An open database for benchmarking guided waves SHM algorithms on a composite full scale outer wing demonstrator

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Outline

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3. **Data pre-processing**
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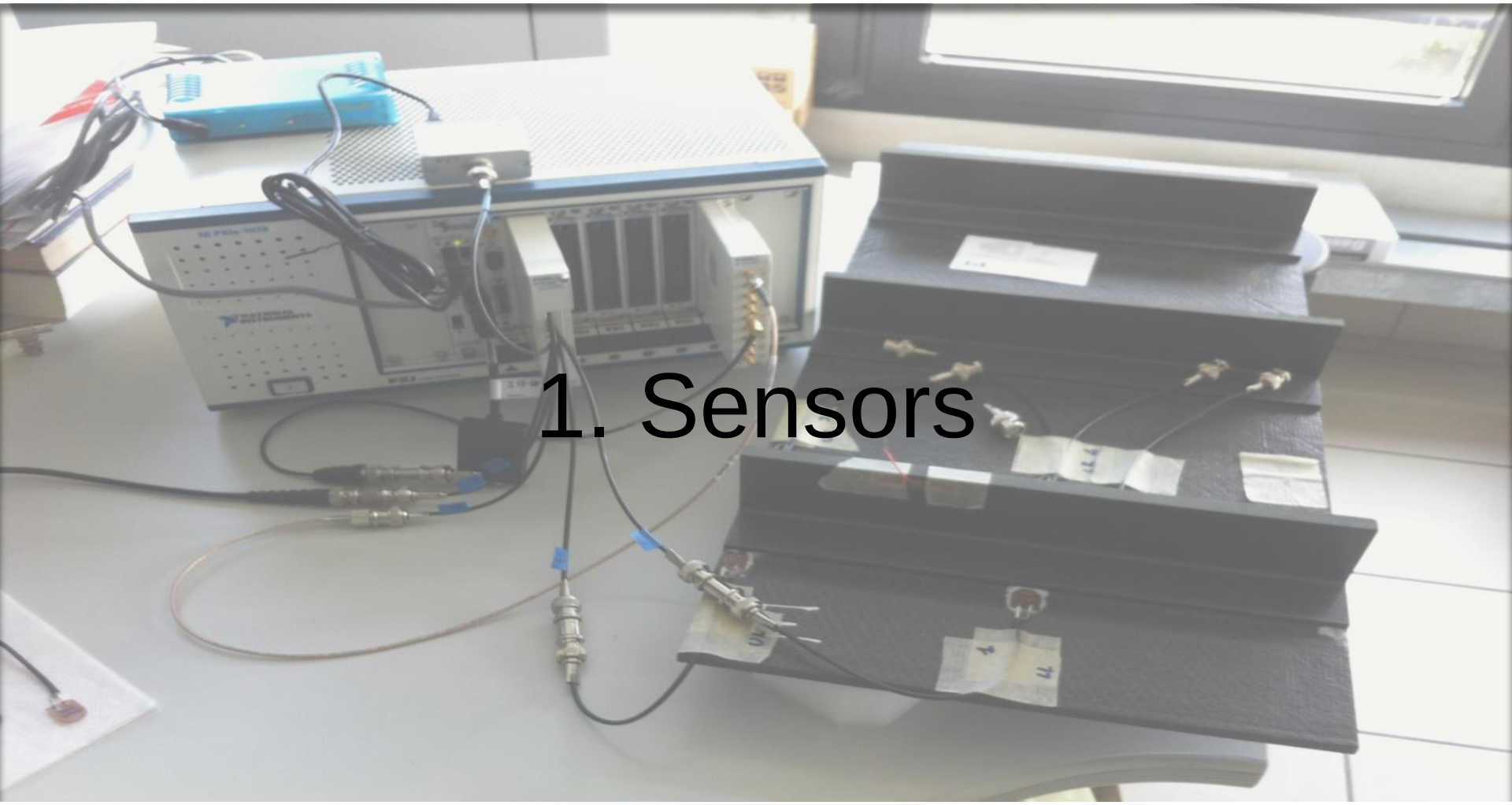
   - B, S and C-scan



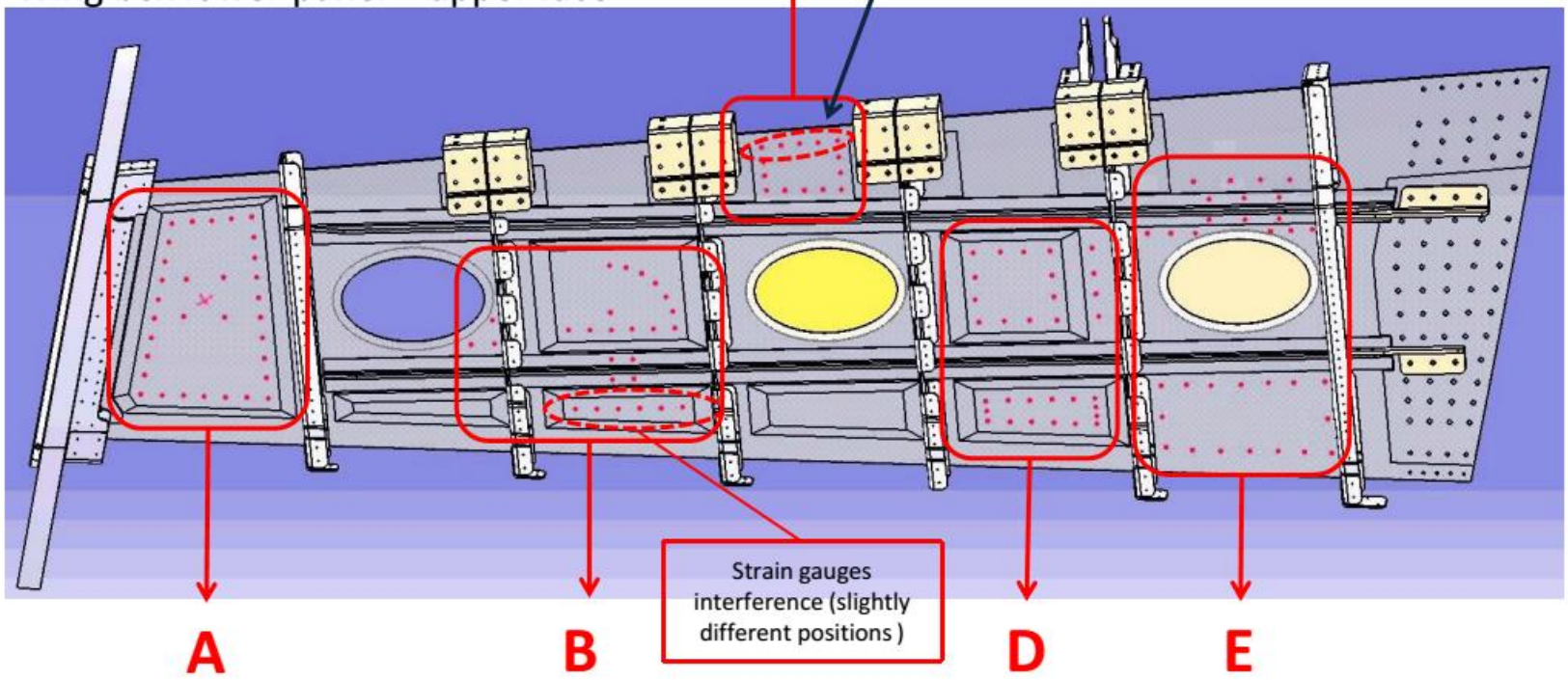
1. Sensors

Sensors grouping

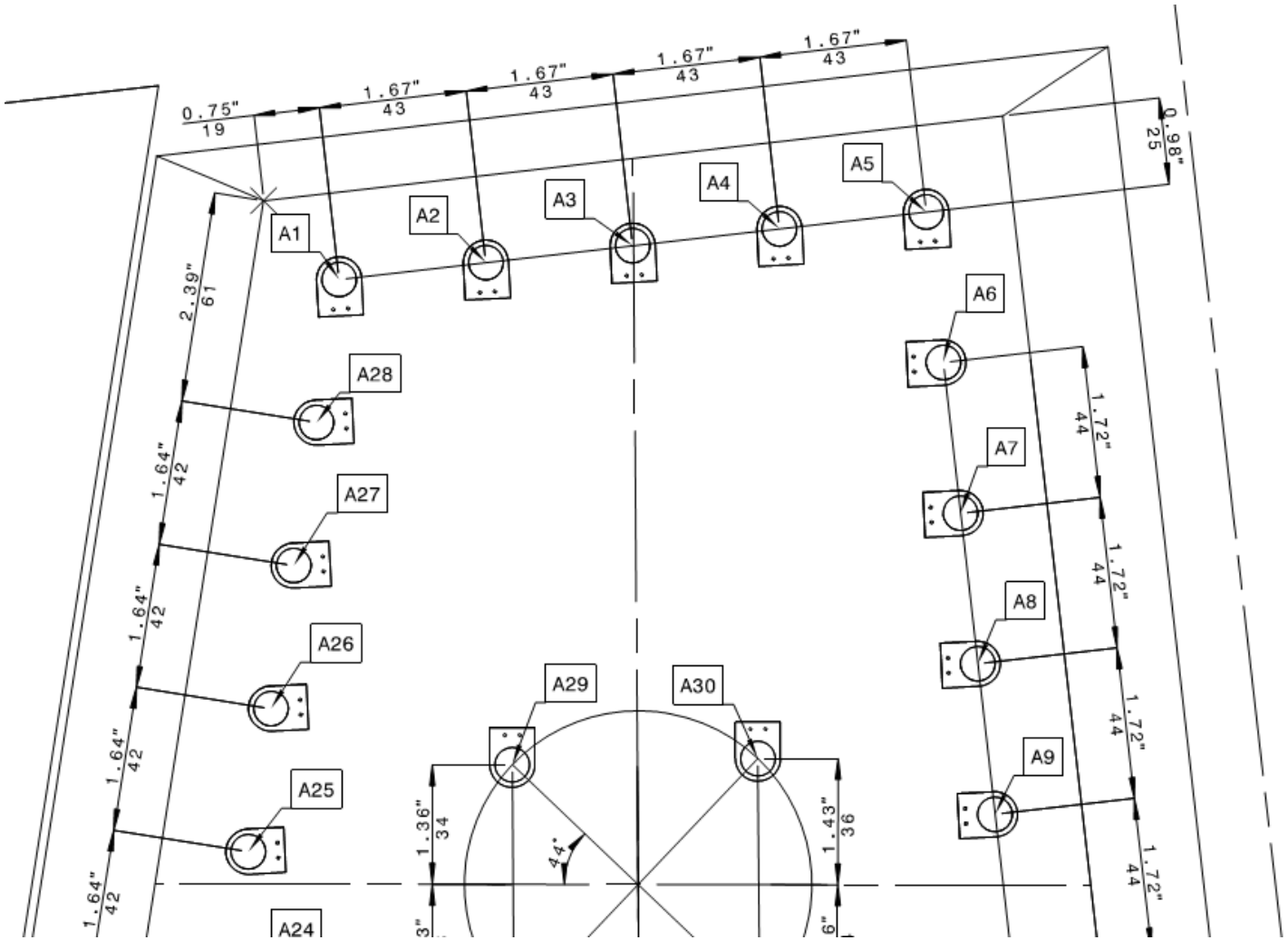
Sensors are grouped in 5 groups

- A1, A2, ..., A32, for a total of 32 sensors
- B1, B2, ..., B26, for a total of 26 sensors
- C1, C2, ..., C12, for a total of 12 sensors
- D1, D2, ..., D31, for a total of 31 sensors
- E1, E2, ..., E32, for a total of 32 sensors

