CEAS COUNCIL OF EUROPEAN AEROSPACE SOCIETIES

Testing of Active Flow Control actuators at harsh environment

Ionut BRINZA (INCAS)

6th CEAS CONFERENCE
16-20 October 2017
Bucharest
ROMANIA

AFLoNext
2ND GENERATION ACTIVE WING

INCAS
National Institute for Aerospace Research "Elie Carafoli"

CEAS COUNCIL OF EUROPEAN AEROSPACE SOCIETIES

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- Introduction
- Results of the harsh environment tests
- Conclusions and future development

INTRODUCTION

General overview :

- The hardware developed in WP 22 for the active flow control based on, Synthetic Jet and Pulsed Jet technologies were subjected to a series of harsh environment tests in the last part of the AFLoNext project.

- The ground tests scope: to evaluate the actuators robustness in extreme environment conditions in order to open their way to a mature TRL.

- Testing of the actuators in the framework of AFLoNext project was performed in INCAS Laboratory according to a test strategy agreed by the hardware developers.

- As a general remark, the test campaign went well except the “Sand and Dust” test-case, where in both cases the actuators failed.

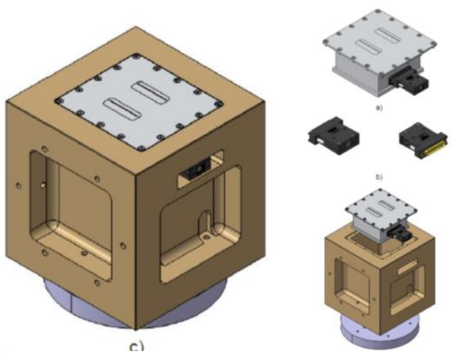
Brief description of the work performed

➢ *Based on our previous experience with the actuators, we perform the "most harshest" tests in the last part of the campaign:*

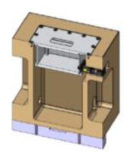
- ✓ External Control of Actuator Panel
- ✓ Testing of functional parameters at normal temperature (baseline measurements)
- ✓ Testing at extreme temperatures (-55°C, +70°C)
- ✓ Testing under artificial rain conditions
- ✓ Testing of operational parameters at icing exposure
- ✓ Testing at mechanical vibration exposure
- ✓ Testing for exposure solid elements contamination
- ✓ Testing at mechanical shocks exposure
- ✓ Testing de-icing fluid
- ✓ Testing at dust and sand winds exposure

Design & Manufacturing of the test Rig
Installation & Instrumentation of the Tile

SYNTHETIC JET : Design, stress and manufacturing status



Test rig for SJ actuators panel:
a) DUT,
b) electrical connector,
c) panel-rig assembly on the vibration machine head plate,
d) panel-rig assembly exploded view,
e) section on the assembly



SYNTHETIC JET : Design, stress and manufacturing status

SJ Test Bench:
- ✓ Milling Interior pockets 80% done.
- ✓ Holes and chamfering – on going

- ✓ Manufacturing is going well, with respect on schedule
- ✓ Delivery date: 16 May 2016

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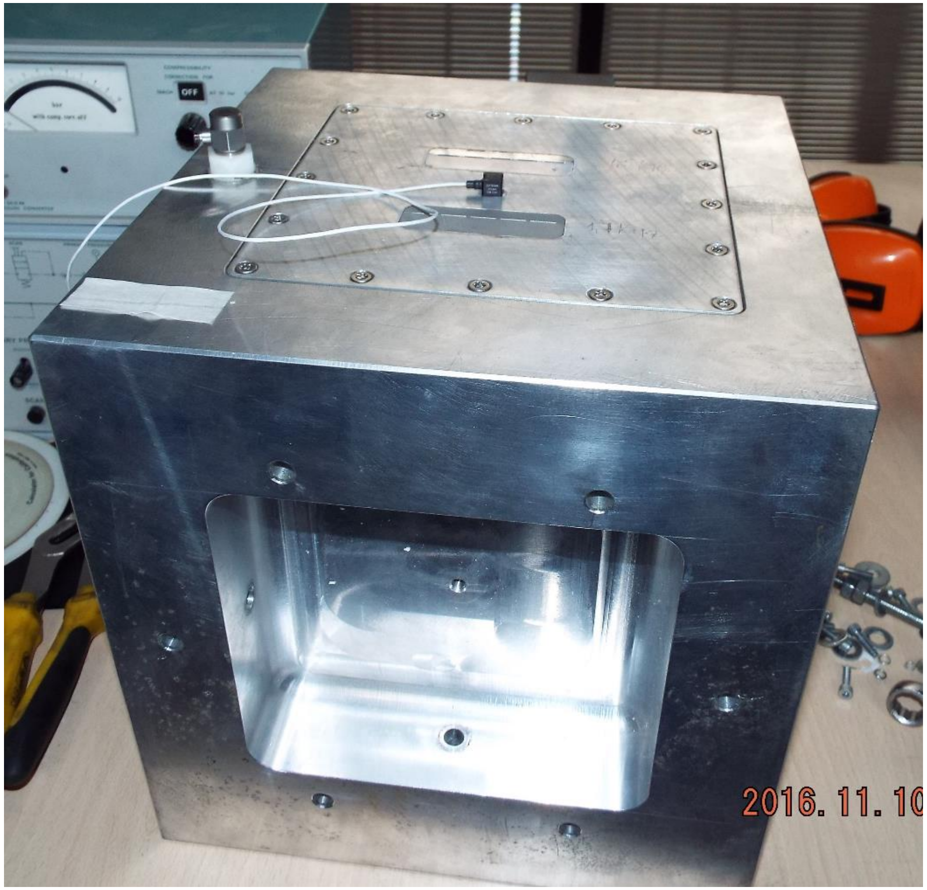
May 2016 15



Design & Manufacturing of the test Rig
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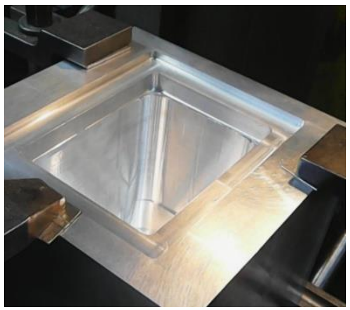
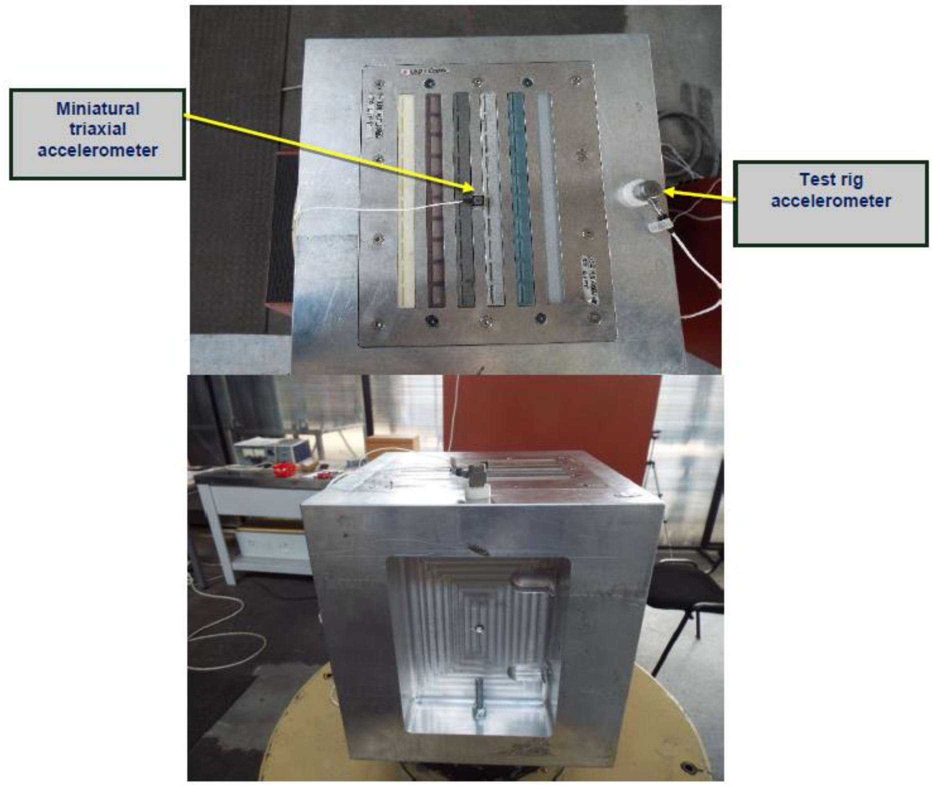




