# LASER-ULTRASONIC INSPECTION OF THE COMPOSITE STRUCTURE OF AN AIRCRAFT IN A MAINTENANCE HANGAR

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## INTRODUCTION

Composite materials used in aerospace structures can be affected by a variety of defects, such as delaminations and disbonds, which may occur during fabrication or may be caused by impact during use. Such defects, which cannot usually be detected by simple visual inspection, may severely affect the mechanical integrity of components. Ultrasonics offers the best possibility for detection of flaws in composite components. However, ultrasonics as conventionally applied using piezoelectric transducers for generation and detection of the probing pulse has several limitations. Namely, the need for an acoustic coupling media or direct contact with the surface, and the requirement of near-normal incidence to the component's surface. Laser-ultrasonics represents a practical means of avoiding the inherent difficulties with conventional ultrasonics [1-2].

In laser-ultrasonics, the ultrasonic probing pulse is generated and detected using laser light. Consequently generation and detection can be made at a distance, without any physical contact with the surface of the component to be inspected. No acoustic coupling medium is required. The component can therefore be inspected in harsh environments, such as during on-line processing [1], or in vacuum conditions. The laser generated ultrasonic probing pulse is emitted in a direction normal to the surface of the component, regardless of the angle of incidence to the surface of the generation laser beam. Large surfaces can thus be scanned at a fairly high speed since the only mechanical movements involved in the scan are the tilt and roll of a mirror. Since normal incidence of the laser beams is not required in laser-ultrasonics, no particular knowledge of the component's shape is needed prior to the inspection. The only requirement is an optical line of sight between the targeted area of the inspected component and the laser-ultrasonic inspection system.

A prototype inspection system was built by the Industrial Materials Institute of the National Research Council of Canada (IMI-NCR) and UltraOptec. The prototype was built to explore and assess the applicability of laser-ultrasonics to several types of materials under different conditions. With this system, we recently explored the applicability of the technique to the inspection of different types of composite components [3-5]. The laboratory investigations have led to very promising results, which confirmed the potential of the technique. The next logical step in the course of the assessment of laser-ultrasonics for the nondestructive inspection of composite aircraft structures was to inspect the composite structure of an intact aircraft. On-site tests were conducted at Bombardier Inc. Canadair (Defense System Division) at the Montreal International Airport in March of 1994. The prototype system was used to scan several components of a Canadian Forces CF-18.

## EXPERIMENTAL SETUP

### Description of the Laser-Ultrasonic Prototype

The laser ultrasonic prototype used for the demonstration is composed of three separate mobile units; the generation unit, the detection unit and the computer control unit. The generation unit houses the generation laser and its focusing optics, the detection beam focusing optics, the collecting optics, and the optical scanning system. The detection unit includes the detection laser, a Fabry-Perot interferometer for demodulation of the received signal beam, the photo detectors and their associated optics. The computer control unit includes the main computer used for data acquisition and processing, and for controlling the scanning system. The generation and detection units are linked by two optical fibers so that they may be physically separated. The generation unit is located near the component to be inspected, while the detection unit is situated in a more convenient location.

The prototype system uses a TEA $CO_2$ laser for generation of ultrasound with a pulse spike width at half-maximum power of approximately 100 ns. The generation spot is focused onto the target to a square shape of approximately 5 mm x 5 mm in dimension. The pulse energy is approximately 100 mJ, giving an energy density of about 0.4 J/cm$^2$. The detection laser is a frequency stabilized long pulse Nd-YAG with a pulse width at half-maximum of approximately 55 $\mu$sec. The output power of the detection beam pulse is regulated by an attenuator which gives a fairly constant power level on the interferometer's photo detector for all the sampled points, independently of the reflectivity of the surface. The steady power level on the photo detector allows for constant detection sensitivity of the system over the entire surface of the inspected component. During the tests, the output power of the detection beam was set to give between 0.3 and 0.5 mW on the interferometer’s detector. Under these conditions, the generation and detection laser beams caused no damage to the inspected surface. The detection beam, after transmission through an optical fiber, is focused onto the surface of the component to a spot of about 5 mm in diameter.

