AUTONOMOUS RAPID INSPECTION OF AEROSPACE STRUCTURES

Yoseph Bar-Cohen
JPL, California Institute of Technology, 4800 Oak Grove Dr. (125-224)
Pasadena, CA 91109, yosi@jpl.nasa.gov

ABSTRACT

Effective assurance of the integrity and performance of aging aircraft structures, particularly those that are made of composite materials, requires rapid inspection of large areas. Removal from the aircraft for NDE at an inspection facility is not economical and preferably the inspection should be performed at the field setting. Detection and characterization of defects are labor intensive, time consuming and when the process is manual the results are subjected to human error. These limitations of the standard NDE methods created a need for portable, user friendly inspection systems that can rapidly and automatically scan large areas of complex structures and locate all the detrimental material conditions. Addressing this need has been an evolutionary process that followed the technology trend, and unique devices were developed to perform field inspection. Such a development required integration of expertise in multidisciplinary areas that include NDE, telerobotics, neural networks, materials science, imbedded computing and automated control. Various portable inspection systems have emerged and the trend is toward fully automatic systems that autonomously inspect aircraft.

KEYWORD

NDE, Autonomous inspection, Crawlers, MACS, MAUS, Aging aircraft inspection, remote operation, intelligent inspection.

INTRODUCTION

The current use of aging aircraft significantly longer than their design life has added a great degree of urgency to the ongoing need for low-cost, rapid, simple-to-operate, reliable and efficient NDE methods for detection and characterization of flaws. The issue of aging aircraft is of concern to the users and operators of both the military and commercial aircraft. The 1988 failure of the Boeing aircraft operated by Aloha Airlines heightened the level of attention to the issue of aging commercial aircraft from manufacturers, users and the Federal Aviation Administration (FAA). in many cases, the problem of field inspection is complex due to the limitation of current technology and the need to disassemble aircraft structures for NDE in lab conditions.

Labor intensive inspection in field conditions demands great attention to details by inspection personnel and is subject to human errors and limited in reliability. The interpretation of the data depends critically on the inspectors' experience, competence, attentiveness and meticulous dedication. For instance, rivet crack inspection with eddy current detectors is known to be a mundane and painstaking task, which can lead to a significant decrease in the inspector attention during a long inspection session, On the other hand, disassembly of structures and inspection in laboratory conditions is costly and not practical in many cases. These inspection limitations are hampering the growth in usage of composite structures for construction of aircraft since these structures are sensitive to impact damage that can occur at any point and any time over large areas. To overcome the limitations of standard NDE methods, reliable field inspection systems are being developed for rapid NDE of large and complex-shape structures. For military aircraft, an additional constraint needs to be accounted and it is requirement to operate also at harsh, hostile and remote conditions (extreme temperature, battlefield, remote expertise, etc.) with minimum human interference.

In recent years, to address the need for rapid inspection in field conditions, various types of portable scanners were developed using such NDE methods as visual, eddy currents, ultrasonics, shearography, and thermography. The emphasis of this manuscript is on ultrasonic NDE scanners, their evolution the expected direction of development and the role that intelligent NDE can play.

RAPID INSPFWTION SCANNERS

For more than four decades, ultrasonics has been one of the leading NDE methods. The development of scanners made the biggest impact on the wide use of this method since scanners allowed producing detailed images of the flaws size and location. Further, the process of recording the data became consistent and allowed the application of simple reception/rejection criteria for the simplification of the inspection standards. For a long time, the automated inspection capability (also known as C-scan) was available only for lab conditions and field inspection was performed manually. The emergence of microprocessors enabled to make such systems capable to perform contour following of structures and to operate concurrently with the details of the CAD drawing. Full aircraft structures, such as the wing of the Harrier, are now tested routinely by such systems in lab conditions (see Figure 1).

