Three-dimensional laser scanning test in aircraft surfaces

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Key words: lasers-canning, aircraft measurements, lidar, terrestrial scanning

SUMMARY

An important aspect of aircraft engineering and maintenance involves the detection and measurement of damage on aircraft surfaces. A damage that exceeds a prescribed threshold must be first detected, and then repaired. Currently this involves visual inspection and direct measuring on aircrafts by engineering staff. Today this is a time consuming process that might be improved by three dimensional laser scanning (TDLS). This technology (also called Light detection and raging or LIDAR) is being broadly explored as an alternative for high precision surveying of objects and structures. This research utilized a damaged section wing that had been removed from an aircraft for repair to test the capabilities of TDLS in detecting and measuring damages. Data was gathered from a series of distances and angles on a previously identified dent. The data was processed in order to generate a series of models of the wing surface in order to minimize the impact of errors in range measurement while still accurately detecting and measuring the damage location itself. It was found that TDLS could identify damages on a wind. However, we could not prove that the application is more reliable than human visual inspections. Future research is proposed for identifying and measure errors associated using TDLS on an aircraft surface.

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1. INTRODUCTION

During the ground inspection of an aircraft, crews inspect all surfaces of an aircraft (including wings and the fuselage) for damage. The damage can take form of cracks, holes, corrosion, dents, or other anomalies. For aviation safety, it is very important to detect all surface damages on an aircraft. It has been proved that a dent of with a depth of 0.05 inches (1.27 mm) could potentially delaminate composite surface materials (Erchart, Ostrom, & Wilhelmsen, 2004).

"Visual detection of anomalies by airline inspectors and other airline personnel has been and will continue to be a major component of the aircraft inspection process" (Ostrom, Wilhemsen, & Scott, 2012). Considering this premise the University of Idaho (Erchart, Ostrom, & Wilhelmsen, 2004) developed an initial study that determines the visual detectability of dents on a composite aircraft inspection specimen by the human eye.

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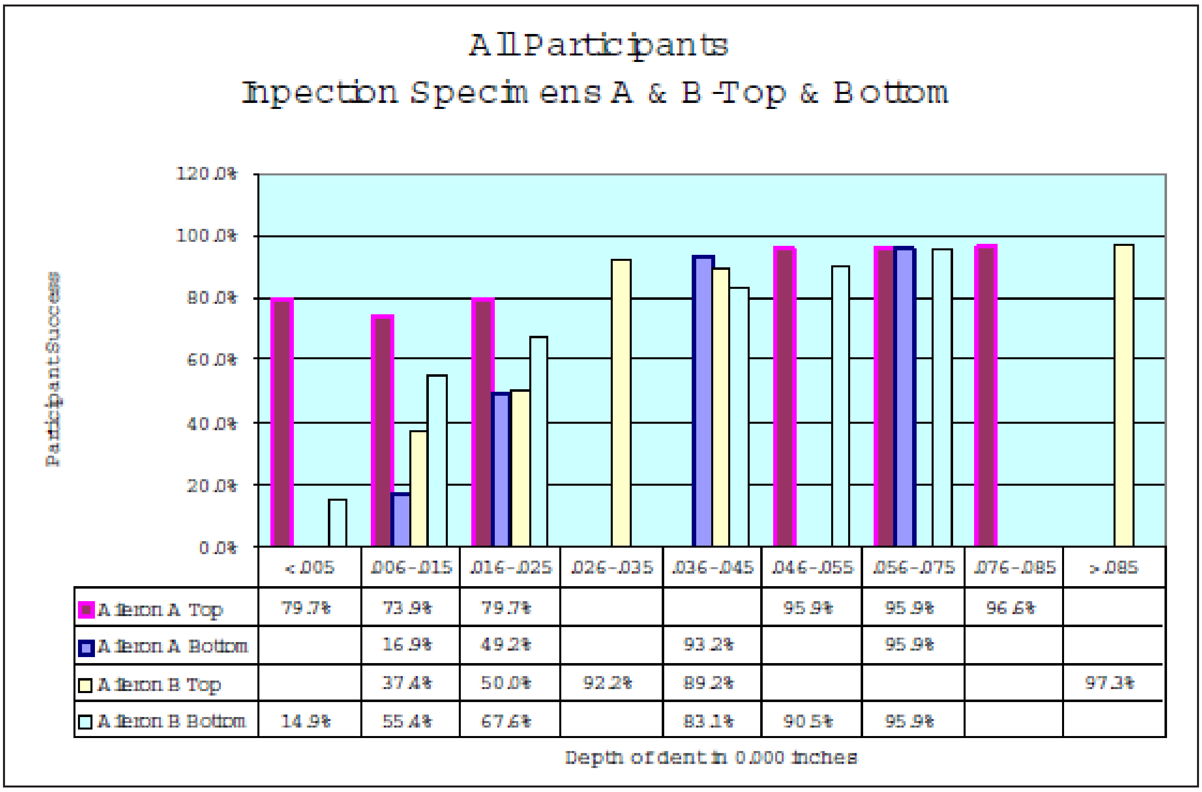