Test No 1.
External Control of the Actuator Panel

- The external control of the actuator panel (consist in)

1. Dimensional verification:
   - ✓ Overall size;
   - ✓ Operational size.
2. Weighting of the aggregate.

Components

-SJ Actuator panel

- 1 row of 5 slots with 30° exit angle
- 1 row of 5 slots with 45° exit angle

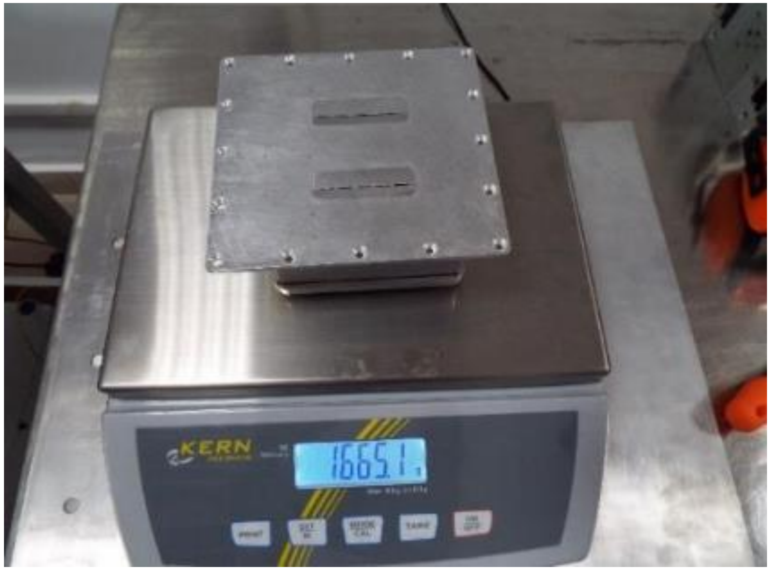
- HJ Actuators panel:

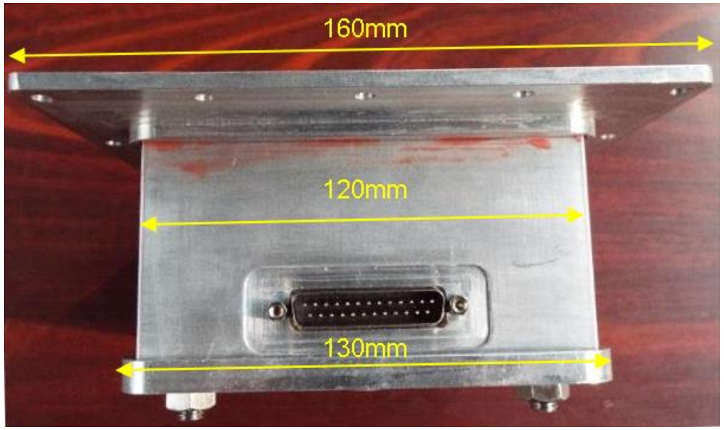
- 1 row - Dummy;
- 1 row of 10 slots with 30° exit angle – Bluestone;
- 1 row of 10 slots with 30° exit angle – Aluminum; - ALM ISSUES
- 1 row of 10 slots with 30° exit angle – Titanium; - ALM ISSUES
- 1 row of 10 slots with 30° exit angle – Formlabs HT;
- 1 row of 10 slots with 30° exit angle – PerFORM ;

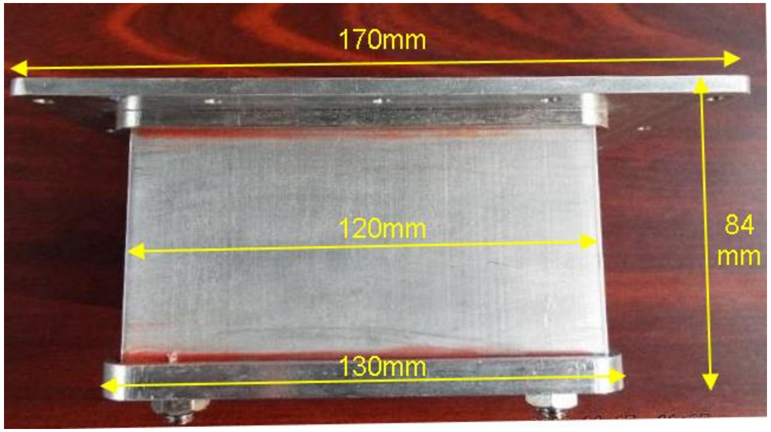
Test No 1.
External Control for SJ Actuator Panel

SJ actuators panel design by FRAUN;

- Test rig actuators panel designed by INCAS;



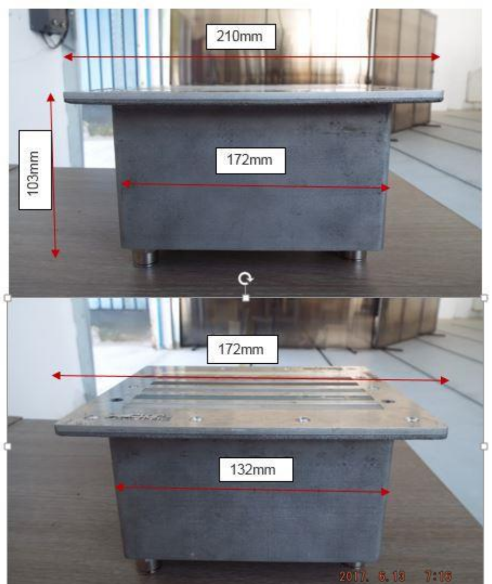


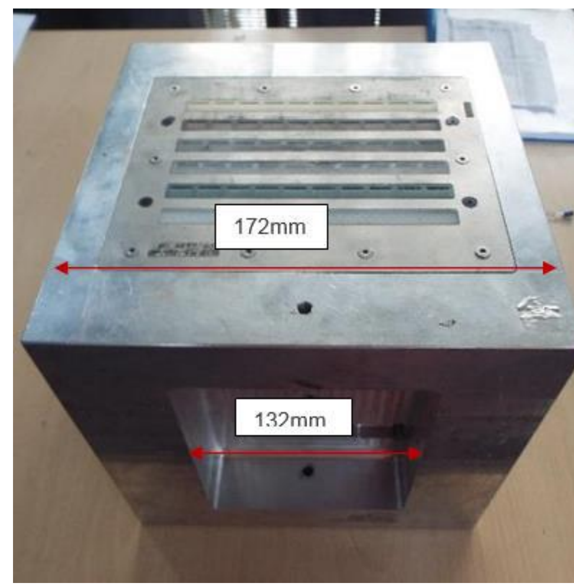


Test No 1.
External Control of the Actuator Panel

HJ actuators panel design by AGI;

