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AUTONOMOUS INSPECTION AND REPAIR OF AIRCRAFT COMPOSITE STRUCTURES

V. Kostopoulos[1], , S. Psarras[1], G. Sotiriadis[1], T. Loutas[1] , I. Gray[2], J. M. Padiyar[2], I. Petrunin[2], J. Raposo[2], L. Zanotti Fragonara[2], V. Tzitzilonis[3], K. Dassios[4], D. Exarchos[4], G. Andrikopoulos[5] and G. Nikolakopoulos[5]

[1] Department of Mechanical Engineering & Aeronautics, University of Patras, Greece, Email: kostopoulos@upatras.gr, thloutas@upatras.gr, spsarras@upatras.gr, gsotiriadis@upatras.gr,
[2]School of Aerospace, Transportation and Manufacturing, Cranfield Universitym, United Kingdom, Email: i.gray@cranfield.ac.uk, m.padiyar@cranfield.ac.uk, i.petrunin@cranfield.ac.uk, j.raposo@cranfield.ac.uk, l.zanottifragonara@cranfield.ac.uk
[3] Exis Innovation Ltd, United Kingdom , Email: vasilis.tzitzilonis@exisinnovation.co.uk
[4] Department of Materials Science and Engineering, University of Ioannina, Greece Email: kdassios@cc.uoi.gr, exarchosd@gmail.com Web Page: http://www.uoi.gr/en/
[5] Department of Computer Science, Electrical and Space Engineering, Lulea University of Technology, Sweden, Email: georgios.andrikopoulos@ltu.se, george.nikolakopoulos@ltu.se

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Abstract

This paper deals with the development of an innovative approach for inspection and repair of damage in aeronautical composites that took place in the first two years of the H2020 CompInnova project which. The aim is a newly designed robotic platform for autonomous inspection using combined infrared thermography (IRT) and phased array (PA) non-destructive investigation for damage detection and characterization, while integrated with laser repair capabilities. This will affect the increasing societal need for safer aircraft in the lowest possible cost, while new and effective techniques of inspection are needed because of the rapidly expanding use of composites in the aerospace industry.

Introduction

Beside the passengers' demand for absolutely safe flights without the passing of any extra cost to their pockets, there is also a global market that will buy, use and get benefitted from a novel technology which will be designed in order to dramatically upgrade and optimize aircraft inspection.

In the aerospace industry high level of safety for passengers and goods transferred are of the utmost importance. Aircraft are subject to ground and periodic testings to examine their integrity and functionality resorting both to traditional visual inspections and non-destructive testing (NDT) as requested by European Avitation Safety Agency (EASA) and Federal Administration Aviation (FAA). Currently, C and D type of checks are carried out every 15-21 months and 6 years respectively on aircrafts. C-checks require up to 6000 man-hours, whilst D checks may require up to 40000 man-hours, therefore there is a paramount industrial interest in the reduction of inspection time due to the high costs of trained technician without compromising in efficacy and accuracy of the NDT [1]. The authors are developing an automated prompt NDT approach capable to detect, evaluate and repair damages in composite aircraft structures.

Damage detection

The field of robotics for aircraft inspection is still relatively immature and more development is needed before an autonomous crawler can become available for robotic inspection of aircraft structures. Several portable scanners have emerged in the last several years, including the Automated Non Destructive Inspector (ANDI) and the portable NDT arm PANDA. Relative recently, JPL developed the Multifunction Automated Crawling System (MACS) offering an open architecture robotic platform for NDE boards and sensors. MACS was designed to inspect large structures particularly in field and depot conditions and it established the foundations for the development of a "walking" computer platform with standard plug-in NDE boards. In the last years, interest in autonomous/automated inspection has been growing, as the innovation projects of large airliners like EasyJet [2] and Air France Industries-KLM [3] in unmanned aerial vehicles for visual inspections (typical examples of A checks) certify. Nonetheless, the problem of autonomous inspections in the case of C and D checks remain unsolved, since multiple robust NDT techniques (i.e. ultrasonic testing, infrared thermography, x-ray radiography, acoustic emissions, shearography or electromagnetic testing) need to be used.

In this context the CompInnova methodology was proposed. PA and IRT are combined in order to detect near-surface and sub-surface damages. Development of a novel thermographic technique termed Pulsed Phase-informed Lock-In Thermography, enables for the first time the rapid and quantitative assessment of damage in the materials. Furthermore, the results are fused using machine learning and image processing techniques for detection and sizing in real time. This will provide the information needed for an automatic laser repair procedure capable of removing precisely ply-by-ply the material. This method allows to have a well-treated surface to apply a repair patch.

Damage characterization and repair

An imaging analysis software for automated defect detection and localization and online storage has been developed, able to deal with both PA and IRT data. In this software, different image processing algorithms were implemented and integrated for real time processing during the inspection. An input code was programmed to allow PA/IRT data (e.g. defect location, 3D damage size etc.) to be easily and automatically inserted to the parametric numerical models of the under-inspection components. The image analysis software is based on 4 modules Figure 1:

- Comparison of the PA or IRT image with previous images of the component;
- Initial image analysis for background separation;
- Automated defect recognition;
- Sizing through contour analysis;
- Patch Geometry Calculation if repair is needed.

