Non-contact tracking of phased-array probe and real-time generation of C-scans for the inspection of composite aerospace structures

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Non-contact tracking of phased-array probe and real-time generation of C-scans for the inspection of composite aerospace structures
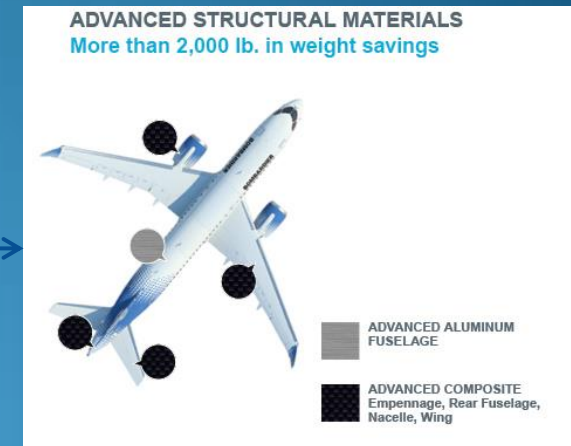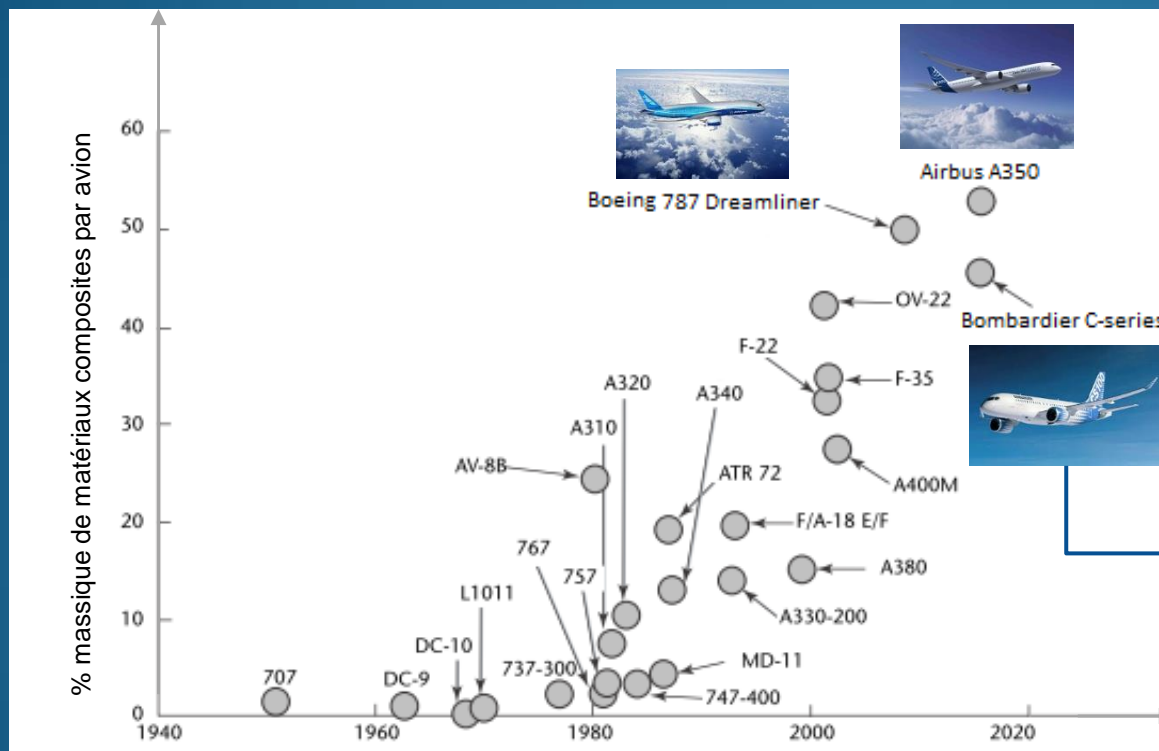
1. Background
2. Method
3. Results
4. Conclusions - Future work

1. Background

- **Composite in aircrafts**

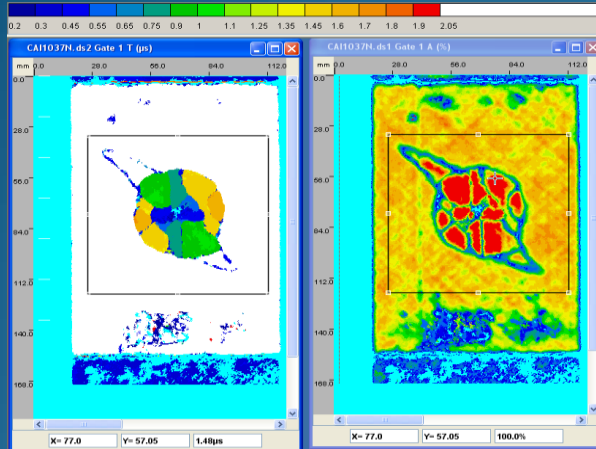   Large composites areas on modern aircrafts
    Including structural parts : requires 100% NDT inspection

1. Background

- **In-service NDT**

  - Detect the flaws induced during aircraft operation
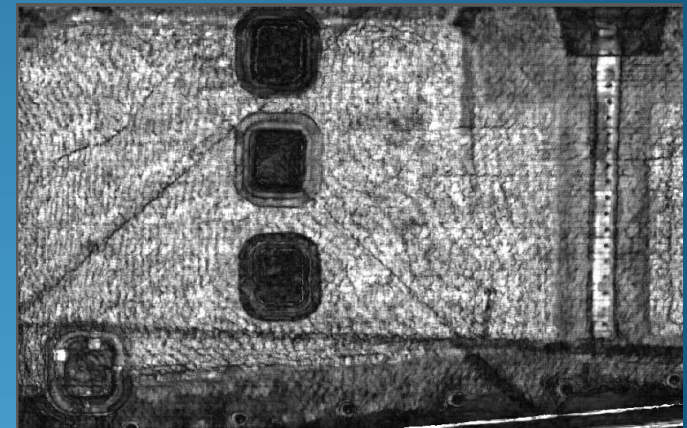