The light scattered by the surface is received by the collecting optics, a Cassegrain mirror telescope, and brought to the interferometer in the detection unit by an optical fiber. The detection light is demodulated by the Fabry-Perot interferometer and appears as light amplitude fluctuations at the output of the interferometer. The output is then detected, amplified and filtered with a photo diode. The analog signal obtained is digitized at a rate of 20 MHz or 40 MHz, depending on the thickness of the inspected component (the lower digitizing frequency being used for thick samples), giving amplitude versus time signals or A-scans, of 256 or 512 points. From this raw data, C-scan images, both time-of-flight and amplitude, are subsequently obtained using the imaging procedures of IMAG; a software developed by UltraOptec for ultrasonic and laser-ultrasonic inspection.

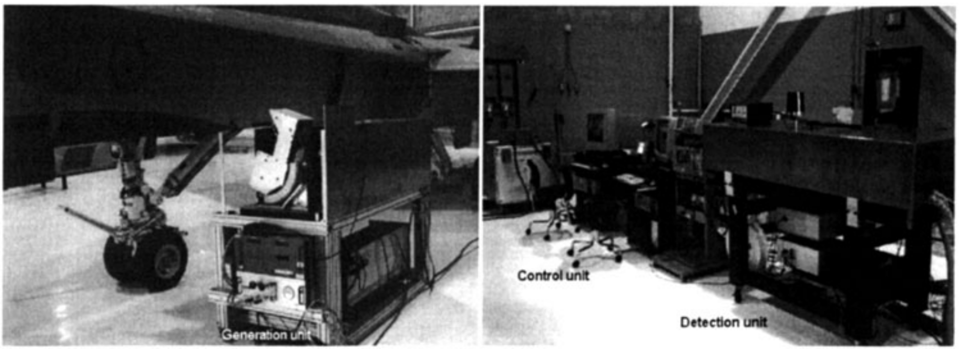


Figure 1: On-site installation of laser-ultrasonic system.

On-site Composite Inspection Setup

The composite components of the aircraft to be inspected were selected to show the advantages of laser-ultrasonics over conventional ultrasonics or other nondestructive inspection techniques. One of the advantages is the elimination of the near-normal incidence requirement, which makes the inspection procedure fairly independent of the actual shape of the inspected component. Emphasis for the inspection was placed on contoured composite structures, such as the left side panels, the outboard landing gear door, the horizontal stabilizer, and the nose cone of the aircraft. Flat composite surfaces, such as portions of the wing, were also inspected.

To inspect a structural component on an aircraft, the generation unit is moved to a distance of roughly 1.4 meters from the component (see figure 1). For vertical or near vertical surfaces, the generation and detection beams are directly focussed onto the component. For horizontal surfaces, such as those of the wing or the horizontal stabilizer, a large folding mirror set at an angle of 45° is used to deflect the beams upwards towards the inspected part.

All components scanned with the laser-ultrasonic prototype were carefully inspected visually to identify any surface damage prior to the laser-ultrasonic scan. No damage or surface modification due to either the generation or the detection lasers was observed during the tests. Power levels of both lasers were set well below any damage threshold of the paint on the CF-18. The presence of paint on the surfaces actually contributes to more efficient laser generation. The paint is also a strong diffuser of light, hence it allows the collection of light from the surface with sufficient power for demodulation, even for large angles of incidence. No particular preparation of the aircraft was made prior to the laser-ultrasonic inspection.

Once the generation unit was properly placed, the inspection area was determined by using the optical scanner system and the Helium-Neon tracer beam which is superimposed with the generation and detection beams. The tracer beam is used to indicate the location of generation and detection of the ultrasound. By manipulating the optical scanner via the control computer, a rectangular inspection area was defined on the component to be inspected. Note that this rectangular area can exceed the dimensions of the inspected part (see inspection of horizontal stabilizer below). During the on-site tests, a sampling step (horizontal and vertical distances between sampling points on the component's surface) of approximately 2.5 mm was used for ultrasonic mapping. Once the inspection area was determined, the complete control of the scan was transferred to the main computer. The data was collected and stored on a recording media. Data acquisition was made at a rate of approximately 20 Hz. This low acquisition rate results from the computer software environment used with the prototype system for the tests. It should be noted that UltraOptec's commercial laser-ultrasonic inspection system uses a different software for control and acquisition, and operates at an acquisition rate of 100 Hz

The collected data was used to generate ultrasonic images (B-scans and C-scans) of the components by using IMAG; a software developed by UltraOptec. This software allows the user to select time gates, threshold levels, and determine time arrivals and amplitudes, as in conventional ultrasonics. Laser-ultrasonic signals are similar to conventional pulse-echo A-scans. The echoes observed in the signal are indications of defects within the part or of a reflection by the back wall of the part. The time origin of penetration of ultrasound into the part is given in laser-ultrasonics by the initial surface elevation signal.