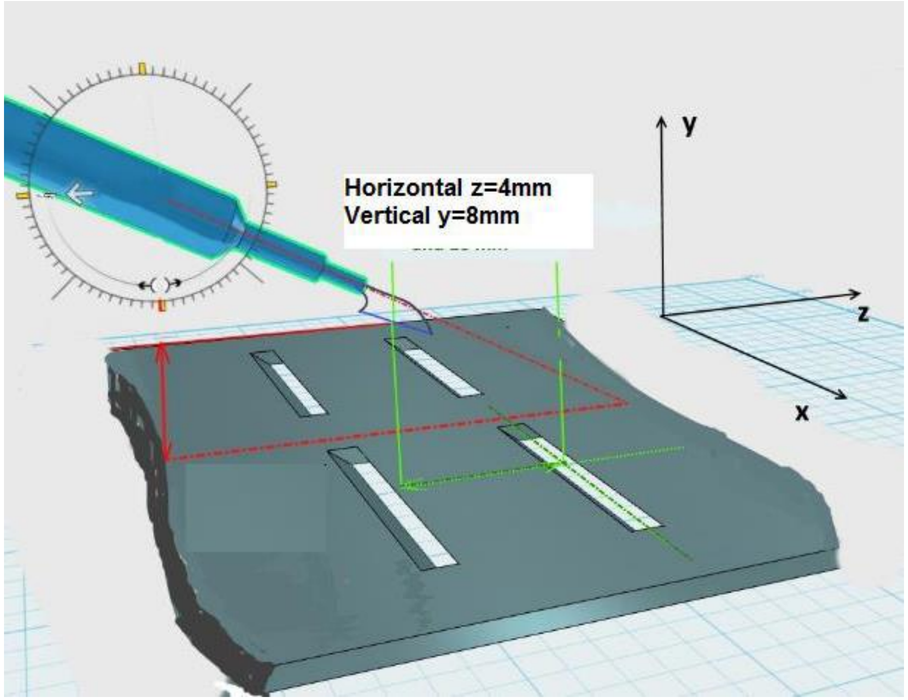
- Test rig for HJ actuators panel designed by INCAS;
- Mounting of the HJ actuators panel on the test rig.





Test No 2.
Functional Parameters (Normal Conditions)

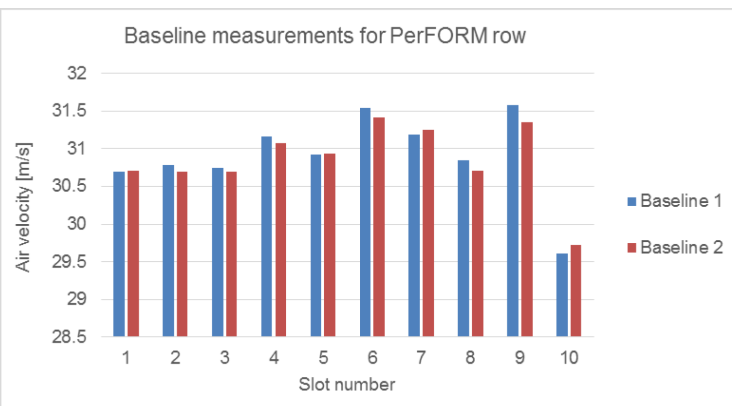
- Measurements will be made for each slot individually, taking into account the system performance and spatial resolution, in a continuous pass across the length of the slot;
- In order to account for the flow geometry, we shall place the probes at a starting position of **4 mm** from the slot and **8 mm** above it, and take a pass at room temperature, and then modifying the distance we will try to find the most interesting flow profile (maximum speed or maximum speed variation).

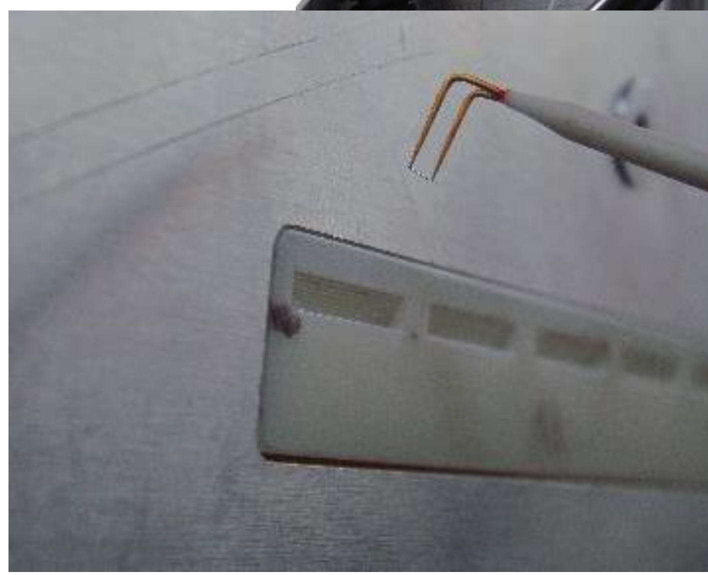


Test No 2.
Functional Parameters (PerFORM) – Hot Wire

- The PerFORM slots were supplied with compressed air at 1 bar (control stage at 1 bar and drive stage at 1,2 bar) – normal temperature

Slot no.	P = 1 bar (Supply pressure)	
	Baseline 1 [m/s]	*Baseline 2 [m/s]*
1	18.954	17.453
2	20.382	20
3	26.627	26.571
4	26.858	26.782
5	27.067	27.086
6	27.078	27.08
7	27.029	27.016
8	27.14	27.061
9	27.158	27.065
10	26.773	26.749
Geometrical configuration	Y = 4 mm, Z = 8mm	Y = 4 mm, Z = 8 mm

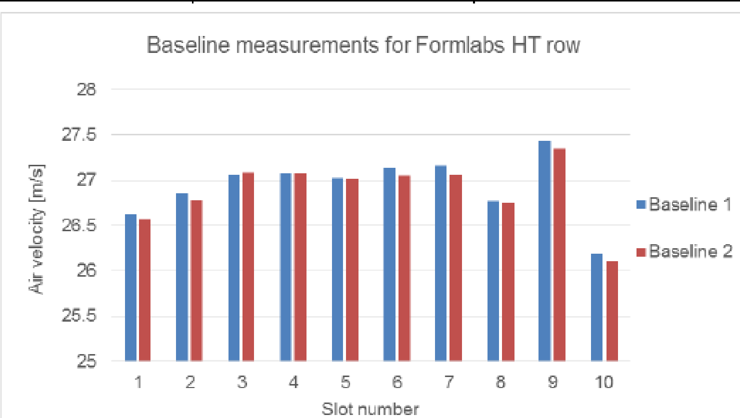


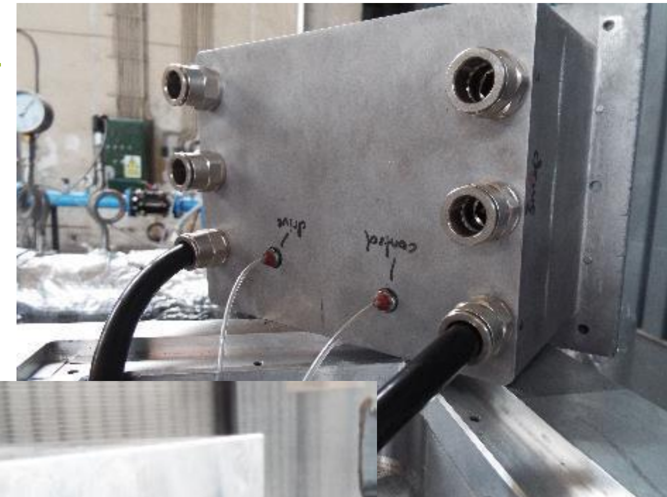


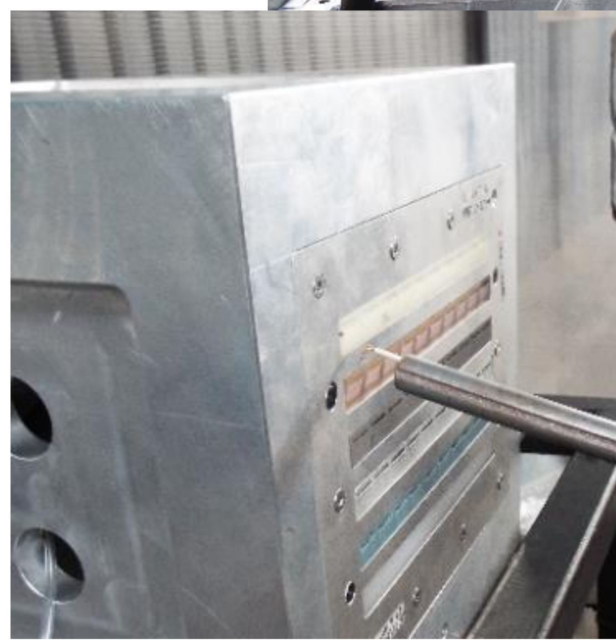
Test No 2.
Functional Parameters (Formlabs) – Hot Wire

- The Formlabs slots were supplied with compressed air at 1 bar (control stage at 1 bar and drive stage at 1,2 bar) – normal temperature.