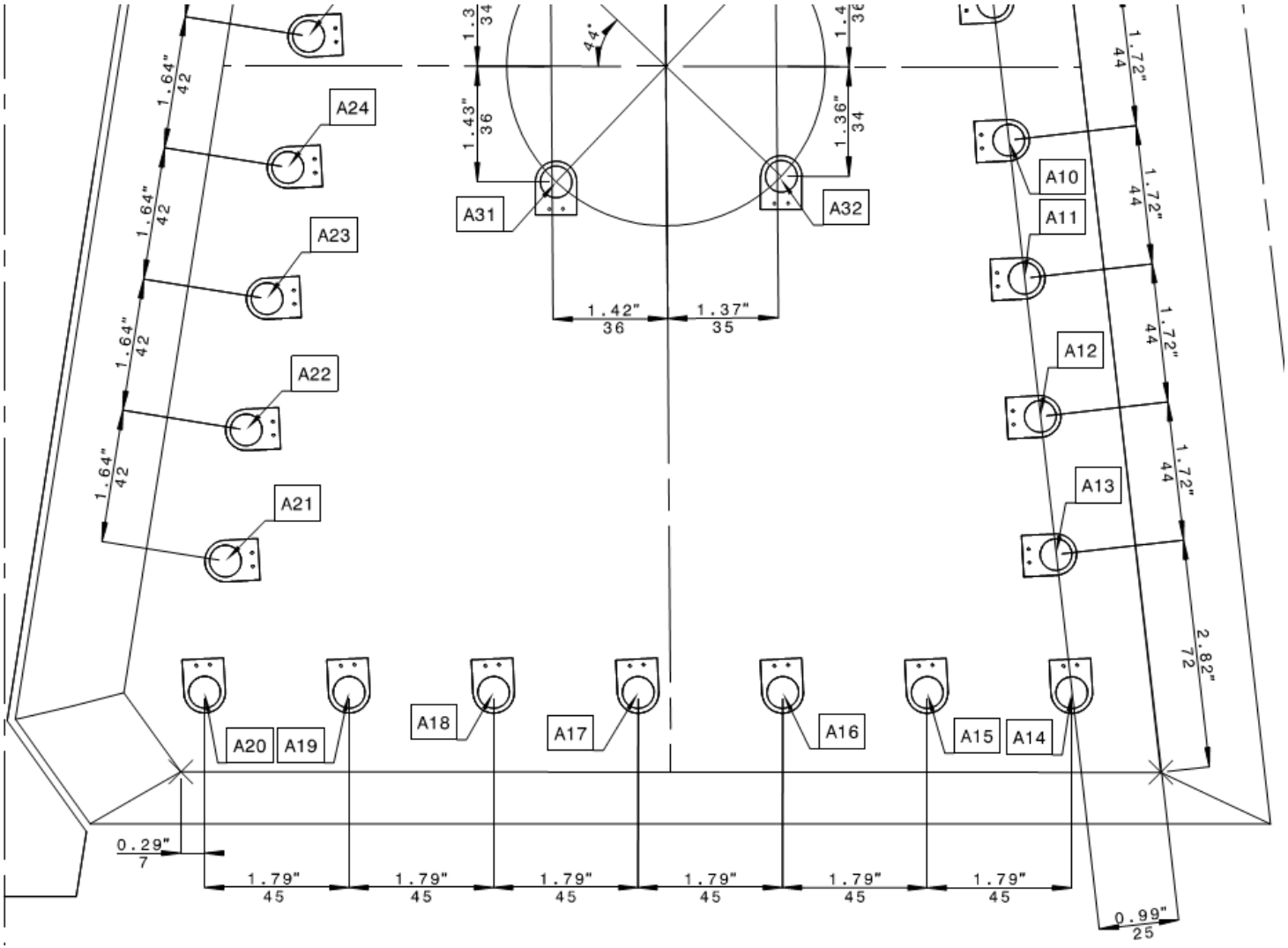
Wing box lower panel – upper face



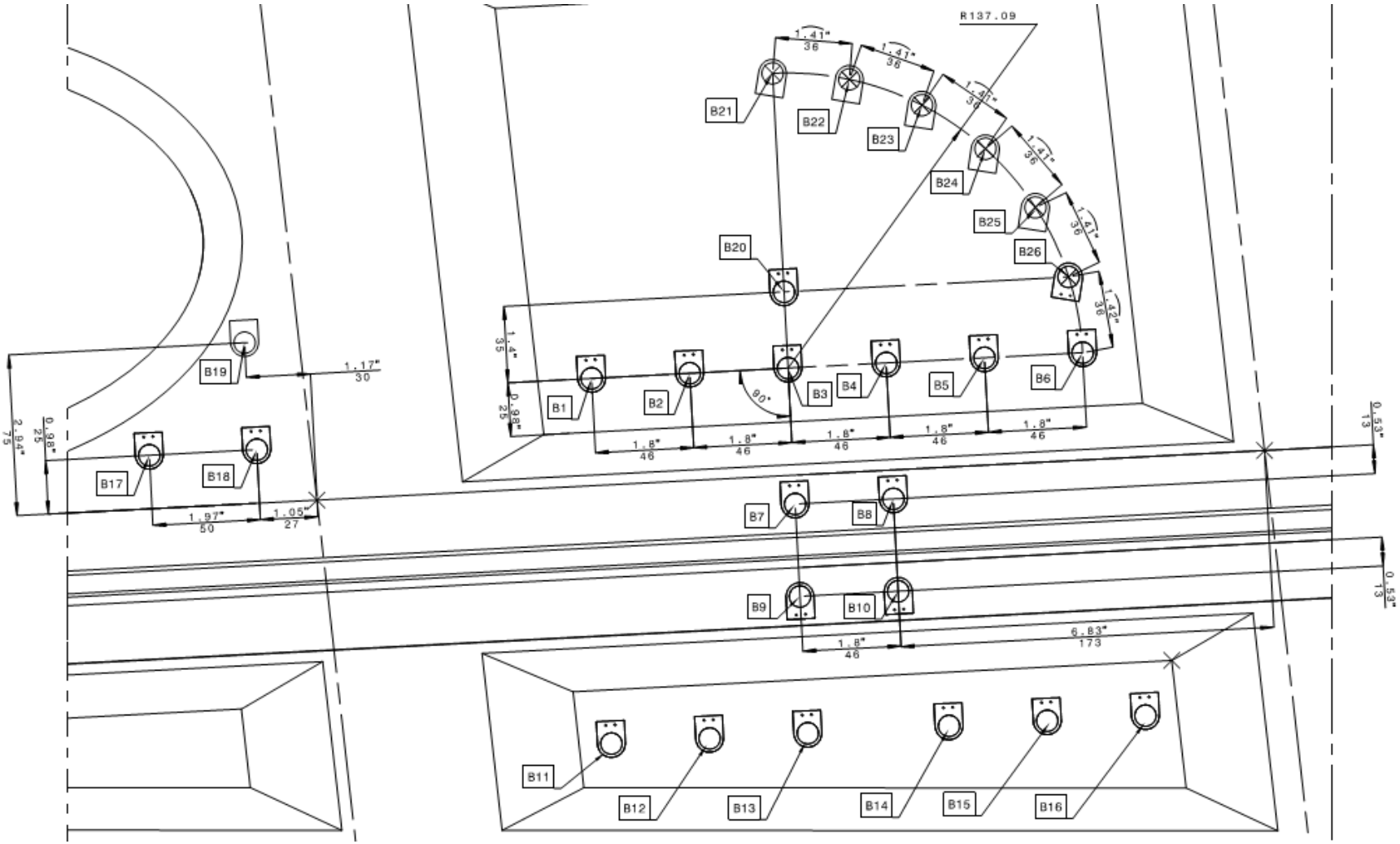
Sensors position subgroup A1



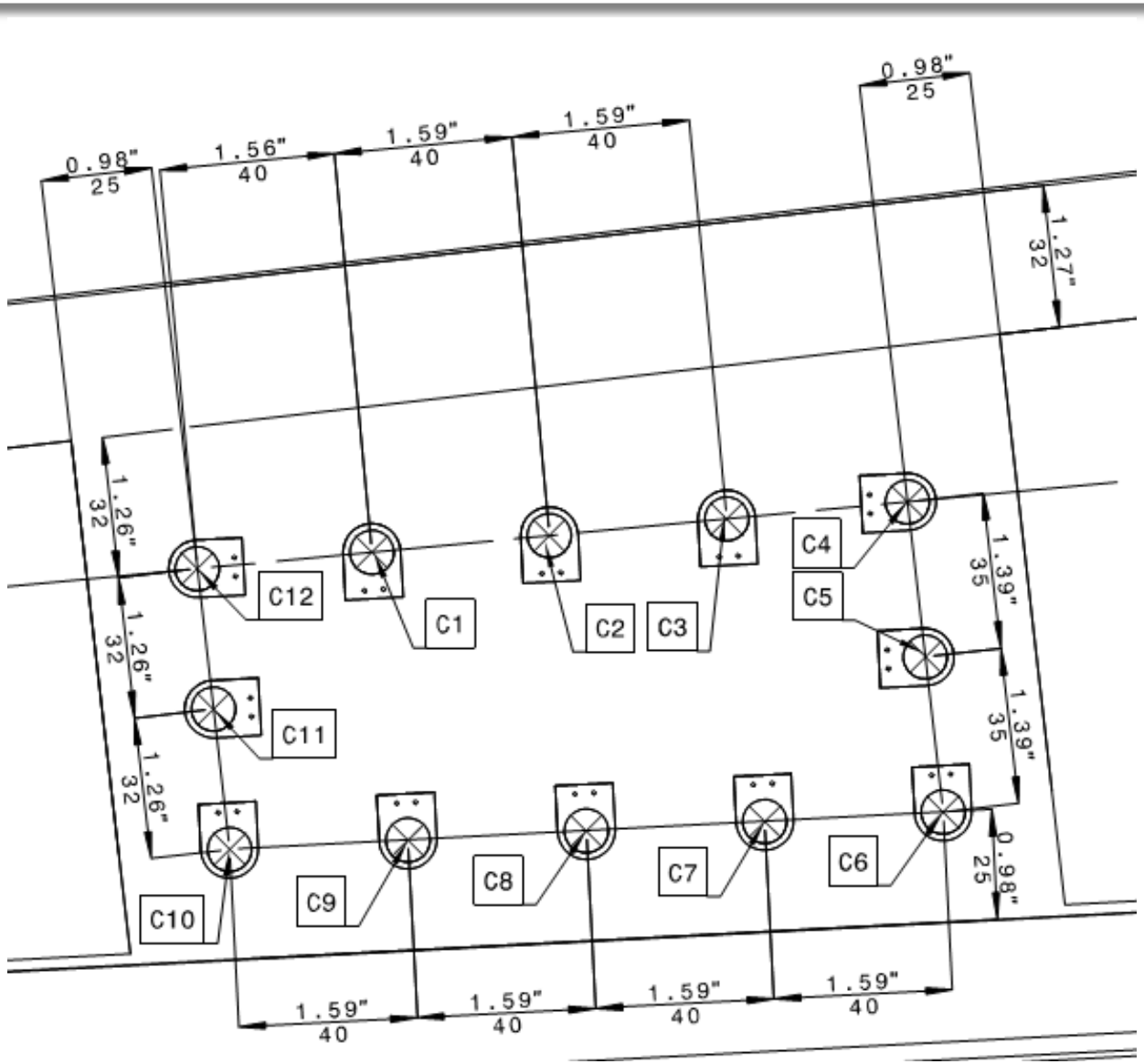
Sensors position subgroup A2



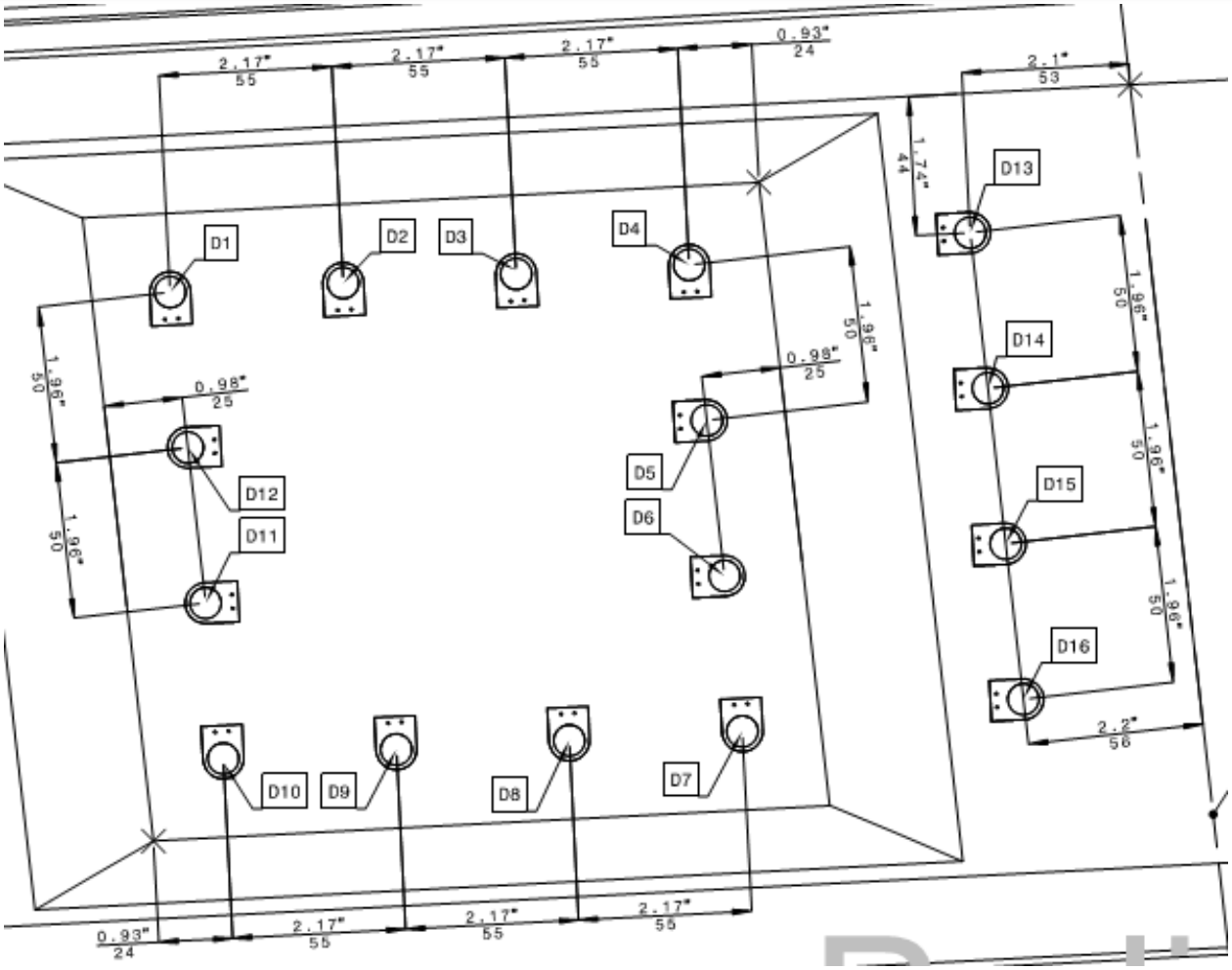
Sensors position subgroup B



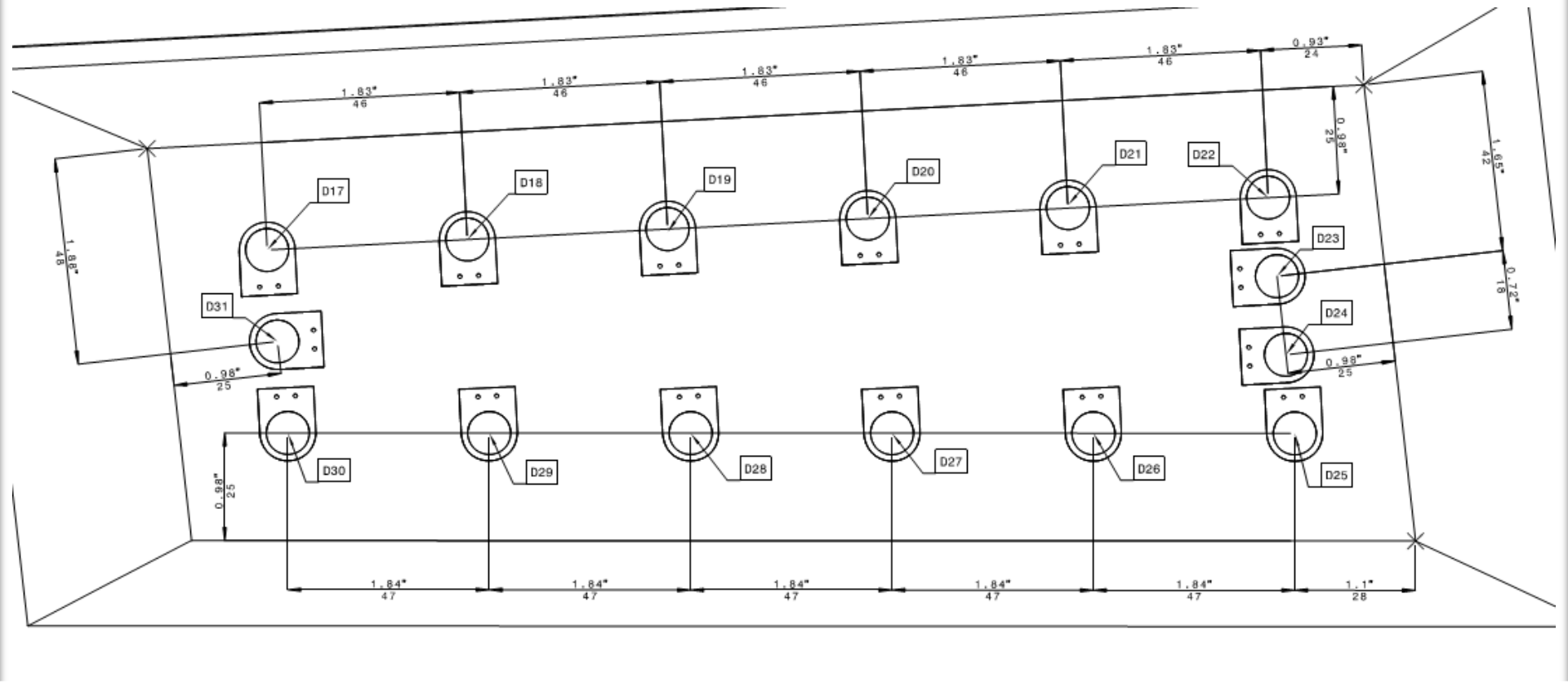
Sensors position subgroup C



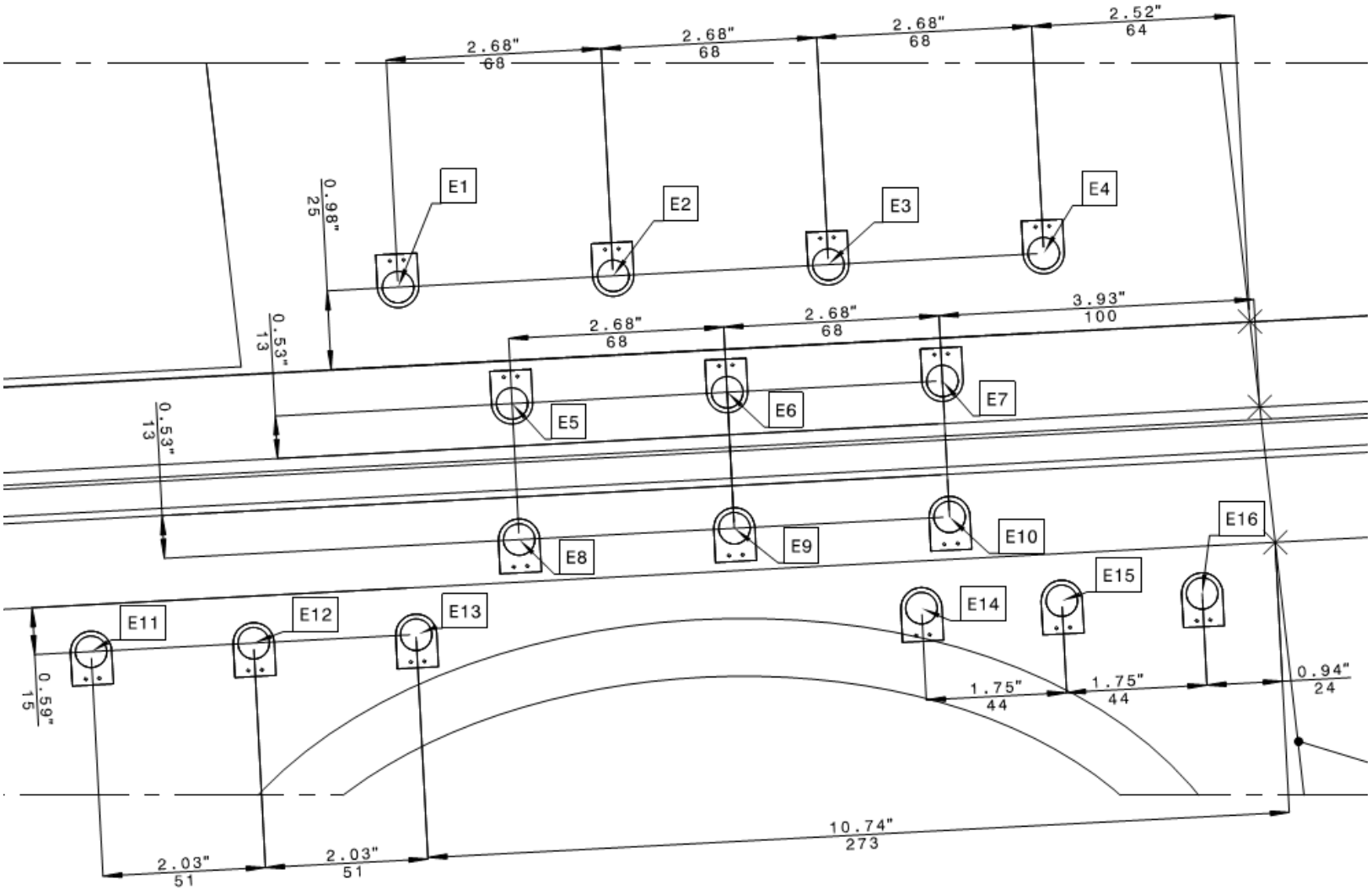
Sensors position subgroup D1



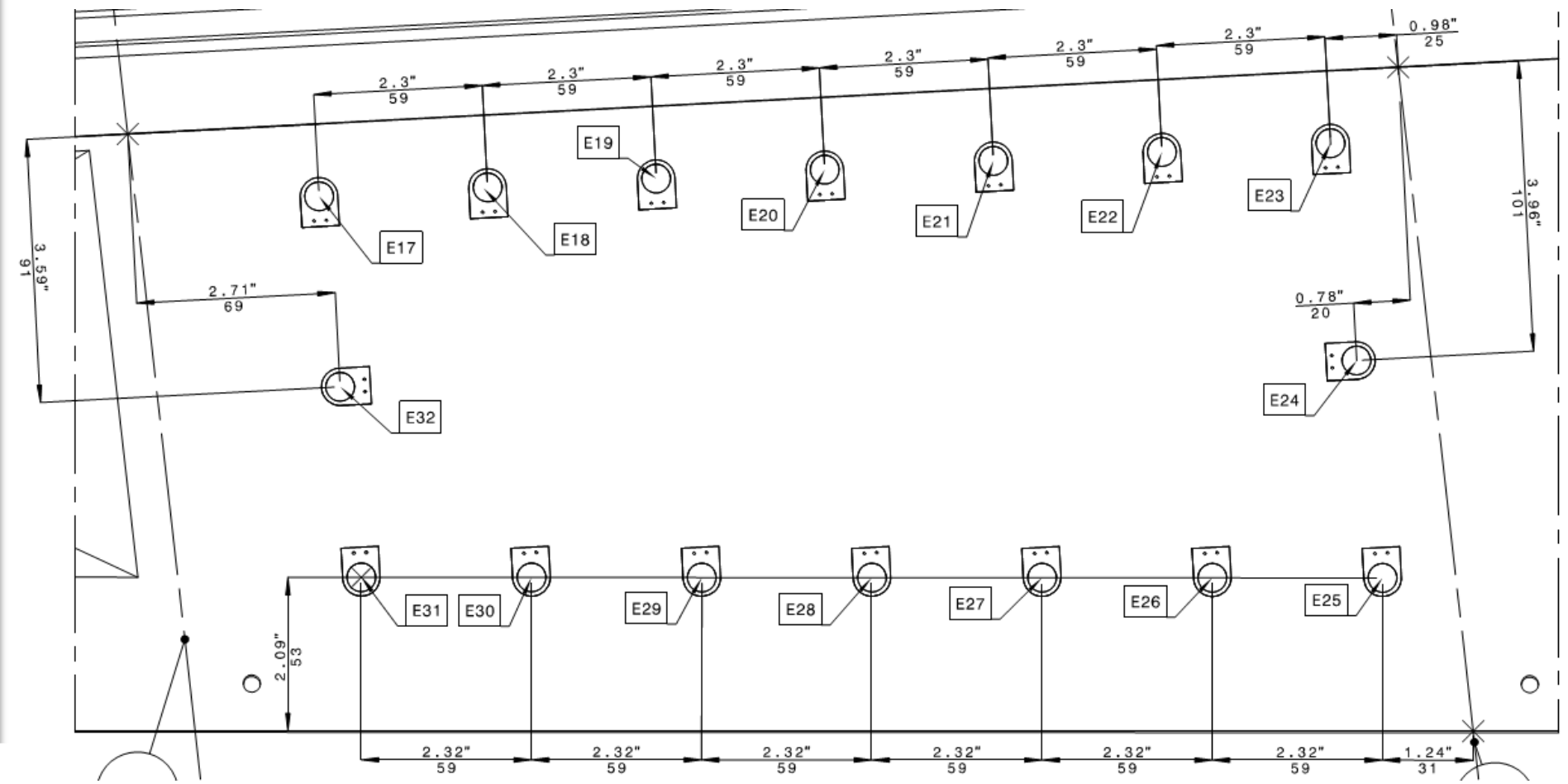
Sensors position subgroup D2



Sensors position subgroup E1



Sensors position subgroup E2



Sensors connections group A

SECTION 0							
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
A1	A2	A3	A4	A5	A6	A7	A8
8	**9**	**10**	**11**	**12**	**13**	**14**	**15**
A9	A10	A32	A31	A25	A26	A27	A28

SECTION 1							
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
A11	A12	A13	A14	A15	A16	A17	A18
8	**9**	**10**	**11**	**12**	**13**	**14**	**15**
A19	A20	A21	A22	A23	A24	A29	A30

Physical cable connection check after SHM showed no faults.

Sensors connections group B

SECTION 2							
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
B1	B2	B3	B4	B5	B6	B7	B8
8	**9**	**10**	**11**	**12**	**13**	**14**	**15**
B9	B10	B11	B12	B13	B14	B15	B16

SECTION 3							
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
B17	B18	B19	B20	B21	B22	B23	B24
8	**9**	**10**	**11**	**12**	**13**	**14**	**15**
B25	B26	-	-	-	-	-	-

(-) Not used

Physical cable connection check after SHM showed the following faults:

B7: cable connection damaged during test article final assembly

B18: cable damaged during test article final assembly

Sensors connections group C

SECTION 4							
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
C1	C2	C3	C4	C5	C6	C7	C8
8	**9**	**10**	**11**	**12**	**13**	**14**	**15**
C9	C11	C12	-	-	-	-	-

SECTION 5							
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
-	-	-	-	-	-	-	-
8	**9**	**10**	**11**	**12**	**13**	**14**	**15**
-	-	-	-	-	-	-	-

(-) Not used

Physical cable connection check after SHM showed no faults.

Sensors connections group D

SECTION 6							
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
*	D17	D18	D19	D20	D21	D22	D23
8	**9**	**10**	**11**	**12**	**13**	**14**	**15**
D24	D25	D26	D27	D28	D29	D30	D31

SECTION 7							
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
D1	D2	D3	D4	D5	D6	D7	D8
8	**9**	**10**	**11**	**12**	**13**	**14**	**15**
D9	D10	D11	D12	D13	D14	D15	D16

(*) Not available due to damaged connector

Physical cable connection check after SHM showed the following faults:

D30: cable connection damaged before test article final assembly

D5: cable connection damaged after impacts

Sensors connections group E

SECTION 8							
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
E1	E2	E3	E4	E5	E6	E7	E8
8	**9**	**10**	**11**	**12**	**13**	**14**	**15**
E9	E10	E11	E12	E13	E14	E15	E16

SECTION 9							
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
E17	E18	E19	E20	E21	E22	E23	E24
8	**9**	**10**	**11**	**12**	**13**	**14**	**15**
E25	E26	E26	E28	E29	E30	E31	E32

Physical cable connection check after SHM showed no faults.

