the PA images. Additionally, a macro routine has been written to convert this information to a convenient format in order to be used as inputs for the DT modelling analysis (see D 5.1). The applicability of the developed signal processing tool was evaluated comparing the quantitative information produced by the raw UT data and by the image processing procedure stated above (see D 5.2). The next step was the development of a simulation regime based on the DT principles (see D 5.3) and the numerical analysis of the selected, for the purpose of the project, components (see D 5.4). The selection of appropriate FE software for the DT module of the TRACE-IT system was made based on specific criteria/features that the software should have (e.g. analysis type, element type etc). More specifically, the DT analysis tool was created based on the DT rules of the CS-25 regulations for large airplanes, while analysis is performed through the aid of Cohesive Zone Material (CZM) modelling technique, providing a successful simulation of the load-displacement response curve. Furthermore, the last activity in this task was the development of a GUI responsible to allow the simple operation and the smooth collaboration between the modular units of the system (see D 5.5). Moreover, a display area was also included through which the operator can view both the PA and DT results after the analysis of a component.

With the successful integration of the scanning system as validated in WP6 (see D 6.1) and the addition of some minor modifications, manual and automated inspections were performed on the laboratory-scale samples (see D 6.2). The current results from the inspection of a planar CFRP and a planar hybrid sample demonstrated the functionality and operations of the fully integrated system prototype as well as its ability to detect delaminations of various size, shape and depth location. The stability of the system using the simultaneous vacuum suction procedure during measurement was also demonstrated with success on the large scale samples during the field trials. In particular, a spoiler and horizontal stabilizer were studied (see D 6.3), where in the former case scanner operation was tested vertically and in the latter case scanner operation was tested upside down. During the spoiler inspection no defects were detected, while in the latter case, a debonding region was examined. From the results produced after the completion of the field trials, the TRACE-IT project has taken the exploitable results to minimum Technology Readiness Level (TRL) 6.

The Plan for Use and Dissemination of the Foreground (PUDF) was drafted and produced (see D7.2) within the entire period of the project. This exploitation plan sets out the details of the types of dissemination activities to be undertaken during the project lifetime. The final PUDF includes the potential to attract investment for the TRACE-IT technology beyond the duration of the project and captures all dissemination and exploitation activities which have been undertaken by the project partners (see D 7.3). The final plan for using and disseminating the foreground and to access relevant IPR (intellectual property rights, industrial rights, patents), as required at the end of the project, provides a complete picture of all activities undertaken, and, most importantly, provides information on the future route to full use (exploitation or use in further research) and further dissemination of knowledge.

The website for TRACE-IT (see D 7.1) is accessible on the public domain using the following URL:
http://www.trace-it.eu
Information in the website is up-to-date.
The project flyer has been designed and disseminated to external parties to create awareness for this project (see D7.1).

Based on the outputs of the research and development work so far, there have been two scientific publications submitted to one National and one International Conference as follows:

E. Cheilakou, P. Theodorakeas, R. Marini, I. Hatziioannidis, M. Koui (2015). Development of an advanced ultrasonic phased array technique for the inspection of aerospace composite structures. In Proc. of the 8th National Conference on NDT of the Hellenic Society, 8-9 May 2015, Athens, Greece.

D. Stamatelos, F. Stamatelos, T. Spathopoulos (2015). Numerical structural integrity assessment of an aircraft's delaminated composite plate against buckling. In Proc. of the 6th International Conference on Experiments/Process/System Modeling/Simulation/ Optimization (6th IC-EpsMsO), 8-11 July 2015, Athens, Greece.

Furthermore, the End User-TAP attended the 58th Annual Airlines for America NonDestructive Forum (58th A4A NDT Forum) in Fort Lauderdale, Florida, between 21 and 24 September 2015. A video was presented to the Forum participants, demonstrating the performance of the TRACE-IT fully integrated system prototype on actual large-scale composite aircraft components that had been captured in TAP facilities during the field trials. Nemetschek, had a very active role in the dissemination activities of the TRACE-IT project presenting and promoting the business opportunity of the product in their own spheres and targeting potential clients and partnerships.