  - Impact damages
  - Disbonds
  - Lightning strikes
  - Dropped tools
  - Water ingress

  - Control the growth of pre-existing defects
  - Give guidance for repair

- **Challenges**

  - Portability
  - Versatility
  - Ease of use
  - Traceability of the results (C-scan highly desirable)

1. Background

- **<u>Scanning techniques for in-service UT</u>**

Manual	Semi-automated	Automated
Manual scan	Manual scan	Automated scan
No position encoding	1 or 2 axes position encoding	2 positions encoding

1. Background

- **Limitations of current techniques**

- Manual UT : convenient but no C-scans…

- Semi-automated or automated UT : generate C-scans

    but several drawbacks…

    - Less convenient
    - Longer preparation time
    - Limited versatility
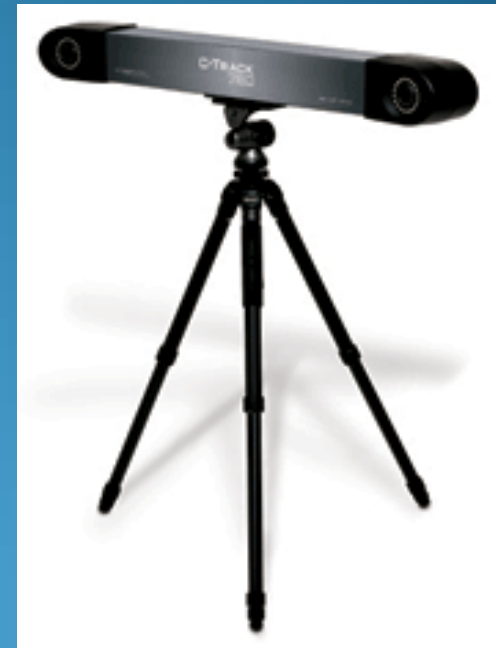   - Can be difficult to adapt to complex geometries

2. Method

- **Objective**

Remove the mechanical scanners and physical encoders to allow for free scanning movements on 3D geometries in any direction.

- **Principle**

Synergy of 2 existing technologies

Portable PAUT instrument

3D Vision system

2. Method

- **Probe tracking**

Targets are placed on the probe

x, *y* and *z* axes are attached to the probe

The vision system provides in real-time:

- 3 position coordinates of the origin *O* of *x*, *y* and *z* axes
- 3 orientation coordinates (rotation of the probe).

- **Challenge**

Convert 6 coordinates measured by the vision system into 2 coordinates (scan – index) required by the UT system while the probe is moved freely on the surface.
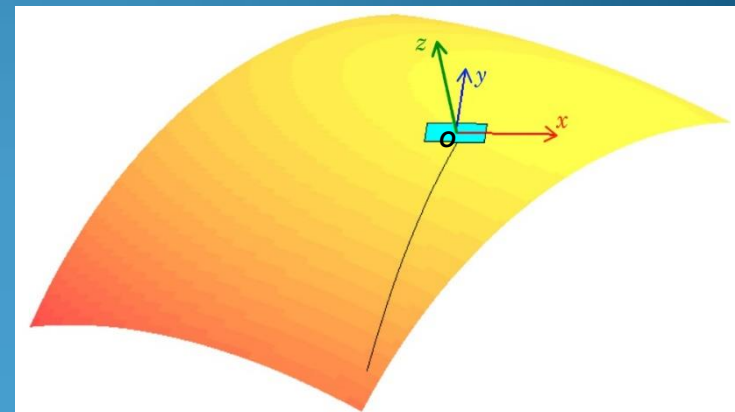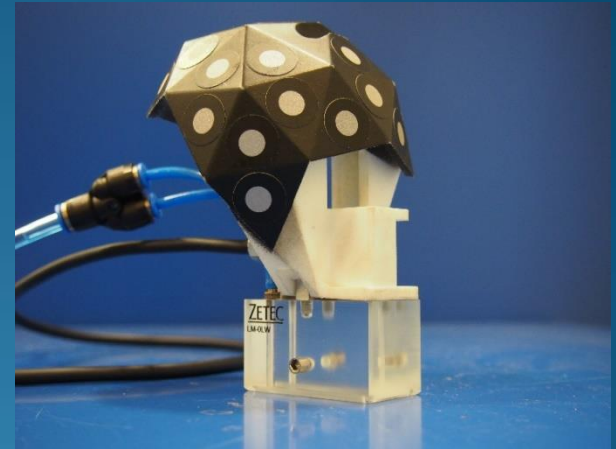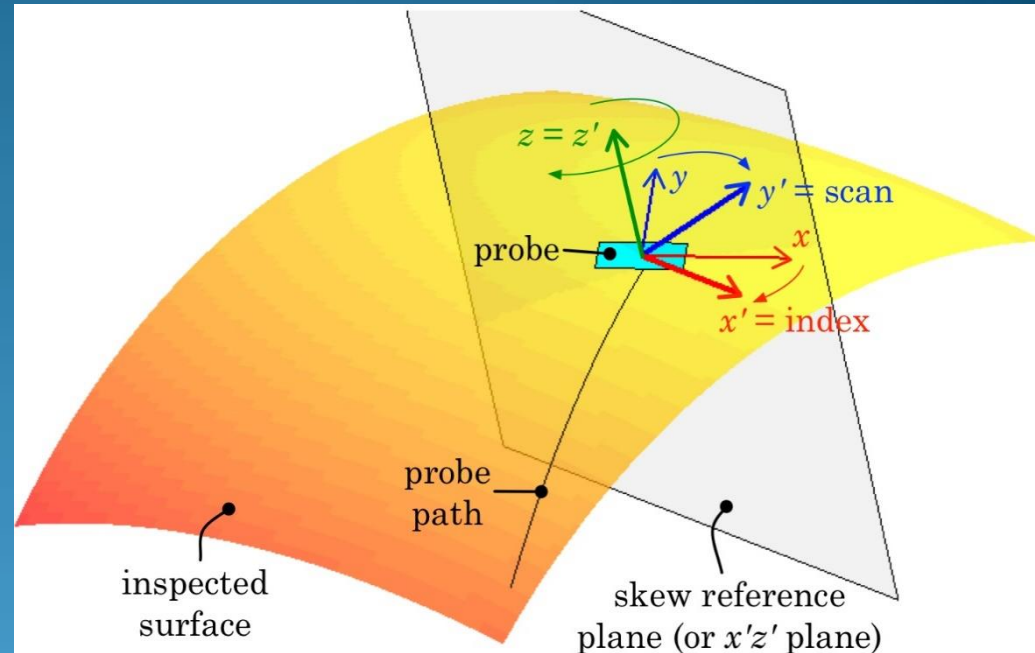
2. Method