2. Data acquisition

Acquisitions summary

- Humidity: from 10% to 50%
- Temperature: from 17°C to 25°C
- Total recorded data: more than 31.000 files (4.1GB)
- Electromagnetic Impedance (all sensors)
  - Low frequency range: 1kHz – 20kHz (step 100Hz, 1 rep.)
  - High frequency range: 20kHz – 100kHz (step 100Hz, 1 rep.)
- Group velocity (at least 2 quasi-orthogonal paths for each group, 2.5kS)
  - Full frequency range: 50kHz – 300kHz (step 10kHz, 10 rep.)
- Pitch-catch tomography (all sensors, 2.5kS)
  - 50kHz, 60kHz, 100kHz (10 rep., 2.5MS/s, ±0.2V)
  - 70kHz, 80kHz, 90kHz (1 rep., 2.5MS/s, ±0.2V)

EMI low frequency acquisitions

- Base folder: emiLow
- File name: emiFull_x_y_emi.txt
- File name fields:

  x – repetition index (always 00)
  y – acquisition index (from 01 to 133)
- Sensors examined section by section: (cfr slides 13-17)

  A1-A10, A32, A31, A25-A28, A11-A24, A29, A30, B1-B26, C1-C12, …
- Data file reading routine: readEmiFile.m

  dataStruct = readEmiFile('emiLow\emiFull_00_01_emi.txt')

EMI high frequency acquisitions

- Base folder: emiHigh
- File name: emiFullExt_x_y_emi.txt
- File name fields:

  x – repetition index (always 00)
  y – acquisition index (from 01 to 133)
- Sensors examined section by section: (cfr slides 13-17)

  A1-A10, A32, A31, A25-A28, A11-A24, A29, A30, B1-B26, C1-C12, …
- Data file reading routine: readEmiFile.m

  dataStruct = readEmiFile('emiHigh\emiFullExt_00_02_emi.txt')

EMI data structure

- dataStruct fields
  - warmup: [sec] warmup time for relay configuration
  - sec: [num] section index
  - src: [num] examined piezo
  - sn1: [num] *reserved*
  - sn2: [num] *reserved*
  - f0: [Hz] start frequency
  - f1: [Hz] stop frequency
  - df: [Hz] frequency increment
  - f: [Hz] acquired frequencies
  - Z: [Ohm] measured impedance magnitude
  - P: [Deg] measured phase angle

Group velocity acquisitions

- Base folder: speed
- File path and name: x\cgFull_x_y_pc.txt
- File name fields:
  - x – repetition index (from 00 to 09)
  - y – acquisition index (from 01 to 260)
- Sensors examined frequency by frequency
  - 1-10 @ 50kHz, 1-10 @ 60kHz, …
- Data file reading routine: readPcFile.m

dataStruct = readPcFile('speed\00\cgFull_00_03_pc.txt')

Excitation sequence:

1. A22 → A12, A20
2. B3 → B6, B13
3. B20 → B21, B22
4. B20 → B23, B24
5. B20 → B25, B26
6. C11 → C5, C10
7. D11 → D6, D15
8. D31 → D23, D30
9. E1 → E13, E4
10. E32 → E24, E31

Pitch-catch acquisitions (1)

- Base folder: acoustic
- File path and name: x\y\z\calibyx_u_v_pc.txt
- File name fields:
  - x – central frequency {50k 60k, 70k, 80k, 90k, 100k}
  - y – sensor group {A, B, C, D, E}
  - z – repetition index (from 00 to 09, depends on frequency) (1)
  - u – internal use, don't care (mostly 00)
  - v – acquisition index (from 01 to 256, depends on group) (2)
- Data file reading routine: readPcFile.m

dataStruct = readPcFile('acoustic\50k\A\00\calibA50k_00_04_pc.txt')

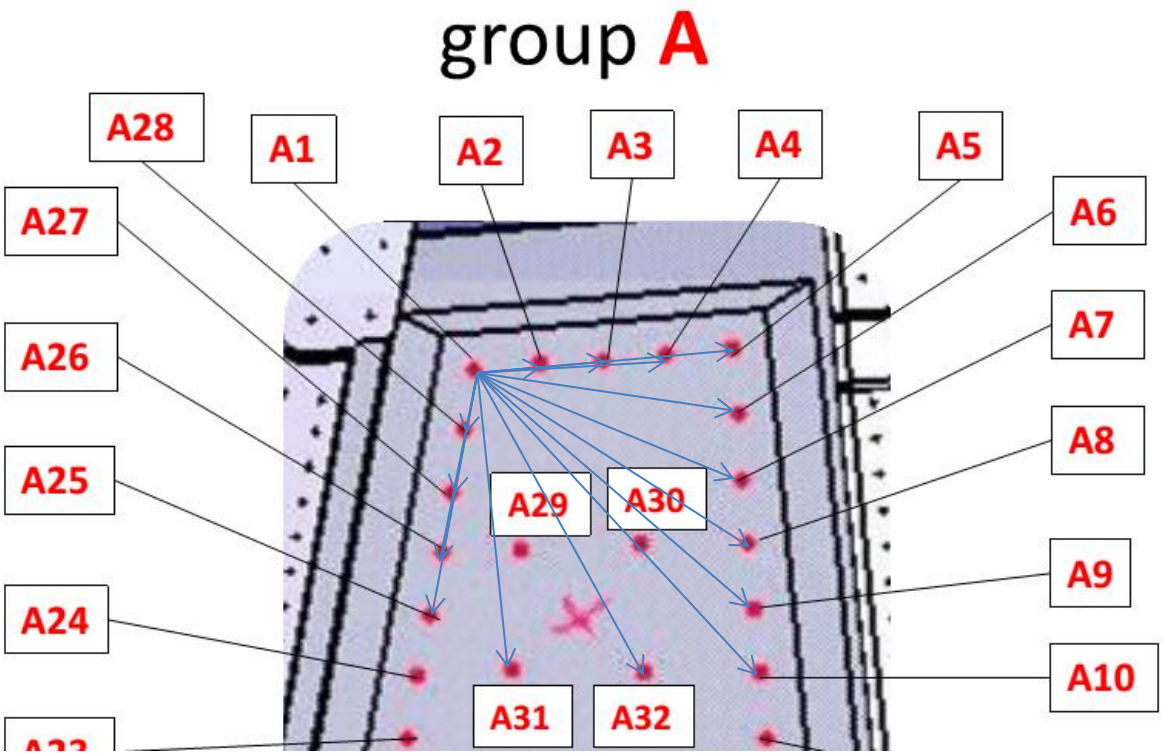
(1) Full range for 50k, 60k and 100k; always 00 otherwise

(2) A: max 256; B: max 131; C: max 72; D: max 233; E: max 256

Pitch-catch acquisitions (2)