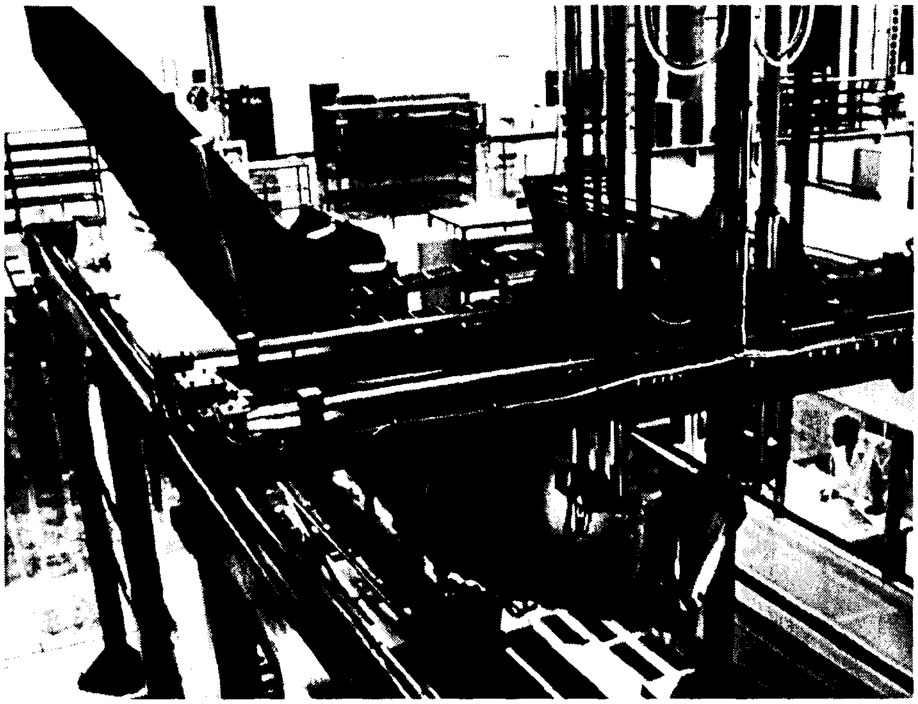

Figure 1: MDC large scanner testing a full wing of an aircraft.

With the evolution of personal computers and microelectronics, it became possible to produce portable C-scanners that can operate in the field [1]. The original portable scanners were relatively heavy and consisted of a simple bridge with mobile set of boxes that were carried to the field and performed scanning, data acquisition, imaging and storage. To support the formation of the C-scan images, encoding methods were developed to provide probe location information while operating on aircraft structures directly in the field. Such position encoding methods include the use of acoustic waves, as is 1S1S that was developed by General Dynamics under a contract from the Air Force (see Figure 2), optical scales, and various other encoding techniques. Due to the inaccuracy of the acoustic encoding technique it was phased out and most of the current portable scanners rely on the use of optical encoders. To inspect vertical surfaces or testing the bottom surface of aircraft wings, strapping techniques and vacuum cups were employed (e.g., QMI's portable scanner, see

Figure 3) securing the attachment of the C-scan bridge. Since aircraft structures have a complex geometry, the use of flat portable C-scan bridges is encountered with difficulties associated with the gap that is formed between the straight bridge and the curved surface of the aircraft. The PANDA Scanner (made by Tektrend) addressed this issue by employing a flexible arm that flexes its curvature to conform with the surface contour and ensuring contact between the transducer that test surface. The introduction of portable c-scan bridges enabled the automation of ultrasonic field inspection and significantly improved the reliability of such field tests, However, such scanners provide an effective inspection capability only over the area that is covered by the seamer bridge. Covering a large area of an aircraft requires performing multiple scans where the operator moves the scanner from one location to another to form scan-tiles until the full structure is covered.

