PROJECT DELIVERABLE REPORT

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Project acronym: **DOTNAC**

Project title: **Development and Optimization of THz NDT on Aeronautics Composite Multi-layered Structures**

Funding Scheme: **Collaborative Project - Small or Medium Scale Focused Research Project**

FINAL REPORT

4.1 Final publishable summary report

4.1.1 Executive summary

The availability of light and robust structures has led to an increased use of composite materials in the aircraft industry. In order to verify and guarantee the high quality of the conventional and new composite elements, innovative approaches for non-destructive testing of these parts are required.

The European research project "DOTNAC" proposes to develop a fast, high resolution, noninvasive and non-contact inspection system for assessing aeronautic composite parts during production using terahertz waves. Conventionally two categories of systems can be discussed: pulsed and continuous wave terahertz systems. Both have been realized and their respective potential as a non-destructive inspection tool has been evaluated.

The implemented FMCW (Frequency-Modulated Continuous-Wave) system is an all-electronic THz system. It consists of three scanning heads with different frequency ranges (around 100 GHz, 150 GHz, and 300 GHz). They are used to acquire data by scanning a sample placed in front of them in reflection mode. Combining the measured in-depth information with a lateral scanning, a 3-D image can be built up. The in-depth resolution depends on the used bandwidth and the roughness of the sample surface, and varies between 2 mm and 6 mm. For the construction of the TDS (Time-Domain System), a pulsed laser system has been implemented in a fibre-optical ECOPS (Electronically Controlled Optical Sampling) pump-probe set-up. The two short-pulse lasers (one for the emitter, one for the detector) are based on Erbium-doped silica glass fibres and emit around 1560 nm centre wavelength. The in-depth resolution is significantly better than the one obtained with the FMCW THz system at the expense of a lower penetration capacity for the materials and structures tested within the scope of the project. The across-range resolution depends again on the beam focus and is comparable to the one of the FMCW system using the focused configuration. The main trade-off that needs to be considered for the TDS is the one involving measurement speed and signal-to-noise ratio.

To achieve these objectives, a series of 20 flat glass fibre reinforced plastics (GFRP) samples (solid laminates and sandwich structures), and 5 carbon fibre reinforced plastics (CFRP) were modified by artificial defects such as inserts, stucks, water inclusions, etc., to create well-controlled and well-known samples to validate the THz systems and algorithms with. In a next step the evaluation as a THz NDT method has been performed on 50 blind samples (12 GFRP and 38 CFRP samples) with embedded defects caused by an intentional miss-process. For validation and evaluation respectively, both THz systems under test have been installed on a two-dimensional scanner for sample inspection. A proof of concept has been provided using a three-dimensional motion platform to demonstrate the feasibility of THz inspection on a real aircraft object.

For the full assessment of the THz NDT performances, all the above-mentioned samples have been inspected by the following conventional techniques: thermographic NDT, radiographic testing (film and digital radiography and computed tomographic radiography testing), and ultrasound testing (2-D Inverse Wave Field Extrapolation, Phase Array, Pulse Echo, and Through Transmission). The best performances per inspection method and per sample/defect type have been identified to demonstrate complementarity between the respective NDT methods or their individual performance.

Regarding the feasibility of a THz application in aeronautics, i.e. inspection of dielectric parts, the THz

technology has proved to be a valuable technique for NDT. The technique is able to detect:

1. Delaminations and foreign inclusions in dielectric laminates such as glass fiber laminates.
2. Delaminations and disbonds in dielectric sandwich structures such as A-sandwich or C-sandwich structures with either honeycomb or syntactic foam cores.

In addition the technique is very sensitive to coating misprocess on conductive substrate such as CFRP and probably to the same extent on dielectric substrates such as glass fiber. On the other hand THz failed to detect porosity in glass fiber laminates. The capability of THz NDT for porosity detection should be further investigated.

In comparison with the classical NDT techniques, NDT-THz looks very competitive. It does not require high and costly radiation protection such as for X-Ray radiography and is totally non-contact in contrast with ultrasound.

To conclude, the performed assessment shows that FMCW and TDS can be considered as complementing techniques that should be tightly associated. The same conclusion can be formulated here, i.e., a combination of the two techniques investigated in this project, FMCW and TDS, seems to be the ideal way of applying THz in NDT. FMCW can provide fast scanning at high detection sensitivity. TDS can complete the data at the critical area by providing very accurate measures of defect sizes and depth at the expense of testing time.

4.1.2 Summary description of the project context and the main objectives

In recent years, the development of THz systems has made a considerable progress and made possible a variety of innovative applications. Among them, Non-Destructive Testing (NDT) of composite materials can take advantage of the high transparency of certain non-conductive materials at THz frequencies. The presence of such materials is foreseen to increase in the next years, especially in aeronautics. Glass-fiber (GF) laminates or composite structures are currently being used thanks to their outstanding structural properties, durability and lightness. In response to the growing industrial interest on these materials, the European research project "DOTNAC" proposes to develop a fast, high resolution, noninvasive and non-contact inspection system for assessing aeronautic composite parts during production using terahertz waves.

Through the realization of an advanced in-process inspection and quality control during the production phase and at the same time an advanced technique for continuous health and usage monitoring of structures and systems, the DOTNAC project opens possibilities to reduce aircraft development, production and operational costs. Indeed, by detecting defects in composite material as early as possible in the production chain, the scrapping or rework of a component can be avoided, contributing immensely to the cost of part production. At the same time, the same non-invasive, non-contact THz inspection technique can be used for assessing composite part condition in service. This type of inspection can effectively and efficiently support the high standards of composite construction and repair, thereby reducing the aircraft operational cost.

The main goal of the DOTNAC project is to develop a fast, high resolution, non-invasive and non-contact inspection system for assessing aeronautic composite parts either during production or maintenance. The developed NDT tool will be easy to integrate in industrial facilities and will fill in the performance gaps that are still present amongst the existing NDT techniques. It will therefore be an extremely useful tool in NDT in terms of sensor fusion. This new method will not replace directly the existing NDT tools, but will deliver complementary results which can be sometimes more precise for some defects.

Achieving this entails the following specific objectives:

- To create an integrated (hardware-software) and optimized THz imaging system using pulsed signals and optical fibre coupling.
- To create an integrated (hardware-software) and optimized THz imaging system using continuous wave signals and electrical cable coupling.

- To demonstrate, in an industrial setting, the effectiveness of a THz NDT tool.
- To assess the performances of the 2 developed THz NDT tools for assessing aeronautic composite parts.
- To develop a user/research community for fast, high resolution, non-invasive & non-contact inspection for assessing aeronautic composite parts during production.

4.1.3 Description of the main S&T results

S&T results can be described at following levels:

- With respect to the hardware:
  - FMCW THz system: system was acquired prior to DOTNAC but optimized for the application as described in DOTNAC
  - TDS THz system: system has been developed from scratch within the frame of DOTNAC
  - Motion platform: system has been developed for a tailored used within the frame of DOTNAC
- With respect to the developed software:
  - Data fusion software for the focused FMCW data
  - Synthetic aperture processing for the wide aperture FMCW data
  - Tomographic processing for the multi-angle TDS data
- With respect to the tested NDT potential:
  - Creation of a full set of samples with defects representative for aeronautics applications
  - Exploitation of the results obtained with conventional NDT techniques and the THz tools

<u>S&T results related to hardware</u>

Originally the FMCW THz system was designed and fabricated by SynViewn during DOTNAC the system has been modified and optimized by Fh-IPM to fulfill the objectives defined for DOTNAC.

The system is 2.5 m high, 1.5 m long 1.2 m wide having a total weight of 300 kg. On its side there is the data acquisition unit, the computer and power alimentation together in a tower. The maximum sample size is limited to 700x700 mm in surface and the maximum scan range is 600x689 mm. The dimensions of the optics limit also the maximum sample thickness to 90 mm for the optic with a focus of 50 mm and to 380 mm for the optic with a focus of 200 mm.

As mentioned in the DoW the FMCW system consists of three scanning heads with different center frequencies (100 GHz, 300 GHz and 850 GHz). After the first tests, the 850 GHz scanning head was replaced by 150 GHz due to poor results. The materials used for the DOTNAC samples made this change necessary. The scanning heads were used to acquire data by scanning a sample placed in front of them in reflection mode (see Figure 1).

Figure 1- Photographs of the FMCW system. Left: side view with housing and control unit. Right: view from the front side showing the three transceivers and three receivers in transmission assembly. The z-direction between the transceivers and receivers is fix

	100 GHz	150 GHz	300 GHz	850 GHz
Frequency range	0.07 THz – 0.11 THz	0.11 THz – 0.17 THz	0.23 THz – 0.32 THz	0.84 THz – 0.87 THz
Bandwidth	40 GHz	60 GHz	90 GHz	
Dynamic range (acquisition times are per pixel)	> 40 dB (at acquisition time 100 µs) > 60 dB (at acquisition time 10 ms) > 70 dB (at acquisition time 100 ms)	> 40 dB (at acquisition time 100 µs) > 60 dB (at acquisition time 10 ms) > 70 dB (at acquisition time 100 ms)	> 35 dB (at acquisition time 100 µs) > 50 dB (at acquisition time 10 ms) > 60 dB (at acquisition time 100 ms)	> 25 dB (at acquisition time 100 µs) > 40 dB / (at acquisition time 100 µs) > 50 dB (at acquisition time 100 µs)
Spatial resolution (laterally)	3 mm	2 mm	1 mm	0.4 mm
Depth resolution in air	9 mm	6 mm	3 mm	10 mm
Depth resolution in typical materials	6 mm	4 mm	2 mm	15 mm

Table 1 - System specifications of the FMCW THz system.

Fh-IPM has done measurements in order to check the manufacturer's specifications. Three metal bars were installed as a sample and measured in transmission and reflection using different frequencies. The dynamic range was determined for two different focusing optics (50 and 200 mm). As a result one can confirm the information provided by the manufacturer (see Table 1).

Fh-IPM has developed a visualization software: An image-editing software for presentation of samples measured using FMCW is available. All levels in X, Y and Z direction are scaled as the signal-noise ratio. Different filters can be used for better representation. 2D and 3D representations are possible. It is possible to set and to display different cut plane. A presentation in color as well as in grey tones is possible.

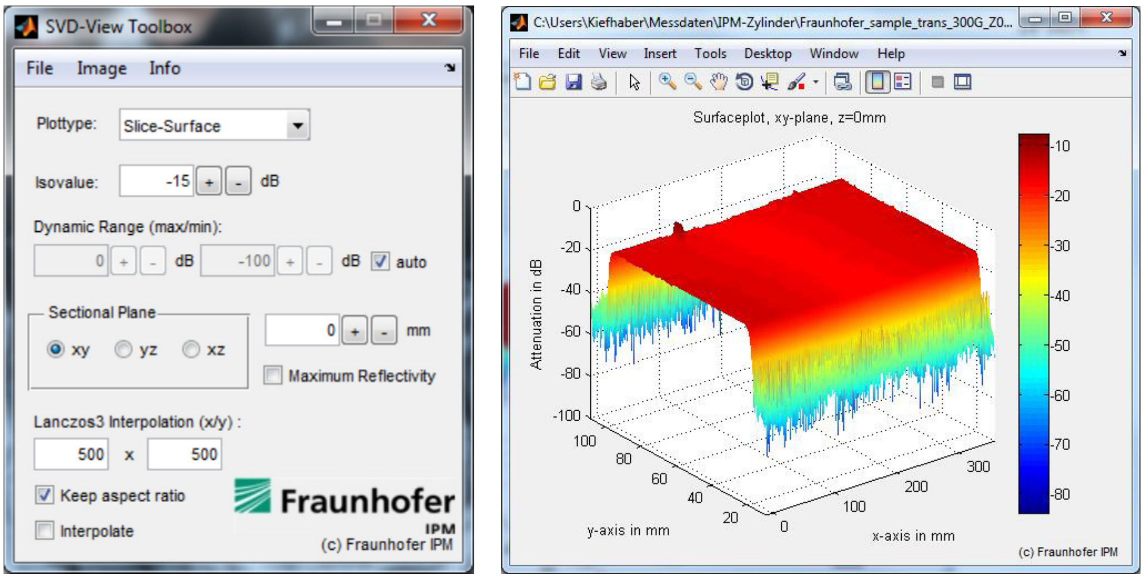


Figure 2- Left: SVD view toolbox. Right: 3D illustration of a test pattern.

