PROJECT FINAL REPORT

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List of Abbreviations

Acronym of Partners

FHW .... FH OÖ Forschungs & Entwicklungs GmbH
CTU .... CESKE VYSOKE UCENI TECHNICKE PRAZE
UPAT .... UNIVERSITY OF PATRAS
KUL................. KATHOLIEKE UNIVERSITEIT LEUVEN
AGI (EADS) ...... AIRBUS GROUP INNOVATIONS (EADS DEUTSCHLAND GMBH)
AIR.................. AIRBUS OPERATIONS GmbH
FACC............... FACC OPERATIONS GmbH

LAC .... LA COMPOSITE SRO
VG .... VOLUME GRAPHICS GmbH
CEA.................. COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES
FHG .... FRAUNHOFER-GESELLSCHAFT zur Förderung der angewandten Forschung e.V.
EASN .... EASN Technology Innovation Services BVBA

Others

D...................... Deliverable
GA .... General Assembly
M..................... Month
PM................... Person months
Q .... Quarter (3 months)
WP .... Work package

1. Final publishable summary report

1.1 Executive Summary

The QUICOM project, which is funded by the European Union's 7th framework programme, developed a technology platform of new and highly detailed inspection methods based on cutting edge X-ray techniques for the characterization of aeronautic specimens concerning material and geometric features within a short time. The main objective of the QUICOM project was to escalate conventional aeronautic NDT techniques in the short run and to replace them in the long run. In more detail, the QUICOM technology platform contains novel, nondestructive, fully 3D, highly detailed, fast and economic techniques based on cutting edge X-ray computed tomography methods. Using these novel means of data acquisition in conjunction with data analysis, modeling and simulation, QUICOM facilitated, implemented and established a new era of CFRP development on all ranges of aeronautic components, namely small high volume parts, composite metallic parts and complex and large parts. QUICOM thus targeted the design, development, implementation and validation of novel X-ray computed tomography techniques for nondestructive structural and material characterization of aeronautic CFRP components. Furthermore, QUICOM modeled CFRP composites and CFRP structures integrating the characterization results as generated by the various investigated techniques. Finally, feedback of the modeling results may now be provided to the design office and manufacturing for advancement the composite component as well as to material development for advancement of the basic composite material. In this context the following overall goals were realized during the lifetime of the project in order to provide reliable, fast and precise NDT:

- Generate a unique understanding of the real inner 3D structures of composite components
- Develop highly detailed nondestructive characterization based on X-ray computed tomography
- Implement the assessment of CRFPs based on XCT data in aeronautic industry
- Provide input for the design office or the potential of rework of the produced CFRP parts based
- Provide input for optimized design of new composite parts
- Assess of damage tolerances of CFRP components

To summarize, the QUICOM consortium successfully implemented the QUICOM technology platform as specified and demonstrated it to be functional in its various aspects at the end of the QUICOM project. Now the different techniques undergo a detailed testing and refinement phase to evaluate and enhance the potential for daily industrial use.

CONTEXT

Within the past decades, a clear trend formed within the aeronautic industry of constantly driving industrial research towards new tailored materials as well as cost-effective, function-oriented, highly integrated and light-weight components. The driving forces behind this trend are found in the high demands of airlines and operators regarding efficiency, environment, safety as well as passenger comfort. Advanced composite materials and especially Carbon Fiber Reinforced Polymers (CFRP) are the most promising materials, which allow integrating these demands in the components of the aircraft of the future (e.g., fuselages, horizontal tail planes, propulsion components, etc.). The next generation of aircrafts, as the Airbus A350 XWB, is made of more than 50% of composite materials. How-ever with the increase of the composite share the efforts for nondestructive testing were exploding. By the time of writing the QUICOM proposal it was not possible to get a comprehensive representation of a specimen including internal and external 3D structure analysis as well as a material analysis without destroying the sample. In this respect the development and characterization of aeronautic components was considered as being on the edge of a new era, which was targeted in QUICOM.

VISION

In the ACARE (Advisory Council for Aeronautical Research in Europe) report "Flightpath 2050: Europe’s Vision for Aviation" and its strategic research agendas for providing more affordable, more economic, cleaner, safer and more secure air travel, the main challenges which the European aeronautics industry is facing are: Maintaining global leadership by providing the best products and associated services in aeronautics and air transport, by ensuring the competitiveness of European industry, supported by a strong research network and balanced regulatory framework, in the face of fierce competition from both established and emerging rivals and by maximizing the aviation sector’s economic contribution and creating value.

In QUICOM these strategic aims were targeted by providing a technology platform of novel, high quality, efficient, and affordable means of nondestructive inspection, as well as simulation and modeling of aeronautic components. In detail QUICOM addressed the fully three dimensional non-destructive characterizations, simulation and modeling of the whole range of aeronautic components: small high volume CFRP parts, composite metallic parts, complex and large CFRP parts. Integrating the targeted characterization results in simulation and modeling allows for precise characterizations of the mechanical properties in CFRP components, by considering real inner structure inhomogeneities (e.g. flaws, pores, etc.). Furthermore the development of a neural network based progressive damage model of CFRPs showed how components behave in operation, in case of strength degradation, fatigue impact and other damages. This closed feedback cycle allows ensuring the quality of aeronautic components and thus their safety. Environmental issues are addressed by the development of tailored components including the knowledge gained in the high quality characterization processes. Also the affordability is ensured as the targeted fast and automatic inspection contribute to lower the nondestructive testing costs for new components.

GOALS and OBJECTIVES

QUICOM aimed at taking the next big step in the characterization, simulation and modeling of aeronautic components. The following goals and objectives were targeted in QUICOM (see Figure 1).

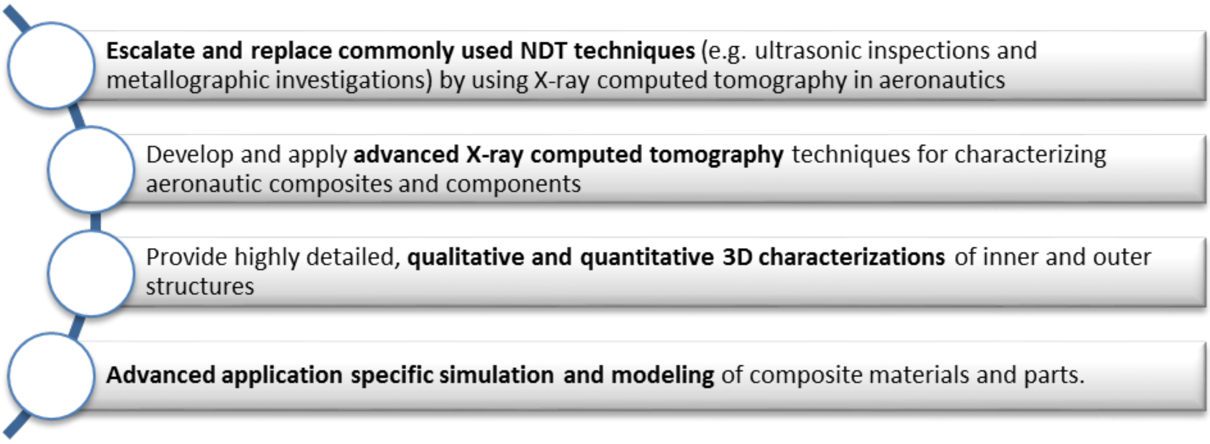


Figure 1: Main goals of QUICOM

In detail, the QUICOM technology platform achieved and realized the following goals:

- For all ranges of aeronautic components from small to large sized parts and various compositions, conventional XCT techniques came to their limit, e.g., regarding scanning protocol, specimen size, data size and evaluation. For these components advanced X-ray techniques were investigated, such as multi energy XCT, robot based XCT, fast XCT techniques, as well as novel data analysis methods. The feasibility of these novel concepts was proved on scaled laboratory systems. Furthermore for specified small and high volume parts, the possibilities and limits of fast inspection concepts were worked out. In addition, the adaptation of XCT acquisition and reconstruction methods to the requirements of large part inspection using robot based XCT systems was investigated on lab size robot XCT system demonstrators at FHG and FACC.
- Several requirements need to be fulfilled for precise nondestructive structural and material characterization of aeronautic CFRP components: Broad dynamic range in radiograms to achieve a contrast high enough to resolve CFRP components with similar attenuation. Moreover a broad dynamic range enables the visualization of low absorption components shielded by metallic parts. These aspects were solved using noiseless single photon counting devices. Furthermore, increasing the signal to noise ratio (SNR) and reducing of the number of the projections (e.g. tomosynthesis, ROI techniques) for specific CFRP problems were investigated.
- Characterizations of aeronautic structures were facilitated by the development of dedicated QUICOM algorithms and methods to address qualitative and quantitative evaluation of aeronautic CFRP components from small parts, hybrid parts (e.g. composite metallic parts) as well as complex and large parts. This included image enhancement techniques, analysis concerning structural features, e.g. orientation or alignment, as well as material decomposition in combination with meaningful visualizations of the results.
- QUICOM also provided reliable 3D XCT images for robust quantitative analysis of production flaws and the deviation of the real structure from the designed structure in order to develop and optimize CFRP computer models. These optimized models allow for generating a detailed understanding about the effect of production flaws, such as voids or a deviation in yarn geometry or shape, on the mechanical behavior of the composite part, and were applied for identification of deviation of the material properties from the norm, based on the measured scatter of the internal structure and on the identified defects (voids and cracks). Finally, the optimized and validated CFRP models are to be used to optimize the design and production of CFRPs.

CONCEPT and IMPLEMENTATION

QUICOM linked the activities of 12 partners from 6 European countries including 6 research partners, 3 large enterprises, 2 SMEs and a network partner to ensure dissemination in order to establish a strong team with expertise in X-ray techniques, software, application, and CFRP materials in order to collaborate on reliable, fully 3D inspections of aeronautic components. To date, there is neither a group in Europe, which is able to carry out such an activity on its own, nor is a project partner able to carry out any single work package on its own. The QUICOM project was running from 10/2012 to 09/2015 in a total project lifetime of 36 months. QUICOM was implemented using a total budget of 5,075 Mio EUR funded by the European Union's FP7 programme within its FP7-AAT-2012-RTD-1 call under the topic 7.1.4.1. Aircraft Development Costs.

Using this setup the progress beyond the state of the art in the QUICOM technology platform was focused on the extensive use of X-ray computed tomography (XCT) techniques to detect defects in small high volume, hybrid and large composite structures. Advanced X-ray methods in different modalities were developed and applied for NDT of composite components. As the different part types require different X-ray techniques, individual concepts were developed for each part type. These concepts may differ in acquisition protocol, X-ray photon energy used, required radiogram dynamic range, irradiation geometry, CT reconstruction method, analysis strategy etc. The QUICOM technology platform assures thorough inspections of the structure at high levels of detail and hence allows for reducing the design, production and rework costs due to an enhanced understanding of the real inner 3D structures. The availability of such an inspection enables higher structural efficiency and higher performance than recent state-of-the-art with the same or higher level of safety. Understanding and knowledge of the damage in a composite structure is a key factor for application of a damage tolerance approach. The computer models, developed and optimized within QUICOM, incorporate the real inner structure of the composite parts after production based on the micro XCT data. Hence they allow generating a detailed understanding on the effect of production flaws, e.g., voids or a deviation in yarn geometry or shape, on the mechanical properties of the composite parts. Furthermore they allow identifying the deviation of the material properties from the norm based on the measured scatter of the internal structure and on the identified flaws. This knowledge is used to optimize the design and production of CFRPs, and provide input for the potential of rework of the produced CFRP parts. Hence a potential increase in the amount of rework and a decrease the production costs is expected, assuring damage tolerance.

1.2 Description of the main results and foregrounds

1.2.1 WP 1 – Management

The overall objective of the Management comprises planning, organization, coordination and controlling of the QUICOM project in order to accomplish the targeted goals. WP1 includes the management of the project's resources regarding the deployment and manipulation of human resources, financial resources, technological resources and natural resources. Furthermore the overall objectives were the supervision of the project strategy as well as gender equality, the execution of decisions, the coordination of procedures and communication both internal and with the EC and the supervision of external activities.

Fulfilment of the project work plan

The coordinator fulfilled the tasks of the overall project management. These tasks included the definition and implementation of the project plan including guidelines and templates for deliverables, meetings, communication, documentation, reporting etc. Furthermore, the coordinator supervised the time line of the project regarding milestones, deliverables and reports.
Generally, the collaboration was very fruitful in the QUICOM project. The partners worked close together and had a lot of meetings, as can be seen in the list of the main meetings below. Every six months, a meeting of the whole consortium took place, hosted by one of the partners respectively. Several dissemination activities have been carried out together by partners and the project's overall objectives have been reached. The consortium is satisfied with the outcome of the project.

Table 1: QUICOM meetings

LIST OF MAIN MEETINGS				
Date (DD.MM.YYYY)	**Place** (City & Country code)	**Participants** Name & partner acronym	**Main Content/Reason**	**WP/s**
19.11.2012	Wels, AT	All partners	Kick-off Meeting	1, all
23.01.2013	Bremen, DE	All partners	Definition of sample specimens	2, 3
24.01.2013	Bremen, DE	AIR, CEA, FHG, UPAT, FACC	WP4 and WP6 side-meeting	4,6
25.01.2013	Furth, DE	FHG, UPAT	available equipment and initial organization guidelines	4
29.01.2013	Leuven, BE	KUL, UPAT	Tasks in WP8 and distribution among partners	8
12.02.2013	WebEx meeting	EASN, FHG	first draft implementation of proposed data organization method	2
13.02.2013	Ried im Innkreis, AT	FHW, EADS, FACC	state of the art of the partners; directions for future work; exchange datasets and test specimens;	3
25.02.2013	Video conference (WebEx meeting)	FHW, EASN, FHG	version 2 of the data organization method	2
27.02.2013	Teleconference	CEA, FHG, UPAT	Determination of phantom format	4
08.03.2013	Teleconference	CEA, FHG, UPAT	Determination of simulation parameters and 3D phantom format - primitives	4
24.04.2013	WebEx- Meeting	FHW, EADS, FACC	results obtained by µ-CT and differences in evaluated degree of porosity; evaluation of exchanged datasets;	3

26.04.2013	Ried im Innkreis, AT	FACC, FHG	Technical meeting on WP6, Task 6.3	6
14.05.2013	Munich, DE	FHW, KUL, EADS, LAC	progress of the scans and evaluations	3
15.-16.05.2013	Ottobrunn, DE	All partners	GA 2 Meeting	1, all
22.05.2013	Teleconference	CEA, FHG, UPAT	Determination of simulation scenarios	4,6
27.05.2013	WebEx-Meeting	FHW, EADS	define a guideline for porosity evaluation (reduce the user dependent influence on porosity evaluation)	3
10.06.2013; 11.–13.06.2013 (training course)	Heidelberg, DE	EADS, VG	Presentation of results and new software modules for composite evaluation. Link to WP7. EADS attended a three-days VGStudio MAX training course	3,7
18 – 20.06.2013	Heidelberg, DE	KUL, VG	KUL attended a three-days VGStudio Max training course + meeting on new software developments	3
27.-29.06.2013	Patras, GR	CEA, FHG, UPAT	Technical Meeting: WP4 progress and WP6 kick-off	4,6
05.07.2013	Teleconference	CEA, FHG, UPAT	Preparation of iCT2014 abstract	4,6
07.-09.07.2013	Skype & Telephone communications	CEA, FHG, UPAT	Finalization of iCT2014 abstract	4,6
17.07.2013	Ried im Innkreis, AT	FHW, FACC, CTU	Requirements for CT simulations	3,5
20 – 22.08.2013	Heidelberg, DE	LAC, VG	LAC attended a three-days VGStudio Max training course	3, 4, 5
07.10.2013	Milan, IT	CEA, FHG, UPAT	Technical meeting	4, 6
07.10.2013	Milan, IT	All WP7 partners	Progress update on WP7	7
08.-09.10.2013	Milan, IT	All partners	GA 3 Meeting	1, all
09.10.2013	Milan, IT	All partners + ROLLS ROYCE (IIG)	1st Industrial Interest Group meeting	10
13.-14.11.2013	Ried, Austria	FHW, FACC, AIR, FHG, CEA, UPAT	WP4 & WP6 3rd Technical Meeting and FACC Visit	4 and 6
10.12.2013	Teleconference	CEA, FHG, UPAT	Preparation of iCT2014 paper final submission	4,6
12.12.2013	Teleconference	CEA, FHG, UPAT	Preparation of iCT2014 paper final submission	4
20.12.2013	Teleconference	CEA, FHG, UPAT	Discussion on WP6	6
25.02.2014	Wels, AT	FHW, CTU, EADS, VG	iCT 2014 conference with side meetings	3, 5, 7
11. 03. 2014	Skype meeting	FHW, CTU	Finalization of deliverable 5.1	5
13.03.2014	Teleconference	CEA, FHG, UPAT	Discussion on WP4 and WP6	4,6
07.04.2014	Leuven, BE	FHW, CTU, LAC, FHG, EADS	Implementation of the Widepix detector into simulation software CTsim, utilization of the material sensitive radiography for metal composites.	5
08.04.2014 – 10.04.2014	Leuven, BE	All partners	GA 4 Meeting + Intermediate review meeting	1, all

06.05.2014	Telc, CZ	FHW, CTU	weighting method, measurement optimization strategies	5
04.06.2014	Fuerth, DE	FHG, CEA, AIR, LAC	Discussion AIR samples	4, 6
05.06.2014	Fuerth, DE	CEA, FHG	Work planning	4, 6
06.06.2014	Fuerth. DE	FHG, CEA, FACC	Discussion FACC samples	4, 6
29.9.2014	Fürth, DE	FHW, EADS, EADS, VG	WP7 meeting, progress update	all +7
30.09. – 01.10.2014	Fuerth /DE	All partners	GA 5 Meeting	1, all
21.01.2015	Vienna, AT	FHW, KUL	Impact Meeting	10
16.03.2015	Prague, CZ	FHW, EADS, VG	WP7 meeting	7
16.–18.03.2015	Prague, CZ	All partners	GA 6 Meeting	1, all
12.-16.07.2015	Ried, AT	FACC, FHG	Robo CT scans	6, 9
06.-08.09.2015	Ried, AT	FACC, FHG	Robo CT scans	6, 9
15.-17.09.2015	Ried + St. Martin/AT	All partners	GA 7 Meeting + Final review meeting	1, all

1.2.2 WP 2 – Detailed specifications

Fulfilment of the project work plan

With respect to Task 2.1, a report on "Industrial needs regarding component types to be inspected and inspection tasks" has been prepared and delivered (D2.1); summary:

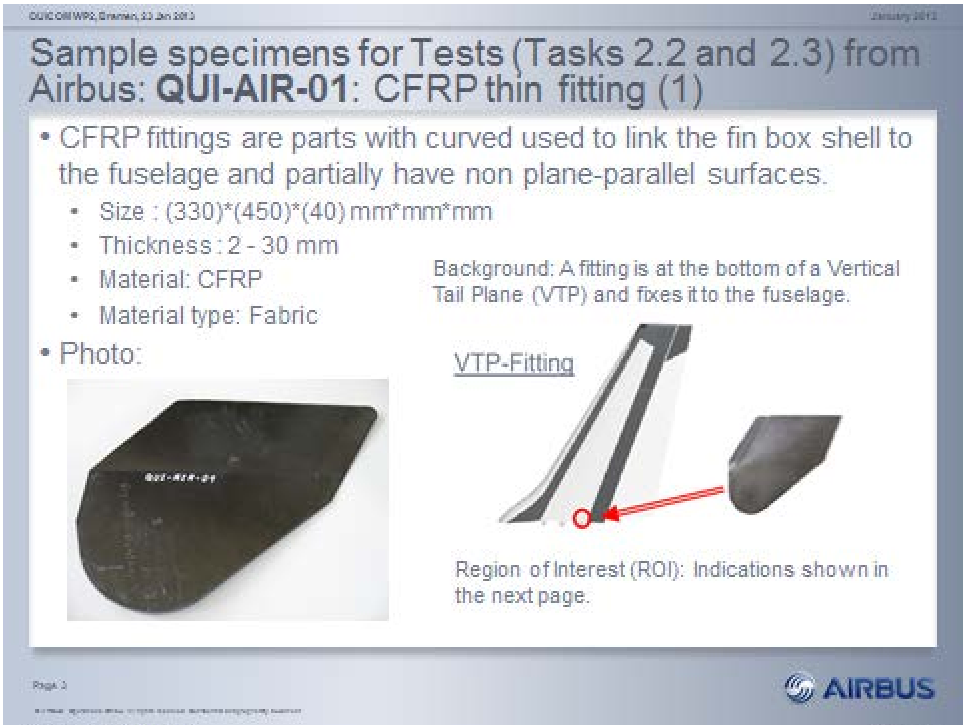
As selected materials and components, report D2.1 mentions fibre composite components whose NDT inspection shall be faster than with normal inspection methods and of the same (or even better) inspection sensitivity; moreover: build-up of composite materials (solid laminate or sandwich or both) and large fibre composite components whose dimensions do not fit with conventional tomographs. As concrete examples, Report D2.1 mentions wing shell, fuselage panel, thermoplastic clips, center hinge fitting, spoiler, and engine cowling.

Concerning defect detection needs, the following main defect types in CFRP have been identified: Delamination, (skin-to-core) debonding, impact damage, inclusion of foreign material, layer porosity, volume porosity, resin rich areas, and crushed core. Defect sizes (minimum values are given; basis: usual requirements at Airbus): Solid laminate: 6 mm x 6 mm; sandwich: 8 mm x 8 mm for cell size 3,2 mm; defect specificities in case of volume porosity: causing an ultrasonic back-wall echo loss of minimum 6 dB at 5 MHz (for Airbus A350 program and later); 2,5% by volume (for Airbus programs before A350).

With respect to Task 2.2, a "Report on samples and test cases including associated reference NDT data" has been prepared and delivered (D2.2); summary:

The defects and structure shall also be characterized. For CFRP-lab samples this includes: A reliable evaluation of the degree of porosity (approx. 0 to 5% by volume of volume porosity, and size, position, clustering of pores, porosity below clear detectability, etc.); reliable evaluation of main orientations (main orientations, angles in 2D and 3D, amplitude and frequency of ondulations); reliable evaluation of fibre fraction ratio; detection of variations in fibre/matrix fraction ratio (approx. 50% to 70%); evaluating the potential of CT for CFRP/metal laminate inspection and testing; delaminations at the interface; defects and misfits at special metal joints; evaluating the potential of CT for defects caused by heat; delaminations; changes of structure caused by heat/lightning.

With respect to Task 2.3: Sample specimens (Figures 1 to 3 show three examples) and NDT Data were collected. Sample specimens were shipped to partners on request. A data organization model was elaborated. Setup and arrangement of an online list of test specimens on the QUICOM homepage was setup and arranged ("QUICOM Samples Repository").



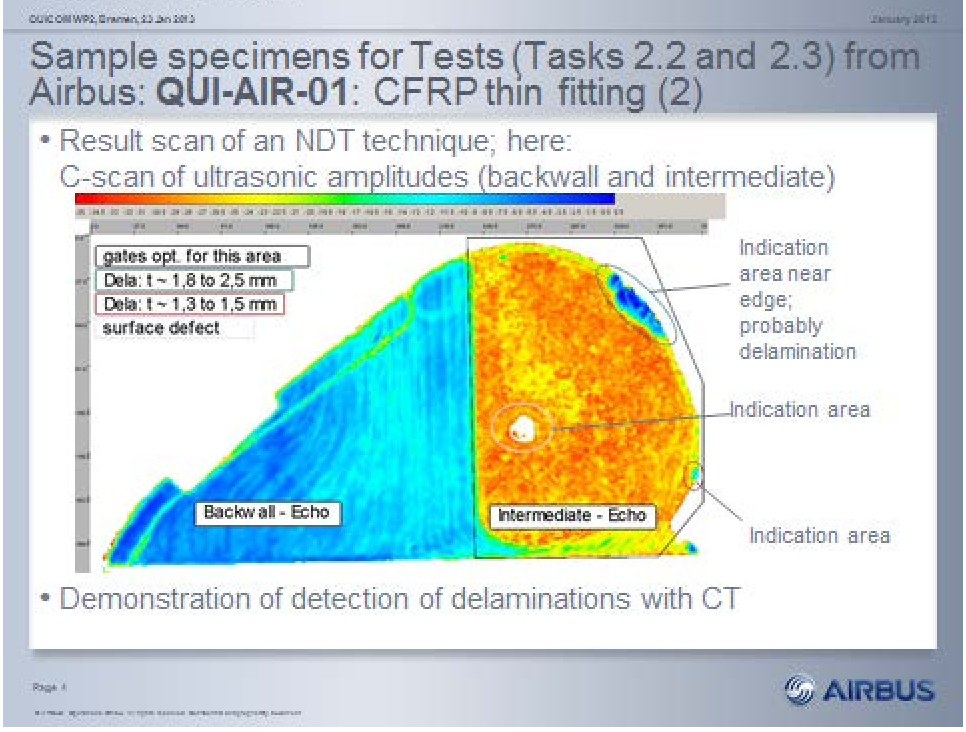


Figure 2: Sample specimen QUI-AIR-01; description of sample (top) and ultrasonic C-scan (bottom)

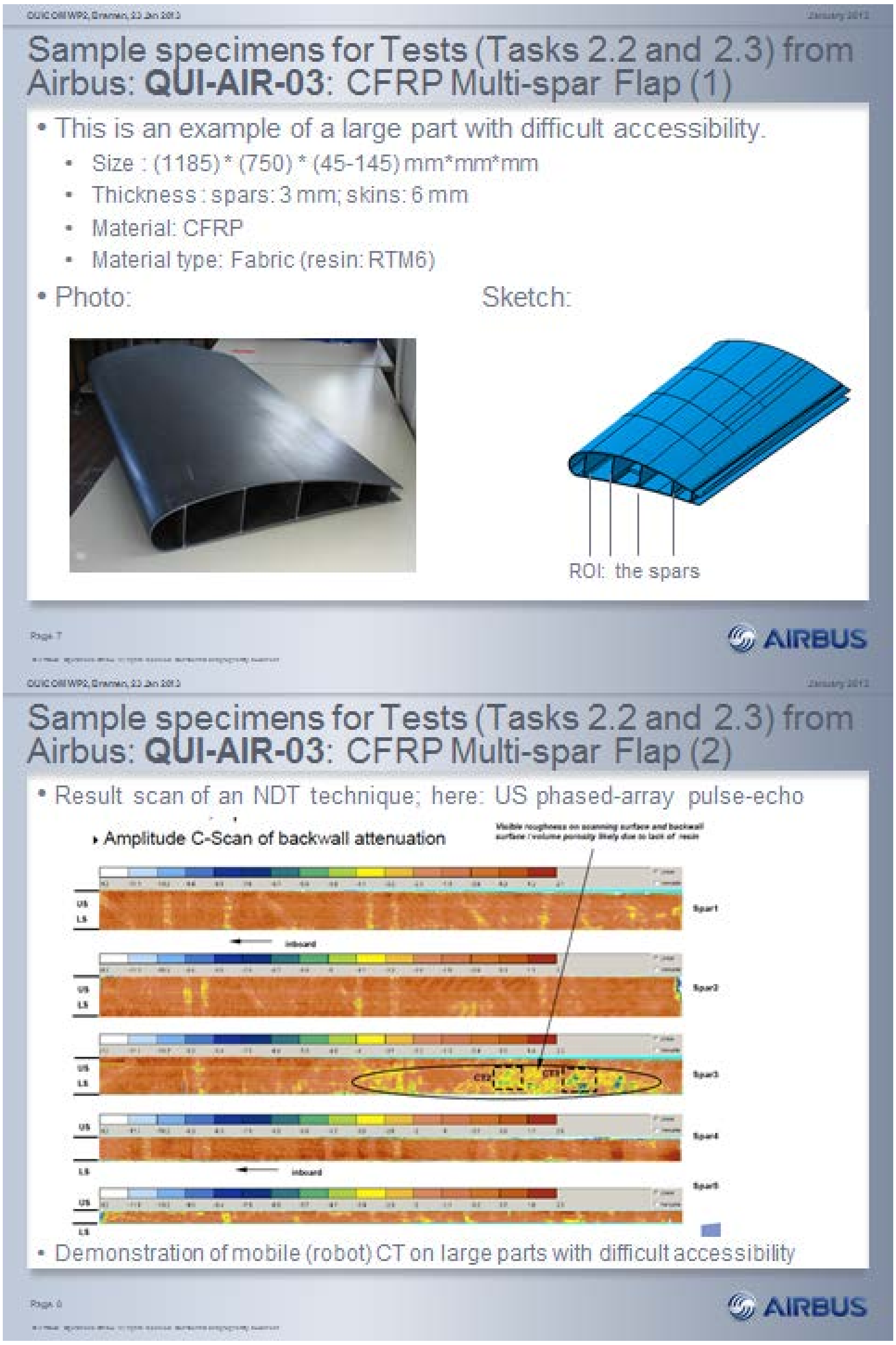


Figure 3: Sample specimen QUI-AIR-03; description of sample (top) and ultrasonic C-scan (bottom)

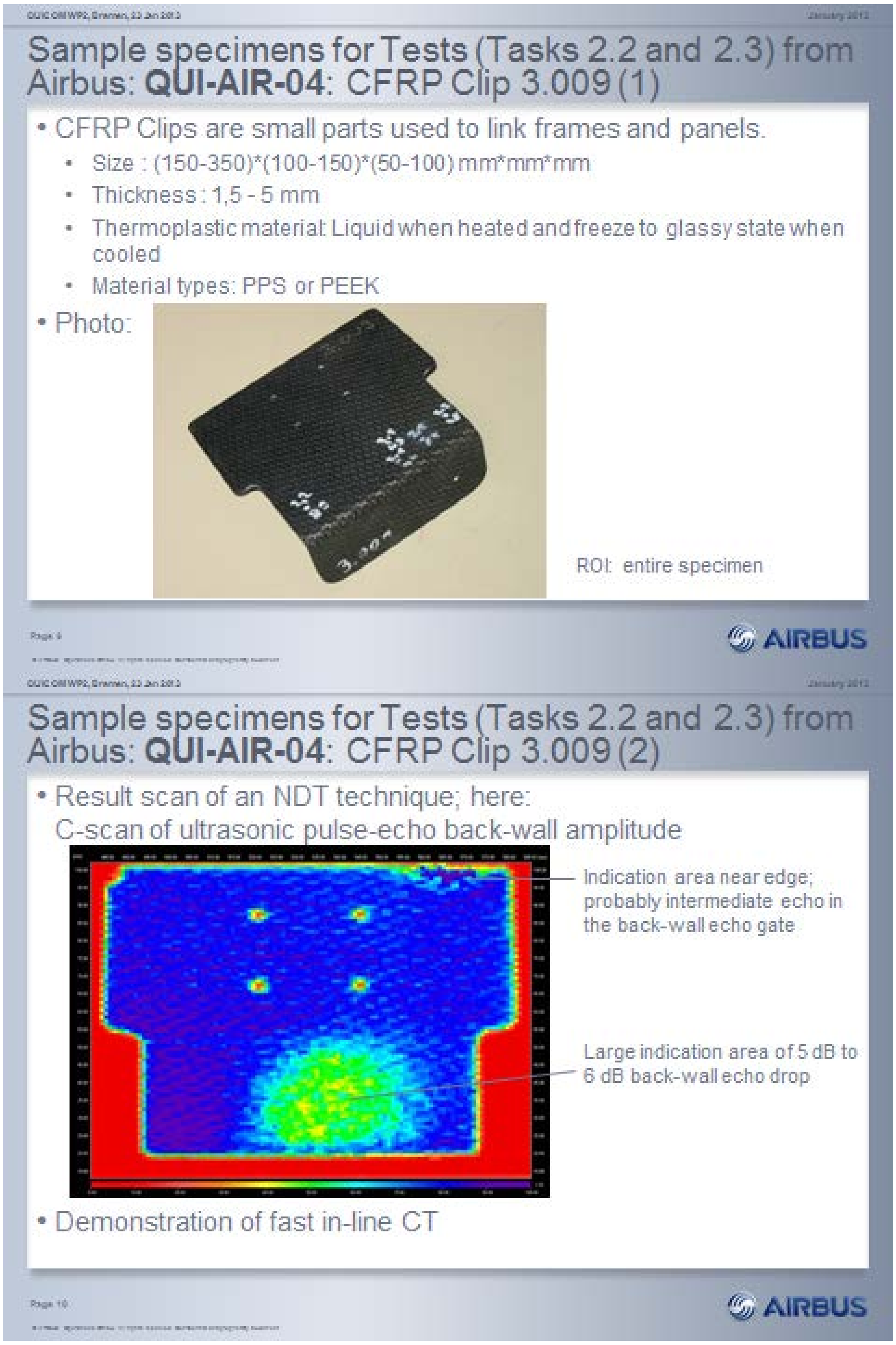


Figure 4: Sample specimen QUI-AIR-04; description of sample (top) and ultrasonic C-scan (bottom)

Scientific and technical results

Clear view of industrial needs for CT was elaborated (on materials and components, flaw types and sizes, and material characterization needs). Representative samples to be used for investigations in this project were collected. A data organization model was implemented. Furthermore, Airbus performed a study on the correlation between ultrasonic inspection and CT.