Additionally, a web training seminar took place on 28 of September (along with the final meeting), where the sequence of operation of the TRACE-IT system was demonstrated to the SMEs, through multiple images and videos. Each RTD performer presented the sequence of operation of each individual project result. A manual describing the sequence of operation was prepared for the training purposes and the thorough understanding of the technology developed (see D 7.4). As part of the dissemination activities, a project video will be also prepared which will be also uploaded to the project's website (see D 7.5).

The liaison with the European Commission has been carried out in an appropriate manner via the coordinator of the TRACE-IT project. Despite the fact that the due deliverables were not submitted in a timely manner, nevertheless, the work produced was of good quality. All participating SMEs (I&T Nardoni, Aerohelice, Nemetscheck & Exis Innovation Ltd) have been very active during the project and contributed on technical level, providing guidance to the RTDs, as well as on dissemination and exploitation issues.

Technical Work Progress

WP1 Project's specifications and mechanical behaviour of composite materials.

WP1 is divided into two main parts having two objectives. The first objective was to arrive at the detailed specifications and performance requirements for the development of the TRACE-IT system, while the second objective was to carry out literature reviews regarding the mechanical behavior of composite materials and the current NDT techniques used for the inspection of aerospace composites. The project specifications and requirements were thoroughly discussed during the Kick Off meeting of the project and have been fully documented. At the beginning of the project and with the advice of the two end users, the consortium has identified the test cases where the TRACE-IT project would be most beneficial to resolve the most critical problems within the aircraft structures. The potential project applications would be carried out on the CFRP skin of a spoiler component of AIRBUS A320/A330 aircraft types and on the CFRP/GFRP Fenestron Skin component of helicopter types such as AGUSTA NH-90 & EUROCOPTER EC-135. The type, location, minimum detectable size and accept-reject criteria of the most common and crucial defects (i.e. delaminations, debonding) affecting the above aircraft structures have been identified. Representative test samples (having specified defects with characteristics much smaller that the maximum accepted criterion) were prepared to be used for the testing and validation of the manual and automated PA system and the DT analysis. Furthermore, literature reviews have been documented regarding the mechanical behavior of composite materials and the most common applied NDT techniques for the assessment of aircraft composite structures. In the former case, information was gained regarding specific loading conditions as well as failure mechanisms on composites, while the latter literature review summarised the main advantages and limitations of the current NDT techniques for composite inspections, information that can be used for relative comparison with the capabilities of the developed TRACE-IT inspection system.

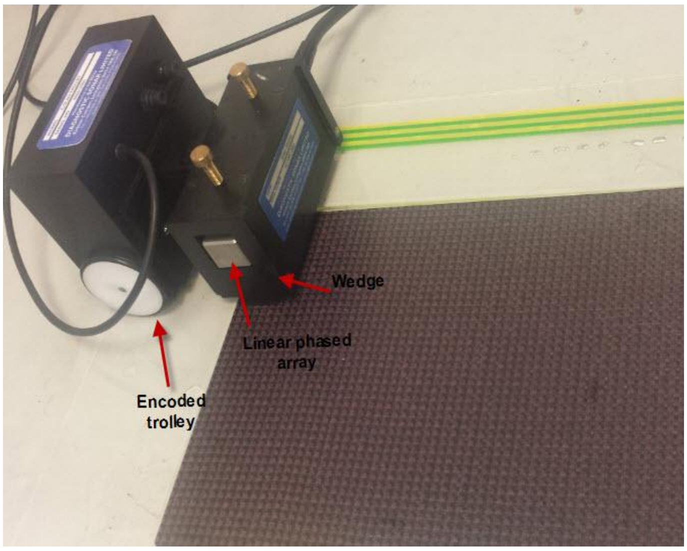
WP2 Development and Functionality of PAUT technique.

