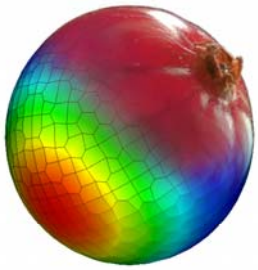


# RIBES

*Radial basis functions at fluid Interface Boundaries to Envelope flow results for advanced Structural analysis*

## RIBES prototype manufacturing

*November 2016*


**Project coordinator:**

Prof. Marco Evangelos Biancolini
*Department of Enterprise Engineering "Mario Lucertini"*
*University of Rome "Tor Vergata"*
*Email biancolini@ing.uniroma2.it*

**Authors:**

Elia Daniele, Angelo De Fenza (*3D TECH Engineering*)

Ubaldo Cella (*University of Rome "Tor Vergata"*)

# Table of Contents

# 1 Introduction

The present document details the manufacturing of the test article. The content of this report was extracted from the document provided by the model manufacturer.

# 2 Model building

The model has been built according to the requirements provided by the University of Rome "Tor Vergata".

The following steps have been accomplished in order to build the model:

1. Structural items building
2. Materials treatments
3. Internal structure assembly
4. Skin assembly

## 2.1 Structural items building

the following items have been built:

- n.1 front spar
- n.1 rear spar
- n.2 front spar thickening
- n.1 machined wing box rib at wing root
- n.9 wing box ribs
- n.10 leading edge ribs
- n.10 trailing edge ribs
- n. 3 stringers on the upper surface
- n.1 skin upper box
- n.1 skin lower box
- n.1 skin leading edge
- n.1 skin V shaped for the trailing edge

Details are shown in Figure 1, Figure 2 and Figure 3.

Figure 1: Detail of structural items during building, machined rib 1.

Figure 2: Detail of spars and ribs.

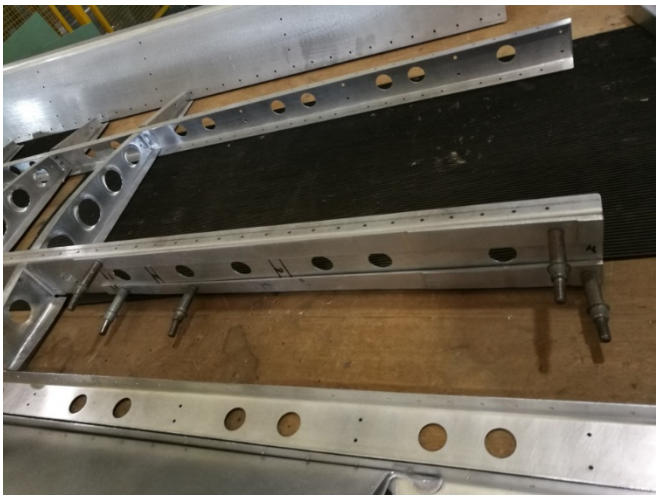


Figure 3: Detail of front spar thickening.

## 2.2 Material Treatment

Two treatments have been done before to assembly and paint the wing, in order to prevent corrosion and to prepare wing structure to paint:

- Alodine treatment (Figure 4)
- Primer treatment (Figure 5)

Figure 4: Alodine Treatment on the upper skin (details of pressure holes).

Figure 5: Primer treatment on the entire structure.

Figure 6 – Pre assembly test detail from root

Figure 7 – Pre assembly test detail from tip

## 2.3 Internal structure assembly

The internal structure has been assembled by linking the spars with the 10 ribs (see Figure 8). The front spar thickening has been nailed on the front spar as shown in Figure 9.

The wing box at wing root has been nailed with:

- n.2 (two) linchpins of 7.92 mm e n.2 (two) nuts to join front spar to the 1st ribs AN type.
- n.2 (two) linchpins of 4.8 mm e n.2 (two) nuts to join rear spar to the 1st ribs AN type.

These nuts have been clamped with dynamometer spanner (see Figure 10 and Figure 12). The internal plate on rib 1 is shown in Figure 11.

Figure 8: Internal structure assembly

Figure 9: – Front spar thickening nailing.

Figure 10 – Front spar nuts

Figure 11 – Rib 1 internal plate

Figure 12 – Rear spar nuts

## 2.4 Skin Assembly

The wing skin has been assembled after the pressure taps and strain gauges installation. The procedure has followed these steps:

1) Lower skin → positioning, wiring
2) Trailing edge skin → positioning, wiring and riveted on the trailing edge ribs and on the lower skin
3) Lower skin → riveted on the wing box ribs
4) Leading edge skin → positioning, wiring and riveted on the lower skin
5) Upper Skin → positioning, wiring
6) Final skin riveted, trailing edge upper skin, leading edge ribs, leading edge upper skin.

The order of skin nailing is shown in Figure 13.

- Skin upper box (yellow)→ 2ND RIVETTED
- Skin lower box (blue) → 3RD RIVETTED
- Skin leading edge (red) → 4TH LAST RIVETTED
- Skin trailing edge (grey) → 1ST RIVETTED

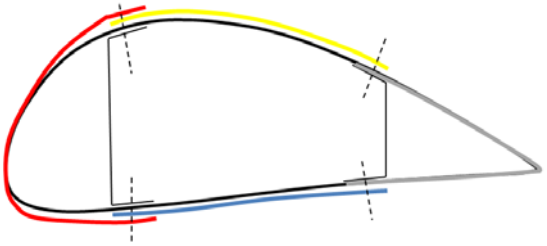


Figure 13 – Skin riveting order

Details of the assembly and wiring are summarized in section 4.

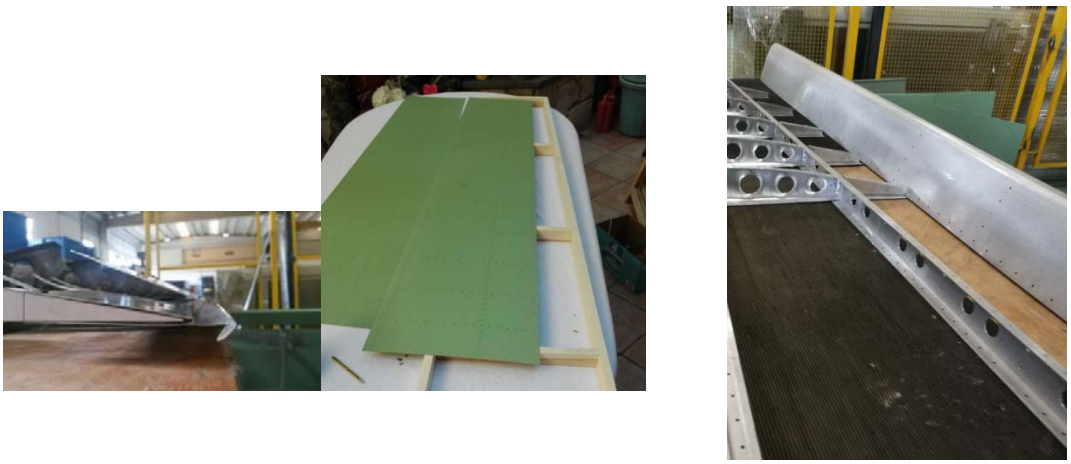


Figure 14: Upper, Lower, leading edge, trailing edge skin.

# 3 Pressure taps installation

A number of 81 pressure taps have been installed in 6 sections of the model, as summarized in Table 1 and clearly shown in Figure 15. Section 1, 2, 4 and 6 are instrumented with only 4 pressure taps each one on the upper surface, in order to check pressure distribution. Section 3 and Section 5 are instrumented with 39 and 26 pressure taps in order to evaluate pressure distribution and wing span loading

Table 1 – Pressure taps locations and number

| NAME ID | SECTION | y(mm) | η | Chord(m) | Number and Number of Pressure taps |
|---|---|---|---|---|---|
| **A** | 1 | 160 | 0.100 | 0.582 | 4 (A1 to A4) te->le, lower->upper |
| **B** | 2 | 450 | 0.281 | 0.549 | 4 (B1 to B4) te->le, lower->upper |
| **C** | 3 | 600 | 0.375 | 0.533 | 39 (C1 to C39) te->le, lower->upper |
| **D** | 4 | 990 | 0.619 | 0.488 | 4 (D1 to D4) te->le, lower->upper |
| **E** | 5 | 1200 | 0.750 | 0.465 | 26 (E1 to E26) te->le, lower->upper |
| **F** | 6 | 1500 | 0.938 | 0.431 | 4 (F1 to F4) te->le, lower->upper |
| | Total | | | | 81 |

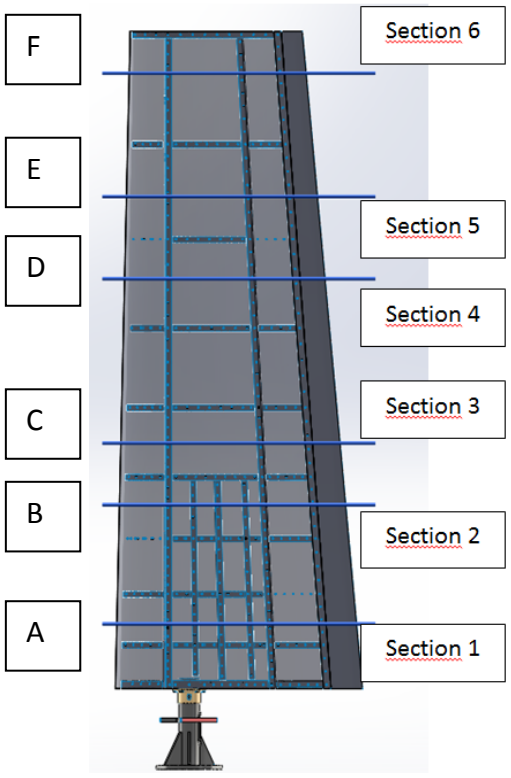



Figure 15 – Planes Location for pressure taps.

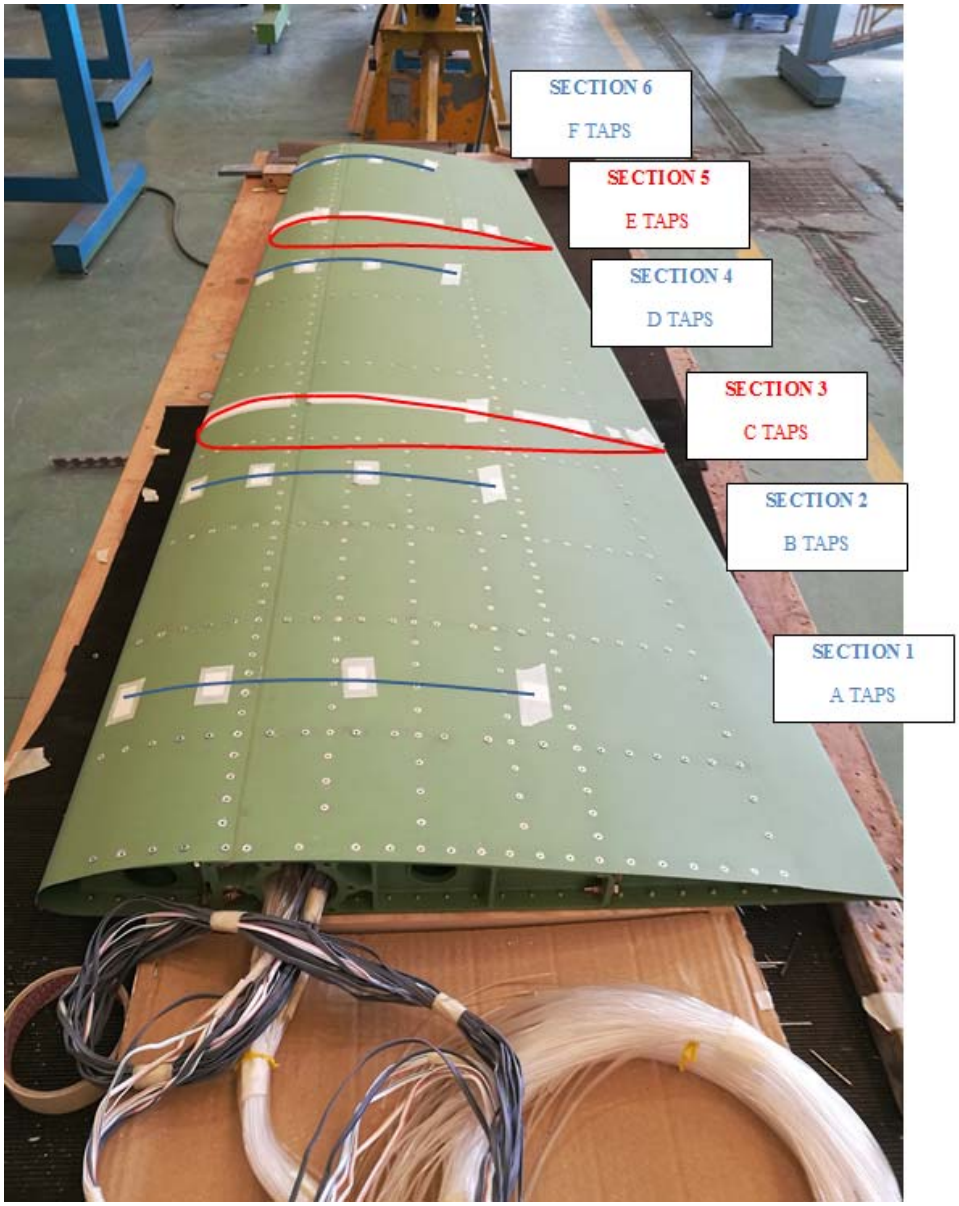



Figure 16 – Pressure taps on the final model.

## 3.1 Pressure taps installation procedure

Pressure taps have been installed on the 4 skins components shown in 2.4.

The following steps have been performed:

- Skin internal surface preparation
- Pin positioning
- Taps positioning
- Taps bonding

Figure 17 and Figure 18 show the pressure taps installation procedure on the leading edge and on trailing edge skin respectively.