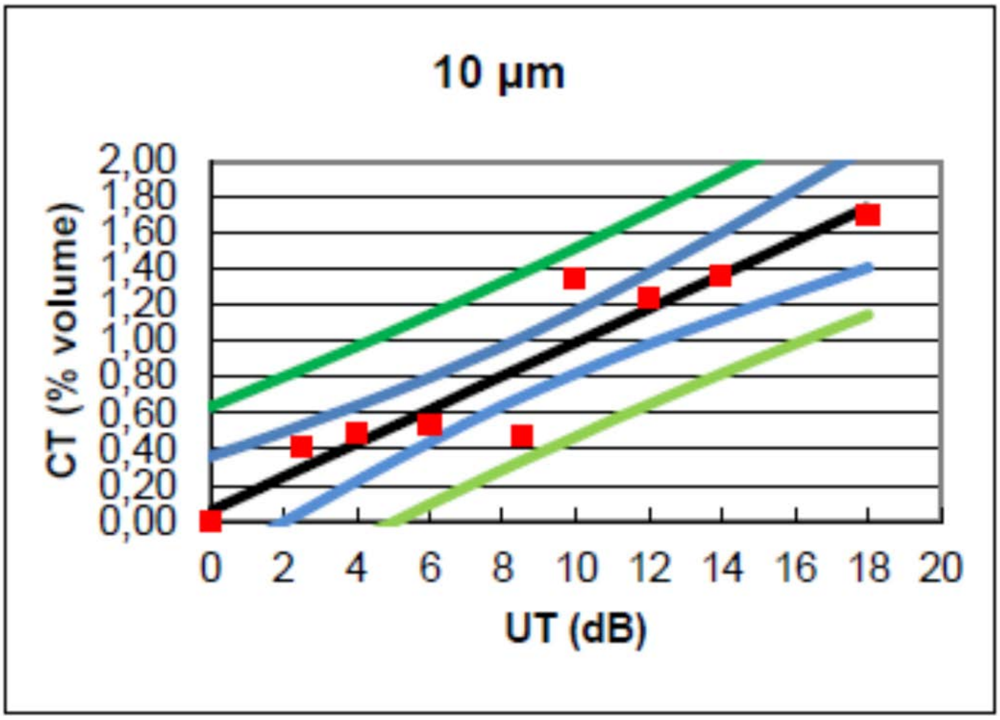


Figure 5: CT volume porosity versus ultrasonic back-wall loss; obtained on a typical CFRP material of approx. 4 mm thickness; voxel size: 10 µm;

Collaboration with other work packages

WP2 results are the basis for further investigations on the work packages of this project.

1.2.3 WP 3 - Optimized micro-scale and meso-scale material characterization

WP3 is focusing on the evaluation and optimization of cutting-edge X-ray computed tomography techniques for imaging CFRP composite parts at the micro- and meso-scale and on optimized image processing for the material characterization of composite components concerning volume porosity, voids such as delaminations, inclusions, cracks, etc., and the geometry, orientation and shape of the inner structures. For this work package the X-ray computer tomography systems of CTU (and collaborator Telč), FHW and KU Leuven were used.

Fulfilment of the project work plan

The workplan of WP 3 has been fulfilled. Scans were made to explore the different defects in Q1 and Q2. In Q3 further scans & evaluations were made, working towards the deliverable scheduled in July 2013 for the porosity testing. Further scans & evaluations were made during Q4, working towards the deliverable scheduled in September 2013, namely D3.1 the report on reliable input images for analysis of geometry, orientation and shape of inner structures of CFRPs. In Q5 further work on the visualization of delamination in CFRP structures was done. Task 3.1 and Task 3.3 are finished. Q6 is the final quarter for this WP in which further images and evaluations were done on the visualization of voids in CFRP structures in order to work towards the deliverable scheduled in the end of March 2014, namely D3.3 the report on reliable and qualitative visualization of voids. Therefore also Task 3.2 is completed.

Scientific and technical results

Task 3.1 Porosity testing

The results of porosity analysis with the different evaluation methods and voxel sizes have shown that there are no significant differences in the determined degrees of porosities between the partners.
The only differences or deviations in evaluated degrees of porosity at the datasets EADS_035_ECD_P5_PORO-2%, EADS_035_ECD_P5_PORO-4%, EADS_036_ECD_P5_PORO-6% and EADS_036_ECD_P5_PORO-8% are caused by a user dependent reference threshold determination method. In order to reduce the effect of this influencing factor, guidelines were defined.
Furthermore, EADS found out that the evaluated degree of porosity depends on various measurement and evaluation parameters. The most significant influencing parameter is the voxel size. Figure 6 shows deviations in evaluated degrees of porosities at different voxel sizes.

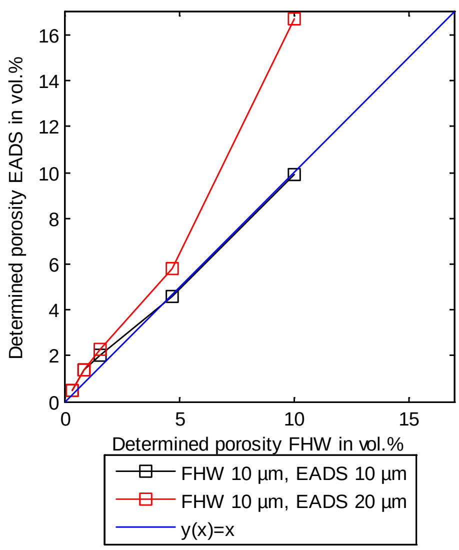


Figure 6: Comparison of determined degrees of porosity evaluated by EADS and FHW at voxel sizes 10 µm and 20 µm

In addition, measurements were performed at CFRP samples with different degree of porosity. The graph of Figure 7 illustrates that there are no significant differences in porosity evaluation by using the two different threshold determination methods which are used by FHW and EADS.

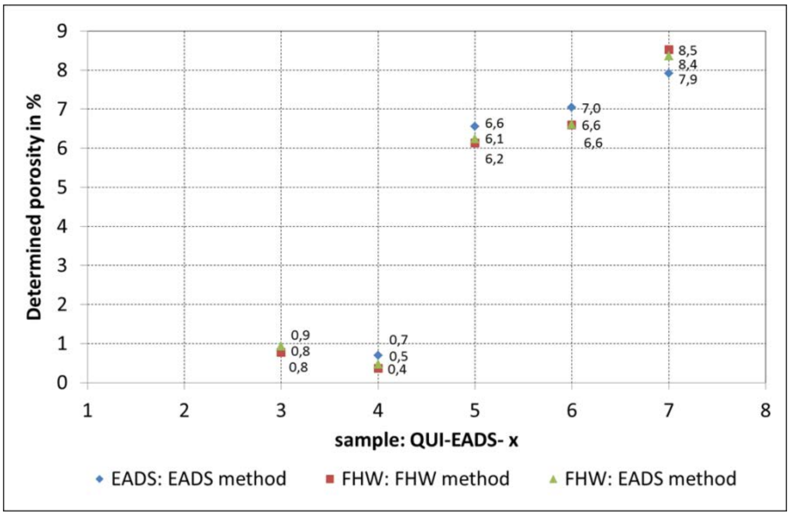


Figure 7: Determined porosity by FHW and EADS at different porosity samples

Porosity determination for selected specimens (036_ECD_P5_PORO-6%, 036_ECD_P5_PORO-8%, EADS 4 neu, EADS 7 neu) where still a discrepancy (between FHW/EADS-porosity values) existed was again performed and compared. It turned out, that the different porosities resulted from the different choice of Region Of Interests (ROIs). These ROIs are applied by the user.
Deliverable D3.2 was submitted in time.

Task 3.2 Delaminations, inclusions, cracks and other voids
The activities of Task 3.2 of the project were mainly focused on development of instrumental radiographic methods for detection of voids and delaminations in CFRP materials. Since the X-ray absorption in these materials is low and volumes of voids and delaminations are very small, the contrast in resulting X-ray radiograms taken with standard flat panel detectors is not often sufficient. Therefore, we used the silicon photon counting detectors Timepix. The contrast in images taken by such detector is defined only by statistical nature of incoming radiation obeying Poissonian statistics. A further benefit of this technology is the energy sensitivity and a very sharp point spread function.
The weak point of technology of hybrid semiconductor detectors was traditionally their small size. This problem was solved by IEAP CTU in 2013 where the first large area photon counting pixel detector WidePIX 10x10 with area of 143 x 143 mm2 was assembled and put into operation. This detector is the world largest device of its type with total 6.5 Mega pixels. This detector was used within the radiographic X-ray systems in Telč and in the laboratory of IEAP CTU.

The problem of the detection of undesired defects of any nature in CFRP samples was solved for three typical cases:

- Voids caused by presence of gas (air) bubbles during the process of curing,
- Disbonding of layers due to lack of resin (this problem is especially critical if occurs between CFRP skin and structured core)
- Delaminations between layers due to mechanical stress or cycling of CFRP structure.

All three cases were solved independently. Besides the detection and visualization of open delaminations using the X-ray CT-technique a very innovative method for the detection of delaminations using X-ray phase effects was developed. This method doesn't require CT scanning and provides a reliable indication of the presence of very thin cracks between layers. The thickness of such delaminations is not relevant, so that this method works even if the crack width is far below spatial resolution of the radiographic system.

Within task 3.2 the proper settings of operational parameters for the detector and for whole radiographic system was realized to reach the best imaging properties for CFRP samples. The modelling of the detector response in X-ray radiographic and tomographic measurements in dependence on various parameters was done by the team of FHW.

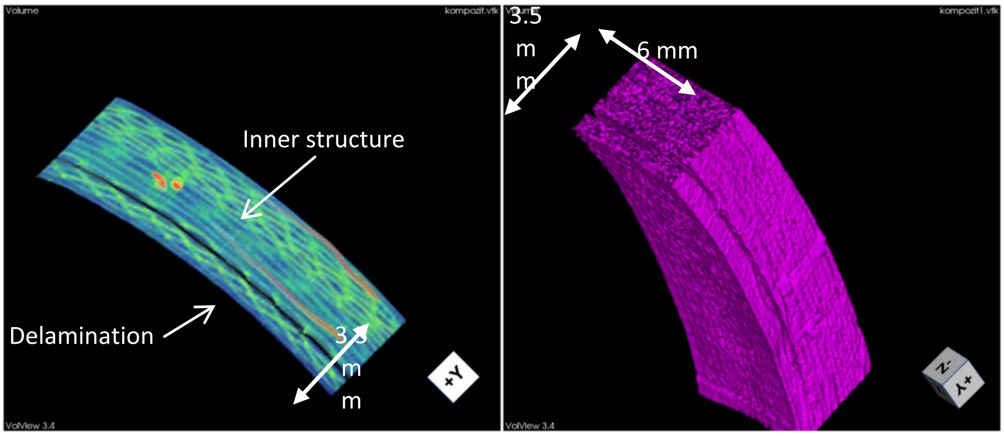


Figure 8: CT reconstruction of the CFRP composite with the delamination

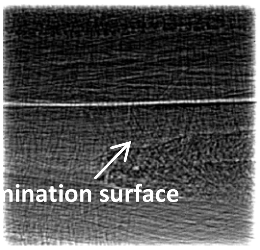


Figure 9: Phase contrast effect on the delamination surface

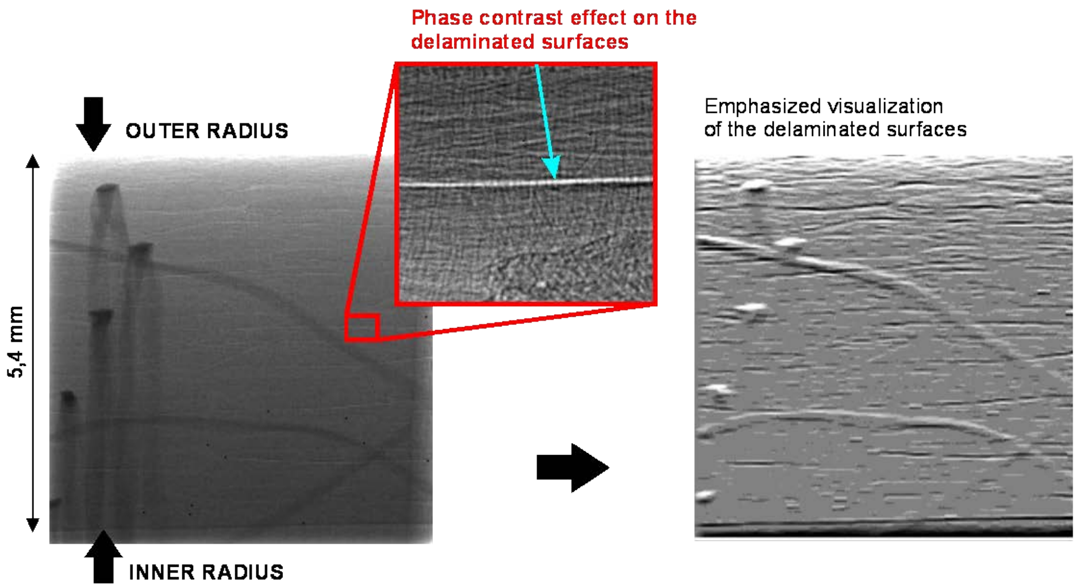


Figure 10: Phase contrast effect on the delamination surface. The concentration of delamination increases toward the outer radius of the curved specimen as can be seen in the filtered image (right).

Evaluation of the coarse porosity inside of the flat CFRP specimens: The porosity in the flat specimens can be evaluated using single high-contrast X-ray radiogram using large area single photon counting WidePIX camera. Since the contrast is very high it is necessary to discriminate the shape of pores from structure of carbon fiber bunches. In many cases the structure of carbon fiber bunches can be suppressed utilizing image processing tools. It is possible especially if these bunches have periodic structure (texture). The porosity is consequently calculated using an appropriate threshold. The resolution of this approach is given by the magnification used during X-ray imaging.
The porosity evaluation using single radiogram was tested with specimens manufactured by LA composite company utilizing large area photon counting detector as follows:

- The radiograms are taken by WidePIX 10x10 camera without magnification (i.e. spatial resolution is 55 µm). Images are processed and linearized using beam hardening correction procedure.

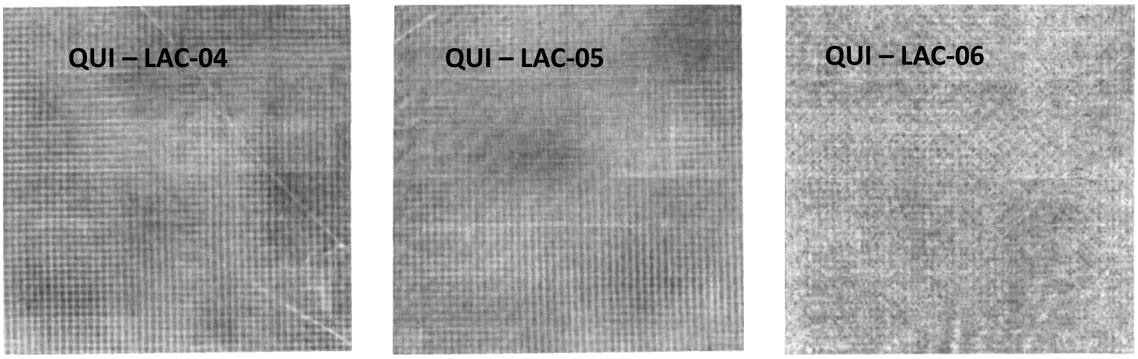


Figure 11: Radiograms of the CFRP sheets (100x100 mm) with significant fiber structure (10 layers, 2 mm thickness). These three samples have different level of porosity. The texture of carbon fiber bunches overlays pores

- Carbon fiber texture is subtracted (performed locally correlating known texture sample in each location) and threshold is applied to separate pores.

Described methodology was applied for three samples with different level of porosity.

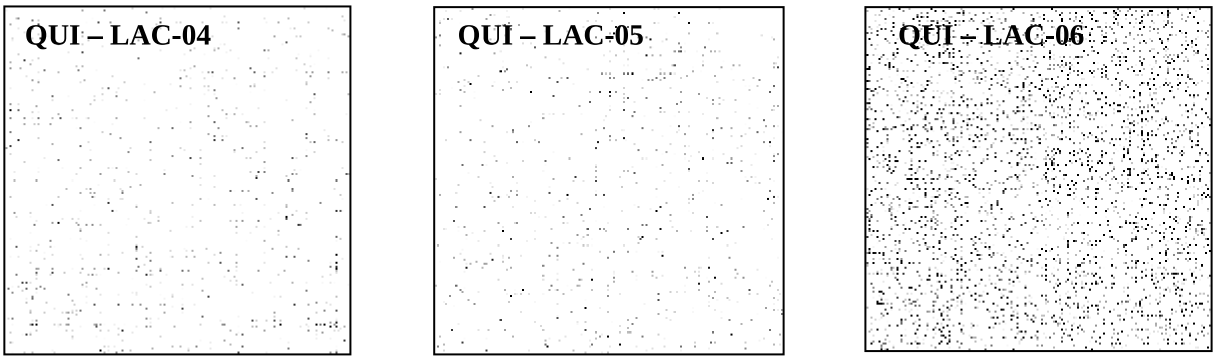


Figure 12: The first two samples have similar coarse porosity of 0.074% and 0.077%, contrary the third sample has ten times higher coarse porosity 0.77 %.

Only coarse porosity was evaluated here as the radiograms were taken with a 55 µm resolution. The same procedure can be used for small scale porosity if higher geometrical magnification would be used during radiography.

Delamination in CFRP structures loaded in fatigue: An angle bar specimen (different from above mentioned) was topographically inspected with following parameters: Voxel size: 24.4 µm; tube at 60 kV and 164 A; 800 projections, 2 sec acquisition time. The Perkin Elmer flat panel detector with pixel size 200 µm and active area 400x400 mm was used. It was proven that the delamination surface can be detected using these parameters. However relatively low contrast 30% is between delamination and surrounding material. This contrast was two times improved (60%), using beam hardening method (J. Jakubek., NIM A 576 223 234, 2007) applied on all CT radiograms.

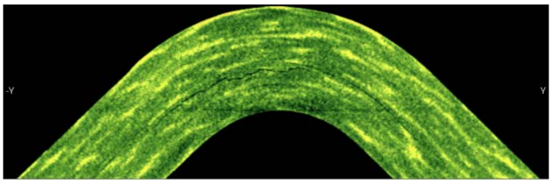


Figure 13: Vertical cross section of the CT reconstruction. Delamination surface is visible with relatively low contrast ~30%.

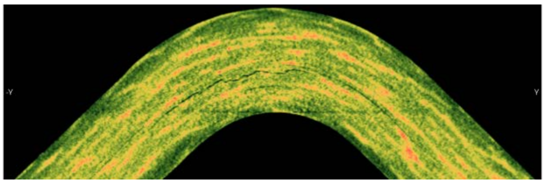


Figure 14: Contrast was almost two times improved using beam hardening correction

The 3D visualization of the delamination is depicted in Figure 15. It is visible that secondary delamination towards inner radius occurred.

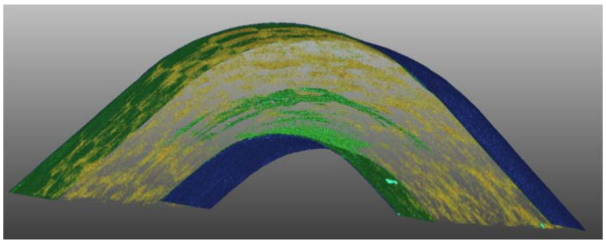


Figure 15: 3D visualization of the delamination surface inside of the angle bar specimen.

Detection of voids caused by air bubbles: Improper parameters of the curing process can cause the presence of gas bubbles resulting into voids in final CFRP composite. These voids have various sizes and often very irregular shapes. CT detection of the voids is standardly based on the evaluation of the local material density. The search of voids is a highly demanding task for composite materials as these are significantly heterogeneous. Voids itself are searched for using a specific voxel density threshold, which has to be lower than minimal density of the healthy material. Obviously this minimal material voxel density should be well bounded to be able reliable define voxel density threshold. Therefore voids can reliably be detected if sufficiently high contrast between voids and surrounding material is available in CT data. Such contrast can be reached utilizing a detector with a very sharp point spread function together with high dynamic range of related radiograms. Besides the point spread function, the minimal detectable void size is limited by the magnification and obviously by the spot size of the X-ray tube. A reliable detection based on tomographic data was tested on three small specimens with different porosity. Specimens were manufactured from 10 layers of the unidirectional CFRP composite. Both the flat-panel Perkin Elmer detector and the single photon counting detector WidePIX were utilized for this test.

CT Measurement with Wide*PIX*$_{10x10}$ detector

The measurement was carried out on two CFRP specimens with dimensions 3.6 x 10.3 x 3 mm. First specimen QUI-LA-69 labelled as reference has lowest possible porosity and second specimen QUI-LA-68 has medium porosity.

Visualization of the QUI-LAC-68 specimen CT reconstruction is depicted in Figure 16. Orientation of the fibre bunches is well visible and contrast between matrix (lighter color) and bunches is high. Two voids passing through whole specimen in the fiber direction are visible in the matrix. Number of microcracks occurred on the one specimen side possible due to specimen cutting.

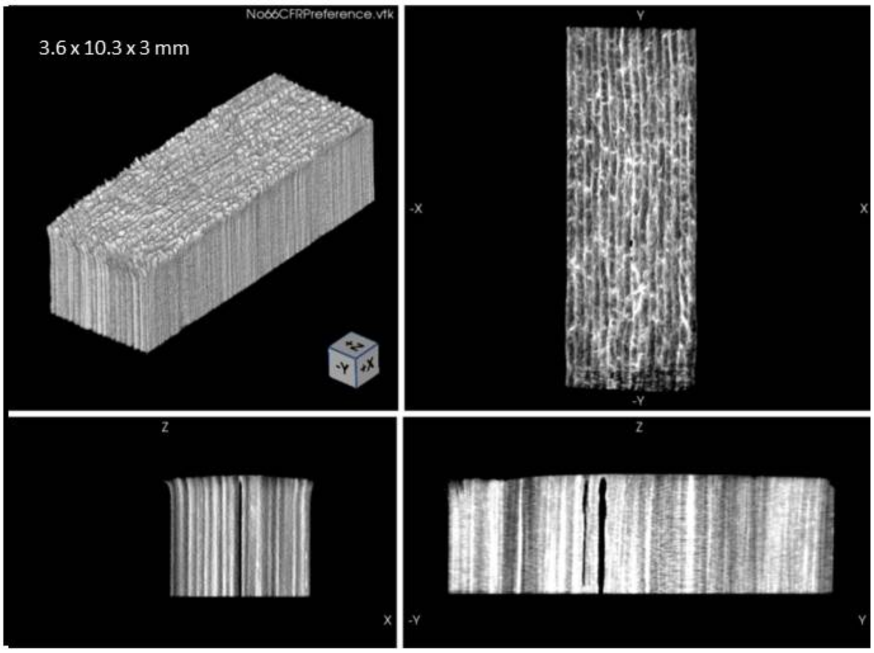


Figure 16: Visualization of the CT reconstruction, reference sample. Lighter color has meaning of the higher density. 3D model top left, XY cross-section top right, vertical cross-sections bottom. Two long narrow voids passing through whole specimen are clearly visible. These voids occurred in the matrix.

Illustration of the evaluation of the specific voxel density threshold is depicted in Figure 17. Voxel density along x direction for each xy slice was plotted into one graph for both analysed specimens; see blue graph for reference specimen and red graph for medium porosity specimen. This calculation was done only for portion of the reconstructed volume (i.e. not all pores are visible in these graphs). Voxel density was normalized by the median value of all voxel densities in these plots. It is clearly visible, that voxel density varies in 250% range. Fortunately the bottom value of the material voxel density is well defined; therefore voxel density threshold could be set on 45% of the median material density. Note, that bottom value of the material voxel density is not dependent on the distance from the specimen surface. It is clear mark, that beam hardening effect was successfully corrected. The bottom threshold of the voxel density depicted by the green line was set on 45% of the median voxel density. Pores detected by this threshold are labelled by the red colour; reference specimen bottom left and medium porosity specimen bottom right. Finally relative porosity calculated has value 0.02 % for reference specimen and 0.22 % for QUI-LAC-68 specimen. Smallest detected pores have 3 voxels diameter, i.e. 42 µm.

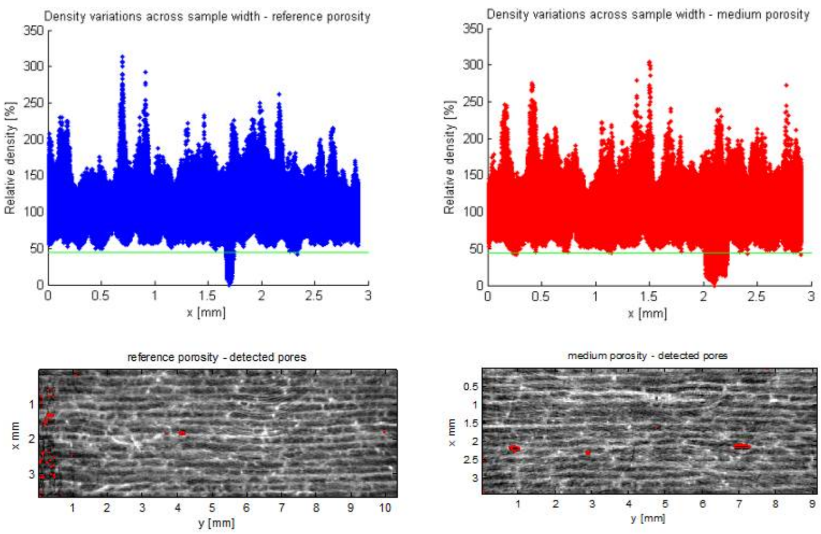


Figure 17: Distribution of the voxel density for reference specimen top left, for medium porosity top right.

CT Measurement with Flat panel detector

The measurement was carried out on the small CFRP 3 x 2 x 2 mm specimen QUI-LA-67 with coarse porosity. The geometry of the CT setup was set to the largest magnification, which was possible to reach with the given sample. The pixel resolution was 2.5 µm. The part of the single slice of the CT reconstruction is shown in Figure 18. The pores in the epoxy matrix are nicely distinguishable (highlighted by green colour). Normalized density profile plotted top right in Figure 18 demonstrates that a decrease from the density representing surrounding material to zero density corresponding to air void needs 3 voxels in average. This implies that the smallest detectable size of a pore is approximately 6 voxels, i.e. 14 - 15 µm.

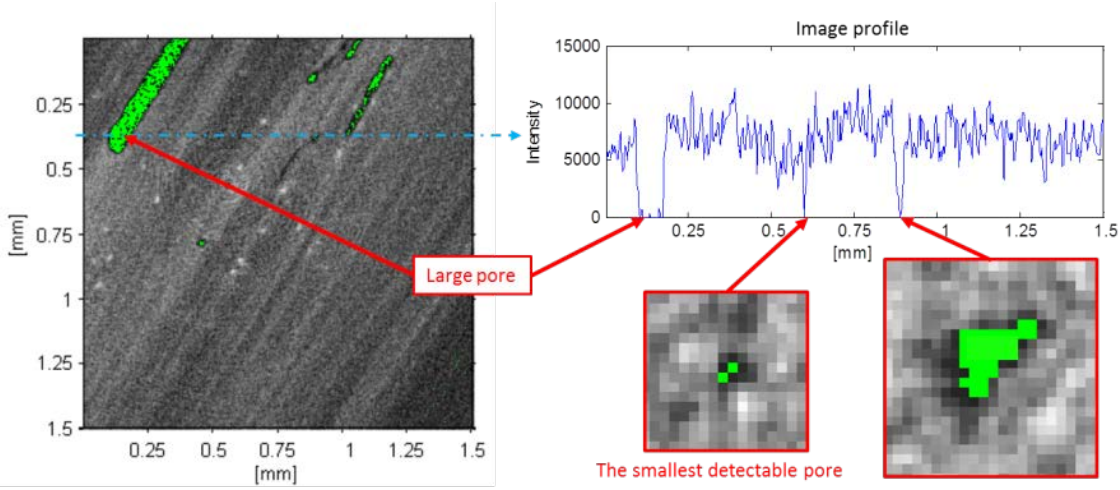


Figure 18: Detection of pores: reconstructed slice left, material voxel density profile top right, detected voids bottom right.

Single shot measurement of absorption, phase and dark field imaging of the delamination

The possibility to use the X-ray micro-radiography technique providing together with the conventional attenuation image also the image formed by phase changes (phase-gradient image) and by the low-angle scattering in the sample (dark-filed image) was evaluated. The advantage of this three-modality approach in the detection of delamination is that both phase-sensitive and scattering images are potentially much more sensitive to changes of interfaces between layers. The dark-field image is furthermore sensitive to object features which are even significantly below the spatial resolution of the

attenuation image. As three independent images are produced, the presence of delaminations or other defects can be compared and correlated in all tree images, which significantly improves the reliability of the method.
The experimental arrangement of the single grating phase contrast method is shown in Figure 19.

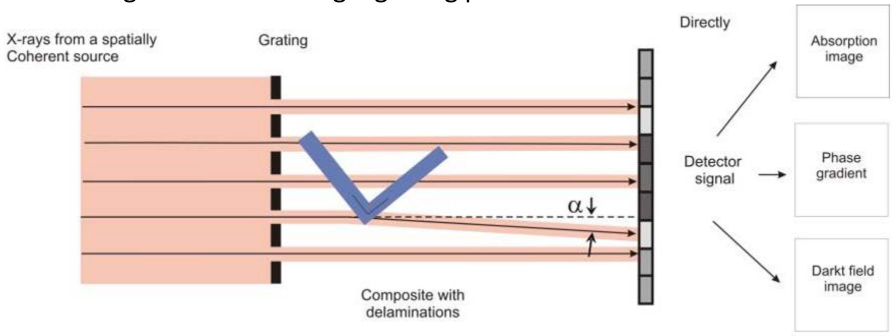


Figure 19: Experimental arrangement of the single grating method applied for the investigation of composite materials.

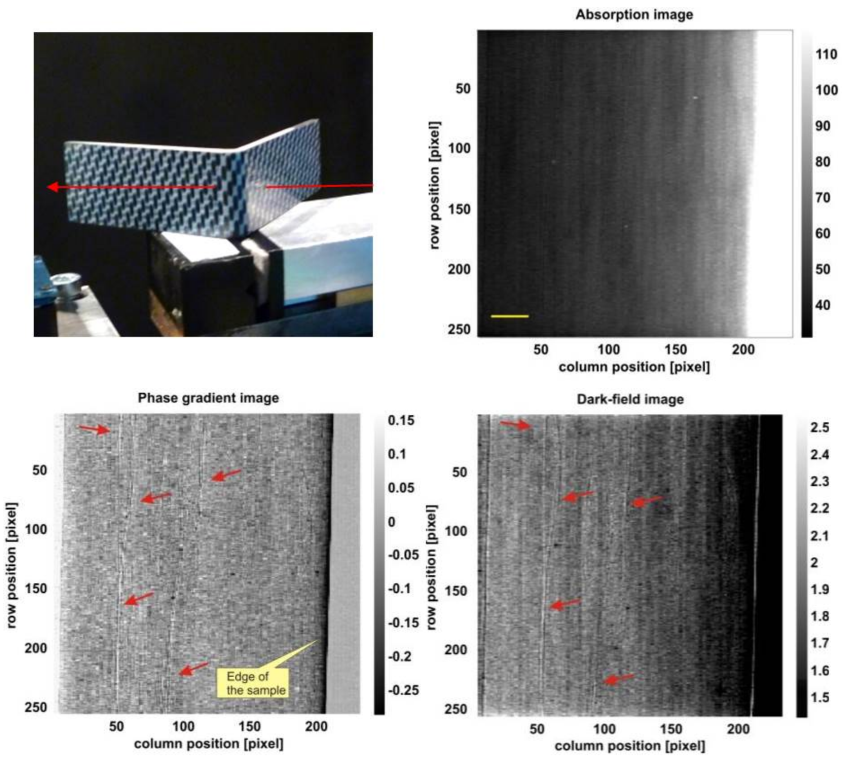


Figure 20: Investigation of the composite material sample by means of three-modal X-ray micro-radiography.

The method provides the attenuation image (top right), the phase-gradient image (bottom left) and the so-called dark-field image (bottom right) showing the scattering ability of the sample to low angles, see Figure 20 for illustration of the three-modal X-ray micro-radiography. One can see that damaged regions are visible especially in the phase-gradient and dark-field images. This fact indicates that the contrast in these suspicions regions is formed specifically by delaminations (rapid changes of refractive index in small hollow spaces). The sample is imaged in the critical (rounded) part in Figure 20.

Voids: For analyzing, exploring and visualizing fibers, voids, cracks and inclusions in fiber reinforced composites (FRPs) FHW has developed a so-called FiberScout[1] tool. With this tool it is possible to classify fibers/voids according to their individual characteristics like shape factor, volume etc. In addition, FHW has implemented an advanced visualization method for analyzing defects (e.g., pores, inclusions, particles, fibers, and cracks) in industrial 3D X-Ray Computed Tomography (XCT) data called MObjects[2]. With this tool it is possible to calculate and visualize the mean shape of pores in the dataset. Moreover, a comparative homogeneity visualization to show the deviation of the average pore has been integrated. At the FHW an additional visual analysis tool to evaluate 4D-CT measurement data is developed. With this tool the extraction of individual features like voids, inclusions and cracks will be possible. Further information can be found in WP7.

Task 3.3 Geometry, orientation and shape of inner structures

Several scans were performed on CFRP, GFRP and steel fibers reinforced plastics on different micro-CT systems and at different settings. The obtained scans are used as input for WP7.

The first analysis was done on fiber orientation using the GFRP scans (results presented in WP7). The segmentation of fibers was tested at first on a sample with steel fibers. An adaptive threshold algorithm was used for the separation on the individual fibers. For the separation of the different CFRP components different smoothing values on the projection images before reconstruction were used. This showed a small differentiation between the resin and the fiber grey values in the histogram, which may lead to the separation of the different structures.

Samples from EADS and LAC were scanned on the SkyScan 1172 and the GE Phoenix Nanotom system available at the KUL and with the RayScan 150 system at EADS. Several tests were done per sample in order to assess the acquisition parameters with respect to the resolution by changing the geometrical magnification or the binning mode of the detector. Furthermore, smoothing the projection or reconstruction images will increase the contrast between fibers and matrix, however, with a trade-off on the resolution. The fiber/matrix ratio analysis method from EADS, using Dual-Energy-CT data works well, but there are additional analyses at samples with different fiber volume fractions needed, in order to validate this evaluation method. The local fiber orientation analysis applied by the orientation evaluation feature in VGStudio MAX, a development from Volume Graphics, works for data with high contrast and clear contours. The sample QUI-EADS-1 has shown that the evaluation algorithms require XCT data with separable roving quality.