The main objective of WP2 was the modelling of different ultrasonic configurations that would potentially be used by the automated inspection system. The performance of different ultrasonic configurations were numerically assessed, through the aid of CIVA modelling software, studying the physical models of the laboratory CFRP samples of the project. The investigated configurations were these of linear electronic scanning (half step configuration was also considered to be assessed) and Full Matrix Capture (FMC) in combination with Total Focusing Method (TFM). The main screening tool for the above investigations was a linear phased array probe consisted of 64 elements with 5MHz central frequency and with an elements' pitch of 0.8 mm (numerical simulations were also performed by a single element probe of the same frequency, in immersion regime for validation and comparison purposes). Both probes were applied without any geometrical focusing and the input signal was a Gaussian pulse at the probes' central frequency. The selection of these specifications was performed based on past experience working with aerospace composites and based on the specifications of mass production probes applied on such inspection scenarios. The results produced from this numerical analysis indicated that that an array probe with a central frequency at 5MHz should be used for the inspection of the aerospace components specified in this project, while a half step configured linear scan at 0 degrees with 16 elements is expected to provide resolution even better than an immersion C-Scan with a resolution of 1mm. Contrary to initials expectations, the TFM algorithm did not provide a step change improvement in the defect imaging. Even if it provided images of slightly higher resolution and lower noise than the linear electronic scan, it suffers from a quite low reconstruction speed. Thus, the best practice seems to be the use the electronic scan configuration as a screening tool and then reconstruct (if required) with TFM only at the areas where a defect has been identified.

In the framework of WP2 another aspect was to numerically assess the Time Reversal Focusing (TRF) technique and evaluate its applicability on the Trace-IT inspection system. For the purposes of TRF applicability evaluation, the probe used for the simulated test was the linear array as on the previous study, nevertheless in order to fully test the applicability of TRF in such specimens it was considered essential to place a much weaker reflector into the HAI1 model and thus a small spherical flaw of 0.5mm diameter was introduced and placed in the middle of the specimen's thickness. In other words, for the TRF modelling and its application for the HAI 1 numerical test, only the geometry of the above sample was the same. Furthermore, another model was created with a 0.25mm spherical flaw and finally a third containing no defects. According to results, better A-Scan results were retrieved through the aid of TRF method. Nevertheless, it is not that useful in imaging the composite and providing useful information for the damage tolerance analysis, as this project seeks to apply. Since the delay timings are not known, the defect cannot be positioned in the specimen geometry and thus an image with it cannot be recreated. The only potential use of the application of TRF method could be concurrently with the normal phased array and TFM algorithm. For each position of the transducer the PAUT equipment would perform electronic scanning and/or FMC and then also apply TRF using a predetermined spatial window. If the TRF A-Scan has any significant peak between the front and back wall echo, then the position can be marked for further investigation.

WP3 Design and development of PA hardware.

The objective of WP3 was to design, develop and validate the PA methodology and the probe of the TRACE-IT system. The UT module has been designed consisted of 128 elements with 5MHz central frequency and elements' pitch of 0.52 mm. For the implementation of manual inspections, a trolley wedge of 30 mm thickness was also prepared. For both manual and automated inspections, a software application was also created, which it can be described by the functionalities of real time visualization of the scanning sprits or the B-scan sectional images, overall C-scan image view after stitching the data from the individual inspection lines, X-Y encoded capabilities, A-scan and C-scan relation and X-Y sizing of defects. Both the hardware module and the software interface are illustrated in Figure 1. Additionally the necessary steps for the manual and automated inspection methodologies were defined. After the design of the proposed methodology and the development of both the hardware and software applications, the applicability of the UT inspection procedure was preliminary assessed (on a manual mode) on the laboratory samples. The initial validation results after measuring with the current probe and the techniques of linear electronic scan, half step electronic scan and FMC were in a good agreement with the numerical predictions, indicating as well that the electronic scan configuration is more appropriate for the inspection of the composite panels. Furthermore, an active aperture using 16 elements seems to provide efficient results regarding the internal defects detectability. Nevertheless, large deviations regarding the sizing of defects were observed in some instances, which were expected to be overcome during the repeat of the automated procedure through the aid of the manipulator, as a greater degree of accuracy would be achieved.