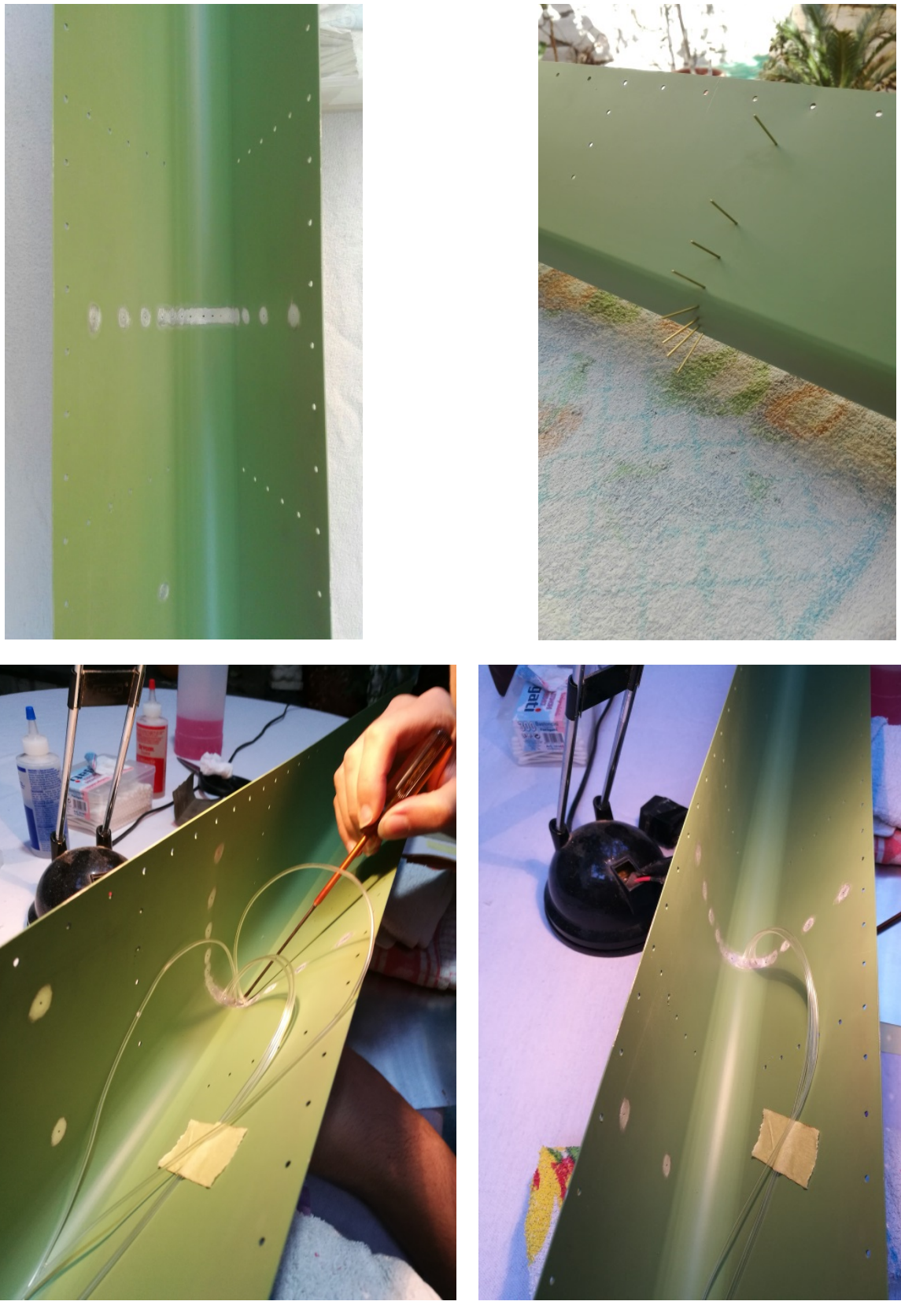


Figure 17 – Leading Edge pressure taps installation

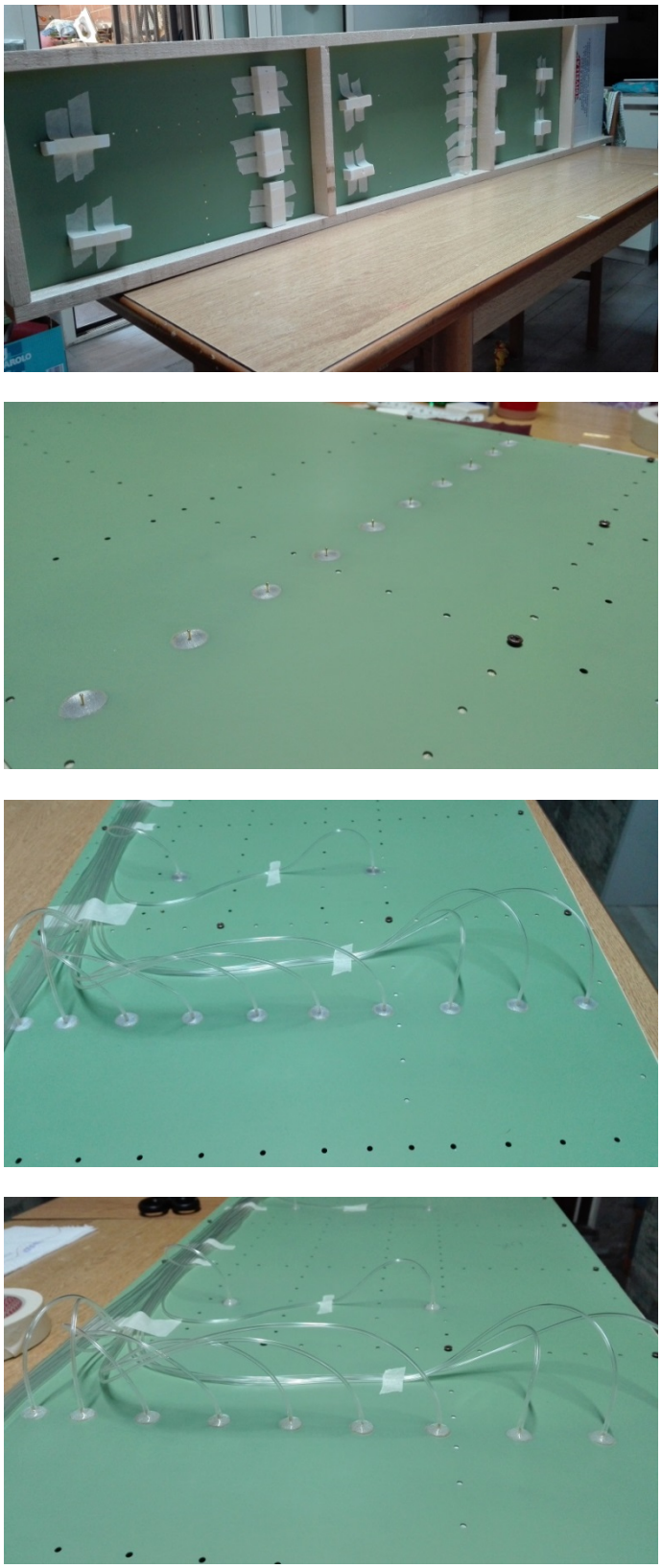


Figure 18 – Upper Skin pressure taps installation

From Figure 19 to Figure 24 all the installed pressure taps are shown, divided for the 6 instrumented wing sections.