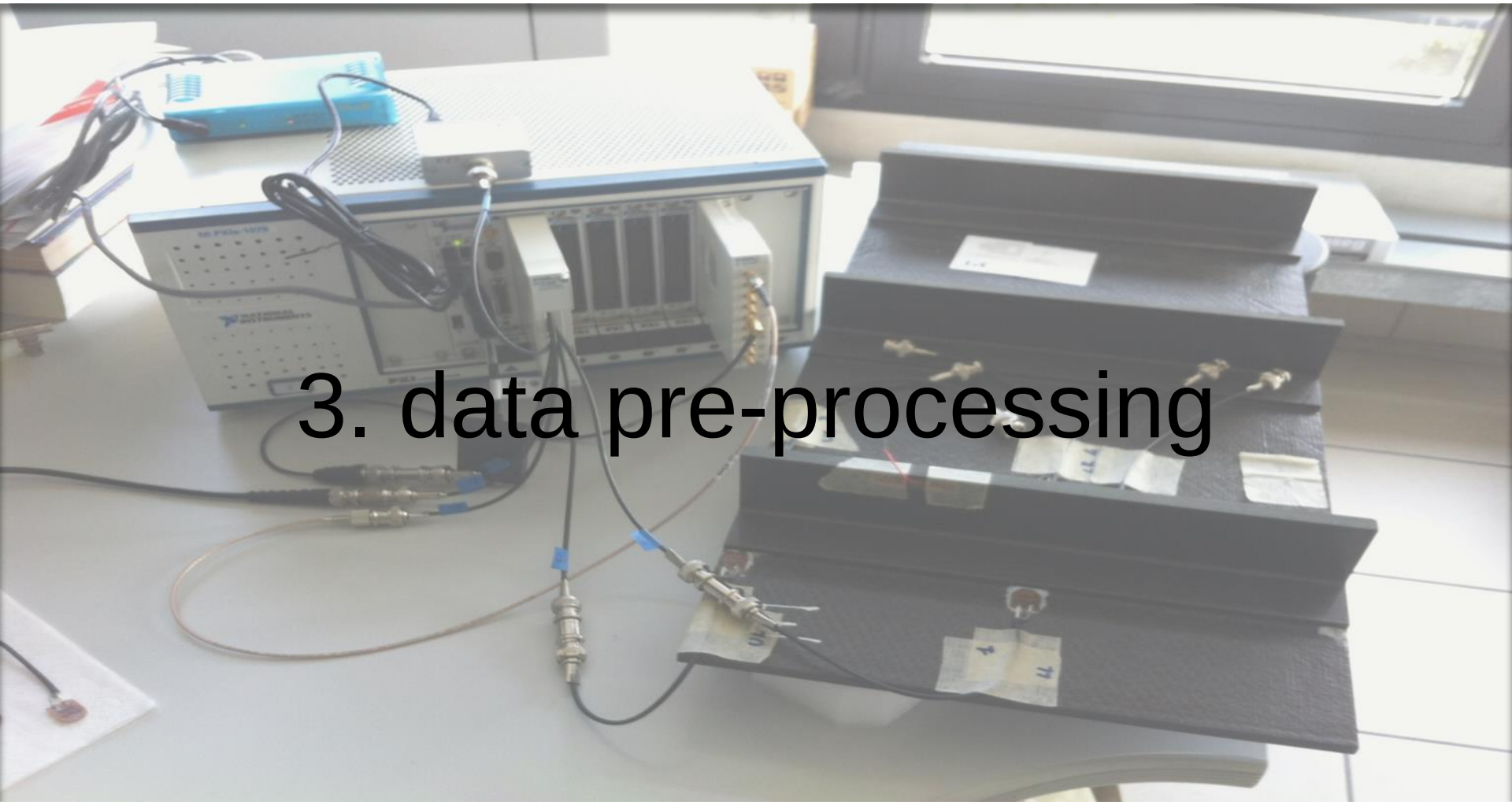
- Pitch-catch path pairs acquired section by section: (cfr slides 13-17)
- In case of uneven sequences, the first path is acquired again at the end

1. A1 → A2, A3;
2. A1 → A4, A5;
3. A1 → A6, A7;
4. A1 → A8, A9;
5. A1 → A10, A32;
6. A1 → A31, A25;
7. A1 → A26, A27;
8. A1 → A28, A2;
9. A2 → A1, A3;
10. A2 → A4, A5;
11. A2 → A6, A7;
12. A2 → A8, A9;
13. …



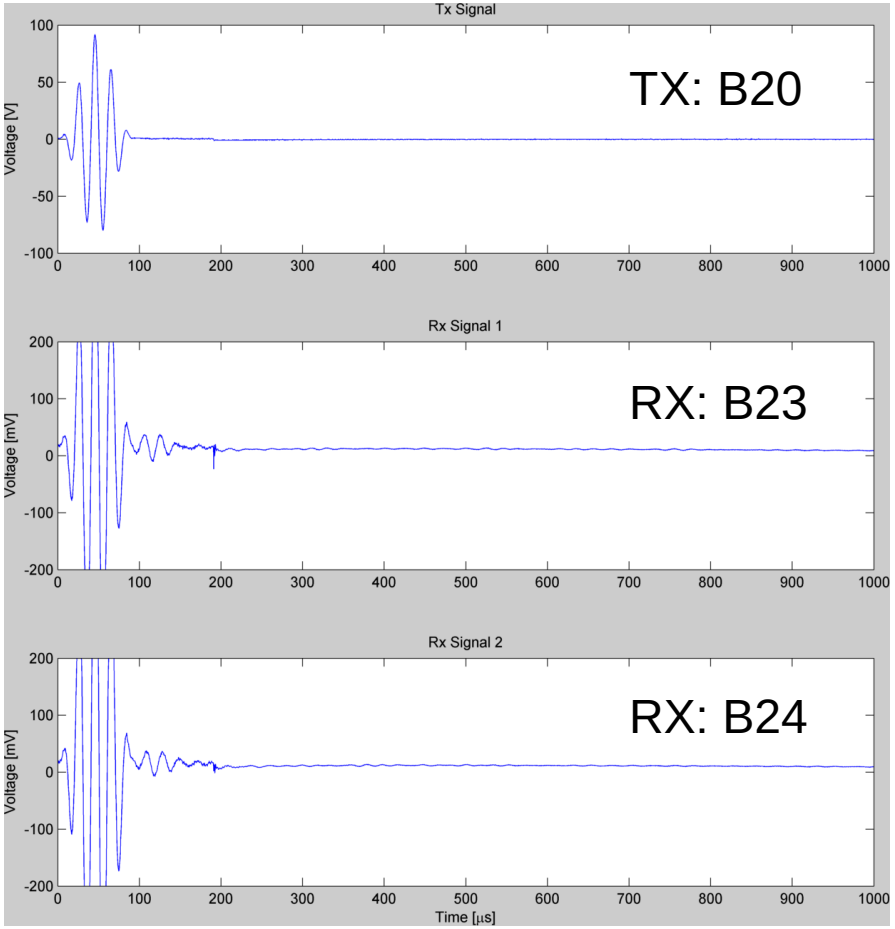
Pitch-catch data structure

- dataStruct fields
  - warmup: [sec] warmup time for relay configuration
  - sec: [num] section index
  - src: [num] actuator piezo
  - sn1: [num] receiver piezo 1
  - sn2: [num] receiver piezo 2
  - wavetype: [string] transmitted waveform type
  - fc: [Hz] central frequency
  - amp: [V] peat-to-peak voltage
  - np: [num] number of periods
  - wintype: [string] waveform windowing type
  - fs: [Hz] sampling frequency
  - Ns: [num] number of acquired samples
  - tx: [V] measured transmitted voltage
  - rx0: [V] measured received voltage from piezo 1
  - rx1: [V] measured received voltage from piezo 2
  - t: [s] acquired time instants

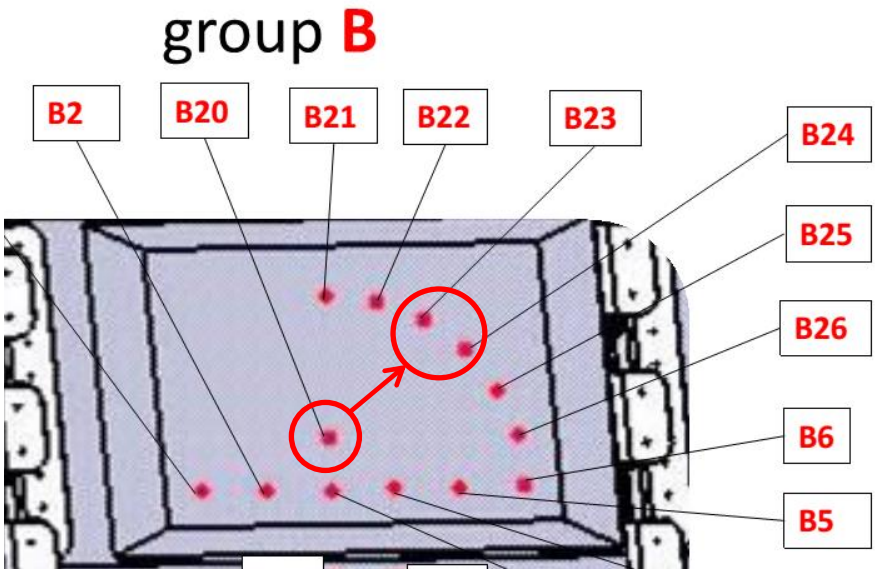


3. data pre-processing

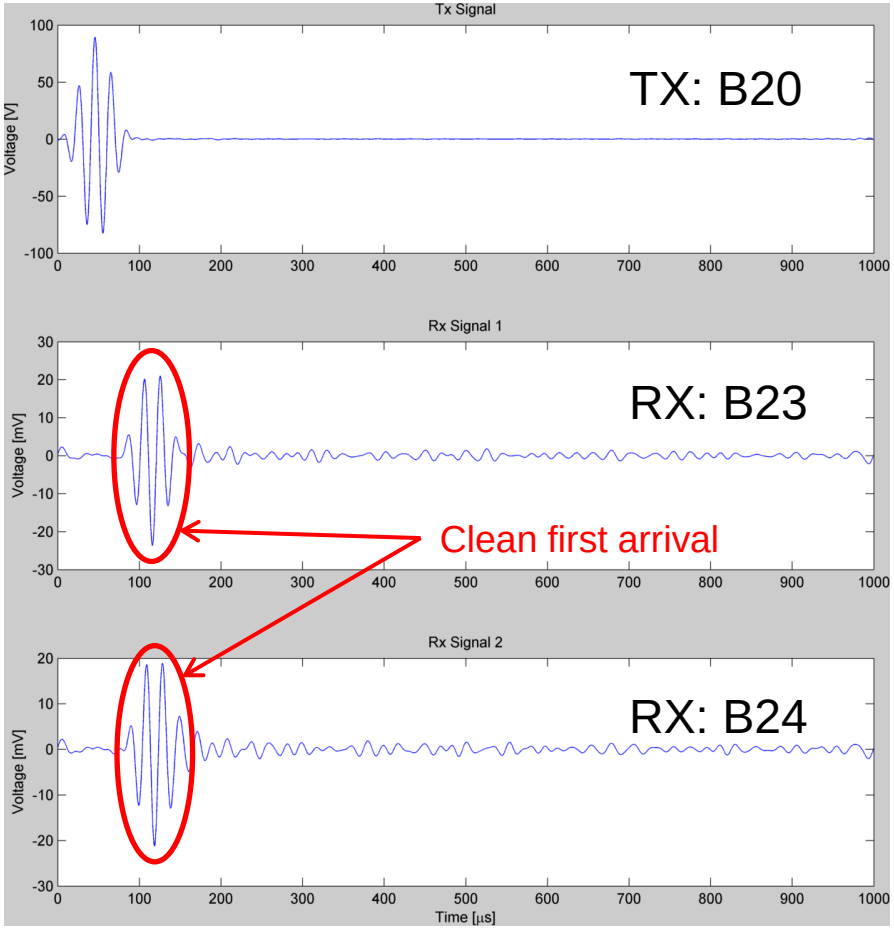
Raw recorded data



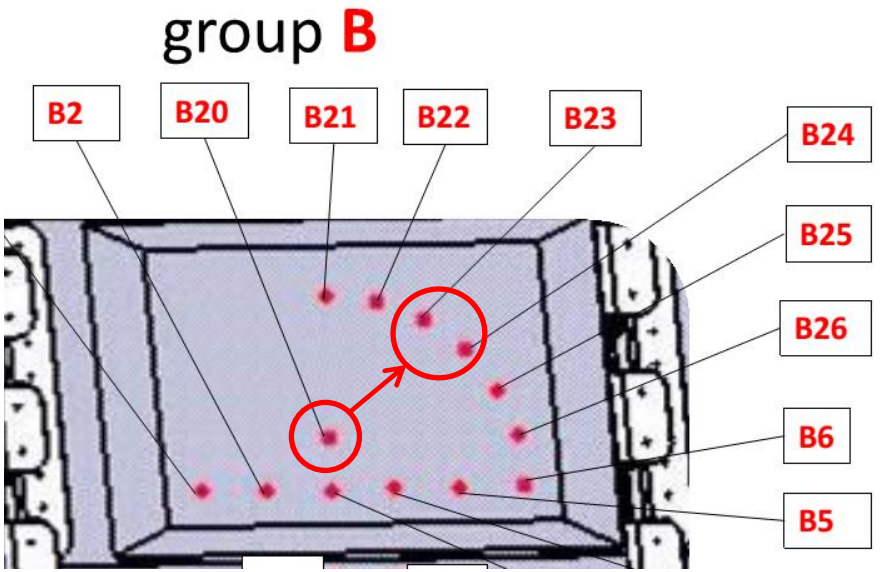
- Example:
  - Sensor B20→B23,B24
  - EM coupling below 50dB

