INNOVATIVE NDT CONCEPTS FOR AEROSPACE INDUSTRY - THE INCA PROJECT

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Abstact:

New materials and manufacturing processes in aircraft industry demand efficient quality assurance in manufacturing and inspection in maintenance. Due to the higher number of air-crafts inspected in the same time, aging effects and new materials and manufacturing processes innovative inspection concepts are strongly needed to reduce the human factor and to increase the throughput and sensitivity.

For this reason several major aircraft companies started a common project named **INCA** (**I**mproved **N**DE **C**oncepts for Innovative **A**ircraft Structures and Efficient Operational Maintenance) consisting of competent European and American partners to investigate promising techniques as solutions for different NDI aspects and to merge some of their research activities in these areas.

Amongst the principles under investigation one can find contact-less laser ultra-sonic method that can avoid the coupling problem for curved and sensitive surfaces. There are shearography and thermography, modern field-wise and also contact-less optically based methods that can be combined with heat, vibration or pressure loading to inspect bonded, layered and other composite structures. INCA also covers GMR and array-like Eddy Current sensors for the inspection of thick metallic structures. New resonance techniques promise to find defects automatically by analysing the frequency response of an object. And finally, real-time X-raying techniques can help to perform in-service X-raying in an easy way.

Practical examples and general application scenarios will be presented to make clear for each single case that a measurement concept not only consists of a sophisticated sensor but also of a well adapted loading mechanism, data evaluation and representation. In addition to that it is important to develop suitable calibration standards and procedures in parallel with the method itself. Especially for thermography and shearography you cannot simply use conventional ultrasonic testing standards.

This contribution gives a rough overview of the current INCA activities, deficits and advantages of the mentioned testing concepts with respect to flexibility, speed, sensitivity as well as costs.

Introduction:

European aircraft industry has achieved a key role in the world market. To reach and maintain this position it has been constantly introducing innovations especially in the field of structural design. Successful introduction of new structural technologies into the European aeronautic industry demands that quality control and maintenance tools are developed in due time fulfilling adequate performances. The objectives of this project are focused on the developments of a selection of NDT methods well suited for adaptation to tomorrow's needs. The following list should demonstrate some of them:

- Higher number of aircrafts: The fleet of European aircraft will continuously grow in future despite all drawbacks that occurred recently. This higher number demands reliable and faster inspection methods in order to keep the pace with the maintenance requirements. Methods like shearography, thermography and digital X-ray techniques are capable to fulfil these requirements.
- Aging aircrafts: The European aircraft fleet is relatively young. In future there will the strong need to inspect aging aircrafts to ensure reliability and offer ways for longer lifetime. The inspection techniques of INCA can easily be adapted to aging aircrafts' needs.

- New aircraft types: Recent developments in European aircraft industry showed that there is an urgent demand to deal with larger areas in short times due to the fact that the aircraft's body becomes larger. INCA's new inspection techniques for contact-less and full-field testing and concepts are necessary to fulfil future demands.
- New structural designs: New materials and processes have been developed and will be developed in future that are not easy to be inspected by conventional means. Integral composite designs, advanced multi-layered structures, metallic laminates and new bonding techniques demand new approaches to a reliable inspection. URS, Thermography, sherography and laser ultrasonics for example are developed with respect to these new structural designs.

Non-contact NDT methods such as laser based ultrasound and optical and thermo-optical techniques show great promise in achieving the necessary increase in inspection quality. However as there is such a broad range of different materials, geometries, and structures the successful application of these methods can only be achieved by careful research and development into optimising each method for aeronautic requirements.