**SECTION A, pressure taps installation**


Figure 19 – Section A, y=160mm, pressure taps installed

**SECTION B, pressure taps installation**

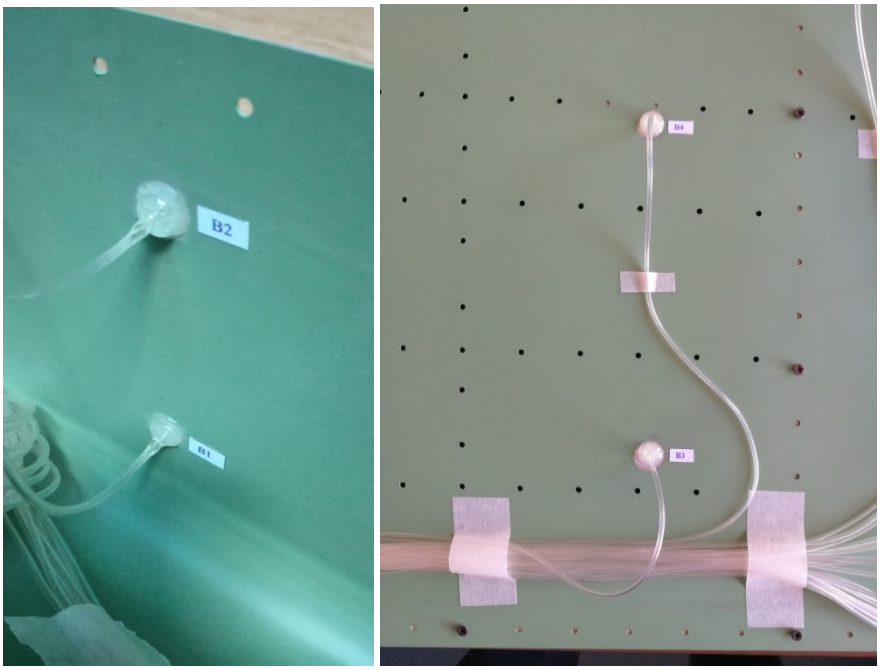



Figure 20 – Section B, y=450mm, pressure taps installed

**SECTION C, pressure taps installation**

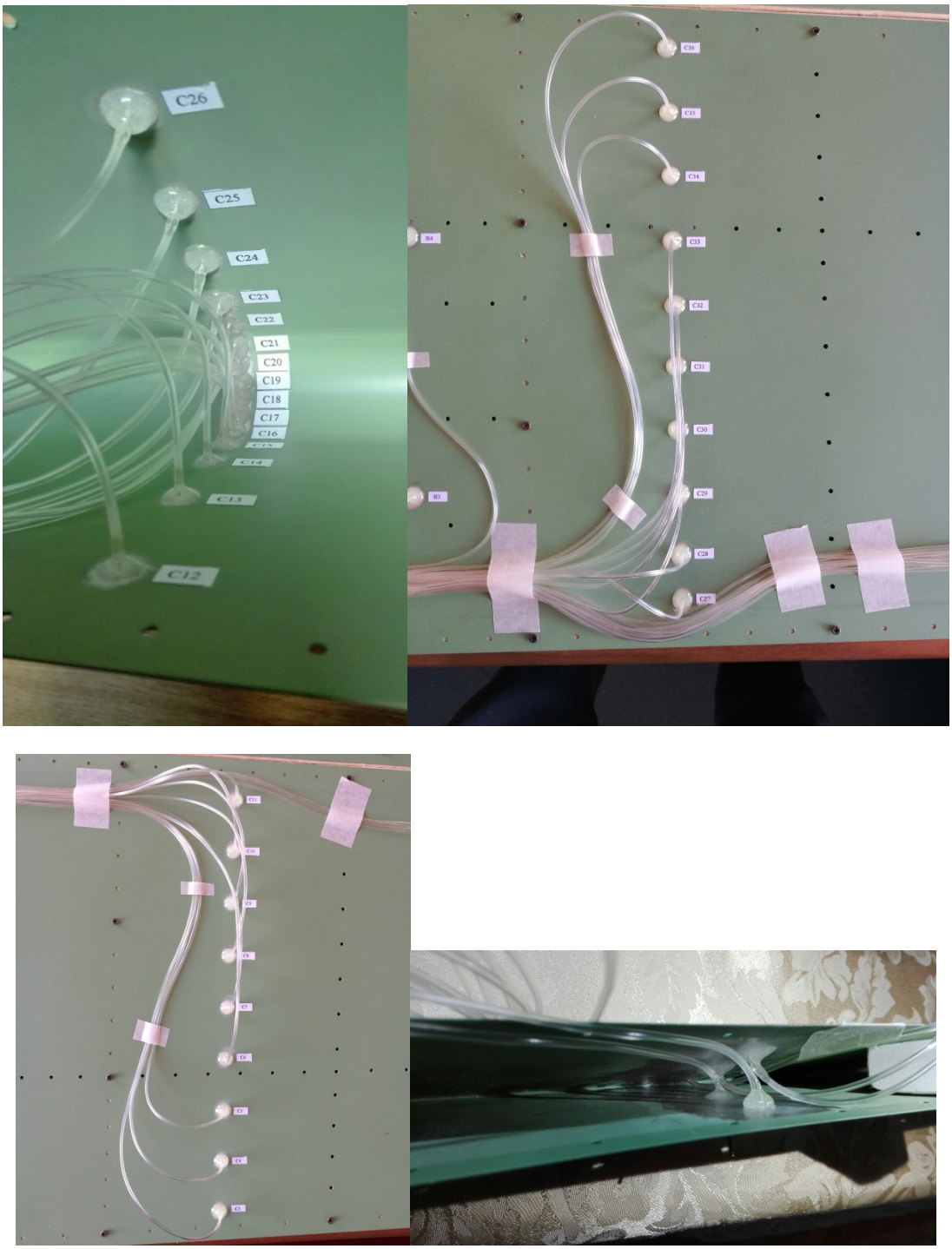



Figure 21 – Section C, y=600mm, pressure taps installed

**SECTION D, pressure taps installation**

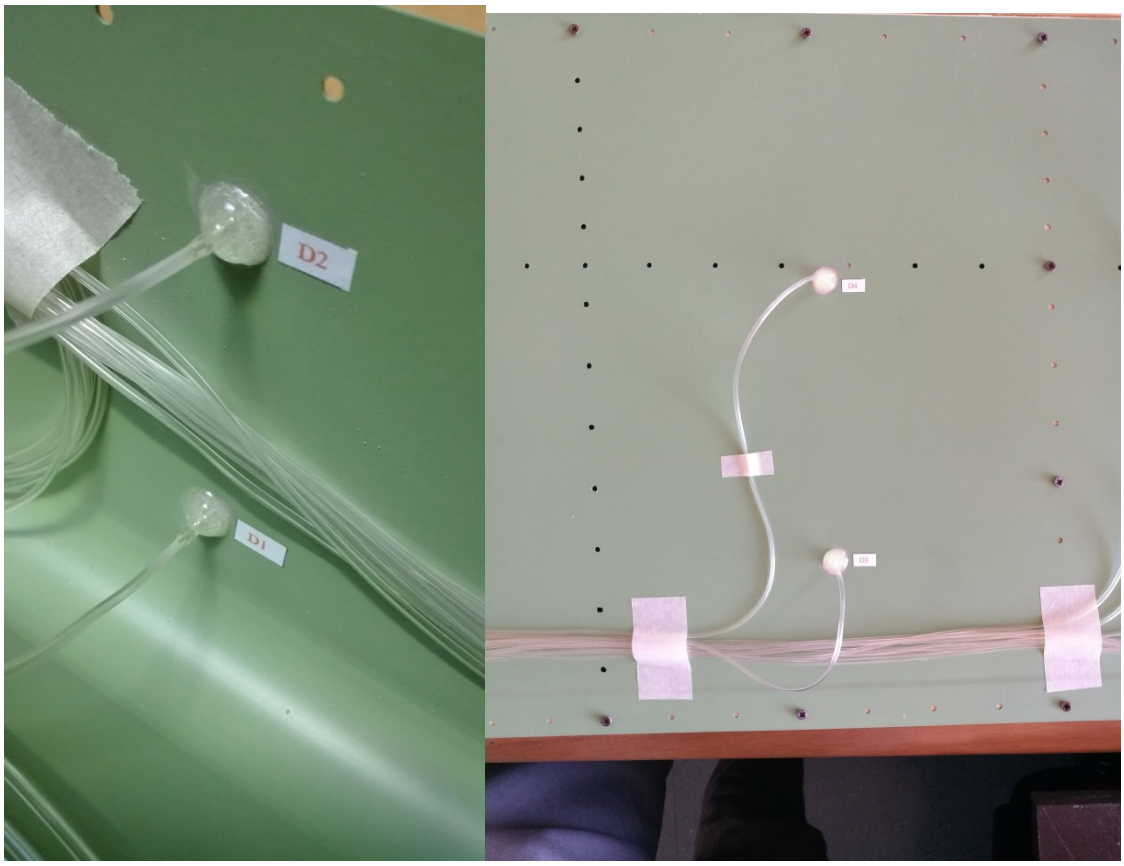
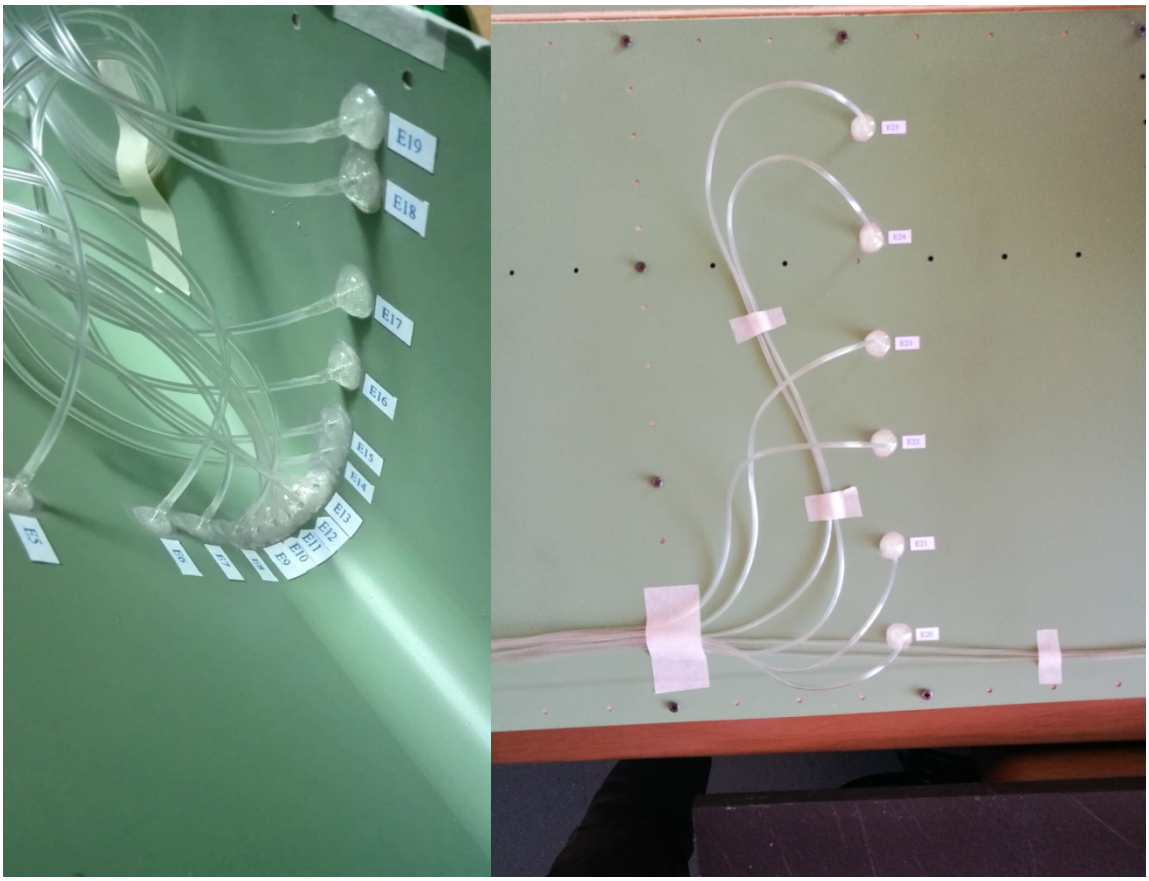



Figure 22 – Section D, y=990mm, pressure taps installed

**SECTION E, pressure taps installation**



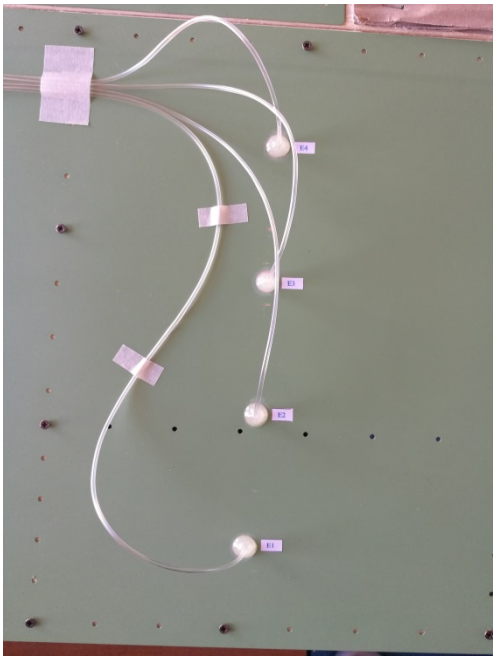



Figure 23 – Section E, y=1200mm, pressure taps installed

**SECTION F, pressure taps installation**

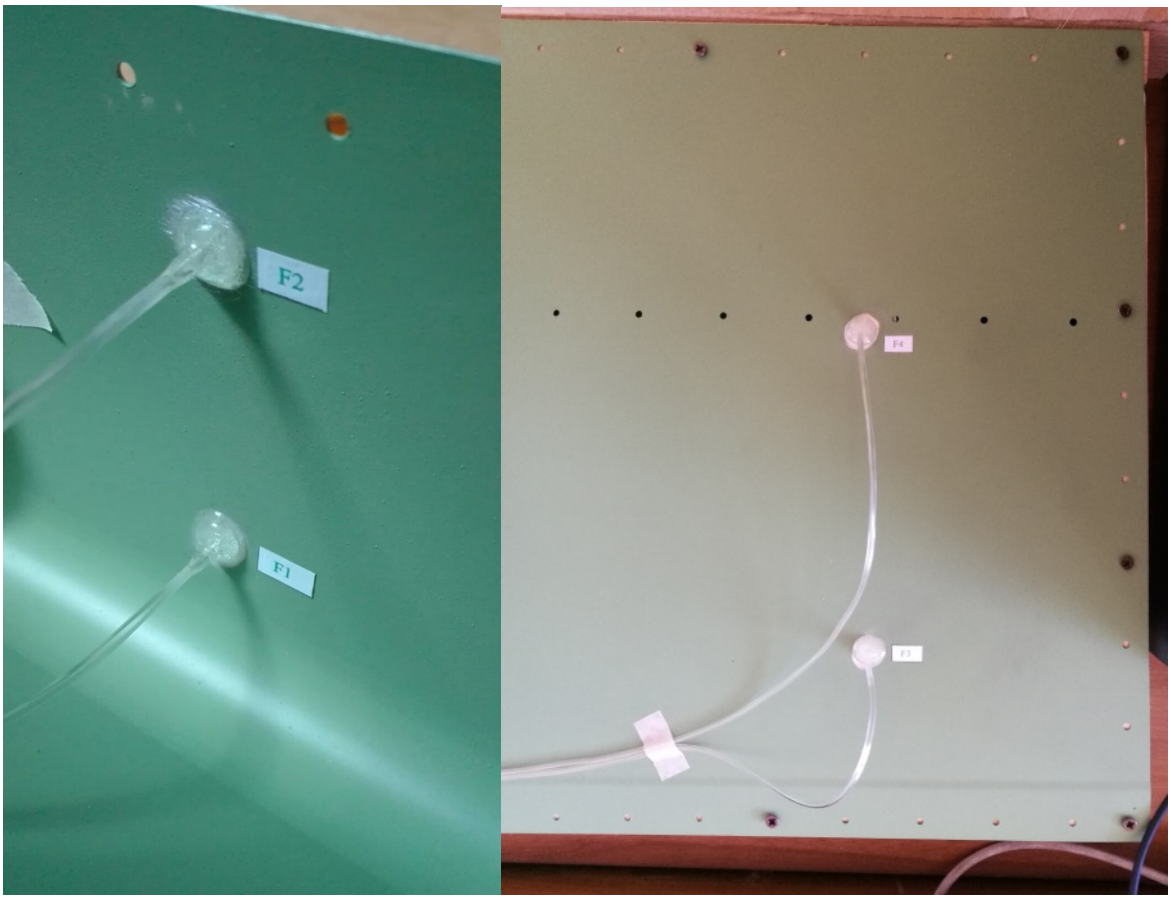



Figure 24 – Section F, y=1500mm, pressure taps installed

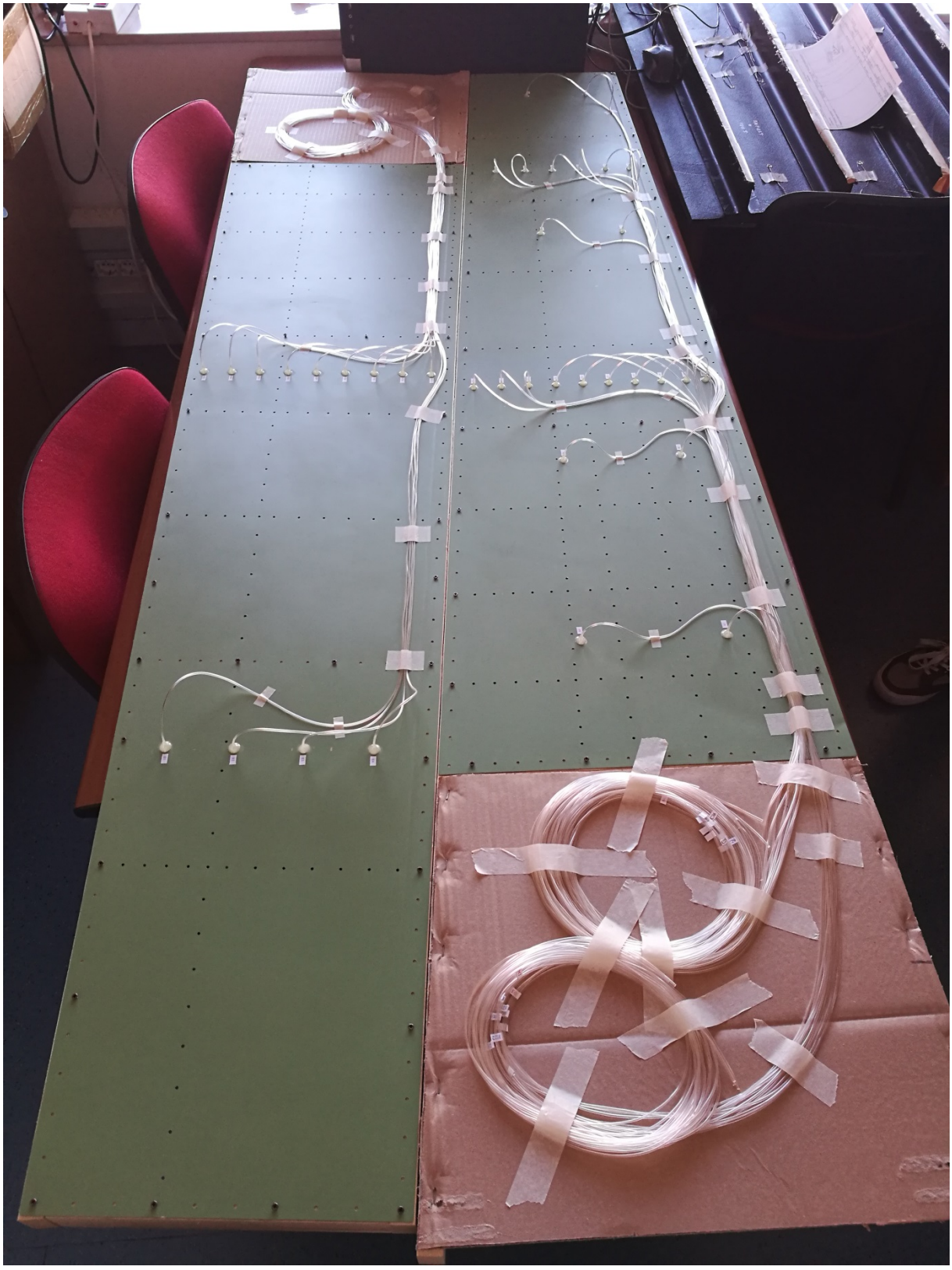


Figure 25 –Pressure taps installed on the upper and lower skin

# 1 STRAIN GAUGES INSTALLATION

Twenty-five (16 unidirectional plus 3 rosettes with 3 signals) strain gauges have been installed on the wing model, as summarized in Figure 26 and Table 2. Rosettes are depicted in bold font.