Collaboration with other work packages

The goal of task 3.3 was to provide reliable qualitative input data for the analysis of the geometry, orientation and shape of the inner structures of CFRP composite parts (WP7), which will serve as input for the modeling in WP8. Additionally, this analysis will be further compared with the manufacturer specifications of the reinforcement, and deviations from the specifications will be identified (e.g. main direction, yarn crimp). To be able to separate the different CFRP components, to evaluate the fiber/matrix content and local/main directions, and to determine the dimensions and directions of the yarns inside the composite, optimized image acquisition protocols and reliable and robust image processing methods will be developed.

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[1] FiberScout: An Interactive Tool for Exploring and Analyzing Fiber Reinforced Polymers. Johannes Weissenböck, Artem Amirkhanov, Weimin Li, Andreas Reh, Alexander Amirkhanov, Meister Eduard Gröller, Johann Kastner, Christoph Heinzl. In IEEE Pacific Visualization, pages 153-160. March 2014. DOI 10.1109/PacificVis.2014.52.

[2] MObjects - A Novel Method for the Visualization and Interactive Exploration of Defects in Industrial XCT Data. A. Reh, C. Gusenbauer, J. Kastner, M.E. Gröller, C.Heinzl. IEEE Transactions on Visualization and Computer Graphics (Volume:19, Issue: 12), pages 2906 – 2915. December 2013. DOI 10.1109/TVCG.2013.177

1.2.4 WP 4 – Small and high volume parts

Work package 4 had the focus of applying X-ray CT techniques to small and high volume parts. Today, those objects are usually being inspected by ultrasonic testing (UT). This established testing modality is hard or impossible to be applied to complex shapes during production. We examined automated radioscopic testing and computed tomography towards their applicability in high-resolution production integrated testing of CFRP aerostructures. We have developed methods for fast radioscopic testing that result in the necessary quantified results for CFRP parts and methods for very fast high-resolution CT and image processing.
The work is structured in three tasks: T4.1 deals with the examination of aspects of different acquisition protocols and parameters by simulation. T4.2 covers acquisition and data processing methods for the fast process integrated radioscopy and T4.3 focuses on fast process integrated XCT and data processing.

Fulfilment of the project work plan

The work plan of WP 4 has been fulfilled. Deliverables 4.1 and 4.2 have been delivered in time. D4.3 was delayed, because during the 6th general assembly meeting, it was decided to postpone this report in order to integrate latest scan results. Nearly all of the planned aspects within the individual tasks have been investigated. In task 4.3, it has been decided not to treat a tomosynthesis acquisition protocol due to the geometry of the selected target specimens, the thermoplast clips. Spectral CT has been applied only at lower resolution due to equipment reasons. The database for fast clip inspection was rather small with four parts and unfortunately no clips with representative delaminations were available for the project.

Scientific and technical results

Task 4.1 Optimization of the scanning protocol

In cooperation with work package 6, an X-ray simulation framework has been established out of three tools (XRayImagingSimulator, Scorpius XLab® and Sindbad), which allows widespread simulation and thus optimization of the geometrical and spectral properties of radioscopy, tomosynthesis and CT setups without the need of their physical presence. Different models of small high volume CFRP parts were created, simulating laminar and woven structure (Figure 21). Additionally different types of defects like porosity, delaminations, lack of resin and inclusion of different materials were modeled using geometric primitives and in form of STL surface descriptions. X-ray imaging properties have been incorporated for focal spot size and modulation transfer function of the detector. By spectral simulation we have been able to take into account the tube spectra and energy dependent quantum efficiency of the detector. Stacks of simulated projections with user defined energy bins have been produced in order to investigate performance of multispectral imaging. Simulation experiments with the generated models provided highly realistic simulation results as shown in Figure 21.
The framework was applied to derive theoretically optimal tube voltages for the target materials, suitable energy bands in dual energy mode and to study variations of the acquisition protocols. Especially the determination of the number of necessary projections for fast multi-clip CT and the evaluation of the artifacts induced by the opening angle in conventional cone beam CT were of great value (Figure 22). Thereby, task 4.1 provided valuable information for the experimental tasks 4.2 and 4.3.

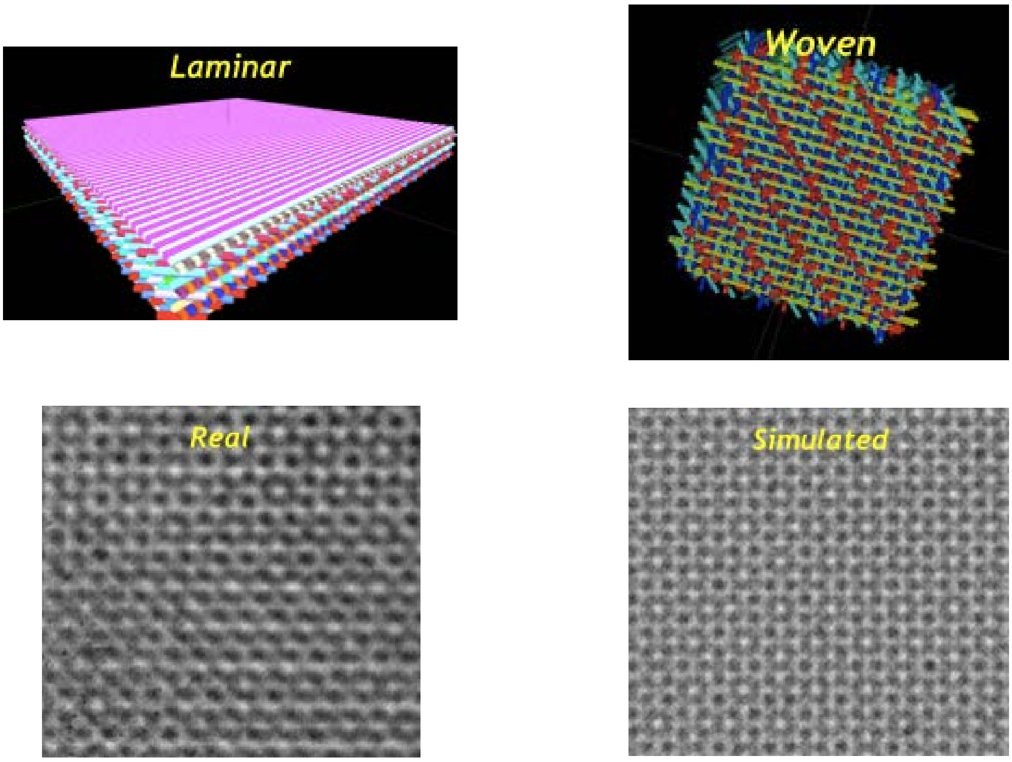


Figure 21: CFRP models of laminar and woven structure (top), comparison of real and simulated projection image (bottom)

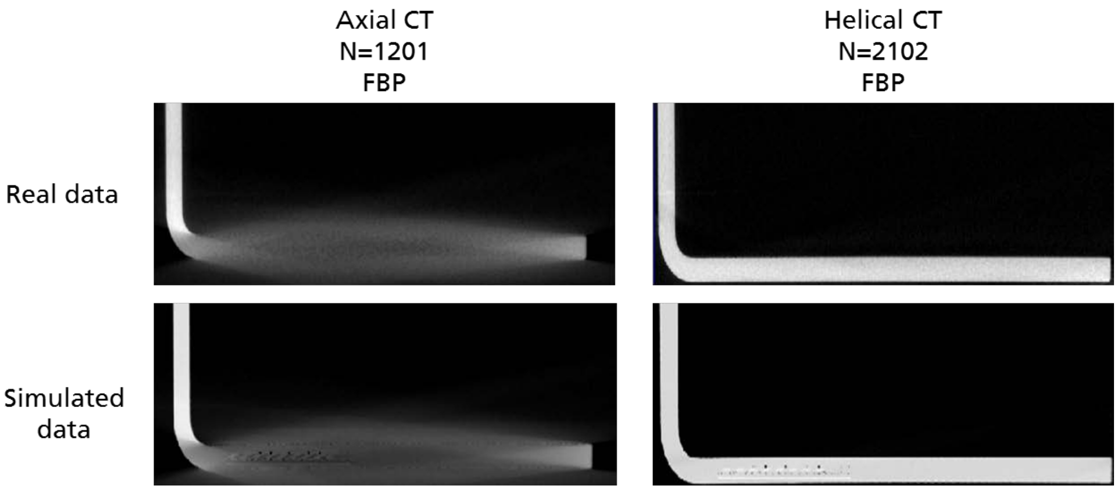


Figure 22: Scanning protocol comparison of simulated and measured helical and axial CT of a clip showing the deficiency of an axial cone beam trajectory and the significance of the simulation framework

Task 4.2 Fast process integrated radioscopy

High sensitivity of today’s X-ray detectors allows the detection even of very slight inhomogeneities within the inspected parts. This is why the very fast radioscopic methods are an important option for near production inspection for a particular subset of defect classes. Within task 4.2, possibilities and limits of radioscopic imaging were investigated with respect to the industrial samples defined in work package 2. Except for delaminations oriented orthogonal to the main beam direction, radioscopic imaging is sensitive to all relevant defect classes.

A first study on automated defect recognition has been executed with an industrial robot moving the object to all necessary testing positions in overall less than 15 seconds (Figure 23). The experiments have shown that a large portion of the existing defects could be visualized with good contrast. Even simple approaches like median based background subtraction showed good results with respect to the detection of inhomogeneity. Dual and multi energy approaches have been investigated in order to narrow down the foreign material identification. In this context, scatter contribution in projection data has been quantified in order to optimize material sensitivity of the calibration step.

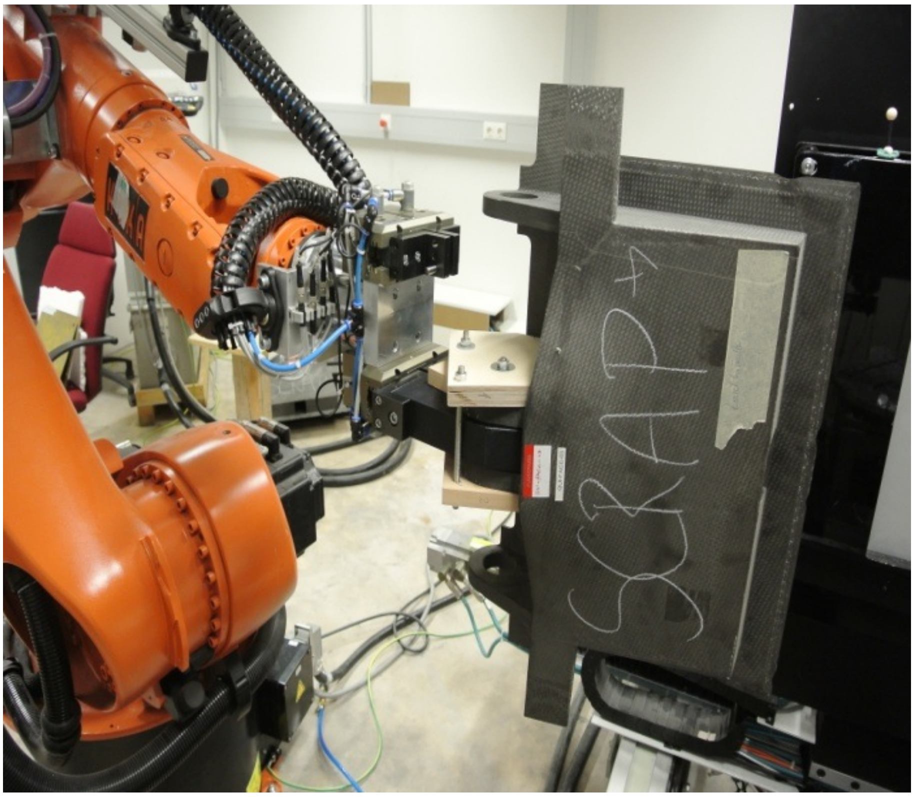


Figure 23: Automated radioscopic testing of one Centre Hinge Fitting

A second study on automated reference based defect recognition has been successfully performed and applied to center hinge fittings from FACC. Using a CFRP gauge, a calibration of image intensity to material thickness has been performed in order to quantify the defects. A specific post-processing of the reference based projection data transforms the results into a representation similar to a ultrasonic C-scan that is more familiar to UT testing personnel. The volume porosity of the inspected region has been determined to amount between 0.5 and 1.5 percent (Figure 24). A validation of the regions of interest has been performed using MicroCT scans of samples cut out of the original object. The evaluation showed an excellent accordance to the radioscopic values. With acquisition times below one second, the principle of a very fast radioscopic inspection method has been proven capable of quantifying volume porosity.

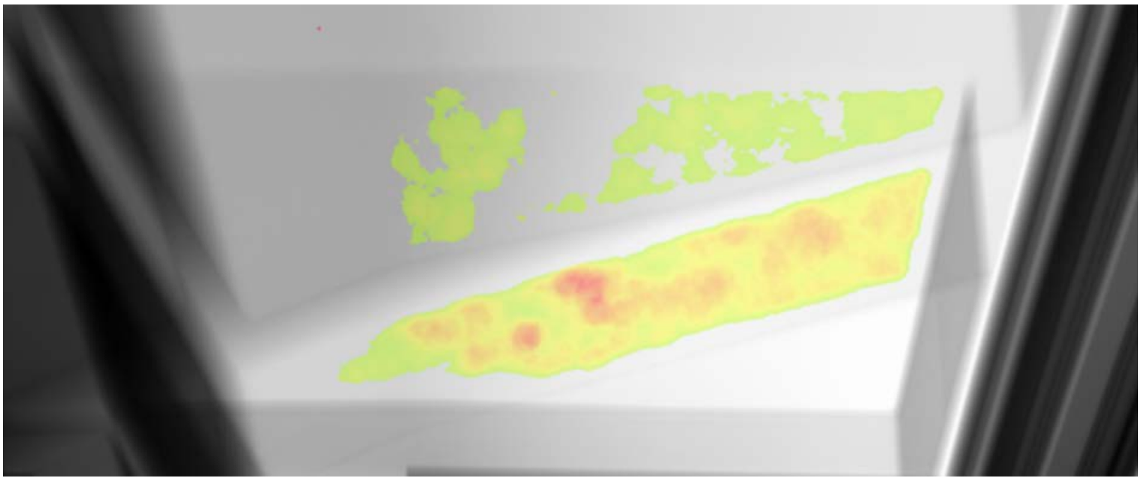


Figure 24: Fast radioscopic volume porosity estimation: volume porosity is annotated from green 0.5% to red 1.5%

Task 4.3 Fast process integrated XCT

This task targets fast 3-D scanning of whole parts at the highest possible spatial resolution, with the ultimate aim of an inline quality control of parts in series production. Different studies have been performed in order to evaluate the potential for application of specific fast CT methods. Base studies were carried out in order to validate the defect sensitivity on standard CT setups with detector matrices of 2k × 2k pixels against the results of ultrasonic testing. This has successfully been performed for the set of four available clips out of thermoplast CFRP with dimensions in the range of 300mm · 150mm · 100mm. This setup allows a reconstructed voxel size of approximately 100 µm and acquisition and reconstruction times of roughly five minutes per scan which corresponds to a scan time of one minute per clip in multi-clip mode (Figure 25). All of the existing defects could be displayed in this configuration.

Figure 25: Volume rendering of one multi-clip CT scan with four clips

For the assessment of the local reconstruction quality of specific CT configurations, a data processing pipeline has been proposed which permits the extraction of statistical features out of specific geometric regions of the individual clips. This processing chain can also be used as a basis for a later automated evaluation of the CFRP quality concerning porosity, foreign inclusions, surface roughness or geometrical properties.

Based on those first experiments and the findings from the simulation studies, a set of investigations for an optimized setup using one specific helical multi-clip configuration has been performed. Most of these investigations have been performed on the new MicroCT setup of Fraunhofer EZRT, which allows to image large parts at very high resolution due to its flexibility and long axes. The tests included the use of medical high power tubes and new high resolution detectors with 4k × 4k matrices, which allow scan times of five to ten minutes per clip at a voxel size of approximately 50 µm resulting in excellent image quality (Figure 26). However, due to the enormous data volume, a pace keeping reconstruction is not available up to date. For the future, a further increase in resolution towards 25 or 30 µm voxel sizes is wanted in order to be able to also detect delaminations with openings in the range of 10 µm. Therefore, a new generation of reconstruction algorithms will be necessary.

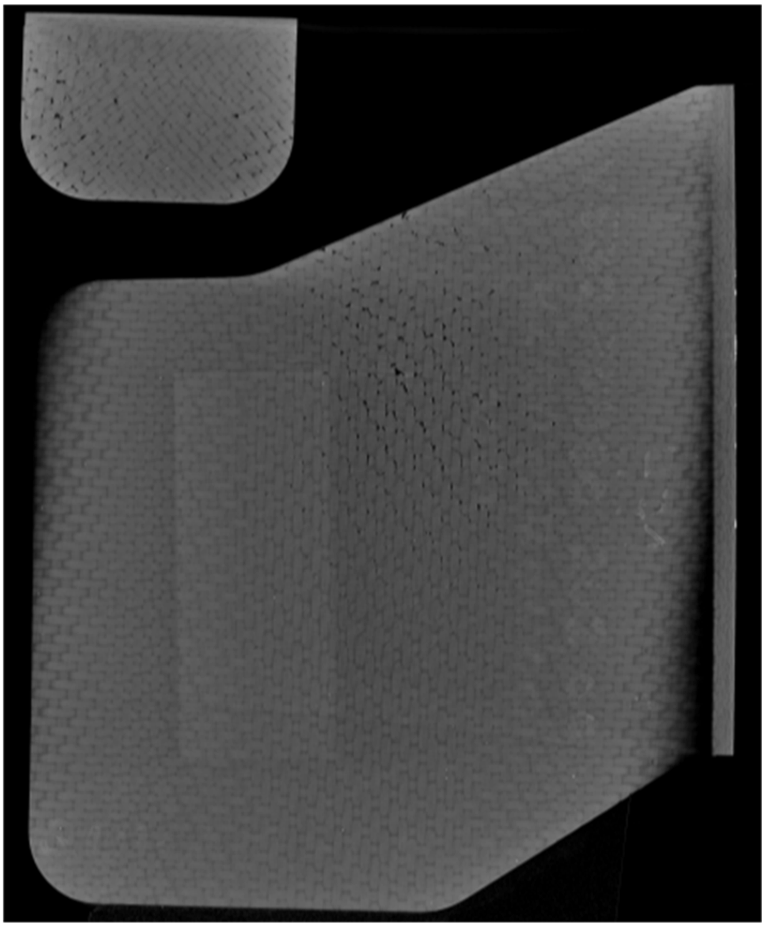


Figure 26: High resolution CT scan of a complete clip at 43 µm voxel size clearly showing the resin poor areas also indicated by UT as well as a good contrast between fiber bundles and matrix

Collaboration with other work packages

There has been intense collaboration work package 6, where a common simulation framework has been set up. Also the new Tomosynthesis MicroCT system has been intensively used by both work packages. The samples for the investigations were provided by partners from work package 2. Parts of the data evaluation chain for clips have been implemented in work package 7. Data for the inline clip processing demonstration have been provided to work package 9.

1.2.5 WP 5 – Composite metallic parts

Fulfilment of the project work plan

Task 5.1: Methodology for composites with metallic inlays

The task 5.1 was focused on the characterization of light-weight, fibre reinforced plastic composites (CFRP or GFRP) combined with metallic inlays. Such material combination solves disadvantages connected with CFRP and GFRP non-conductivity. Identification of the defect as for instance disbonding and porosity was performed by CTU (X-ray methods), FHW (Multi material X-ray simulations) EADS and LAC (fabrication of samples with defects).

It was proven, that several types of imperfections can be detected and analysed using single X ray imaging and consequent enhanced data processing and analysing. This approach can be advantageous especially for honeycomb structures with Cu mesh on the top, where scanning of relatively large flat parts is possible. It was documented that CT reconstruction of materials composed from materials with significantly different attenuation requires more sophisticated approaches than standardly used. Appropriate beam hardening correction linearizes data and improves contrast in the reconstructed volume. Consequently reliable global threshold can be defined for searching of the pores. In the case of the Cu grid, utilizing single photon counting detector energy threshold above Cu K-line suppress deterioration of the Cu on the CT reconstruction. Simulation was helpful for choosing of the right energy threshold or energy bands to obtain best possible CT reconstructions. Employed single photon counting detector improves contrast and detectability of the small pores. Boundaries of the small pores are deteriorated in the case of the flat panel detector type due to properties of the detector scintillator.

Task 5.2: Methodology for sandwich structures with metal core

Task 5.2 was focused on the characterization of honeycomb sandwiches with metallic honeycomb core and CFRP skin. Specifically, aluminium cores are considered due to their best strength to weight ratio and excellent impact resistance. Identification of the defects as for instance disbonding and porosity were performed by CTU (X-ray methods), FHW (Multi material X-ray simulations) and LAC (fabrication of samples with defects). Disbonds between core and skin have crucial influence on the structural integrity of the sandwich plate. Porosity in the CFRP skin is also parameter which has to be analysed.

It was proven that disbonding can be successfully resolved utilizing so called Dual Energy Computed tomography method (DECT) even if the reconstruction object is not in optimal position in respect to direct 3D visualization of such disbonding, see Figure 27.

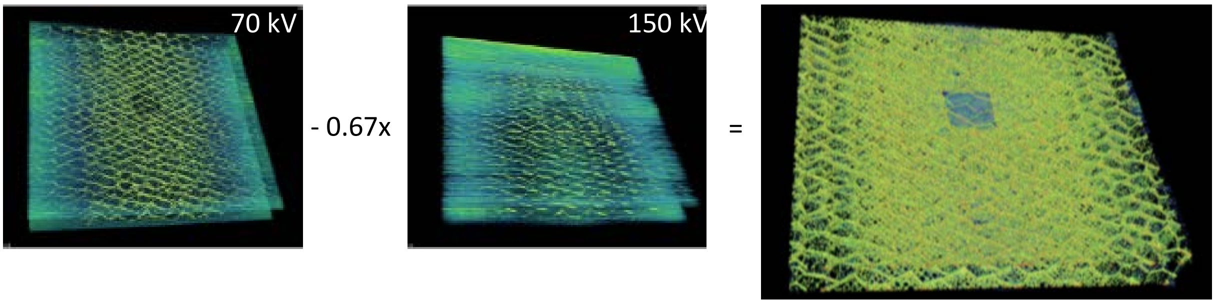


Figure 27: WP5.2.1: Disbonding area is almost invisible in 3D utilizing standard reconstruction at different tube potentials left and middle. Enhanced visualization of the artificial disbonding which is well visible right, even in the 3D.

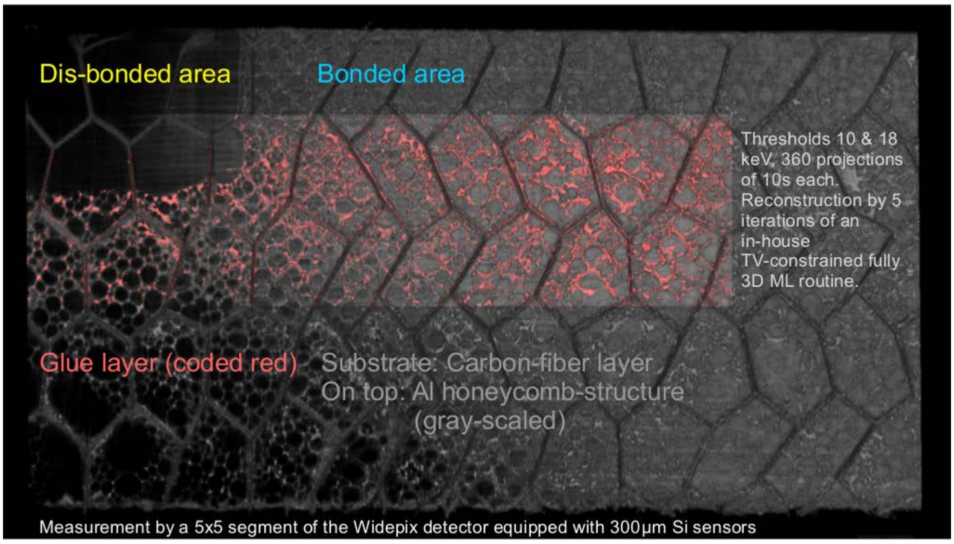


Figure 28: Gray-scaled rendering of the reconstructed volume (20 transversal layers were used). Within a rectangular area the rendered volume was overlaid by the material-decomposed data (coded in red). The glue is clearly isolated from the other constituents of the volume.

Experimental work time was dramatically reduced thanks to numerical simulations provided by FHW as right choice of tube potentials and X-ray beam prefiltering has crucial influence on DECT quality. For instance, it was shown that low and high tube potentials have to be as much different as possible with respect on the detector efficiency and image contrast. It was shown that porosity in the honeycomb skin can be reliable detected thanks to the suppressing of the surrounding material utilizing DECT tools. It was proven that disbonding can be resolved even in the single radioscopy utilizing high dynamic range data acquired by the single photon counting detector. Lastly a clear separation of the glue-layer has been achieved by means of material decomposition, see Figure 28.

Task 5.3: Methodology for metal fasteners jointing related composite parts

The WP5 is focused on the characterization of light-weight, fibre reinforced plastic composites combined with metal fasteners. Advanced X-ray radiography methodologies utilizing Dual Energy Computed tomography tools as well as high dynamic range radioscopy and high resolution tomography based on single photon counting detector were developed to be able identify flaws which are standardly shielded by the metal artifact effects. Identification of the defects, namely disbonding, porosity and cracks, were performed by CTU (X-ray methods) and LAC (fabrication of samples with defects). Results were compared with benchmark measurements based on X-ray phase contrast imaging provided by the subcontractor (CSEM).

Identification of the disbonding due to lack of resin in tested specimen was influenced by the metal artifacts as well as beam hardening effect caused by significantly different attenuations (CFRP, Cu mesh, steel). It was proven that it is almost impossible identify disbonding area utilizing standard tomography, however disbonding area can be clearly identified utilizing DECT tools, see Figure 29. Disbonding was also successfully identified utilizing grating based X-ray phase contrast imaging (XPCI) technique provided by the subcontractor, although image contrast was rather low. Delamination presented in another specimen was fully identified utilizing iterative tomographic reconstruction employing single photon counting detector. It was proven, that this delamination is visible also utilizing standard filtered back projection reconstruction but results are quite noisy and delamination is not well visible. The same specimen was inspected utilizing XPCI technique - it was proven that delamination is detectable but partially only.

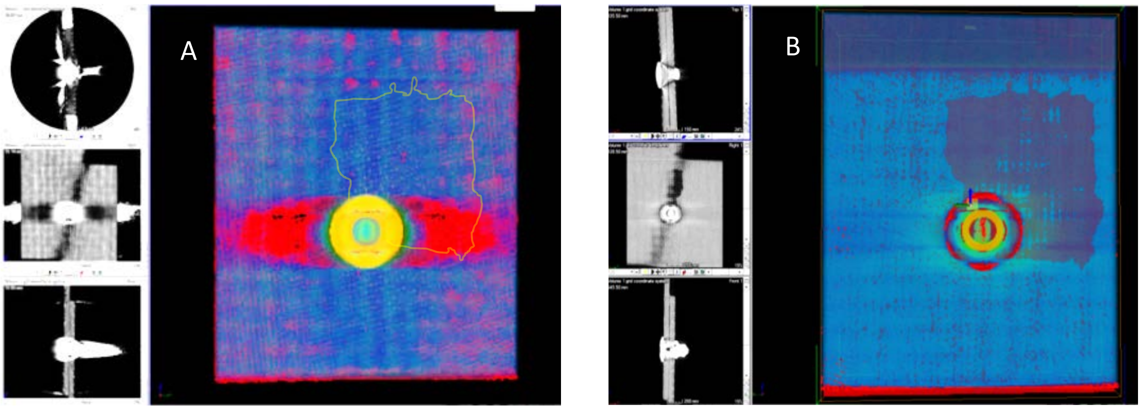


Figure 29: Visualization of the CT reconstruction: A – standard CT reconstruction, no evidence of the disbonding (its expected area is marked by the yellow line), strong metal artifacts; B - visualization of the image based DECT data, disbonding area is clearly visible, metal artifacts disappeared.

Crack and needle shape voids were successfully identified in other specimen utilizing both iterative tomographic reconstruction and XPCI technique. Similarly as for other specimens, XPCI technique gives results within relatively short measuring time moreover, contrast is good. Obviously, spatial shape of the crack and distribution of the voids can be obtained tomographically only.

One can conclude that all inspected flaws were successfully identified and visualized utilizing advanced X-ray methodologies.

Scientific and technical results

Dual Energy CT technique targeted to identification of flaws was successfully developed and validated for various samples with support of numerical simulations.

Utilization of the single photon counting detector with spectroscopic capability was successfully tested on various samples.

An advanced radioscopic method for the identification of the disbonding area between skin and core of the honeycomb structure was developed and successfully tested. This method is advantageous especially for scanning of large sandwich structures.

A new method for the correction of the tube spot movement was developed within this work package. This method allows reliable identification of pores especially for computed tomography with micrometric scale resolution.

The results were presented on several conferences: International Workshop on Radiation Imaging Detectors, Conference on Industrial Computed Tomography, International Workshop on Aerostructure and Digital Industrial Radiology and Computed Tomography.

The results were and will be published in the impacted international Journal of Instrumentations.

Collaboration with other work packages

Newly developed method for correction of the tube spot movement was utilized for evaluation of the porosity within WP7. DECT method for the identification of the area with a lack of resin was employed as software demonstrator within WP9. Results of this work package were presented in several ways within WP10.

1.2.6 WP 6 – Complex and large parts

Work package 6 had the focus of applying X-ray CT techniques to large and complex parts. Those large objects were not yet able to be inspected by regular CT methods. This is either due to their sheer size that does not allow using regular CT systems for these objects or due to the material thickness that results in high penetration lengths and by those strong artefacts in the CT images. We examined existing and developed new methods for the application of X-ray computed tomography with these kinds of aeronautic objects. One main focus of this work package has been the further development of robot based computed tomography.
The work is structured in three tasks: T6.1 deals with the examination of aspects of different acquisition protocols and parameters by simulation. T6.2 covers acquisition and correction methods for the testing of thick objects and T6.3 focuses on the robot based XCT.

Fulfilment of the project work plan

The three different tasks of this work package had to be reported upon within individual reports. Robot based CT was chosen as one highlighted result for the final demonstration of the project and thus the RoboCT demonstration had to be reported separately in D9.3. All four detailed reports have been provided documenting the fulfilment of all items of the work plan. D6.1 on simulation and D6.2 on the testing of thick parts have been delivered in time. D6.3 and D9.3 on the work on and demonstration of the robot based computed tomography have been delivered with some delay. We decided to postpone them since the robot based NDT system at FACC became available and promised significant results that should not be missed in the final reports. Unfortunately, no multispectral approach could be implemented within the RobotCT setup due to lack of the respective equipment. Within task T6.3, the RobotCT approach has successfully been transferred from FHG lab setup to first experiments with the industrial robot setup at FACC, which has not been foreseen in the original work plan.

Scientific and technical results

Task 6.1 CT Simulation for optimal acquisition scenario
A simulation framework was implemented commonly with work package 4. Here, it was used mainly for planning and preparation of the proper X-ray acquisition parameters. Three different X-ray imaging simulators and four different CFRP phantoms (Figure 30) were used to examine different imaging modalities. Results have been quantitatively evaluated using figures of merit and could clearly demonstrate the potential of these X-ray imaging modalities in NDT of large CFRP aero structures. Realistic phantoms were modeled based on real parts provided by project partners using dedicated modelling modules. Apart from the computational wing model, the model of CFRP structure (developed for the purposes of task 4.1) was used to compose individual ROIs with defects that were afterwards examined using different techniques. Additionally, a first insight about the influence of calibration misalignments on the reconstruction quality was gained by studying some typical cases. Especially in the case of the tomosynthesis spar inspection of the multi-spar flap, the simulation tool gave valuable indications for the subsequent scans. Investigations showed that defects can still be visualized at a certain degree even with small angular acquisition angles. This result provides an alternative approach especially during scanning of large parts like the wing of an airplane where the limited accessibility is of importance. Similar observations and results were found in the case of misalignments in the acquisition trajectory. The newly proposed surface estimation approach from marker scans has been prototyped by using simulated data. Later, it could be applied successfully to the true X-ray scans. A simulation component is also part of the OptimiCT tool which was applied to reduce reconstruction artifacts in case of strongly absorbing thick CFRP parts.