In this respect, major efforts will be put on the development of laser ultrasonic technology. The potential of this technology has already been demonstrated in the USA and in France. It is a non-contact method well suited for complex shape inspection. Hence, it becomes now necessary that the partners establish their own knowledge and capabilities prior to a qualified introduction of this technology.
Besides, it is also important to look for improvements that could be made on methods already widely spread. The developments carried out are suited for easy and quick retrofit of systems currently used in production and maintenance. The second task builds on the strong European capability in optical NDT by incorporating new stressing techniques and applying signal and image enhancement to the previously developed shearography and thermography systems. These new optical and thermo-optical test methods promise the necessary increase in inspection quality, but the broad range of different materials, geometries, structures make lots of knowledge necessary to adapt the methods for the full range of aeronautic inspection demands. Basic instrumentation for these non-contact methods is available on the market, but still a gap is to fill out with improvements to make them fit for the use in a rough industrial environment, as these methods are essential to ensure fast, reliable and cost efficient quality control and maintenance inspection for a lot of new advanced structural materials.
Also the traditional NDT methods like X-Ray, Eddy Current (EC) and Ultrasonic Resonance Spectroscopy (URS) promise significant increase in sensitivity, reliability and inspection speed, as new sensor technologies - being now available - and new data evaluation methods will be integrated, tried out and verified. Data treatment techniques will be applied across the complete range of developments and the improvement of NDT data merging or fusion techniques shall overcome the limited confidence if interpreting data only from one single inspection method

Results and Discussion:
Laser-coupled ultrasonic technology (principle in Fig. 1) has been studied for nearly twenty years in many laboratories, in Europe and North America. Two partners of the INCA project, Dassault Aviation and EADS CRC, bought such a system about a decade ago for evaluating the technique on aeronautical applications. Internal work and European project work demonstrated the high potential of laser ultrasonics for testing composite structures. The technique is especially suited for the inspection of large composite parts, with complex geometry. More and more composite structures are being developed and introduced for aircraft programmes as they enable to reduce operation costs by reduced weight. For future programmes (e.g. composite fuselage), a key element is to have inspection systems adapted to such complex parts. In this respect, the aeronautical European industry is eager to complete the evolution of laser ultrasonic technology in order to get the maximum performances of such a testing system and to set up European industrial capabilities for this technology before introducing it into the quality assurance process in a qualified way.
The INCA scientific approach is based on the set-up of a test platform at MYOS site on one side and the development of defined sub-systems on the other side. The sub-system requirements will be defined by the end-users and validated on representative cases using the test plat-form.

The test platform architecture was defined from end-users experience in laser ultrasonic inspection with an old LUIS72 (UltraOptec, Canada) system. Preliminary specifications and requirements lead to establish an evolutionary laser ultrasonic platform as a basis for validations and developments of defined sub-systems. The test platform is made of five main units: the CO_2 generation laser (SDI, SouthAfrica), the long pulse detection laser (Tecnar, Canada), the photo-refractive interferometer (Tecnar), the simple XY motion system (NewPort) and the electronics boards for data acquisition and exploitation (Nutronik). The components were accepted after a reception validation step in 2003. Now the subsystems integration is progressing until June 2004 in MYOS facility (see Fig. 2), with the contribution of Nutronik for the motion controller and UT boards. Finally, validation tests (carried out by end-users with the help of integrators) will assess the performances of the assembled platform with respect to the specifications and requirements. To ensure mobility and to prepare the tests at partner's site, EADS CRC has provided a shelter to MYOS that is ready to contain the whole Laser Ultrasonic platform.

In parallel, the development of generation and detection subsystems to improve performances in term of sensitivity, bandwidth and speed are in progress. Concerning the development of generation lasers to improve efficiency on composite, two ways are investigated. One is to improve industrial laser already existing but requiring modification: BAE Systems has shown that reducing the Nitrogen content in the gas mix has a beneficial effect in avoiding heating and possible damage to the test material, while IMI is investigating the modification of the CO_2 laser resonator with a variable reflectivity mirror. The second axis involves a new original laser called *thin disk laser*. University Stuttgart is in charge of the design and experimental realization of an adapted diode-pumped Yb:YAG thin disk laser (Fig. 3). The improvement work on the Pockels-cell driver and disc bonding and coating is nearly finished and the laser pulse energy is going to reach about 100mJ. An optical parametric oscillator (OPO) operated in the mid IR wavelength range is being developed by Onera, to be coupled to the disk laser (Fig. 4). A study on wavelength selection and requirements (carried-out by Dassault, EADS CRC, BAE Systems and GE) has proved that the OPO is a very suitable solution to improve generation efficiency in composite materials, because the efficiency values are high and the damage threshold too. The improvement of the KTA crystal coating increased the maximum energy available. At the present time the maximum output energy delivered by the OPO at Onera is about 10mJ for a 100mJ input pump power.