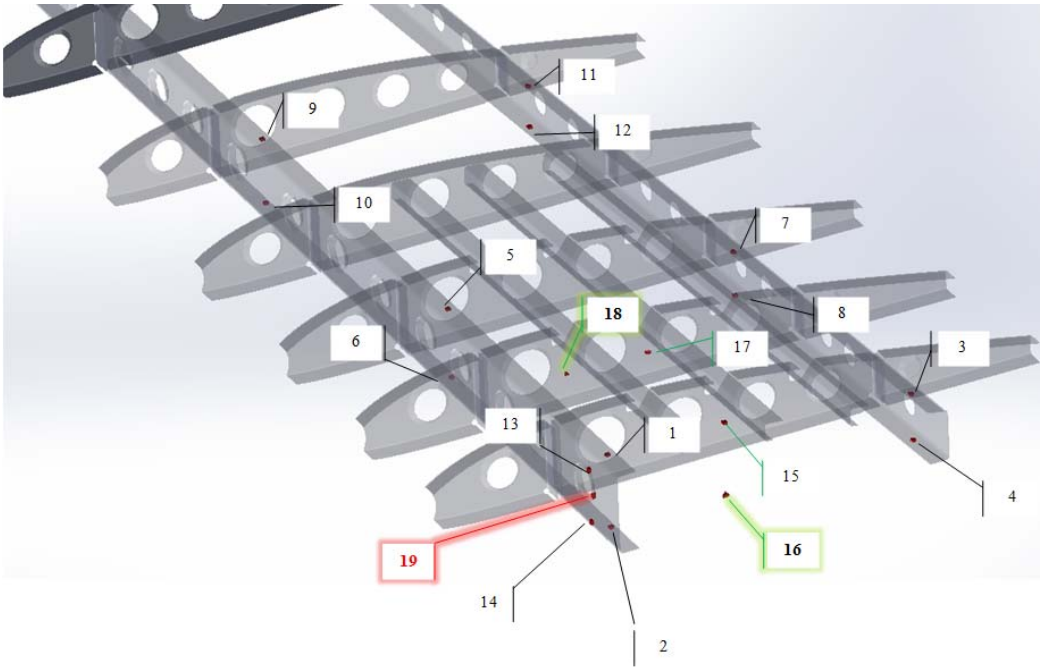



Figure 26 – Strain gauges installation, 15 on the spars, 4 on the skin.

Due to installation issues, the final reference position of the strain gauges is summarized in Table 2.

Table 2 – Strain gauges locations number, number and type

| ID | Bay | POSITION | INSTALLATION | TYPE | y (mm) | eta |
|---|---|---|---|---|---|---|
| 1 | 1 | between rib1-rib2 | front spar | UNIDIRECTIONAL | 35.5 | 0.025 |
| 2 | 1 | between rib1-rib2 | front spar | UNIDIRECTIONAL | 35.5 | 0.025 |
| 3 | 1 | between rib1-rib2 | rear spar | UNIDIRECTIONAL | 35.5 | 0.025 |
| 4 | 1 | between rib1-rib2 | rear spar | UNIDIRECTIONAL | 35.5 | 0.025 |
| 5 | 3 | between rib3-rib4 | front spar | UNIDIRECTIONAL | 310 | 0.194 |
| 6 | 3 | between rib3-rib4 | front spar | UNIDIRECTIONAL | 310 | 0.194 |
| 7 | 3 | between rib3-rib4 | rear spar | UNIDIRECTIONAL | 297 | 0.194 |
| 8 | 3 | between rib3-rib4 | rear spar | UNIDIRECTIONAL | 297 | 0.194 |
| 9 | 5 | between rib5-rib6 | front spar | UNIDIRECTIONAL | 600 | 0.391 |
| 10 | 5 | between rib5-rib6 | front spar | UNIDIRECTIONAL | 600 | 0.391 |
| 11 | 5 | between rib5-rib6 | rear spar | UNIDIRECTIONAL | 598 | 0.391 |
| 12 | 5 | between rib5-rib6 | rear spar | UNIDIRECTIONAL | 598 | 0.391 |
| 13 | 1 | between rib1-rib2 | front spar thickening | UNIDIRECTIONAL | 35.5 | 0.025 |
| 14 | 1 | between rib1-rib2 | front spar thickening | UNIDIRECTIONAL | 35.5 | 0.025 |
| 15 | 1 | 1stbay, between 1st and 2nd stringer | Upper Skin | UNIDIRECTIONAL | 35.5 | 0.025 |
| 16 | 1 | 1stbay, correspondence to UD N.15 | Lower Skin | ROSETTE-3SIGNAL | 35.5 | 0.025 |
| 17 | 2 | 2ndbay, between 1st and 2nd stringer | Upper Skin | UNIDIRECTIONAL | 169 | 0.106 |
| 18 | 2 | 2ndbay, between 2nd and 3rd stringer | Upper Skin | ROSETTE-3SIGNAL | 169 | 0.106 |
| 19 | 1 | between rib1-rib2 | front spar | ROSETTE-3SIGNAL | 35.5 | 0.025 |

The strain gauges aim to provide the following measurements:

- Strain gauges from 1 to 12 (**unidirectional**) located on the front and rear spar caps provide information on how bending moment is differently absorbed by the spars, along spanwise (3 different wing sections).
- Strain gauges 13 and 14 (**unidirectional**) give information on the efficiency of increased stiffness provided by the thickening of the front spar.
- **Rosette 19** (**0°-45°-90° directions**) allows measuring the complete state of strain of the shear web, including possible diagonal tension state.
- Strain gauges and rosettes from 15 to 18 (**unidirectional**), placed on the upper (**unidirectional 15, 17 and rosette 18**) and lower (**rosette 16**) wing skin, monitor tension (compression, traction) levels and eventual panel instability occurring close to the wing root.

In particular, according to the customer, after numerical simulations, rosette n. 16 and 18 have been added in order to better evaluate stringers stiffening and panel instability.

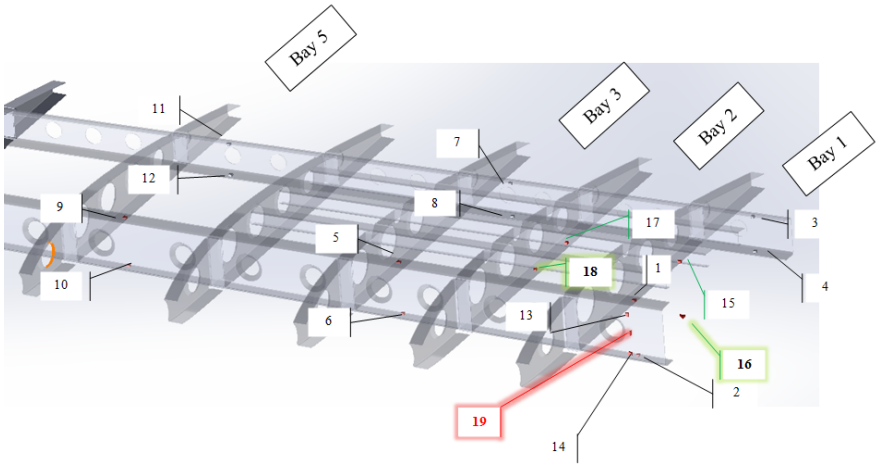



Figure 27 – Strain gauges installation, 15 on the spars, 4 on the skin, bays.

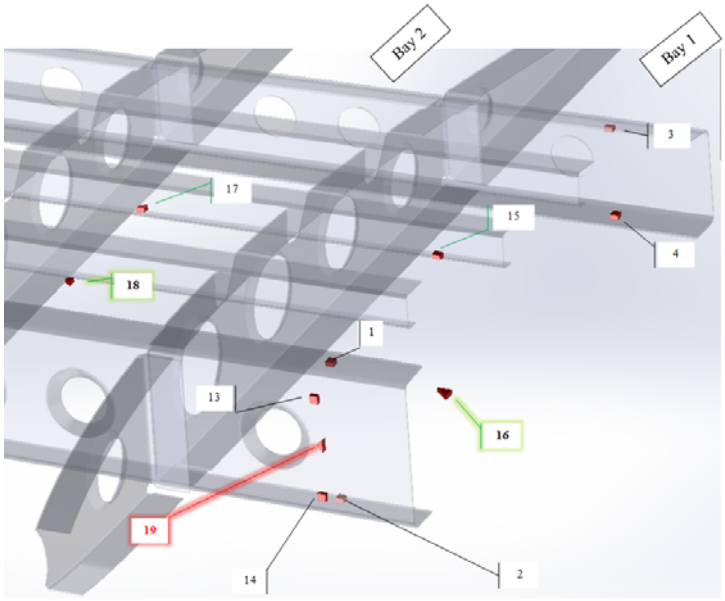



Figure 28 – Strain gauges installation, 15 on the spars, 4 on the skin, bays 1 and 2.

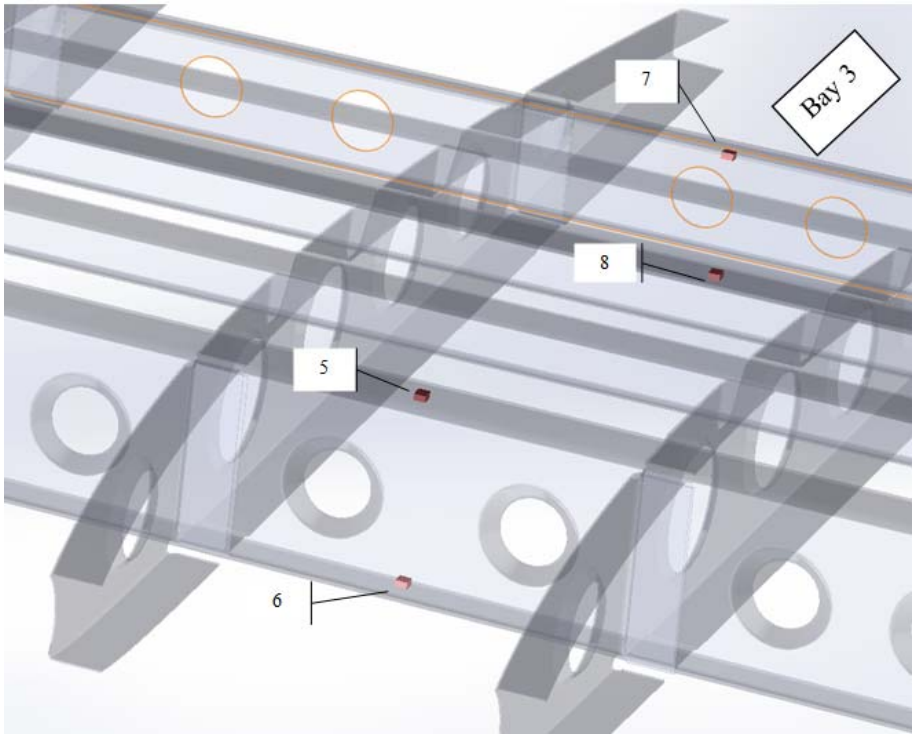



Figure 29 – Strain gauges installation, 15 on the spars, 4 on the skin, bay 3.

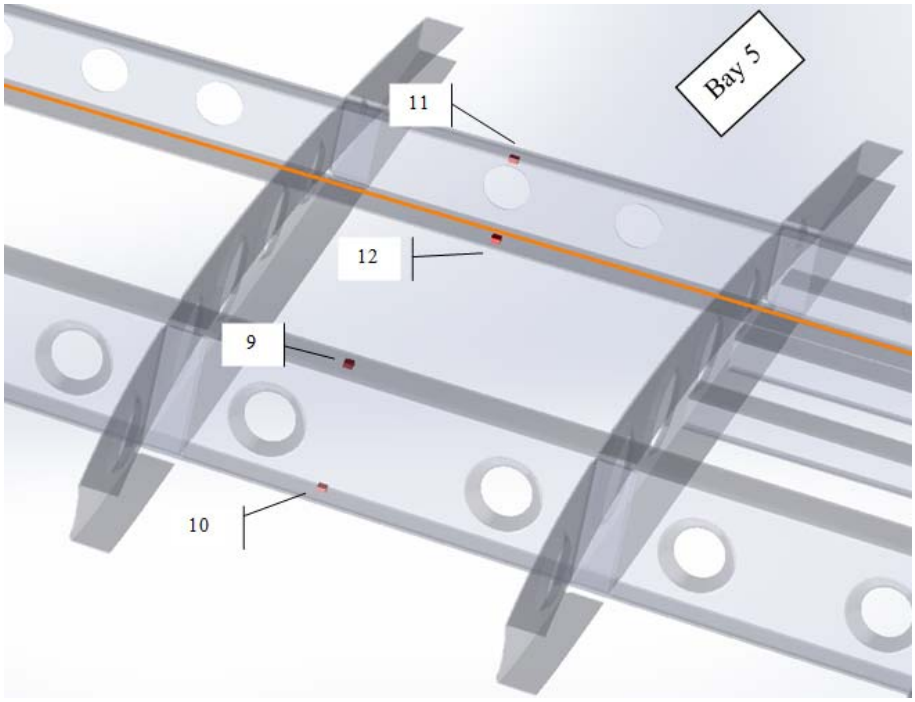



Figure 30 – Strain gauges installation, 15 on the spars, 4 on the skin, bay 5.