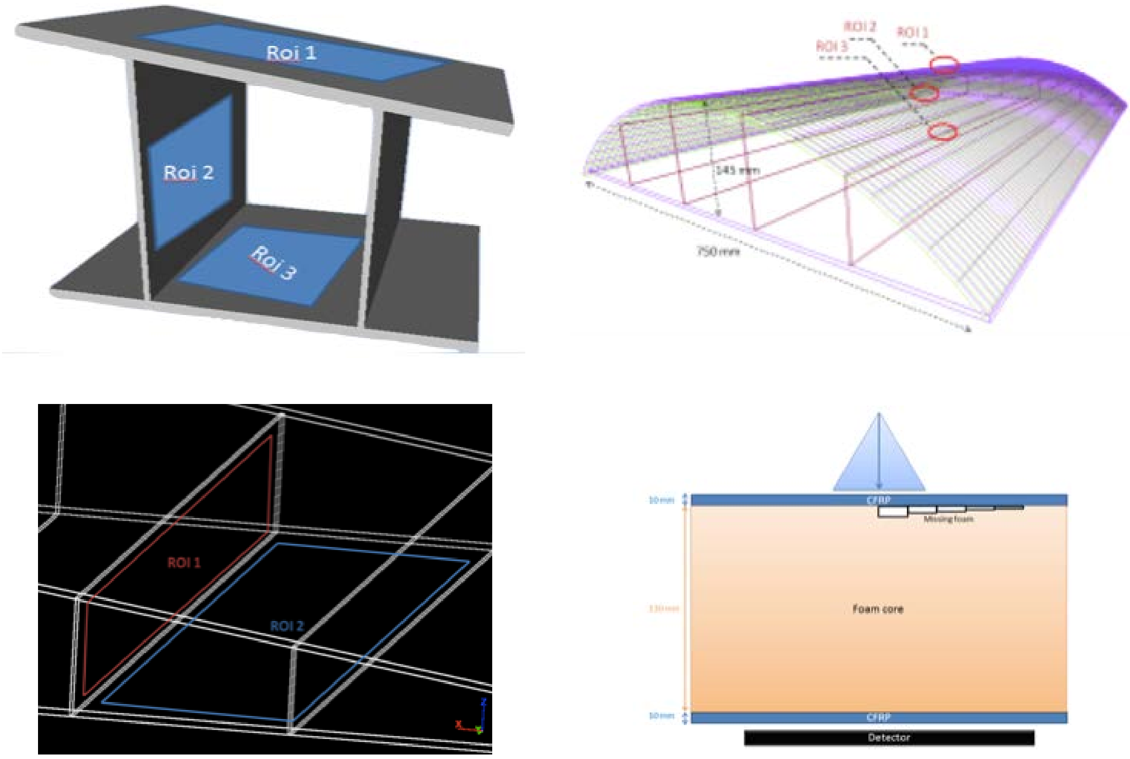


Figure 30: Four generated phantoms based on real parts provided by project partners

Task 6.2 Testing of thick parts

We examined acquisition protocols and correction methods for the inspection of large and thick parts. A large amount of these measurements became possible with a new MicroCT system that was taken in operation by Fraunhofer EZRT. This system (Figure 31) is equipped with a microfocus tube with very small focal spot and varying X-ray detectors with e.g. 100 µm pixel pitch on a 4096 × 4096 matrix. This enables us to perform highest resolution MicroCT acquisitions with down to sub-micrometer voxel sizes. The very long manipulation axes for object, source and detector allow acquiring helical scans or vertical measurement stacking for large CT scans of vertically long objects and measuring field extension for objects with large horizontal diameters. Long horizontal and vertical axes for source and detector allow acquiring highest resolution tomosynthesis scans of large semi-planar objects (i.e. objects with a high aspect ratio).

QUI-AIR-01 is a CFRP fitting for the airplane’s vertical tail plane (VTP). The massive CFRP component (Figure 32) measures 330 mm · 450 mm · 40 mm with a thickness of up to 30 mm. The UT testing personnel found the indication for a delamination in the ultrasonic C-scan. We applied high resolution CT both of the whole object and the region of interest (ROI) of the delamination and algorithmic methods for artefact reduction. We were able to detect the void in CT images with 25 µm voxel size. Figure 32 shows the delamination in the UT C-scan and in slices from the final CT image. The delamination could clearly be visualized in the CT images. Computed tomography has shown to provide additional information on the defect in terms of its geometry in shape (Figure 32 bottom) and depth in the material (Figure 32 middle). One can clearly comprehend how the delamination forms along the structure of the CFRP’s fiber bundles.

QUI-AIR-02 is another, much thicker CFRP fitting measuring 410 mm · 150 mm · 75 mm with an almost constant thickness of 75 mm (Figure 33). The UT C-scan does not allow to reason for any inner structures or defects due to the material thickness and thus, there is no established NDT method available for testing of such objects. CT of this specimen implies penetration lengths of up to 200 mm of massive CFRP. This results in long acquisition times and strong artefacts from scatter and beam hardening which have drastic impact on the resulting image quality if uncorrected. We performed acquisitions with a MicroCT system (Figure 31) at 225 kV and down to 56 µm voxel size and compared these to scans on the

MacroCT system with a new 600 kV X-ray source with strong prefiltering at 170 µm voxel size. We applied algorithmic techniques for the correction of beam hardening and scatter artefacts. In the final MicroCT scan, we acquired a CT image of the whole object at 100 µm voxel size. We were able to correct for the artefacts without having had to apply very strong prefiltering (and such without extremely long acquisition times). Figure 33 shows a slice through the CT image. The composite structure of the material can be recognized and we could detect some microscopic voids that were completely invisible to UT.
We used the new MicroCT system to prove the feasibility of high-resolution CT on very large objects with QUI-AIR-03 (Figure 31). This specimen is a CFRP flap in integral construction technique with inner spars that cannot yet be tested by established NDT methods. We applied a combination of multiple techniques for the enlargement of the CT scan volume to perform the largest known MicroCT acquisition, at all. Horizontal measuring field enlargement by a factor of three gave us a scan diameter of 855 mm at 66 µm voxel size. Vertical measurement stacking allowed to precisely combining seven individual acquisitions to one CT image of 1120 mm height (Figure 34). In full resolution, the CT image has a data size of 4.18 TiB. For easier handling we reconstructed only the bounding box region of the object at a lower resolution of 264 µm resulting in a CT image of 67 GiB. Figure 35 compares the indication from a manual UT scan of one inner spar with the CT slice from this large volume CT. One can clearly see cracks in the composite structure, probably due to a lack of resin, and some surface contamination. Whilst region and dimensions match the indications from UT, the CT image provides much better information on the kind and geometry of these indications. If necessary, full CT is even applicable in production where the object is completely inaccessible for UT testing.

Figure 31: Tomosynthesis MicroCT system at Fraunhofer EZRT with QUI-AIR-03

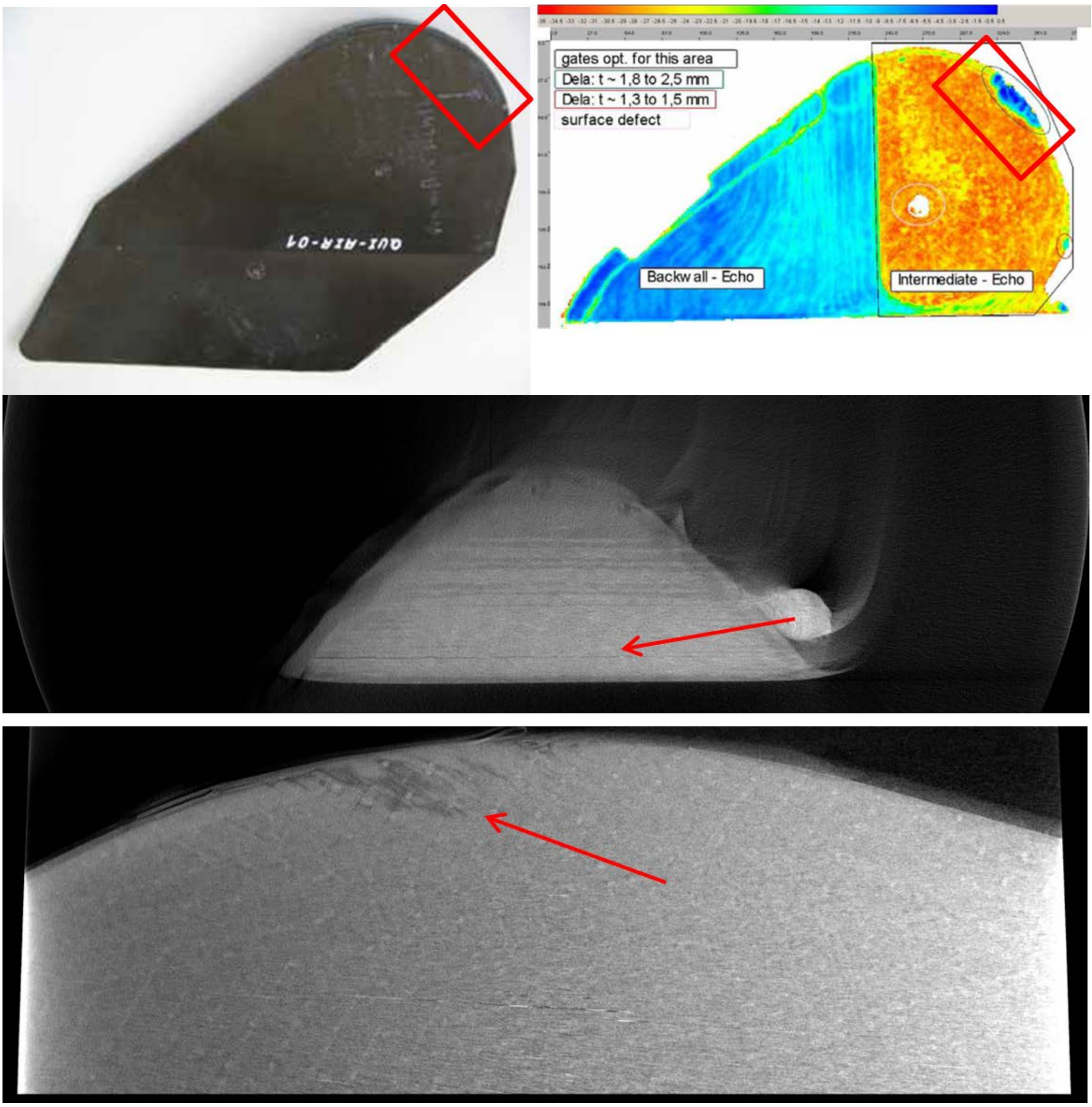


Figure 32: QUI-AIR-01 with UT indication for a delamination (top), CT image of the affected ROI with delamination: slice orthogonal to the surface (middle) and slice parallel to the surface (bottom) through the delamination

With the same system, we acquired a high resolution ROI CT of this indication. The scan covers a region of 158 mm · 158 mm · 129 mm around the spar's indicated location at 40 µm voxel size. Figure 36 shows one slice of the CT image with the same structures already described for the large volume CT scan – but with much higher level of detail. This acquisition serves as ground truth information for the evaluation of the RoboCT scans.

Acquisition of CT images in an industrial production environment often does not allow nor require the acquisition of such complex scans due to time constraints or the accessibility of the object. Limited information acquisition protocols were examined with laboratory CT systems and RoboCT. These acquisitions provide three-dimensional CT images with missing in-depth information which leads to unknown orientation and curvature of the material layers in the CT images of CFRP components. We developed and examined methods to compensate for these effects. We estimate the object surface from an additional acquisition with applied surface markers and use this information to regularize the missing information in algebraic reconstruction and to reproject the CT image to the curved shape of the object. Figure 37 shows a regular tomosynthesis image of the skin of QUI-AIR-03 on the left and the same slice after incorporation of surface information. The material layers became parallel to the image slice and porosity in the material becomes visible only after correction.

Figure 33: Thick fitting QUI-AIR-02 (top) and CT slice with composite structure and some void within (bottom)

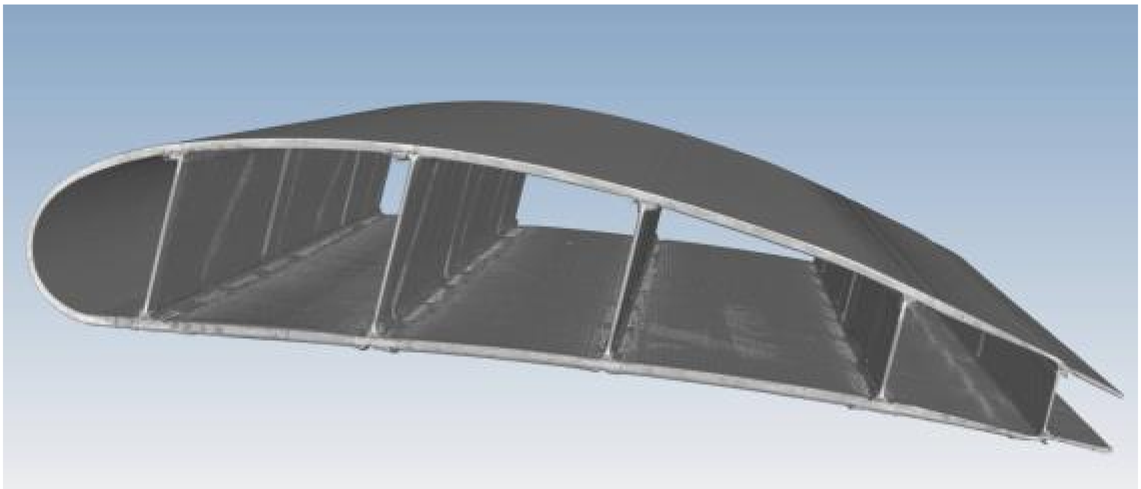


Figure 34: Volume rendering of the large volume CT of QUI-AIR-03

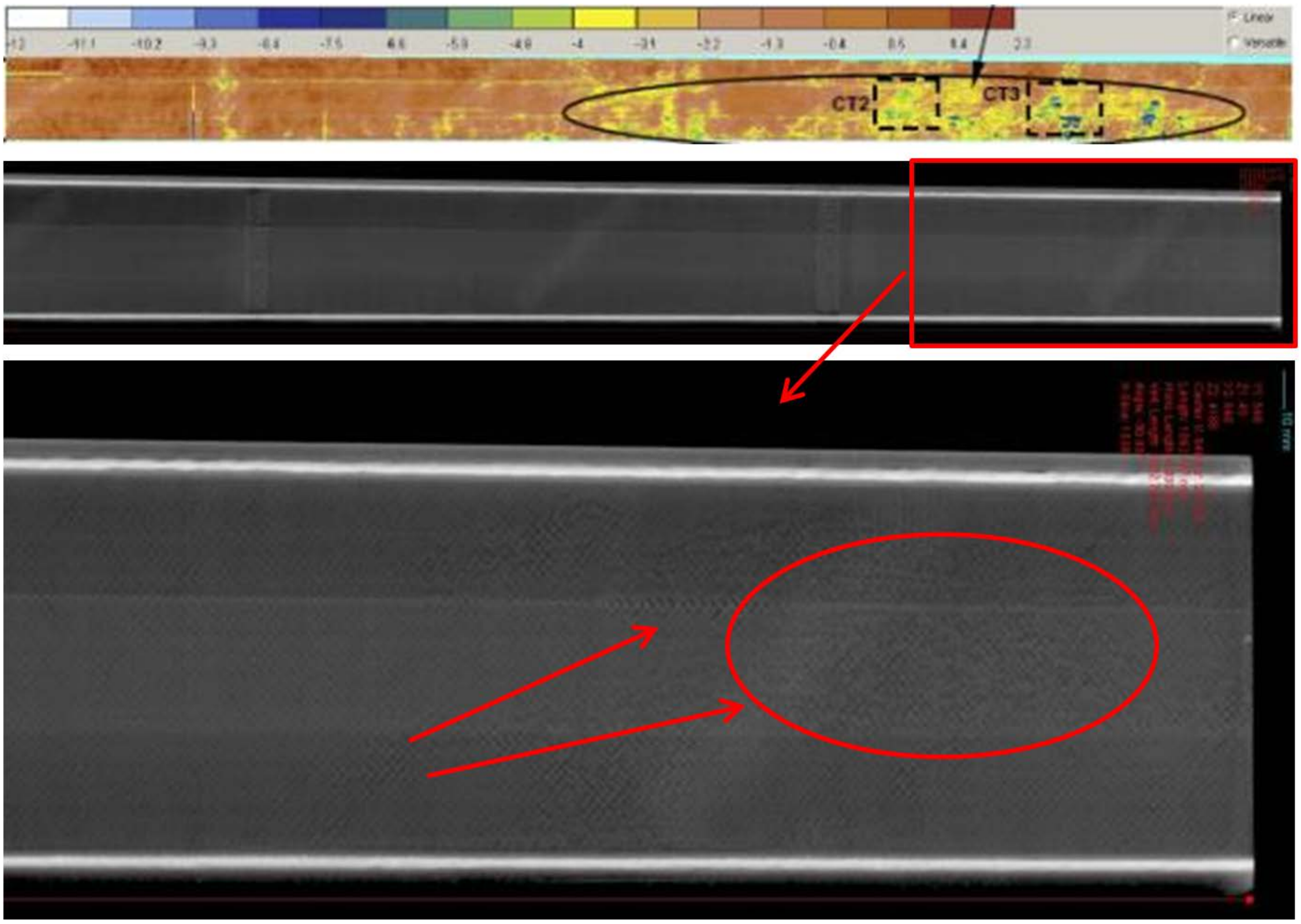


Figure 35: Spar 3 out of the UT C-scan (top) vs. large volume CT of QUI-AIR-03 (center) enlargement of the annotated ROI with lack of resin and surface contamination (bottom)

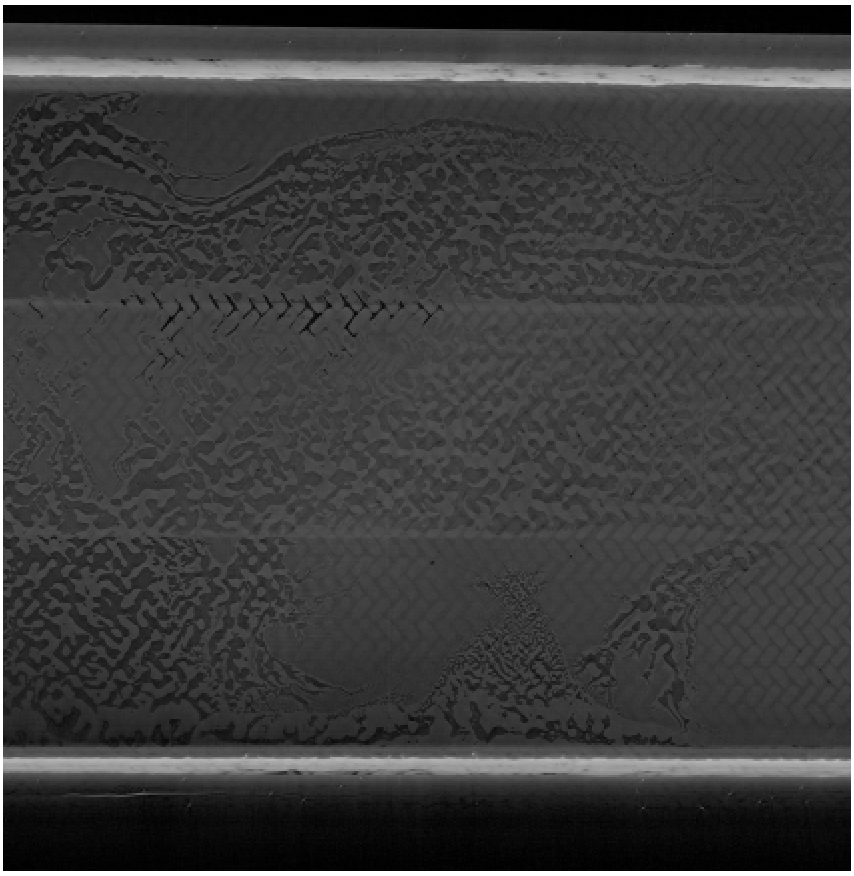


Figure 36: High resolution ROI CT of the affected spar of QUI-AIR-03

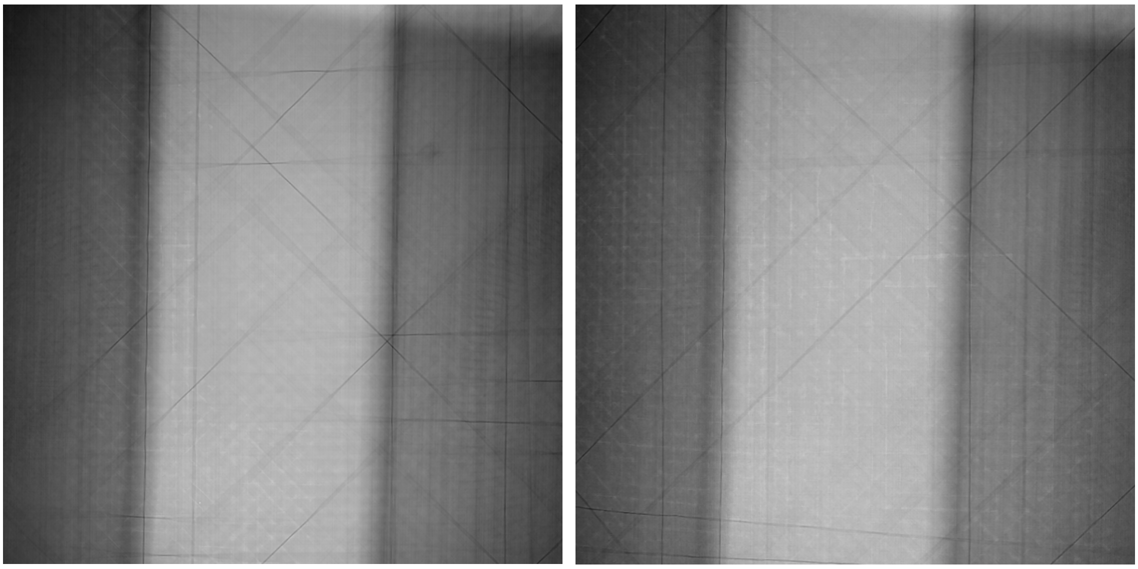


Figure 37: Laminography of the skin of QUI-AIR-03 before (left) and after (right) reprojection of the CT data to the estimated object surface

Task6.3 Robot-based XCT

One main focus of QUICOM and work package 6 has lain on the further development and evaluation of robot based X-ray CT. The principle is to replace usual manipulation systems of computed tomography devices with linear axes by industrial robots with swivel joints. Those industrial robots carry X-ray source and detector (Figure 38).

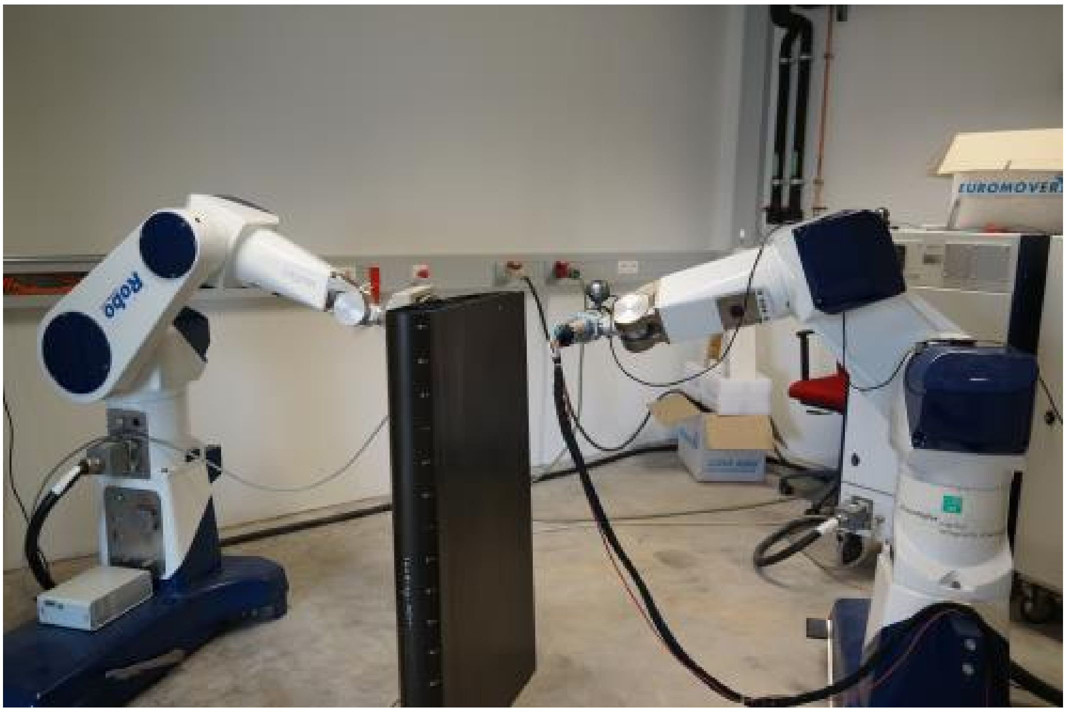


Figure 38: Mobile RoboCT setup at Fraunhofer EZRT with Airbus CFRP flap QUI-AIR-03

With the integration of industrial robots, we want to reach two goals. We want to get higher flexibility in the possible acquisition trajectories – especially for objects that are not accessible for full 360° CT. And we want to come to a solution for mobile X-ray CT. In mobile application it is often impossible to provide a precise and calibrated manipulation system which is otherwise necessary for computed tomography. We solved this by developing a method to estimate the unknown geometry so that the perspectives of the individual X-ray images are known precisely enough for high resolution CT. Fraunhofer EZRT had driven first basic research on the topic of robot based CT for several years before QUICOM.
In this project, we implemented a demonstrational toolchain for the work with a setup of cooperative robots carrying the X-ray equipment and evaluated the results against ground truth data that were acquired with lab CT systems (Figure 31). The main algorithmic task in RoboCT lies in finding a solution for all unknown misalignments that exist in such a system in comparison to a well calibrated lab CT device. We implemented our toolchain so that now, we have one first demonstrational application that leads the user through the process. This begins with calibrating a pair of robots in a new environment in order to identify a solution for the geometric unknowns. Based on this geometrical calibration, the user is assisted to plan an acquisition trajectory. The user interface gives a graphical representation of the planned trajectory and assists in identifying unreachable positions and orientations in relation to the specimen (Figure 39). The scan can be controlled and acquired from within the user interface and the 3-D reconstruction can be triggered incorporating the previously estimated geometry. We performed final measurements on specimens from Airbus and FACC. The RoboCT scans on QUI-AIR-03 and QUI-FACC-01 have been evaluated against lab CT and tomosynthesis and we were able to detect all indicated defects. Figure 40 shows a slice through the RoboCT image of the indicated spar from QUI-AIR-03 with the crack in the CFRP structure known already from the ground truth measurement in Figure 36.

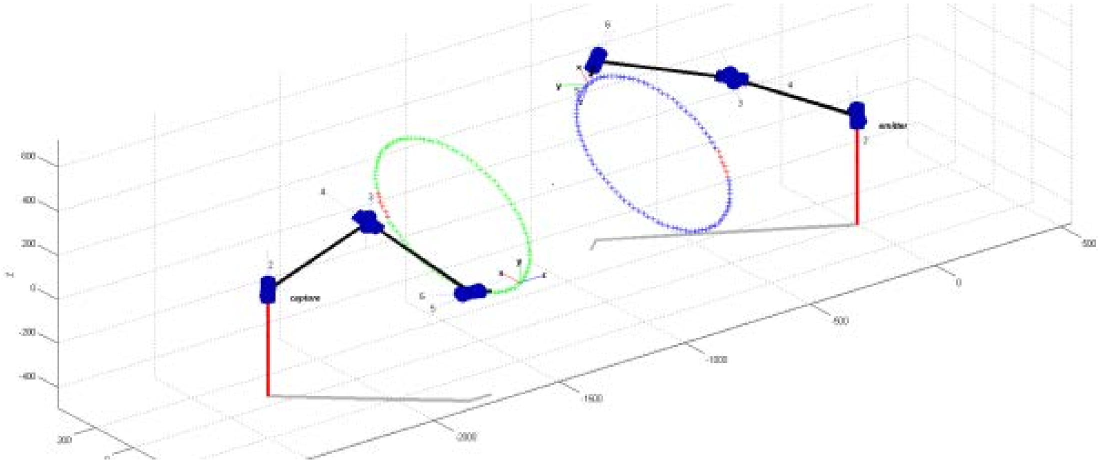


Figure 39: Trajectory planning for a laminographic acquisition with detector trajectory (green), source trajectory (blue), unreachable positions (red) and robot poses

At the end of QUICOM we could demonstrate the developed methods with the robot based inspection system at FACC. The demonstrational measurement showed a relevant use case and could clearly outline the business case for RoboCT as escalation technique for NDT. (see chapter 1.2.9)

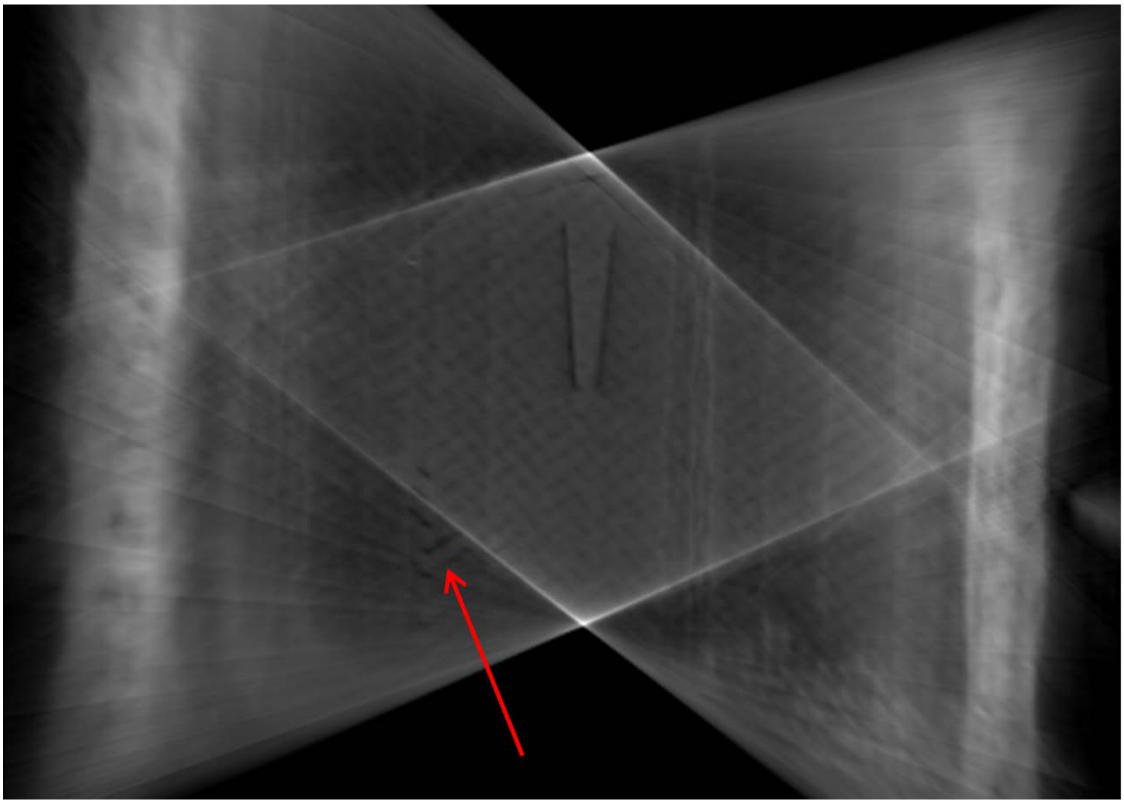


Figure 40: Slice through RoboCT laminography of QUI-AIR-03 with cracks and lack of resin

Collaboration with other work packages

A strong collaboration existed with WP 4 targeting a common simulation framework. Together with WP 2 partners, relevant samples were chosen for investigation and the respective results were discussed and evaluated. The large volume CT of QUI-AIR-03, together with ROI CTs and Tomosynthesis scans at different ROIs were provided as data for multi-scene visualization in WP 7 and 9. For WP 9, the RoboCT represented the main experimental CT setup.

1.2.7 WP 7 – Development of visual analysis tools for fiber-reinforced polymer x-ray computed tomography data

Fulfilment of the project work plan

WP7 was focusing on the development of algorithms for the analysis of the XCT data, generated in WP3, WP4, WP5, and WP6. It included the development of algorithms for quantitative void characterization and visualization, of inner structures of composite components concerning porosity, main/local orientation of cracks, delaminations, and structure as well as fiber/resin content, and voids as well as for the quantification of the geometry, orientation and shape of the inner structures. WP7 also involved the visualization of the results obtained in the previous work packages, and the handling of these large XCT datasets. Finally, the developed methods had been compared to standard ultrasonic testing. The project work plan had been fulfilled to a great extent.

Scientific and technical results

One focus of the WP7 was quantitative void characterization. **VG** addressed this topic by developing and integrating an **advanced, local adaptive, subvoxel precise defect detection algorithm** for composite materials. It could be shown, that, starting from a reasonable starting contour, local adaptive methods are able to provide very accurate and stable results. In general, the starting contour can be extracted from the dataset itself by histogram analysis, so this method has no need to scan reference parts anymore.

The subvoxel precise approach allowed further to get stable and accurate analysis even at lower voxel resolution; this means larger parts can be examined.

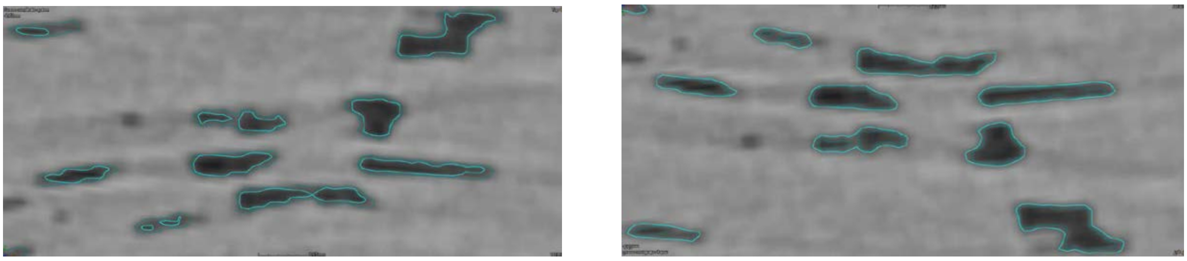


Figure 41: Example: Larger parts can be examined.

In the following figure the effect of reducing the error in global porosity by using the local adaptive correction is shown. For a list of given thresholds the relative error in porosity for both with and without local adaptive correction has been calculated.

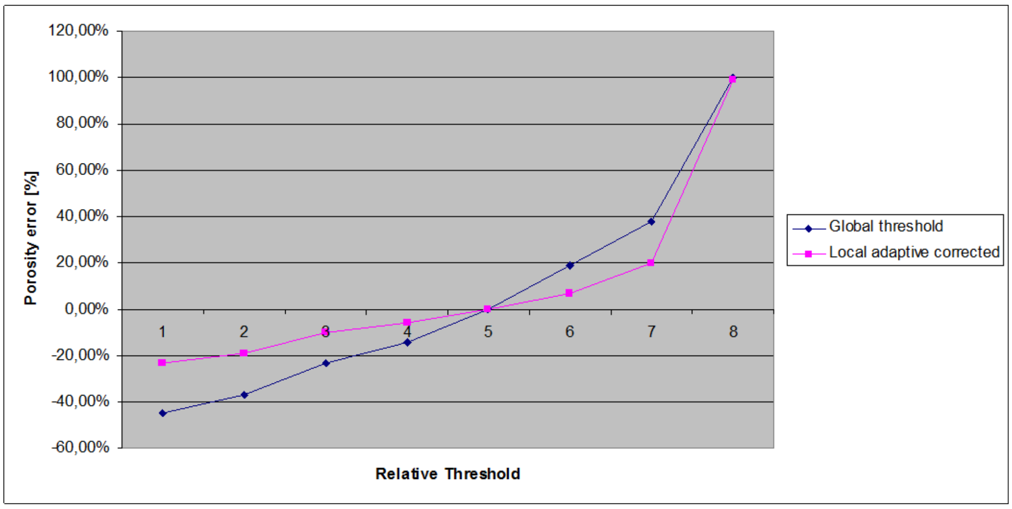


Figure 42: effect of reducing the error in global porosity by using the local adaptive correction

Finally the

developed methods have been compared with the reference method, establish at AGI since a while. It could be shown, that the results are comparable in a great extent.