Generation lasers for metallic materials require different characteristics compared to the composite materials. Two axes have been investigated: a theoretical model developed by GE has shown the potential of X-ray lasers for thermo-elastic generation in metallic samples. Technical contacts are in progress between CESI and other European research institutes to hire such a laser source. On the other side, CESI is investigating a 3ω and 4ω optical device allowing operating the disk laser (Fig. 5, developed for composite materials) in the UV range. The requirements and specifications of the optical device are complete, and the development of a harmonic switch is in nearly finished and available as a demonstrator.

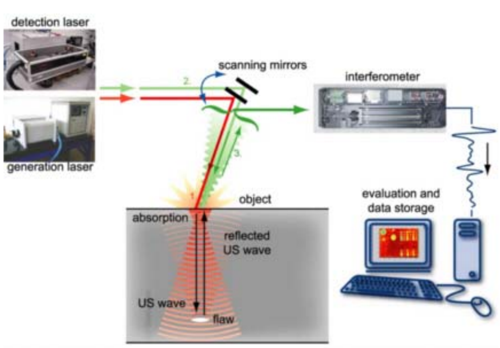

Fig. 1: Laser-coupled ultrasonic testing principle. In INCA the guiding mirror are replaced by a XY-translation stage

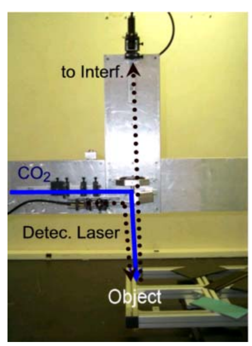

Fig. 2: Coupling device of the INCA platform that guides the laser light on the object

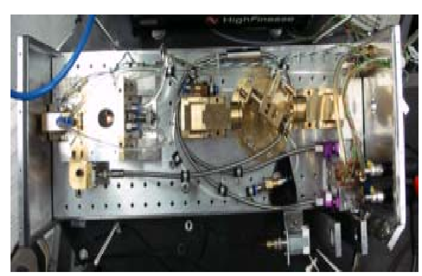

Fig. 3: View into the opened thin disc laser demonstrator for laser US applications

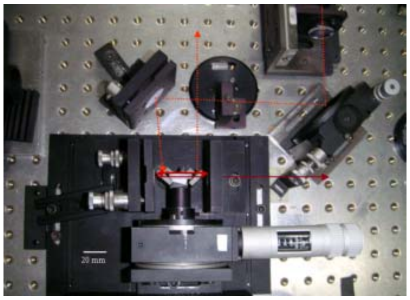

Fig. 4: Onera optical parametric oscillator for 3.1-3.4µm laser light generation

Fig. 5: CESI optical parametric oscillator for mid-IR laser light

Another main task is dedicated to the improvement of detection lasers. The work of IMI has been concentrated on a flash lamp pumped oscillator, instead of the usual scheme of a small single frequency oscillator followed by an amplifier. A stable mounting of the ring configuration has been completed and gives satisfactory results. The detection limit with photo-refractive demodulator detection was verified and was found in agreement with expectations. A second system developed at the IMI, inducing generation plus detection could lead to a new compactness and extremely low cost Laser Ultrasound NDT system (Fig. 6). IMI also carried out a theoretical study on the advantages and drawbacks of pre-amplification and post-amplification scheme for laser detection that showed pre-amplification beneficial against post-amplification in special cases. Concerning post-amplification, CESI is working on a diode-pumped fibre optic amplifier (Fig. 7). All optical components are working and a demonstrator is available and working.