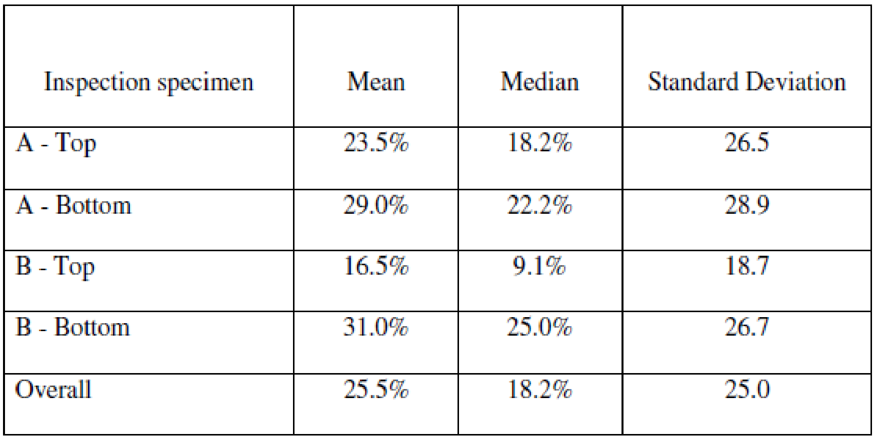
	<.005	.006-.015	.016-.025	.026-.035	.036-.045	.046-.055	.056-.075	.076-.085	>.085
■ Aileron A Top	79.7%	73.9%	79.7%			95.9%	95.9%	96.6%	
■ Aileron A Bottom		16.9%	49.2%		93.2%		95.9%		
□ Aileron B Top		37.4%	50.0%	92.2%	89.2%				97.3%
□ Aileron B Bottom	14.9%	55.4%	67.6%		83.1%	90.5%	95.9%		

FIGURE 1.SUMMARY GRAPH, PARTICIPANTS-INSPECTION SPECIMENS A&B (ERCHART, OSTROM, & WILHELMSEN, 2004)

Figure 1 shows that there is no clear differentiation in the attention to details between men or women. It also shows that dents greater than 0.06 inches are identifiable in more than 80% of cases. It is, therefore, questionable that current visual inspections are sufficient as there are a 20% of dents that are not identified, compromising flight safety (Erchart, Ostrom, & Wilhelmsen, 2004).

In the previous studies, false positives were also obtained. A false positive is defined as the identification of a dent that was not there. This value was calculated by dividing the total number of falsely identified dents by the number of actual dents on the specimens (Erchart, Ostrom, & Wilhelmsen, 2004). The results are shown next.

Table 1. Summary of false positive (Erchart, Ostrom, & Wilhelmsen, 2004)



Inspection specimen	Mean	Median	Standard Deviation
A - Top	23.5%	18.2%	26.5
A - Bottom	29.0%	22.2%	28.9
B - Top	16.5%	9.1%	18.7
B - Bottom	31.0%	25.0%	26.7
Overall	25.5%	18.2%	25.0

There is important to considerate the re-work time caused by false positives as shown in table 1. In this study false positive were around 25%, which is a considerable figure.

Next, we explore current technologies and techniques in the literature for nondestructive evaluation (NDE) of materials and of the use of TDLS.

2. BACKGROUND

2.1. State-of-the-art of non-destructive inspection (NDI) methods

“Much effort is being taken to find the most reliable NDI technique for the detection, location and characterization of damage in composite materials. The main state-of-the-art NDT techniques for composite materials are as follows: visual inspection; optical methods; eddy-current (electro-magnetic testing); ultrasonic inspection; laser ultrasonic; acoustic emission; vibration analysis; radiography; thermography and Lamb waves” (Diamanti & Soutis, 2010).

2.1.1. Visual inspection parameters affecting visual inspection

The FAA AC 43.204 manual called “Visual inspection for aircraft” was first published in 1994 and then updated in 1997. It contains detailed specifications regarding all aspects of visual inspection (Baaran, 2009). Parameters relevant to this study are:

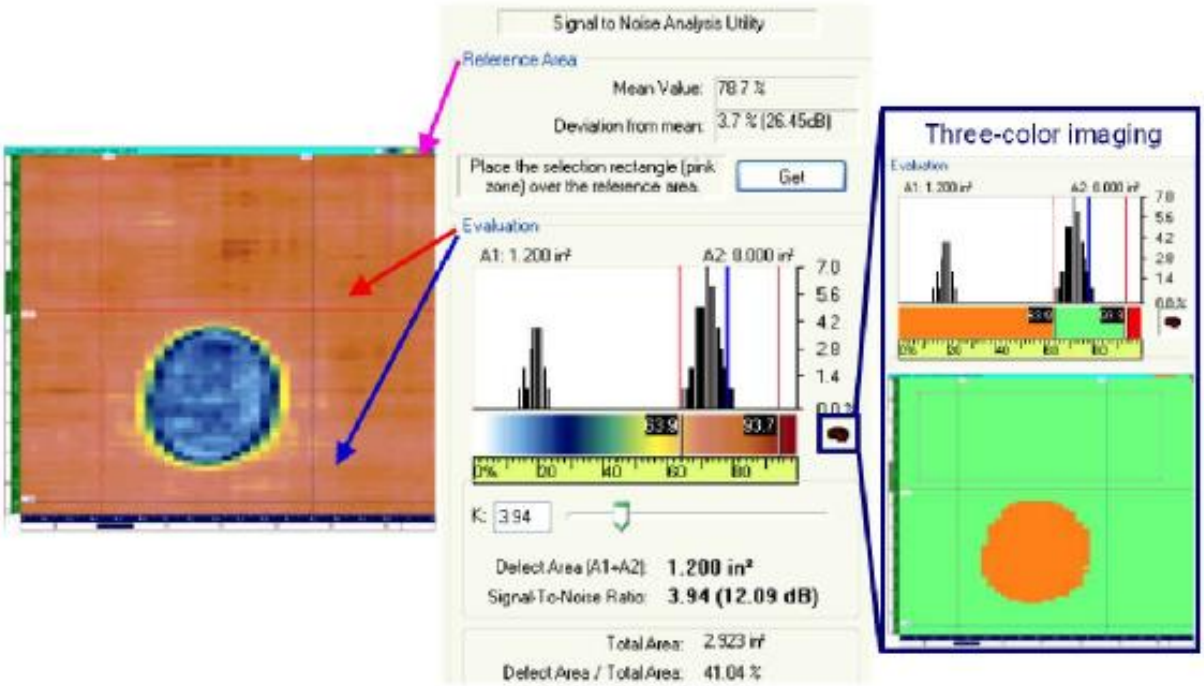
- Inspection personnel qualifications and training
- Inspection area access
- Lighting
- Pre-cleaning
- Color.
- Working environment factors, such as excessive climatic factors and noise.

2.1.2. Ultrasonic phased array tools

An Ultrasonic Phased array tool is an inspection unit combined with a two-axis scanner, a phased array probe and a wedge design. The last one is important because it includes a water pocket that improves coupling efficiency (Habermehl, Lamarre, & Roach, 2009).

With this, technique data interpretation is easier compared to amplitude or time-of-flight (TOF) because a color-coded map of large areas is provided by the C-scans, where echo amplitudes are recorded in relation to probe position and represent the main defect viewing. To detect all defects from areas the previously mentioned scans require an appropriate gate. However, in some cases it can be used the amplitude base method, that doesn’t requires an appropriate gate by a direct delamination detection or monitoring the backwall drop. Regardless of the good results of the methods mentioned before, there are some limitations with the mid-range (Habermehl, Lamarre, & Roach, 2009).

Therefore this method, for the inspection of aircraft surfaces, is a effective method as well as for precise measures on the processed data. However, this is not a reliable method for big area inspection and damage identification.



Mean Value: 78.7 %
Deviation from mean: 3.7 % (26.45dB)

Place the selection rectangle (pink zone) over the reference area.

K: 3.94

Defect Area (A1+A2): 1.200 in²
Signal-To-Noise Ratio: 3.94 (12.09 dB)

Total Area: 2.923 in²
Defect Area / Total Area: 41.04 %

FIGURE 2.REPRESENTATIVE RESULTS ON AN AMPLITUDE C-SCAN (LEFT), C-SCAN CONVERTED INTO THREE COLORS FOR ASSISTED DEFECT VIEWING (RIGHT) (HABERMEHL, LAMARRE, & ROACH, 2009)

2.1.3. Line scanning thermography

Line Scanning Thermography is a dynamic thermal imaging technique that makes a continuous scan of the area. There are some techniques that involves the scanning speeds and heat intensity that provides deeper scans and are very helpful to detect subsurface flaws (Chung, Ley, Godinez, & Bandos, 2011). The presence of sub-surface features, such as impact damage, delamination and moisture penetration are revealed as thermal gradients on the surface (Chung, Ley, Godinez, & Bandos, 2011).

The defects on the analyzed part in this method are shown as hot spots on the thermal profile. The time of scanning in thermography is small compared with the UT scans. However, the resolution of the UT is better. Line scanning thermography is recommended for a “first run”, and for the scanning of aircraft surfaces should be complemented with another method with more resolution (Chung, Ley, Godinez, & Bandos, 2011).