Name	Reference	VG DefX CFRP	VG DefX CFRP + Local Refinement	abs. Difference	rel. Difference
AGI 3	0,82%	0,82%	0,74%	0,08%	10,00%
AGI 4	0,70%	0,70%	0,63%	0,07%	10,00%
AGI 5	6,55%	7,51%	6.49%	-0,06%	-0,01%
AGI 6	7,04%	7,90%	7.48%	0,44%	6.20%
AGI 7	7,92%	6,55%	7,66%	-0,26%	-3.20%

Table 2: comparison of the developed methods with the reference method

VG focused also on the **separation of pore cluster** in reasonable sub components to perform on these components an extraction of pore measures like volume, surface, main orientation and form factors. See in the following figures the result of this fully automated pore cluster separation.

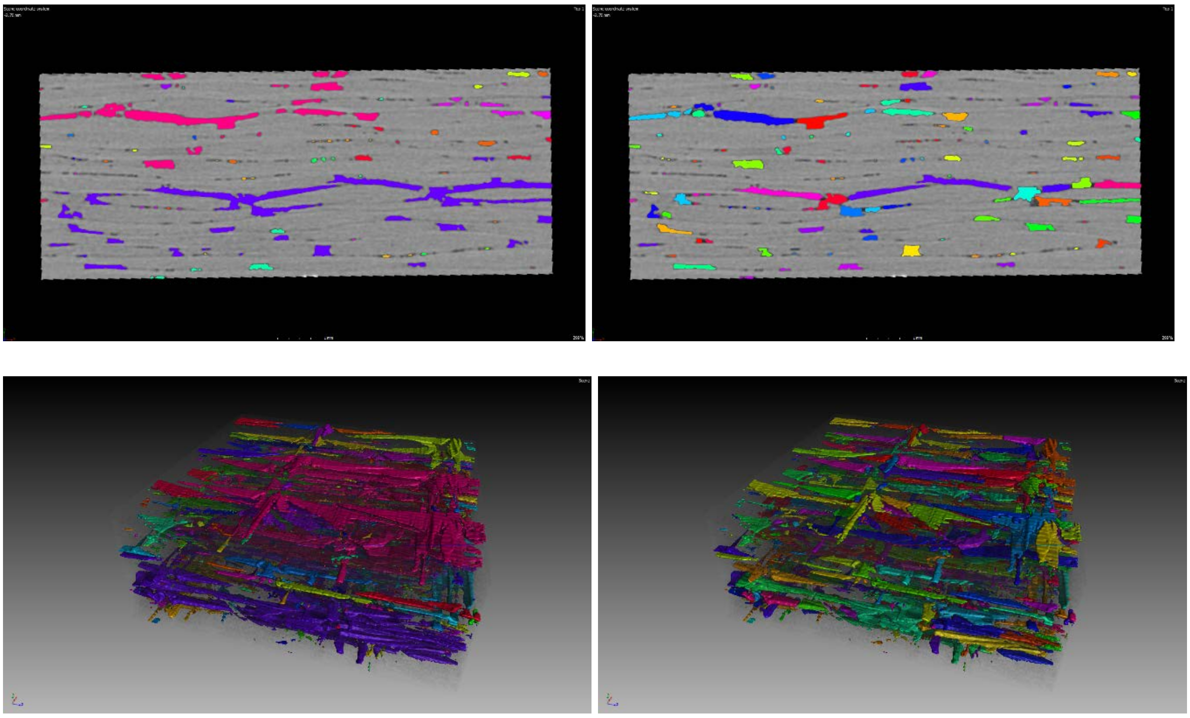


Figure 43: separation of pore cluster

FHW developed during the Quicom project in WP7 the **FiberScout** tool and integrated it into VGStudio MAX. It allows an interactive exploration and analysis of fibers and voids in X-ray computed tomography (XCT) scanned fiber-reinforced polymers (FRPs). By using several different visualization approaches (e.g., parallel coordinates, scatterplot matrix) each single fiber and void can be accurately selected and classified according to their specific characteristics (e.g., orientation, length). In order to visualize the average of a defined fiber or void class, the concept of **MObjects** (Mean Objects) was integrated into the FiberScout system. In addition, the **MetaTracts** algorithm was designed to identify and extract FRP fiber bundles in the raw XCT data. The generated MetaTracts can be interactively explored using the FiberScout tool. The workflow of the FiberScout is shown in Figure 47. Furthermore, the **PorosityAnalyser** system was realized in WP7 by FHW within the QUICOM project to evaluate and visually analyze pore segmentation pipelines in FRPs. This tool allows a convenient setup of segmentation pipelines (segmentation and smoothing filters), a batch execution of the defined segmentation pipelines within multidimensional parameter ranges and a visual examination of the segmentation results (e.g., porosity, algorithms runtime) to find sufficient segmentation pipeline parameters.

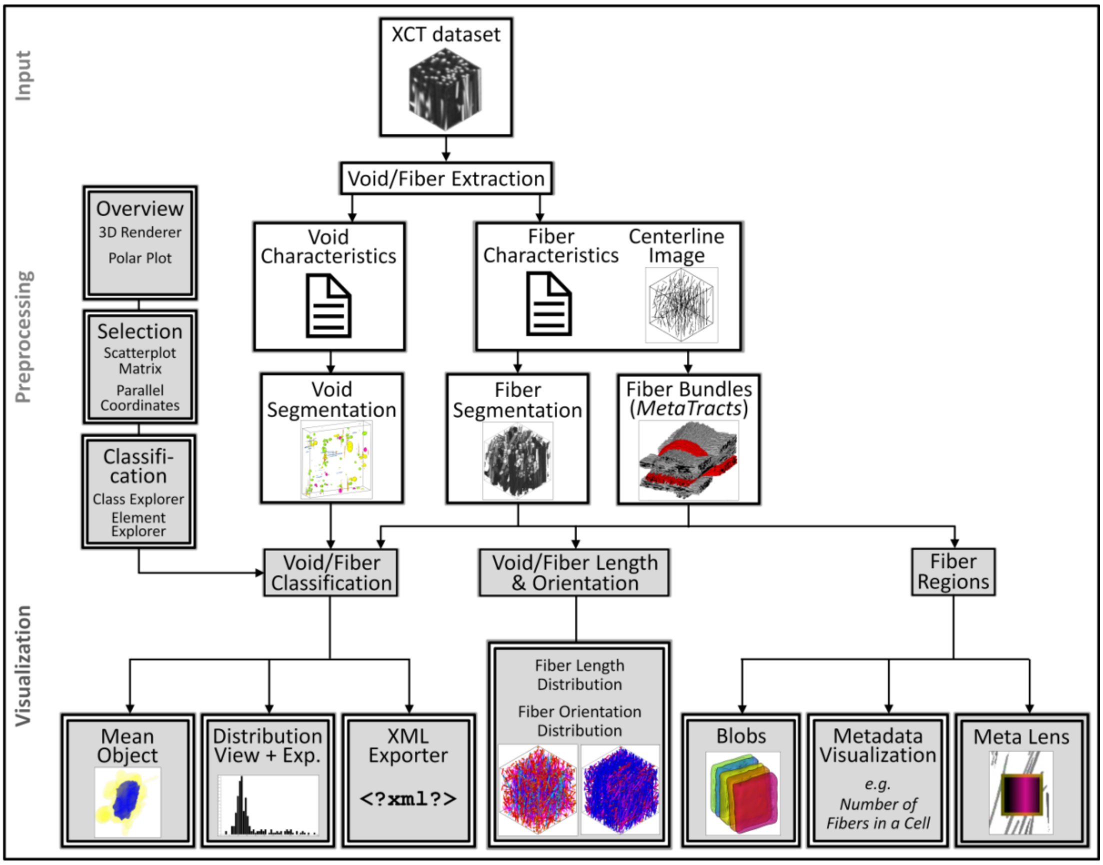


Figure 44: Workflow of the FiberScout tool with its different visualization concepts.

The CFRP modeling strategy adopted in WP8 is based on a voxel mesh approach. In order to provide necessary input data to the WP8 modeling algorithms, image processing algorithms were developed by **KUL** and studied in the framework of WP7. The purpose of these image processing algorithms is to extract data on orientation and distribution of inner structures in the modeled FRP sample. Local fibre orientations were calculated using a structure tensor method. In order to ensure the precision required for the modelling of CFRP, which are highly anisotropic, the precision of the method was extensively studied and a method to estimate the precision was proposed. As a general rule, the resolution required to reliably estimate fibre orientations in CT images is around 2.5 µm for carbon fibre. The precision declines gradually with decreasing resolution (Figure 48); image artefacts may introduce bias in the method output and must be suppressed. The study also showed that the precision is affected by the noise level and the local fibre volume fraction in the material. A method to perform matrix/yarn/voids segmentation was developed, which is based on Gaussian mixture models. The method involves cutting ROIs representative for the components of the material in order to calibrate the statistical model. In case if it is not possible to cut a representative ROI (e.g. very small fraction of the matrix), another method can be applied, which uses K-means (unsupervised) segmentation. In combination with the post-processing algorithm, this method of segmentation gives fair results. The developed algorithms were implemented in the software, which provides all necessary functions to create a voxel finite element model from a CT image. The results generated in WP7 were published in 2 journal papers and 4 conference papers.

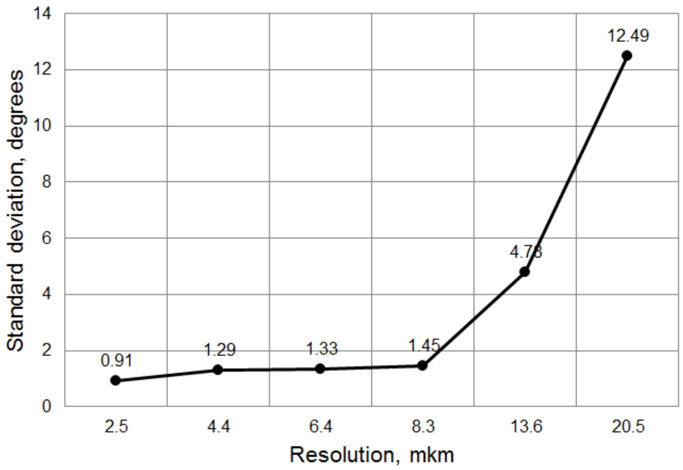


Figure 45. Standard deviation of the calculated angle of orientation versus resolution of the image. UD steel/epoxy composite with the fibre diameter of 25 µm.

UPAT further focused in the frame of WP7 in the examination of the porosity content of several specimens. This work was conducted by the Laboratory of Technology and Strength of Materials. This variety contains specimens by the EADS (Airbus Group) and the LA Composite.
At first, CT scans from AGI were examined with the use of VG Studio MAX. A parametric study with the implementation of global threshold was conducted in order to be as precise as possible in the porosity detection. The samples can be seen in the following images. The materials were the RTM6 epoxy resin and the 24k roving in plain weave lay up of 16 plies. The defect detection revealed a porosity volume fraction from 0.91 up to 7.59% from AGI3 to AGI7 samples as presented in Deliverable7.2.
As for the LA Composite samples, they were made of EhKF 420 epoxy resin and HTA 24k carbon fibres in 32 UniDirectional plies. A parametrical study utilizing reconstructed data was conducted with the use of VG Studio MAX so as to identify the porosity content and use all the available data for modelling in the frame of WP8. The results of the defect detection revealed porosity content from 0.82% up to 3.43%. In the following figures photos of the samples and results can be seen.

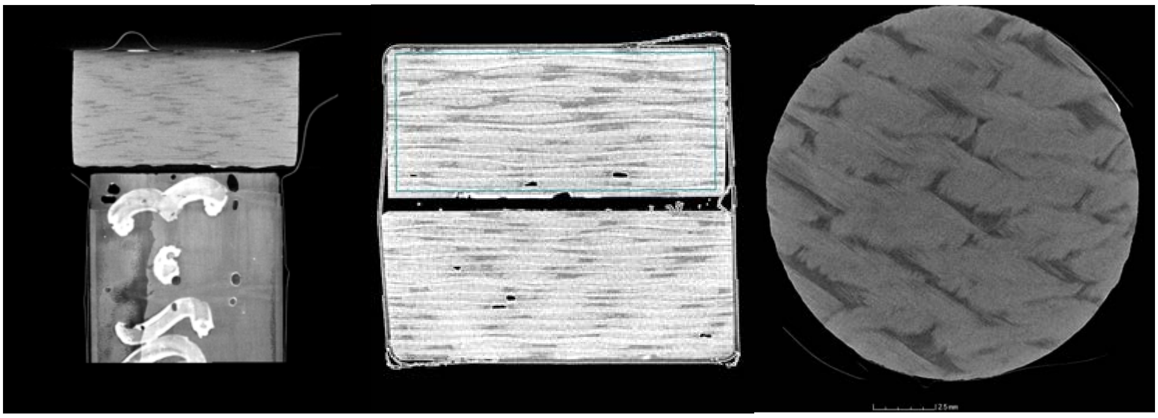


Figure 46: Samples from AGI (Airbus group) in the VG Studio MAX

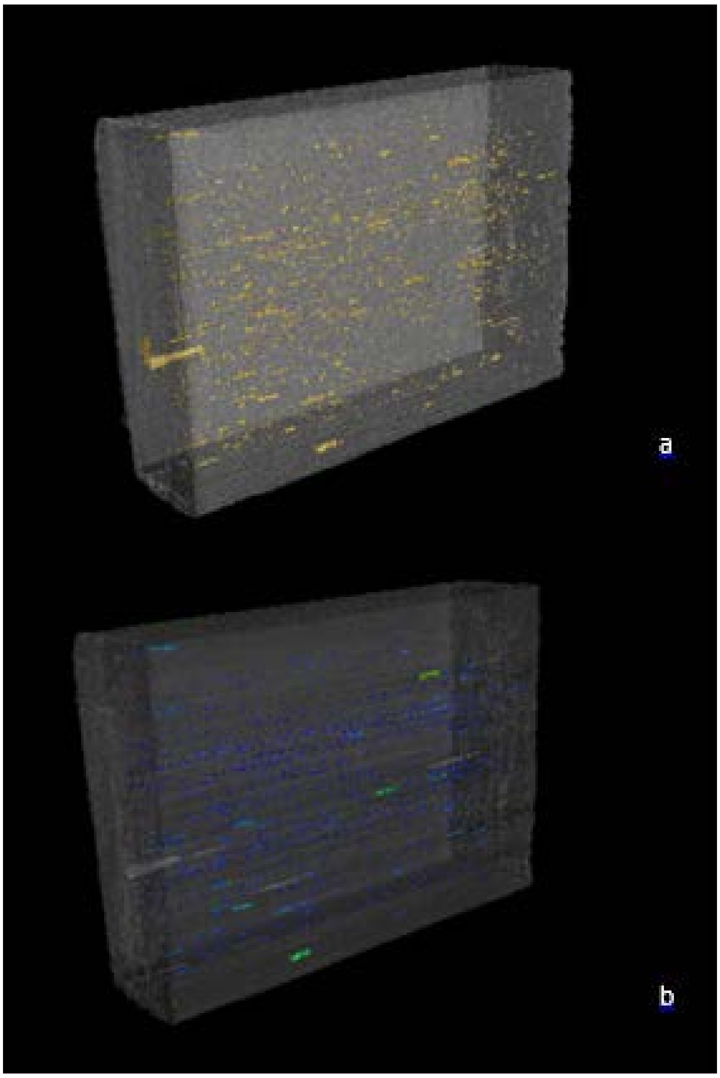


Figure 47: The Reference material sample from the LA Composite inserted in the VG Studio MAX and after the defect detection with different volume thresholds. In case b the porosity is underestimated (parametric study)

Sample (Porosity Level)	Enhanced v2.1 algorithm (Surface determination by example areas, VG automatic threshold value)	VG DefX v2.2 algorithm (Automatic VG threshold value)	VG DefX v2.2 algorithm (Surface determination by example area, VG threshold value)	Chemical Decomposition
Reference	0.82 %	0.74 %	0.35 %	4.46 %
Minimum	1.56 %	1.31 %	1.14 %	5.41 %
Medium	1.62 %	1.52 %	1.28 %	5.89 %
Extensive	3.43 %	4.22 %	3.19 %	11 %

Table 3: Results of the defect detection with global threshold and different calibration parameters compared with chemical decomposition

CTU focused in the frame of WP7 on the effects influencing porosity, delamination and micro-cracks evaluation based on CT reconstructions. Reliable identification of these flaws in such heterogeneous material as CFPR is supposes suitable contrast between pores and surrounding material. It was proven that appropriate beam hardening correction increases contrast several times comparing with standardly used flat field correction. It was also found that correction of the tube spot movement significantly improves desired contrast. For instance, it was found that some flaws were not identified in the reconstructed volume of the inspected LA Composite sample if spot movement correction was not done. Comparison of the identified porosity and micro-cracks calculated by the VG studio Max (VG DefX v2.2 algorithm) is depicted in Figure 51.

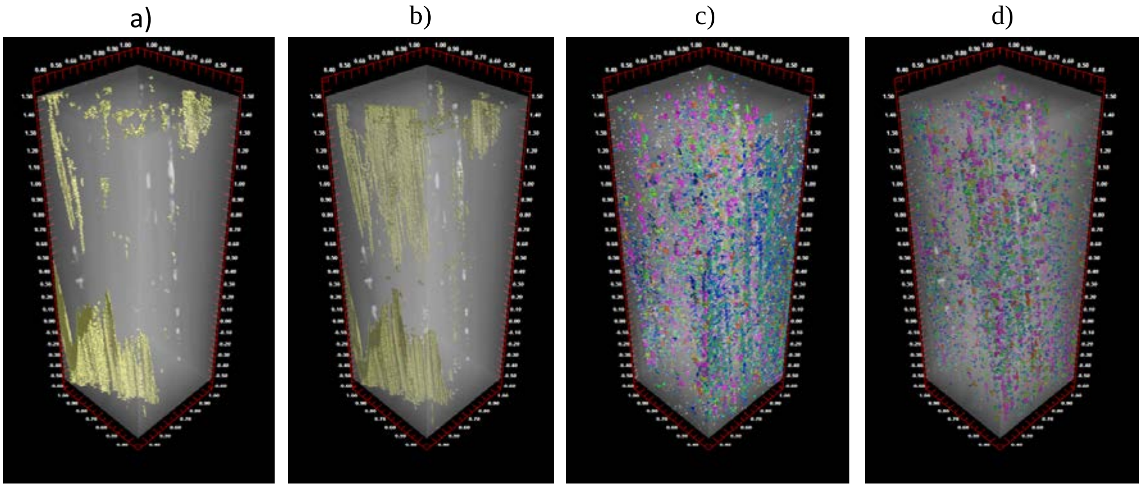


Figure 48: Reconstructed volume with 2.5 m voxel size crack identified without spot movement correction a), with correction b). Porosity evaluated without spot movement correction c), with spot movement correction d).

Cracks are not fully identified without spot movement correction, while these cracks are reliably identified with the spot movement correction. Some inclusions are visible as well (white spots). Higher porosity is measured utilizing a correction of the spot movement when comparing with not corrected reconstructions. The colour coding represents the pore volume. The porosity calculated by the VG studio Max was 1.5 % for the reconstruction without a spot movement correction and 1.9 % for the reconstruction with correction.

Concerning the specific aspects of large data set handling, **VG** developed and integrated several concepts to deal with the huge amount of memory of these datasets:

- Integrated sparse grid concept for datasets and analysis results
- Added multi resolution grid approach
- Added possibility to unload/reload datasets in running application or to reduce resolution on demand
- High performance multicore IO

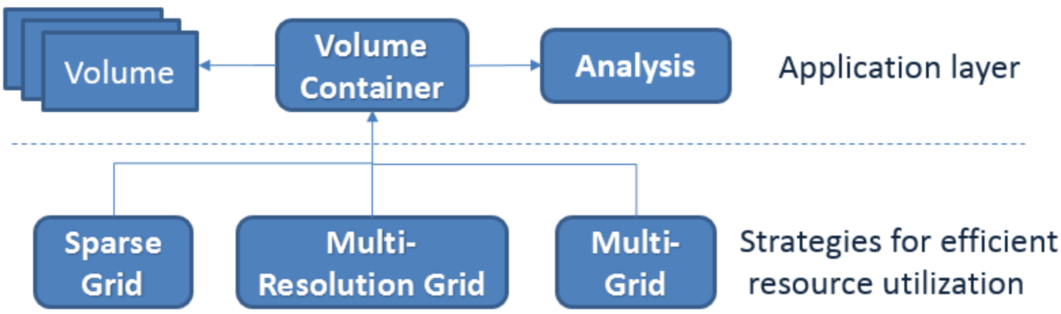


Figure 49: concept to deal with huge amount of memory of datasets

Finally, the developed methods of porosity detection had been compared to standard ultrasonic testing by **AIR** and **AGI,** using the integrated functionality of VGStudio MAX. As you can see in the following diagram, a significant correlation between the two modalities could be achieved.

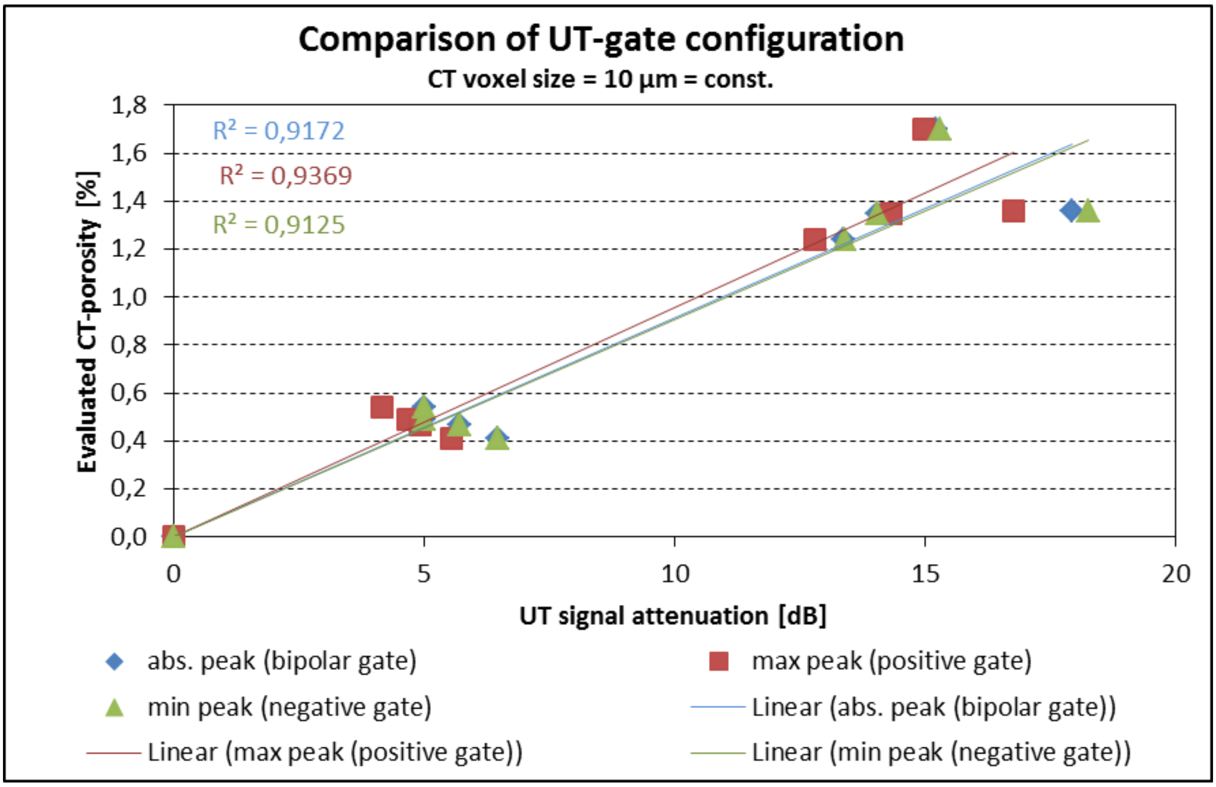


Figure 50: correlation between standard ultrasonic testing and developed methods of porosity detection

The main challenge of using CT for the inspection of thermoplast CFRP clips is the relation of the object dimension (approx. 200 x 100 x 300 mm³) and the complex geometry to the minimum size of relevant defects (approx. 10 to 100 µm), which results in very large reconstructed volumes. **FHG** proposed a specific data evaluation chain, which is intended to be used for a fast automated interpretation of CT volume data in multi-clip mode at a moderate spatial resolution. The main interest herein is the determination of the homogeneity of the reconstructed volume and the local porosity within the parts. The focus is put more on an efficient handling and the proof of principle of the evaluation procedure than on a reliable analysis itself. The goals to use this evaluation chain is twofold: to provide a tool for quality assessment of the CT reconstruction itself, in order to be able to optimize scanning and reconstruction parameters, and to show the possible principle transition of the established ultrasonic inspection procedure towards an automated interpretation of CT data in the near future.
The method estimates the reconstruction quality by means of the homogeneity within the measured object. This is done by computing the SNR inside the dissected geometric primitives. Firstly the measured clips were separated into single partial volumes for each clip. This step is necessary only, if the measurement contains for efficiency reasons more than only one clip. In a second step each clip was dissected into its geometric primitives, namely planes and radii. To prepare a layer-by-layer analysis the dissection realigned each clip component such, that the principal axes were oriented along axes of the coordinate system. After that the SNR and porosity statistics was calculated for each plane. Result of the layer-by-layer analysis is a user-definable local depth dependent porosity profile, which can give valuable information about the specific layers containing the porosity. In addition, the segmented primitives can also be examined for surface roughness and geometric properties like thickness or distortion (Figure 54).

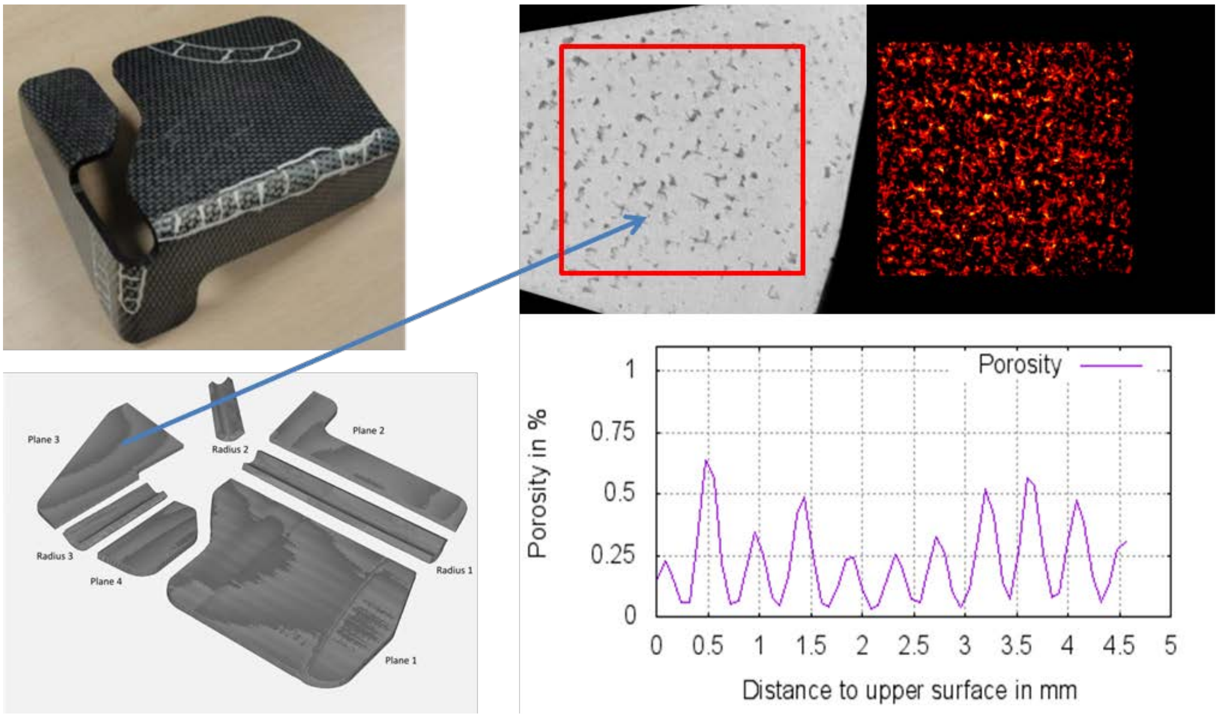


Figure 51: Principle of the clip evaluation approach: Photo of a test clip (top left), result of the clip dissection into geometric primitives (bottom left), region of interest within one plane with projected porosity over the whole thickness (top right), depth resolved porosity profile through the material thickness (bottom right). The porosity can be assigned clearly to layers of a specific orientation.

Collaboration with other work packages

WP7 called for a strong collaboration with other work packages because different inputs were required from these. Based on the work of VG, FHW, KUL and FHG different tools, algorithms and methods were developed to visualize the results obtained in the previous work packages. In this sense there was a strong collaboration with WP2, WP3, WP9 and WP10. FHW, VG and UPAT used the defined reference test samples in WP2 to determine and evaluate the porosity values of the samples in WP3. FHW used the determined results from WP3 to develop several visualization techniques in WP7 which lead to the FiberScout and PorosityAnalyser visualization systems. Both tools were presented in the WP9 demonstration session at the QUICOM final review meeting. FHW presented the publications on the visualization systems (FiberScout and PorosityAnalyser) at international conferences, as required by WP10.

1.2.8 WP 8 – CFRP modeling and simulation

The aim of the WP8 was to produce progressive damage models for the simulation of CFRPs with defects (porosity), create CFRP models for the assessment of the fibre misalignment, validate the models with mechanical tests and train artificial neural networks which connect the input (defects) with the output (mechanical properties).

Fulfilment of the project work plan

Task 8.1: CFRP modeling based on input data from CT scans (KUL): 100%
Task 8.2: Progressive damage model for the simulation of CFRPs (UPAT): 100%
Task 8.3: Validation of the developed composite computer models (KUL-UPAT): 100%
All the deliverables in WP8 were delivered.

Scientific and technical results

KUL: The modelling approach adopted in WP8 is based on a voxel mesh representation of the material structure. The voxel mesh is generated from the CT data using the algorithms developed in WP7 and converted to a finite element model. The voxel-based approach has a number of advantages: (a) it allows modelling any composite architecture regardless of the geometrical complexity; (b) it avoids difficulties with the FE mesh generation for complex topologies; and (c) it avoids the problem of yarns interpenetration. These advantages make the voxel-based approach a good choice for a highly detailed material modelling from CT images. The final goal of the modelling is to predict the effective elastic properties and the strength of the material, as well as its damage response. The prediction of the elastic response with the voxel-FE models is based on a two-scale homogenization process. The micro-scale homogenization is performed to estimate the local mechanical properties of the impregnated reinforcement and uses the Chamis model. This model requires the input of the mechanical properties of the constituent fibre and matrix, and the fibre volume fraction as well. The local fibre volume fraction inside the reinforcement (the yarn) can be calculated on the basis of the experimental value for the total fibre volume fraction V_f in the composite as $V_f^* = V_f / V_{yarn}$, where V_{yarn} is the volume fraction of the reinforcement (yarn), which is obtained from the CT image segmentation. Alternatively, if the fibre packing ratio inside the reinforcement is known (for example, from measurements in optical images), it can be used directly. The meso-level homogenization is performed by computing the strain fields inside a unit cell of the material using FE (Figure 55). In order to maintain the correct volume fraction of the material components in the unit cell, the cell size must be defined on the basis of the measurements of yarn sett from the CT images. This approach was used to calculate the Young's moduli in warp, weft and 45° bias direction, as well as the Poisson coefficients, using as input a CT image with a resolution of 2.48 µm. The results showed a good agreement with the experimental values obtained from tensile tests (Figure **56**).
The strength and progressive damage response were modelled using the continuum damage mechanics approach (CDM) and the theory of Ladeveze in particular. As for the failure criteria, Christensen failure criterion was used for the pure matrix between the reinforcement; the Puck action plane criterion for the transversal failure of the impregnated reinforcement; and the maximum strain criterion for the longitudinal failure of the impregnated reinforcement. The most important factor in the longitudinal strength of CFRP is the ultimate strain of the fibre, which is around 1.8%. The ultimate strain of the composite in the longitudinal direction shown in tensile tests is lower, around 1.5%, due to stress concentrations. The transversal strength of the reinforcement is determined by the strength of the matrix. The Puck failure criterion showed a good accuracy in predicting the transversal failure in world-wide failure exercises. It also allows predicting the crack plane orientation in the transverse plane, which was used in the progressive damage modelling to adjust the material properties accordingly, as the transversely isotropic material before failure becomes fully orthotropic after the failure. The theory of progressive damage was developed by Ladeveze, which is based on the balance of the elastic energy release rate and the fracture surface energy density. The damage tensor depends on a single parameter

for the matrix and on two parameters for the reinforcement (longitudinal and transversal failure). The progressive damage algorithms were implemented for Abaqus in a UMAT Fortran code and an external code in C#. The model was validated with a 3D reinforced carbon/epoxy material, for which there are extensive experimental data were retrieved for its mechanical response in a wide range of strains, and for which the internal damage development was monitored. The model yielded a good prediction for the longitudinal strength, with the ultimate strain predicted around 1.5%. The bias 45° degree loading curve was also reproduced by the model, with some discrepancy, in particular the absence of the final composite failure. The current work is focused on the improvement of the modelling approach in the CDM framework and on incorporating a non-linear behaviour of the matrix into the model.