Slot no.	P = 1 bar (Supply pressure)	
	Baseline 1 [m/s]	*Baseline 2 [m/s]*
1	16.371	16.814
2	20.392	20.014
3	30.694	30.71
4	30.78	30.696
5	30.745	30.696
6	31.164	31.069
7	30.925	30.93
8	31.54	31.408
9	31.192	31.244
10	30.847	30.709
Geometrical configuration	Y = 4 mm, Z = 8mm	Y = 4 mm, Z = 8 mm

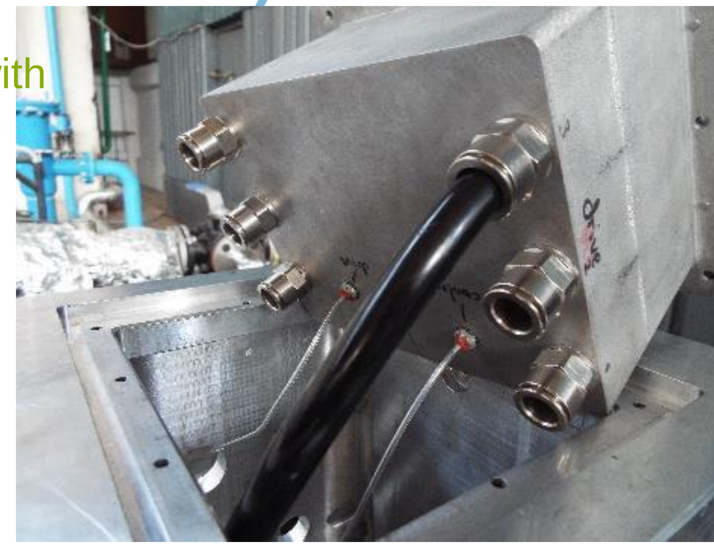






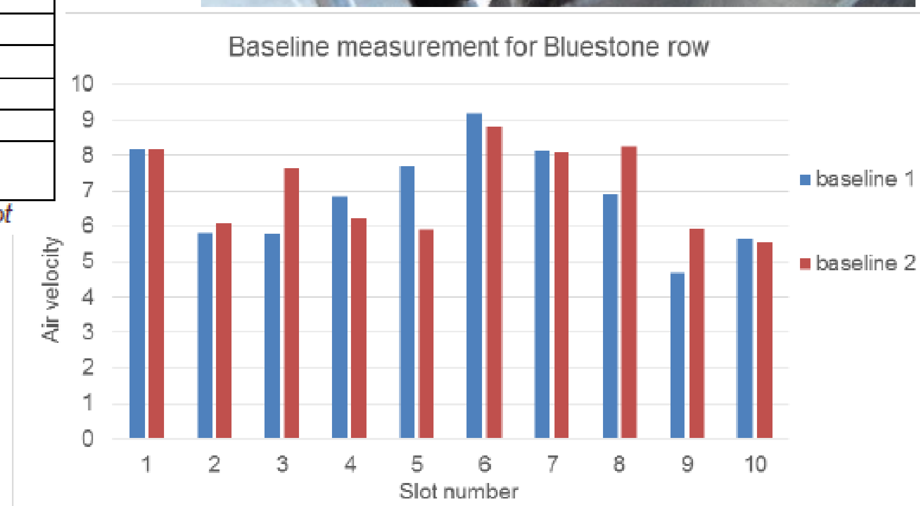
Test No 2.
Functional Parameters (Bluestone) – Hot Wire

- The Bluestone slots were supplied with compressed air at 0.6 bar – normal temperature
- the inclination angle of the hot wire was 15°.



Slot no.	P = 0,6 bar (Supply pressure)	
	Baseline 1 [m/s]	*Baseline 2 [m/s]*
1	8.19	8.20
2	5.81	6.08
3	5.79	7.64
4	6.82	6.24
5	7.68	5.90
6	9.20	8.83
7	8.12	8.08
8	6.90	8.26
9	4.69	5.94
10	5.63	5.56
Geometrical configuration	Z = 4 mm, Y = 8mm	Z = 4 mm, Y = 8 mm

Hot wire air velocity baseline measurements for Bluestone slot

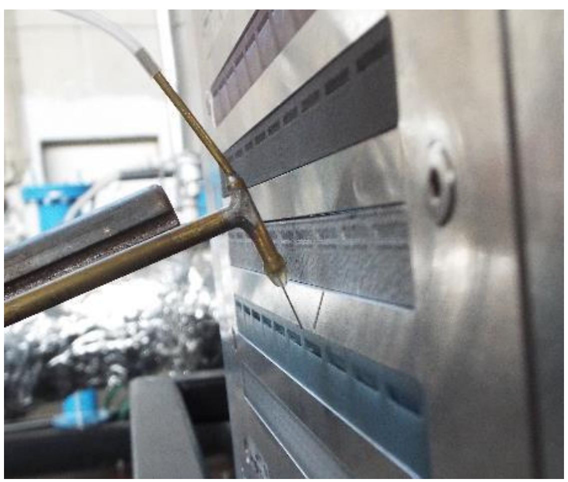


Hot wire measurements for Bluestone slot

Test No 2.
Functional Parameters - Pitot Tube

- The Pitot tube was aligned for air velocity baseline measurements at 15° incidence
- Measurements were made for each slot individually in a continuous pass along the length of the slot.
- In order to account for the flow geometry, we placed the probes at the following positions – see table
- Bluestone, Formlabs and PerFORM pulsed jets

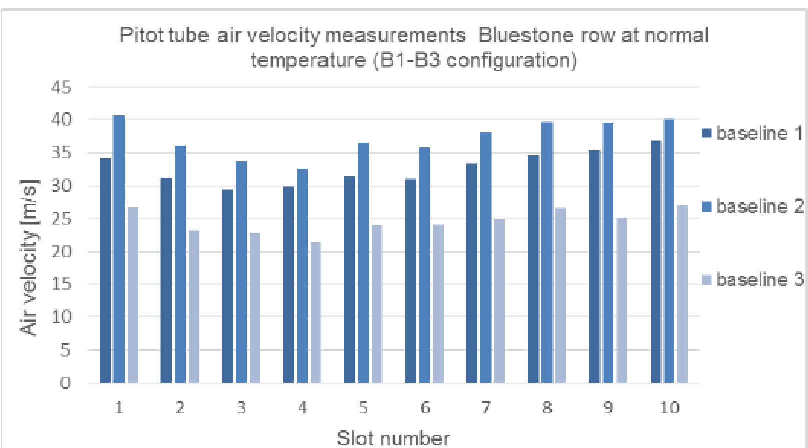
Slots no.	Distance to slot from the Pitot tube		Row*	
	Z [mm]	Y [mm]		
B1	1	10	1	Bluestone row
B2	1,5	10	1	
B3	2	10	1	
B4	2	15	1	
B5	1,5	15	1	
B6	1	15	1	
B7	1	10	2	Formlabs HT row
B8	1,5	10	2	
B9	2	10	2	
B10	2	15	2	
B11	1,5	15	2	
B12	1	15	2	
B13	1	10	3	PerFORM row
B14	1,5	10	3	
B15	2	10	3	
B16	2	15	3	
B17	1,5	15	3	
B18	1	15	3	