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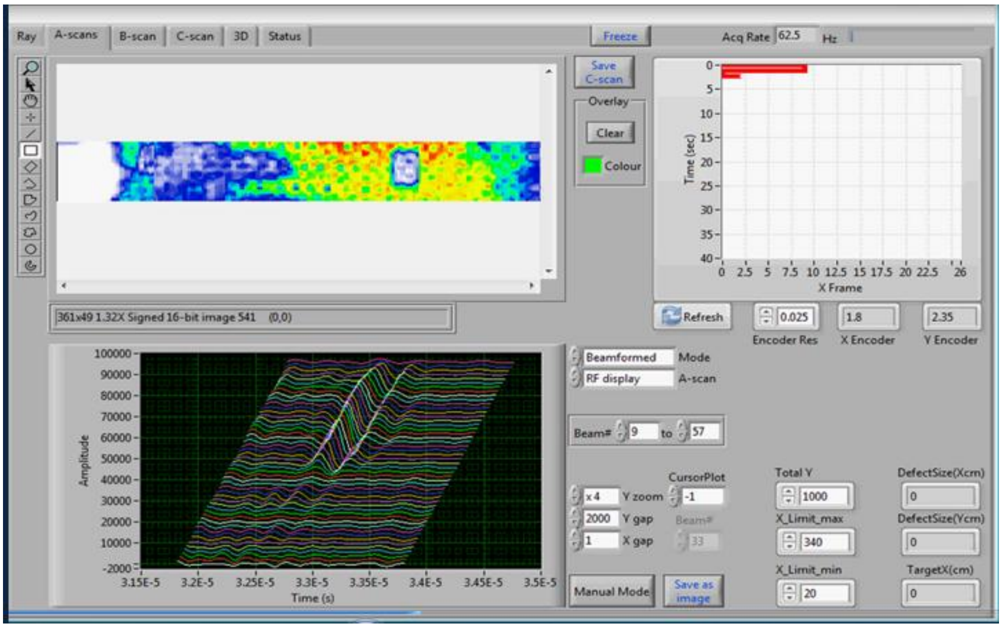
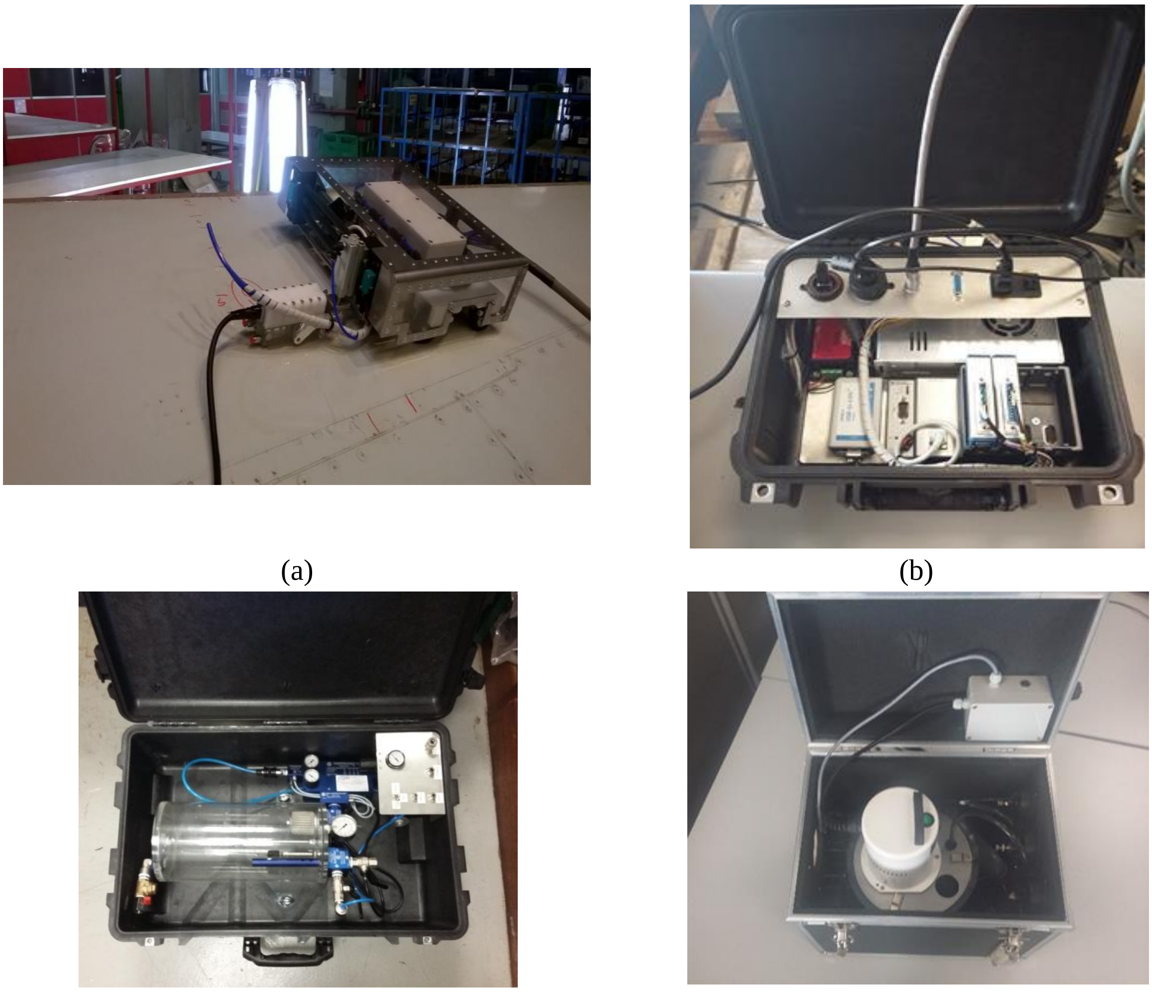