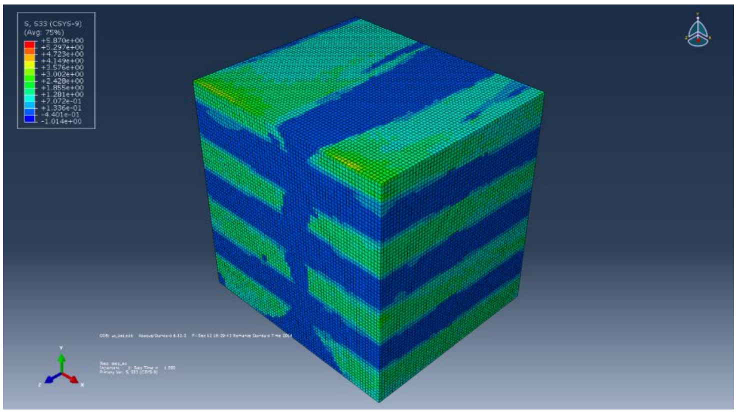


Figure 52. Voxel-FE model of a unit cell of the 3D reinforced carbon/epoxy composite.

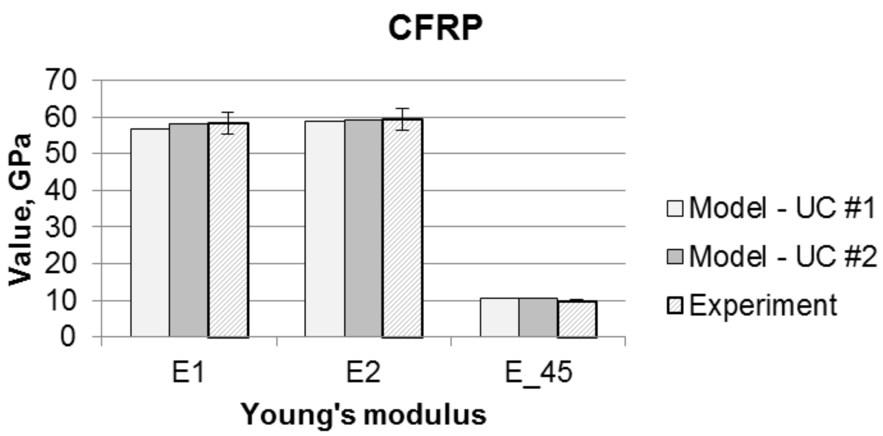


Figure 53. Model predictions for the Young's moduli in warp, weft and bias directions and comparison to the experimental values.

UPAT (LTSM): The multilevel modelling approach was adopted by the Laboratory of technology and Strength of Materials in order to assess the effect of porosity in the mechanical properties of uni-directional fibre reinforced polymers. The porosity analysis was conducted with the use of VG Studio MAX in WP7. The detected porosity was categorized in order to produce representative unit cells in two levels. The first level contained the small pores of which the shape was mostly spherical. The models' dimensions were constructed analogically to the porosity volume fraction. The progressive damage model method was implemented with the adaption of the appropriate material model and with a strain based failure criterion. Three different porosity levels were achieved during the manufacturing process and they were also detected, thus these three levels were considered. In the second level the large pores detected in the matrix were clustered into one mean pore with the implementation of the MObject technique developed by FHW in the previous WP. Three different MObjects were inserted as voids into a unit cell the dimensions of which were analogous to the void volume fraction in the material. In both levels, the tensile, compressive and shear properties were evaluated. For the previously mentioned models, the neat resin properties were derived through mechanical tests conducted by LTSM namely tension, compression and shear according to the ASTM standards.

The progressive damage model was used also implemented in the simulation of namely 4 different mechanical tests (transverse tension, three point bending, short beam test (ILSS) and v-notched rail shear test). The micromechanical relations of the rule of mixture were used and the Hashin failure criteria were implemented. The results of the multiscale analysis of the defects in the epoxy resin (matrix) of the CFRP were used for the calculation of the composite properties. In parallel, the previously mentioned mechanical tests were conducted in order to validate the models with the use of the ASTM and ISO standards. The results showed that the progressive damage models had a good accuracy in the prediction of the tensile strength and stiffness, the flexural and the shear properties of the composite. In Figure 58 the accuracy of the developed models for a specific porosity level in the case of Transverse tension is presented.

Finally, 4 artificial neural networks were trained for every mechanical test, thus for the prediction of the corresponding mechanical properties. In these ANNs the input was all the characteristics of porosity. The 75% of the samples were used for training and the 25% for the validation.

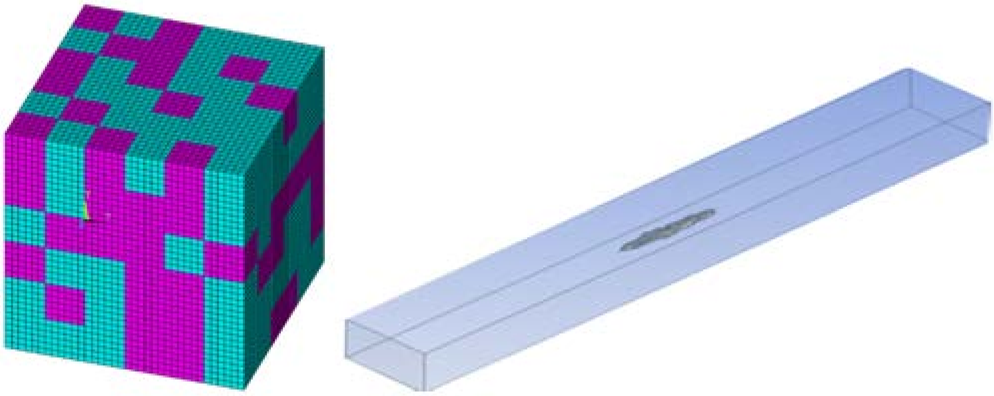


Figure 54:The cubic RUC which contained the small pores (left) and the RUC with the MObject (right)

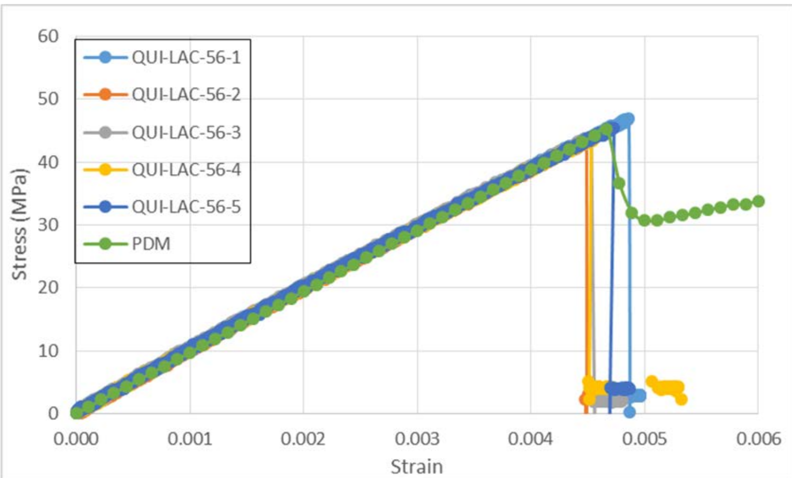


Figure 55: The comparison between the PDM results and the tested specimens for a porosity case study in the transverse tensile test

LAC: LA composite has been involved in this work package in order to manufacture specific specimens with precisely defined defects. The geometry of the specimens with given types of defects and their extent has been defined in cooperation with other partners in this Work Package.

LAC created drawings for each type of defect and its extent. These drawings have been used for the manufacturing engineering of the specimens. This manufacturing engineering phase was crucial for the definition of the processes, equipment and tools used for the manufacturing of the specimens.

Specimens with four porosity levels have been defined. One set of specimens with referenced porosity, second set of specimens with minimum porosity, specimens with medium porosity and specimens with extensive porosity. Different levels of the porosity were achieved by application of different parameters of the curing cycle for the same material. The manufacturing process started with layup of the panels with a given stacking sequence for each type of specimens and porosity level. 4 different panels were manufactured for each porosity level. After the layup the panels were cured with given cycles in order to reach the requested porosity level. The parameters of the curing cycle for each porosity level are shown on the figure below.

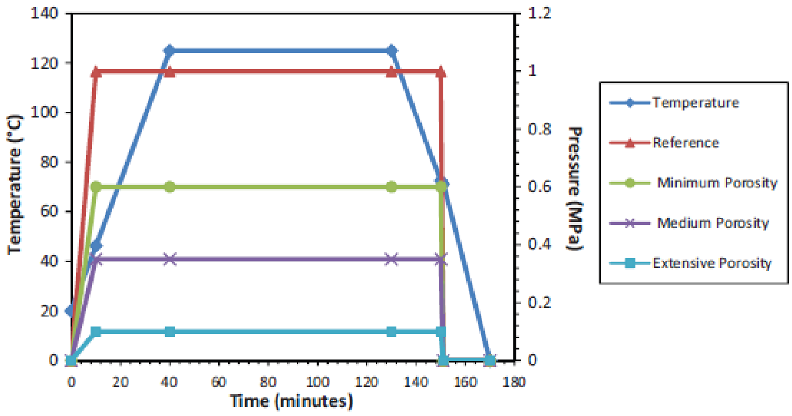


Figure 56: curing parameters for given porosity levels

The porosity level in each panel has been evaluated by chemical analysis by LA composite. Samples cut from the test panels were sent also to the other partners for CT scanning and evaluation of the porosity from the scans.

Specimens for mechanical tests according to ASTM standards were manufactured from the panels: tensile test, 3 – point bending, V – Notched Rail Shear and Short beam test (ILSS)

Final stage of the process was done by the inspection of the specimens. The types of specimens for the examination of the porosity are listed in the table at the end of this document. For the resin tests and the definition of the resin properties three types of specimens has been defined according to the ASTM standards for tensile test, compression and torsion testing. In the following table, the manufactured specimens are listed.

ID of the specimen	Description
QUI-LAC-54	Tensile specimen (reference)
QUI-LAC-55	Tensile specimen (min. porosity)
QUI-LAC-56	Tensile specimen (medium porosity)
QUI-LAC-57	Tensile specimen (Extensive porosity)
QUI-LAC-58	3 point bending specimen (reference)
QUI-LAC-59	3 point bending specimen (min. porosity)
QUI-LAC-60	3 point bending specimen (medium porosity)
QUI-LAC-61	3 point bending specimen (Extensive porosity)
QUI-LAC-62	V-Notched Rail specimen (reference)
QUI-LAC-63	V-Notched Rail specimen (min. porosity)
QUI-LAC-64	V-Notched Rail specimen (medium porosity)
QUI-LAC-65	V-Notched Rail specimen (Extensive porosity)

QUI-LAC-66	ILSS specimen (reference)
QUI-LAC-67	ILSS specimen (min. porosity)
QUI-LAC-68	ILSS specimen (medium porosity)
QUI-LAC-69	ILSS specimen (Extensive porosity)
QUI-LAC-80	Tensile specimen resin
QUI-LAC-81	Compression specimen resin
QUI-LAC-82	Torsion specimen resin

Table 4: List of specimens manufactured especially for WP8

Collaboration with other work packages

The collaboration with other work packages was good.

Samples of the plates manufactured by LAC were scanned by CTU and the porosity was quantified with the use of VG Studio MAX in the frame of WP7 by LTSM. The result of the porosity analysis was used in the frame of WP8 as input for modelling and simulation.

The MObject technique was developed by FHW in the frame of WP7 and was used for creating the mean large pore in the multiscale analysis of LTSM.

1.2.9 WP 9 – Demonstration

Fulfilment of the project work plan

The results from this work package were reported in four deliverables. All four reports have been delivered, documenting the fulfillment of the work plan of WP9. D9.1 covered the demonstration on the validity of the composite computer models and D9.2 reported on the evaluation process of the project. D9.3 covered the demonstration of the robot CT setup for specified test samples. Finally, D9.4 reported on the overall demonstration showcase that has been performed at the final review meeting.

Scientific and technical results

Task 9.1 Evaluation of the developed composite computer models

Within Task 9.1 the validity of the composite computer models were demonstrated. Details on the validity of the models for their specific applications were obtained and on the applicability of the models for the industrial use. Furthermore, it was validated, if and how these models can be integrated into the design and the production of CFRP's.

Task 9.2 Evaluation of the X-ray techniques and integrated algorithms

During the QUICOM project X-ray techniques have been developed and algorithms have been implemented and integrated. Within task 9.2 the obtained results were evaluated and compared to the identified needs. More precisely, the objective was to determine:

- if the specifications and needs are fulfilled,
- if the methods are user friendly,
- if these new techniques are applicable and,
- how these methods and algorithms can be integrated into standard procedures.

The adequacy of each component with the available techniques was particularly highlighted. The limits were identified and, where possible, capabilities compared to those of other techniques (ultrasound).

Task 9.3 Demonstration of Robot based XCT

At the end of the QUICOM project, the newly installed robot based NDT system at FACC became available (Figure 41). FACC integrated a setup of cooperative robots for ultrasonic transmission testing, for two-dimensional radioscopic testing as well as for robot based XCT. While this installation is precise enough for radioscopy and UT, there remain geometric unknowns and misalignments in the range of a factor of four to ten above of what would be acceptable for computed tomography. We had the opportunity to test our methods in first experiments with this industrial installation. FACC provided a relevant specimen directly out of production: the winglet of 1 500 mm · 1 500 mm · 800 mm size (Figure 42) shows an unclear indication in UT. The indicated ROI lies in the core of the sandwich material where neither UT nor X-ray radioscopy can provide a clear rating on the underlying defect. We achieved to acquire a RoboCT scan of this ROI (Figure 43). The CT scan gives a clear image of the honeycomb structure and the defects within. There are three lines of deformed cells, one of which is collapsed. Only this first CT image has given the testing personnel the necessary information to clear this winglet, saving a component worth more than 10 000 €. With this RoboCT demonstration, we could prove that RoboCT is a feasible escalation technique for NDT in the production environment.

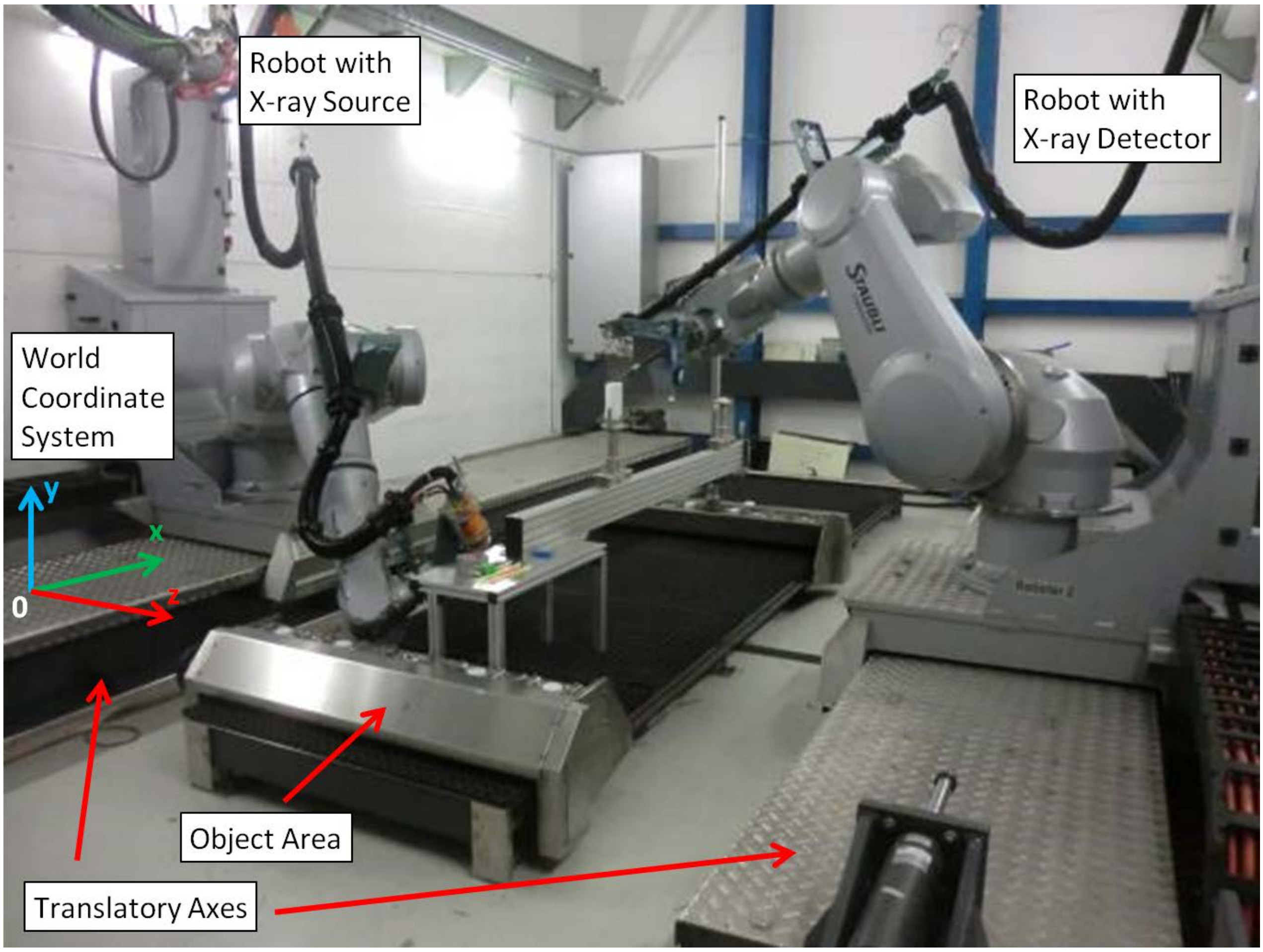


Figure 57: Robot based inspection system at FACC

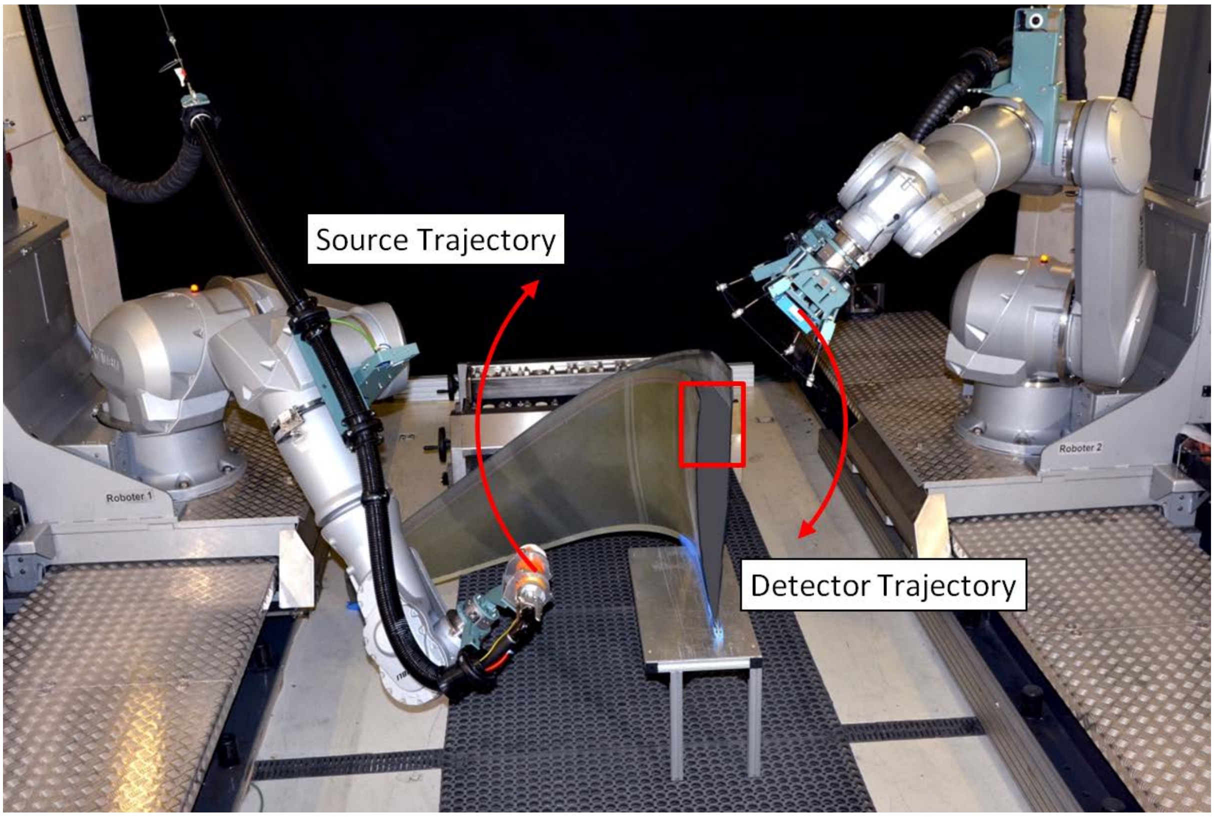


Figure 58: FACC Robots with a limited angle CT trajectory at QUI-FACC-Winglet

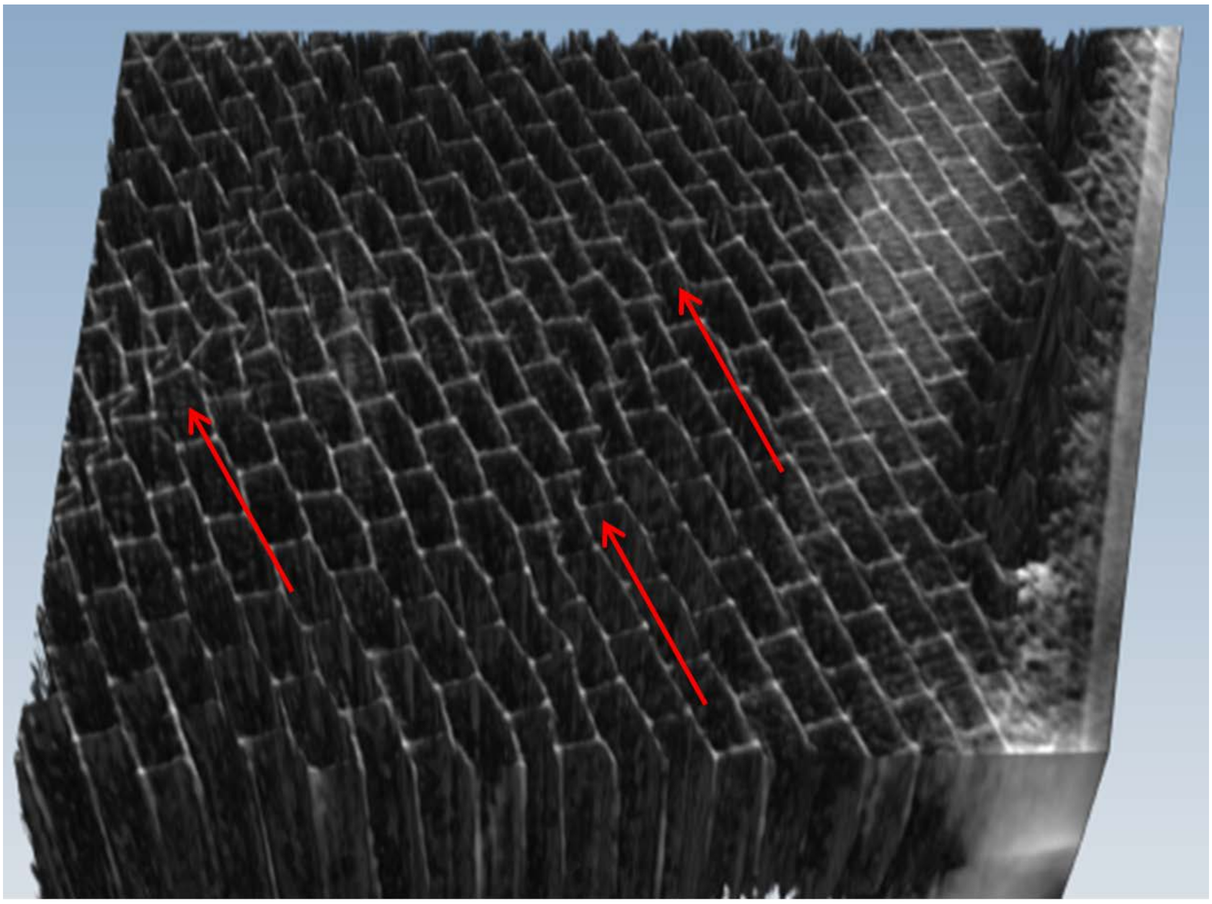


Figure 59: Volume rendering of the honeycomb core of QUI-FACC-Winglet with deviations in the core structure

Task 9.4 Demonstration of Showcases

Demonstration illustrates the potentialities of the various techniques developed within the QUICOM project. In terms of hardware, the robot based XCT setup at FACC site is used for demonstration, but also some partners' XCT devices may be available. The software demonstrator (VG) allows demonstrating the developed techniques and algorithms.

The demonstration of the Robot based CT (FHG) for large aeronautic components corresponds to the task 9.3. Task 9.4 concentrates on the demonstration of the software tools implemented during the project.

The following demonstrations were presented at the final meeting (Ried, 17/09/15):

- WP4: Inline inspection of thermoplast clips using VG Inline
- WP5: Handling of dual energy scan of composite parts with metallic inlay
- WP6: Multispar flap: Examination of ROI scans in combination with a scan of the complete part
- WP7: Comparison of UT and CT based on data of AGI
- WP7: FiberScout integration into VGStudio MAX, FiberScout visualization techniques demonstration, PorosityAnalyzer demonstration
- WP8: Demonstration of VoxTex capabilities

Collaboration with other work packages

Work package 9 is about the evaluation and demonstration of the complete QUICOM technology platform. As such, it covers all work packages and contributions by every partner. All software contributions integrate in one common software demonstrator.

1.2.10 WP 10 – Dissemination and Exploitation

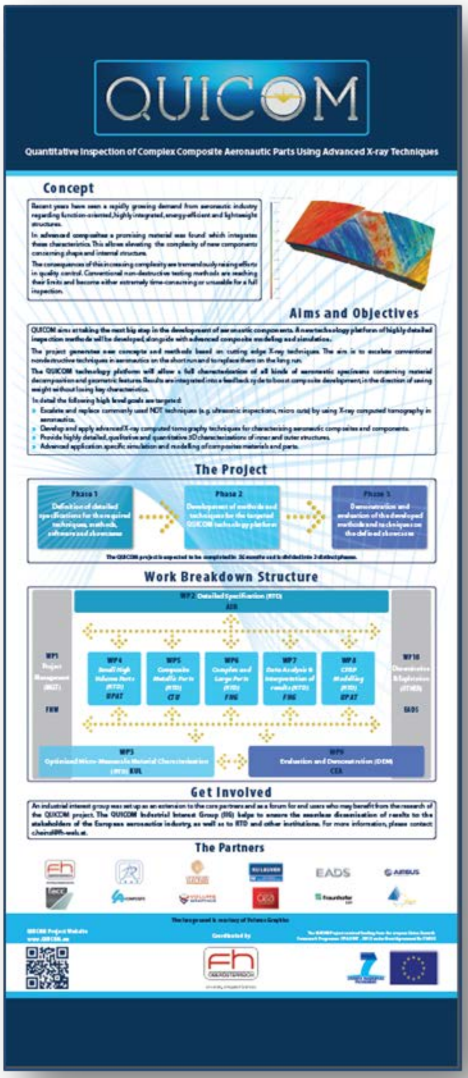
Fulfilment of the project work plan

WP10 activities aimed to amplify the impact of the project through a series of dissemination, communication and exploitation activities. The **communication** of the QUICOM results is of paramount importance for the project in order to maximize its impact and trigger effects across the project's entire range of target audiences. **Dissemination** is an integral part of the project's activities aiming to spread awareness upon the scientific challenges faced by the QUICOM project (current state-of-the-art and planned methodology beyond that), presenting and enhancing in this way, part of the current research profile of the European Aeronautics area. In a similar way, a proactive **exploitation** strategy is necessary in order to ensure that the economic and commercial impacts of the foreground(s) generated within the project are maximized and further allow for long-term commercial collaborations among the consortium partners to emerge.

To this end, WP10 activities where divided into four distinctive tasks, as these are presented below.

Task 10.1: QUICOM website, flyers and newsletters (task leader: EASN)

The project communication pack was developed during the early months of the project and included the project logo, leaflet, poster, website and templates. These have been briefly presented in deliverable **D10.1: QUICOM Website + Folder**. It is further worth noting that **two 80cmX205cm rollup banners** were developed in order to present an overview of the project and the progress realized until the end of first year. The banners were created with regard to the *3rd EASN Workshop* which took place on October 2013, where a QUICOM project session was organized. Hard copies of the project's leaflets and posters were distributed to all consortium partners for their dissemination activities. The rollup banners were also available and mailed to partners upon demand, in order to have displayed at their communication actions. During the lifetime of the project, QUICOM leaflets/posters/banners were distributed/displayed at **nine (9) scientific and technical events.**



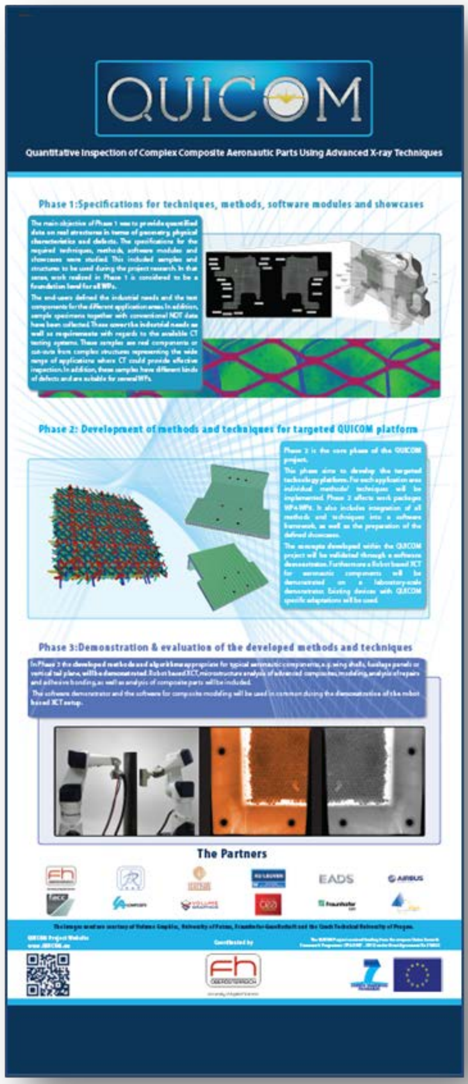


Figure 60: QUICOM Banner I, Project Overview

Figure 61: QUICOM Banner II, YEAR 1 Progress

Furthermore, the QUICOM Project Legacy Folder was developed by EASN-TIS before the project end and it includes an updated version of leaflets and posters, as well as an online video channel. The **Project Legacy Folder** is a collection of informative material on the research realized and the results achieved during the project lifetime. It aims to summarize the outcomes and impact of the project, disseminate both the scientific impact and the exploitability of the final results and to showcase the expertise introduced and work realized by all partners. The newly-developed leaflets and posters provide a brief overview of the **main end-user outcomes developed within QUICOM, emphasizing on the three main pillars of the project: simulation, software and hardware**. The final versions of the QUICOM leaflets and posters are accessible and downloadable from the project website at www.quicom.eu The QUICOM online video channel was created on www.youtube.com and it features **simulations, samples from experiments and measurements, as well as a more general presentation of the project**. By creating this video channel, the QUICOM research activities can become accessible to an infinite number of users worldwide, when they are searching for specific keywords (e.g. XCT, NDT, etc.). Moreover, the contents of the channel can be easily embedded at the project website. The QUICOM video channel is accessible at https://www.youtube.com/channel/UCZM1R8G0IW8FcBbIo0G8zSQ

After the delivery of the public website and the development of the project's leaflets and posters during the first months, T10.1 activities after the first half of the project focused on the **continuous updates of the public website**. This is being translated to both the content and the layout. Content updates include keeping up with the latest QUICOM-related news (events, presentations, members of the Industrial Interest Group, etc.), project progress and obtained results, performed dissemination activities and outreach actions. The website layout was accordingly adapted to the new information generated, towards maximizing the visibility of the project's progress, ensuring that the QUICOM Homepage acts as a gateway to support and communicate all project-related activities to the general public.
During the early phases of the project's development, **QUICOM newsletters** were developed to describe the overall project progress and engage stakeholders in the project's activities. A total of **three (3) QUICOM newsletters** were circulated at the Industrial Interest Group, as well as a series of other scientists and industrial representatives, while they are also available for viewing/downloading at the QUICOM public website. The **European Aeronautics Science Network (EASN)** has been exploited as a dissemination amplifier towards communicating the project's news to the European aeronautics academia, industry, as well as policy makers. A permanent reference has been included at the EASN portal since the beginning of the project. Furthermore, **eight (8) progress updates** are being published at the Association's periodic newsletter, which has an outreach of 10,000 professionals in the aeronautics sector. Another portal used for a major outreach was the Transport Research and Innovation Portal – TRIP, where a permanent reference on the project was published. In addition, FH-Wels has published a media briefing on their website, presenting the project's activities, challenges and expected results.

Task 10.2: Dissemination on QUICOM results (task leader: EASN)
An extremely imperative precondition so as to ensure augmented exploitation, high impact and increased likelihood of uptake of the project's results, is to prudently and effectually disseminate and communicate the appropriate information to the relevant and interested audiences in a concise and well-articulated manner. Dissemination activities enhance knowledge sharing and the acceleration of innovation, while they contribute to the European excellence by enhancing the scientific and industrial profile of the European research and development. These mainly include publications in high ranked journals and participation in high-impact scientific events, and to spread the project research and results to the scientific community, towards enhancing its scientific impact.