## RESULTS

In the following sections, we will show several gray scale images obtained by using laser-ultrasonics during these tests. When looking at the images, one can observe that the shape of the inspected component viewed in the image appears slightly modified in relation to its real shape. This effect is a consequence of the scanning configuration used in our system. The scanner interrogates the part from a fixed point in space. Hence, the image obtained results from the projection of the part's surface onto a conical surface. The distortion can be corrected by software, as long as the exact shape of the part is known. For complex parts, 3D visualization is required to facilitate interpretation [6]. For the present work, no correction was made for the projection effect.

### Inspection of a Composite Side Panel

The first component inspected during these tests was a side panel of the aircraft fuselage, identified as panel 10L. This panel is one of the left forward fuselage doors of the aircraft. It is composed of an aluminum honeycomb core with a graphite epoxy skin with one ply of fiberglass overlay on the inner surface of the skin. The component is slightly curved. Given the maximum horizontal angle of a scan with the prototype system, two separate laser-ultrasonic scans were performed to cover the complete surface of the component. A first section of 674 mm x 390 mm was inspected, followed by a second inspection of 672 mm x 366 mm. Between the two acquisitions, the generation unit was moved and centered on the targeted area. By combining the two amplitude C-scans, a complete image of the panel is obtained and presented in figure 2. The underlying structure of the panel is clearly visible in the image. Notice that one can see the composite back reinforcement structure used for affixing the panel to the fuselage.

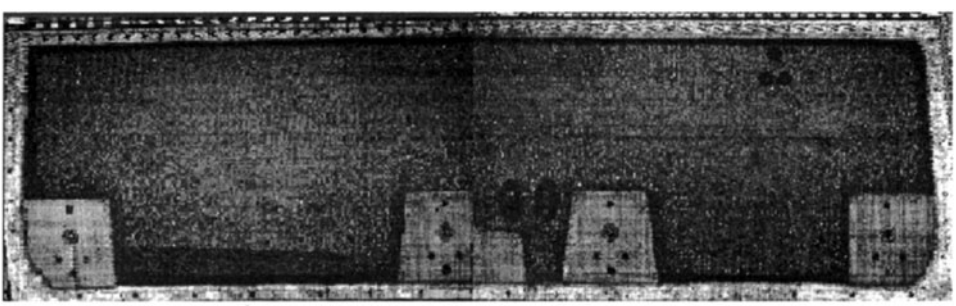

Figure 2: Laser-ultrasonic amplitude C-scan of panel 10L.

Inspection of the Inner Wing

The inner wing, which is the part of the CF-18 wing that can not be folded, is a complex structure composed of different layers of composite materials; mainly graphite epoxy. Although the inner wing is almost flat and could therefore easily be inspected using a conventional ultrasonic scanner, laser-ultrasonic scans were made to demonstrate the flexibility of the system to quickly inspect all of the composite structures of the aircraft. Two different sections of the inner wing are presented here: a section near a fuel intake (531 mm x 380 mm), and a second section adjacent to the previous one (533 mm x 435 mm).

Figure 3 shows a time-of-flight C-scan and an amplitude C-scan of the area near the fuel plug. The images reveal the structure around the fuel tank access plug. In the left section of the images, one can see a complex structure composed of multiple plies of composite material. The right section of the inspection area includes a thick composite structure of varying thickness, up to approximately 0.75 inch. In the midsection of the time-of-flight C-scan, one can see a darker region indicating the presence of a sealant which had spread outward during the fabrication of this section. The amplitude C-scan reveals several rows of fasteners (light white spots) present in this component.