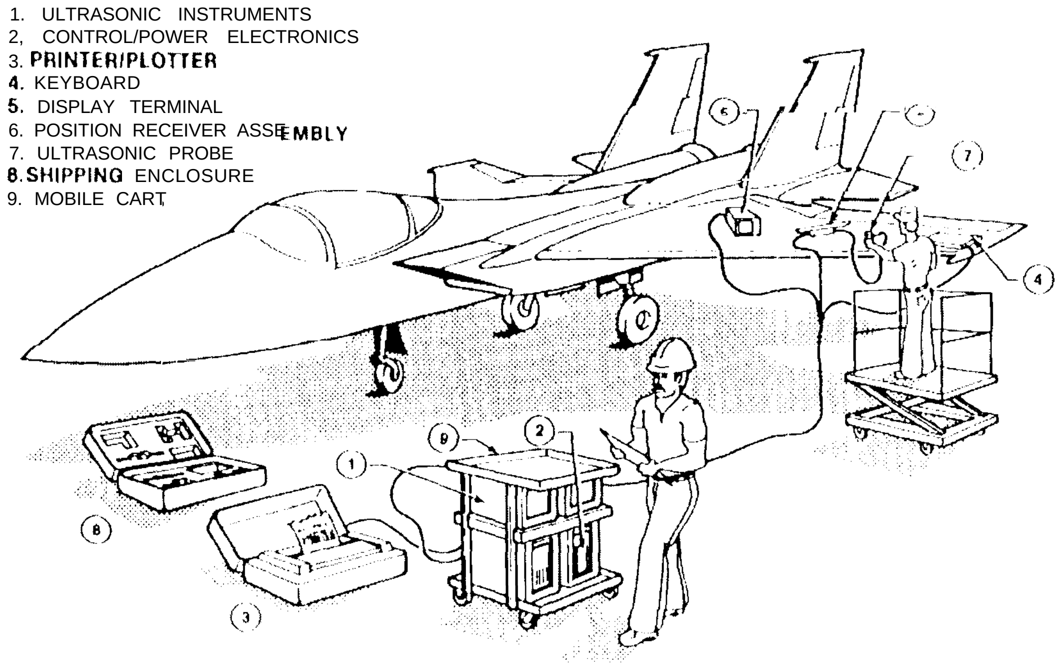

Figure 2: 1S1S

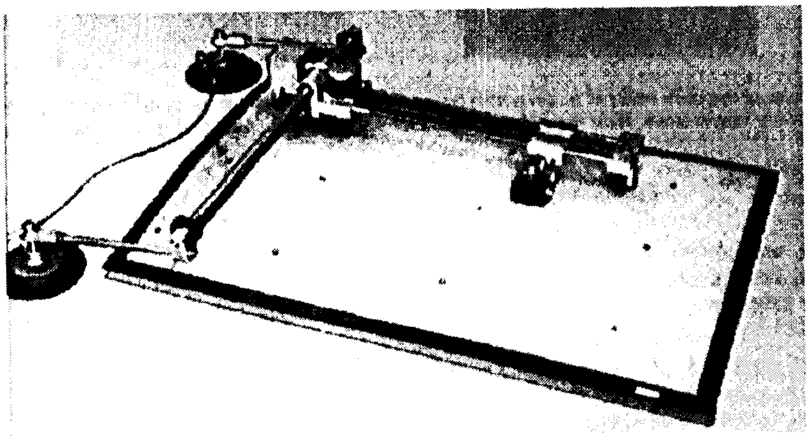

Figure 3: QMI scanner using a portable bridge and two suction cups to secure the bridge position during scan.

INSPECTION CRAWLERS

Automated devices that can be attached to an aircraft skin and travel on it while scanning and inspecting it can greatly expedite the rate of inspection and minimize human interference in this task that requires minimal skill, increasingly crawling devices are being reported as a solution to the need for mobile unconstrained seamers. The use of suction cups has become a leading form of controlled adherence to aircraft surfaces and several successful devices were reported in the last several years. The Automated Non Destructive Inspector and the Autocrawler are some of the more known mobile portable scanners [1-2]. In recognition of the need to have a compact, more maneuverable crawler, JPL recently developed a small, highly dexterous crawler with a payload to weight ratio of about 10:1. This Multifunction Automated Crawling System (MACS) was designed to perform complex scanning tasks [3]. MACS employs ultrasonic motors for mobility and suction cups for surface adherence. MACS has two legs for linear motion and a rotation element for turning, thus allowing to perform any simultaneous combination of motion from linear to rotation around the central axis. In Figure 4, MACS is shown crawling vertically on the surface of an Air Force C-5 aircraft. A schematic view of the steps that are involved with mobilizing MACS and the position of the various suction cups and legs are shown in Figure 5.

Applications of MACS include inspection of composite and metallic structures for detection of cracks, corrosion, impact damage, unbonds, delaminations, fire damage, porosity and other flaws, paint thickness measurement. Also, MACS can be used to identify dents and individual fasteners. The development of MACS was benefited from the ongoing JPL development of miniature planetary rovers, telerobotic technology and NDE techniques.

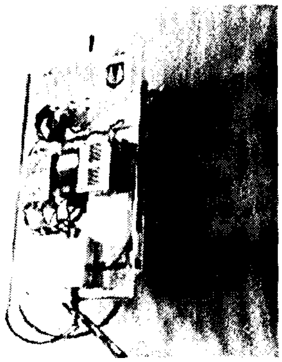

Figure 4: MACS crawling on the C-5 aircraft [patent pending].