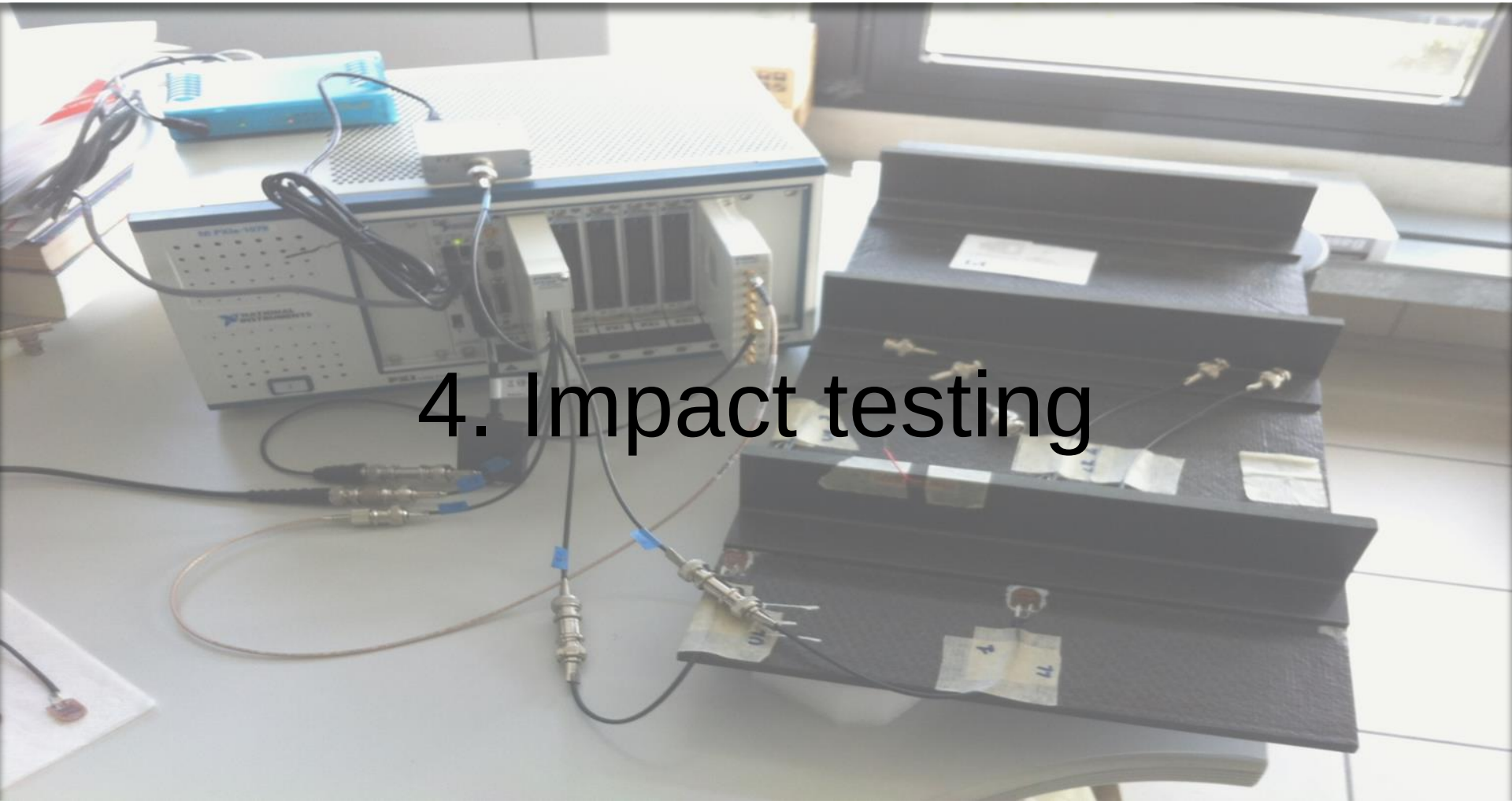


Pre-processed data



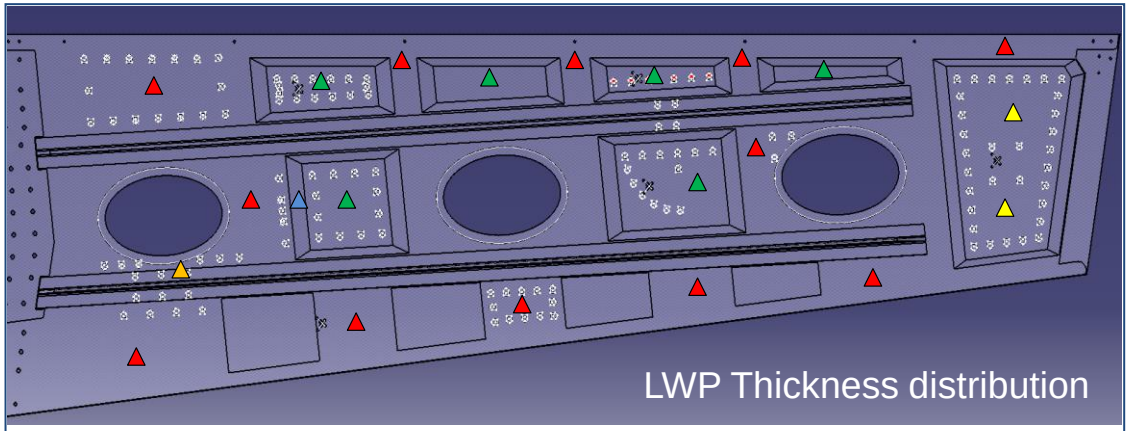
- Exploitation of recorded TX signal
- EM coupling automatic estimation
  - EMc reduced below 90dB
- Signal clipping recovery



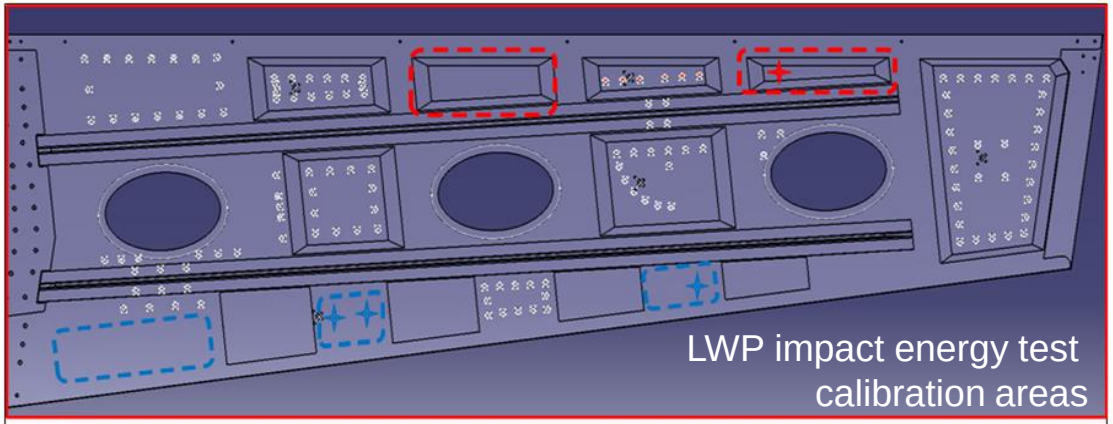


4. Impact testing

Impact energy calibration

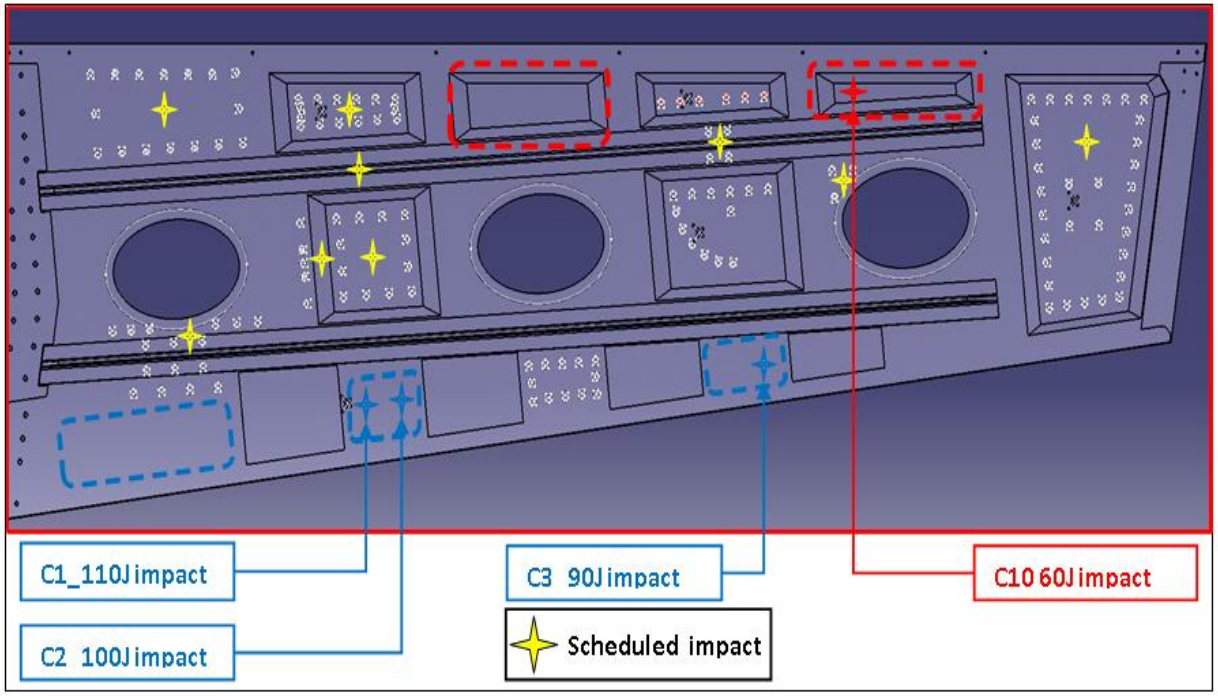


- 6.4 mm thickness
- 8.3 mm thickness
- 10 mm thickness
- 12.5 mm thickness
- ramp thickness from 6.4 to 8.3 mm



- 8.3 mm thickness calibration impact → tested impact energies: 110, 100, 90, 80 Joule
- 6.4 mm thickness calibration impact → tested impact energy: 60 Joule

Impact energy calibration

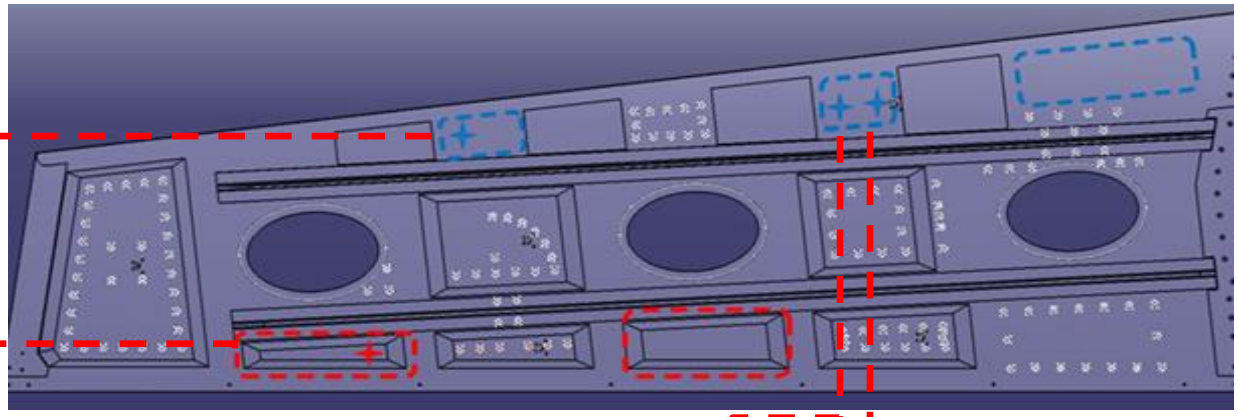


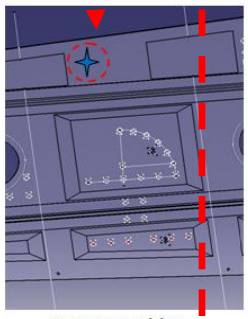
The experimental calibrated energy found are:

- 60 J for 6.4 mm thickness;
- 80 J for 8.3 mm thickness;
- 120 J for 10 mm thickness.

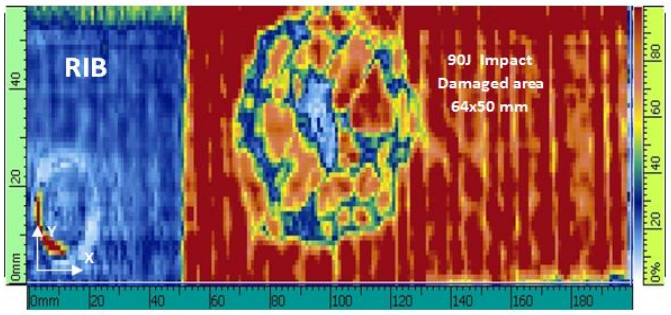
- Each impact inspected with Olympus Omniscan C_scan
- Impact gun equipped with an hemispherical nose 1 inch in diameter.