The Strain gauges installed are:

- Uniaxial Tokyo Sokki Kenkyujo FLA-3-23-5LT
- Rosette Tokyo Sokki Kenkyujo FRA-3-23-5LT

Additional equipments used during installation are:

- Sanding Handpads
- MicroMeaasurements M-PREP Neutralizer 5A
- MicroMeaasurements M-PREP Conditioner 5A
- MicroMeasurements M-BOND 200 (Glue)
- MicroMeasurements 200 Catalyst C
- MicroMeasurements M-COAT A (Sealant)

The Installation is briefly described below synthetizing several phases needed for effective operation of strain gauges:

1. Cleaning of support surfaces (Figure 31) and equipments using the neutralizer;
2. Sanding of the aluminum surface around the prefixed location of SGs (Figure 32);
3. Preparation of the position and alignment of SG axes;
4. Application of the masking for delimiting the area around SG location (Figure 33);
5. Preparation of the delimited surface using conditioner and neutralizer;
6. Application of the sensor on the surface:
    - Positioning;
    - Catalyst application on the upper surface of the SG waiting 60 seconds before glue application;
    - Installation of the SG (Figure 34) through glue application and a 150 seconds hand pressing (Figure 35);
7. Preparation and application of Sealant (the masking is now removed);
8. Verification of electrical resistance of SGs (The resistance depends on the nominal resistance of the SG (120Ω), the uncertainty declared by manufacturer (0.5% of nominal value) and the cables resistance). Results according to measurements are reported in Table 3.

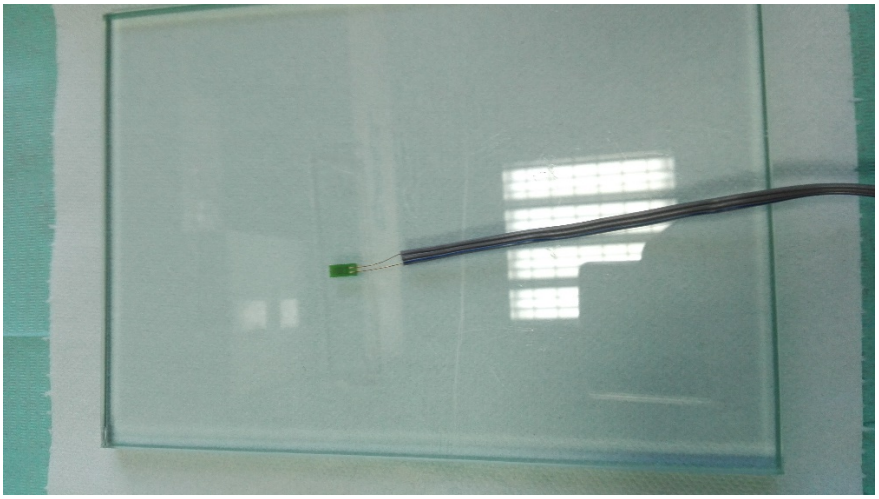


Figure 31 – Support surface for the preparation of SG before installation.


Figure 32 – Sanding of the aluminum surface around the location of SGs n. 13, 14 and 19

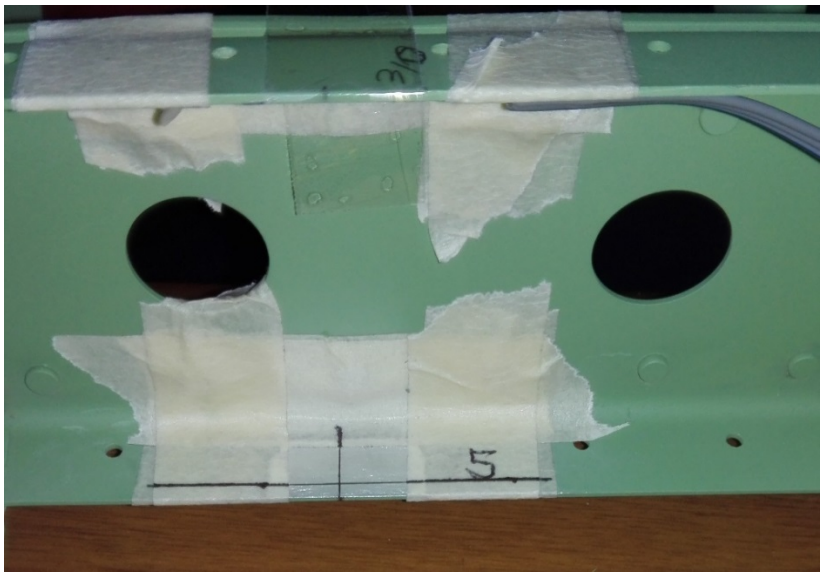



Figure 33 – Application of the masking around the delimited area sanded for the application of SG n. 5

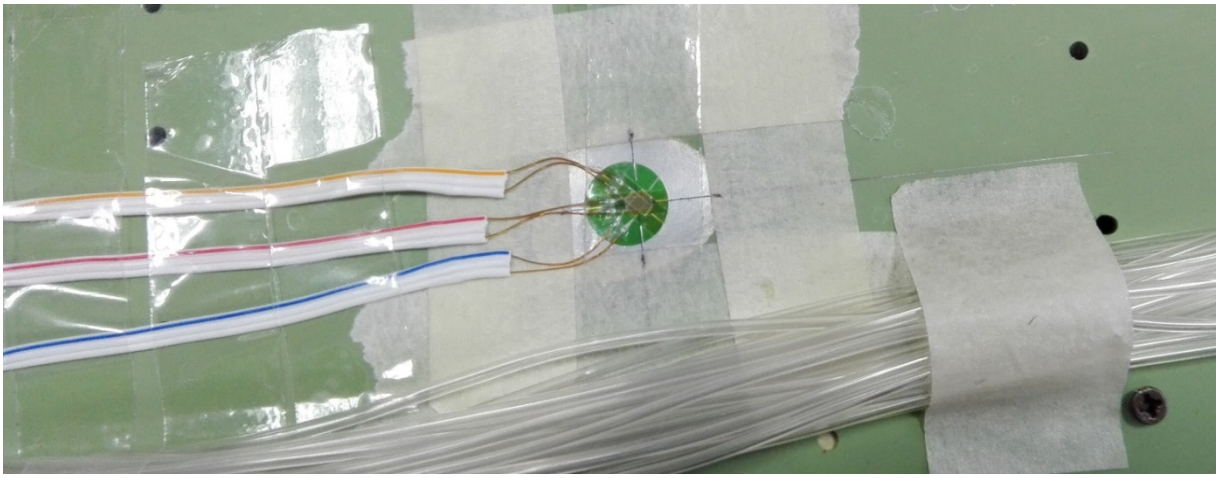


Figure 34 – Installation of SGs 18 on the upper skin.

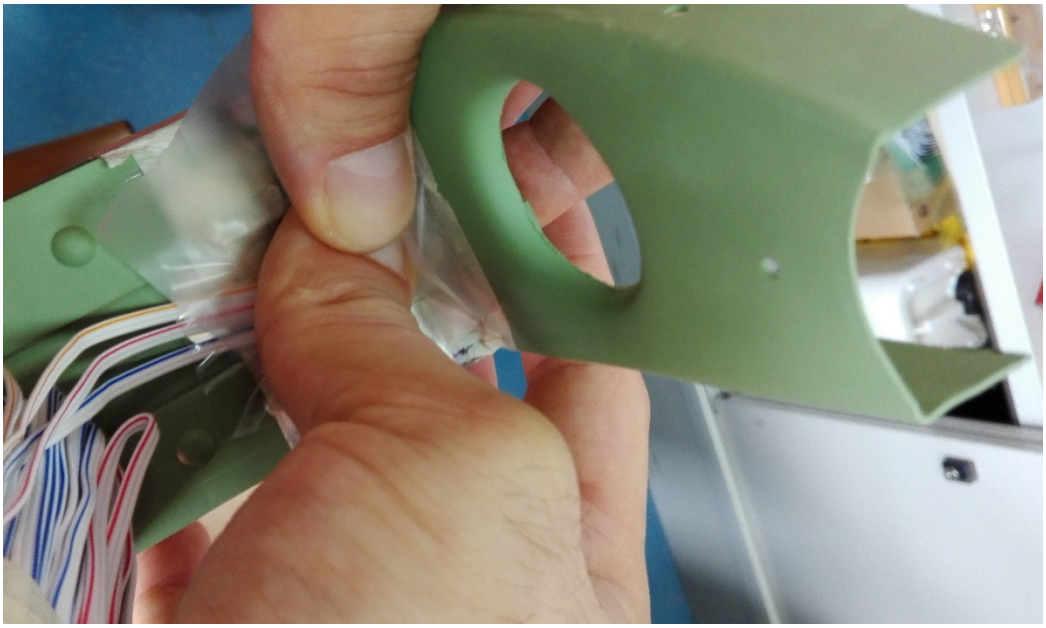


Figure 35 – Hand pressing for the adhesive bonding of the SG on the surface

Table 3 – Measurements of Resistance evaluated on the cable tips.

| ID | Bay | POSITION | INSTALLATION | TYPE | R (Ω) |
|---|---|---|---|---|---|
| 1 | 1 | between rib1-rib2 | front spar | UNIDIRECTIONAL | 121 |
| 2 | 1 | between rib1-rib2 | front spar | UNIDIRECTIONAL | 121.4 |
| 3 | 1 | between rib1-rib2 | rear spar | UNIDIRECTIONAL | 121 |
| 4 | 1 | between rib1-rib2 | rear spar | UNIDIRECTIONAL | 121.6 |
| 5 | 3 | between rib3-rib4 | front spar | UNIDIRECTIONAL | 121 |
| 6 | 3 | between rib3-rib4 | front spar | UNIDIRECTIONAL | 121 |
| 7 | 3 | between rib3-rib4 | rear spar | UNIDIRECTIONAL | 121 |
| 8 | 3 | between rib3-rib4 | rear spar | UNIDIRECTIONAL | 121 |
| 9 | 5 | between rib5-rib6 | front spar | UNIDIRECTIONAL | 120.8 |
| 10 | 5 | between rib5-rib6 | front spar | UNIDIRECTIONAL | 120 |
| 11 | 5 | between rib5-rib6 | rear spar | UNIDIRECTIONAL | 121 |
| 12 | 5 | between rib5-rib6 | rear spar | UNIDIRECTIONAL | 121 |
| 13 | 1 | between rib1-rib2 | front spar thickening | UNIDIRECTIONAL | 121 |
| 14 | 1 | between rib1-rib2 | front spar thickening | UNIDIRECTIONAL | 121 |
| 15 | 1 | 1stbay, between 1st and 2nd stringer | Upper Skin | UNIDIRECTIONAL | 121.2 |
| 16a | 1 | 1stbay, correspondence to UD N.15 | Lower Skin | ROSETTE-1SIGNAL (+45°) | 121.6 |
| 16b | 1 | 1stbay, correspondence to UD N.15 | Lower Skin | ROSETTE-1SIGNAL (0°) | 122 |
| 16c | 1 | 1stbay, correspondence to UD N.15 | Lower Skin | ROSETTE-1SIGNAL (-45°) | 122 |
| 17 | 2 | 2ndbay, between 1st and 2nd stringer | Upper Skin | UNIDIRECTIONAL | 121.2 |
| 18a | 2 | 2ndbay, between 2nd and 3rd stringer | Upper Skin | ROSETTE-1SIGNAL (+45°) | 122.2 |
| 18b | 2 | 2ndbay, between 2nd and 3rd stringer | Upper Skin | ROSETTE-1SIGNAL (0°) | 122.2 |
| 18c | 2 | 2ndbay, between 2nd and 3rd stringer | Upper Skin | ROSETTE-1SIGNAL (-45°) | 121.6 |
| 19a | 1 | between rib1-rib2 | front spar | ROSETTE-1SIGNAL (+45°) | 121.8 |
| 19b | 1 | between rib1-rib2 | front spar | ROSETTE-1SIGNAL (0°) | 121.8 |
| 19c | 1 | between rib1-rib2 | front spar | ROSETTE-1SIGNAL (-45°) | 121.8 |

An overview of the position of several SGs installed on the front and rear spar is depicted in Figure 37. Position and working directions of SGs of the rosette n.19 installed on the front spar web are described in Figure 38. Position and working directions of SGs and rosette n.18 installed on the upper skin are shown in Figure 39. Finally, position and working directions of rosette n. 16 installed on the lower skin are detailed in Figure 40. It has to be point out that all strain gauges installed on the skin are bonded on the y station respectively reported in Table 2 and centerline of the bay identified by the stiffeners along x direction. Finally, (x, y) coordinates of strain gauges 15 and 16b are the same.