Development of an algorithm calculating a local skew angle

A **skew reference plane** formed by z-axis and a reference direction is initially defined by the user.

To find the **local skew angle,** we calculate the rotation around z to bring x-axis in the skew reference plane.

x', y' and *z'* are the corrected axes. *z'* is equal to *z*.
x' and *y'* are found by rotation of *x* and *y* axes and are respectively the *index* and *scan* axes required by the UT software.

2. Method

- **Developed surface**

Once the skew angle is known, a rotation matrix R from (x, y, z) axes to (x', y', z') axes is defined :

$$X' = R\ X,$$

where X' and X are column vectors that give the Cartesian coordinates of a given point, respectively in ($x'y'z'$) and (xyz) axis systems.

If the probe moves along a vector A in (xyz) system, then the scan (S) and index (I) distances are found with equation :

$$\begin{bmatrix} I \\ S \\ H \end{bmatrix} = R\boldsymbol{A}$$

H is the vertical distance with respect to the surface (which should be null if the probe follows closely the surface).
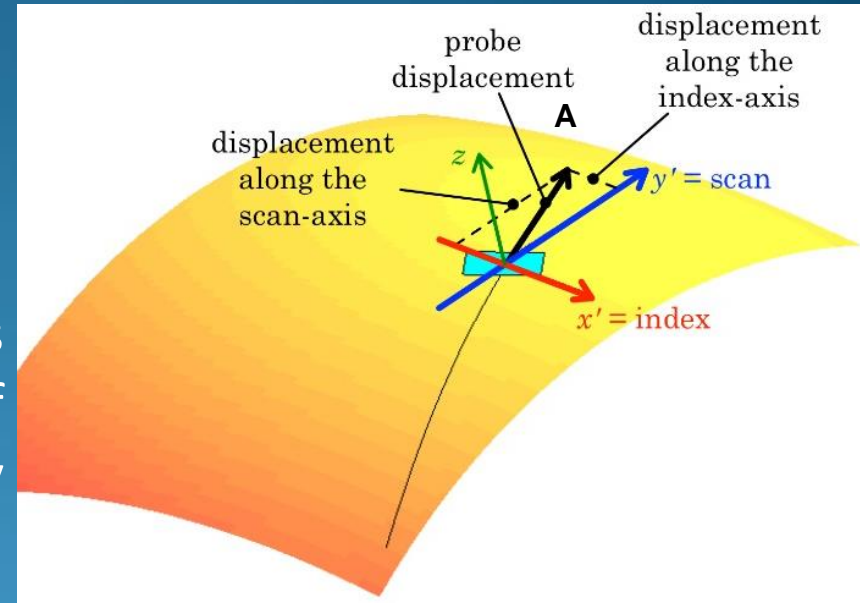
2. Method

- **Developed surface**

Assumptions :
- the surface topography is unknown
- the surface must be developed

Since the surface development depends on the probe's path, the displacement of the probe along *scan* and *index* can only be calculated by iterations.

Each new position is thus calculated from the previous one. To determine the displacement along *scan* and *index*, the displacement vector **A** is projected onto *x'* and *y'*.

- **Developed surface**

As the acquisition is discrete, errors occur between calculated and actual movements.

Depending on the acquisition rate (here 30 Hz), the expected displacement can be more or less close to the real topography.