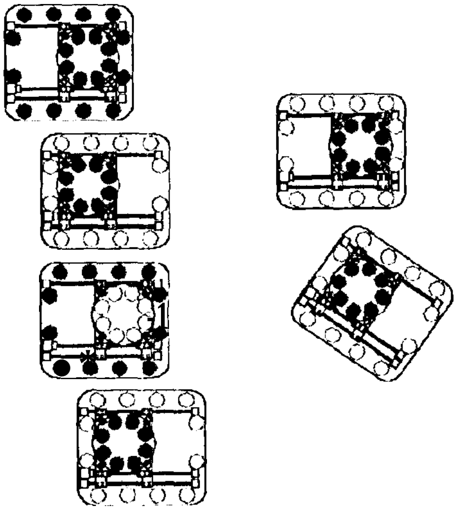

Figure 5: MACS crawler mobility control. Solid circles represent activated suction cups and hollow circles represent resting cups. Forward travel is shown on the left and a simultaneous travel/rotation is shown on the right.

AUTONOMOUS CRAWLERS USING INTELLIGENT NDE

Autonomy of NDE crawlers is a key technology for the automation of such devices for field scanning of complex aerospace structures. An autonomous crawler can be monitored remotely by centrally located experts that are equipped with know-how, database, analytical tools, CAD drawing, and accept/reject criteria. Such a capability will allow rapid response to inspection needs, particularly in cases of crisis where there is a need to rapidly examine a full flight of a particular aircraft model all over the world. An autonomous crawler can be operated during aircraft idle time allowing to reduce the need to ground aircraft for inspection. A combination of visual, eddy current and ultrasonic payload (methods that offer portable sensors) are expected to be the leading NDE methods that are used on an autonomous crawler.

The technology that can enable such capabilities has been in development at JPL for the exploration of Mars, where the Mars Pathfinder already enjoyed some of its benefits. Miniature robotic technologies with on-board intelligence are being developed for future missions where the rovers will examine, select and collect samples from Mars while avoiding obstacles during operation in an unknown terrain. Since communication between Earth and Mars takes about 12 minutes each way, the need for autonomous operation rather than remote control is critical to the success of the missions. The JPL's crawler MACS is currently using umbilical cord for power, communication/control and to provide air pressure for the ejection and activation of the vacuum cups. Future efforts will involve increased autonomous operation and a Complete wireless portability. potential future development includes a miniature on-board vacuum pump, power and completing capability. Further, intelligent NDE techniques can be used to allow detection and characterization of flaws and material properties determination [4]. Crawlers can employ local Global Positioning Systems (GPS) to determine the absolute coordinate without the need for a complex, expensive and heavy encoder. Further, such GPS systems will allow relating the location of the crawler on the aircraft to the detailed drawing and assist in the data interpretation and flaw location and identification.

The use of such crawlers as MACS to serve as a shuttle crawler to carry the probe bead of the McDonnell Douglas' MAUS unit (which is highly supported by the Air Force) can provide a powerful inspection tool. MAUS is a device that uses a hand-held scanner to move a series of probes horizontally while an operator moves the scanner vertically. Employing a crawler as the MACS for forward and backward mobility will enable to autonomously inspect vertical surfaces and bottom of aircraft structures. To protect elements of the aircraft that rise above the surface from accidental damage, a virtual vision system will be used with collision avoidance software. To enhance the inspection capability of the combined systems, a neural network data interpretation can be used. MACS can be controlled remotely via the use of Internet allowing multiple users to control it using password and thus limiting the access to the control capability.

FIGURE 6: A view of the MAUS portable scanner in operation. The scanner is a band-held unit.

ACKNOWLEDGEMENT

The development of MACS was done under a Jet Propulsion Laboratory, California Institute of Technology, contract with the Air Force Material Command, Kelly Air Force Base.

REFERENCES

1. P. Backes and Y. Bar-Cohen, "Miniaturization Technologies for Aircraft Inspection," JPL Report D- 13876, (July 1 996).
2. V. Bahr, "Wall- Climbing Robot in Non-Structural Environment," Transact ion Robotics Research, Robotics International, Society of Manufacturing Engineering, Vol. 2 (1992), pp. 1-24.
3. Y. Bar-Cohen, B. Joffe and P. Backes "Multifunction Automated Crawling System (MACS)", Disclosure of New Technology, Item No. 9460, Docket 19847, November 29, 1995. (Patent Pending, CIT 2432, Submitted on August 1, 1996).
4. C. A. Vazquez and Y. Bar-Cohen, "Application of Artificial Intelligence to NDE," Report No. K4870, (MDC, Long Beach, CA. April 1990) pp. 1-32,