(b)

Figure 1. (a) Experimental setup of the manual UT inspection and (b) software application for controlling the acquisition and the results display.

WP4 Design and development of the manipulating device

The main objective of WP4 was the development of a portable, automated scanning system for composites inspection. System's operation regards the testing of planar and slightly curved surfaces using the UT methodology-hardware developed in WP3. The system can be divided in two major hardware sections. The first one consists in the scanner itself with dimensions of 366 mm x 405mm x130 mm and the other one includes all the auxiliary control units, which are the electronic control unit (responsible for controlling the electronic units assembled in the scanner), the air control unit (responsible for the air /vacuum control) and the optional coupling medium supply unit (responsible for the supply of the coupling medium to transmit the sound from the probe to the inspected part). The scanner is an automated and remotely controlled system that can move through the surface of a component, performing NDT measurements, while the control units are external electronic and hydraulic devices that are engaged in the process management and process control. The main characteristics of the manipulating device are its lightweight construction (approx. 4 Kg), fully functional to be placed and/or transferred on several areas of interest, ability to move-inspect flat and low radius curved surfaces as well as ability to move in vertical and upside down positions, automated scanning capability in X-Y coordinates, remote control of the scanner (15meters required between the scanner and the external units), fixation to the surface without damaging the part (nonmagnetic surface), ability to perform linear and nonlinear trajectories, all wheel drive, main computing hardware located outside the scanner and automatic ultrasonic couplant supply.



(a) (b)

(c) (d)

Figure 2. Hardware sections of the manipulating system with (a) scanning device, (b) electronic control unit, (c) air/vacuum control unit, and (d) couplant supply unit.

Attending an efficient accomplishment of the scanner's specifications, the following modules were implemented: 1) Main base, which consists in the structural base where all the other modules are connected, 2) Measuring module, which is responsible for the NDT measurements, 3) Movement module, which is responsible for the movement of the scanner, 4) Fixing module, which is responsible for the fixing of the scanner to the surface and, in addiction, for the normal force to the surface that allows the previous module to have traction/grip, 5) Coordinate module, including the two encoders mounted nearby the measuring module, 6) Electric module, which consists in all the controllers and all the on-board electronic devices, and 7) Casing, which protects the different components of the system when subjected to possible collisions of the scanner with any object in the scanner's surroundings.