For improving the sensitivity of interferometric detection, the work has been focused on photo-refractive laser ultrasonic sensor. Photo-refractive interferometers have been demonstrated to be powerful devices for detecting ultrasound with high bandwidth and with sensitivity approaching the ultimate sensitivity detection. LCF/IO works on the experimental characterization of the different configurations of implementation of a single channel photo-refractive laser ultrasonic sensor. This task is now almost finished except for some further discussions and evaluations of the Nd:YAG laser in collaboration with IMI. Another promising field of interest is the study of a multi-channel photo-refractive sensor by LCF/IO. The aim is to develop a multi-point detector (Fig. 8) and a proper optical system, to make the measurement on several points on the target. LCF/IO is continuing the implementation of the set-up of the sensor that will be used for its characterization and its evaluation. The implementation with low cross talk between the channels is now finished and the first measurements have been performed successfully towards a fast, multi-channel laser US arrangement.

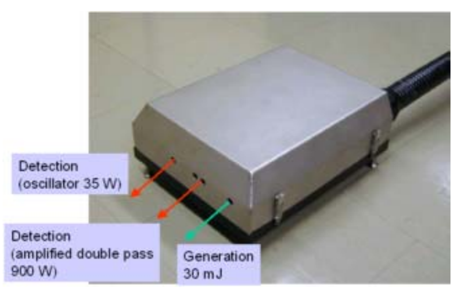

Fig. 6: Laser US head by IMI integrating generation and detection laser in a 30x30cm^2 device

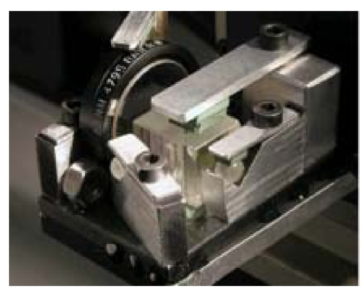

Fig. 7: CESI coupling device of the fibre post-amplifier

Concerning data acquisition and signal processing, Tecnatom develops an adapted ultrasonic board. Its UT hardware (Fig. 9) has been designed on a modular way (PCI based): the carrier board, the A/D converter board and the DSP board. The requirement definition of the ultrasonic board is finished, the hardware will be completed and integrated as soon as first experimental signals will be issued from the test platform. As the laser generated ultrasonic signal is transient in nature and embedded in noise, University of Central Lancashire (UCLAN) has developed a real-time digital signal processing system (based on wavelet transform) for restoration, detection and

extraction of the noisy laser generated ultrasonic echoes. To improve further the performance, a new method was developed by UCLAN to design an optimal wavelet function. The new method yields a new type of wavelet that is adaptive to the waveform shape of the ultrasonic echoes to be detected. Initial evaluation based on simulated data shows improvement in performances in terms of automatic attenuation estimation.
GE worked on the system performance prediction and measurement, developing a set of common standards and benchmarks to measure source and receiver performances. GE has supplied a test equipment fixture to the end-users partners, for measuring the efficiency of ultrasound generation. As a result of the QFD (quality function deployment) carried-out by GE with the participation of the INCA consortium, the main requirements and criteria for an optimal have been elaborated.

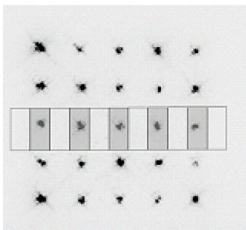

Fig. 8: Multi-channel by LCF/IO laser US. Picture of the image of the 25 detection points with detector line scheme

Fig. 9: Laser US data acquisition and evaluation board

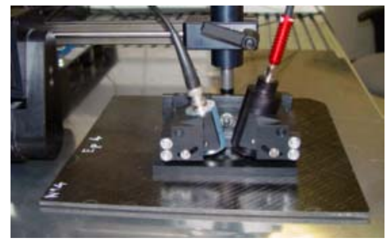

Fig. 10: laser US portable head from Dassault in pitch-and-catch configuration

An additional development is dedicated to an original concept of low cost and portable equipment for non-destructive inspection, using generation by compact Nd:YAG laser coupled to a fibre optic connection and detection by air-coupled transducer. Preliminary tests have been performed by Dassault to show the potential of air-coupled transducers to detect laser-generated ultrasound in a wide range of materials (pitch-and-catch arrangement). Cracks in metallic samples and impact dam-age in composite materials have been detected with this new concept. The portable head has been manufactured according to the specifications, and the integration with the generation laser and with a portable XY-scanner provided by CSM is in progress.
Platform testing results on CFRP components will be available mid of 2004 and be presented during WCNDT2004 conference.