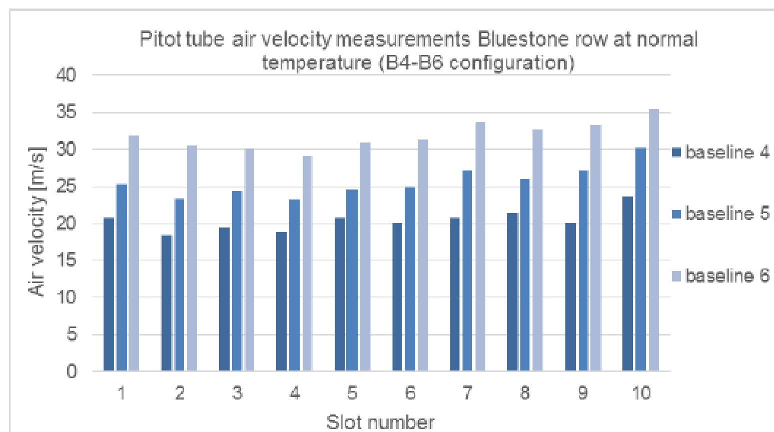


Test No 2. - Normal temperature
Functional Parameters (Bluestone) – Pitot Tube

Slot no.	Geometrical configuration test (Slots no.)					
	B1 [m/s]	*B2 [m/s]*	*B3 [m/s]*	*B4 [m/s]*	*B5 [m/s]*	*B6 [m/s]*
1	34.15455	40.8035	26.72721	20.71034	25.27393	31.77187
2	31.21377	36.11915	23.22099	18.30966	23.25044	30.41906
3	29.47537	33.63394	22.76764	19.44375	24.33113	30.11523
4	29.97508	32.59802	21.43666	18.89079	23.09473	29.16372
5	31.26852	36.52825	23.87095	20.70891	24.64905	30.86535
6	30.94282	35.72034	24.17088	20.07125	24.82775	31.24978
7	33.31027	38.06848	24.9254	20.72111	27.12354	33.70853
8	34.59852	39.61176	26.63974	21.3996	25.93078	32.65395
9	35.46373	39.46964	25.17728	20.11494	27.14709	33.27043
10	36.79481	40.13821	26.9614	23.54953	30.2152	35.33805

Pitot tube baseline measurements for Bluestone row at normal temperature



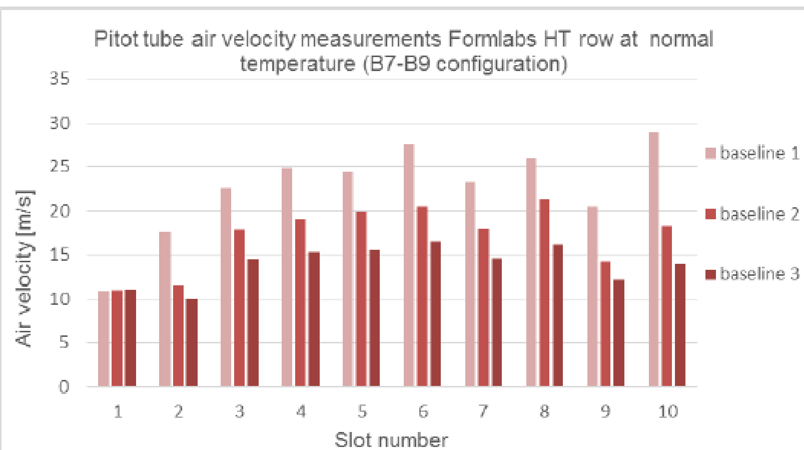


Pitot tube air velocity measurements for Bluestone row with geometrical configuration at y=10mm *at y=15 mm*

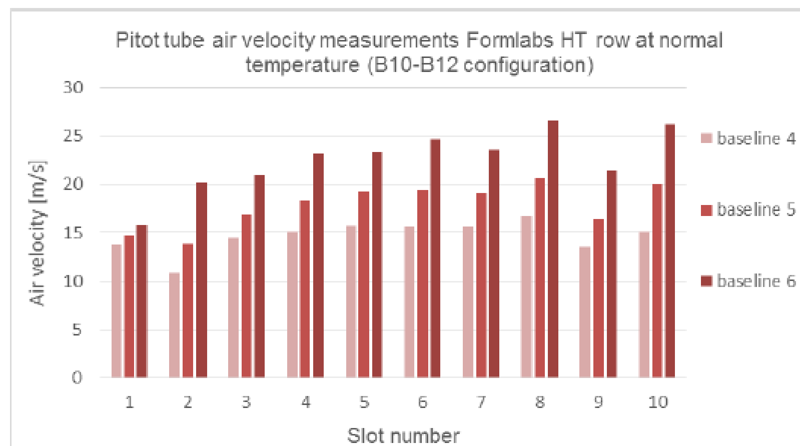
Test No 2. Normal temperature Functional Parameters (Formlabs) – Pitot Tube

Slot no.	Geometrical configuration test					
	B7 [m/s]	*B8 [m/s]*	*B9 [m/s]*	*B10 [m/s]*	*B11 [m/s]*	*B12 [m/s]*
1	10.89089	10.94521	11.06674	13.73946	14.63608	15.79801
2	17.72434	11.51086	10.07005	10.87493	13.85509	20.14677
3	22.58702	17.97853	14.50063	14.48188	16.95374	20.98589
4	24.84823	19.1251	15.36846	15.09915	18.28268	23.11185
5	24.37938	19.92373	15.57045	15.72164	19.27162	23.3975
6	27.56736	20.56616	16.45758	15.68231	19.49846	24.64453
7	23.33627	18.08464	14.66511	15.65447	19.18501	23.54251
8	26.06447	21.29538	16.11162	16.77306	20.57577	26.66471
9	20.54244	14.24035	12.11786	13.53863	16.44824	21.45248
10	28.98904	18.24518	14.05918	15.1566	20.10131	26.25219

Pitot tube baseline measurements for Formlabs HT row at normal temperature



Pitot tube air velocity measurements for Formlabs HT row with geometrical configuration at y=10mm

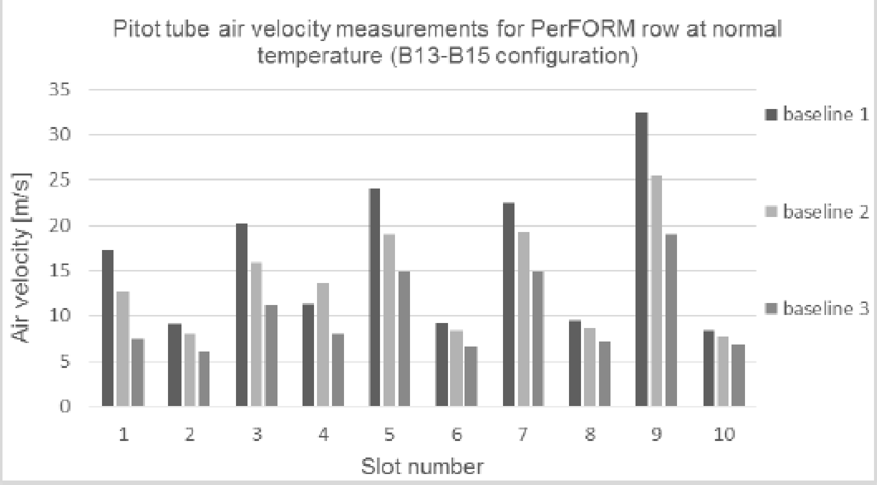


Pitot tube air velocity measurements for Formlabs HT row with geometrical configuration at y=15mm