High acq. rate

Low acq. rate

The path is then corrected to suppress any movement in *z'*. The displacement from one point to another is renormalized along x' and y'-axes (orange segments).
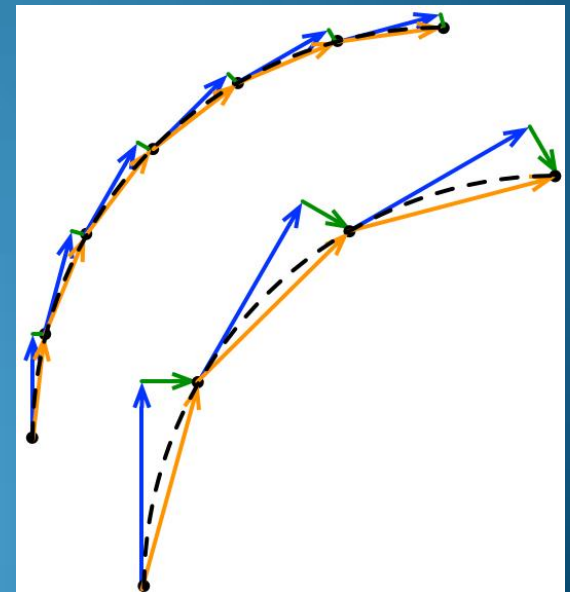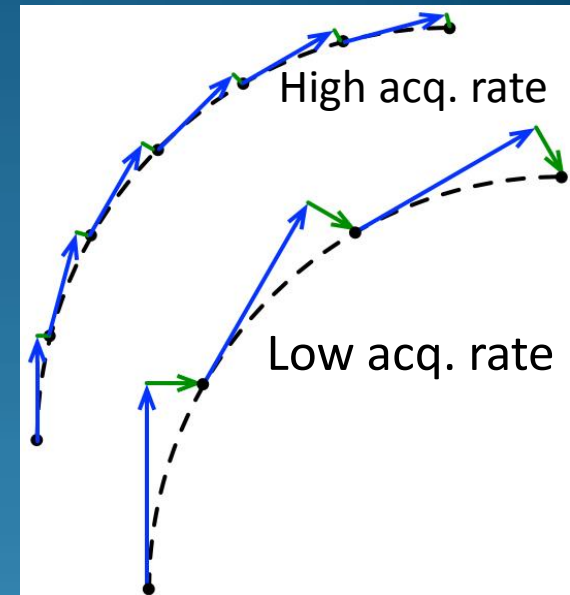
2. Method

- **"Lift" feature**

The probe can be lifted away from the surface, causing an interruption of the data sent to UT unit (**"lift"**).

The algorithm waits for precise conditions to be met before sending data again to the UT system (**"stick"**).

- **"Lift" condition :**   displacement ≥ 0.5 mm according to z in a single acquisition.

- **"Stick" condition :** two approaches were tested : **local** and **global** stick conditions

2. Method

- **Global condition**

If the probe position (origin of x, y and z axes) is stable for at least 1s, data is sent to the UT unit again.

The total displacement from the lift position is then projected along *x'* and *y'* at the stick position to update *scan* and *index*. This approach is simple, but can lead to large errors because of the projection.
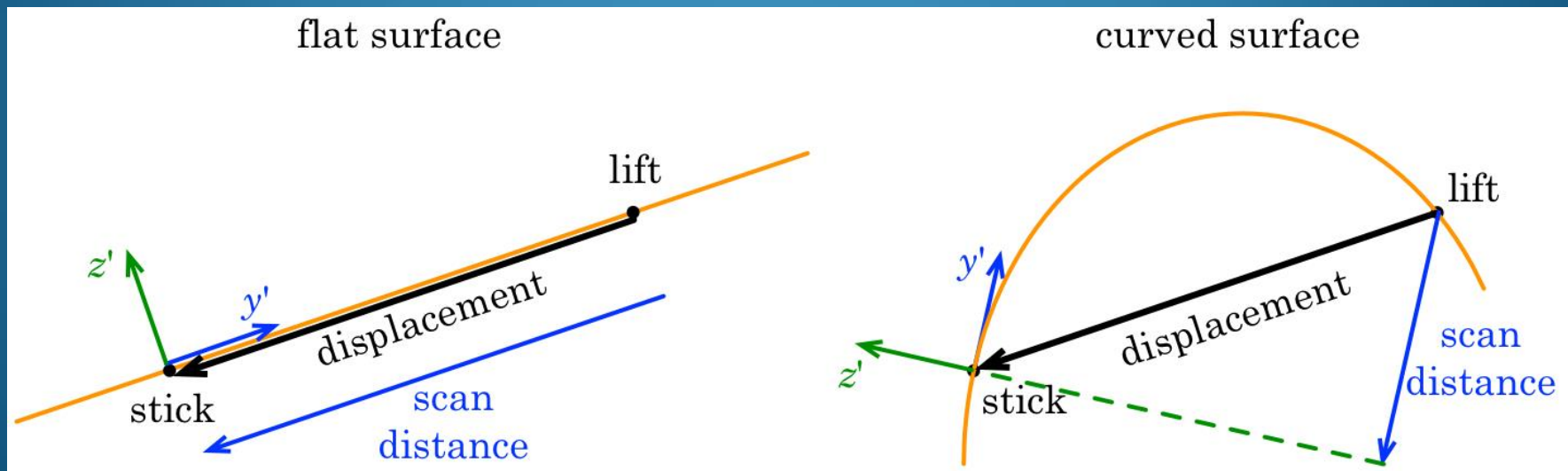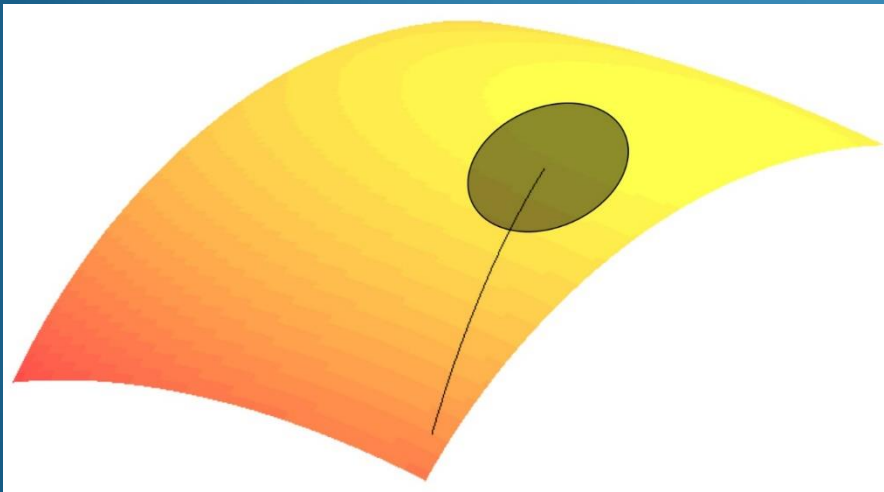
2. Method

- **Local condition**

If the probe position is stable for 0.1s AND the probe is brought back in the vicinity of the lift position (for exemple, at a distance ≤ 20 mm).