Figure 62 - QUICOM Progress

The partners recognize the importance of spreading awareness on the novelty results of QUICOM and the entire consortium has actively contributed to the **dissemination** of the project. The multi-disciplinary nature of QUICOM attracts scientists, researchers and industry representatives from

- NDT research and application,
- manufacturing,
- modeling, simulation and visualization
- X-ray and CT-scanning

In what follows the QUICOM dissemination activities are briefly presented below*:*

- **Six (6) publications** in scientific peer-reviewed journals
- **35 papers publications** in various conference and workshop proceedings
- **Twenty-four (24) conference presentations**
- **Six (6) workshop presentations**
- **Five (5) poster presentations**
- **One (1) seminar presentation**

Task 10.3: Exploitation of QUICOM results (task leader: AGI)

While dissemination activities aim to raise awareness upon the project's scope, methods and results, exploitation is equally important in order to fabricate ways for introducing the project's developed foreground into the commercial market, as a final end-user product/service. Exploitation of the QUICOM results is pursued both by the project partners, as well as external investors. The main groups being targeted are large enterprises or small-medium enterprises working on NDT methodologies, XCT scanning, 3D visualization, manufacturing, modelling and simulation, willing to integrate the QUICOM processes into their activities. Furthermore, exploitation activities can be realized by universities and research institutions, through new educational material, lecture notes, exercises, academic theses and training of employees.

Task 10.4: Industrial Interest Group (task leader: FHW)

From the early months of the project, **Task 10.4: Industrial Interest Group** sought to communicate with industrial representatives and to engage them in the QUICOM research, progress and achievements. The aim of the QUICOM IIG is to receive external advice with regards to the industrial requirements and to ultimately provide the role of consultant, especially for exploitation topics.

The consortium had the opportunity to discuss with IIG members its progress and activities, during two extended sessions, held as part of the General Assembly meetings (3rd GA meeting, Milan, Italy, 7-9 October 2013 and 6th GA meeting, Prague, Czech Republic, 16-18 March 2015). The QUICOM industrial interest group is continuously enlarged and new potential partners are continuously proposed by the consortium.

Scientific and technical results

The scientific results mainly refer to (peer reviewed) publications in journals, articles in books or media and within conference participations in proceedings.

Collaboration with other work packages

The dissemination and exploitation work package involves every other work package, mainly the technical work packages two to nine.

1.3 Impact

Main challenges regarding the ACARE's strategic research agenda are **maintaining global leadership** to provide **more affordable, more economic, cleaner, safer and more secure air travel**. In QUICOM these strategic aims are targeted by providing a **technology platform of novel, high quality, efficient, and affordable means of non-destructive inspection, as well as simulation and modelling of aeronautic components.**

1.3.1 QUICOM's impact on Aircraft Development Costs

Development costs of complex and large composite structures are **reduced by 10% due to QUICOM's robot based XCT and the XCT** techniques developed for complex and large parts, which allow for:

- fast and highly detailed inspections
- fewer rejections
- increased rework of component
- less processing costs, less reclamation costs and follow-on costs

Therefore, the QUICOM research enables:

- **fewer rejections** facilitated through the determination of the real inner structure **by mature XCT techniques** developed within the project
- **reduction of the current development timeframe** for composite aeronautic components **by 15%** due to fast process integrated radioscopy, tomosynthesis and XCT using optimized scanning protocols, especially for small high volume parts
- **complete 3D inspection in a single measurement** for the first time for **hybrid composite components**, using the XCT techniques developed in QUICOM

1.3.2 QUICOM's impact on Green Aircraft

When development departments design parts of the structure a minimal additional factor of safety 1.05 is commonly used. Detailed QUICOM techniques help to avoid this additional factor of safety and thus **reduce the weight** of the parts inspected with QUICOM techniques **to 95%.** Furthermore, QUICOM techniques **reduce the costs related to nonconforming parts between 5 and 10%.** Consequently, lower weight is directly related to lower fuel consumption and CO2 emissions:

- regarding the **total flyaway weight of composite structures of 10155 tons in 2015** and the weight savings due to QUICOM techniques, **only 5% weight reduction yield** a potential for a total 508 tons of saved flyaway weight.
- in the case of the **A350 XWB, 5% weight reduction** of composite components **yield a weight reduction of 5.4 tons, each start**

1.3.3 QUICOM's impact on Aircraft Operation Costs

Due to the weight reduction of advanced composite structures compared to aluminum components, the weight savings will account for significant fuel savings. Considering the **A350XWB**, its fuel consumption at today's fuel price, the **weight penalty results in approximately 1500-2000€/kg**. Further considering the weight reductions of composited components facilitated through QUICOM (5% weight reduction of composite components) yields a **weight reduction of 5.4 tons**, which accounts for **a reduction of the direct operating costs by 8.1 to 10.8M€ for each single A350XWB over its lifetime.** Similar reductions will be achieved for all future aircraft types, small to large, with high composite use.

1.3.4 QUICOM's impact on Aircraft Safety

QUICOM provides simulation models which have been derived to **model and parametrize the internal structures of CFRPs.** With QUICOMs CFRP models **local mechanical properties and damage thresholds** of the impregnated yarns as well as the **micromechanical and meso- FE modeling elastic and progressive damage response** of the composite can be determined. QUICOM provides a **multi-scale progressive damage model for CFRP materials** to assess the defects of initial defects on the tensile strength and fatigue life of the laminates. These initial defects are detected by micro XCT and forwarded to the model in order to simulate the damage progression as a function of the increasing load and elapsed number of cycles. **Advanced characterization, modeling and development results** contribute to a reduction of the manufacturing costs of new components as well as spare parts, which ensure safety by maintaining or even outperforming given specs.

1.3.5 Relevant Markets

Complex composites increasingly gain interest in the aeronautic as well as other industries. The World market for CFRP composites reached US$16.479,4 million in 2013, while it is expected to grow at **CAGR of 12.8%** from 2014 to 2019. At the same time, the Global Aerospace Composite market is expected to grow at a **CAGR of 6.34%** during the period 2014-2019 starting from US$9.59bn in 2013.

1.3.6 Assessment of activities per type and target groups reached

The figure below presents a graphical illustration of the project's dissemination and communication activities realized during its entire duration, where a well distributed family of activities is shown. The majority of the activities realized are participations at scientific events (34% in total) which significantly enhance the scientific impact of the project and the generation of knowledge on the innovative methods and achieved results beyond the current state of the art. This is accordingly accompanied by publications in conference proceedings (33%), while a significant amount of journal publications is also noted (9%). Newsletters/ news releases ensure a targeted, brief and concise communication of the progress updates at audiences relative to the project's activities and focus (e.g. EASN Association members), and cover 11% of the total activities. Finally, it is worth nothing that a significant amount of focus was placed on attracting young scientists and engineers (20% in total). A series of academic theses and newly developed lectures notes and other academic material ensure the training of young students on state—of-the-art technologies, thus providing them with the necessary skills for driving innovative research and development in the aeronautic industry.

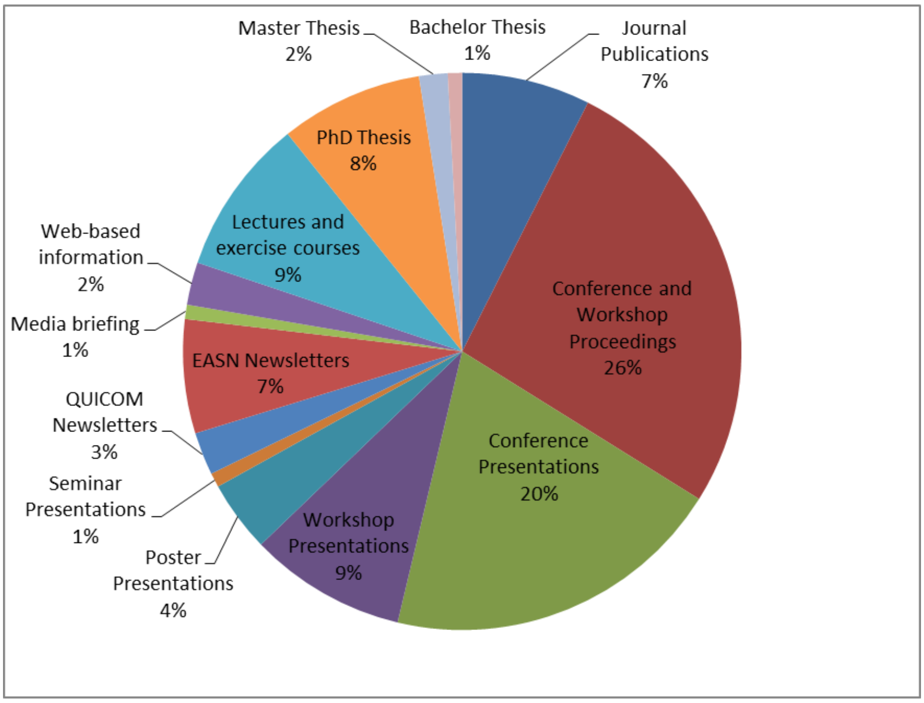


Figure 63: Distribution of QUICOM dissemination activities per type (M1-M36)

Each activity realized is ultimately addressed to a specific target audience, following the objectives of the project and the expectations of the dissemination and exploitation strategy. Having due regard to the activities realized so far, we can consider the following groups as having been targeted and contacted:

1. Scientific and technical presentations took place at events mainly being addressed at researchers, industry representatives and academics. This accordingly applies to the proceedings related to these events
2. The EASN newsletter is being addressed to researchers, industry representatives, academics, policy makers, etc.
3. The currently available online information related to QUICOM is directly addressed at researchers, industry representatives, academics and policy makers. However, its universal and open availability makes it possible for it to be traced from almost anyone (e.g. students and the general public)

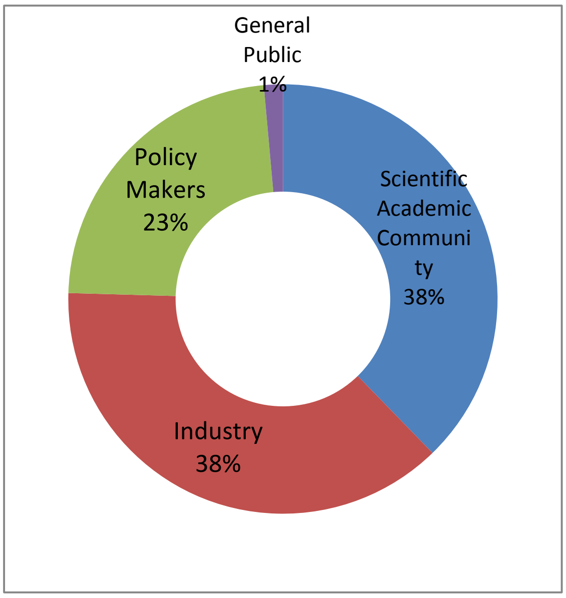


Figure 64: Target groups reached through the dissemination and communication realized (M1-M36)

A rough estimation of the target groups approached is illustrated in the figure above. The scientific community (scientists, researchers, post-doctoral, students, etc.) includes experts in fields closely related to the research challenges that QUICOM addresses and thus their awareness ensures and enhances the project's visibility and recognition for the achievements realized beyond the current state of the art. Accordingly the engagement of the industry favors the exploration of new research horizons, based on the industrial needs, as well as the commercial uptake of the project's results. The main focus of the project's activities is placed on these two groups (38% respectively each). A much smaller focus is placed on policy makers (23%), while the general public is far less approached (1%).

1.3.7 Assessment of the geographical impact achieved

A wide geographical impact maximizes the opportunities for new collaborations and exploitation of the project results, while it also enhances the profile of each partner individually, of the consortium as a whole, and of the European scientific profile. Based on Google Analytics, we can estimate the current geographical impact of the project, i.e. the geographical origin its users. QUICOM has managed to generate a strong international impact with followers in Europe, the USA and Asia. The face-to-face activities which were realized across Europe and the USA surely played a significant role towards spreading the QUICOM project on an international level. The figures below depict the places where the major QUICOM face-to-face dissemination and communication activities have taken place.

Figure 65: QUICOM face-to-face activities across Europe

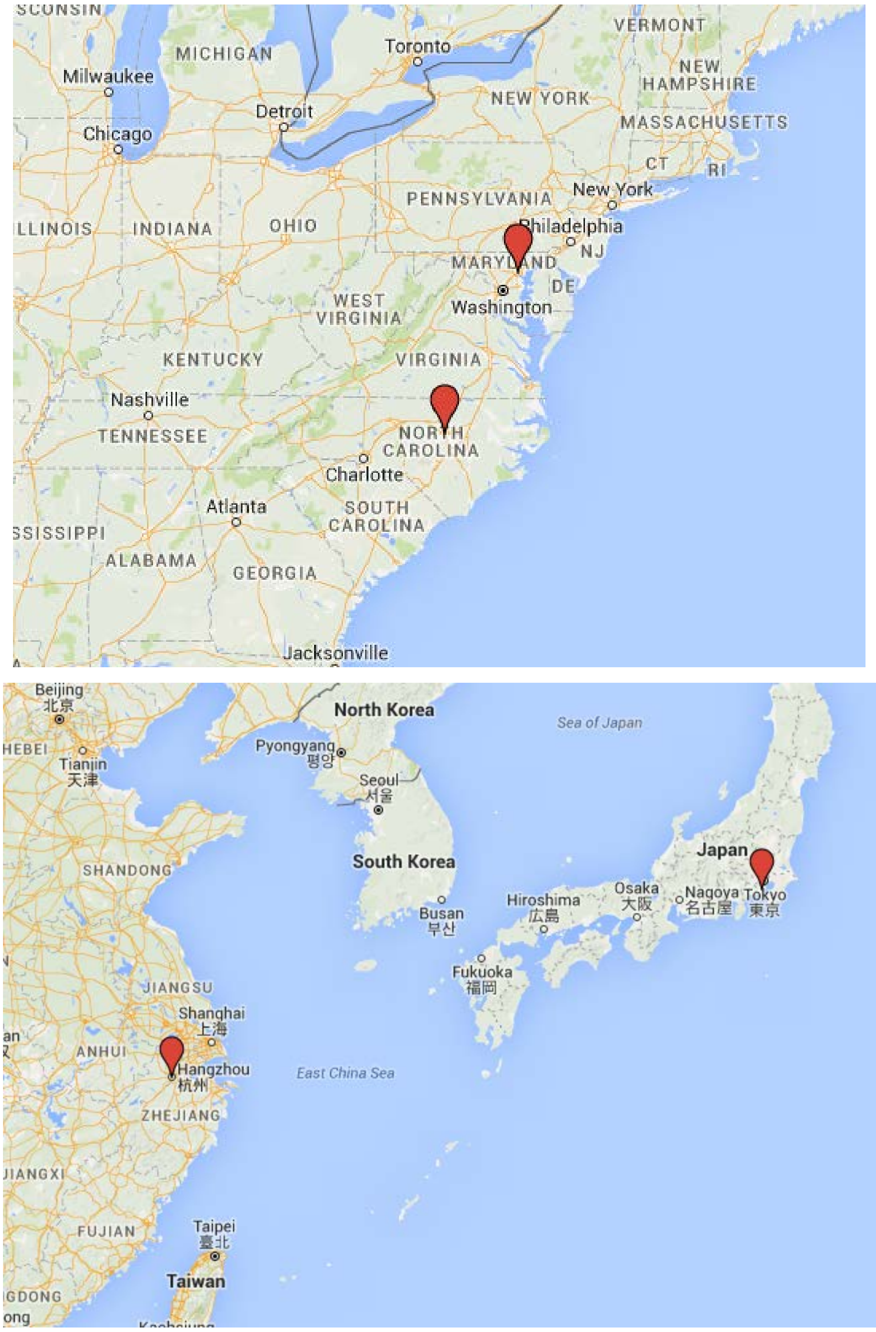


Figure 66: QUICOM face-to-face activities across the USA (top) and Asia (bottom)

1.3.8 Knowledge management & protection

From the beginning of the project, EASN sought to ensure that the necessary measures and procedures are being applied towards the protection of the knowledge developed within the project and the Intellectual Property Rights (IPR) of the involved partners. Specifically, according to Annex II of the Grant Agreement *"at least 45 days prior notice of any dissemination activity shall be given to the other beneficiaries concerned. (…) Any of those beneficiaries may object within 30 days of the notification. (…) In such cases the dissemination activity may not take place unless appropriate steps are taken to safeguard these legitimate interests."*

To this end, a dedicated on-line tool (namely the QUICOM e-approval tool) has been set-up during the first months of the project. The aim of the QUICOM e-approval tool was to:

- Keep partners up-to-date with all project-related dissemination activities
- Provide to partners the ability to raise a comment (with regards to the validity of the results, missing or incorrect information, etc.) or objection (when they feel that their legitimate interests in relation to its foreground or background could suffer disproportionately great harm)
- In-time inform the respective author of the consortium's feedback
- Enable all the aforementioned activities in an automatic, effective and timely manner

The QUICOM e-approval tool will remain online and fully operational for at least two years following the end of the project, in order to appropriately protect the developed foreground and the interests of the involved parties in any future dissemination activities.

1.3.9 Open Access

Although not a requirement under the funding scheme of QUICOM, the project partners have realized a series of Open Access publications (papers and posters), mainly in collaboration with NDT.net (http://www.ndt.net/index.php), an online open access database for non-destructive testing. These publications are already available online in open access, and can be easily found through the QUICOM website (http://quicom.eu/index.php/diss-act). Furthermore, after contacting the organizers of each event, the publishers and co-publishers, it was confirmed that such publications could be deposited in other platforms across the web and these publications at Zenodo (https://zenodo.org/). Furthermore, QUICOM's dedicated page on OpenAIRE is available at https://www.openaire.eu/search/project?projectId=corda ::e1068256a130aa4b8c41578f26232114

2. Use and dissemination of foreground

Section A: List of publications and dissemination activities

Table 5: List of (peer reviewed) publications

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
1.	*Advanced Visualization Methods for Porosity in Carbon Fiber Reinforced Polymers*	Reh A., Plank B., Kastner J., Gröller E., Heinzl C. **(FHW)**	Proceedings of the 1rst International Conference on Tomography of Materials and Structures (ICTMS 2013)	1-5/07/2013	ICTMS 2013	Ghent, Belgium, 2013	pp. 4	http://research.fh-ooe.at/en/publication/3616	No
2.	*QUICOM - Quantitative inspection of complex composite aeronautic parts using advanced X-ray techniques*	Heinzl C., Kastner J. **(FHW)**	Proceedings of the 3rd International EASN Association Workshop on Aerostructures	10/2013	EASN	Milan, Italy, 2013	Not applicable	http://www.easn.net	No

[3] For publications in scientific journals
[4] For conference proceedings publications
[5] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view or to the final manuscript accepted for publication (link to article in repository).
[6] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
3.	*MObjects - A Novel Method for the Visualization and Interactive. Exploration of Defects in Industrial XCT Data*	Reh A., Gusenbauer C., Kastner J., Gröller E., Heinzl C. **(FHW)**	IEEE Transactions on Visualization and Computer Graphics (TVCG)	Vol. 19, No.12	IEEE	December 2013	pp. 2906-2915	http://dx.doi.org/10.1109/TVCG.2013.177	No
4.	*FiberScout: An Interactive Tool for Exploring and Analyzing Fiber Reinforced Polymers*	Weissenböck J., Amirkhanov Ar., Li W., Reh A., Amirkhanov Al., Kastner J., Gröller E., Heinzl C. **(FHW)**	Proceedings of the IEEE Pacific Visualization Symposium (PacificVis) 2014	4-7/03/2014	IEEE	Yokohama, Japan , 2014	pg. 153 - 160	http://dx.doi.org/10.1109/PacificVis.2014.52	No
5.	*Quantitative Messung und Visualisierung von Faserorientierungs- und Faserlängenverteilung von Glas-, Kohle- und Zellulosefaserverstärkten Kunststoffen mittels µ-Röntgen-*	Weissenböck J., Arikan M.., Salaberger D., Heinzl C., Kastner J. **(FHW)**	Proceedings of the DGZfP Jahrestagung 2014	DGZfP-Berichtsband BB 148 – CD, 26-28/05/2014, ISBN 978-3-940283-61-0	DGZfP	Potsdam, Germany, 2014	pp. 21	http://jt2014.dgzfp.de/portals/jt2014/BB/p21.pdf	Yes

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
	Computertomografie								
6.	*Advanced Visualization and Exploration Techniques for Fiber Reinforced Polymers*	Weissenböck J., Reh A., Salaberger D., Heinzl C., Kastner J. **(FHW)**	Proceedings of the 11th European Conference on Non-Destructive Testing (ECNDT), Prague, Czech Republic	06-10/10/2014	NDT.net	Prague, Czech Republic, 2014	pp. 8	http://www.ndt.net/events/ECNDT2014/app/content/Paper/195_Weissenbock.pdf	Yes
7.	*Software tools for robust extraction, analysis and visualization of porosities in XCT scans of fiber-reinforced polymers*	Heinzl C., Weissenböck J., Kastner J. **(FHW)** Dierig T., Günther T. **(VG)** Kiefel D., Stössel R. **(EADS)**	Proceedings of the 6th Symposium for Non-Destructive Testing (NDT) in Aerospace	12-14/11/2014	NDT.net	Madrid, Spain, 2014	Not applicable	http://www.ndt.net/events/aeroNDT2014/app/content/Paper/29_Heinzl_Rev4.pdf	Yes
8.	*Meta Tracts - A Method for Robust Extraction and Visualization of Fiber Bundles in Fiber Reinforced*	Bhattacharya A., Wenger R., Heinzl C. **(FHW)**	Proceedings of the 8th IEEE Pacific Visualization Symposium (PacificVis 2015)	2015	IEEE	Hangzhou, China, 2015	tbc	tbc	tbc

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
	Composites								
9.	*Fuzzy Feature Tracking Visual Analysis of Industrial 4D-XCT Data*	Reh A., Amirkhanov A., Kastner J., Gröller E., Heinzl C., **(FHW)**	Computers & Graphics Journal	2015	Elsevier	2015	8	doi:10.1016/j.cag.2015.04.001	No
10.	*Porosity Analyzer*	Weissen-böck J., **(FHW)**	IEEE Visualization 2015	To be completed	To be completed	2015	tbc	tbc	tbc
11.	*Modeling of Carbon Fiber Composites from CT-Scans using Texture Analysis*	Hahn C., Winterstein E., Plank B. **(FHW)**, Straumit I., Lomov S., Hinterhölzl R., Binetruy C. **(KUL)**	tbc	tbc	tbc	tbc	tbc	tbc	tbc
12.	X-ray inspection of composite materials for aircraft structures using large area single photon counting detector WidePix	Jakubek J., Jakubek M., Jandejsek I., Platkevic M., Soukup P., Turecek D., Vavrik D., Zemlicka J. **(CTU)**	Proceedings of the 3rd International EASN Association Workshop on Aerostructures	10/2013	EASN	Milan, Italy, 2013	Not applicable	http://www.easn.net	No
13.	*X-ray Inspection of Composite*	Jandejsek I., Jakubek J.,	Journal of Instrumentation	Vol. 9, May 2014	IOP Publishing	29/05/2014	Not applicable	http://dx.doi.org/10.1088/	No

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
	Materials for Aircraft Structures Using Detectors of Medipix Type	Jakubek M., Soukup P., Turecek D., Vavrik D., Zemlicka J., Krejcia F. **(CTU)**, Pruchac P. **(LAC)**	(JINST) – IOP Science					1748-0221/9/05/C05062	
14.	*X-ray radiography and tomography study of a delamination in a CFRP and honeycomb structures*	Daniel Vavrik, Jan Jakubek, Ivan Jandejsek, Jan Zemlicka **(CTU)**, Ivana Kumpova	Proceedings of the 6th Conference on Industrial Computed Tomography – iCT2016, Wels, Austria	9-12/02/2016	iCT2016	Wels, Austria, 2016	tbc	tbc	Yes
15.	*Visualization of delamination in composite materials utilizing advanced X-ray imaging techniques*	Vavrik D., Jakubeka J., Jandejsek I., Krejci F., Kumpova I., Zemlicka J. **(CTU)**	tbc	Tbc	Tbc	tbc	tbc	tbc	tbc
16.	*Non Tomographic 3D Imaging of Delaminations in Multilayer Fiber Reinforced Plastic*	J. Jakubek **(CTU)**	Proceedings of the 5th EASN Workshop on Aerostructures	tbc	EASN	2015	tbc	http://www.easn.net	No

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
	Composites Using Phase Sensitive X-ray Radiography								
17.	*Large area radioscopic inspection of the aerospace structures*	D. Vavrik **(CTU)**	Proceedings of the 5th EASN Workshop on Aerostructures	tbc	EASN	2015	tbc	http://www.easn.net	No
18.	*Modeling of small CFRP aerostructure parts for X-ray Imaging Simulation*	Bliznakova K., Dermitzakis A., Kamarianakis Z., Buliev I., Pallikarakis N. **(UPAT)**	Proceedings of the 3rd International EASN Association Workshop on Aerostructures	10/2013	EASN	Milan, Italy, 2013	Not applicable	http://www.easn.net	No
19.	*Modeling of small CFRP aerostructure parts for X-ray Imaging Simulation*	Bliznakova K., Kamarianakis Z., Dermitzakis A., Bliznakov Z., Buliev I., Pallikarakis N. **(UPAT)**	Special issue of the International Journal of Structural Integrity (IJSI), Emerald	5(3)	Emerald	2014	pp. 227 - 240	http://dx.doi.org/10.1108/IJSI-02-2014-0009	No
20.	*Modelling of Small Carbon Fiber Reinforced*	Bliznakova K., Dermitzakis A., Bliznakov Z.,	Journal of Composite	September 2014	SAGE	2014	pp. 1-13	http://dx.doi.org/10.1177/0021998314	No

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
	Polymers for X-Ray Imaging Simulation	Kamarianakis Z., Buliev I., Pallikarakis N. **(UPAT)**	Materials					550219 http://jcm.sagepub.com/cgi/reprint/0021998314550219v1.pdf?ijkey=kLqwzezYKtK5Ig1&keytype=ref	
21.	*Characterization of Porous CFRP laminates by Mechanical Testing and X-Ray Computed Tomography*	Stamopoulos A. Tserpes K. **UPAT (LTSM)** Vavrik D. **CTU** Prucha P. **LAC**	Proceeding of the 6th International Symposium on NDT in Aerospace	12-14/11/2014	TBD	Madrid, Spain, 2014	tbc	http://www.ndt.net/events/aeroNDT2014/app/content/Paper/30_Tserpes_Rev2.pdf	Yes
22.	*A Numerical Model to Quantify the Effects of Defects on the Mechanical Properties of Textile Composites*	Tserpes K. **(UPAT)**	Elsevier Journal Composites Part B: Engineering	tbc	Elsevier	2015	tbc	tbc	Yes

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
23.	*Simulation Studies: Defect Identification in CFRP specimens*	Pallikarakis N. **(UPAT)**	tbc	Tbc	Tbc	2015	Tbc	Tbc	tbc
24.	*Comparison of Reconstruction Methods for CFRP X-Ray Imaging*	Kamarianakis Z. **(UPAT)**	tbc	tbc	tbc	2015	tbc	tbc	tbc
25.	*Modeling of composite materials with fibre misalignment and porosity using X-ray computed tomography data*	K. Tserpes **(UPAT)**	Proceedings of the 5th EASN Workshop on Aerostructures	tbc	EASN	2015	tbc	http://www.easn.net	No
26.	*Modeling of composite materials with fiber misalignment and porosity using X-ray computed tomography data*	Tserpes K.I. **(UPAT),** Straumit I **(KUL)**, Stamopoulos A. **(UPAT)**, Lomov Stepan V. **(KUL)**, Wevers Martine **(KUL)**	EASN 5th International Workshop of Aerostructures	tbc	tbc	Manchester, UK, 2015	tbc	tbc	tbc
27.	*The effect of*	Stamopoulos A.	Composites Part	tbc	Elsevier	2015	tbc	tbc	tbc

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
	porosity characteristics measured by x-ray computed tomography on the mechanical properties of CFRP laminates	Tserpes K. **UPAT (LTSM)** Vavrik D. **CTU** Prucha P. **LAC**	A: Applied Science and Manufacturing journal						
28.	*Determination of local fibers orientation in composite material from micro-CT data*	Straumit I., Lomov S., Verpoest I., Wevers M. **(KUL)**	Proceedings of the TexComp-11 conference, Leuven, Belgium	19-20/09/2013	tbc	Leuven, Belgium, 2013	tbc	tbc	Yes
29.	*Using micro-CT for studying inner structures of CFRP components*	Van de Casteele E., Wevers M. **(KUL)**	Proceedings of the 3rd International EASN Association Workshop on Aerostructures	10/2013	EASN	Milan, Italy, 2013	Not applicable	http://www.easn.net	No
30.	*Influence of the orientation of fibrous structures in a composite*	Straumit I., Lomov S., Wevers M. **(KUL)**	Proceedings of the Bruker Micro-CT User	05-08/05/2014	Bruker microCT	Ostend, Belgium, 2014	Not applicable	http://www.skyscan.be/company/UM2014/004_Ily	Yes

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
	material relative to the sample's rotation axis on the local apparent degree of anisotropy derived from micro-CT		meeting					a_Straumit.pdf	
31.	*Automatic transformation of 3D micro-CT images into finite element models with anisotropic local properties*	Straumit I., Lomov S., Bensadoun F., Wevers M. **(KUL)**	Proceedings of the 16th European Conference on Composite Materials (ECCM16)	22-26/06/2014	ECCM16	Seville, Spain, 2014	tbc	tbc	tbc
32.	*Analysis and segmentation of a three-dimensional X-ray computed tomography image of a textile composite*	Straumit I., Lomov S., Wevers M. **(KUL)**	Computational Modeling of Objects Presented in Images. Fundamentals, Methods, and Applications Lecture Notes in Computer Science (4th International Conference,	Volume 8641, 2014	Springer	2014	pp 133-142	http://dx.doi.org/10.1007/978-3-319-09994-1_12	No

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
			CompIMAGE 2014, Pittsburgh, PA, USA, September 3-5, 2014)						
33.	*Quantification of the internal structure and automatic generation of voxel models of textile composites from X-ray computed tomography data*	Straumit I., Lomov S., Wevers M. **(KUL)**	Elsevier Journal Composites Part A: Applied Science and Manufacturing	Volume 69, February 2015	Elsevier	2015	150–158	http://dx.doi.org/10.1016/j.compositesa.2014.11.016	No
34.	*Identification of the flax fibre modulus from the impregnated fibre bundle test using X-ray computed tomography and FE modelling*	Straumit I., Bensadoun F., Lomov S., Wevers M. **(KUL)**	Elsevier Journal of Composites Science & Technology	TBD	Elsevier	tbc	tbc	tbc	tbc
35.	*Measurement of the modulation transfer function*	Straumit I., Lomov S.,	Elsevier Journal of Non-destructive	TBD	Elsevier	Tbc	Tbc	Tbc	tbc

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
	of X-ray computed tomography systems using an edge phantom	Wevers M. **(KUL)**	testing & evaluation International						
36.	*Using Micro-CT for determining fiber orientations in CFRP materials*	Van de Casteele E., Straumit I., Lomov S., Wevers M. **(KUL)**	Tbc	Tbc	Tbc	Tbc	Tbc	Tbc	tbc
37.	*Permeability estimation of composite preforms on the basis of 3D X-ray computed tomography images*	Straumit I., Plank B., Hahn C., Winterstein E., Lomov S. V., Wevers M. **(KUL)**	Proceedings of the TexComp-12 Conference,	26-29/05/2015	tbc	Raleigh NC, U.S.A., 2015	Tbc	Tbc	tbc
38.	*Voxel-based modelling of textile composites from µCT data: the problem of matrix-yarns-voids segmentation*	Straumit I., Bensadoun F., Lomov S. V., Wevers M. **(KUL)**	Proceedings of the 9th European Solid Mechanics Conference (ESMC 2015)	06-10/07/2015	tbc	Leganés - Madrid, Spain, 2015	Tbc	Tbc	tbc

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
39.	*Effective properties of unidirectional flax/epoxy composites with twisted yarns*	Straumit I., Bensadoun F., Lomov S. V. , Wevers M. **(KUL)**	Proceedings of the 20th International Conference on Composite Materials	19-24/07/2015	tbc	Copenhagen, Denmark, 2015	Tbc	Tbc	tbc
40.	*Calculating permeability of textile reinforcements based on X-ray computed tomography images*	Straumit I. **(KUL)**, Hahn C., Winterstein E., Plank B. **(FHW)**, Lomov S.V., Wevers M. **(KUL)**	Composites Part A: Applied Science and Manufacturing Journal	Tbc	Elsevier	Tbc	Tbc	Tbc	tbc
41.	*Correction of the Localized Distortions in the Orientation Vector Fields Extracted from Images*	Ilya Straumit I., Lomov S. V., Wevers M. **(KUL)**	Proceedings of the 16th International Conference on Computer Analysis of Images and Patterns (CAIP 2015)	2015	Tbc	Tbc	Tbc	Tbc	tbc
42.	*CFRP porosity characterization using μ-Computed*	Kiefel D., Stoessel R. **(AIRBUS GROUP)** Plank	Proceedings of the iCT2014 – 5th Conference on Industrial	25-28/02/2014	iCT2014	Wels, Austria, 2014	Not applicable	http://www.ndt.net/article/ctc2014/pap	Yes

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
	Tomography with optimized test parameters supported by XCT-simulation	B., Heinzl C., Kastner J. **(FHW)**	Computed Tomography					ers/35.pdf	
43.	*Porosity evaluation in CFRP using CT*	Kiefel D., Stoessel R., et.all **(AIRBUS GROUP)**	Proceedings of the Quantitative Non-Destructive Evaluation Conference	20-25/07/2014	QNDE	Boise, USA, 2014	Not applicable	Not published, yet	To be defined
44.	*Reliability Optimization of Quantitative CFRP Porosity Characterization Using µ-XCT*	Denis Kiefel, Rainer Stoessel, Nicolas Dominguez **(AGI)**	Proceedings of the International Symposium on Digital Industrial Radiology and Computed Tomography	tbc	tbc	Ghent, Belgium, 2015	Tbc	Tbc	tbc
45.	*NDT techniques suitable for inspection of parts for small aircrafts (UL and FA23 category)*	Prucha P. **(LAC)**	Czech Aerospace Proceedings	tbc	Association of the Aviation Manufacturers of the Czech Republic	2015	Tbc	tbc	Yes
46.	*Simulation study for optimization of*	Ducros N., Rebuffel V.	Proceedings of the iCT2014 –	25-28/02/2014	iCT2014	Wels, Austria,	Not	http://www.ndt.net/article/	Yes

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
	X-ray inspection setup applied to CFRP aerostructrures	**(CEA)**, Bliznakova K., Dermitzakis A., Kamarianaki Z. **(UPAT)**, Hassler U., Osman A., Tigkos K. **(FHG)**	5th Conference on Industrial Computed Tomography			2014	applicable	ctc2014/papers/75.pdf	
47.	*High energy CT scanning applied to large aerospace samples*	Hassler U., Boehnel M., Errmann G., Osman A. **(FHG)**	Proceedings of the 3rd International EASN Association Workshop on Aerostructures	10/2013	EASN	Milan, Italy, 2013	Not applicable	http://www.easn.net	No
48.	*Regularisation approach for tomosynthesis x-ray inspection*	Tigkos K., Hassler U., Holub W., Woerlein N., Rehak M. **(FHG)**	Proceedings of the 40th Annual Review of Progress in Quantitative Nondestructive Evaluation Conference	Vol. 1581, 21-26/07/2014	AIP	Baltimore, Maryland, USA, 2014	pg. 1793-1800	http://dx.doi.org/10.1063/1.4865041	No
49.	*Roboter based radioscopic inspection and computed*	W. Holub **(FHG)**	Proceedings of the 5th EASN Workshop on Aerostructures	tbc	EASN	2015	tbc	http://www.easn.net	No

NO.	Title of the publication	Main author (Name, organization)	Title of the journal or periodical or the series	Volume and Issue[3], or date[4] or frequency	Publisher	Place and Year of Publication	Relevant pages	Permanent Identifiers[5]	Is/will be open access[6] provided to the publication?
	tomography								
50.	*Geometric adjustment of X-ray Tomosynthesis*	T. Grulich, W. Holub, U. Hassler **(FHG)**, A. Aichert, A. Maier	13th Fully Three Dimensional Image Reconstruction in Radiology and Nuclear Medicine	2015		Newport, RI, USA	pp. 468-470	https://www.fully3d.org/	

Table 6: List of dissemination activities

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
1.	Conference Presentation	Reh A., Plank B., Kastner J., Gröller E., Heinzl C. **(FHW)**	*Advanced Visualization Methods for Porosity in Carbon Fiber Reinforced Polymers*	1rst International Conference on Tomography of Materials and Structures (ICTMS 2013), Ghent, Belgium	01-05/07/2013	Industry, Higher Education, Scientific Community (European XCT community)	250	Europe, International
2.	Workshop Presentation	Heinzl C., Kastner J. **(FHW)**	*QUICOM - Quantitative inspection of complex composite aeronautic parts using advanced X-ray techniques*	3rd International EASN Association Workshop on Aerostructures, Milano, Italy	09-11/10/2013	Industry, Higher Education, Scientific Community (European aeronautic community)	150	Europe, International
3.	Conference Presentation	Reh A., Gusenbauer C., Kastner J., Gröller E., Heinzl C. **(FHW)**	*MObjects - A Novel Method for the Visualization and Interactive Exploration of Defects in Industrial XCT*	IEEE Visualisation and Computer Graphics Conference, Atlanta, Georgia, USA	13-18/10/2013	Industry, Higher Education, Scientific Community (Visualization community)	1000	International

[7] Conference presentation, workshop presentation, web based project information, press release, flyer , articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.
[8] Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias ('multiple choices' is possible).