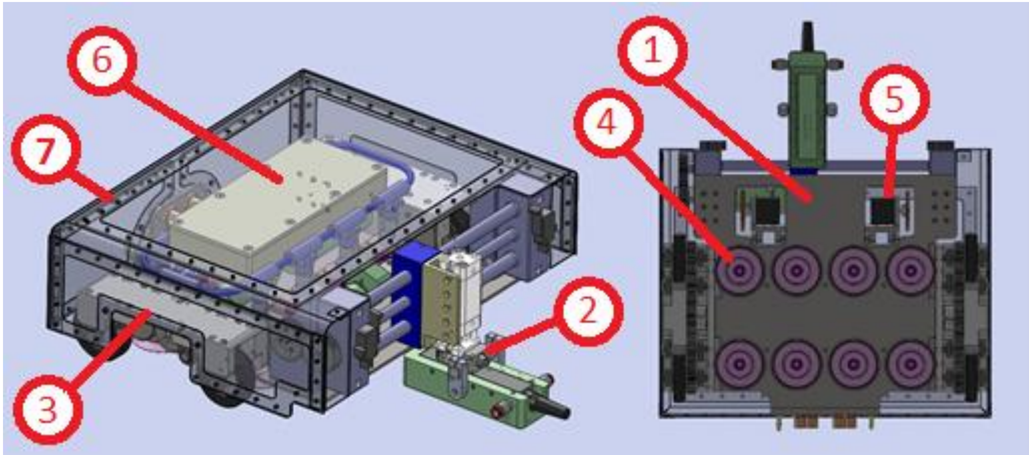


Figure 3. CAD drawing showing the main components comprising the manipulator with: 1) Main base, 2) Measuring module, 3) Movement module, 4) Fixation module, 5) Coordinate module, 6) Electric module, 7) Casing.

Along with the hardware equipment produced on this phase, a control and mapping software was also implemented for the scanner manipulator and control. The software to control and mapping the trajectory of the inspection scanner was developed in a LabView-v2014 environment. This program has as main features the inspection scanner control, scanner trajectory mapping and the communication with the Ultrasonic module for sharing the phased array probe coordinates. The developed interface for the control of scanner's operation is illustrated in Figure 4.

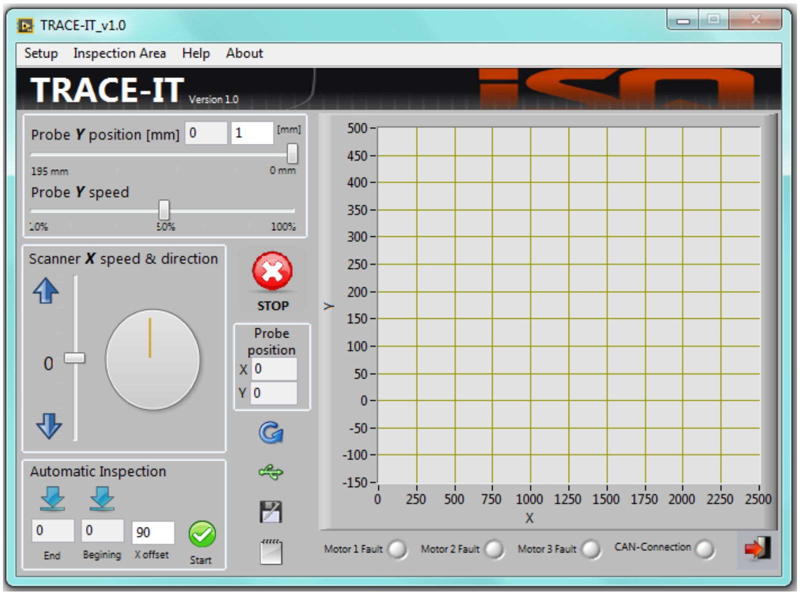


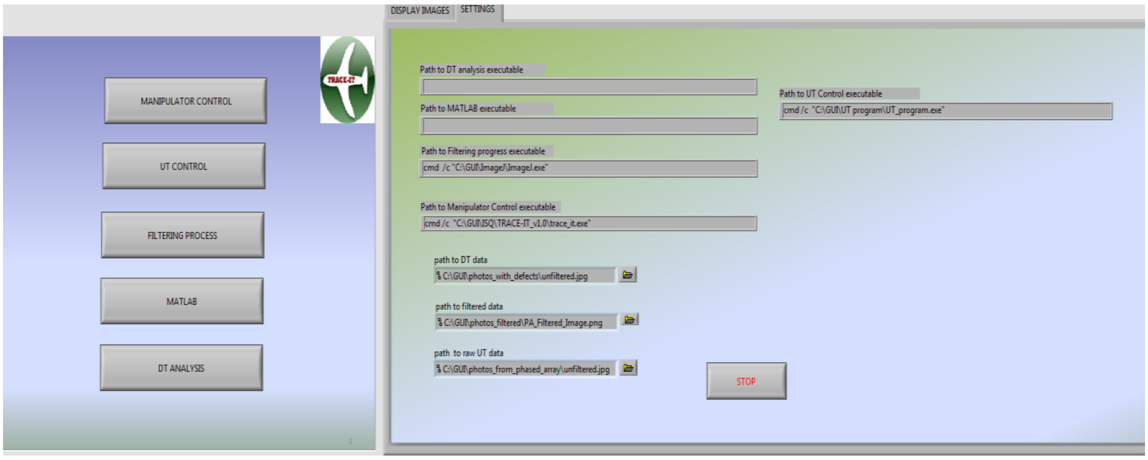
Figure 4. Scanner control program main user-interface.