The total displacement from the lift position to the stick position is then projected along x' and y' axes at the stick step to update the displacement along scan and index.
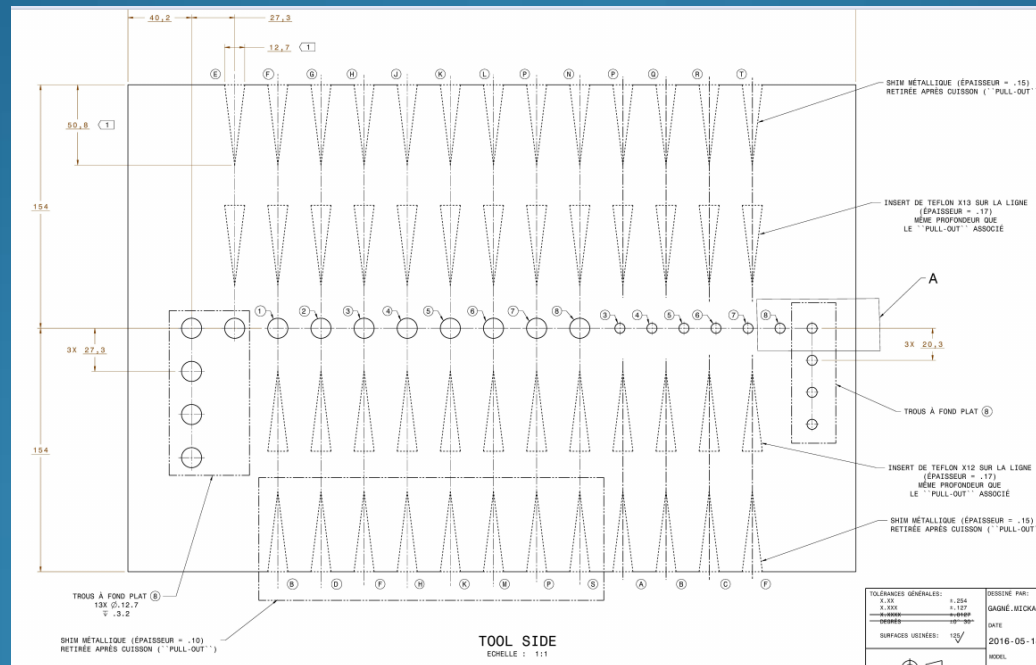

This approach prevents C-scan distortions.

3. Results

The method were tested on 2 different composite parts :

- A 2D composite reference standard (plate) including artificial defects (flat bottom holes, pull-out and Teflon inserts)
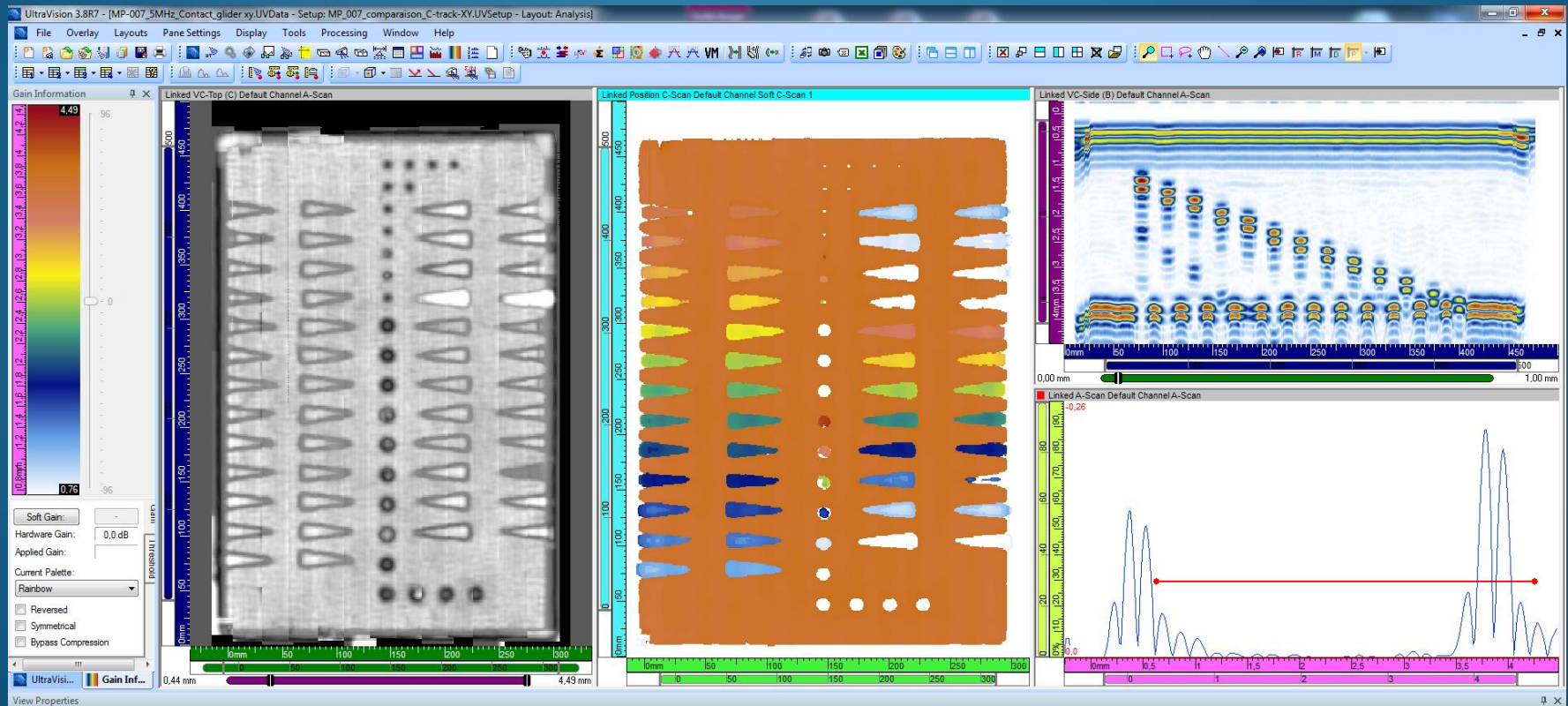