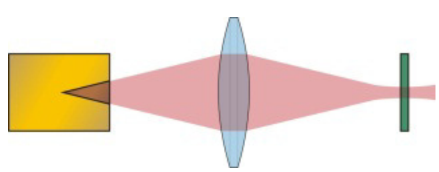
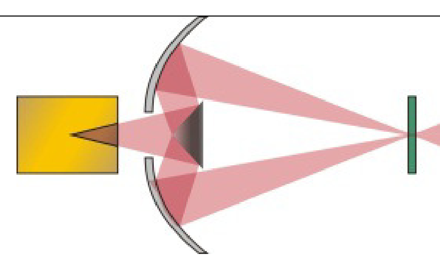
Setup with measuring head, lens and sample	Setup with measuring head, prism, parabolic mirrors and sample
	
A-Sandwich with rohacell, 100 GHz, front	A-Sandwich with rohacell, 100 GHz, front

Figure 3 - Testing of different optics to evaluate the trade-off azimuth resolution versus in-depth information

The focused set-up uses a set of lenses creating a focused beam with a beam waist characterized by the Rayleigh length. Depending on the type of optics, a trade-off can be made between azimuth resolution and in-depth information. For that reason different sets of optics have been test out and an assessment on the image quality has been made.
To complete the list of configurations, a wide angle set-up was tested out (omitting the lenses all together) and a specific calibration procedure for this measurement configuration has been created. The processing of the acquired data is discussed in the software section hereafter.

The complete FMCW system has been mounted on a 3D scanning system (see description hereafter), developed by Verhaert. After a fully integrated and optimized hard- and software, the developed THz NDT tool has been used to image the initially defined composite materials and structures.

As a complementary system to the FMCW THz system the TD THz system has been developed from scratch within the project. The TD THz system is equipped with a twin femtosecond laser configuration (with approximately 1560 nm centre wavelength), in which the repetition rate of one of the lasers can be either synchronized to the other or deliberately modified to induce a fixed or variable time delay between the laser pulses. Both lasers are terminated with an external fibre delivery of more than 6 m length which is internally pre-compensated with respect to dispersion and non-linear pulse broadening. The time window that can be captured in ECOPS[1] mode at 100 Hz scan rate is 146 ps. The system itself would allow operation at higher frequencies (500 Hz was tested), but the integrated data acquisition architecture so far only runs at 10 Hz. This is, however, not a fundamental limit. The lasers, their control electronics, further electronics for generation, read-out and amplification of the THz pulses (voltage source, waveform generator, voltage amplifier) are placed in a mobile cubic rack with less than 100 kg total weight that serves as basic supply unit for the TD system to drive the remote sensor and feed the data to the DAQ card and software, which are installed on a dedicated PC. The system requires only access to a standard European 230 V AC power socket.
The sensor heads for emitter and detector contain photoconductive antennas that are permanently coupled to fibre patchcords for connecting them rigidly with the pump lasers. THz radiation is coupled out and in, respectively, by highly resistive silicon lenses. For THz beam shaping, each head includes an internal collimating and an external focusing lens (material: TPX). To match the working distance of the 3D scanner unit, 200 mm is chosen as focal length. The THz optical elements are aligned and rigidly positioned by means of an opto-mechanic cage system. The sensor heads are mounted on a common baseplate for reflection measurements under an angle of incidence to the sample normal of 10°. This baseplate also incorporates a transimpedance amplifier for pre-amplification of the signal close to the detector. The weight of the sensor assembly is less than 2 kg. For the analysis of alternative THz optics and the measurements on planar samples in an XY-stage, the focusing optics can be easily dismounted and exchanged. Additionally, a second baseplate was manufactured in which the relative angle of the measurement heads can be changed to accommodate different working distances.
The standard sensor assembly can be integrated into the 3D platform (see description of motion platform hereafter) via a mating bracket; the 6 m long fibre delivery facilitates the execution of the scan trajectories. The DAQ software was integrated with the motion platform control routines into a TD 3D scan interface.

[1] Electronically Controlled Optical Sampling

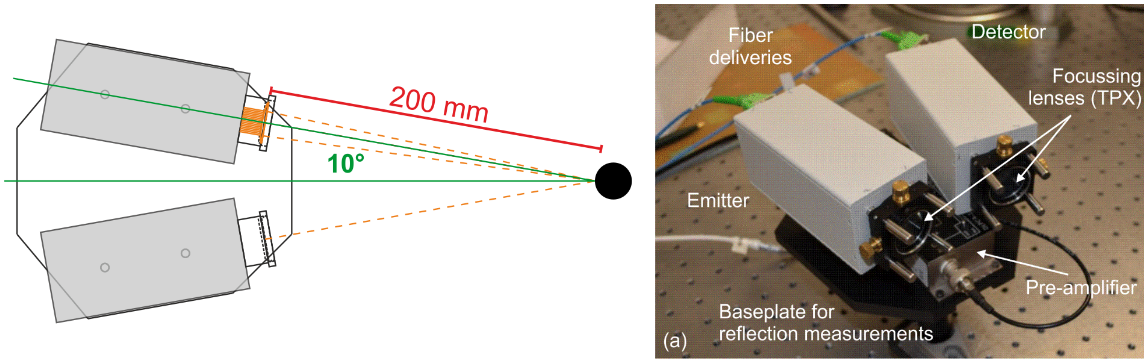


Figure 4 - Left: Schematic of the sensor assembly (top view); the full black circle represents the test radome. Right: The assembled TD sensor mounted on an optical table.

Concerning the motion platform for the testing of complex shaped objects, the original requirements described in the DoW to build an XYθ scanning stage have been replaced since they did not take into account that the sensor has to be perpendicular and at fixed distance to the surface. Instead, the requirements evolved towards an XYZθψ scanning stage. The addition of more stages clearly increases the complexity and cost of mechanical components, hardware and software. For the testing of the motion platform, a radome has been chosen as test object.

During a first concept study phase, multiple layouts have been evaluated. In the end, a concept was chosen which offered the best balance between fulfilling the requirements stated in the previous chapter and available budget. Small concessions had to be made, e.g. by allowing that only 70% of the radome surface has to be scanned, size could be reduced and one motion stage less had to be integrated. These concessions were made to reduce complexity and cost overruns due to changes with respect to the original DoW.

Figure 5 shows the final design. It consists of 3 linear axis and 2 rotation axis. Both the sensor and sample will perform a smooth synchronized motion such the surface can be scanned with high precision and as fast as possible.

To be able to obtain high accuracy, at least part of system has to operate in real-time. However, real-time systems such as PLC's do not offer the same flexibility as a Windows based system. Therefore, a mixed system was chosen. The host system consists of a Windows based PC which does not operate in real-time. However, the host PC incorporates a motion controller board and a DAQ board which can operate in real-time by themselves.

Communication is required between the two boards to allow synchronization between motion and data acquisition. This is done using a direct hardware link (NI RTSI bus) such that the communication happens in real-time and is not randomly delayed by the host OS. Figure 5 shows the overall system architecture.

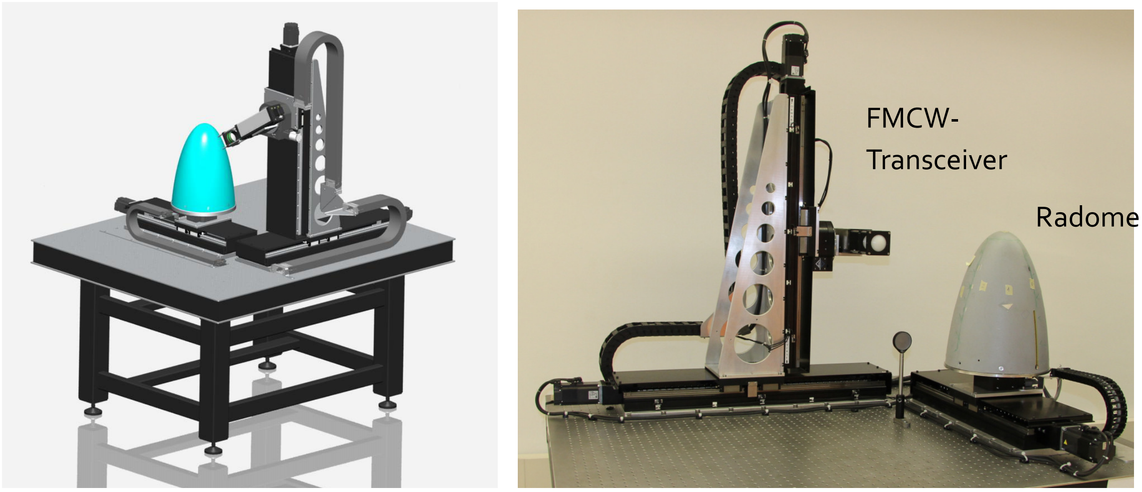


Figure 5- Left: 3D CAD model of the 5-axis motion platform; Right: Photograph of the realized motion platform with mounted FMCW-Transceiver and radome test sample.

The motion controller board is a National Instruments PCI 7356 board and the data acquisition board a National Instruments PCI 6115 board.Following limitations have been identified: The targeted scan speed of 1 m/s cannot be reached in all cases. The linear stages have a maximum allowable speed of > 1m/s. However, due to their limited length and limits on the acceleration, this speed cannot always be reached. The effect on total scan times will be very limited.

<u>S&T results related to software</u>

For the FMCW focused set-up, a data fusion software has been created. In FMCW, the depth resolution depends on the bandwidth of the radiated frequency ramp.

The 300 GHz head uses a wide frequency band of 90 GHz and thus has a good depth resolution which is considerably better than that of the 100 GHz and 150 GHz heads. However much of the materials relevant to the DOTNAC project are not well transparent for 300 GHz radiation while on the other hand a depth resolution of 4 mm (150 GHz head) is not sufficient to detect some of the defects. Thus the aim of the data fusion software is to merge the data from the 100 GHz and 150 GHz heads creating SVF files with 100 GHz bandwidth resulting in a depth resolution that competes with the 300 GHz heads at the good transparency of low-frequency THz radiation.

In order to prepare data fusion, several steps are performed.

- Before the measurements, the FMCW heads are calibrated with a set of calibration mirrors.
- The frequency axes of both heads are aligned by Fourier transformation and zero padding.
- Depending on the precise hardware characteristics, there may be a small frequency gap between the 100 GHz band and the 150 GHz band. This gap is closed with a suitable algorithm.

After these preparations the SVF files from both heads are merged into a single wide-band SVF file.

Application of the data fusion on focused FMCW data has been proven to be very effective for better in-depth resolution of defects.