WP5 Development of programming code for advanced PA data processing and TRACE-IT analysis.

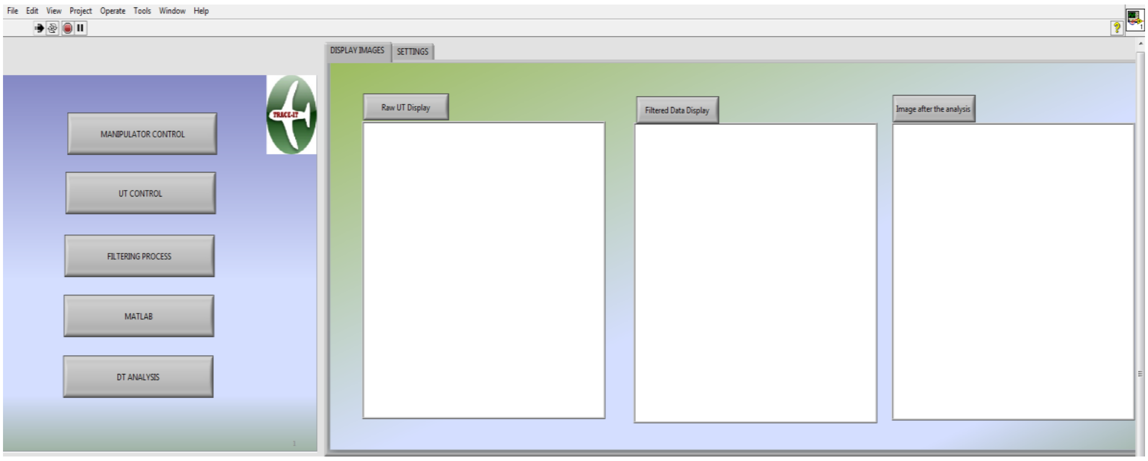
The main objective of WP5 was to develop the required algorithms and macro routines for both processing the PA data and extracting the suitable features to be inputted into the numerical DT models and to generate the parametric numerical models that would be run the analysis and process the results in a repetitive sequence. After the determination of the proper amount of data for the DT modelling analysis that the image processing algorithm should extract, image processing tools based on threshold value and golden samples methods were evaluated in order to be used for the processing of PA images. Image processing based on the determination of a threshold value was selected as this technique was found to be more suitable for the purposes of the developed methodology. After the definition of the proper image filtering procedure, through the aid of an open source processing software (ImageJ), different threshold value theorems were evaluated leading to the selection of Maximum Entropy theorem, which can be programmed relatively easy and it was proposed for further implementation to the MATLAB written algorithm. The produced image processing algorithm is comprised by different sections, where after the initial declaring of the input parameters and the image processing and filtering for noise reduction and information enhancement, the application of image threshold filtering is followed enabling the calculation and the extraction of the image properties (required information for the performance of the DT analysis with NDT data). Implementation of the algorithm was conducted in MATLAB V.7.0 R14 and compiled in Windows using the MATLAB Compiler V.7.0 R14. The execution time of the algorithm implemented in MATLAB was tested on a common laptop (Intel Core2 Duo, CPU P8400 @ 2.26GHz, RAM 4.00GB, Windows 7 64-bit) and using this basic computational effort, the execution time of operations related to image processing was approximately 150ms, while the properties of the image can be extracted within 10ms.

After the development of a suitable image processing algorithm, a study for the selection of the appropriate FE software for the DT module of the TRACE-IT system was performed. The FE software selection has been carried out by initially setting the criteria/features that the software should have (e.g. analysis type, element type etc). A refined list of the most promising FE software for the TRACE-IT application was made by considering that fracture mechanics problems for composite structures (e.g. delamination) needed to be solved. Additionally, FE capabilities regarding the communication of the selected FE software with the other modules of the TRACE-IT system and possible future needs were also foreseen. Eventually, Ansys FE modelling software was selected as the most efficient FE software for the TRACE-IT system and the implementation of the DT analysis. More specifically, the DT analysis tool was created based on the DT rules of the CS-25 regulations for large airplanes, while analysis is performed through the aid of Cohesive Zone Material (CZM) modelling technique, providing a successful simulation of the load-displacement response curve.