2.1.4. Lamb waves

Lamb waves are elastic waves that are generated in a solid plate with free boundaries (Diamanti & Soutis, 2010). There are various methods to generate these kinds of waves. For example, they can be generated using piezoelectric transducers and electromagnetic acoustic transducers (EMATs). In this method, the defects are detected by the change in wavelength (NDT Resource Center, n.d.).

Lamb waves have the ability to travel long distances, so they are good for time saving.

2.1.5. Lidar

Light detecting and raging (LIDAR) has been used previously in the inspection of surfaces. For example, at University of Idaho, an investigation was conducted where as a proof of the concept researchers used LIDAR scans to capture and project in three dimensions the damage inflected in composite material (Ostrom, Wilhemsen, & Scott, 2012). As this experiment prove that damage can be detected by a LIDAR scan and identified by human visual inspection on the projected three-dimensional imagery, some steps furder are the experimentation with identification and measure technics using the data obtained by LIBAR instruments.

2.2. Damage metrics

According to FAA, the origins of damage include accidental, fatigue and environmental causes that may be categorized according to its severity as follows (Baaran, 2009).

- **Category 1:** Allowable damage that may go undetected by scheduled or direct field inspection, allowable manufacturing defects; damage below Allowable Damage Limit (ADL), e.g. barely visible impact damage (BVID).
- **Category 2:** Damage detected by scheduled or directed field inspection at specified intervals, e.g. exterior skin damage, interior stringer blade damage.
- **Category 3:** Obvious damage detected within a few flights, e.g. accidental damage to lower fuselage or lost bonded repair patch.
- **Category 4:** Discrete source damage immediately known by pilot to limit flight maneuvers, e.g. rotor disk cut through fuselage or severe rudder lightning damage.
- **Category 5:** Severe damage created by anomalous ground or flight events. Such damage represents damage/manufacturing events that are outside of design considerations. It does not drive stress analysis, it rather relates to a feedback loop from maintenance/operations to the authorities. Analogous to an automobile accident special directed inspections are needed for category 5 damage.

Damage of categories 1 to 4 has to be taken into account during aircraft design. For damages of category 2 to 5 repair scenarios are required (Baaran, 2009).

3. TERRESTRIAL LASER SCANNER

Terrestrial Laser Scanning (TLS) is a technique that enables the collection of 3D measurements generating a point cloud in a coordinate system. The project used a Terrestrial laser scanner (TLS). General characteristics are listed below.

Range error	**Focus range**	**Resolution**
±2mm @10m	0.6m a 120m	to 70 Mpxl
Speed of measure		**Ranges**
122000-976000 pts/seg		305°/360°

Figure 3. General characteristics, Faro laser scanner (FARO, 2013)

The use of laser scanner for inspection and measurement fall into some challenges. Parameters such as surface finish, material type, surface color and the speckle pattern of the laser impact the quality of the data collected (Ross, Harding, & Eric, 2011). These challenges exist for any applications of TLS. Solutions for these challenges have been developed such us using different angle of view to reduce noise, put white coating on the part to reduce errors by color, material and surface type (Ostrom, Wilhemsen, & Scott, 2012) . This last method may not be acceptable in practical situations due to time, cost and material handling considerations.

TLS uses a near infrared laser. and the measure technology that uses is change of phase. The reflected light has intensity information that provides information about the reflectance of the surface and it is possible to correlate it with object material and surface finish.

4. CASE OF STUDY: APPLICABILITY OF THE CONCEPT TO IDENTIFY AND MEASURE AT DIFFERENT AIRCRAFT ENGINEERING AND MAINTENANCE PROCESSES

The case of study was divided in three parts. The first part is a laboratory situation where the engineers need to measure a previous identified dent on an A320 leading edge shown in Figure 4.

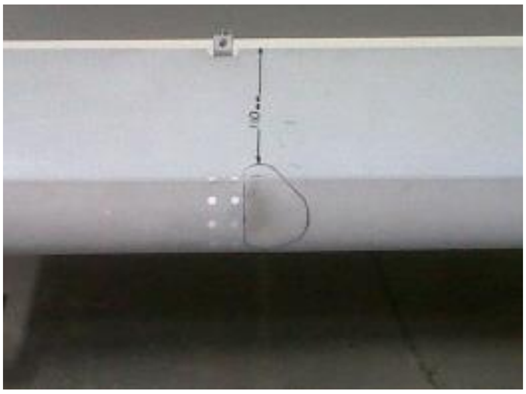


FIGURE 4. DENT ON A320 LEADING EDGE

The second part is a laboratory situation where the engineers need to identify a scratch on an A320 quartz fiber nose radome, shown in Figure 5.

FIGURE 5. A320 NOSE RADOME

The third part is a simulated practical situation where the engineers need to determine if there are potentially harmful dents on an aircraft wing. The inspected aircraft wing is shown in Figure 6.