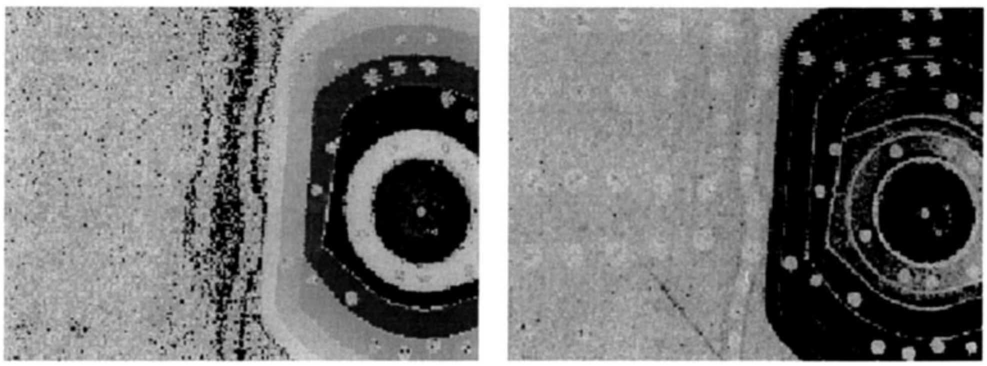

Figure 3: Laser-ultrasonic images of a section near the fuel plug; left - time-of-flight C-scan, right - amplitude C-scan.

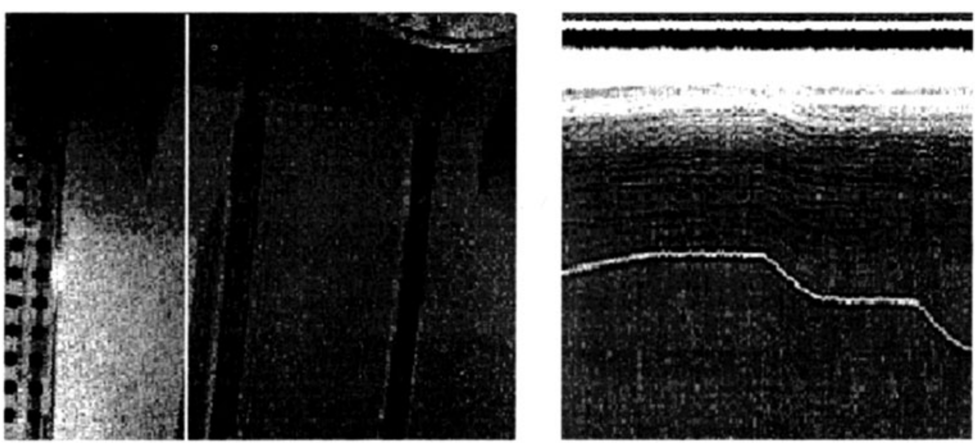

Figure 4: Laser-ultrasonic images of a section under the fuel tanks; left: amplitude C-scan, right: B-scan, cut along the white line shown on the left.

The second area inspected is a lower portion of the inner wing under the wing's fuel tanks. On the top right of the image shown in figure 4, one can see the lower edge of the section previously scanned. The image clearly shows the boxlike fuel tank inside the wing. One can also observe the stiffeners of the structure. To better see the thickness variations in the component, a B-scan along the white line shown in the C-scan is also displayed in figure 4. One can clearly see the thickness variation along this line.

## Inspection of the Horizontal Stabilizer

The horizontal stabilizer is a complex composite structure with an aluminum honeycomb core. The surface of the horizontal stabilizer is slightly curved. This fact could cause some difficulty for scanning with a conventional ultrasonic system. Two gray scale amplitude C-scan images of the section of the horizontal stabilizer are presented in figures 5 and 6: a section encompassing the outer edge corner of the stabilizer (576 mm x 298 mm), and a section near the attachment point of the stabilizer to the airplane fuselage (450 mm x 360 mm).

The first scan shown in figure 5 demonstrates the ability of our laser-ultrasonic system to completely inspect a given part, including its edges. The inspection area determined by the operator (which is always rectangular) can be larger than the inspected component. When the beams do not reach the component, no signal is returned. With proper setting of the C-scan image parameters (time and amplitude gates), these sections can appear dark. In the image shown in figure 5, one can clearly see the edge structure of the stabilizer. Thickness variations within the part can also be clearly observed.