In addition to laser ultrasonic a variety of promising NDT techniques are investigation in the INCA project. At the end of the project new demonstrators for the according are expected.

Ultrasonic Resonance Spectroscopy (URS) by University Uppsala is a novel technique capable of detecting defects for example in ferrous and nonferrous metals, powdered metals and ceramics. Regarding the detection of typical defects in composites, sandwiches and bonded structures, URS shows high potential for the investigation of such a type of defect. This technique has also given indications to detect defects like kissing bonds, which so far are considered hardly detectable by NDT. INCA research gives better knowledge of the capabilities of URS and also tries to automate scanning and evaluation to get a fast, rational and documented inspection. The inspections with URS is optimised by using tailor made transducers and optimal configurations for different materials. The URS technique is combined with a versatile automated scanner and a neuronal network (NN) defect classification tool. URS-inspections are performed with a scanner and real time evaluation and classification of defects by the NN-tool are done.

The eddy current testing of aeronautical metallic components is the main NDT method for fatigue test and in service aircraft. As well known, for measuring the perturbation of magnetic field around a crack in the conductive materials, different magnetic field sensors are applied and, therefore, the sensor is one of the main components of an eddy current inspection system. The main relevant performances of the sensors are high resolution, high sensitivity, high frequency range, robustness and simple structure. A new concept for eddy current testing is

investigated by Alenia and Airbus, which is based on GMR (giant magneto resistance, Fig. 11) sensors. In addition to that, data processing of the GMR sensor data follows new concepts. A sophisticated new software front end (a regression algorithm, which proved to be promising) supports the new capabilities of improved sensor resolution and offers faster, more reliable and easier readable output data streams for the subsequent evaluation and documentation process. Focus of the development is the lap joint inspection where at the Airbus for instance different configurations exist. From medium thickness where cracks under a cover of about 2.4-2.8 mm aluminium sheet material have to be inspected to much thicker structures as they are present for instance in the joint of the pressure bulk head with the fuselage – there are cracks to be inspected covered by 6-8 mm aluminium or even more. Here, conventional coil arrangements need high current at low frequencies, which decreases sensitivity and lateral resolution. Future structures realized with metal laminates (GLARE®) need also more sensitive ET sensors to cope with the increasing thick-ness which is realized with these metal laminates for instance in the A380. Airbus focuses on the use of GMR's to deal with this challenge. GMR's are magnetometers and measure the resulting field directly and not via the induction law.
A first probe prototype was realized. It consists of a conventional driver coil and the GMR chip in a second housing. The probe type is a pitch & catch configuration with variable distance between transmitter and receiver.

Shearography has a high potential as rapid inspection method for large areas. Since the start of INCA the number of applications for this optical, contact-free method could be increased. The systematic approach for adapted stressing of the inspected component also increased the applicability of shearography. Shearography is a powerful tool for the investigation of technical components with respect to material faults and structural imperfections. It is possible to detect damages like pores, delaminations, cracks or even faults in bonded composites or monolithic structures. However, to raise the acceptance level in manufacturing and maintenance environment as an equivalent NDT-tool the shearographic technique has to provide innovations. Existing set-ups use bulky and heavy cabinets for loading and sensors. The necessary light illumination is generated with expensive and spacious laser sources. The software is usually operational with scientific or highly experienced personal only. The systems are less flexible to work with hardware newer generation like metal-oxide semiconductors (CMOS). Therefore, the overall objective in the INCA project was the improvement of the applicability for the shearography technique under industrial and maintenance conditions. A system was developed by EADS Military Aircraft that offers a lightweight cabinet, comfortable object stressing, easy-to-use software interface that cope with non-cooperative surfaces and advances laser diode technology (Fig. 12). First experiments show very good results on composite or sandwich structures.