For the comparison of images (acquired in different scans) a Structural Similarity algorithm was implemented. The main advantage of this technique is the decrease of the computational complexity resulting real time process with good accuracy results. Additionally, the creation of an archive database with previous inspection data provides the capability to the user to choose any previous PA-UT or IRT image of the component to compare with the current inspected data. This comparison can give information regarding the ageing of the inspected part during service life. Also, this is a quick method to give the trigger for further investigation or not.

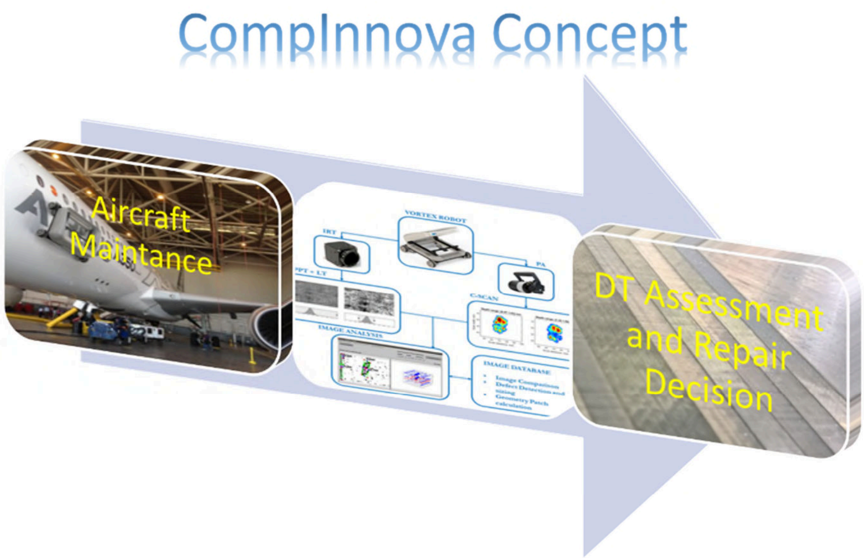

Figure 1. Block Diagram of the autonomus inspection and repair

The primary analysis is based on image segmentation using different thresholding algorithms followed by automated defect detection and sizing algorithm which was integrated into a Graphical User interface (Figure 1). In addition, an algorithm for the calculation of the patch geometry was implemented. Lastly, a database was developed to store all the necessary data from the inspections. The combination of both PA-UT and IRT imaging subsystems, providing a reliable and automatic process, will be validated and fine-tuned further during the lab-trials.

A robotic platform, based on a vortex-based actuation system, will be used to carry out NDT resorting to combined infrared thermography (IRT) and phased array ultrasonic (PA) for damage detection and characterization. The robot is going to be able to attach and move on surfaces of different orientations via the use of a vortex-based actuation system, thus providing the ability to autonomously access, scan and repair the different sections of an aircraft fuselage. The robotic platform is combining infrared thermography (IRT) and phased array (PA) non-destructive investigation for damage detection and characterization and is going to be integrated with laser repair capabilities. PA and IRT are combined in order to detect near-surface and sub-surface damages. Furthermore, the results are fused for detection and sizing in real time and stored in a database for later comparison. This will provide the information needed for an automatic laser repair procedure capable of removing precisely ply-by-ply the material. This method allows to have a well-treated surface to apply a repair patch. An advanced localization system allows the integrated system for a customizable and robust inspection and repair procedure, adjusted to fit the set requirements.

Market Data

NDT inspection companies, composite manufacturers, aircraft Original Equipment Manufacturers, motor manufacturers and aircraft maintenance & inspection companies, alongside with the European Community as a whole will take advantage of the project's impact in all possible aspects, which will offer a clear cost advantage to every involving participant. CompInnova will meet the end users' needs in quality, performance, functionality and flexibility while the cost and the effort will be significantly lower to the current solutions. Aircraft companies are increasingly using composites predominately in order to reduce weight and maintenance costs of the airplane. Boeing, as the first commercial aircraft manufacturer decided to design and manufacture 50% (by weight) of the airframe structure including the entire hull of its new B787 Dreamliner from composite materials. The Advisory Council for Aeronautics Research in Europe (ACARE) believes that composites still have further step change potential in the future. As can be seen from Figure 2 the production of aircrafts and maintenance repair services account the 70% of the aerospace industry according to the Aerospace and Defence Industries Association of Europe (ASD) annual report in 2010.