FIGURE 6. AIRCRAFT WING TO BE TESTED

All the measures took place at Avianca's Bogotá D.C., Colombia maintenance hangars and metallic structures and composites materials workshop.

5. METHODOLOGY DEVELOPMENT

5.1. Measurement planning

“Getting good data in a relatively short time is the purpose of scan planning for inspection. High efficiency, good accuracy and relatively low density data conveying the exact shape can be achieved with an ideal scan strategy for effective data collection of a part surface” (Chen, Du, Jia, & Song, 2010).

For the case of study, in general, the measures were taken at different distances from de object of interest and with different angles of incidence. The main purpose of this scan planning is to avoid the challenges and noise mentioned on the Terrestrial laser scanner section above.

For the first part of the case of study, the measures were taken at 1, 2, 4 and 8 meters from the object of interest and with two different angles. We called these two measurements of the leading edge “tilt1” and “tilt2” at the results section. Every single measure took around 2.5 minutes.

For the second part two measures were taken, at 4 and 8 meters. Every single measure took 4.5 minutes.

Finally, for the third part, two measures were taken at a distance of 4 and 8 meters and every single measure took 10 minutes.

The processing of the data is divided in the development of two types of different technics and methodologies. The first area is identification technics and the second one is mensuration technics. Figure 7 shows the processing framework used to create the identification and mensuration technics.

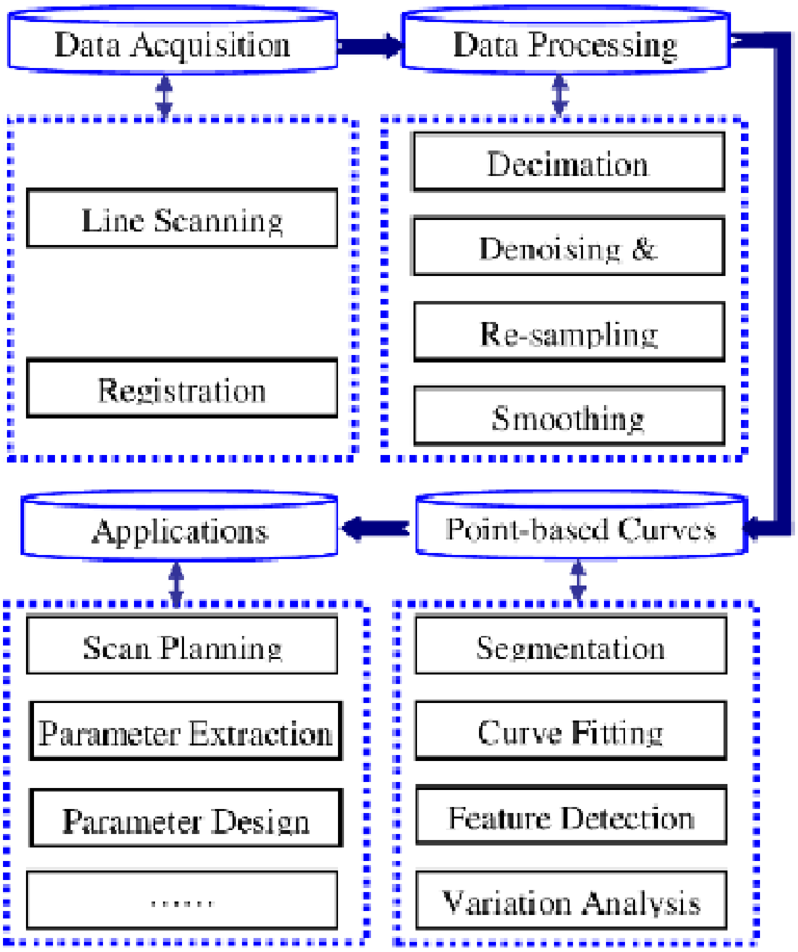


FIGURE 7. DATA PIPELINE AND PROCESSING FRAMEWORK (CHEN, DU, JIA, & SONG, 2010)

5.2. Identification technics

Identification technics refers to a structured methodology for identification of damage by visual inspection of a specimen. This step leads the procedure to the measurement of the damage.

5.2.1. By light intensity

Because the near-infrared nature of the scanner, it is possible to detect different levels of intensity in the raw point cloud. The intensity map is determined by several factors, some are listed below: material type, angle of incidence, strength of the reflected signal, sharp discontinuities or edges. Figure 8 shows a photo of a nose radome of quartz fiber and the raw point cloud displaying the intensity map.