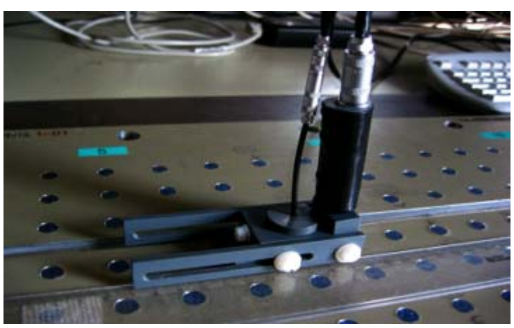

Fig. 11: First version of a GMR sensor used for cracks detection on lap joints of metallic laminates

Fig. 12: INCA Shearography demonstrator in in-service use on a real aircraft

When structures, composite and metallic, are assembled some types of defects require X-raying inspection methods. Sometimes access problems arise, which limits its use. Nowadays there are promising detectors technologies and automated displacement machines that can solve this problem of bulkiness and on the other hand offer real-time working capability parallel to a reduced use of chemical materials compared to the classical X-ray process on assembled structure inspections. Fig. 13 shows the first demonstrator of a real-time X-raying system for in-service use developed by NDT Expert. An additional advantage is their high sensitivity that improves the effectiveness of the inspection as well as the reduction of X-raying working time, which saves maintenance costs.

Fig. 13: Images of the first prototype of the Galaxy system for the ImageStar detector steering

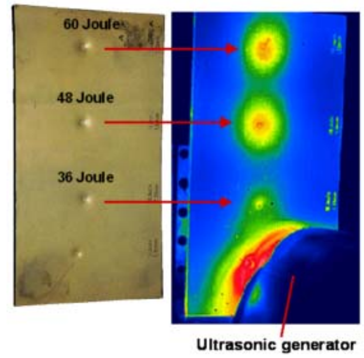

Fig. 14: Use of ultrasonic excited lock-in thermography for impact detection on a GFRP/metallic laminate (9 metal layers) with debondings

Pulse thermography, thermal-wave-imaging or modulation (lock-in) thermography are currently the top thermo-optical inspection methods responsible for a break through of this technology in the aeronautical NDT which could be proved by several experiments. For thermography one of the main critical factors is the definition of suitable stressing methods and the development of inspection procedures easy to be applied/transferred by/to the factory floor and in-service inspection. While standardized thermographic systems are available in a wide range, new, specially adapted stressing systems and inspection procedures are investigated and tested in INCA. Two major directions are investigated: first IR loading by flash or IR lamps and secondly ultrasonic excitation (e.g. by high power US transducers) that generates heat by internal friction if delaminations, corrosion or cracks are present. According inspection equipment was designed, manufactured and installed in the INCA project by Airbus Deutschland as a demonstrator version that shows promising results for delamination and impact detection in composite materials and laminates (Fig. 14).

For all measurement techniques a common database has been established providing a basis for the exchange of test samples, to compare the results and to optimise the data representation and evaluation. Modern data fusion software tools (by University of Central Lancashire, Fig. 15) are used to map NDT results on CAD surfaces for better visualization and defect analysis and for quantitative comparison of different NDT results of the same composite.

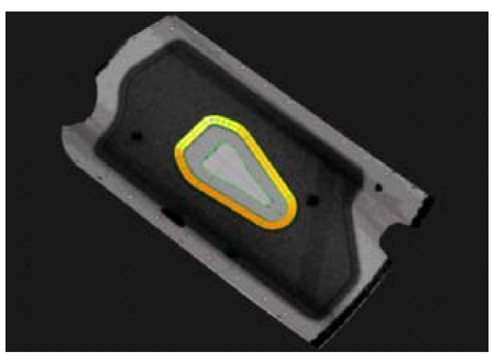

Fig. 15: X-ray picture mapped on a digital, CAD based object representation

Conclusion:

The INCA project covers a considerable variety of different innovate technologies in various states of maturity. The shearography, X-ray and thermography developments are expected to be on the market soon as an extension of existing NDI equipment and as an approach to the inspection of new materials and components. Laser ultrasonic is

a technically mature technology the reliability and costs of which still have to be improved and that need special adaptation to the aircraft manufacturers' needs with respect to the shape of the components, CRFP surface conditions and flexibility. GMR sensor are under development and adaptation also outside the INCA project and the combined experience will lead to near-term solutions, too.
All INCA technologies will lead to improved inspection capabilities and will enable the introduction of new, economically and ecologically efficient, aircraft materials, components and designs.

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