For the wide angle configuration of the FMCW system, appropriate data processing algorithms have been developed to compress the unfocused raw data. Conventional synthetic aperture algorithms were studied, developed and adapted to be applied into wide-beam measurements in NDT. A flexible SAT[2] simulator was created reproducing the FMCW sensors that would be used in future real NDT

[2] Synthetic Aperture THz

situations. Theoretical and simple scenes (point targets) were simulated and reconstructed using 2-D SAT algorithms. Real measurements replicating simple scenes, using a corner reflector, were also tested out as a validation of the implemented algorithms. SAT algorithms were extended to handle 3-D SAT data volumes produced by 2-D scans of flat samples. According to the experimental results obtained (Table 2), frequency-domain algorithms were chosen since time-domain algorithms presented unfeasible running times for very similar image qualities.

SAT algorithm	Time	Technique
Time-Domain	~ 7 hours	Convolution
Time-Domain, approx.	~ 10 min	Inner product
Range-Doppler	< 2 min	FFT/IFFT
Omega-k	< 1 min 40 sec	FFT/IFFT

Table 2 - Performances of different 3-D SAT algorithms are compared.

After validation of the 3-D SAT algorithms with arbitrary scenes, real composite calibration samples on Rohacell and honeycomb cores were measured and reconstructed. Detection capabilities are limited by a combination of the reflectivity of the each defect's material and its size. Those defects physically smaller than the system's resolution cell will not be imaged correctly, regardless their reflectivity properties.

In parallel, the image processing methodology tool for semiautomatic target detecting in 3-D SAT imagery was developed, first on simple and more complex scenes generated by the SAT simulator.

Denoising and image contrast enhancement procedures were used to obtain such results.

As a part of the optimisation stage, the following actions were taken:

- Reducing data collection in azimuth and elevation to the minimum.
- Restricting the ranges of interest where SAT processing will be applied.
- Efficiency enhancement: single-precision data, using less volatile memory by allocating and deallocating data structures during the execution of the 3-D SAT processing, and avoiding dynamic memory allocation.
- A dedicated noise reduction and image enhancement routine.
- Image processor that promotes sensitivity vs. robustness.

Moreover, a test bed for circular SAT processing was initiated in accordance to the possibilities of performing radome measurements within the project timeframe. Using as a starting point the 2.5-D scanner delivered by Verhaert, a simulator for circular, non-constant radius scanning paths was developed.

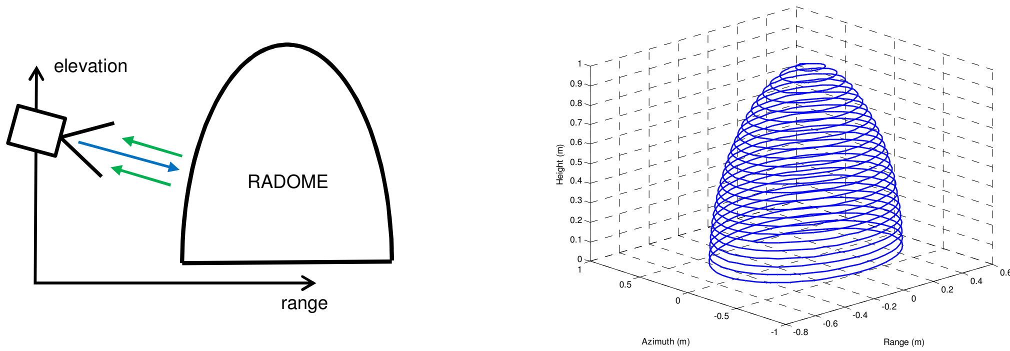


Figure 6 - Left, schematic showing a sensor-radome configuration. Right, simulated scanning path of a sensor whose radius varies in elevation following the shape of an arbitrary radome.

Graphic user interfaces (GUI) were created for an easy, intuitive and completely guided use of the SAT processing algorithms and raw FMCW data visualisation.

Qterahertz is a software specially realised for THz imaging (by Bordeaux University). It was determined to be a robust tool for the non-destructive evaluation of multi-layered materials and volumetric opaque objects. Two principal imaging architectures (pulsed TD system and FMCW system) were developed for performing THz imaging. The TD imaging technique has the ability to gather material dependent spectroscopic information about the sample. In addition, the time-of-flight of THz electric field allows one to obtain image data that provide information about the thickness, composition and structure of the surface and hidden layers.
THz time-of-flight technique will be utilized in order to resolve defects embedded beneath and to determine the thickness of layers. The quality of the images was dependent on the contrast of the spectral responses of the media with respect to each other as well as absorption of all the covering layers.
The program makes it possible to select a specific parameter employed to build the image. In the time domain, we can select the amplitude for a specific time-delay, the maximum or minimum amplitudes, the contrast (difference between maximum and minimum values) or the time delay corresponding to the maximum amplitude (so called "phase-delay" image). In the frequency domain, we can simply select the amplitude for a specific frequency in order to perform spectroscopic THz imaging from 0.1 to 3 THz.
This new tool is especially dedicated to developers or end users. It is very efficient due to the huge quantity of data, information we have to collect, to analyse during image processing in the terahertz range.

For the 3D reconstruction of TD data, the tomosynthesis approach has been evaluated. Tomosynthesis is inspired from a medical imaging technique especially used to reconstruct mammography images. This method of acquisition allows a 3D reconstruction of small depth objects from a few numbers of projections. Unlike Tomography where projections are measured all around the object, in tomosynthesis, they are done according to a limited range angle (usually between -50° and 50°). To recover a XY plane for a specific Z position, we use an algorithm that superpose and shift all the acquired projections. All we have to do is superposing point by point all the projections. This operation gives a plane of focus. In order to have another focus, it is necessary to shift the projections before performing the superposition. The shifting process determines the depth where we focus. The OCT or time of flight principle (TOF), the signal obtained depends on the amplitude and the optical way of an electromagnetic wave reflected or backscattered. Instead of the transmission tomography where the ray crosses entirely the object, in OCT, the ray will be reflected by the internal structure of the object. As in the tomosynthesis technique each plane are acquired depth per depth. However, the only data collected are in the plane of the detectors all the other data are lost.

Moreover, we extracted the frequency dependent refractive index of a 3D target thanks to phase knowledge and a challenge would be to reconstruct a trustworthy image of the device with the filtered back projection algorithm. However, we faced the drawback which is related to the fact that this approach will be very time consuming from technological point of view but also from a numerical point of view. Probably some trade-off will have to be done between resolution and computation time. Additionally an array of detectors should be tested out with the (X,Y,_) scanning platform by CNRS in an attempt to reduce the data acquisition time by a significant factor. Efforts to improve the lateral resolution of the setup must be carried out in synchronisation with the implementation of the mechanical stage for the 3D acquisition.

<u>Assessment of the THz NDT potential</u>

The ultimate goal of DOTNAC was the evaluation of the THz technology as a NDT tool applied to composite materials used in aeronautics and their typical defects. To reach this objective, different groups of samples were manufactured and typical defects were intentionally produced in them. Taking into account the main characteristics of composite materials employed in the aeronautical industry and the most common defects, a variety of samples was produced to calibrate the THz system during the system integration and to compare the THz inspection results with the ones obtained with traditional NDT methods.

The tested defects were the most typical defects encountered in the aeronautical industry, i.e, delaminations, foreign inclusions, debonds, porosity, surface and near subsurface scratch. Moreover coating issues on both conductive/ dielectric composites were also investigated.

These samples were manufactured in two different materials, conductive and dielectric materials, and the characteristics of the samples are briefly resumed in the following paragraphs.

After some preliminary inspections with THz technology the calibration samples were inspected by means of the different NDT technologies, as well conventional as with the FMCW and TD THz system.

The results obtained from the series of inspections were analysed and afterwards a comparative study among the conventional and THz NDT techniques was realized.

As a result of the comparative study carried out to this group of samples, different statistical graphics have been produced showing the capabilities of detection of the NDT technologies and comparing with each other. An example for the sandwich structures has been given in the figure below.

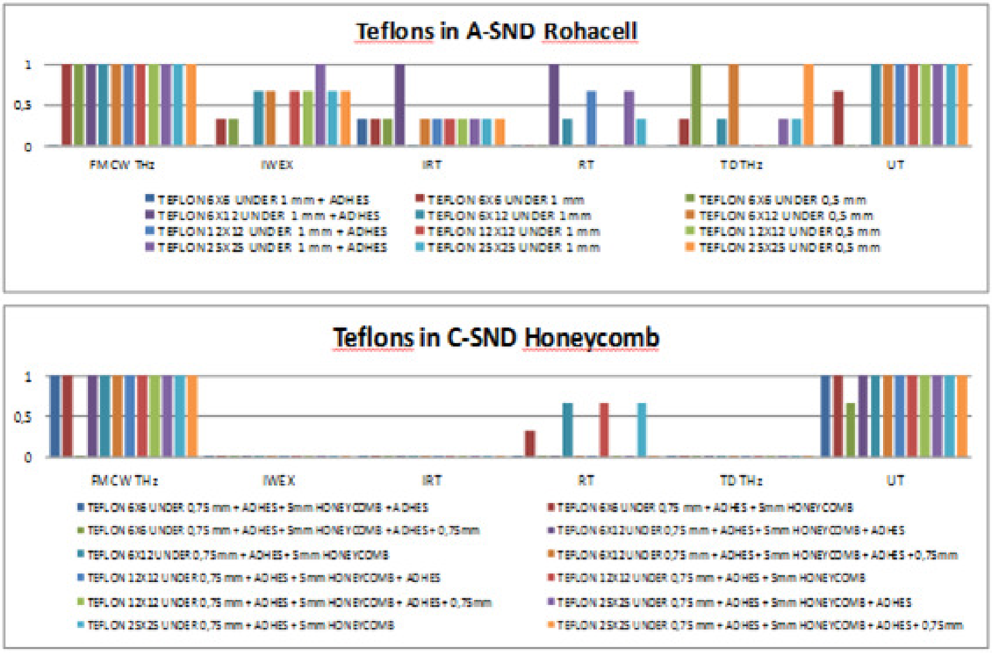


Figure 7 - Comparative analysis of the level of detection of Teflons obtained with the different NDT techniques in sandwich samples

For the effective and efficient management of the enormous amount of measured test data, a web-based centralized platform has been created. Through this platform the analysis of all the data collected from the NDT inspections could be efficiently realized. The centralized platform was programmed by CIMNE and allowed the upload of the results of the inspections as well as the necessary information regarding the test conditions. After several proposals provided by the consortium, the final solution chosen for the structure of the platform was the organisation of the data according to the type of materials, type of defects and type of NDT technique applied, enabling an advanced and automatic analysis methodology.

In the image below an overview of the graphic style and general contents of the platform is shown. The URL to access the platform is: https://www.dotnac-project.eu/dap.