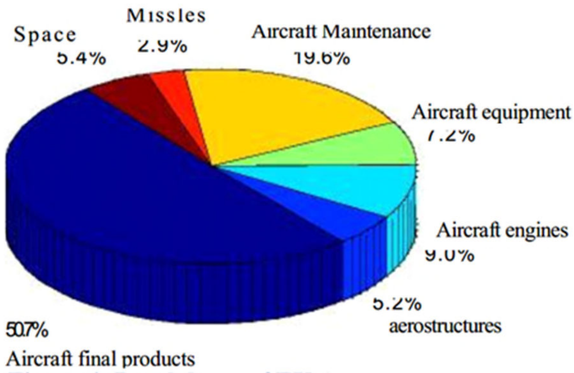

Figure 2 Breakdown of EU Aerospace Industry turnover by production

The market for aerospace composites, encompassing both production and maintenance, repair and overhaul (MRO) services is by the AeroStrategy's 2009 estimate worth approximately €7.3 billion. Demand for MRO service of composites, such as repair of thrust reversers, radomes, nacelles, control surfaces, structural components and cabin interiors, is sizable at €1.8 billion, and it's growing, Figure 3. The predictions about the future are that the increasing percentage of composites in new transport aircraft and continued growth in the demand for MRO services will combine to nearly double the aerospace composites mrket. The belief is that the market will reach €9.8 billion till 2016 at a compound annual growth rate of nearly 7% (fig. 5). The next decade (20162026) the increase in the composite market is believed to be sharper.

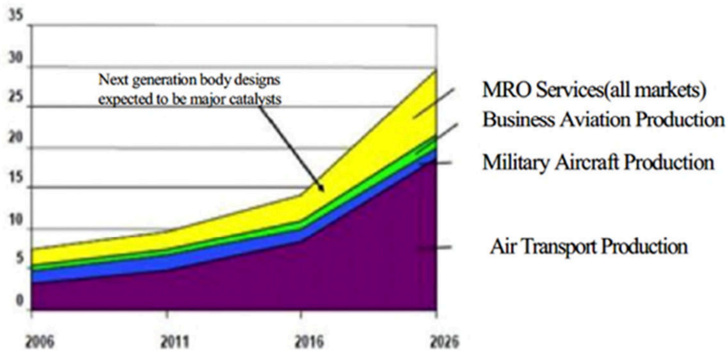

Figure 3 Aerospace composite market forecat (in Billions of Euros)

The global non-destructive test equipment is forecasted to reach €900 million by 2015 and the market's growth is expected to continue at a steady rate through the next few years. Within the NDT community, development teams are focusing on finding tools and strategies to help the future NDT operators to detect and quantify potential internal structural variations of composite materials in fast and accurate manner.

Eco-Social Impact

Autonomus inspection and repair will achieve two aims simultaneously, namely improve quality and productivity and at the same time provide a relative decrease in direct and indirect costs by strongly reducing direct costs and weight. Economic growth will be maintained by increasing the competitiveness of EU industry through world leading products introduced with lower development and manufacturing costs, supporting the demand for highly skilled jobs with a knowledge transfer vision. The development and deployment of new structures - technologies will have a direct impact on reducing the gross weight than any other technology area. This will be clearly reflected in reduction of CO2 emissions. The concept proposed will also decrease the direct costs of operation due to less weight and potentially time and effort spent on inspections and maintenance. The four challenging environmental targets for 2020 set by the Advisory Council for Aeronautical Research (ACARE) radical changes in current aircraft design rules and philosophy must be implemented: (1) 50% cut in CO2 emission per passenger/km, (2) 50% cut in perceived aircraft noise, (3) 80% cut in nitrous oxide (NOx) emissions, (4) greener life cycle.

Among the most promising technologies identified were improved aerodynamic efficiency, better manufacturing and recycling processes and low-weight structures. A possible breakthrough, to achieve the reduction of CO2 emissions for commercial aircraft by 50% per passenger-kilometre in the long-term and a greener life-cycle, is through novel and reliable tools, materials, techniques able to increase the structural efficiency of aircraft structures, extending the impact and damage tolerance boundaries of materials (and therefore lighter material), reduced materials usage and with direct consequences on the extension of the service life of operating structures.

Conclusions

The Project Outcome will be a robotic scanner for composites inspection using different NDT imaging systems. The three different modules (PA, IRT and laser repair) are integrated on an autonomous robotic platform. The robot is going to be able to attach and move on surfaces of different orientations via the use of a vortex-based actuation system, thus providing the ability to autonomously access, scan and repair the different sections of an aircraft fuselage, aiming the Aerospace industry that budgets €7.3 Billion with benefits as the following. Clear economic impact on the partners involved in the NDT, composite and aerospace sector and EU economy.Development of a new EC guideline in inspection and maintenance of composites for aerospace use.Reliable and easy to maintain technology with a cost reduction in the order of 30% without compromising safety.Save time as it is based on "in-situ" or "pseudo-continuous" method.Enhanced competitiveness of EC aircraft in terms of reduced environmental impact, higher safety standards and lower whole life cost. And finally, contributing substantially to the decrease of direct operational costs by 50% by 2020 and to the reduction of accidents by 80% (again by 2020). It is obvious that this project fulfils the societal and policy objectives.

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