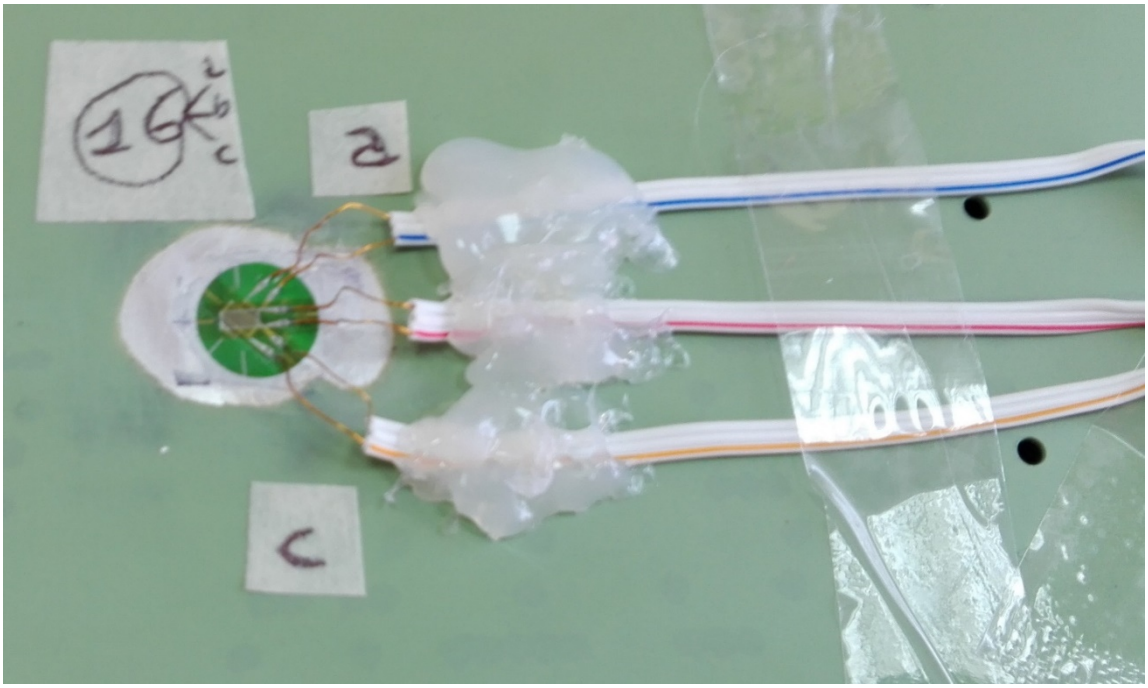



Figure 36 – Hand pressing for the adhesive bonding of the SG on the surface

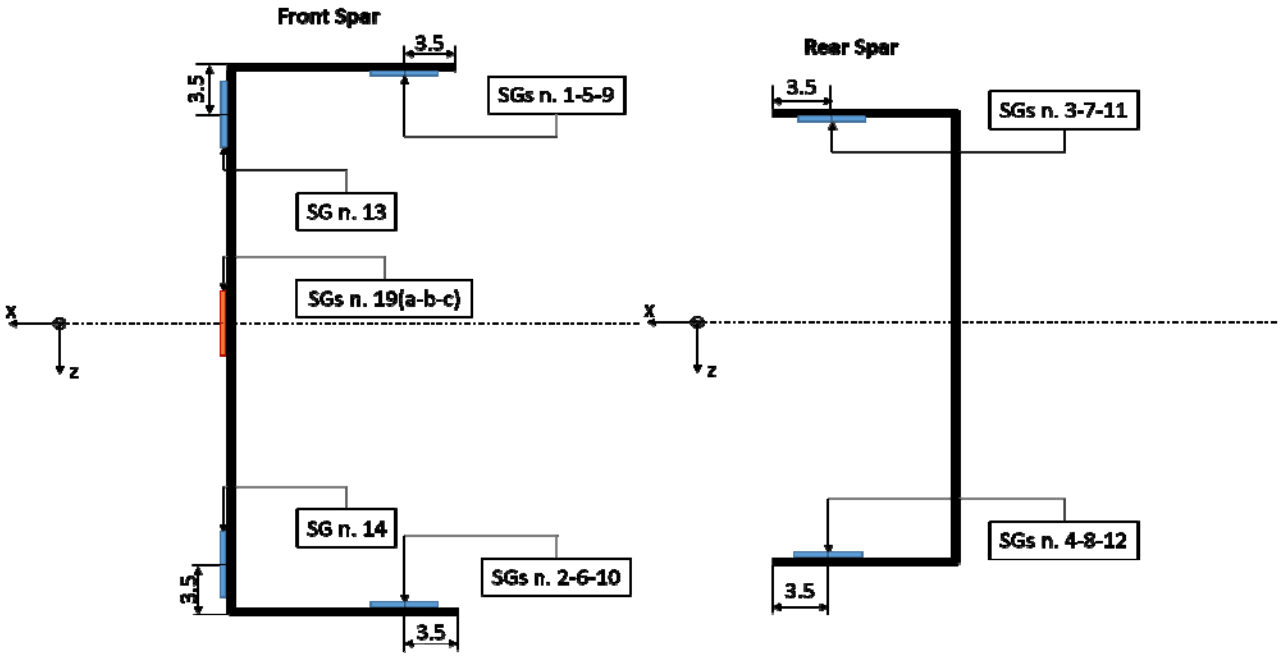



Figure 37 – Position of uniaxial SGs (blue elements) and rosette (orange element) installed on the spars. Distance reported are in [mm].

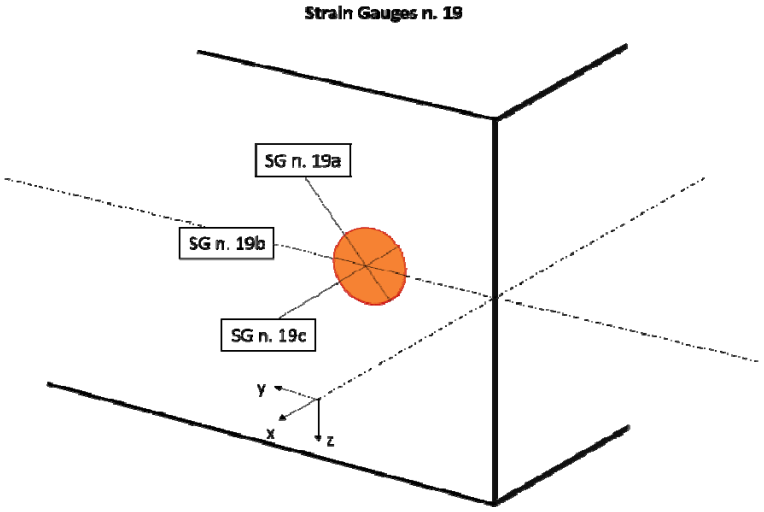



Figure 38 – Position of rosette n.19 (orange element) installed on the web of the front spar.

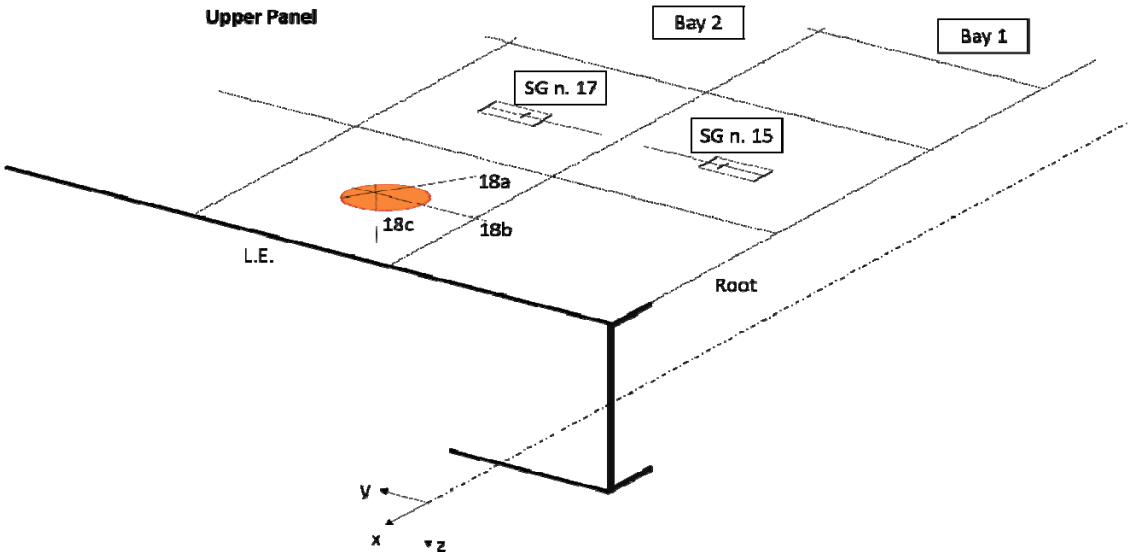



Figure 39 – Position of SGs (white elements) and rosette (orange element) installed on the upper skin.

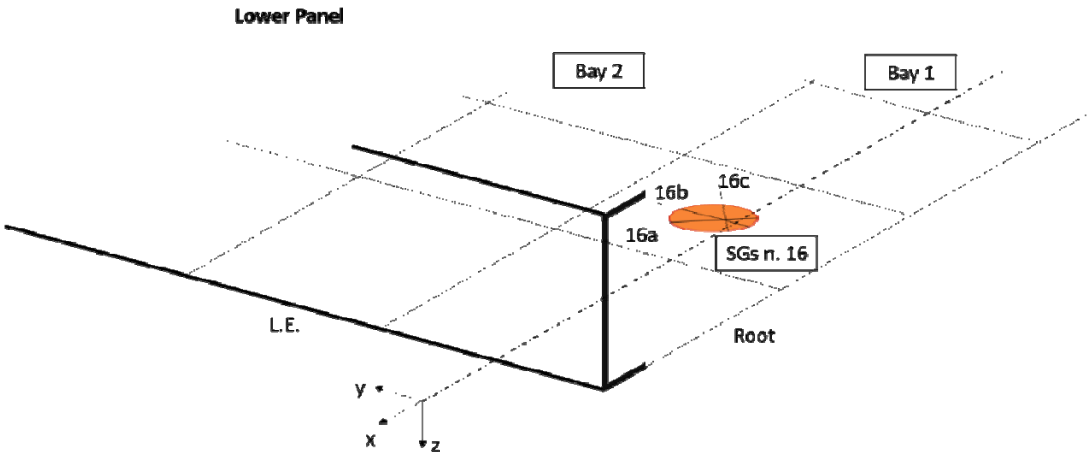



Figure 40 – Position of rosette n.16 (orange element) installed on the lower skin.

Details of the strain gauges installed on the wing internal structure and on the wing skin are shown in Figure 41 to Figure 43.

Figure 41 – Strain gauges installed on the internal structure.

Figure 42 – Details of strain gauges installed on the internal structure.

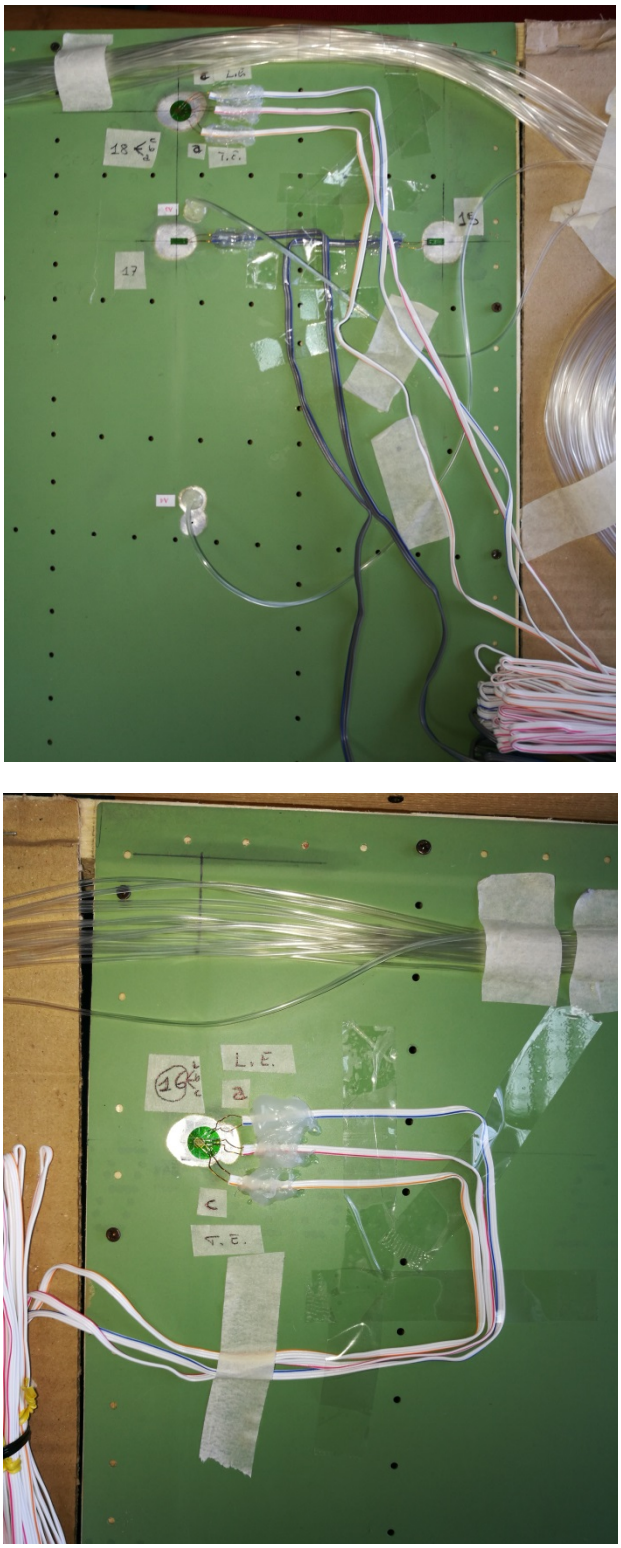



**Figure 43 – Details of strain gauges installed on the upper (up) and lower skin.**

# 2 ASSEMBLY AND WIRING

The model assembly has followed the steps shown in Figure 44. First the lower skin has been positioned on the internal structure and partially riveted, then the trailing edge has been positioned and riveted on the lower skin. Subsequently the leading edge skin has been positioned, wiring all the tubes and wires. Finally the upper skin has been positioned from the top and the finally riveted with all the others components. All the steps are presented from Figure 45 to Figure 68.