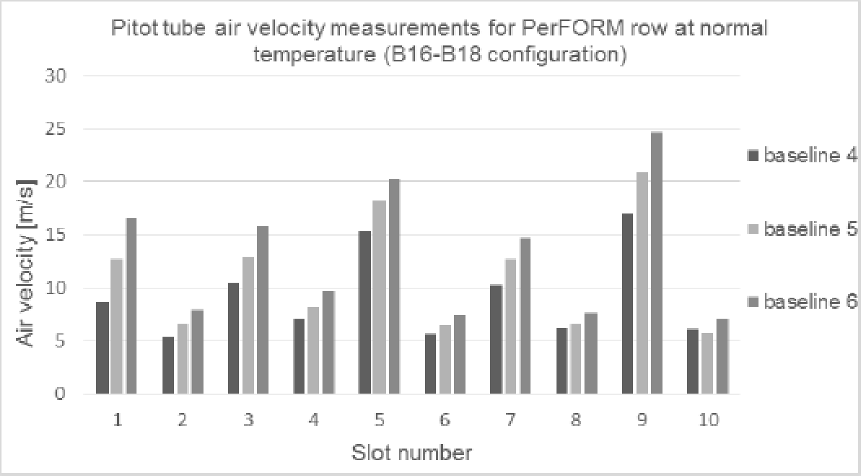
Test No 2. Normal temperature
Functional Parameters (PerFORM) – Pitot Tube

Slot no.	Geometrical configuration test					
	B13 [m/s]	*B14 [m/s]*	*B15 [m/s]*	*B16 [m/s]*	*B17 [m/s]*	*B18 [m/s]*
1	17.34348	12.73277	7.506609	8.692592	12.75953	16.54636
2	9.078555	8.008869	6.13293	5.463977	6.573743	7.967553
3	20.2331	15.91473	11.23205	10.43729	12.92385	15.78265
4	11.40619	13.62164	8.030867	7.068533	8.128159	9.697499
5	24.1499	19.07448	14.95203	15.3929	18.20298	20.29602
6	9.219115	8.349563	6.585614	5.697303	6.500868	7.443509
7	22.44105	19.23992	14.97639	10.26368	12.71031	14.72405
8	9.52705	8.655051	7.311728	6.131502	6.554407	7.595791
9	32.48517	25.43259	19.02891	16.92161	20.86575	24.65237
10	8.360952	7.81044	6.850765	6.019213	5.728572	7.090061

Pitot tube baseline measurements for PerFORM row at normal temperature



Pitot tube air velocity measurements for PerFORM row with geometrical configuration at y=10mm



Pitot tube air velocity measurements for PerFORM row with geometrical configuration at y=15mm

Test No 3.
Extreme Temperatures - OK

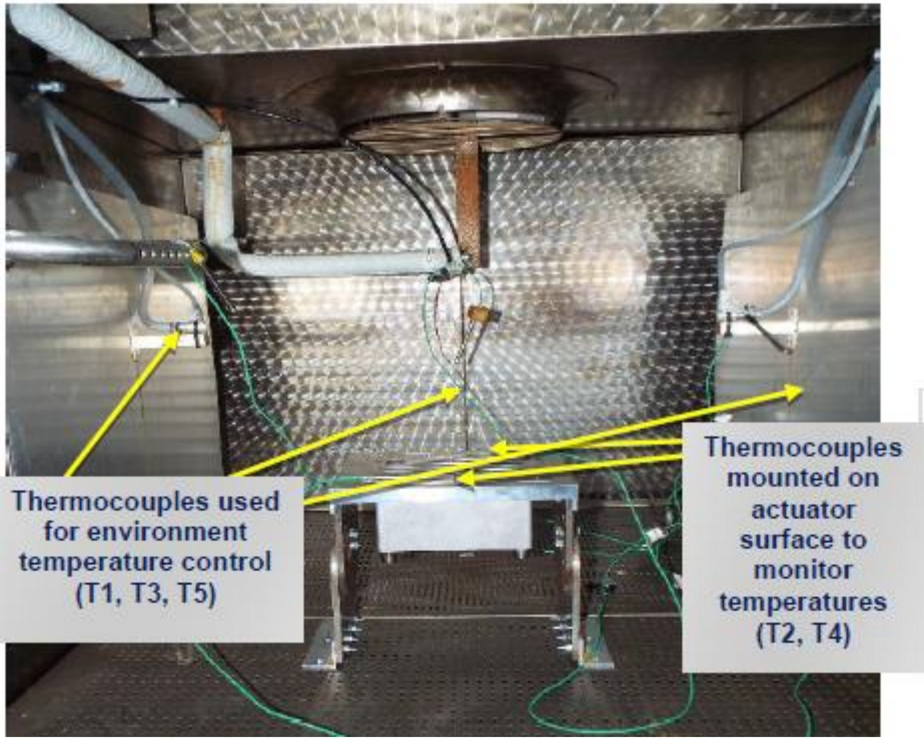
- The actuators panel was installed on a dedicated test bench-interface.
- The entire assembly is placed into an enclosure where the working temperature is established at +70^{0}C
- (EUROCAE ED-14G, Section 4.5.4).

- Nominated temperature levels was maintained for 1 hour to stabilize the temperature.

- Climatic test chamber: Ilka STBV-1000
  - ✓ Temperature control ± 200^{0}C
  - ✓ Max vacuum. 1.5 Torr (reachable in ½ h)
  - ✓ Test chamber volume: 1 m³
  - ✓ Test chamber length: 1.16 m
  - ✓ Test chamber width: 1.0 m
  - ✓ Test chamber height: 0.84 m

Test No 3.
Extreme Temperatures-low temperature (1)

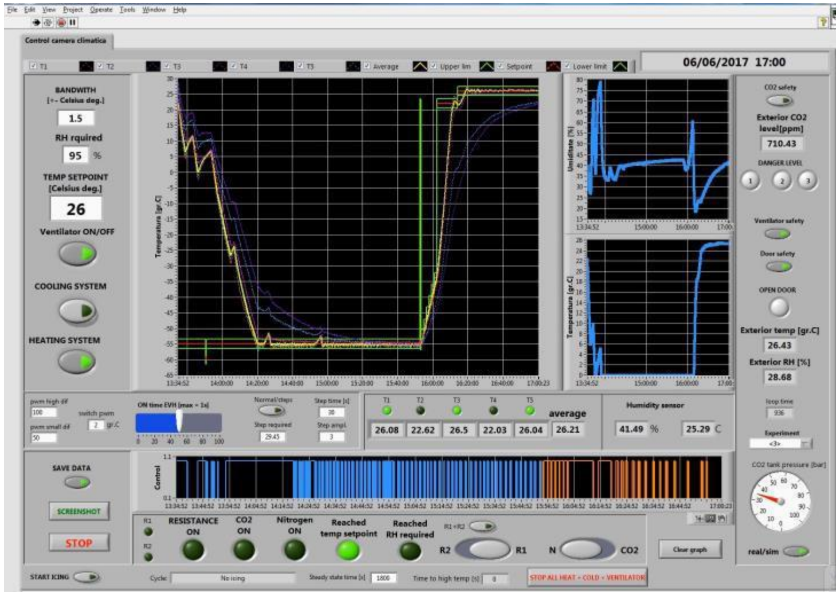
- The actuator was visually inspected and weighted before its placement in the climatic chamber test rig and equipped with temperature sensors to monitor its surface temperature

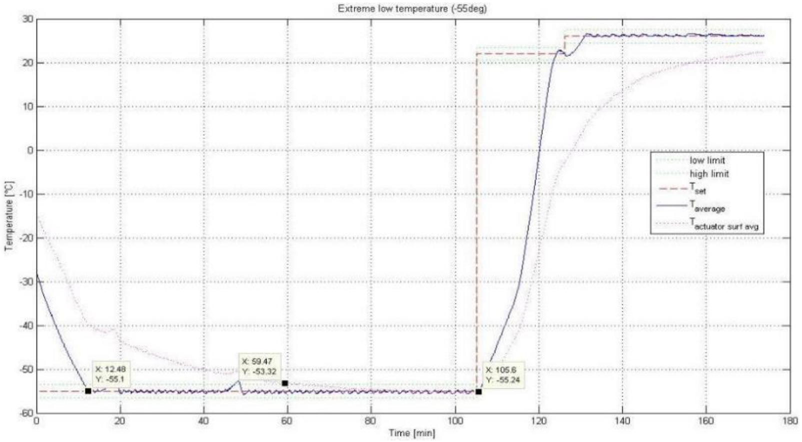


- ✓ Mass of the actuator before the test – m_i= 3310,88g
- ✓ Ambient temperature around climatic chamber before test = 26°C
- ✓ Relative humidity around climatic chamber before test = 28,25%
- ✓ Initial climatic chamber average temperature = 24,5°C

Test No 3.
Extreme Temperatures-low temperature (2)

- After the one hour exposure at -55°C temperature, the climatic chamber door was opened (while the ventilator was still working to assure an uniform distribution of temperature in the environment around the actuator) to visually inspect the device surface and record images of the setup.
- After reaching ambient temperature the actuators panel was removed from the test rig and visually inspected and weighted. There were no changes or deformations observed in the device test rig or insulating material.