Impact energy calibration

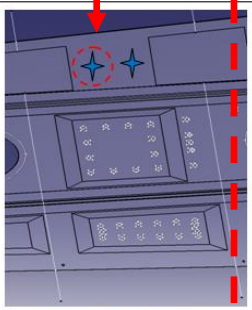




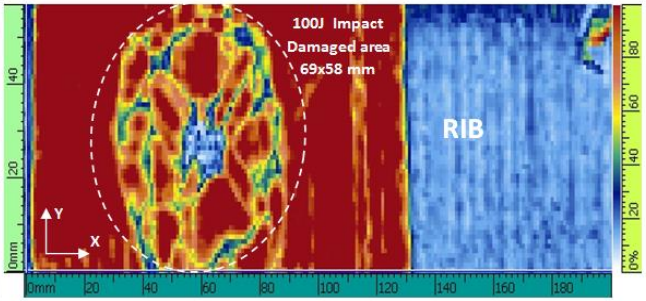
Impact position



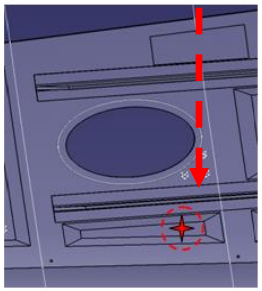
Impact C_scan view



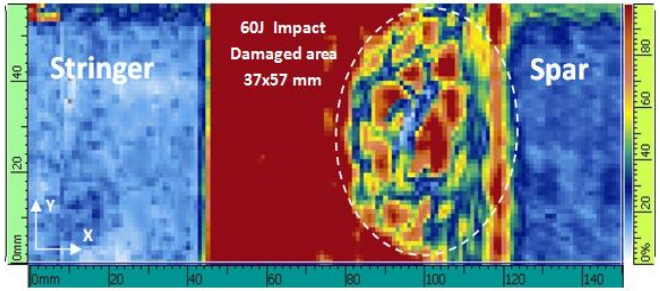
Impact position



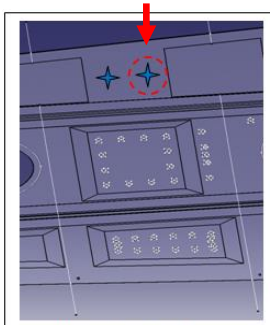
Impact C_scan view



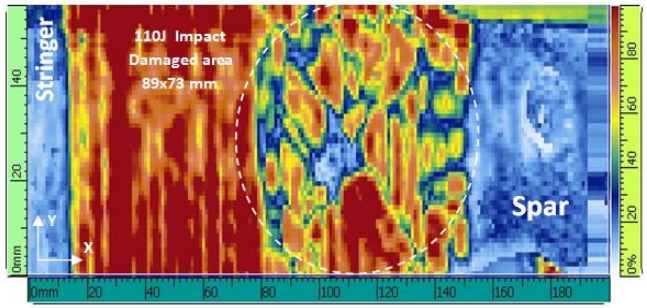
Impact position



Impact C_scan view

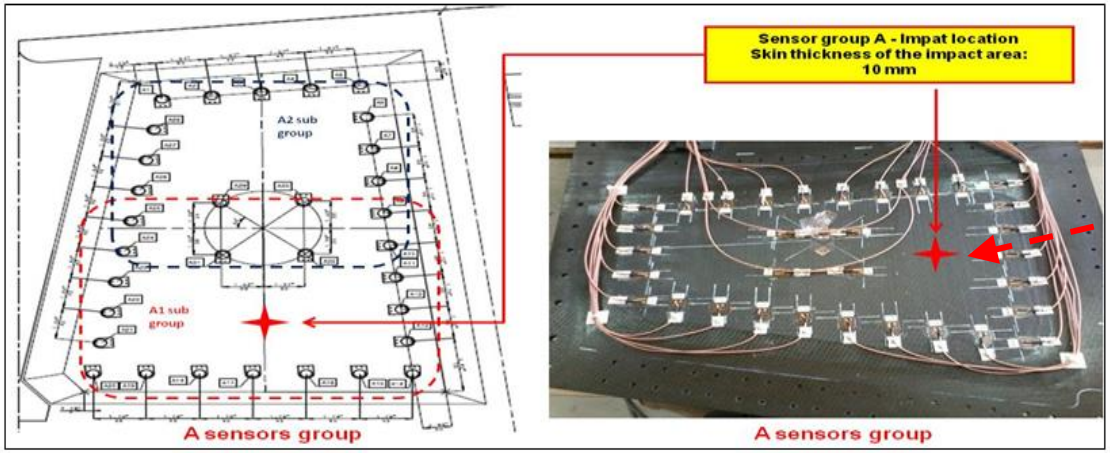


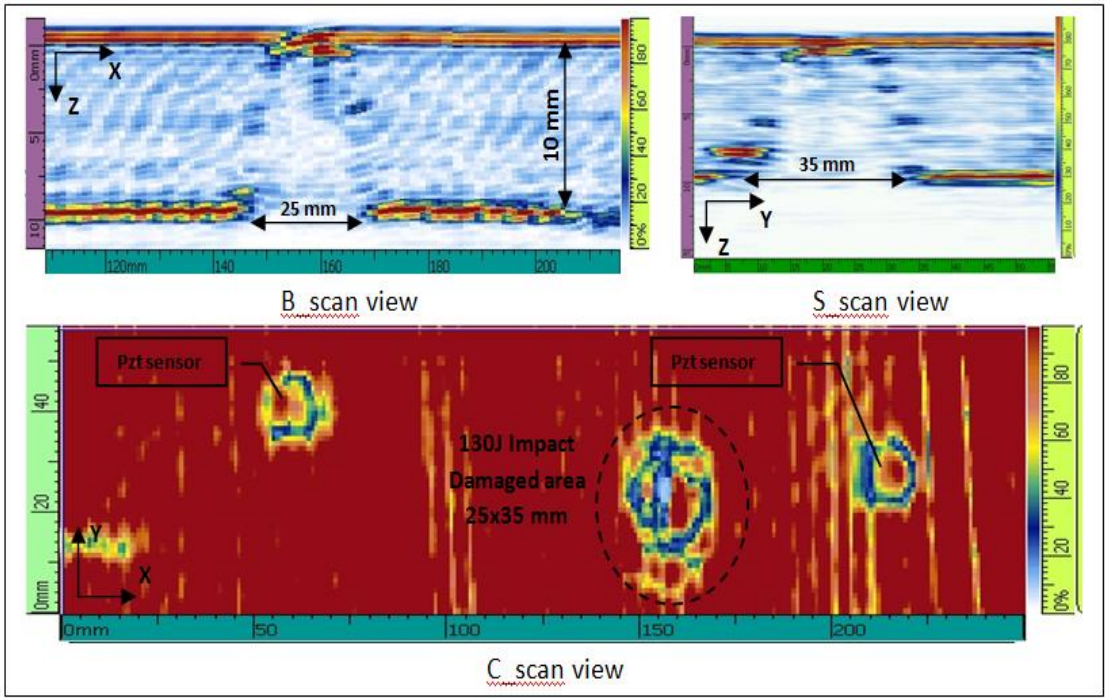
Impact position

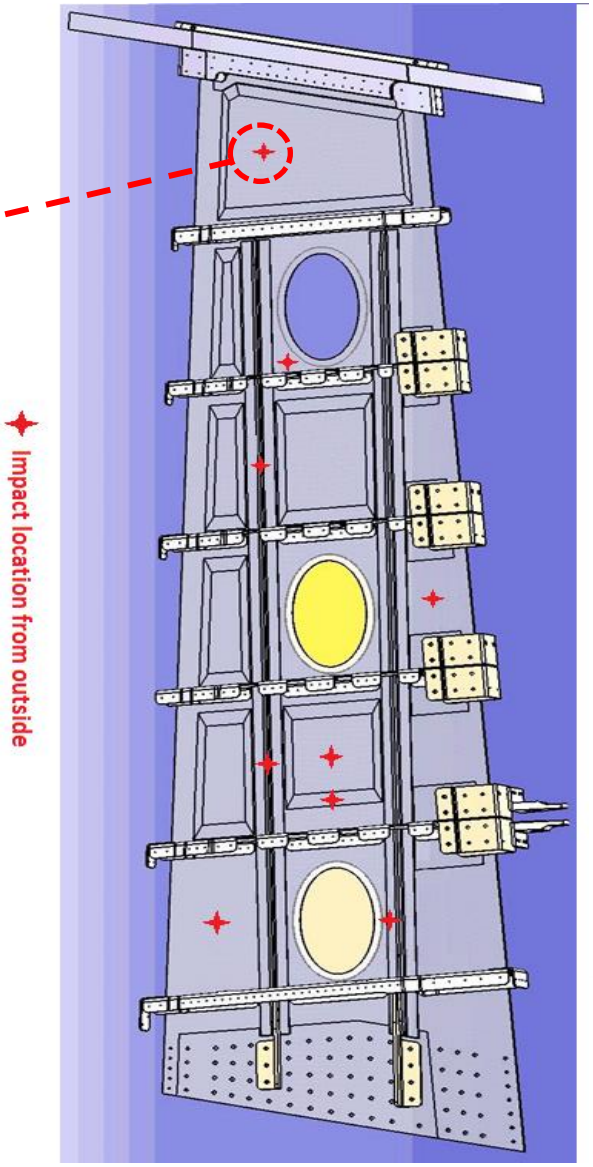


Impact C_scan view

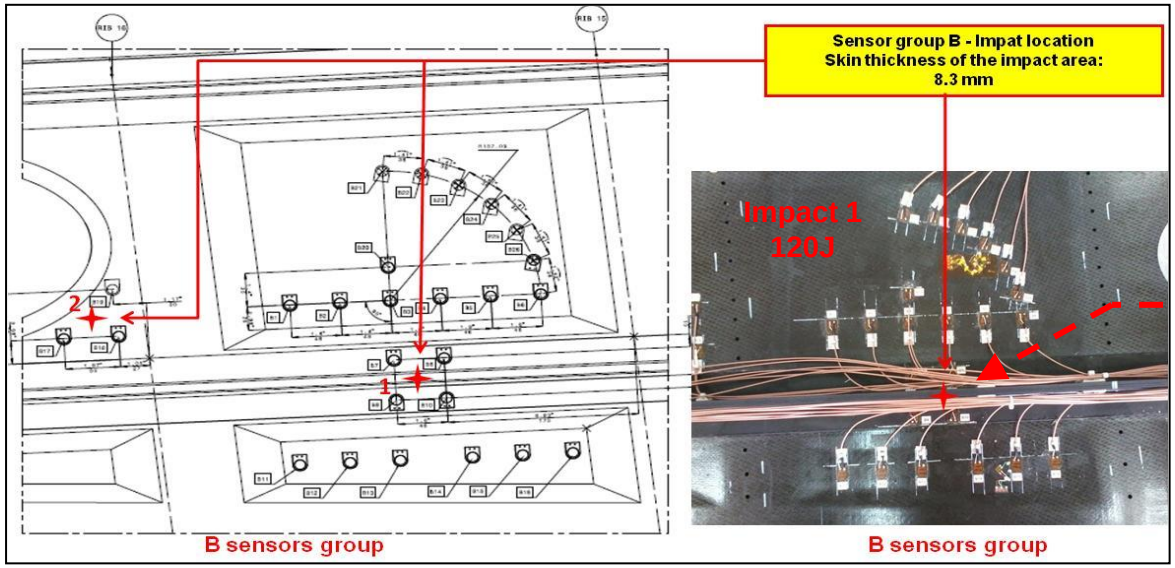