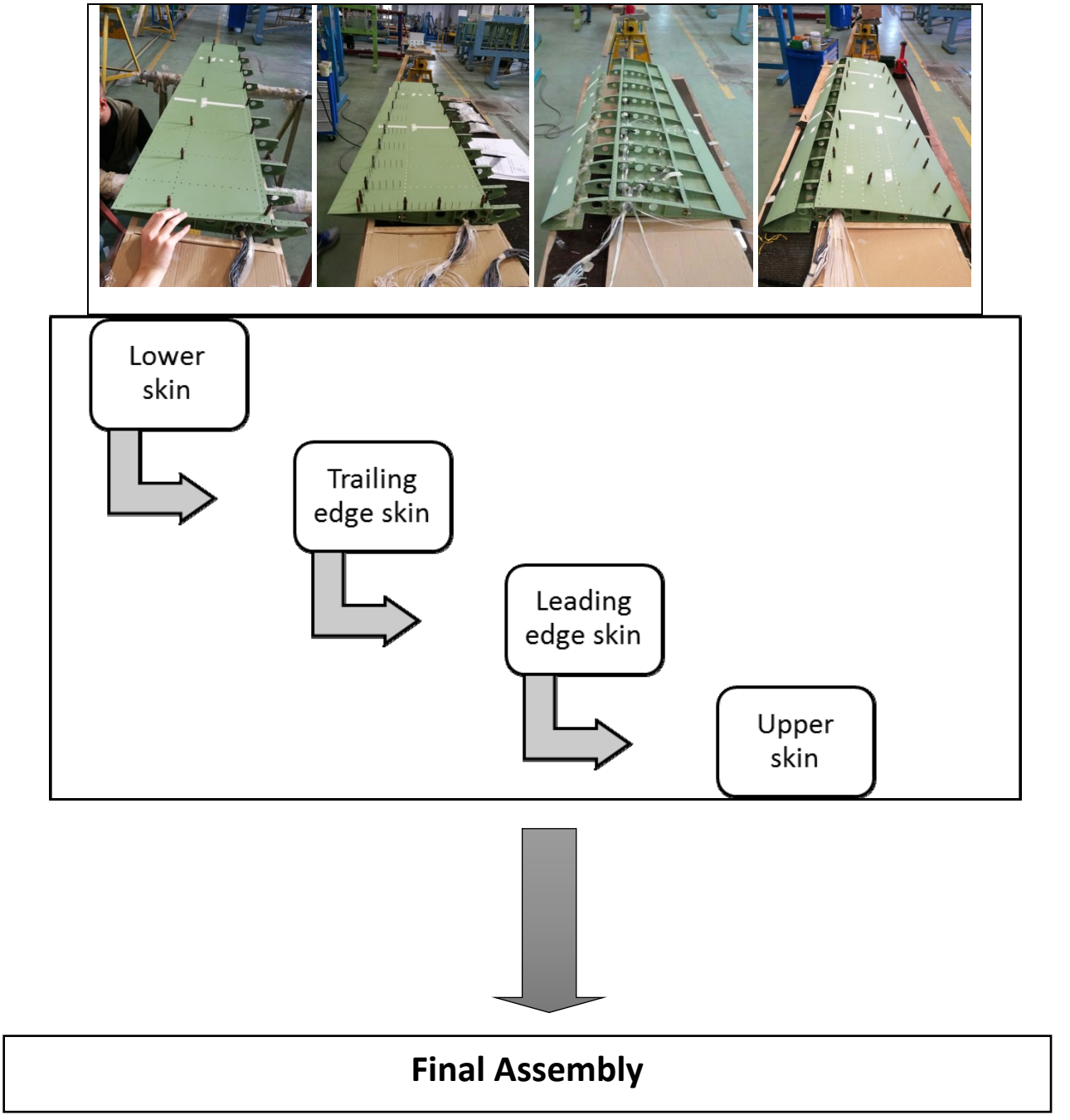



Figure 44 – Final model assembly schema

**LOWER SKIN** POSITIONING, WIRING, RIVETING

Figure 45 – Lower skin wiring

Figure 46 – Lower skin positioning

Figure 47 – Lower skin riveted on the wing box ribs

Figure 48 – Lower skin final configuration (detail of cables)

**TRAILING EDGE SKIN** POSITIONING, WIRING, RIVETING

Figure 49 – Trailing edge skin positioning

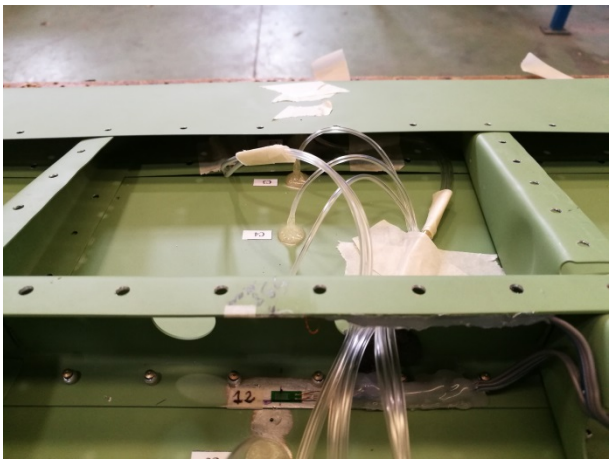


Figure 50 – Lower skin wiring, detail of SG 12 and pressure taps

Figure 51 – Trailing edge riveting

Figure 52 – Trailing edge riveting and final configuration

**LEADING EDGE SKIN** POSITIONING, WIRING

Figure 53 – Leading edge skin positioning

Figure 54 – Leading edge skin wiring

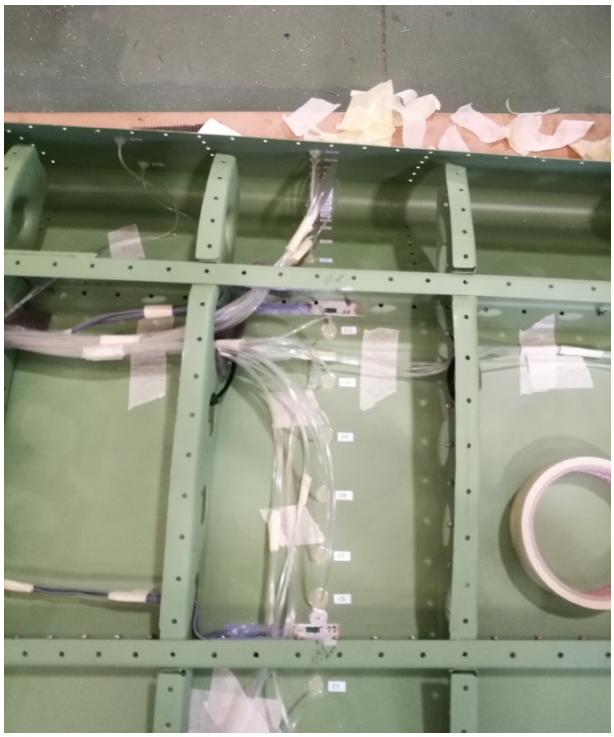


Figure 55 – Leading edge wiring details of cables

Figure 56 – Leading edge skin wiring

**LEADING EDGE SKIN** POSITIONING, WIRING

Figure 57 – Upper skin stringers positioning, wiring

Figure 58 – Upper skin positioning from the top

Figure 59 – Upper skin wiring root

Figure 60 – Upper skin wiring tip

**UPPER SKIN** POSITIONING, WIRING, RIVETING

Figure 61 – Upper skin from the top

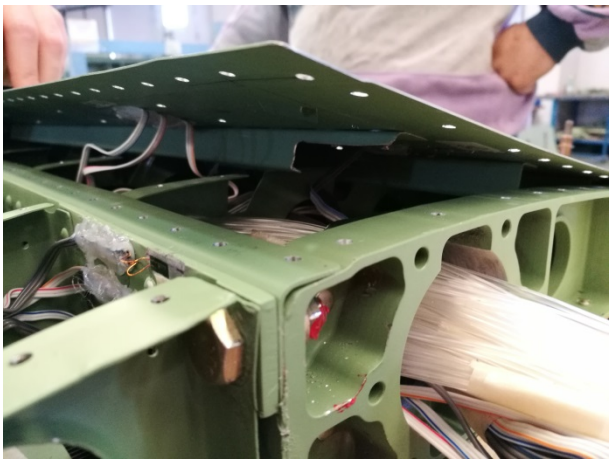


Figure 62 – Upper skin positioning, detail of first stringer cutting

Figure 63 – Upper skin positioning

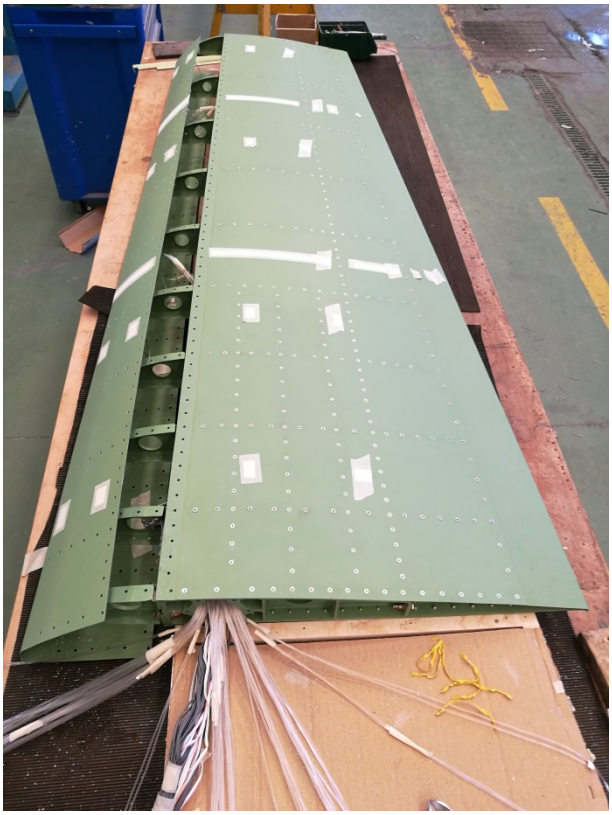


Figure 64 – Upper skin riveting

**FINAL ASSEMBLY** POSITIONING, WIRING, RIVETING

Figure 65 – Leading edge skin last part to be riveted

Figure 66 – Leading edge skin positioning, top view

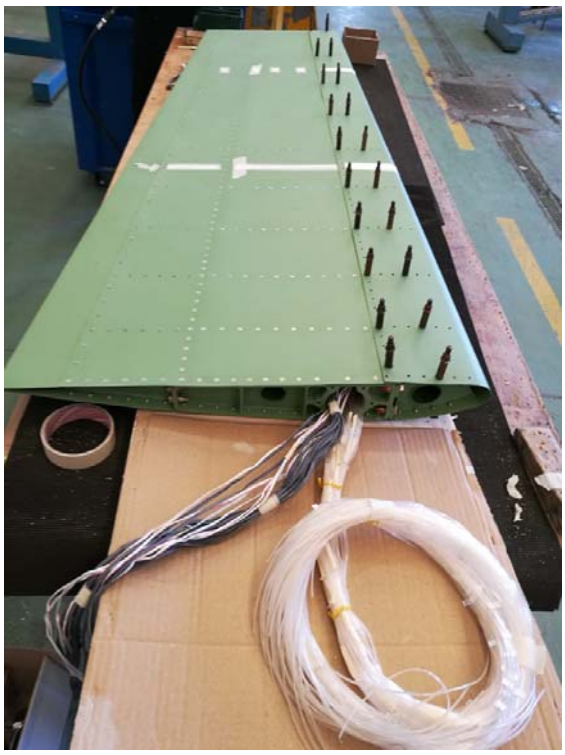


Figure 67 – Leading edge positioning, bottom view

Figure 68 – Leading edge skin final riveting

# 3 PAINTING

The final assembled model has been plastered and painted in order to avoid any rivets and skin gaps and discontinuities, as shown in Figure 69.

Figure 69 – Wing model painting phases

After complete painting the model is presented in figures below.

# 4 MODEL VERIFICATION AND RECONSTRUCTION

The model geometry has been also reconstructed through a **HEXAGON metrology electronic harm,** see Figure 70**.**

**Figure 70 – Wing model in the metrology room, HEXAGON metrology harm**

Pressure taps instrumented sections plus root and tip section have been measured, total number of 8 wing sections. The final measurements have been done on the model painted.