A second objective of this research activity task was the development of a Graphical User Interface (GUI) integrating all the modular units (e.g. PA, DT and Positioning System Unit). For this purpose, a software application was created, in a LabView-v2015 environment, aiming mainly to provide the needed interconnection between the individual software applications for the manipulator control, the UT inspection control and the post-inspection analysis through the aid of Damage Tolerance technique. Despite the fact that GUI development primary considered the control facilitation of the different components, a results display area has also been built, providing the operator the required readings for producing a prompt and reliable interpretation both in terms of the overall process smoothness, as well as in terms of a brief information retrieval about the operability of the inspected component. Furthermore, options to control the storage of the different informative contents (UT results, filtered imaging data, DT images) were also considered. The main windows of the TRACE-IT control GUI are illustrated in Figure 5.



(a)



(b)

Figure 5. Trace-IT GUI showing (a) the main control and the settings control areas and (b) the main control and images display area.

WP6 System Integration, Laboratory and field industrial trials

The main objective of WP6 was to evaluate the suitability and performance of the fully integrated TRACE-IT prototype system. Initially, system integration and preliminary trials took place in ISQ and TAP facilities the period between 20 and 24 of July 2015, focusing mainly to the study of the performance of the system's hardware components. Preliminary testing defined that in order to acquired results of greater sensitivity, a different wedge had to be prepared increasing its thickness to 35 mm, which further resulted to the design of a different wedge and to minor modifications for the new wedge mounting onto the manipulating device. Moreover, a driver installation issue was observed disabling the operation of the manipulator from the control PC, but this was considered of minor importance as the communication of the PA module and the manipulator module in terms of encoded readings was performed in a satisfactory manner. On the other hand, preliminary trials in TAP facilities showed the proper operation of the manipulating device to move on actual aerospace components (e.g. a spoiler component), while it was further tested successfully to move upside down and vertically. The second trial activities took place in ISQ and TAP facilities between 14 and 17 of September 2015, where further inspections on HAI1 and HAI2 laboratory samples were carried out in order to fully assess the performance of the current system. The current results from the inspection of the planar CFRP and hybrid samples, demonstrated the functionality of the fully integrated system to detect artificial delaminations of different shape, size and depth location. The stability of the system using the simultaneous vacuum suction procedure during measurement was also demonstrated with success on the large scale samples at TAP facilities. In particular, a spoiler and horizontal stabilizer were studied, where in the former case scanner operation was tested vertically and in the latter case scanner operation was tested upside down. During the spoiler inspection no defects were detected, while in the latter case a disbanding region was examined.

Potential impact and main dissemination activities and exploitation results

While in Europe 2010 was the safest year ever in the history of civil aviation, the consistent growth in air traffic over the coming decades means that action is needed to develop and implement solutions that will make sure EU improve upon its remarkable safety record. Structural failure of critical components is a major cause of air accidents leading to fuselage loss and fatalities. By effecting a step change in maintenance procedures with the proposed combination of an automated UT inspection system and a DT assessment methodology of the inspected component, the TRACE-IT project has the potential to provide a tangible contribution to aviation safety. This project demonstrates an advanced NDT inspection system that will enable a major improvement in the preventive maintenance process by enabling detection of defects in critical air transport composites and by assessing their influence degree in the operational life of the component. This in turn will improve the safety of EU citizens. Meanwhile, due to the reduction of time and cost for aircraft infrastructure maintenance that the proposed system will offer, airline companies will have an increase of the value for money and as a result they will be able to reduce their tickets' prices and make air travel more affordable to European citizens. In the short term, the market pull in the aerospace sector is significant where the need is to develop more reliable NDT techniques for aircraft structures. This represents a business growth opportunity for the SMEs of the project improving their competitiveness as it is estimated that worldwide air traffic will treble in the next 20 years. As a consequence, the aircraft fleet will double in the same period which would require more maintenance, repair and overhaul (MRO).