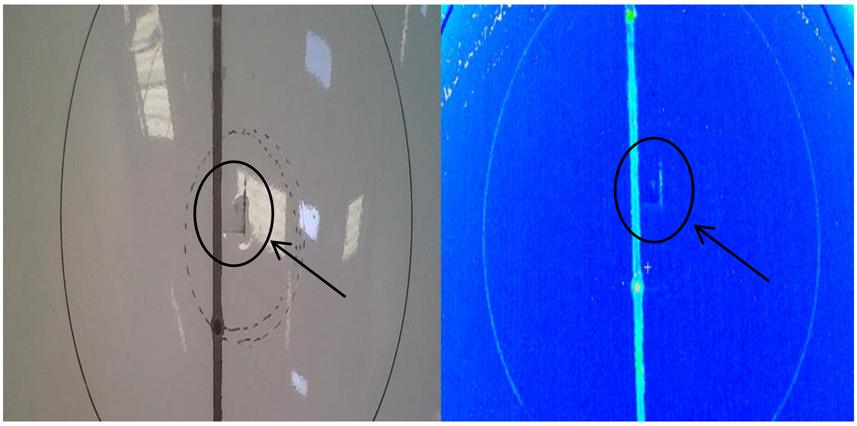


Figure 8. Intensity map of a nose radome specimen

5.2.2. Surface shading based on an imaginary light adjacent to the surface

The point cloud can be processed to create a mesh in order to obtain a smooth surface of the measure. By placing an imaginary light adjacent to the surface it is simple to identify a discontinuity at the surface. This is possible because the reflectance mesh properties. Figure 9 shows the post-processed mesh of the measured leading edge.

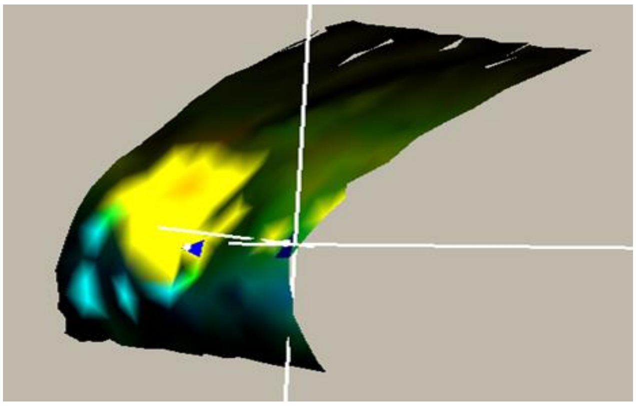


FIGURE 9. SHADED SURFACE OF LEADING EDGE

The white vertex at the edge of the surface represents the inserted Point Light (PL). A PL source emits light in all directions of the model and the shaded surface is the one that represents a smooth surface without sharp discontinuities. Along these lines, it is possible to identify a dent or a series of them by applying this technique and identify the highlighted sections of the surface.

5.3. Mensuration technics

5.3.1. By datum and maximum distance

A datum can be taken at the regular surface of the leading edge. Different points on the dent can be measured to estimate de maximum depth of the dent. The depth of the dent must be measure using one edge of the local coordinate system.

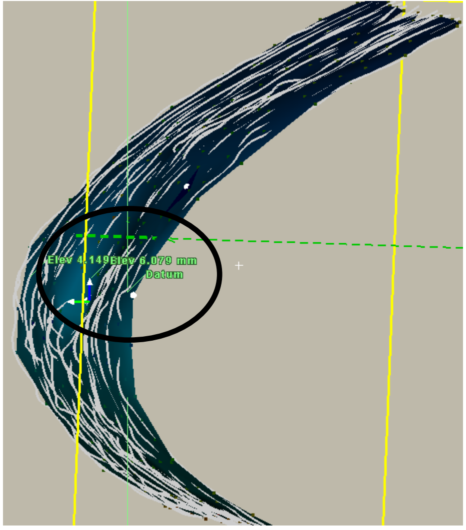


Figure 10. Datum data for the leading edge

5.3.2. Series of cubic splines by slices

As manner of curve fitting command, the surface can be divided in a series of slices. From every slice, points along the surface are taken to know the 3D coordinates of the point. A spline is traced as representation of measure process. Figure 11 shows this representation.

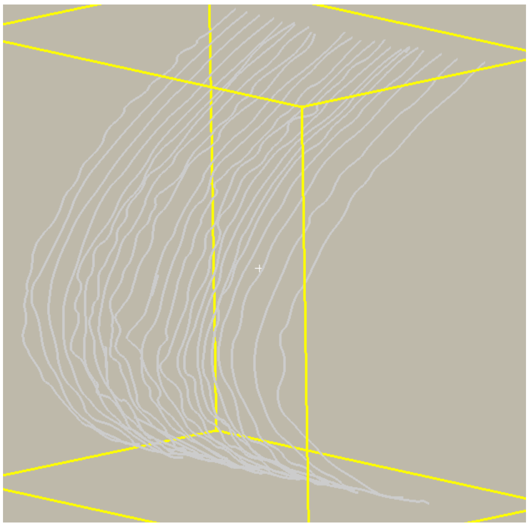


FIGURE 11. REPRESENTATION OF SPLINES IN DIFFERENT SLICES

For the measure the coordinates of the point are processed to fit a cubic spline at a slice without the dent and one with the dent. The difference between the plots of the obtained equations will lets us know the shape of the regular leading edge and the damaged one.