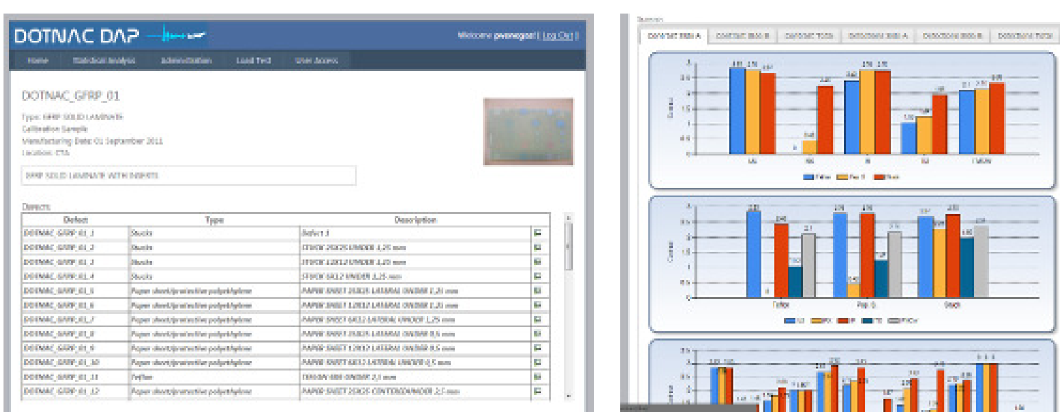


Figure 8 - Statistical analysis in the DAP (right) and uploaded results shown in the DAP (left).

Last but not least, the full validation of the THz systems has been performed by applying the same series of conventional and THz techniques on a specifically created group of blind samples. Again a comparative analysis has been performed for the final assessment of the THz NDT potential. And finally an on-site test was organized to demonstrate the THz capability on a radome within an industrial environment.

Regarding the comparison of the two THz systems with the conventional NDT techniques tested (i.e., Infrared Thermography (IRT), Radiography (RX) and Ultrasounds (UT)), it has been verified that:

- The evaluated TD THz system outperforms any of the other NDT methods tested for the inspection of coating misprocesses (even with regard to the IRT).
- The FMCW THz system clearly overcomes the UT inspection difficulties for C-sandwich structures with foam or H/C core (in the case of portable UT systems) and, in some cases, even the inspection by RX as well.
- Furthermore, the results obtained by the FMCW THz system on these types of components are totally comparable to those resulting from the NDT techniques of IRT and UT non-portable systems ("in-workshop" UT systems).
- For the two developed THz systems, these have shown an equal / similar detection level that IRT, RX and some of the UT methods performed in the case of the A-sandwich foam or H/C core components. And, additionally, it has also been observed that:
    - In the case of Group G (A-sandwich H/C and C-sandwich H/C panels with real debonds or delaminations), the smaller defects of less have not been well resolved, although the FMCW results are better than the corresponding TD.
    - In the case of Group H (A-sandwich (Rohacell core) panels with real debonds) the better results are for TD instead of FMCW.
- For Fiberglass Solid Laminates has been verified that both THz systems are clear alternatives for the inspection by RX and that, when the obtained THz signal is subsequently processed (signal processing), both systems have yielded quite comparable results to those obtained by UT.

Regarding the application of the two THz systems as NDT tool for the different materials / structures tested, it can be stated that the THz waves have the capacity to see-through different sample configurations of FGRP composites (such as laminates, foam and sandwich structures) and, therefore, can detect most of the relevant defects which can be found in aeronautical composite parts (such as delaminations, odd materials, inclusions, among others).

Based on the different tests performed in this part of the project:

- The THz technology is capable of penetrating the FGRP sandwich panels, beyond the foam and honeycomb cores (one of the main limiting factors of the conventional NDT techniques).
- Among the two THz systems examined, FMCW ("Frequency Modulated Continuous Wave System") seems to be the one with the widest spectral application for typical FGRP composite materials found in aeronautics.
- For composite materials made of CFRP (which are not testable in the THz region due to their transparency), the positive detections have been limited only to the case of coating misprocesses inspected by TD.

Regarding the logical end user requirements of *maximum testable thickness* / *minimum defect size detectable* the tests performed by the developed THz systems have demonstrated the good trade-off between its penetration capacity versus resolution achieved. In the case of the FMCW THz, although the penetration capacity is conditioned to the nature of the material, a depth comprised between 1cm to 3cm is easily achieved, whereas it cannot exceed 1cm for the TD THz system.

As for the resolution achieved, minima of 1mm for the spatial resolution have been obtained for both systems. But related to the depth resolution, the resulting minimums have been of 2mm for the FMCW THz system and of 20µm in the case of the TD THz system.

The radome sample selected as example for the inspection of real parts has demonstrated the capability of the THz systems (when they are integrated in a scanner) for its uses on real-life aeronautic components. Besides that, the application of several measurement sensors allows very short measuring times with comparatively high image resolution. And the tests performed with its integration in the 5-Axis Motion Platform developed have proven that data acquisition of 1.000 measurements per second (that is, 10.000 points inspected in 10 seconds) is possible.
Therefore, it can be stated that both systems of THz developed in the DOTNAC project are feasible for their use in the inspection of “aircraft parts" (such as could be the vertical stabilizer of the tail, parts of wings and parts of the fuselage) and they can be an alternative to the inspection with UT of curved parts.

In terms of the industrial capacity and the industrial feasibility of the THz systems developed in this project, they are deemed appropriate for uses such as on:

- An “On-aircraft” NDT system, that is, when the equipment can be moved to the part to be tested in order to inspect the suspicious area (a complete scan of the whole part is not usually necessary). In this configuration variety, the system is manually placed on the object under test and the measurement is performed automatically.
- An “In-workshop” NDT system, which means, the system cannot be mobilized easily or it is not possible to move it and, therefore, the part to be tested needs to be transported to the workshop where the system is located. This equipment configuration, which can be integrated in the customer’s industrial facilities, will allow the inspection and the assessment of 3-D objects with a more complex shape. And, for example, it might be equipped with custom-made FMCW THz sensor offering dual linear polarisation for enhanced defect detection and full phase information extraction for enhanced contrast in the THz image.

Lastly, the potential of combining information received from different NDT techniques will allow advantage to be taken of the detection capabilities of each one (which employ different physical properties for evaluating the state of the material) and the fusion of these techniques will provide much more information in the quality control of aeronautical specimens (remember that no single method is capable of detecting all the different defects or damage).
For example it has been proven that THz technology is capable of penetrating inside the GFRP sandwich panels, beyond the foam and honeycomb cores (one of the main limiting factors of the conventional NDT techniques). And, on the other hand, IRT is capable of inspecting any type of material (metallic or not metallic) but with a limited depth for the detection defects. These two techniques (contactless, non-destructive and non-intrusive) provide a complementary capability for defect detection, obtaining (with their fusion) a flexible NDT tool applicable to a wide range of aeronautical materials.

<u>Compliance with the requirements of the Ethics Review</u>
All the partners working with THz systems have guaranteed the safety of the personnel working with THz waves and laser systems. The appropriate health and safety procedures conforming to relevant local/national guidelines/legislation are followed for staff involved in this project.
Immediate exposure to the THz waves has been prohibited at all moments, and the laser beams were contained within the system so the laser system (as part of the THz wave system) could be defined as a class 1 laser.

4.1.4 Description of impact, main dissemination activities and exploitation results

Description of impact

DOTNAC has been designed to be responsive to the call of European authorities responsible for the aeronautics and transport policy. A highly interdisciplinary fundamental and applied research is proposed for the development of an advanced THz-NDT tool. The aims of the project meet the high-technology nature of the Transport industry, making research and innovation crucial to its further development and leading to European competitiveness. By the realization of an advanced in-process inspection and quality control during the production phase and at the same advanced technique for continuous health and usage monitoring of structures and systems, the DOTNAC project opens possibilities to reduce aircraft development, production and operational costs. Indeed, by detecting defects in composite material as early as possible in the production chain, the scrapping or rework of a component can be avoided, contributing immensely to the to the cost of part production. At the same time, the same non-invasive, non-contact THz inspection technique can be used for assessing composite part condition in service. This type of inspection can effectively and efficiently support the high standards of composite construction and repair, thereby reducing the aircraft operational costs.

The world NDT equipment market is witnessing growth, promoted by the recovery in the economies of developed countries as well as the demand from developing markets (the in-line process NDT business segment is increasing at two times the rate of overall business). Focus on R&D in newer digital-driven NDT modalities, and translation of these into value-delivering solutions are expected to be paramount in ensuring the success of NDT equipment vendors in the market.

Following steps are foreseen to bring about these impacts:

• The proposed consortium combines the experienced skill of the participants coming from different sectors, namely from academia, SME and research centra. All of them are highly acknowledged in their area of activity.

• DOTNAC carries both scientific and industrial importance integrating trans-nationally the necessary critical mass of resources, for the development of the proposed THz-NDT tool and the global assessment of the potential of this tool is an immense challenge commanding a joint project of diverse expertise reflecting all aspects of a sensor system.

• A new concept is offered by DOTNAC in order to combine all the necessary NDT requirements, which are most of the time mutually exclusive (i.e. improving one feature will have a negative influence on others).

• The DOTNAC NDT solution will offer inspecting a range of composite materials as well as detecting virtually all types of defects of an aircraft part during the production line, before and potentially on-site after the installation on the aircraft using a safe, contact-free, high resolution, easy to integrate in industrial facilities.

• The use of two fast imaging systems, completed with a novel THz signal and imaging processor based on the tomography principles and a novel THz signal and imaging processor based on the synthetic aperture.

In terms of cost reduction and efficiency, the new THz tool will not only help to detect but also to size a defect. That means, it will be possible to determine automatically (or semi-automatically) if that defect is acceptable or not. This will reduce the human interpretation, allowing a reduction of risk and time and an increase of the quality of NDT inspection. All together this means, on one hand, cost reduction, since less time will be necessary to inspect with the same or higher quality and, on the other hand, better efficiency due to the reduction of the human interpretation factor. All the conventional NDT techniques and some advanced techniques still have a high human interpretation factor.

Main dissemination activities

First of all, a DOTNAC website has been created with two aims :

- Dissemination of the project (public part).
- Storage of information and reports, for exchange between partners (private part).

The main architecture of the website resulted from iterations between all partners based on designs provided by Innov Support. The website has been hosted through the facilities at CIMNE. Since the

operational launch of the website multiple updates (mainly maintenance and improvement tasks) have been implemented.
The private interface is accessible through a tightly controlled User ID and Password scheme, with specific access rights in function of the partner role in the project. The website URL is http://www.dotnac-project.eu
Innov Support has produced the 6 monthly versions of the PuDK (Plan for using and disseminating the Knowledge), integrating the dissemination and exploitation activities and plans for all the DOTNAC partners.
Leaflets of the project have been created to hand out during the multiple conferences and workshops the DOTNAC partners participated.

The DOTNAC project has generated furthermore interesting dissemination activities through the participation to specific conferences throughout the whole project and publication in journals. The full list of publications is provided in the next section.

During the second half of the DOTNAC project, 2 Industrial and Technology Followers Group (ITFG) workshops have been organised. Attendance of ITFG members was generated through the approach by all DOTNAC partners to their industrial and technological contacts. This has ensured an attendance of approximately 25 ITFG members for each ITFG workshop and ensured the participation of a series of dedicated contact entries.

Schedule of the ITFG workshops:

- The 1st ITFG workshop was organised in Bordeaux (France) at CNRS – Université de Bordeaux on October 17th 2012.
- The 2nd workshop was organised in Barcelona (Spain) at Applus+ - LGAI Technological Center on June 27th 2013.

Both ITFG workshops included the following major constituents:

- Presentations by the DOTNAC consortium of the activities and results achieved by DOTNAC at the time of the workshop.
- Demonstration of work on real system setup
- Question and answer (Q/A) session between the ITFG members and the DOTNAC consortium.

The outcome of each ITFG workshop (primarily the feedback collected during the Q/A sessions were then further addressed by all DOTNAC partners in a ITFG workshop follow up meeting between the DOTNAC partners to analyse all the feedback and comments that were collected during the ITFG workshop. Where possible the activities of the remainder of the project have taken into account these comments. The partners have implemented the specific comments with respect to the processing of the both ITFG workshops and the potentiality of dissemination and exploitation of the DOTNAC results.