✓ Mass of the actuator after the test

m= 3312.06g

✓ Ambient temperature around climatic chamber after test

T= 26.53°C

✓ Relative humidity around climatic chamber after test

RH= 28.68%.

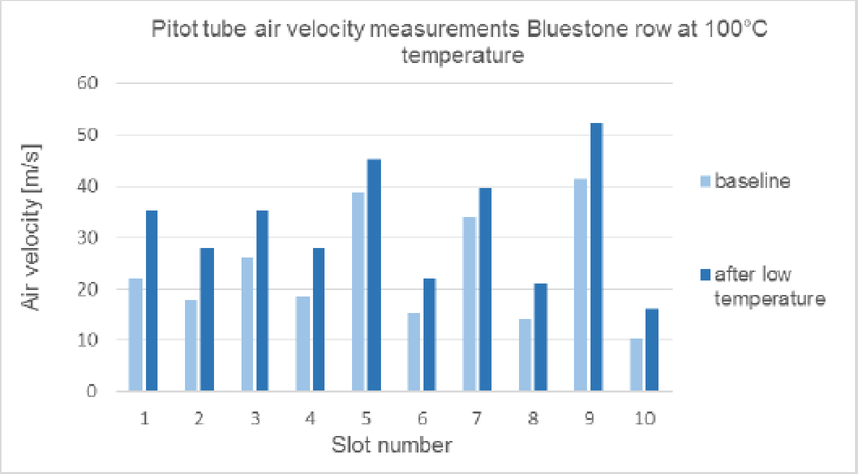
Test No 3.
Extreme Temperatures-low temperature (3)

Aerodynamic measurements after low temperature test

- Measurements were made for each slot individually, taking into account the system performance and spatial resolution, in a continuous pass along the length of the slot. We placed the probes at a incidence 15o and take a pass at 100°C temperature, and then modifying the geometry configuration of Pitot tube, we tried to find the most interesting flow profile (maximum speed or maximum speed variation).

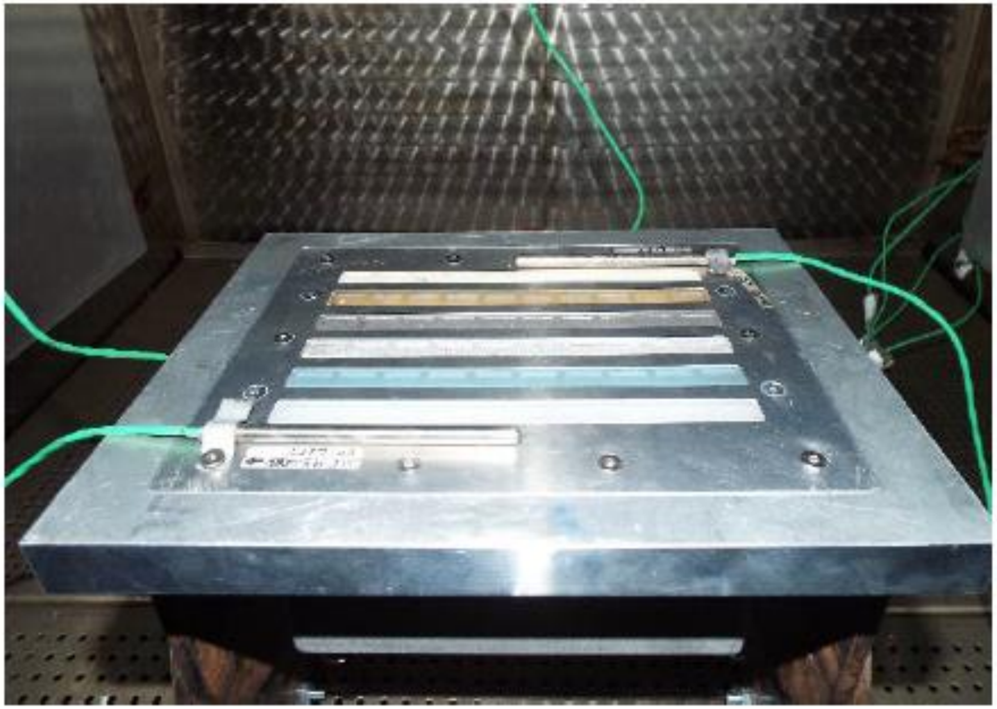
Slot no.	*Baseline [m/s]*	*After low temperature [m/s]*	*Temperature [°C]*	*Supply pressure [bar]*	*Mass flow rate [kg/h]*
1	21.8792	35.08745	102.05	0.6	20
2	17.91537	27.9144			
3	26.26505	35.13384			
4	18.59675	27.85247			
5	38.80303	45.24886			
6	15.36219	21.89363			
7	33.85234	39.63			
8	14.01861	21.12581			
9	41.44787	52.29194			
10	10.48856	16.21679			

Post test results for distances z=1mm ; y=10mm



Test No 3.
Extreme Temperatures-high temperature (1)

- The actuator was visually inspected and weighted before its placement in the climatic chamber test rig and equipped with temperature sensors to monitor its surface temperature



Thermocouples mounted on the actuator surface to monitor temperatures (T2, T4)

- ✓ Mass of the actuator before the test – m_i= 3310,88g
- ✓ Ambient temperature around climatic chamber before test = 23,95°C
- ✓ Relative humidity around climatic chamber before test = 41,11%
- ✓ Initial climatic chamber average temperature = 24,2°C

Test No 3.
Extreme Temperatures-high temperature (2)

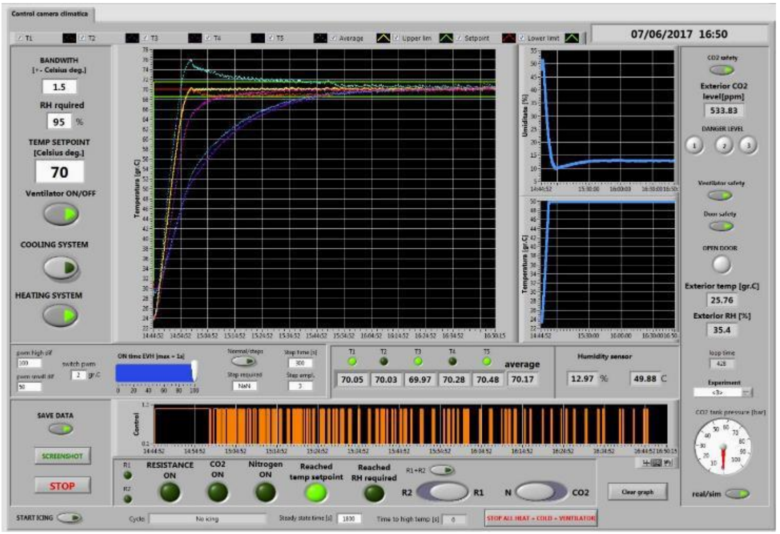
- After the one hour exposure of the device at 70°C the climatic chamber door was opened for visual inspection after which the environment was left to cool slowly until it reached ambient temperature to avoid thermal shocks.
- The device was removed from the test rig and visually inspected to see any changes after the high temperature test. No changes of the actuators or insulating material degradation were observed.