6. RESULTS AND DISCUSSION

6.1. Measurement of the leading edge

The measures at 2 and 4 meters were not reliable because the dispersion of the point was elevated and some parts of the surface were not measured. It appears that at these distances the scanner lost a lot of information due to noise angle of incidence. This funding is consistent with those from other results (Ross, Harding, & Eric, 2011). References were consulted and then it was known that a similar phase based Faro laser scanning was tested and results are shown at Figure 12.

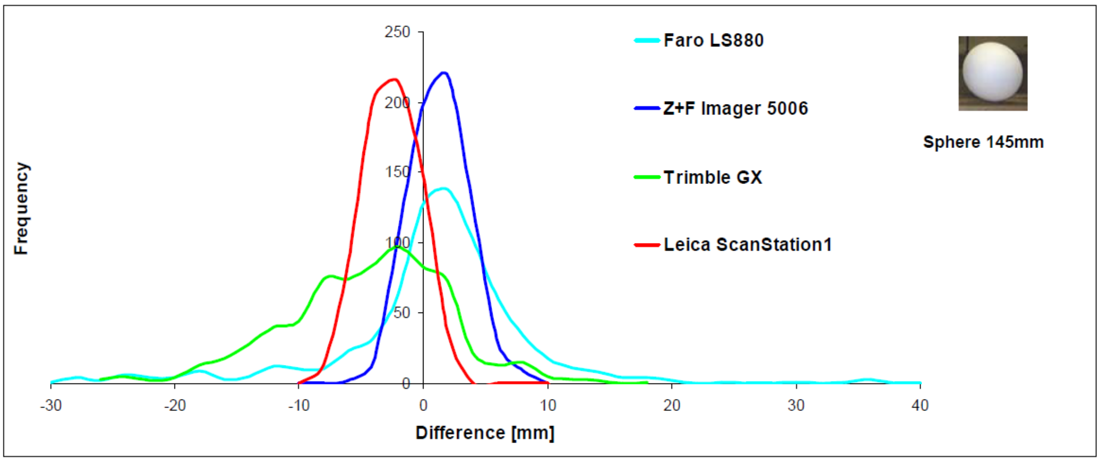


FIGURE 12. DISTRIBUTION OF DIFFERENCES BETWEEN SCANNED DISTANCES AND REFERENCE DISTANCES FOR FOUR TESTED TERRESTRIAL LASER SCANNER (KERSTEN, MECHELKE, LINDSTAEDT, & STERNBERG, 2009)

Figure 12 shows us that the maximum difference between a scanned distance and a reference distance is between 1 and 5 mm.

6.1.1. By datum and maximum distance

Table 2 shows the different parameters from the point clouds generated by every measure. Measures at 2 and 4 meters of the tilt 1 and measure at 4 meters are not shown on the results because not accurate information was possible to be taken.

TABLE 2. PROPERTIES OF THE POINT CLOUDS

Measure	**Distance [m]**	**Separation of scan lines [mm]**	**Separation scan point in line [mm]**	**Density scan mesh[pts/cm^2]**

Leading Edge (tilt 1)	1	Not measurable	Not measurable	-
	8	1.407	1.2	59
Leading Edge (tilt 2)	1	Not measurable	Not measurable	-
	2	1.09	0.754	122
	8	2.3	1.27	34

TABLE 3. MEASURES AND PROPERTIES

	Estimate of damage			**Range error**
Measure	**Extension[mm]**	**Height [mm]**	**Depth [mm]**	**Measured [mm]**
Flap (tilt 1)	-	-	-	6.2
	53.72	71.8	9.898	3.94
Flap (tilt 2)	-	-	-	5.6
	52.814	72.674	7.4	2.1
	53.9	71.18	10.372	2.5

Based on Table 3, it is possible to determine that the different measures were accurate between them. The maximum range error was calculated to determine the difference between the measures of the different scan lines. For inspecting aircrafts, it was found that this maximum range error is large, around 3.9 mm, but the Standard deviation (ST) provides confidence that the maximum is not representative.

6.1.2. By datum and maximum distance

The developed methodology of fit cubic profiles gives the Figure 13 as result.