Dedicated posters were produced for the 2nd ITFG workshop. All presentations, demonstrations and posters associated to both ITFG workshops have been uploaded on the public part of the DOTNAC website.

Exploitation results

Innov Support has produced the 6 monthly versions of the PuDK (Plan for using and disseminating the Knowledge). Innov Support has, through the PuDK, collected the description of the exploitable results so far produced by the DOTNAC partners and the associated potential exploitation routes for these results. In addition the actualised exploitation plans of the various project members have been also been captured.
Based on the data collected in the various PuDKs as well as the use of a Technology Implementation Plan form, Innov Support has elaborated an exploitation strategy and scenario. This will be accompanied with the elaboration of a business plan to be executed in the context of the DOTNAC project. This information has been further worked out in deliverable D8.43 (Precompetition survey – Future technology exploitation roadmap).

4.2 Use and dissemination of foreground

The DOTNAC project has already generated interesting dissemination activities through:

1. The participation to the conferences specified in table 3.

N°	Planned/actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
1	Jan 2011	Photonics West	Research oriented	International	The final count was close to 19,390 people	CNRS
2	31st March 2011	AeroDays 2011 - Aeronautics Conference	Industry and research oriented	International	1000 participants for the conference	RMA
3	Sept. 2011	Proceedings of Aerodays 2011	Industry and research oriented	International	N/A	RMA
4	Oct 2011	IR THz MMWave Conference (Houston, USA)	Research oriented	International	430	RMA
5	8-10Feb 2012	OPTRO 2012	Industry and research oriented	International	250	RMA, Fh-IPM
6	6-7 March 2012	VDI/VDE-International Forum on Terahertz Spectroscopy and Imaging 2012	Industry and research oriented	International	120	Fh-IPM, UNIKL
7	April 2012	International Symposium on NDT in Aerospace	Researchers/Industrials	International	TBS	CTA
8	April 2012	SPIE Defense, Security, and Sensing (Baltimore, USA)	Researchers/Industrials	International	6700 participant for the conference	RMA, Fh-IPM
9	April 2012	IEEE RadarCon (Atlanta, USA)	Researchers/Industrials	International	Not provided	RMA, Fh-IPM
10	May 2012	EUSAR 2012	Industry and research oriented	International	250	RMA, Fh-IPM
11	17-20 June 2012	3rd EOS Topical Meeting on TeraHertz Science & Technology (TST 2012)	Researchers/Industrials	International	120	UNIKL
12	September 2012	MMS 2012 (Turkey)	Researchers/Industrials	International	130	RMA, Fh-IPM

13	23-28.09.2012	37th International Conference on Infrared, Millimeter and THz Waves (IRMMW-THz 37); Wollongong, Australia	Researchers/Industrials	International	450	UNIKL
14	16-17 May 2013	Aerospace valley Arcachon	Research , Industrials	National	300	CNRS
15	1-6 Sept 2013	38th International Conference on Infrared, Millimeter and THz Waves (IRMMW-THz 37); Mainz, Germany	Researchers/Industrials	International	650	RMA, Fh-IPM, UNIKL, CNRS

Table 3 - Summary conference participation

2. The publication of papers and posters as specified in table 4:

Publication reference	**Type**
Nonlinear holographic imaging of terahertz radiation (Proceedings Paper) - Authors: J. C. Delagnes, P. Mounaix, L. Canioni, Published 21 February 2011	Conference paper
AeroDays Proceedings (September 2011) - RMA	Conference presentation and publication in Book of AeroDays
Optimization of reconstruction methods applied to 3D terahertz computed Tomography *(invited),* Patrick Mounaix, oral presentation POEM2011 Wuhan, Nov 2011	Conference paper
Propagation Beam Consideration for 3D THz Computed Tomography, Recur, B; Guillet, J P; Manek-Hönninger, I; Delagnes, J C; Benharbone, W; Desbarats, P; Domenger, J P; Canioni, L; Mounaix, P' Optics Express, Vol. 20 Issue 6, pp.5817-5829 (2012)	Publication
OPTRO2012, Assessment Of 3-D Signal and Image Processing using FMCW THz Signals, OECD Conference Center, Paris, France / 8–10 February 2012, E. Cristofani, A. Brook, M. Vandewal, C. Matheis, J. Jonuscheit	Conference paper
EUSAR 2012: High-Resolution 3D SAR Imaging applied To Non-Destructive Testing of Multi-Layered Materials, Edison Cristofani And Marijke Vandewal	Conference poster
VDI/VDE-International Forum on Terahertz Spectroscopy and Imaging, 2012: B. Recur, P. Desbarats, JP Guillet, I. Manek-Hönninger, W. Benharbonne, JC Delagnes, P. Mounaix, Propagation beam consideration for 3D terahertz tomography, In 5th International Forum on Terahertz Spectroscopy and Imaging, Kaiserslautern, Germany, March 2012	Conference paper
VDI/VDE-International Forum on Terahertz Spectroscopy and Imaging, 2012: E. Cristofani, A. Brook, M. Vandewal, C. Matheis, and J. Jonuscheit., Synthetic aperture processing applied to FMCW THz imagery, In 5th International Forum on Terahertz Spectroscopy and Imaging, Kaiserslautern, Germany, March 2012	Conference paper
VDI/VDE-International Forum on Terahertz Spectroscopy and Imaging, 2012: M. Vandewal, DOTNAC, In 5th International Forum on Terahertz Spectroscopy and	Conference poster

Imaging, Kaiserslautern, Germany, March 2012	
VDI/VDE-International Forum on Terahertz Spectroscopy and Imaging, 2012: Assessment of 3D Image Processing using FMCW THz Imagery, Anna Brook, Edison Cristofani, Marijke Vandewal, Joachim Jonuscheit	Conference poster
”Terahertz radiation for tomographic inspection” in optical engineering SPIE Optical Engineering Special section on «Terahertz and Millimeter Wave Imaging» , Accepted in press	Publication
VDI/VDE-International Forum on Terahertz Spectroscopy and Imaging, 2012: W. Zouaghi, F. Ospald, J.-M. Rämer, and R. Beigang, “Emitters and detectors for a THz time domain material inspection system pumped at 1560 nm”, 5th International Forum on Terahertz Spectroscopy and Imaging, Kaiserslautern, Germany, March 2012	Conference poster
IEEE RadarCon 2012: A. Brook, E. Cristofani, M. Vandewal, C. Matheis & J. Jonuscheit, 3-D Radar Image Processing Methodology for Non-Destructive testing of Aeronautics Composite Materials, Proceedings of IEEE Radarcon2012, Atlanta, May 2012	Conference paper
IEEE RadarCon 2012: In-depth High-Resolution SAR Imaging Using Omega-k Applied to FMCW Systems, Edison Cristofani, Marijke Vandewal, Carsten Matheis, Joachim Jonuscheit	Conference paper
IEEE RadarCon 2012: M. Vandewal, DOTNAC, Proceedings of IEEE Radarcon2012, Atlanta, May 2012	Conference poster
SPIE DSS 2012: A. Brook, E. Cristofani, and M. Vandewal, A 3D THz image processing methodology for a fully integrated, semi-automatic and near real-time operational system, In Proc. of SPIE Defense, Security, and Sensing Symposium 2012, Baltimore, USA, April 2012	Conference paper
SPIE DSS 2012: E. Cristofani, A. Brook, and M. Vandewal, 3D synthetic aperture processing on high-frequency, wide-beam, microwave systems, In Proc. of SPIE Defense, Security, and Sensing Symposium 2012, Baltimore, April 2012	Conference paper
SPIE DSS 2012: M. Vandewal, DOTNAC, In Proc. of SPIE Defense, Security, and Sensing Symposium 2012, Baltimore, USA, April 2012	Conference poster
“Proyecto DOTNAC: la revolución de los terahercios” (DOTNAC Project: the therahertz’s revolution), Accepted in press. AEND, Magazine nº 58 – 1st trimester – 2012 pp 6-8.	Publication
W. Zouaghi, F. Ospald, J.-M. Rämer, and R. Beigang, “Emitters and detectors for a THz time domain material inspection system pumped at 1560 nm”, 3rd EOS Topical Meeting on Terahertz Science & Technology (TST 2012), Prague, Czech Republic, June 2012	Conference poster
A. Brook, E. Cristofani, M. Vandewal & J. Jonuscheit, “In-depth Detection and Reconstruction Techniques using High-frequency Microwaves for Non-destructive Testing on Multi-layered Composite Materials”, Proceedings of MMS 2012, Turkey, September 2012	Conference paper
F. Ospald, W. Zouaghi, J.-M. Rämer, and R. Beigang, “Comparison of THz Emitters and Detectors pumped at 1560 nm: DAST, ErAs:InGaAs, LTG GaAs”, 37th International Conference on Infrared, Millimeter and THz Waves (IRMMW-THz 37); Wollongong, Australia, September 2012	Conference paper

W. Zouaghi, F. Ospald, D. Molter, and R. Beigang, “Comparison of high-speed terahertz sampling techniques at different wavelengths”, 37th International Conference on Infrared, Millimeter and THz Waves (IRMMW-THz 37); Wollongong, Australia, September 2012	Conference paper
JP. Guillet[1], B. Recur[2] I. Manek-Hönninger[1], J.C. Delagnes[1], P. Desbarats[2] and P.Mounaix[1], “3D-Terahertz Tomography using a more realistic beam propagation model applied to different image reconstruction methods”, 37th International Conference on Infrared, Millimeter and THz Waves (IRMMW-THz 37); Wollongong, Australia, September 2012	Conference paper
M. Vandewal, E. Cristofani, A. Brook, W. Vleugels, F. Ospald, R. Beigang, S. Wohnsiedler, C. Matheis, J. Jonuscheit, JP. Guillet, B.Recur, P. Mounaix, I. Manek Hönninger, P. Venegas, I. Lopez, R. Martinez, Y. Sternberg, “Structural Health Monitoring using a Scanning THz System”, 38th International Conference on Infrared, Millimeter and THz Waves (IRMMW-THz 38); Mainz, Germany, September 2013	Conference paper
J.-M. Rämer, F. Ospald, G. von Freymann, and R. Beigang, “Generation and detection of terahertz radiation up to 4.5 THz by low-temperature grown GaAs photoconductive antennas excited at 1560 nm”; Applied Physics Letters **103**, 021119 (2013)	Publication
F. Ospald et al., “Aeronautics Composite Material Inspection with a Terahertz Time-Domain Spectroscopy System”; submitted to SPIE Optical Engineering	Publication (accepted)
F. Ospald, W. Zouaghi, D. Molter, R. Beigang, J.-P. Guillet, J-B. Perrault, I. Manek-Hönninger, and P. Mounaix[b] “3D Terahertz Imaging for the Control of Aeronautics Multilayered Structures”, 38th International Conference on Infrared, Millimeter and THz Waves (IRMMW-THz 38); Mainz, Germany, September 2013	Conference poster
J.-M. Rämer, F. Ospald, G. von Freymann, and R. Beigang, “Generation and detection of terahertz radiation up to 4.5 THz using LTG-GaAs PCAs illuminated at 1560 nm”; 38th International Conference on Infrared, Millimeter and THz Waves (IRMMW-THz 38); Mainz, Germany, September 2013	Conference paper

Table 4 - Summary publications and posters

3. Further planned participations to conferences (and associated publications) as a follow-up of DOTNAC as specified in table 5:

N°	Planned/actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
1	Nov 2013	Aerospace sensors & testing (Airtec 2013)	Researchers/Industrials	International	TBD	RMA, Fh-IPM
2	Nov 2013	Aerospace sensors & testing (Airtec 2013)	Researchers/Industrials	International	TBD	Whole Consortium

Table 5 - Future planned participations to conferences/seminars

Description of the dissemination activities

Partner 1 – RMA

- AeroDays 2011: This conference took place from 30th March till 01st of April. The DOTNAC coordinator has presented the project at this conference which was co-organized by the European Commission. Now a book will be edited resuming all the related papers of the topics presented at AeroDays 2011. The DOTNAC coordinator has done this for DOTNAC.
- IRMMW-THz 2011: RMA has presented a poster on THz propagation through diffusing materials. The website of this conference is www.irmmw-thz2011.org. Permission has been asked to the EC project officer to attend this non-European conference, and this has been granted.
- EUSAR 2012: This conference concentrates on the type of processing used by RMA within the frame of DOTNAC, but then mainly at radar frequencies. Since the lower frequencies used in DOTNAC can be seen as high frequency radar signals, it has an added value to present the progress on the applied synthetic aperture processing within DOTNAC and to learn from the contributions from the other participants on how to improve the processing. The website of this conference is www.conference.vde.com/eusar/EUSAR2012.
- OPTRO 2012: At this conference RMA has presented together with Fh-IPM an integrated hardware-software approach we will follow within DOTNAC. The conference has proposed THz activities as one of the key topics to be addressed. The website of this conference is www.optro2012.com
- IEEE RadarCon 2012: Similar to the EUSAR2012, this conference concentrates on the type of processing used by RMA within the frame of DOTNAC, but then mainly at radar frequencies, and additionally focuses on the image processing part particular at this part of the spectrum, which is still valid for the SubTHz waves RMA has to deal with. Therefore it has an added value to present the progress within DOTNAC at this conference and at the same time learn from the contributions from others. The DOTNAC project itself has also been presented as a poster.
- VDE THz Workshop: this is a specific THz oriented workshop with research related papers as well as industry oriented talks and exhibitions. RMA has presented 2 posters: 1 on the DOTNAC project in general, 1 on the image processing activities of RMA within DOTNAC. Additionally RMA has given a presentation on the signal processing activities within DOTNAC.
- SPIE Defense, Security, and Sensing conference in Baltimore: RMA has presented two papers: 1 on image processing and 1 one signal processing in THz dedicated sessions. A global DOTNAC poster has also be presented to disseminate in a general way the project. Permission has been asked and has been granted by the EC project officer for this non-European conference.
- 12th Mediterranean Microwave Symposium (MMS2012): RMA has presented the last results obtained with the image processing techniques developed to analyze via automatic processing as well the data obtained through the focused THz FMCW system as with the wide angle THz FMCW system.
- As a follow-up of the ITFG at Bordeaux in October 2012, RMA has organized in November at the premises of RMA another (small-scale) ITFG to inform the national institutes which could not make it to Bordeaux. Sabena Technics, Aerotecs, and the flight NDI of the Belgian Armed Forces were present to assist this intermediate presentation of DOTNAC results.
- During the 38th IRMMW-THz conference in Sep 2013 in Germany, RMA has presented, as the coordinator of the DOTNAC, the overall results obtained during the project, and more specifically the potential of a THz system, as well pulsed as continuous wave, to be used as a NDT technique.

Partner 2 - Verhaert

No specific dissemination plans identified thus far.

Partner 3 – Innov Support

Innov Support has no specific own dissemination plans. As Innov Support provides dissemination management support for the DOTNAC project, it supports all the management tasks associated to preparation of the dissemination of the project, its results and activities during the project, i.e.:

- Development and management of the DOTNAC website and its contents (http://www.dotnac-project.eu).
- Development of the DOTNAC leaflet.
- Support to the preparation of the set up (announcements, invitations, registrations, synthesis of workshop outcomes, etc.) of the various IFG workshops.
- Support of DOTNAC partners for publication of DOTNAC related articles in agreed publications.
- Support for registration and/or review of papers to be provided at agreed conferences.
- Where required participation to specific business events, conferences, etc. agreed within DOTNAC consortium.
- Set up of Dissemination Strategy and Plan.

Partner 4 – UNIKL

The dissemination activities of UNIKL within the DOTNAC project are primarily carried out via the typical dissemination channels of a university, namely publications in appropriate scientific journals and conference contributions. In both cases, the scope of the journal/conference must cover the applied science characteristic of our research for DOTNAC.

The group of René Beigang has made numerous contributions to, amongst others, „Applied Physics Letters“ and „Optics Express“, magazines that are suitable for new developments regarding THz emitters and detectors. Articles with a technological emphasis, possibly up to a description of the characteristics of the integrated system, could be submitted to engineering-oriented journals, e.g. „IEEE Photonics Technology Letters”.

UNIKL contributed a poster each to the “5th International Forum on Terahertz Spectroscopy and Imaging” (05/06.03.2012, Kaiserslautern, Germany) and the “3rd EOS Topical Meeting on Terahertz Science & Technology (TST 2012)” (17.-20.6.2012, Prague, Czech Republic). Two oral presentations were given at the “37th International Conference on Infrared, Millimeter and THz Waves (IRMMW-THz 37)” (23.-28.09.2012, Wollongong, Australia);); one oral presentation and one poster (together with CNRS) were contributed to the “38th International Conference on Infrared, Millimeter and THz Waves (IRMMW-THz 38)” (01.-09.09.2013, Mainz, Germany). UNIKL contributed as well to the oral DOTNAC consortium presentation at the latter conference. A peer-reviewed paper about pumping of GaAs photoconductive antennas with 1560 nm lasers was published in Applied Physics Letters journal (vol. 103, 021119 (2013)). A review paper about THz time domain spectroscopy on the DOTNAC samples has been submitted for publication in a special THz section of SPIE Optical Engineering journal, which will be published in April 2014.

Partner 5 – Fh-IPM

Fh-IPM has several papers and conference contribution in collaboration with RMA. The activities are described by RMA. The following activities are described only where Fh-IPM was leading partner.

- DACH DGZfP Jahrestagung: the German society of non-destructive testing (DGZfP) has an annual meeting which is the most important meeting of German NDT specialists. Every three year is meeting is in combination of the annual meeting from the NDT society of Austria and Switzerland. This year was such a meeting. This year a session which was related to terahertz techniques only was organized for the first time. Fh-IPM has had an oral presentation on the results obtained in DOTNAC.

- NDT for Aerospace: is a specific workshop oriented to NDT application in the aeronautics. It will be organized every two years. Fh-IPM has had an oral presentation on the results obtained in DOTNAC.

Partner 6 - CNRS

LOMA has already performed dissemination of the DOTNAC project and the activities that are carried out in DOTNAC. Precisely, we propose an original technique of THz imaging by non linear holographic approach. 3D imaging technique will be presented in Nov. 2-5, 2011 in Wuhan, China, in conjunction with the 10th International Conference on Photonics and Imaging in Biology and Medicine (PIBM 2011) and the 8th Optics Valley of China International Optoelectronic Exposition and Forum (OVC EXPO). It is one of the most comprehensive events to provide an outstanding opportunity to share the latest information with international experts in this field.

Covering the four technical areas of Biomedical Photonics, Industrial Photonics, Information Photonics, and Photonics for Energy, POEM 2011 strives to maximize the opportunity for communication among all the attendees by integrating various kinds of activities, such as conferences, workshops, symposia, short courses, industry forums, and special sessions.

LOMA will furthermore perform diffusion of the project in the context of The Aerospace Valley World Competitiveness Cluster which allies the Midi-Pyrenees & Aquitaine regions to constitute Europe's leading pool of jobs in the field of aeronautics, space and embedded systems: (http://www.aerospace-valley.com/en/). LOMA is also in contact with a local platform on NDT developments.

The paper contribution to Photonics West can be found via the following link: Nonlinear holographic imaging of terahertz radiation (Proceedings Paper) - Authors: J. C. Delagnes, P. Mounaix, L. Canioni Published 21 February 2011.

LOMA presented in POEM 2011, the major conference on THz field in China the work on 3D terahertz computed tomography has been performed using a monochromatic millimeter wave imaging system coupled with an infrared temperature sensor. Three different reconstruction methods (standard back-projection algorithm and two iterative analyses) have been compared in order to reconstruct large size 3D objects. The quality (intensity, contrast and geometric preservation) of reconstructed cross-sectional images has been discussed together with the optimization of the number of projections. (slide show available)

LOMA participated to the European Defense Meeting (EDM) on 23 and 24 November 2011 in Bordeaux

LOMA published one paper and a second one was accepted with minor revisions:

- Propagation beam consideration for 3D THz computed tomography, Optics Express Vol. 20, Iss. 6, pp. 5817–5829 (2012), B. Recur, J. P. Guillet, I. Manek-Hönninger, J. C. Delagnes, W. Benharbone, P. Desbarats, J. P. Domenger, L. Canioni, and P. Mounaix (http://www.opticsinfobase.org/oe/upcomingissue.cfm).
- Terahertz radiation for tomographic inspection, B. Recur, J.P. Guillet, L. Bassel, C. Fragnol, I. Manek-Honninger,J.C. Delagnes, W. Benharbonne, P. Desbarat, J.P. Domenger and P. Mounaix, In Optical Engineering : a Special Section on Terahertz and Millimeter Wave Imaging

LOMA will provide oral contribution to the International Forum on Terahertz Spectroscopy and Imaging - March 06th/07th 2012, Kaiserslautern, Germany in connection to the 5th Workshop on Terahertz Technology.

LOMA (as conference organizer) plans further DOTNAC dissemination at the 37th International Conference on Infrared, Millimeter and THz Waves“ (IRMMW-THz 37, 23-28.09.2012, Wollongong, Australia), POEM 2012.
LOMA plans further DOTNAC dissemination at the 38th International Conference on Infrared, Millimeter and THz Waves“ (IRMMW-THz 38, 2-6.09.2013, Mainz,Germany).
LOMA presented the project and the results in the context of The Aerospace Valley World Competitiveness Cluster which allies the Midi-Pyrenees & Aquitaine regions to constitute Europe's leading pool of jobs in the field of aeronautics, space and embedded systems: (http://www.aerospace-valley.com/en/). LOMA is also in contact with a local platform on NDT developments
Participation to a paper in optical engineering with all DOTNAC partners.

Partner 7 – CTA

CTA performs dissemination of the DOTNAC project, and the activities that are involved in it, by means of its web page www.ctaero.com, where DOTNAC is a reference project for CTA. On its webpage CTA explains the main objectives concerning DOTNAC project, as well as the methods to reach them, and it is regularly updated with the evolution of the activities being carried out so clients, partners or any interested people are able to get informed.
Furthermore CTA is member of HEGAN (Basque Aerospace Cluster) and is disseminating DOTNAC project objectives among other members who are mainly aeronautical manufacturers. CTA will also do diffusion of the results of the project in the IR forums as well as the aeronautical events in which CTA participates, such as the Photomechanics 2013 congress, which will take place in Montpellier in May 2013, and the 12th International workshop on advanced infrared technology and applications AITA-12.
On the other hand CTA is preparing several articles about the preliminary results obtained under the calibration samples with the conventional NDT techniques and the THz system to be published in different journals. With the development of the project and the obtaining of new results new articles will be proposed to be edited, for instance comparisons among conventional NDT techniques and THz, comparison between IRT and THz, comparison between data processing techniques applied in IRT and in THz, and so on.