B, S and C-scan impact subgroup A2

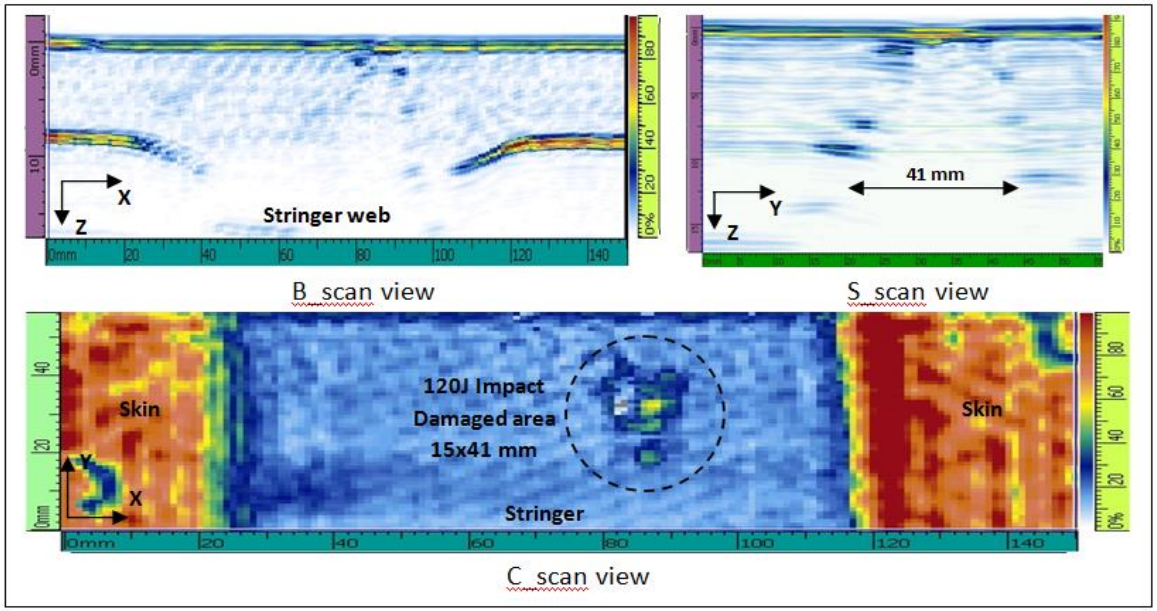


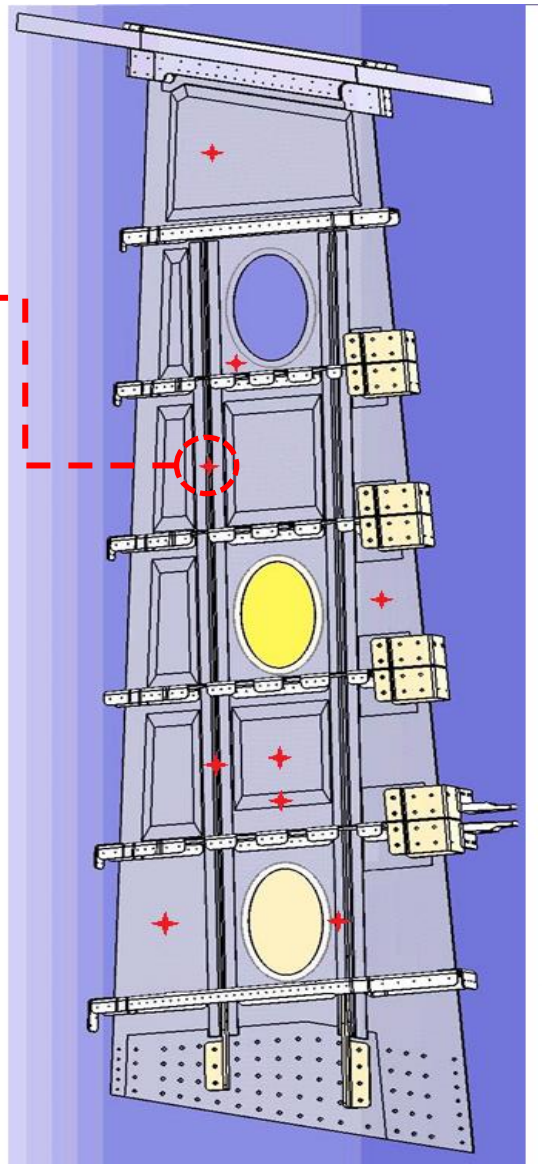




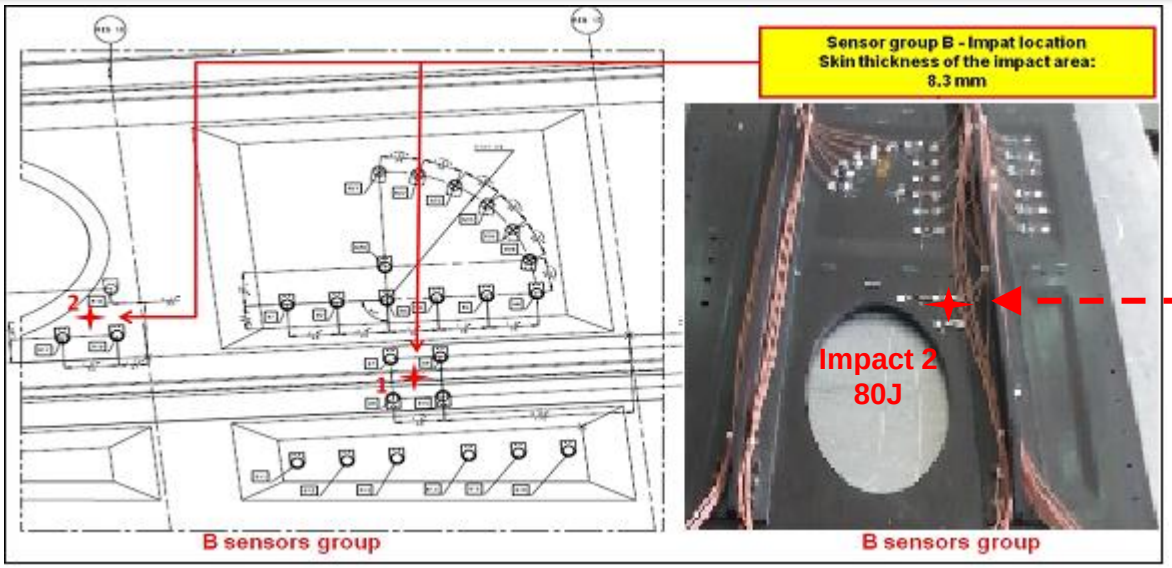
B, S and C-scan impact subgroup B

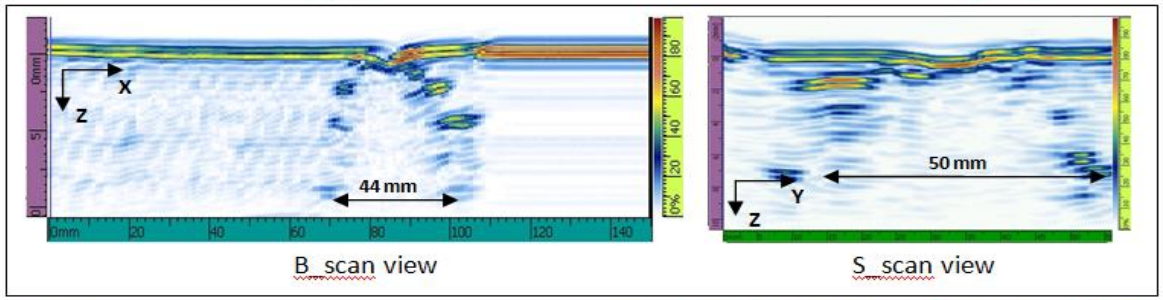


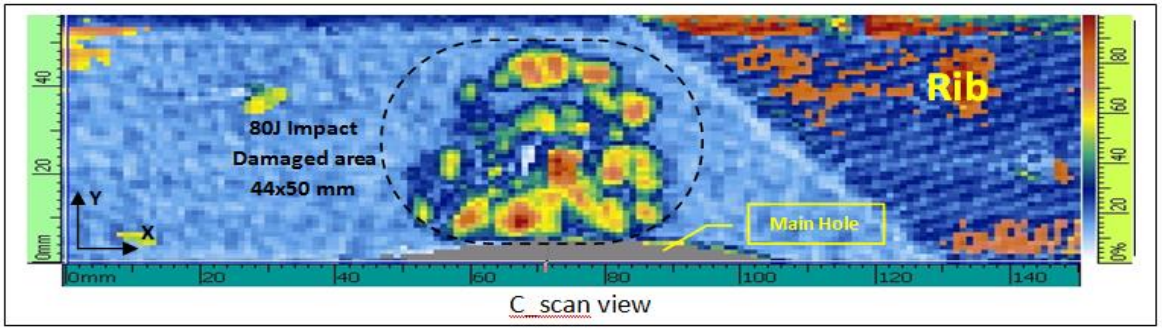




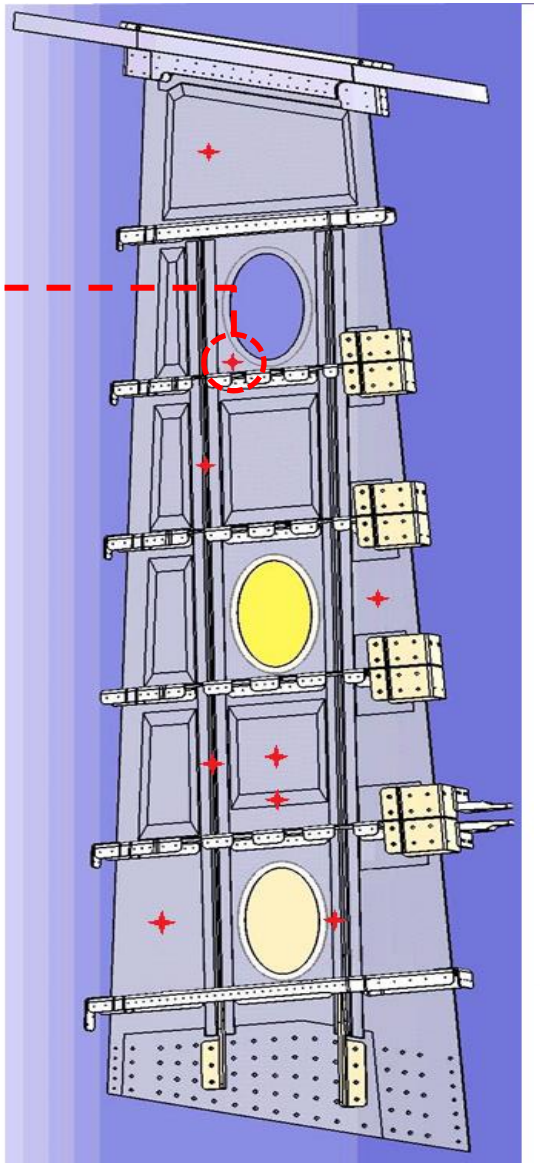
B, S and C-scan impact subgroup B



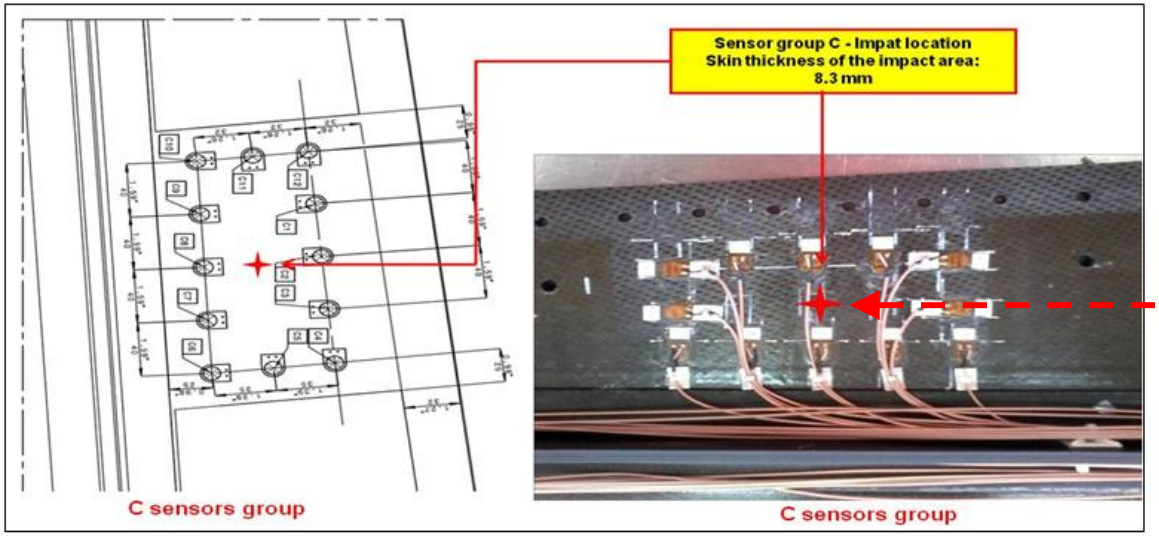


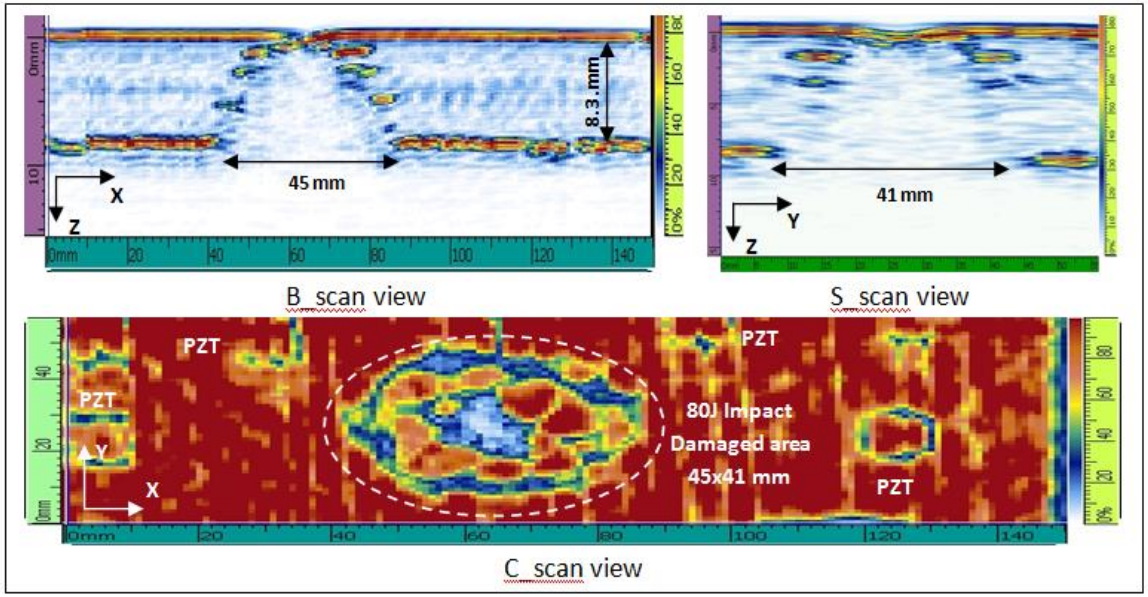


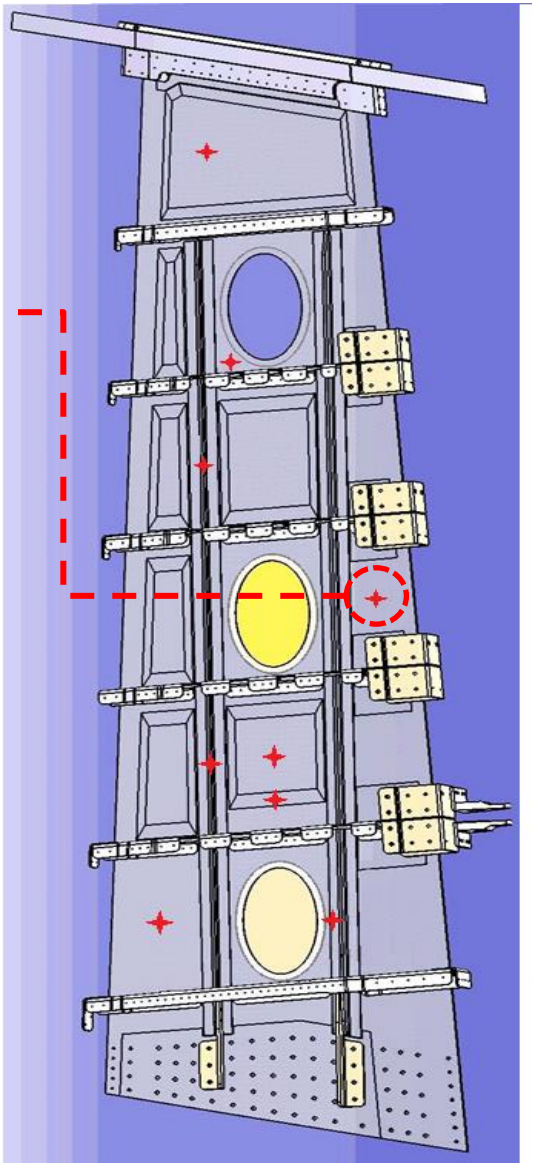
Impact location from outside



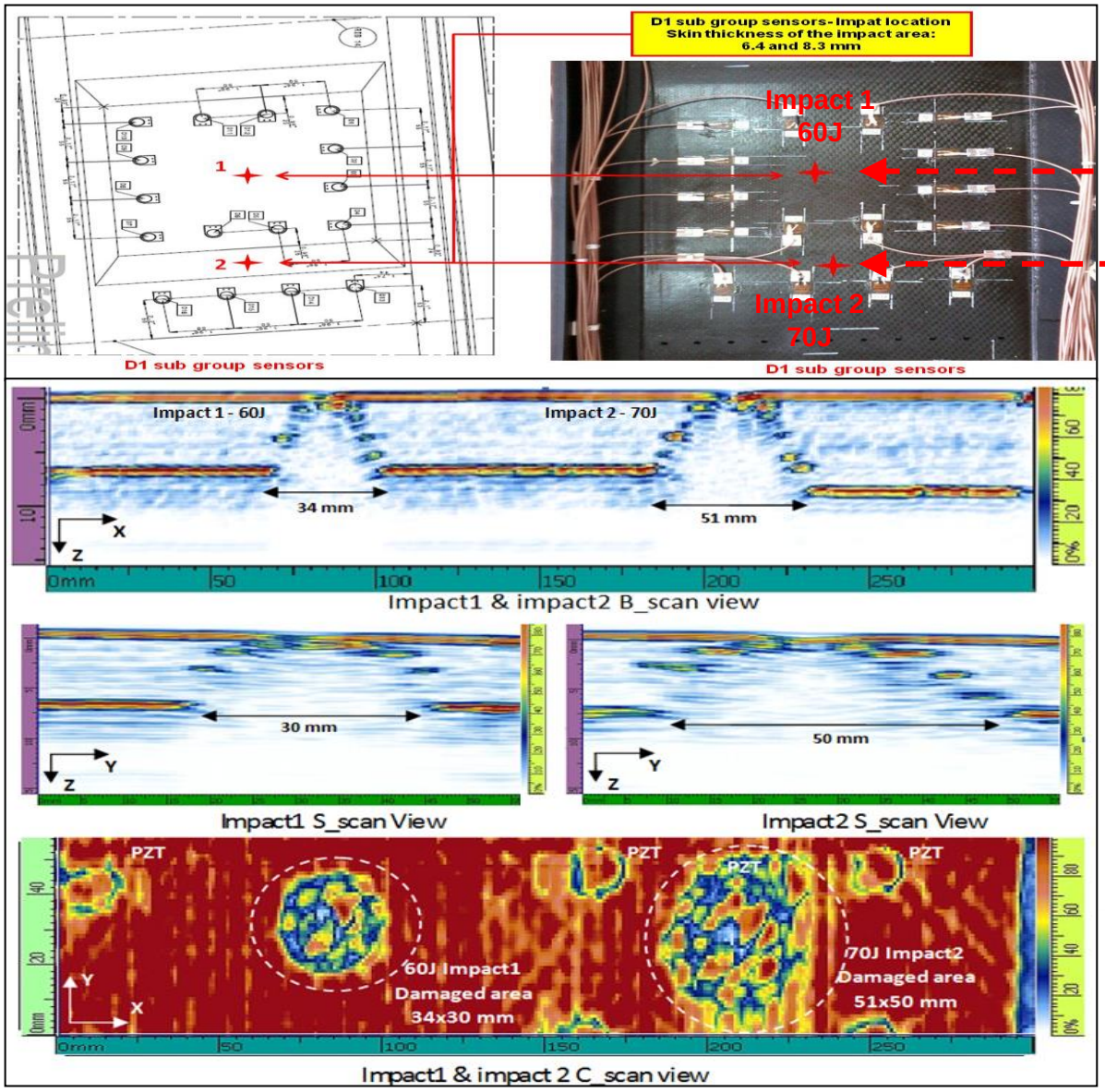