- A real aircraft component, with 3D geometry (curvatures in both directions)

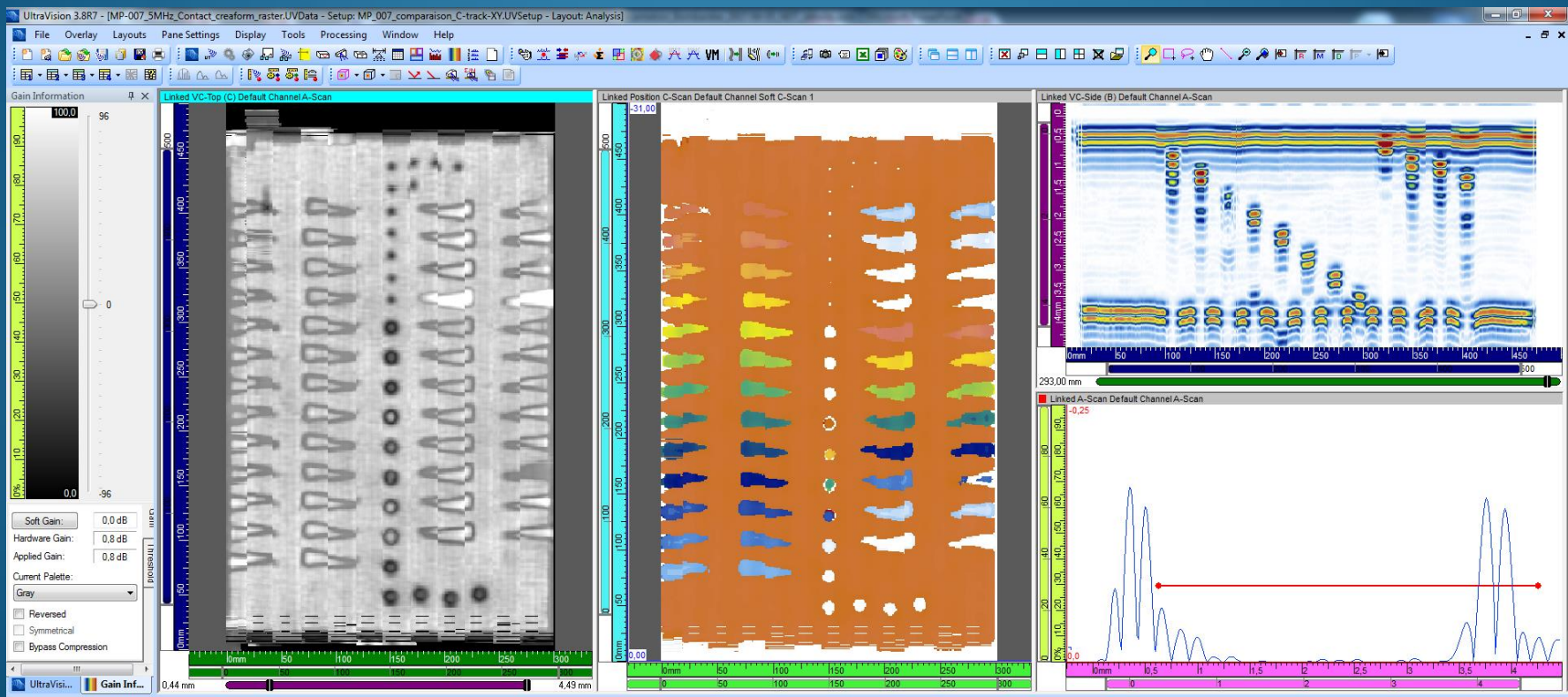# 3. Results

2D composite plate

- Probe mounted in 2-axes scanner
- Mechanical encoding of the position
- Raster scan movement