Partner 8 – LGAI

LGAI has performed the following set of dissemination activities related to the new THz technology and including them in its normal technical-commercial activity:

- Airbus**:** Several presentations in Madrid, Toulouse, Hamburg and Barcelona of the DOTNAC project linked with commercial contact with test managers. Also a technical presentation of the project has been given to the NDT manager in Airbus Spain during a visit to the Applus^{+} laboratory in Bellaterra. Airbus Spain's NDT manager is interested participating in the Industrial Followers Group (official acceptance document in progress).
- Messier Dowty: the project has been mentioned in a commercial contact with test managers at Messier Dowty central offices.
- Rolls Royce: the project has been mentioned in a technical audit of the Applus^{+} mechanical test laboratory.
- Thales Avionics: the project has been presented to a Technical Responsible of the Engineering Dpt. during a meeting of another R&D aeronautical project.
- Alstom Wind, Gamesa (industries of wind power sector): the project has been mentioned during commercial contacts with test managers of these companies.

- Aries Complex, Alestis, Aernova, Aerolia, Safran Group (other industries of aeronautical sector): the project has been mentioned during commercial contacts with test managers of these companies**.**
- Shell Global Solutions International BV (oil & gas sector): the project has been mentioned and presented to the team leader of the department of *Inspection Technology Mechanical, Materials & Integrity*.
- Heerema Marine Contractor: the ptoject has been presented the Innovation Department.
- ACC1Ó and CDTI (R&D funding Agencies): the project has been included in the presentations of the R&D activity of Applus LGAI to these entities.

The results of the project have been disseminated within the NDT Technical-Commercial Dpts. of Applus Group around the world, in order that they can make diffusion to their customers.

Partner 9 – CIMNE

CIMNE will disseminate the DOTNAC project results through scientific publications in international referred journals and international technical conferences. CIMNE will also contribute to the dissemination of the project by offering technical support and participating in the maintenance of the project website.

Partner 10 – IAI

For IAI the most important step was the comparative analysis between the standard NDT techniques and the new emerging THz technique. After reaching conclusions from the calibration and test samples provided for the project, conclusions that proved the high potential capabilities of THz, IAI has contacted several local companies that might be interested in the new technology. IAI will continue showing the capability of the technique to any partner. In addition IAI is planning to present the technique at future local NDT conferences and is ready to attend some international meeting(s) on NDT or Aeronautics in order to present the technique.

The DOTNAC project has produced a number of results, where some of these results have been integrated in 2 specific THz NDT system prototypes. The possible constraints that may limit the utilization of the results have been analysed within the DOTNAC project. Following the indications provided by the partners responsible for results development, the DOTNAC results can be grouped in the following sets according to their use conditions.

1. Know-how and methods:
    a. Know how on design and manufacturing of calibrated samples (dedicated to the aeronautical supply chain).
    b. Knowledge capture in the field of multi-axis motion control systems and platforms.
    c. Production of fiberglass composite samples with induced typical defects, including monolithic and cored ones.
    d. Defects detection in composite materials with thermographic NDT tools. Consultancy in NDT inspections employing infrared thermography.
    e. General understanding of THz capability in NDT.
    f. Methods for the validation of new NDT technologies by means of comparison using calibrated samples (dedicated to the aeronautical supply chain).
    g. Comparative analysis of NDT technologies (conventional and new developed THz) applied to different types of composite materials.
2. Software:

a. 2-D/3-D THz data simulator for wide beam configuration.
b. 2-D/3-D data processor for THz raw data acquired in wide beam configuration.
c. 3-D semi-automatic defect detection and localisation for focused and wide beam configuration.
d. Synthetic bandwidth by combining 2 frequency bands.
e. Tomosynthesis reconstruction method of THz data.
f. Super-resolution algorithm.
g. Zvisu (prototype for the visualization of data in a 3D space).

3 Hardware:
a. Samples
   i. Glass fibre composite samples containing calibrated defects.
   ii. Composite test samples with real defects.
   iii. Coating misprocess on CFRP.
b. Motion platform demonstrator for scanning flat samples and radomes using FMCW and TD systems.

4 System (Integrated H/W + S/W):
a. Terahertz time domain (TD) system based on electronically controlled optical sampling.
b. Frequency Modulated Continuous Wave (FMCW) system.

Description of the exploitation results

This section provides an overview, per exploitable result, of how the knowledge created as a result of the execution of the DOTNAC project activities could be commercially exploited or used in further research (if relevant). This data is obtained from each partner that owns the knowledge and has an active role in its exploitation. Both past and planned future activities are included.
An overview of the potentially exploitable results arising from the DOTNAC project is shown in the table hereafter.

N°	Description of the exploitable Foreground	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use or any other use	Owner & Other Partner(s) involved
1	Data simulator	2-D/3-D THz data simulator for wide beam configuration	Aeronautics, mainly transportation systems. NDT.	Ready for exploitation	**RMA** (S/W written and owned by RMA)
2	Data processor	2-D/3-D data processor for THz raw data acquired in wide beam configuration	Aeronautics, mainly transportation systems. NDT.	Ready for exploitation	**RMA** (S/W written and owned by RMA)
3	Data fusion	Synthetic bandwidth by combining 2 frequency bands	Aeronautics, mainly transportation systems. NDT.	Ready for exploitation	**Fh-IPM** (S/W_written and owned by Fh-IPM)
4	Defect detection and localisation	3-D semi-automatic defect detection and localisation for	Aeronautics, mainly transportation	Ready for exploitation	**RMA** (S/W written and owned by

N°	Description of the exploitable Foreground	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use or any other use	Owner & Other Partner(s) involved
	algorithm	focused and wide beam configuration	systems. NDT.		RMA)
5	Samples	Glass fibre composite samples containing calibrated defects.	Aeronautics	Ready for exploitation	**CTA**
6	Samples	Composite test samples with real defects	Aeronautics	Ready for exploitation	**IAI**
7	Samples	Coating misprocess on CFRP	Aeronautics	Ready for exploitation	**IAI & LGAI**
8	Analysis	Comparative analysis of NDT technologies (conventional and new developed THz) applied to different types of composite materials	Aeronautics	Ready for exploitation	**LGAI et all**
9	TD system	Terahertz time domain system based on electronically controlled optical sampling	Industries that use composite materials, including aeronautics (mainly transportation systems). NDT.	Ready for exploitation	**UNIKL**, **Fh-IPM** (involved in further use, proprietors of the demonstrator hard- and software)
10	Motion platform demonstrator	Motion platform demonstrator for scanning flat samples and radomes using FMCW and TD systems	Aeronautics	Ready for exploitation	**Verhaert**
11	Knowledge capturing	Knowledge capture in the field of multi-axis motion control systems and platforms	Generic	Ready for exploitation	**Verhaert**
12	Tomosynthesis reconstruction model	Tomosynthesis reconstruction method of THz data	Generic	Ready for exploitation	**CNRS**
13	Know How	Fiberglas composite samples. A series of samples with induced typical defects, including monolithic and cored ones.	Aeronautics, mainly manufacturing industry.	Ready for exploitation	**CTA**
14	Non Destructive Testing of	Defects detection in composite materials with thermographic	Wide range of sectors which employ	Ready for exploitation	**CTA**

N°	Description of the exploitable Foreground	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use or any other use	Owner & Other Partner(s) involved
	composite materials by means of IRT.	NDT tools. Consultancy in NDT inspections employing infrared thermography.	composite material, including aeronautics.		
15	Super-resolution	This algorithm (accessible via the reconstruction menu) allows the fusion of N images of a resolution p into one image of a resolution p/N. This process induces a blur on the reconstructed image.	Non-destructive testing	Ready for exploitation	**CNRS (UNIKL, Fh-IPM)**
16	General understanding of THz capability in NDT	Ability to identify actual industrial issues for NDT-THz	Aeronautics	Ready for exploitation	**IAI et all**
17	Zvisu	Zvisu is a prototype for the visualization of data in a 3D space. This software is able to load files given by the acquisition process	Non Destructive Testing	Ready for exploitation	**CNRS**

#1 - 2-D/3-D THz data simulator for wide beam configuration

Purpose: For feasibility studies and preliminary assessment purposes, it is highly interesting to be able to simulate in an inexpensive and near-real time the potential of a certain measurement technique. For DOTNAC, a wide angle configuration was included for the acquisition of THz data which require high performing processing algorithms to obtain good quality images of the object under test. The creation of a simulator for this measurement configuration performs following steps:

- Simulation of the raw data as the data would be measured when using a wide illumination beam on a 2-D scanner. These data can be generated as well for a 2-D object as a 3-D object.
- Processing of the raw data using a so-called "synthetic aperture" approach, to handle the wide beam illumination and to create high resolution images.

How the foreground might be exploited: The simulator S/W will allow the user to rapidly and reliably test the specific measurement conditions and system configuration parameters needed for an optimum result. It will also offer the possibility to test and tune a new processing algorithm in a controlled environment.

When: ready for exploitation

By whom: RMA

#2 - 2-D/3-D data processor for THz raw data acquired in wide beam configuration

Purpose: The THz data processor for data acquired in wide beam configuration enables the creation of high resolution images starting from raw, unfocused data. It has been optimized for real data and can handle as well 2-D as 3-D data sets. It is extended with a graphical user interface to allow easy execution of the processing algorithm and the choice of important processing parameters.

How the foreground might be exploited: The data processor allows easy tuning of the algorithm parameters to optimize the processing for the used frequency, the size of the data set, as well as the sampling needed in case of redundant information. An easy visualisation of the obtained image can be done through an additional user interface which also allows direct visualisation of data acquired with the focused beam configuration.
When: ready for exploitation
By whom: RMA

#3 - Data fusion software for multi-frequency FMCW THz imaging system
Purpose: The aim of the data fusion software is to merge data SVF files of different frequencies in order to increase the depth resolution, i.e., the spatial resolution in direction of the THz beam. An algorithm was developed for merging FMCW data from two neighbouring frequency ranges to the effect of adding up the bandwidths and improving the depth resolution in a frequency band where typical DOTNAC samples are well transparent. The algorithm was tested and successfully demonstrated with a suitable calibrations sample and relevant DOTNAC samples. A Graphic User Interface (GUI) window was developed with access to all relevant variables. Further emphasis was placed on error handling, a help system and an extended message system including sound messages.
How the foreground might be exploited: Can be deployed in connection to the future use of the FMCW THz imaging system.
When: ready for exploitation
By whom: Fh-IPM

#4 - 3-D semi-automatic defect detection and localisation for focused and wide beam configuration
Purpose: When confronted with 3-D data sets representing the spatial contents of an object under test, it is very time-consuming, as well as challenging to analyse these data manually for defect detection and localisation purposes. Therefore a processing box has been developed to de-noise and enhance the image on the one hand, and to automatically isolate anomalies in the data set on the other hand. Taking into account the type of material can be entered as well as the general shape of the expected defect, this leads to a semi-automatic defect detector and localizer which synthetically highlights the detected defects in the 3-D volume of the object, or projects them in a 2-D view of the object overlaid on the original THz image.
How the foreground might be exploited: The image processing box can handle as well images generated in the focused as in the wide beam configuration. It is extended with 2 graphical user interfaces to allow in both configurations an easy access to the data in the different stadiums of the image processing, and an easy visualisation and interpretation of the obtained results.
When: ready for exploitation
By whom: RMA

#5 – Test composite samples containing calibrated defects
Purpose: A group of samples (27) were designed and manufactured according to the premises obtained from the former mentioned studies for the DOTNAC project during 2011 and 2012.
Different thicknesses of materials and layers have been applied, as well as cores made with Rohacell and Honeycomb. All the calibration samples have been manufactures in glass fibre material. The defects introduced include inserts of various materials (Teflon, stucks and paper sheets), water inclusions and impacts, in order to simulate the typical defects of this kind of material.
How the foreground might be exploited: A report defining the dimensional characteristics of the samples, as well as giving information about the materials they are made of and the defects that have been introduced is made. Also a constructive idea is given for all the samples. These samples have been the base material for laboratory tests, leading to the correct DOTNAC demonstrator development. These samples and the associated report can be re-used for future NDT testing purposes.
When: ready for exploitation
By whom: CTA

#6 – Composite test samples with real defects

Purpose: DOTNAC studied delaminations and disbonds that are characterized by a thin film of air separating two consecutive layers. These defects have thus an “air barrier” creating an electrical impedance mismatch detected by THz radiation. The classical method for simulating delaminations or disbonds in composites is by inserting foreign material such as Teflon or brass. Since the electrical impedance of these materials is very different to the one of air, it turns out that they will not correctly reflect the reaction of THz radiation to real defects and therefore may bring to wrong conclusions. In order to assess more accurately the potential abilities of THz in NDT it was decided to manufacture test samples with real delaminations and disbonds. These samples have been manufactures and tested. Though they brought to similar general conclusions as the classical calibration samples with inclusions, it was observed that defect detection is more difficult with these samples.