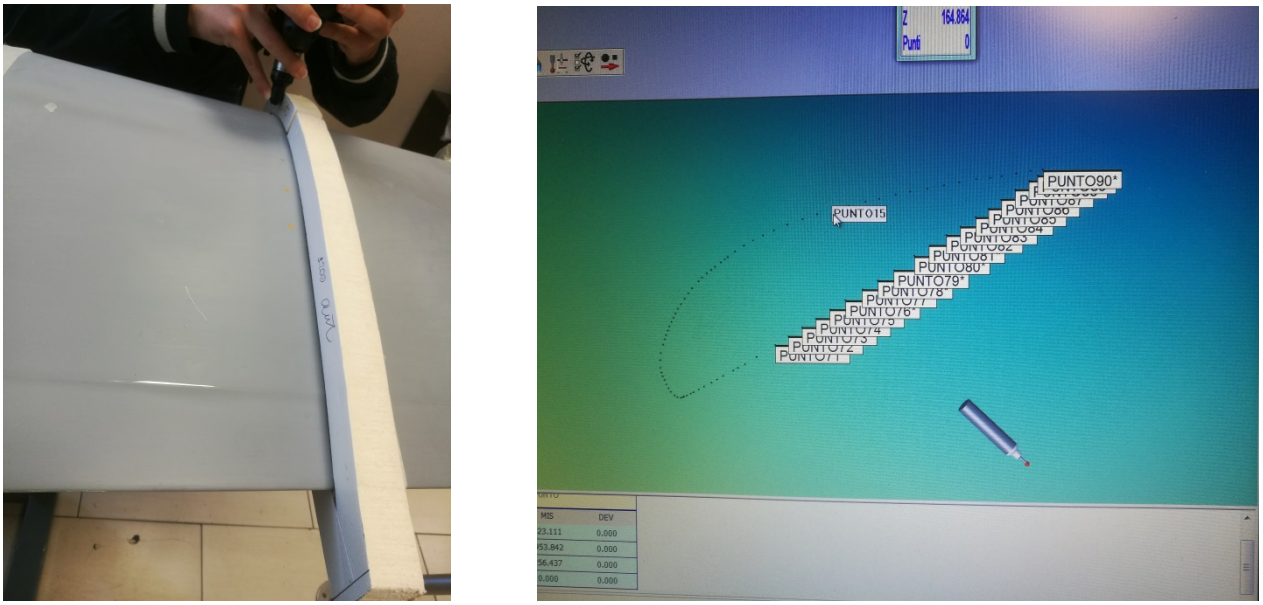



**Figure 71 – Wing model section reconstruction with HEXAGON metrology harm.**

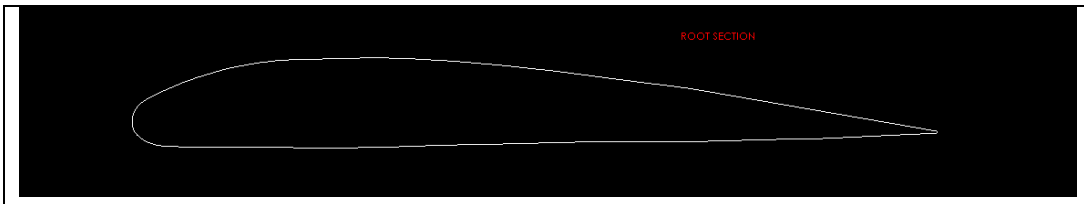
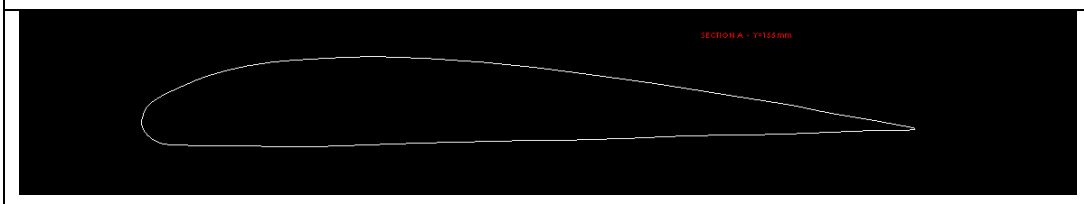
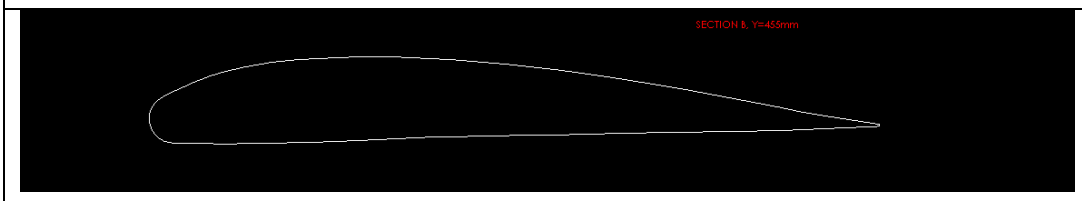
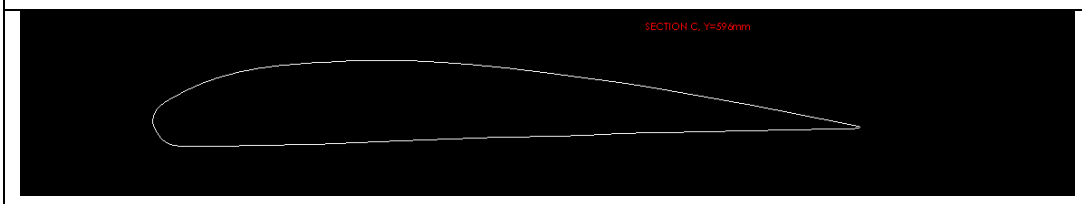
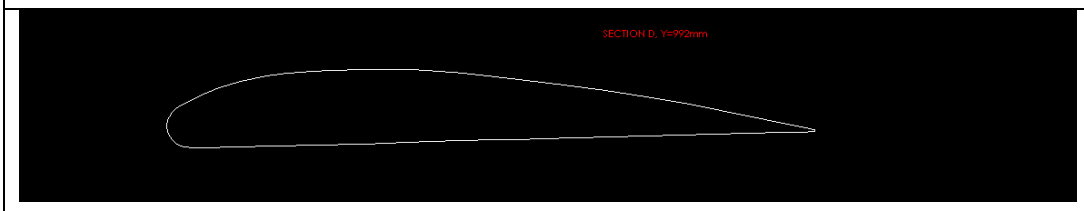
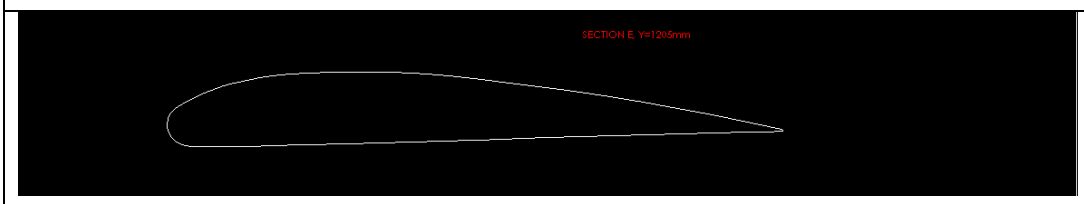
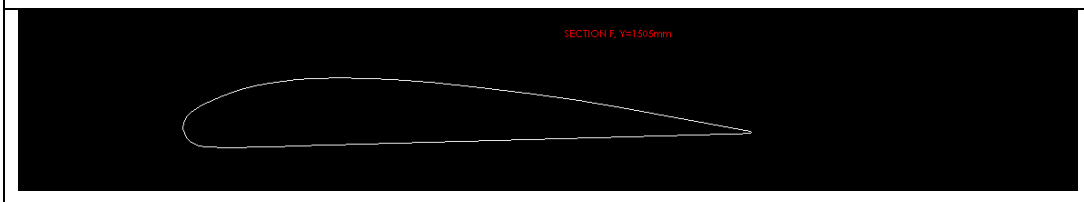
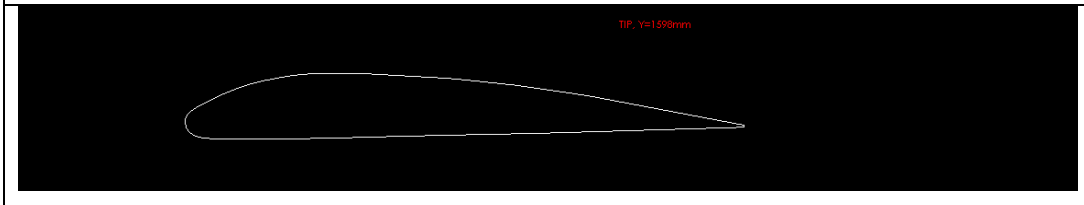
| | |
|---|---|
|  | ROOT |
|  | Y=155mm |
|  | Y=455mm |
|  | Y=596mm |
|  | Y=992mm |
|  | Y=1205mm |
|  | Y=1505mm |
|  | Y=1598mm |

**Figure 72 – Wing model reconstructed sections**

# 5 MODEL WIND TUNNEL INSTALLATION

The ultimate wing model has been installed in the UNINA main wind tunnel facility of the Department of Industrial Engineering. Some verification has been performed in order to evaluate the instrumentations functionalities.

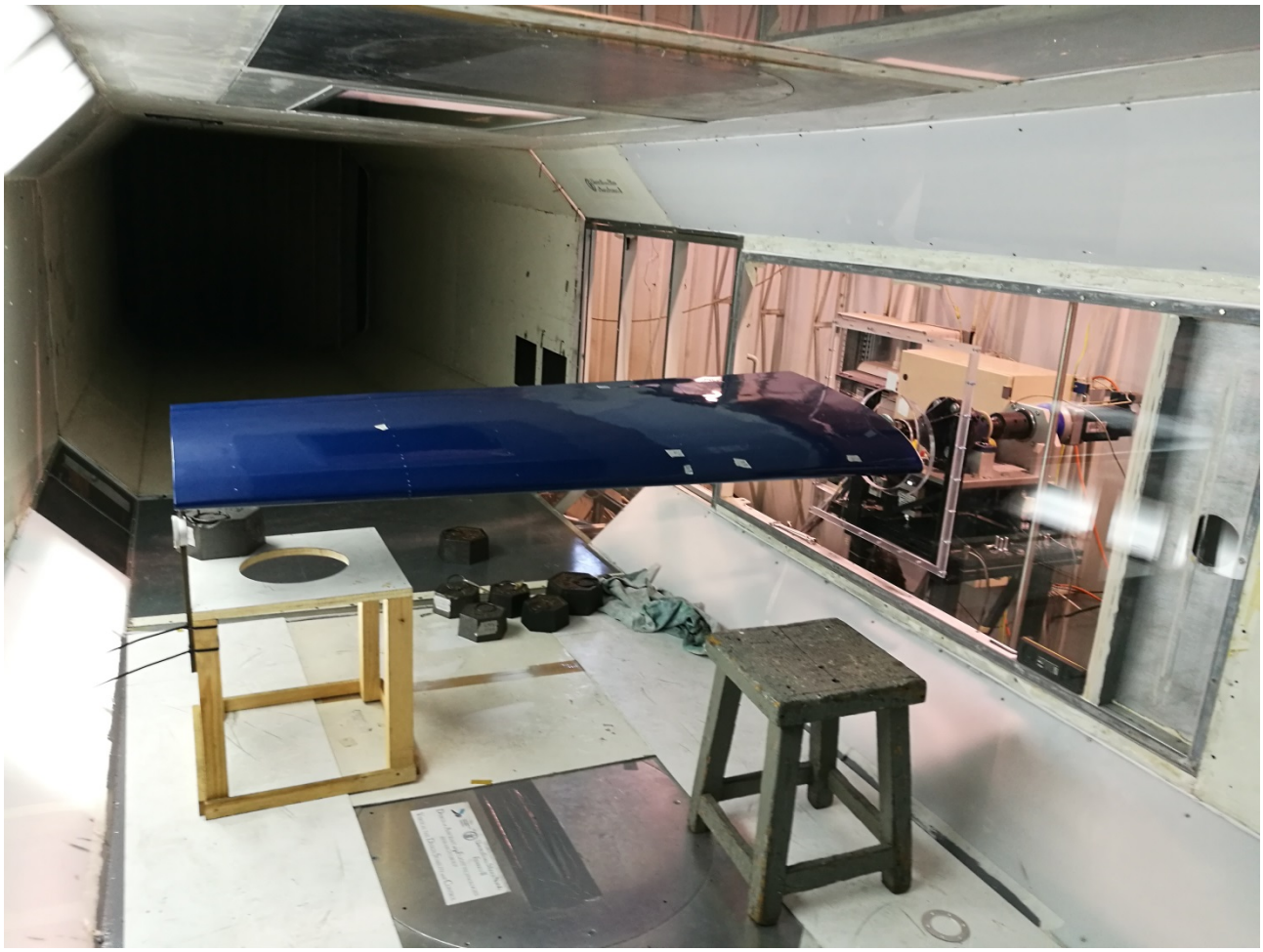


Figure 73 – Wing model in the UNINA wind tunnel facility.

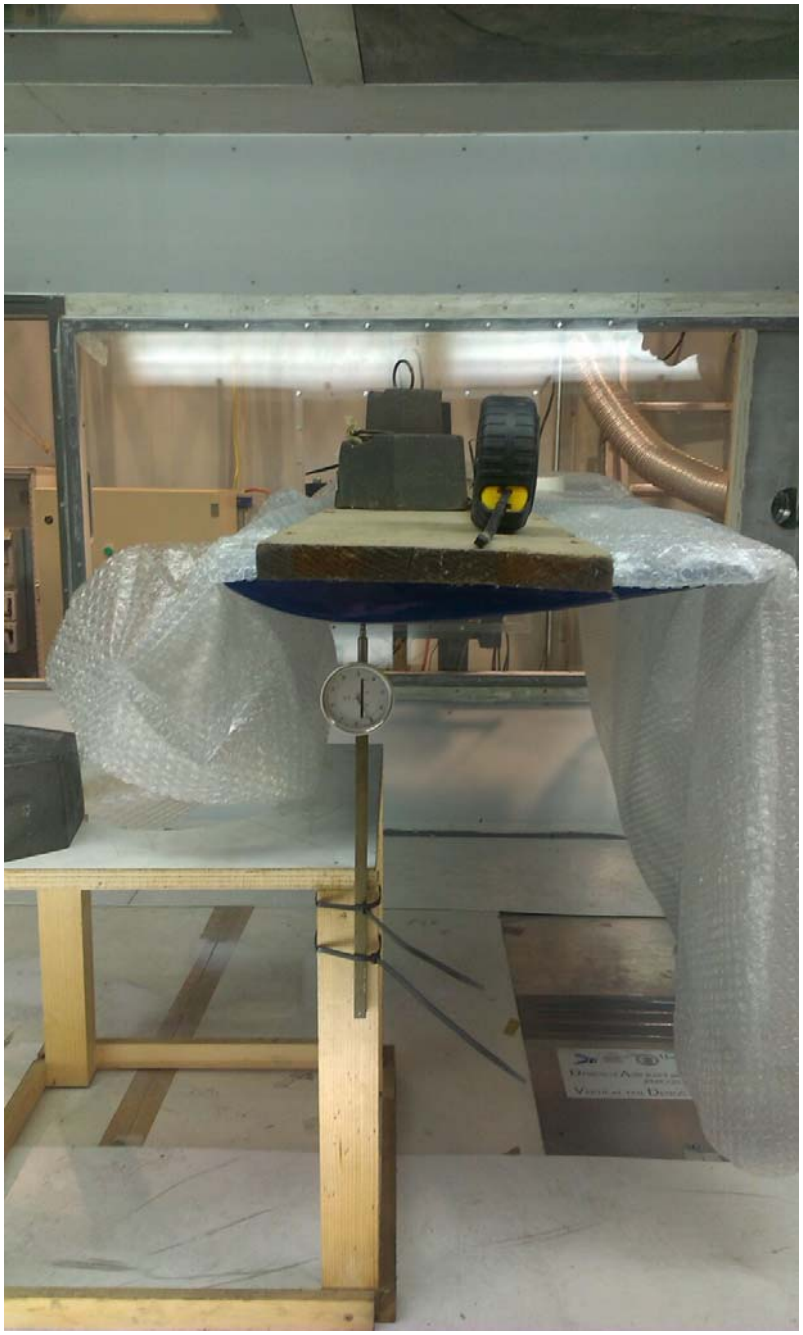


Figure 74 – Wing model in the UNINA wind tunnel facility, static loads test.