3. Results

2D composite plate

- Probe mounted in 2-axes scanner
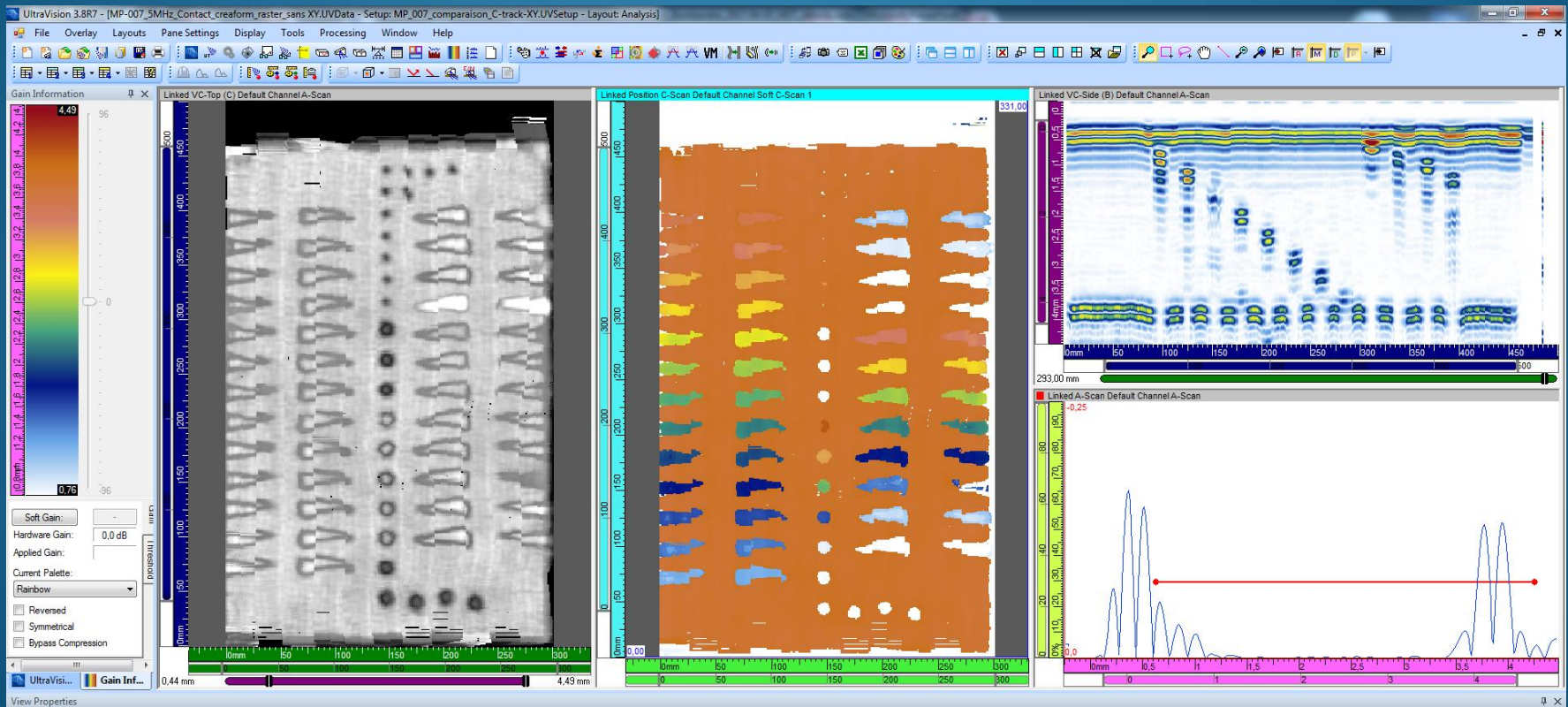- Non-contact encoding of the position
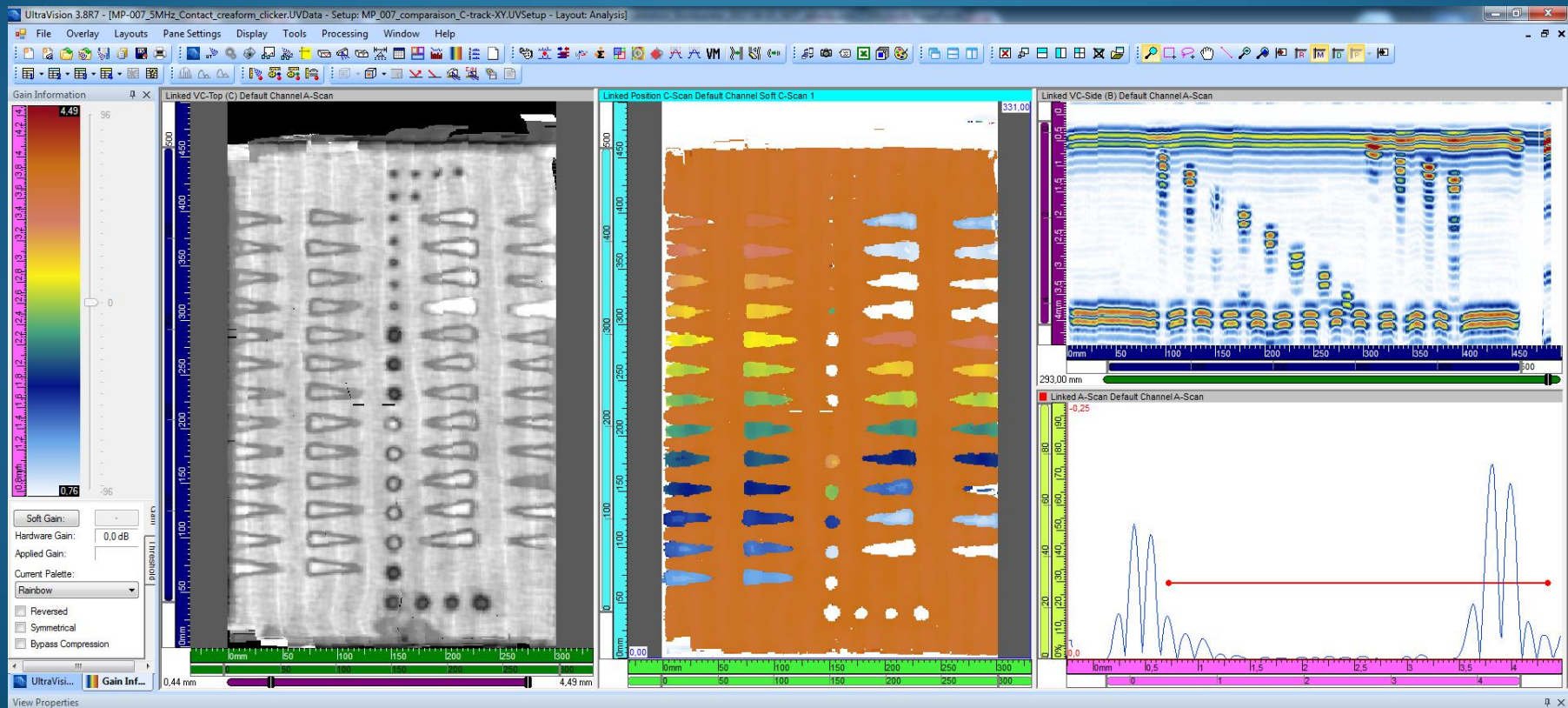- Raster scan movement