The second scan, shown in figure 6, depicts a section near the attachment point of the horizontal stabilizer to the aircraft's fuselage. The section is composed of a variety of structures. Two amplitude C-scans produced by different gate settings are presented in figure 6. The left image is obtained by gating the A-scan to conserve only the positive polarity echoes, whereas the right image uses echoes with negative polarity. This demonstrates the ability of laser-ultrasonics to focus on a particular structure by manipulating the C-scan gates. In the upper half of the images, one can observe a titanium composite joint of varying thickness. In the left image, one can clearly see the honeycomb structure in the lower left section, while in the right image, one can observe a structure that is barely visible in the left image.

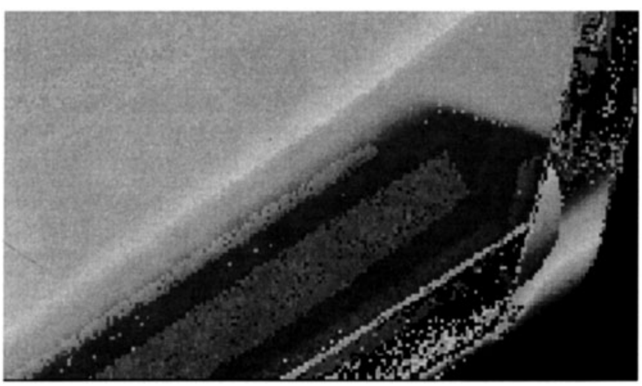

Figure 5: Laser-ultrasonic image of the edge of the horizontal stabilizer.

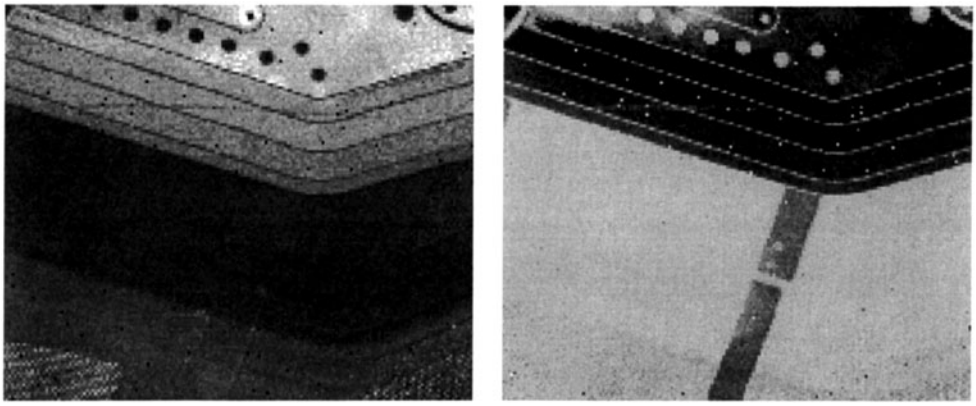

Figure 6: Laser-ultrasonic C-scan images of the horizontal stabilizer.

## CONCLUSION

Laser-ultrasonics is a nondestructive inspection technique that combines the capabilities of ultrasonics with the flexibility of optics for detecting, locating and sizing defects in a material. We have previously shown that laser-ultrasonics is a reliable technique for inspecting composite parts of complex geometry in a laboratory environment. The present work demonstrates the ability of laser-ultrasonics to inspect similar composite parts, directly on an aircraft and in the typical environment of a maintenance hangar. In particular, we have shown that our laser-ultrasonic system can readily inspect components directly on an aircraft with a great variety of contours: flat surfaces (lower inner wing), slightly curved surfaces (side panels and horizontal stabilizer), highly curved surfaces (nose cone, not reported here) and oddly shaped surfaces (main landing outboard door, not reported here). Our laser-ultrasonics system allows quick and easy inspection of all types of contoured surfaces with minimal preparation. Also, since the system is associated with data acquisition and software technology that provides full storage of data, the evolution of any flaw throughout the lifetime of a structure can be monitored by periodic inspections. In conclusion, the present work shows that the laser-ultrasonic technology is now sufficiently mature to be used for the routine inspection of the composite structures of aircraft.

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