How the foreground might be exploited: This ability has been clearly demonstrated by the different experiments and opens a new field of activity for the THz technology.

When: ready for exploitation

By whom: IAI

#7 – Coating misprocess on CFRP

Purpose: Though THz radiation is not applicable for defect detection within carbon composite structures because of their electrical conductivity it can be applied in the inspection of coating over carbon composite and detect coating misprocess. A total of 34 test samples with different misprocess coating such as surface contamination, bad surface preparation, incorrect primer or external layer thickness (polyurethane , Rain Erosion), primer layer skipping have been manufactured and tested. The results show a great sensitivity of THz test to coating misprocess.

How the foreground might be exploited: This point has been actually shown on a test radome that was mounted on a 3D scanner and fully scanned in several minutes. The next efforts will be shall be on the data processing.

When: ready for exploitation

By whom: IAI and LGAI

#8 – Comparative analysis of NDT Technologies (conventional and new developed THz) applied to different types of composite materials

Purpose: The result is not a product; it is the knowledge about the performance of different NDT techniques applied to various composite materials used in aeronautics. The know-how acquired on the performance and level of detection of each technique for the various materials and defects will allow the partners of the project to offer new or improved NDT inspection services for composite materials (LGAI, CTA), or to apply this knowhow to their own production processes (IAI).

The following table summarizes the performance of the two new developed THz techniques (FMCW and TD) when applied to inspection of different kind of composite aeronautical materials with different kind of defects.

STRUCTURES & MATERIAL / DEFECT	A-/C-sandwich honeycomb	A-/C-sandwich foam	Fiberglass laminate	Carbon fiber laminate
Water (trapped moisture)	FMCW	TD		
Foreign inclusions	FMCW & (TD)	FMCW	FMCW & TD	
Debonds	FMCW & (TD)	FMCW & (TD)		
Delaminations	FMCW & (TD)		FMCW & TD	
Coating misprocesses				TD

Green	Strong NDT defect detection
Yellow	Very good defect detection
Grey	No defect detection (lack of penetration)

How the foreground might be exploited: Compared to the conventional NDT techniques tested:

- Outperforms other NDT methods for the inspection of coating misprocesses: **only TD**
- Clearly overcomes the UT inspection difficulties (methods on-site) for C-sandwich structures with foam or H/C core. Furthermore, the results obtained on these types of components are

totally comparable to those resulting from the NDT techniques of IRT and UT non-portable systems: **FMCW**
- Equal / similar detection level to IRT, X-RAY and some of the UT methods performed, for A-sandwich foam or H/C core: **FMCW & TD**
- Comparable results to UT for Fiberglass Solid Laminate inspections: **FMCW & TD**

When: ready for exploitation
By whom: LGAI and all other DOTNAC partners

#9 - Terahertz time domain system based on electronically controlled optical sampling
Purpose:. A portable setup for opto-electronic generation and time-domain sampling of pulsed terahertz (THz) radiation was developed. The system consists of three main functional sub-units:
- A customized, commercial twin laser-system with electronically controlled optical sampling (ECOPS) functionality and 6 m fibre delivery
- A THz sensor with photoconductive antennas as emitter and detector
- Data acquisition (DAQ) hardware and software to pre-processes, record, display and process the THz time–domain data

How the foreground might be exploited:. The system can be combined with a scanning stage for applications in THz imaging, layer thickness measurement or spectroscopy, e.g. for quality control. Its advantage is a genuine robustness because of the lack of moving parts. The speed can be pushed to approximately 1000 waveforms of 100 picosecond duration per second, at bandwidths > 1 THz. Potential application fields include coatings, plastic or ceramic parts, and substance identification. Key point for improvement is the THz pulse duration/bandwidth, which must be as short/high as possible to improve resolution and spectroscopic capability. Besides hard- and software measures to counteract pulse-to-pulse jitter, this requires improved optical pulse handling to deliver short, side-lobe free pulses at the end of the fibre deliveries.
The ECOPS laser system and/or the DAQ package can be applied in different other settings where a fast response in the time domain should be captured and analysed in a pump-probe fashion, for example transient reflectivity or absorption changes because of enhanced free-carrier concentration in semiconductors.
When: ready for exploitation
By whom: UNIKL and Fh-IPM

#10 - Motion platform demonstrator for scanning flat samples and radomes using FMCW and TD systems
Purpose: The purpose of the demonstrator was to be able to scan flat samples of 300x300mm and a small radome provided by IAI. The radome is axis symmetrical with a base diameter of 290mm and a height of 400mm. While scanning, the sensor will maintain perpendicular orientation to the sample surface as well as maintain a fixed distance to the surface such that the sensor remains in focus. The platform consists of 3 linear stages with a precision of 10 μm and 2 rotational stages with a precision better than 100 arcsec. This allows to point the system to any point on a sample with an accuracy of 50 μm.
How the foreground might be exploited: The platform is capable of integration of both Synview FMCW sensors (operating at 100, 150, 300, 850 GHz) and the Fraunhofer TD system. Using the FMCW sensors, the system is capable of obtaining scan rates of 500 samples/second; using the TD sensor, it is limited to 10 samples/second. The speeds of both systems can still be increased if improvements are made to both the sensor (hardware/software communication) and the motion controller. The platform has been custom built, so it can be adapted to respond to future user's needs.
When: ready for exploitation
By whom: Verhaert

#11 - Knowledge capture in the field of multi-axis motion control systems and platforms
Purpose: Verhaert acquired the knowledge to design and build complex motion platform systems and integrate state-of-the-art sensors. This was demonstrated by the realisation of the multi-axis motion platform with integrated THz sensors. Verhaert demonstrated the capabilities to:

- Perform the system architecture design (system concept, component selection, ...)
- Perform mechanical design and integration
- Perform electrical/electronic design and integration
- Perform software architecture design and implementation
- Integrated system validation & testing (mechanical, electrical, software, ...)

How the foreground might be exploited: Verhaert will apply this knowledge in future motion related projects and actively market these capabilities in its innovation consulting portfolio.
When: ready for exploitation
By whom: Verhaert

#12 - Tomosynthesis reconstruction method of THz data
Purpose: Acquired data from FMCW sensor measures directly data in pseudo 3-D dimension in the sense that the resolution in depth is better than the lateral resolution. DOTNAC experiments show that we have a lateral resolution of approximately 5mm which is not sufficient for NDT of small depth and planar objects. To overcome this problem, 3D acquisitions/reconstructions methods have been experimented within the DOTNAC project, based on medical imaging 3D tomography and tomosynthesis However, these methods have to be adapted in order to take into account the specific form of the terahertz beam. While specific tomography methods have already been published, tomosynthesis ones are original to this project and show potential interest for NDT tools, especially for small depths and planar objects.
How the foreground might be exploited: Application fields targeted are aeronautic industries but these technique could be used for defence and security applications or others domains where terahertz imaging gives new information.
When: ready for exploitation
By whom: CNRS

#13 – Fiberglas composite samples knowhow
Purpose: Every new developed NDT technology has to be subjected to an evaluation of its detection capabilities. The most efficient and reliable way of carrying out this task is by inspecting real materials with real defects. However, the production of these defects in a controlled way, such that it allows a quantitative analysis of the detection capabilities, is a difficult task, sometimes even impossible depending on the type of defects to be studied. Therefore the so called “calibration samples” are usually employed, which consist of real materials containing induced defects simulating real defects. The characteristics of these simulated defects, their nature, sizes and depths, so they reliably simulate a real defect, is an important knowhow for subsequent NDT technologies evaluation.
How the foreground might be exploited: The applications of this knowhow will be realized firstly in aeronautic industries for evaluation of new NDT technologies, and afterwards it would be also used in other industries in which composite materials are also employed, such as wind industry, automotive and so on.
When: ready for exploitation.
By whom: CTA

#14 – Defects detection in composite materials with thermographic NDT tools
Purpose: The extensive experience with IRT NDT inspections in composite materials makes it possible a double application of IRT technology. On the one hand, IRT may be used for comparison of the detection capabilities of new NDT technologies, such as the case of THz NDT, providing a reliable comparative measure of the necessary detection abilities. And on the other hand, this technology is enough matured and relatively established in the NDT industry so it may be also used for detection of real defects in composite materials, taking advantage of the good features of this technology.
How the foreground might be exploited: New NDT technologies could be evaluated and validated by means of IRT, and also composite materials manufacturers and end users may be offered for IRT inspections there where an IRT inspection is feasible.
When: ready for exploitation
By whom: CTA

#15 – Super-resolution

Purpose: This algorithm (accessible via the reconstruction menu) allows the fusion of N images of a resolution p into one image of a resolution p/N. This process induces a blur on the reconstructed image.

How the foreground might be exploited: Application fields targeted are aeronautic industries but these technique could be used for defence and security applications or others domains where terahertz imaging gives new information.

When: ready for exploitation

By whom: CNRS, UNIKL and Fh-IPM

#16 – General understanding of THz capability in NDT

Purpose: THz is an emerging technology. As a result its capability in NDT is still not well understood in the scientific community and even practically unknown in the industrial community. The different experimental tests performed in this project clarify this issue. Different aeronautic structures with different defect types have been tested and analysed. Looking at DOTNAC results and conclusions we can correctly assess the ability of THz in testing different structures and different defect types and thus make decision for future implementation of the technique.

How the foreground might be exploited: Provision of consultancy services and exploration of further research opportunities.

When: ready for exploitation

By whom: IAI and all other DOTNAC partners

#17 – Zvisu

Purpose: During the project, different objects and image processing were acquired with the different setup design for DOTNAC. Then a new need was identified that required new tools to load , visualize in 3D and analyse different images. Zvisu is a prototype for the visualization of data in a 3D space. One of the main result is the possibility to open the files in few minutes (depending of the computer memory and processor capability) , reconstruct the total 3D shape of the sample. This makes it possible to navigate in the 3D space and to rotate samples with a mouse.

How the foreground might be exploited: Application fields targeted are aeronautic industries but these technique could be used for defence and security applications or others domains where terahertz imaging gives new information.

When: ready for exploitation

By whom: CNRS