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
			Data					
4.	Conference Presentation	Weissenböck J. **(FHW)**	*FiberScout: An Interactive Tool for Exploring and Analyzing Fiber Reinforced Polymers*	iCT2014 – 5th Conference on Industrial Computed Tomography, Wels, Austria	25-28/02/2014	Industry, Higher Education, Scientific Community (European XCT community)	250	Europe, International
5.	Banner/poster display and/or leaflet distribution	**FHW**	*QUICOM Banners – Project Overview and Progress so far*	iCT2014 – 5th Conference on Industrial Computed Tomography, Wels, Austria	25-28/02/2014	Industry, Higher Education, Scientific Community (European XCT community)	250	Europe, International
6.	Web-based Information	**FHW**	*The QUICOM project*	Project description in the FHW Website, (www.3dct.at)	03/2013	Industry, Higher Education, Scientific Community, General Public	To be completed	Europe, International
7.	Newsletter	**FHW**	*QUICOM Newsletter – First results available*	Contact with interested stakeholders	04/2013	Industry, Scientific Community	20	Europe, International
8.	Article published in the popular press	**FHW**	*QUICOM: QUantitative Inspection of COMplex composite*	Aeronautics and Air Transport Research 7th Framework Programme 2007 – 2013 (project Synopsis – Volume 3 Calls	16/01/2014	Industry, Higher Education, Scientific Community, Policy makers, General Public	Appx. 10.000	Europe, International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
			aeronautic parts using advanced X-ray techniques	2012& 2013)				
9.	Conference Presentation	Weissenböck J., Amirkhanov Ar., Li W., Reh A., Amirkhanov Al., Kastner J., Gröller E., Heinzl C. **(FHW)**	*FiberScout: An Interactive Tool for Exploring and Analyzing Fiber Reinforced Polymers*	IEEE Pacific Visualization Symposium (PacificVis) 2014, Yokohama, Japan	04-07/03/ 2014	Industry, Higher Education, Scientific Community	300	International
10.	Media briefing	**FHW**	*The QUICOM project*	"International erfolgreich: FH OÖ holt 2013 noch mehr EU-Forschungsgelder nach Oberösterreich", Linzer Landhaus (http://www.fh-ooe.at/news-events/aktuelles/news/news/article/international-erfolgreich-fh-ooe-holt-2013-noch-mehr-eu-forschungsgelder-nach-oberoesterreich/)	10/03/2014	Industry, Higher Education, Scientific Community, General Public	20	Austria
11.	Poster presentation	Weissenböck J., Arikan M.., Salaberger D., Heinzl C., Kastner J.	*Quantitative Messung und Visualisierung von Faserorientierung*	DGZfP Jahrestagung 2014, Potsdam, Germany	26-28/05/2014	Industry, Higher Education, Scientific Community	150	Europe, International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
		(FHW)	*s- und Faserlängenverteilung von Glas-, Kohle- und Zellulosefaserverstärkten Kunststoffen mittels µ-Röntgen-Computertomografie*					
12.	Conference Presentation	**FHW**	*Advanced Visualization and Exploration Techniques for Fiber Reinforced Polymers*	11th European Conference on Non-Destructive Testing (ECNDT), Prague, Czech Republic	6-10/10/2014	Industry, Higher Education, Scientific Community (R&D in CT technology)	1500	Europe, International
13.	Newsletter	**FHW**	*QUICOM Newsletter – Introduction to the QUICOM project*	Contact with interested stakeholders	12/2013	Industry, Scientific Community	20	Europe, International
14.	Conference presentation	C. Heinzl, J. Weissenböck, J. Kastner. **(FHW)** T. Dierig, T. Günther. **(VG)**	*Software tools for robust extraction, analysis and visualization of porosities in XCT*	6th Symposium for Non-Destructive Testing (NDT) in Aerospace, Madrid, Spain	12-14/11/2014	Industry, Higher Education, Scientific Community	300	Europe, International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
		D. Kiefel, R. Stössel. **(EADS)**	*scans of fiber-reinforced polymers*					
15.	Conference Presentation	Bhattacharya A., Wenger R., Heinzl C. **(FHW)**	*Meta Tracts - A Method for Robust Extraction and Visualization of Fiber Bundles in Fiber Reinforced Composites*	8th IEEE Pacific Visualization Symposium (PacificVis 2015), Hangzhou, China	14-17/04/2015	Industry, Higher Education, Scientific Community	300	International
16.	Conference Presentation	Heinzl C. **(FHW)**	*Fuzzy Feature Tracking Visual Analysis of Industrial 4D-XCT Data*	TBD	TBD	TBD	TBD	TBD
17.	Newsletter	**FHW**	*Focus on Phase 2*	Contact with interested stakeholders	02/2015	Industry, Scientific Community	20	Europe, International
18.	Workshop presentation	**C. Heinzl (FHW)**	*The QUICOM project – Overview and current state*	5th International EASN Workshop on Aerostructures, Manchester, UK	02-04/09/2015	Industry, Higher Education, Scientific Community (European aeronautic community)	150	Europe, International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
19.	Conference presentation	**C. Heinzl (FHW)**	*The QUICOM project – Overview and current state*	AERODAYS 2015, London, UK	20-23/10/2015	Industry, Higher Education, Scientific Community (European aeronautic community)	<5,000	Europe, International
20.	Workshop presentation	Jakubek J., Jakubek M., Jandejsek I., Platkevic M., Soukup P., Turecek D., Vavrik D., Zemlicka J. **(CTU)**	*X-ray inspection of composite materials for aircraft structures using large area single photon counting detector WidePix*	3rd International EASN Association Workshop on Aerostructure, Milan, Italy	09-11/10/2013	Industry, Higher Education, Scientific Community (European aeronautic community)	150	Europe, International
21.	Poster presentation	Jandejsek I. **(CTU)**	*X-ray Inspection of Composite Materials for Aircraft Structures Using Detectors of Medipix Type*	15th International Workshop on Radiation Imaging Detectors, Paris, France	23-27/06/2013	Industry, Higher Education, Scientific Community	200	Europe, International
22.	*Poster presentation*	Daniel Vavrik, Jan Jakubek, Ivan Jandejsek, Frantisek Krejci	*Visualization of the delamination within aerospace composite*	16th International Workshop on Radiation Imaging Detectors, Trieste, Italy	22-26/06/2014	Industry, Higher Education, Scientific	200	Word, International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
		Zemlicka **(CTU)**, Ivana Kumpova	*material utilizing advanced phase contrast and high resolution computed tomography techniques*			Community		
23.	*Conference Presentation*	Daniel Vavrik, Jan Jakubek, Ivan Jandejsek, Jan Zemlicka **(CTU)**, Ivana Kumpova	*X-ray radiography and tomography study of a delamination in a CFRP and honeycomb structures*	6th Conference on Industrial Computed Tomography – iCT2016, Wels, Austria	9-12/02/2016	Industry, Higher Education, Scientific Community (R&D in CT technology)	250	Europe International
24.	*Workshop Presentation*	J. Jakubek **(CTU)**	*Non Tomographic 3D Imaging of Delaminations in Multilayer Fiber Reinforced Plastic Composites Using Phase Sensitive X-ray Radiography*	5th International EASN Workshop on Aerostructures, Manchester, UK	02-04/09/2015	Industry, Higher Education, Scientific Community (European aeronautic community)	150	Europe, International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
25.	*Workshop Presentation*	D. Vavrik **(CTU)**	*Large area radioscopic inspection of the aerospace structures*	5th International EASN Workshop on Aerostructures, Manchester, UK	02-04/09/2015	Industry, Higher Education, Scientific Community (European aeronautic community)	150	Europe, International
26.	Workshop Presentation	Bliznakova K., Dermitzakis A., Kamarianakis Z., Buliev I., Pallikarakis N. **(UPAT)**	*Modeling of small CFRP aerostructure parts for X-ray Imaging Simulation*	3rd International EASN Association Workshop on Aerostructures, Milan, Italy	9-11/10/2013	Industry, Higher Education, Scientific Community (European aeronautic community)	150	Europe, International
27.	Leaflets distribution	**UPAT (LTSM)**	*The QUICOM project*	ICAF 2014-8th ICSAES Conference Series, 2nd International Conference of Air-Worthiness and Fatigue	14-18/07/2014	Industry, Higher Education, Scientific Community	150	Patras, Greece
28.	Conference Presentation	Stamopoulos A. Tserpes K. **UPAT (LTSM)** Vavrik D. **CTU** Prucha P. **LAC**	Characterization of Porous CFRP laminates by Mechanical Testing and X-Ray Computed Tomography	6th International Symposium on NDT in Aerospace, Madrid, Spain	12-14/11/2014	Industry, Higher Education, Scientific Community (European aeronautic community)	300	Europe, International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
29.	PhD Thesis	A.Stamopoulos **UPAT (LTSM)**	*Development of Mathematical Models for the Prediction of Strength of Composite Materials based on data acquired from X-CT tests.*	University of Patras	2017	Industry, Higher Education, Scientific Community	To be completed	Greece, Europe
30.	Workshop presentation	K. Tserpes **(UPAT)**	*Modeling of composite materials with fibre misalignment and porosity using X-ray computed tomography data*	5th International EASN Workshop on Aerostructures, Manchester, UK	02-04/09/2015	Industry, Higher Education, Scientific Community (European aeronautic community)	150	Europe, International
31.	Banner/poster display and/or leaflet distribution	**UPAT (LTSM)**	*The QUICOM project*	Patras IQ 2015 (2nd Patras Innovation Quest) http://www.patrasiq.gr/2015/	2015	Industry, Higher Education, Scientific Community, General Public	5000	Greece
32.	PhD Thesis	Ilya Straumit **(KUL)**	*Estimation of the mechanical properties of composite materials on the*	KU Leuven	2017	Industry, Higher Education, Scientific Community	To be completed	Belgium, Europe

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
			basis of X-ray computed tomography data					
33.	Master Thesis	Xinwei Zhang **(KUL)**	*X-ray analysis of internal structure of fabrics after deformation*	KU Leuven	2014	Industry, Higher Education, Scientific Community	To be completed	Belgium, Europe
34.	Web-based information	**KUL**	*The QUICOM Project*	Entity website (http://www.mtm.kuleuven.be/Onderzoek/ndt/Projects)	2013	Industry, Higher Education, Scientific Community, General Public	To be completed	Europe, International
35.	Web-based information	**KUL**	*The QUICOM Project*	Entity website (http://www.mtm.kuleuven.be/Onderzoek/Composites/projects)	2013	Industry, Higher Education, Scientific Community, General Public	To be completed	Europe, International
36.	Presentation	Wevers M., **(KUL)**	*CT in Material analysis*	CT in Science and Engineering, CT in production Quality Control, KU Leuven, Leuven, Belgium	4/06/2013	Higher Education, Scientific Community	100	Europe
37.	Conference Presentation	Straumit I., Lomov S., Verpoest I.,	*Determination of local fibers orientation in*	TexComp-11 conference, Leuven, Belgium	16-20/09/2013	Industry, Higher Education, Scientific	200	Europe, International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
		Wevers M. **(KUL)**	*composite material from micro-CT data*			Community		
38.	Distribution of project leaflets	**KUL**	*QUICOM leaflets*	TexComp-11, Leuven, Belgium	19-20/09/2013	Industry, Higher Education, Scientific Community	200	Europe, International
39.	Workshop presentation	Van de Casteele E., Wevers M. **(KUL)**	*Using micro-CT for studying inner structures of CFRP components*	3rd International EASN Workshop on Aerostructures, Milan, Italy	09-11/10/2013	Industry, Higher Education, Scientific Community	150	Europe, International
40.	Conference presentation	Straumit I., Lomov S., Wevers M. **(KUL)**	*Influence of the orientation of fibrous structures in a composite material relative to the sample's rotation axis on the local apparent degree of anisotropy derived from micro-CT*	Bruker Micro-CT User meeting, Ostend, Belgium	05-08/05/2014	Industry, Higher Education, Scientific Community (Micro-CT user community)	100	Europe, International
41.	Conference	Straumit I., Lomov S.,	*Automatic transformation of*	16th European Conference on Composite Materials	22-	Industry, Higher Education,	To be	Europe,

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
	Presentation	Bensadoun F., Wevers M. **(KUL)**	*3D micro-CT images into finite element models with anisotropic local properties*	(ECCM16), Seville, Spain	26/06/2014	Scientific Community	completed	International
42.	Conference Presentation	Straumit I., Plank B., Hahn C., Winterstein E., Lomov S. V., Wevers M. **(KUL)**	*Permeability estimation of composite preforms on the basis of 3D X-ray computed tomography images*	TexComp-12 Conference, Raleigh, NC, U.S.A.	26-29/05/2015	Industry, Higher Education, Scientific Community	TBD	International
43.	Conference Presentation	Straumit I., Bensadoun F., Lomov S. V., Wevers M. **(KUL)**	*Voxel-based modelling of textile composites from μCT data: the problem of matrix-yarns-voids segmentation*	9th European Solid Mechanics Conference (ESMC 2015) Leganés-Madrid, Spain	06-10/07/2015	Industry, Higher Education, Scientific Community	TBD	Europe
44.	Conference Presentation	Straumit I., Bensadoun F., Lomov S. V. , Wevers M.	*Effective properties of unidirectional flax/epoxy composites with*	20th International Conference on Composite Materials, Copenhagen, Denmark	19-24/07/2015	Industry, Higher Education, Scientific Community	TBD	Europe, International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
		(KUL)	*twisted yarns*					
45.	Conference Presentation	Ilya Straumit I., Lomov S. V., Wevers M. **(KUL)**	*Correction of the Localized Distortions in the Orientation Vector Fields Extracted from Images*	16th International Conference on Computer Analysis of Images and Patterns (CAIP 2015), Valletta, Malta	02-04/09/2015	Industry, Higher Education, Scientific Community	TBD	Europe, International
46.	Workshop presentation	Stoessel R. **(AIRBUS GROUP)**	*VG-Studio for CFRP applications*	1st VG user Workshop, Heidelberg Germany	18-19/09/2013	Industry, Scientific Community, Higher Education (VG Studio users)	50	Europe, International
47.	Conference Presentation	Kiefel D., Stoessel R. **(AIRBUS GROUP)** Plank B., Heinzl C., Kastner J. **(FHW)**	*CFRP porosity characterization using µ-Computed Tomography with optimized test parameters supported by XCT-simulation*	iCT2014 - 5th Conference on Industrial Computed Tomography 2014, Wels, Austria	25-28/02/2014	Industry, Higher Education, Scientific Community	200	Europe, International
48.	Conference Presentation	Kiefel D., Stoessel R., et.all **(AIRBUS GROUP)**	*Porosity evaluation in CFRP using CT*	Quantitative Non-Destructive Evaluation Conference (QNDE), Boise, USA	20-25/07/2014	Industry, Higher Education, Scientific Community, Policy	400	International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
						makers		
49.	Seminar presentation	Stoessel R., Kiefel D. **(AIRBUS GROUP)**	*µ-CT for CFRP inspection like porosity assessment and defect analysis*	Internal Airbus Group workshops like Airbus Group NDT Days	October 2013	Airbus Group NDT Experts, Managers and decision makers	50-70	Airbus Group France, Germany, Spain, UK
50.	Seminar presentation	Stoessel R., Kiefel D. **(AIRBUS GROUP)**	*µ-CT for CFRP inspection like porosity assessment and defect analysis*	Internal Airbus Group workshops like Airbus Group NDT Days	October 2014	Airbus Group NDT Experts, Managers and decision makers	50-70	Airbus Group France, Germany, Spain, UK
51.	Seminar presentation	Stoessel R., Kiefel D. **(AIRBUS GROUP)**	*µ-CT for CFRP inspection like porosity assessment and defect analysis*	Internal Airbus Group workshops like Airbus Group NDT Days	October 2015	Airbus Group NDT Experts, Managers and decision makers	50-70	Airbus Group France, Germany, Spain, UK
52.	Conference Presentation	Kiefel D., Stoessel R., et.all **(AIRBUS GROUP)**	*Reliability Optimization of Quantitative CFRP Porosity Characterization Using µ-XCT*	International Symposium on Digital Industrial Radiology and Computed Tomography Ghent, Belgium, 2015	22-25/06/2015	Industry, Higher Education, Scientific Community, Policy makers	To be completed	International
53.	PhD-thesis	Kiefel Denis	*Quantitative Porosity Characterization*	PhD Thesis, TU Munich, Germany	End of 2015/Beginni	Academics, PhD reviewer, invited	tbd	Germany, International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
		(AGI)	*of CFRP Materials with Micro Computed Tomography*		ng of 2016	people		
54.	Web-based information	**LAC**	*The QUICOM project*	QUICOM description in the company website (http://www.lacomposite.com/en/spolecnost-la-composite.html)	2013	Industry, Higher Education, Scientific Community, General Public	To be completed	Europe, International
55.	Conference presentation	U. Hassler, M. Rehak, W. Holub, E. Penne, T. Grulich	*Proposal of a data evaluation chain for the inspection of thermoplast clips*	2nd International Conference on Tomography of Materials and Structures (ICTMS 2015), Quebec, Canada	29/06-03/07/2015	Industry, Higher Education, Scientific Community	To be completed	International
56.	Conference Presentation	Ducros N., Rebuffel V. **(CEA)**, Bliznakova K., Dermitzakis A., Kamarianaki Z. **(UPAT)**, Hassler U., Osman A., Tigkos K. (**FHG)**	*Simulation study for optimization of X-ray inspection setup applied to CFRP aerostructrures*	iCT2014 – 5th Conference on Industrial Computed Tomography, Wels, Austria	25-28/02/2014	Industry, Higher Education, Scientific Community	300	Europe, International
57.	Workshop Presentation	Hassler U., Boehnel M., Errmann G.,	*High energy CT scanning applied to large*	3rd International EASN Association Workshop on	09-11/10/2013	Industry, Higher Education, Scientific	150	Europe, International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
		Osman A. **(FHG)**	*aerospace samples*	Aerostructures, Milan, Italy		Community (R&D in CT technology)		
58.	Conference Presentation	Tigkos K., Hassler U., Holub W., Woerlein N., Rehak M. **(FHG)**	*Regularisation approach for tomosynthesis x-ray inspection*	40th Annual Review of Progress in Quantitative Nondestructive Evaluation Conference, Baltimore, Maryland, USA	21-26/07/2014	Industry, Higher Education, Scientific Community	400	International
59.	Conference presentation	**SKZ**	*Röntgentechnik zur ZFP großer Faserverbundbauteile*	Innovative ZfP für moderne Kunststoffe, Wuerzburg, Germany	2014	Industry, Higher Education, Scientific Community	30	South germany
60.	Conference presentation	**VDI**	*Röntgentechnik zur ZFP großer Faserverbundbauteile*	Composites effizient verarbeiten, Nuremberg, Germany	2015	Industry, Higher Education, Scientific Community	200	Germany
61.	Conference presentation	**DGZFP**	*Process Integrated Inspection of Thermoplast Clips*	7th International Symposium on NDT in Aerospace, Bremen, Germany	2015	Industry, Higher Education, Scientific Community	300	Europe
62.	Poster presentation	**ICTMS**	*PROPOSAL OF A DATA EVALUATION CHAIN FOR THE INSPECTION OF*	2. International Conference on Tomography of Materials and Structures, Quebec, Canada	2015	Industry, Higher Education, Scientific Community	250	International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
			THERMOPLAST CLIPS					
63.	Poster presentation	**DGZFP**	*TOMOSYNTHESIS OF CURVED STRUCTURES INCORPORATION OF SURFACE INFORMATION*	Digital Industrial Radiology and Computed Tomography, Ghent, Belgium	2015	Industry, Higher Education, Scientific Community	300	Europe
64.	Conference presentation	**DGZFP**	*ROBO-CT UND TOMOSYNTHESE - LAMINOGRAPHISCHE MIKRO-CT*	DACH Jahrestagung, Salzburg, Austria	2015	Industry, Higher Education, Scientific Community	700	Germany, Austria, Switzerland
65.	Workshop presentation	W. Holub **(FHG)**	*Roboter based radioscopic inspection and computed tomography*	5th International EASN Workshop on Aerostructures, Manchester, UK	02-04/09/2015	Industry, Higher Education, Scientific Community (European aeronautic community)	150	Europe, International
66.	Newsletter	**EASN**	Progress updates of the QUICOM project in the EASN periodic newsletter	http://www.easn.net/newsletters/EASN_Newsletter_December_2012.html	12/2012	Industry, Higher Education, Scientific Community (European aeronautic	10000	Europe, International

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NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
						community)		
67.	Web-based information	**EASN**	*QUICOM public website*	QUICOM public website (www.quicom.eu, www.quicom-project.eu)	March 2013	Industry, Higher Education, Scientific Community, General Public	20[9]	Europe, International
68.	Web-based information	**EASN**	*The QUICOM project*	Project description in the EASN-TIS Website (http://www.easn-tis.com/projects-2/)	June 2013	Industry, Higher Education, Scientific Community, General Public	20[10]	Europe, International
69.	Web-based information	**EASN**	*The QUICOM project*	Project description in the EASN Association Website (http://www.easn.net/research-projects/2/)	06/2013	Industry, Higher Education, Scientific Community, General Public	98[11]	Europe, International
70.	Leaflets distribution & Poster display	**EASN**	*The QUICOM project*	ICEAF III - 3rd International Conference of Engineering Against Failure, Kos, Greece	26-28/06/2013	Industry, Higher Education, Scientific Community (European aeronautic	150	Europe, International

[9] 20 (12 news/8returning visitors) average daily pageviews according to www.googleanalytics.com
[10] 20 (15 news/5 returning visitors) average daily pageviews according to www.googleanalytics.com
[11] 98 (65 news/33 returning visitors) average daily pageviews according to www.googleanalytics.com

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
						community)		
71.	Newsletter	**EASN**	Progress updates of the QUICOM project in the EASN periodic newsletter	http://www.easn.net/newsletters/easn_newsletter_july_2013_files/EASN_Newsletter_July_2013.html	07/2013	Industry, Higher Education, Scientific Community (European aeronautic community)	10000	Europe, International
72.	Leaflets distribution, Poster & Banner display	**EASN**	*The QUICOM project*	3rd International EASN Workshop on Aerostructures, Milan, Italy	09-11/10/2013	Industry, Higher Education, Scientific Community (European aeronautic community)	150	Europe, International
73.	Newsletter	**EASN**	Progress updates of the QUICOM project in the EASN periodic newsletter	http://www.easn.net/newsletters/EASN_Newsletter_November_2013.html	11/2013	Industry, Higher Education, Scientific Community (European aeronautic community)	10000	Europe, International
74.	Newsletter	**EASN**	Progress updates of the QUICOM project in the EASN periodic	http://www.easn.net/newsletters/EASN_Newsletter_April_2014.html	04/2014	Industry, Higher Education, Scientific Community	10000	Europe, International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
			newsletter			(European aeronautic community)		
75.	Newsletter	**EASN**	Progress updates of the QUICOM project in the EASN periodic newsletter	http://www.easn.net/newsletters/EASN_Newsletter_July_2014.html	07/2014	Industry, Higher Education, Scientific Community (European aeronautic community)	10000	Europe, International
76.	Leaflets distribution, Poster & Banner display	**EASN**	*The QUICOM project*	4rth International EASN Workshop on Flight Physics and Aircraft Design, Aachen, Germany	27-29/10/2014	Industry, Higher Education, Scientific Community (European aeronautic community)	150	Europe, International
77.	Newsletter	**EASN**	Progress updates of the QUICOM project in the EASN periodic newsletter	http://www.easn.net/newsletters/EASN_Newsletter_December_2014.html	12/2014	Industry, Higher Education, Scientific Community (European aeronautic community)	10000	Europe, International
78.	Web-based	**EASN**	*The QUICOM*	Transport Research and	18/09/2014	Industry, Higher Education,	To be	Europe,

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
	information		*project*	Innovation Portal (TRIP) http://www.transport-research.info/web/projects/project_details.cfm?ID=47558		Scientific Community, General Public	completed	International
79.	Leaflets distribution, Poster & Banner display	**EASN**	*The QUICOM project*	ICEAF IV - 4th International Conference of Engineering Against Failure, Skiathos, Greece	24-26/06/2015	Industry, Higher Education, Scientific Community (European aeronautic community)	150	Europe, International
80.	Video Channel	**EASN**	*The QUICOM project*	https://www.youtube.com/channel/UCZM1R8G0IW8FcBblo0G8zSQ	2015	Industry, Higher Education, Scientific Community, General Public	10000	Europe, International
81.	Newsletter	**EASN**	Progress updates of the QUICOM project in the EASN periodic newsletter	http://www.easn.net/newsletters/EASN_Newsletter_April_2015.html	04/2015	Industry, Higher Education, Scientific Community (European aeronautic community)	10000	Europe, International

List of PERFORMED AND PLANNED **Dissemination Activities**								
NO.	Type of activities[7]	Main leader (Name/organization)	Title of the disseminated material	Title and place of the Dissemination Activity	Date	Type of Audience[8]	Size of audience	Geographic coverage
82.	Newsletter	**EASN**	Progress updates of the QUICOM project in the EASN periodic newsletter	http://www.easn.net/newsletters/EASN_Newsletter_July_2015.html	07/2015	Industry, Higher Education, Scientific Community (European aeronautic community)	10000	Europe, International
83.	Leaflets distribution, Poster & Banner display	**EASN**	*The QUICOM project*	5rth International EASN Workshop on Aerostructures, Manchester, UK	02-04/09/2015	Industry, Higher Education, Scientific Community (European aeronautic community)	150	Europe, International
84.	Leaflets distribution, Poster & Banner display	**EASN**	*The QUICOM project*	AERODAYS 2015 Conference	20-23/10/2015	Industry, Higher Education, Scientific Community (European aeronautic community)	3000	Europe, International

Section B: Exploitation (confidential)

All the information regarding Exploitation is confidential, therefore, there is no information to report in here.

Table 7: List of Exploitation activities

Type of Exploitable Foreground	Description of exploitable foreground	Confidential (yes/no)	Foreseen embargo date (DD.MM.YYYY)	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable, commercial or any other use	Patents or other IPR exploitation (licenses)	Owner & Other Beneficiary(s) involved

3. Report on societal implications

Replies to the following questions will assist the Commission to obtain statistics and indicators on societal and socio-economic issues addressed by projects. The questions are arranged in a number of key themes. As well as producing certain statistics, the replies will also help identify those projects that have shown a real engagement with wider societal issues, and thereby identify interesting approaches to these issues and best practices. The replies for individual projects will not be made public.

A General Information *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:	314562
Title of Project:	QUICOM
Name and Title of Coordinator:	Dr. Christoph Heinzl
B Ethics	
1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	***No***
2. Please indicate whether your project involved any of the following issues (tick box) :	
RESEARCH ON HUMANS	
• Did the project involve children?	No
• Did the project involve patients?	No
• Did the project involve persons not able to give consent?	No
• Did the project involve adult healthy volunteers?	No
• Did the project involve Human genetic material?	No
• Did the project involve Human biological samples?	No
• Did the project involve Human data collection?	No
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	No
• Did the project involve Human Foetal Tissue / Cells?	No
• Did the project involve Human Embryonic Stem Cells (hESCs)?	No
• Did the project on human Embryonic Stem Cells involve cells in culture?	No
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	No
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	No
• Did the project involve tracking the location or observation of people?	No
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	No
• Were those animals transgenic small laboratory animals?	No

• Were those animals transgenic farm animals?	No
• Were those animals cloned farm animals?	No
• Were those animals non-human primates?	No
Research Involving Developing Countries	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	No
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	No
Dual Use	
• Research having direct military use	No
• Research having the potential for terrorist abuse	No

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator (per partner)	2	9
Work package leaders	2	9
Experienced researchers (i.e. PhD holders)	6	32
PhD Students	1	8
Other	8	32

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**6**
Of which, indicate the number of men:	5

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project? ○ No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective				Very effective
x	Design and implement an equal opportunity policy	○	○	○	○	x
x	Set targets to achieve a gender balance in the workforce	○	○	○	x	○
❑	Organise conferences and workshops on gender	○	○	○	○	○
x	Actions to improve work-life balance	○	○	○	○	x
○	Other:					

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

x No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

x No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

x Yes- please specify materials for several university level lectures and training courses

○ No

F Interdisciplinary

10. Which disciplines (see list below) are involved in your project?

x Main discipline[12]: 2.

x Associated discipline[12]: 1.1 | x Associated discipline[12]: 1.2

G Engaging with Civil society and policy makers

11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*

○ Yes
x No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

○ No
○ Yes- in determining what research should be performed
○ Yes - in implementing the research
○ Yes, in communicating /disseminating / using the results of the project

[12] Insert number from list below (Frascati Manual).

11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ ○	Yes No

12. Did you engage with government / public bodies or policy makers (including international organisations)

- ○ No
- ○ Yes- in framing the research agenda
- ○ Yes - in implementing the research agenda
- ○ Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

- ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
- ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
- ○ No

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade Fisheries and Maritime Affairs Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy Research and Innovation Space Taxation Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ○ International level

H Use and dissemination

14. How many Articles were published/accepted for publication in peer-reviewed journals?	**41**
To how many of these is open access[13] provided?	**11**
How many of these are published in open access journals?	**-**
How many of these are published in open repositories?	**11**
To how many of these is open access not provided?	**19**
Please check all applicable reasons for not providing open access:	
X publisher's licensing agreement would not permit publishing in a repository X no suitable repository available X no suitable open access journal available X no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[14]: ……………	

15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**0**

16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	
	Registered design	
	Other	

17. How many spin-off companies were created / are planned as a direct result of the project?	**0**
Indicate the approximate number of additional jobs in these companies:	

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

x	Increase in employment, or	x	In small & medium-sized enterprises
x	Safeguard employment, or	x	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify		

[13] Open Access is defined as free of charge access for anyone via Internet.
[14] For instance: classification for security project.

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs: Difficult to estimate / not possible to quantify	*Indicate figure:*

I Media and Communication to the general public

20. As part of the project, were any of the beneficiaries professionals in communication or media relations?

Yes

21. As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

x	Press Release	x	Coverage in specialist press
x	Media briefing	x	Coverage in general (non-specialist) press
❑	TV coverage / report	x	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
x	Brochures /posters / flyers	x	Website for the general public / internet
x	DVD /Film /Multimedia	❑	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

x	Language of the coordinator	x	English
❑	Other language(s)		

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)

3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)

3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES

4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)

4.2 Veterinary medicine

5. SOCIAL SCIENCES

5.1 Psychology

5.2 Economics

5.3 Educational sciences (education and training and other allied subjects)

5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES

6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)

6.2 Languages and literature (ancient and modern)

6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]