B, S and C-scan impact subgroup C

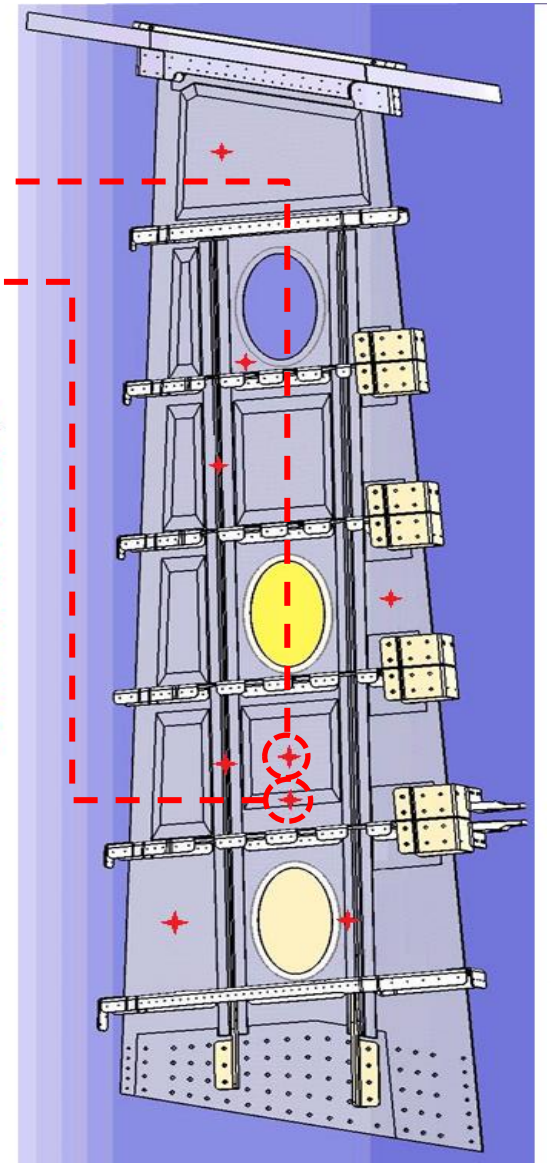




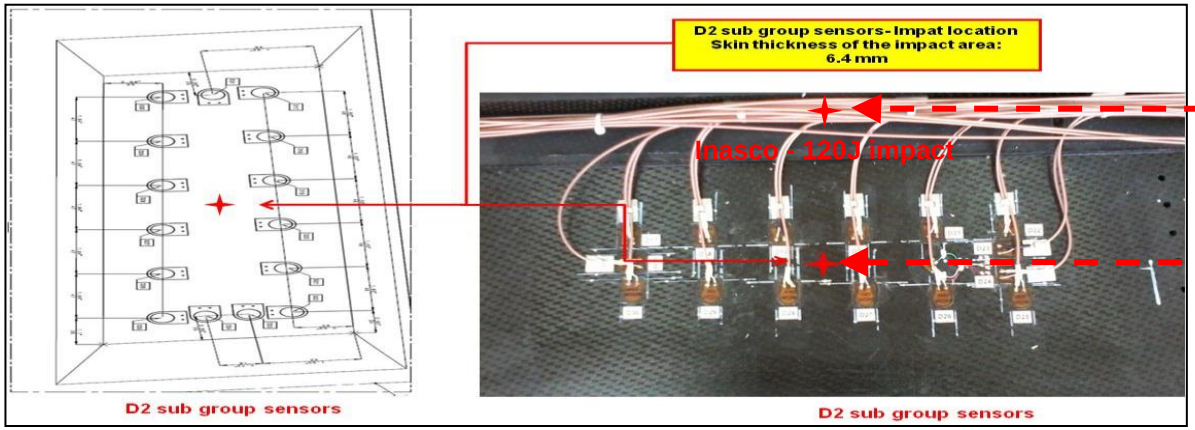


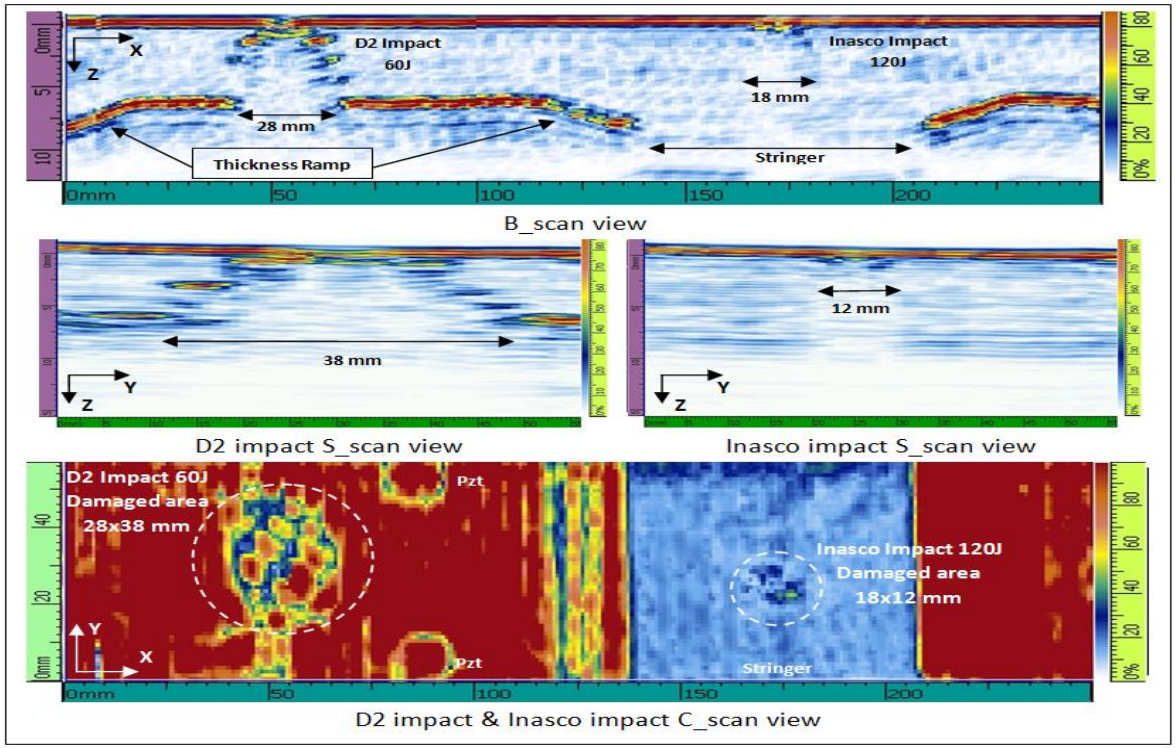
B, S and C-scan impact subgroup D1

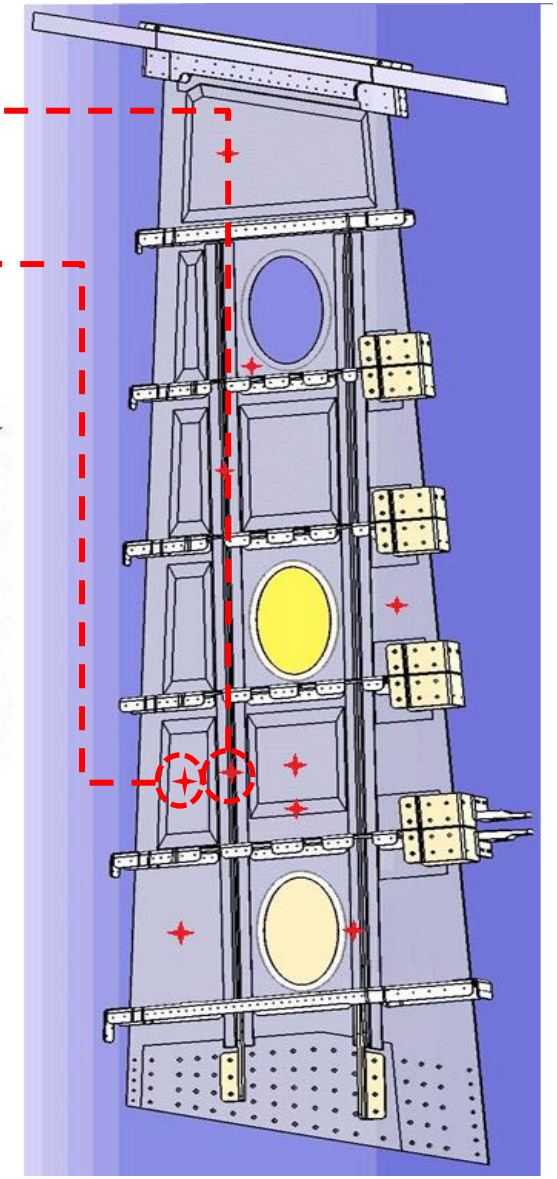




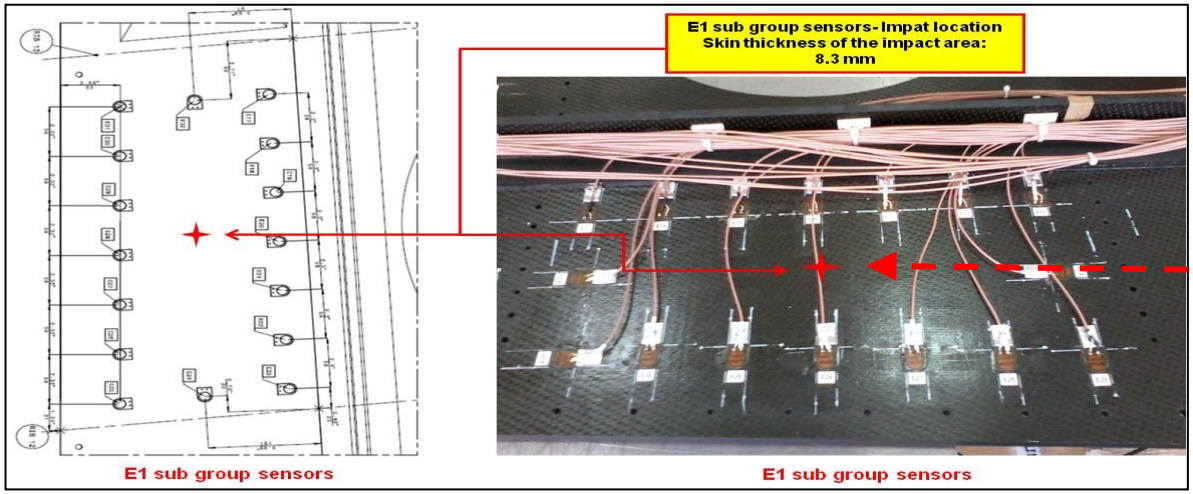
B, S and C-scan impact subgroup D2

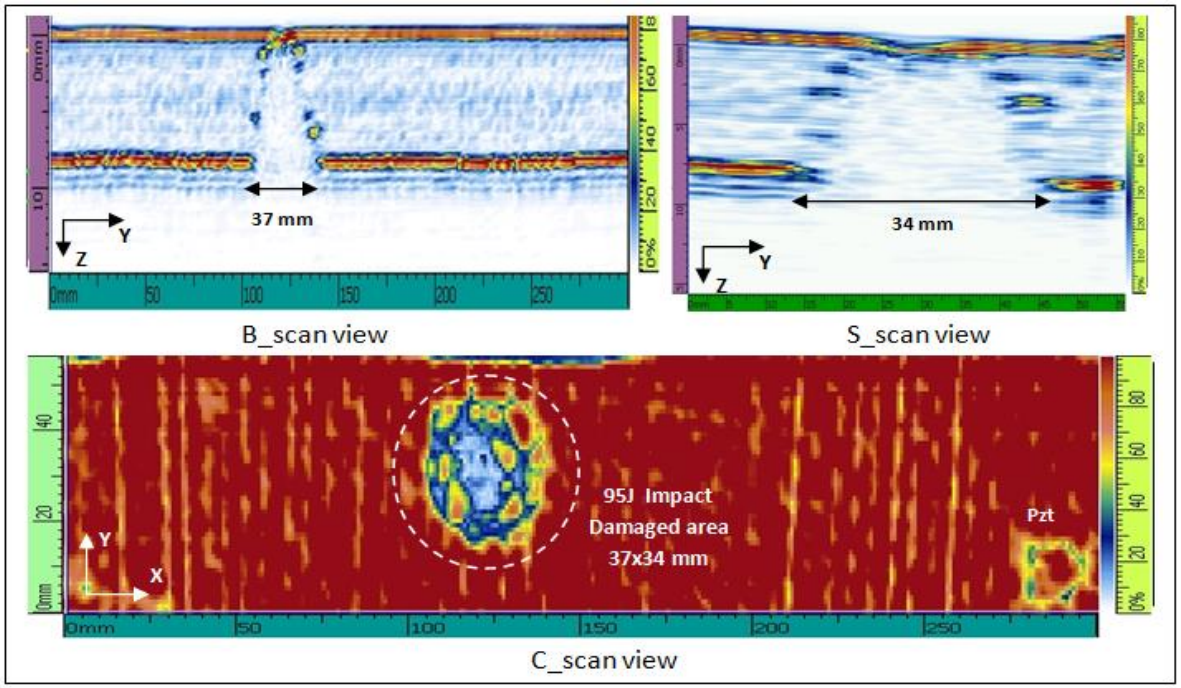


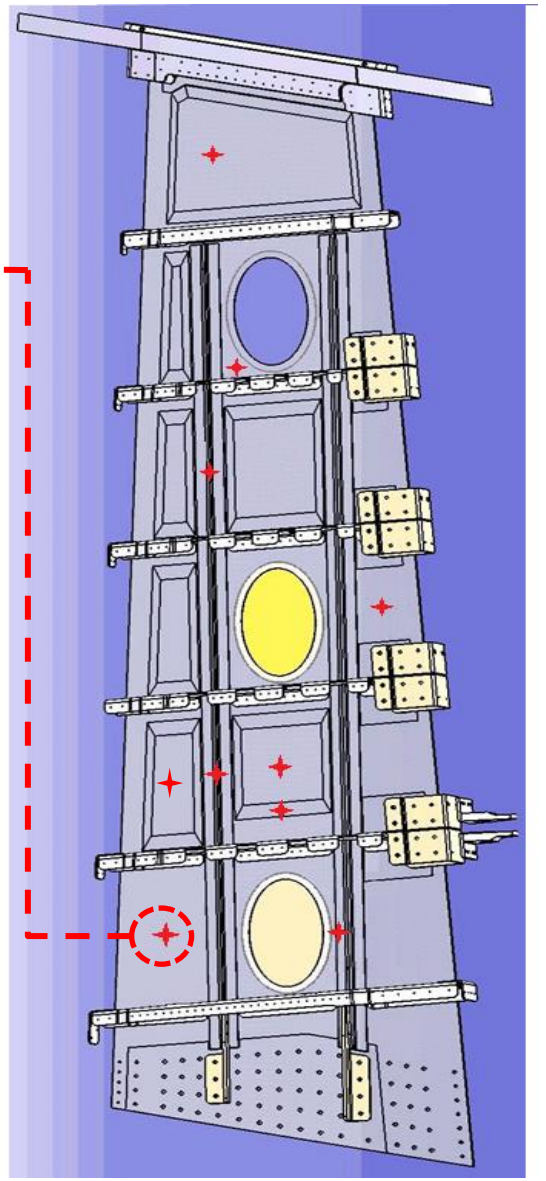




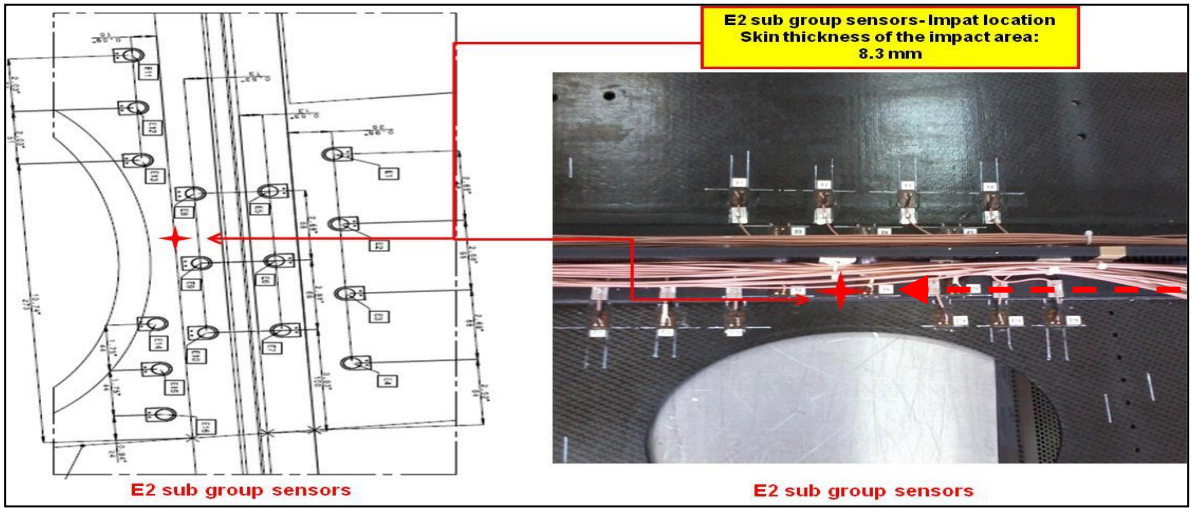
B, S and C-scan impact subgroup E1

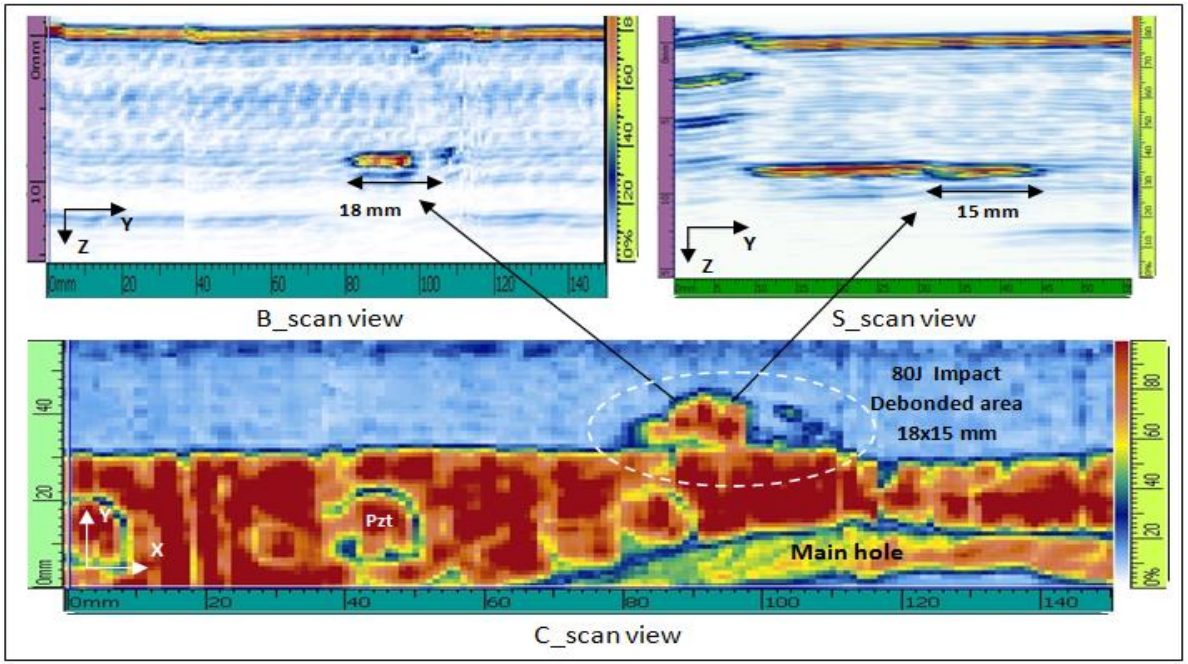






B, S and C-scan impact subgroup E2





Impact location from outside