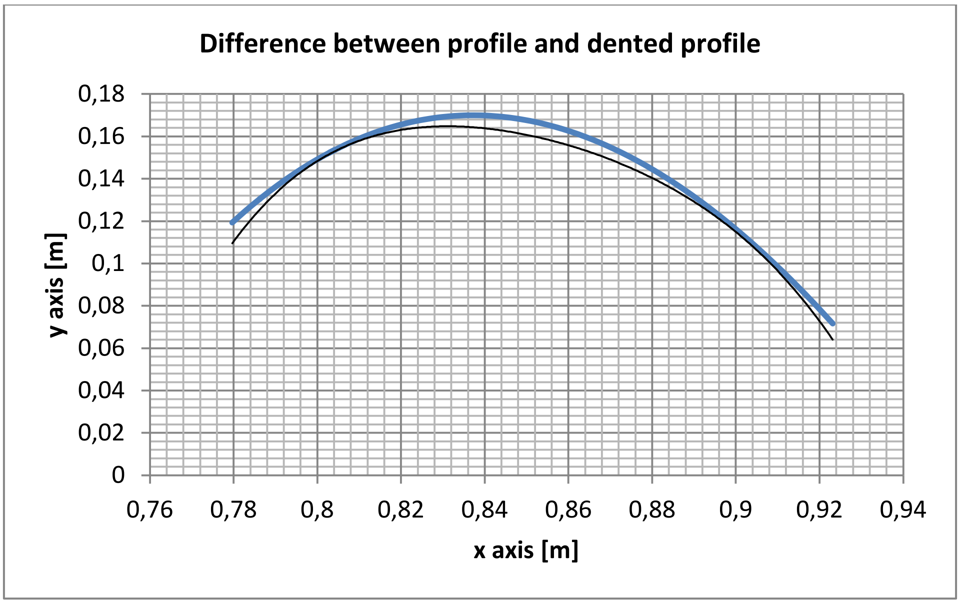


FIGURE 13. DIFFERENCE BETWEEN PROFILE AND DENTED PROFILE

Figure 13 shows the difference between the fit of a cubic spline to a regular surface section and a dented section. The basic concept behind this method is to calculate, mathematically, the approximated difference at any point between a given non-damaged profile and the approximation of the dented profile. This analysis can be fast-performed and determine if the profile needs a more detailed measure and analysis.

The maximum difference was 6 mm. This is larger than the measures with the previous method. However, it is still approximate for the previous readings of 7-10mm. This type of method approximate the measure by a mathematical formula, but it was still in doubt is if the real measure is the maximum or the minimum of the approximation.

This research could establish with these technics is an approximate value of the measure with a range error.

6.2. Identification on the nose radome

The four meters measure was inappropriate. This is because the shiny surface of the radome and reasons explained in chap 6.1. The eight meters measure is presented on figure 14. It is easy to identify by light intensity the scratch on the radome.

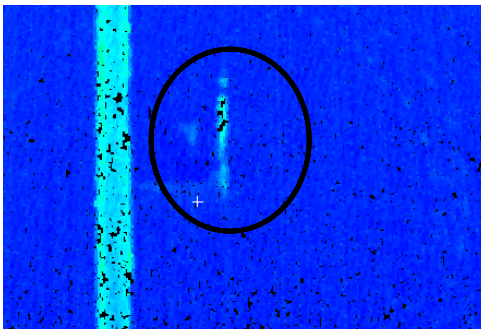


FIGURE 14. NOSE RADOME, SCRATCH IDENTIFICATION

6.3. Identification on the aircraft wing

The measures at practical situation show us that the shiny surface of most of airplanes is the major challenge for the laser scanner applicability. Figure 15 shows the measured point clouds of the wing measured. The black color represents no data collected by the scanner. And the data collected represents surfaces with mate colors.

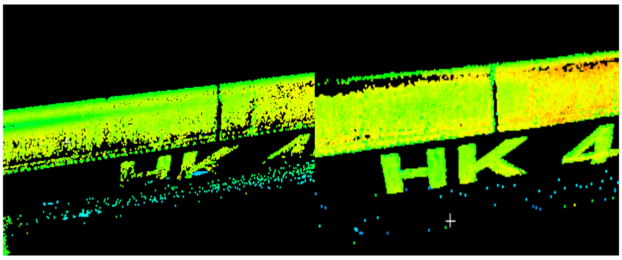


Figure 15. Wing measured, left at 8 meters/right at 4 meters

7. CONCLUSIONS

- Surface shading based on an imaginary light adjacent to the surface is a methodology to identify dents. Scratches are difficult to identify with this technic because they don't affect significantly the smoothness of the surface.
- The light intensity technic for identification of damages in an aircraft surface appears as a powerful tool for low time consuming processes technics.
- We found that TLS for aircraft surface inspection is not recommendable to measure at high incidence angles and at distances between 2 and 5 meters.
- The most reliable solution for the shiny surfaces challenge is to coat the surface. This might not be a viable solution for aircraft inspection because of cost and extra time required.
- With the mensuration technics analyzed, the best way was found to be a mean or approximate datum of the dispersion of the data and the range error.
- The described analysis of the laser scanner data does not describe a proved more reliable inspection than a technical human visual inspection.

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BIOGRAPHICAL NOTES

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