3. Results

2D composite plate

- Free probe
- Non-contact encoding of the position
- Raster scan movement

3. Results

2D composite plate

- Free probe
- Non-contact encoding
- Uni-directionnal movement
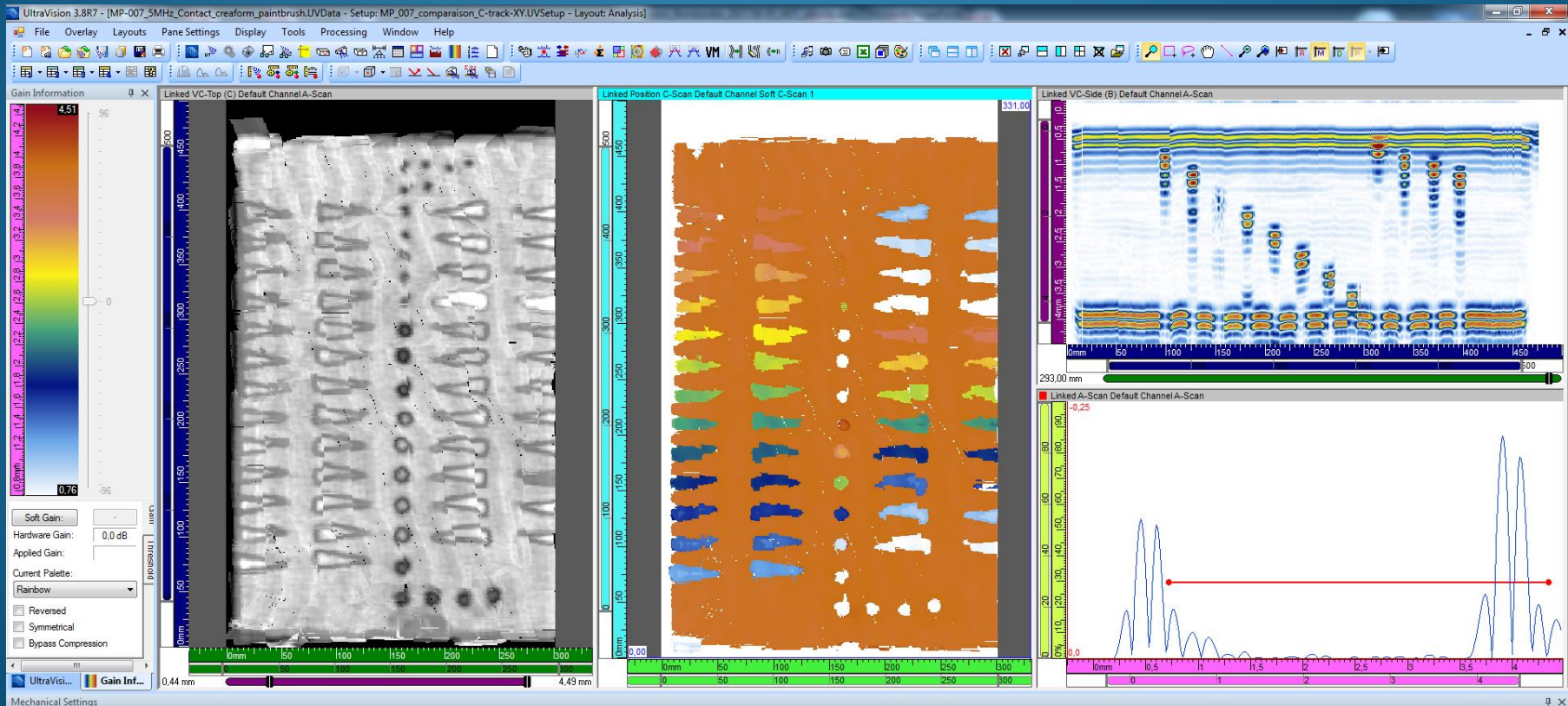
3. Results

2D composite plate

- Free probe
- Non-contact encoding
- Free movement ("paintbrush" mode)

3. Results

3D composite component

Tail cone

- 3D geometry : curvature in different directions
- Composite part (monolithic and sandwich)
- Thickness variations

3. Results

3D composite structural component

3. Results

3D composite structural component : lift feature

- **Current limitations and potential solutions**

- The vision system acquisition rate is currently limited (30 Hz) leading to low scanning speed → using a faster system will allow for normal scan speed.

- « Hysteresis » problem : positioning errors depending on the scan direction.

- Accuracy of the « stick » position after a lift is still to be optimized → depending on the parts geometries, several scenarios will be tested.

4. Conclusions

- **A successful proof of concept of a PAUT method with no mechanical scanner or physical encoder has been made.**

- **The probe can be moved freely in any direction ("paintbrush" scan) on 3D geometries.**

- **C-scans are generated in real-time.**

- **The inspection automatically stops if the probe is lifted away from the surface and can be resumed.**

4. Future Work

- **Increase scanning speed**

- **Treat a collection of real aircraft components to optimize the inspection strategies and the overall positioning accuracy**

- **In post-treatment, use the 3D coordinates collected during the inspection to generate 3D C-scans**

- **Industrialization of the concept**

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