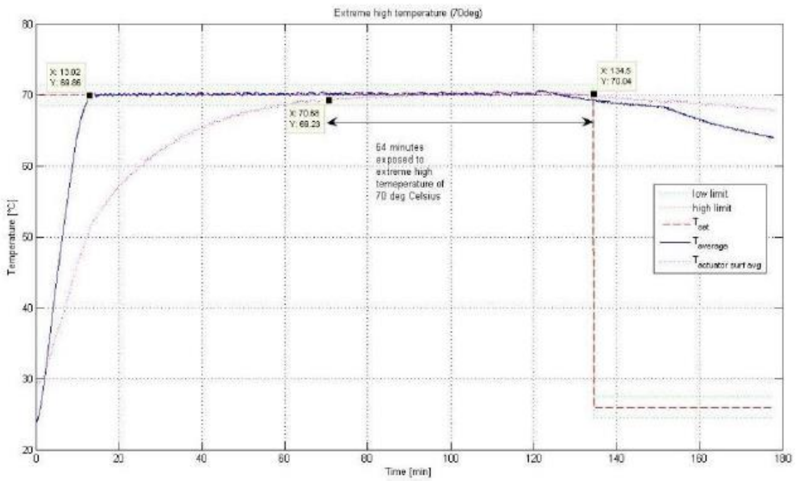
✓ Mass of the actuator after the test

m= 3311.16g

✓ Ambient temperature around climatic chamber after test
T=25.76°C

✓ Relative humidity around climatic chamber after test
RH=35.4 %





High temperature test result

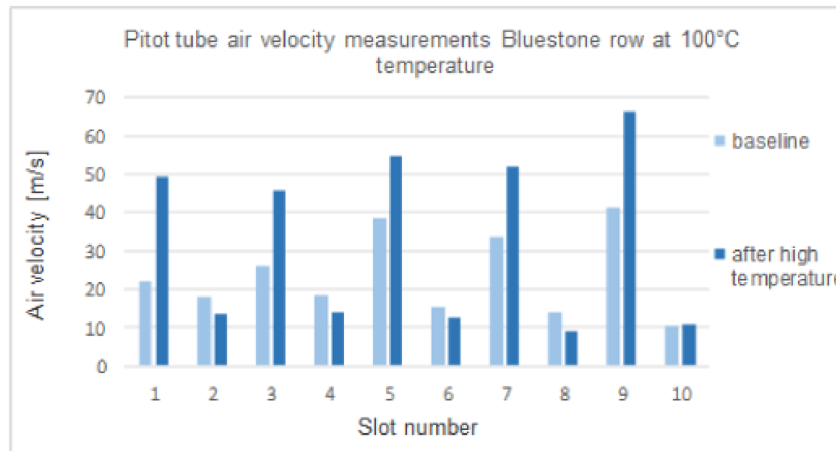
Test No 3.
Extreme Temperatures-high temperature (3)

Aerodynamic measurements after low temperature test

- Measurements were made for each slot individually, taking into account the system performance and spatial resolution, in a continuous pass along the length of the slot. We placed the probes at a incidence 15deg and take a pass at 100°C temperature, and then modifying the geometry configuration of Pitot tube, we tried to find the most interesting flow profile (maximum speed or maximum speed variation).
- Air velocity measurements with Pitot tube were made for each slot individually, taking into account the system performance and spatial resolution, in a continuous pass along the length of the slot. We placed the probes at a starting position: 1, 1.5 and 2 mm from the slot and 10 mm above it then 1, 1.5 and 2 mm from the slot and 15 mm above it and take a pass at 100°C temperature.

Slot. no.	*Baseline [m/s]*	*After high temperature [m/s]*	*Temperature [°C]*	*Supply pressure [bar]*	*Mass flow rate [kg/h]*
1	21.8792	49.54906	95.45	0.61	19
2	17.91537	13.720209			
3	26.26505	45.894267			
4	18.59675	13.906711			
5	38.80303	54.539794			
6	15.36219	12.44773			
7	33.85234	51.91855			
8	14.01861	8.895664			
9	41.44787	66.443182			
10	10.48856	10.834416			

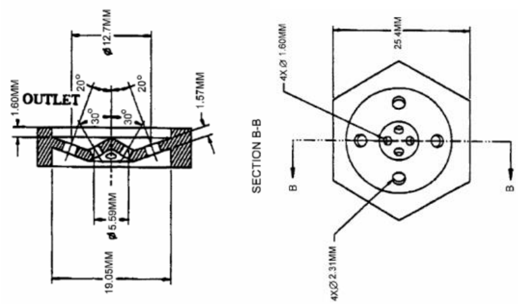
Post test results for distances z=1mm ; y=10mm



Comparison between baseline and post high temperature test for distances z=1mm ; y=10mm

Test No 4.
Artificial Rain - OK

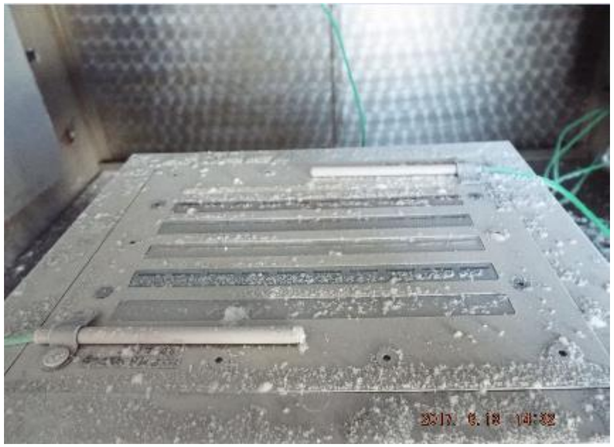
- Testing of operational parameters under artificial rain conditions aims to verify if there is any risk of water penetration inside the actuators panel.
- The test is performed according to EUROCAE ED-14G standard, Section 10.3.3. The actuators panel is installed on a suitable holder in a similar fitting position and with similar mechanical connections as on the aircraft.
- The actuators panels are supplied with 230 V AC for electronical components.

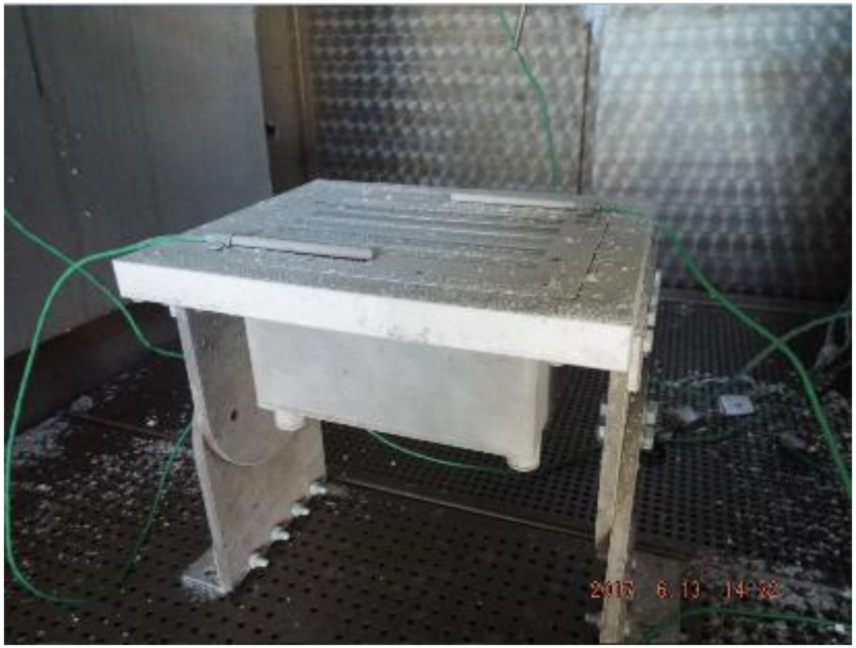


Test No 5.
Icing Exposure -n OK

The icing test aims to determine to what extent the actuators panel is affected by the ice formation and it is performed according to Section 24.4.2, EUROCAE ED-14G standard;

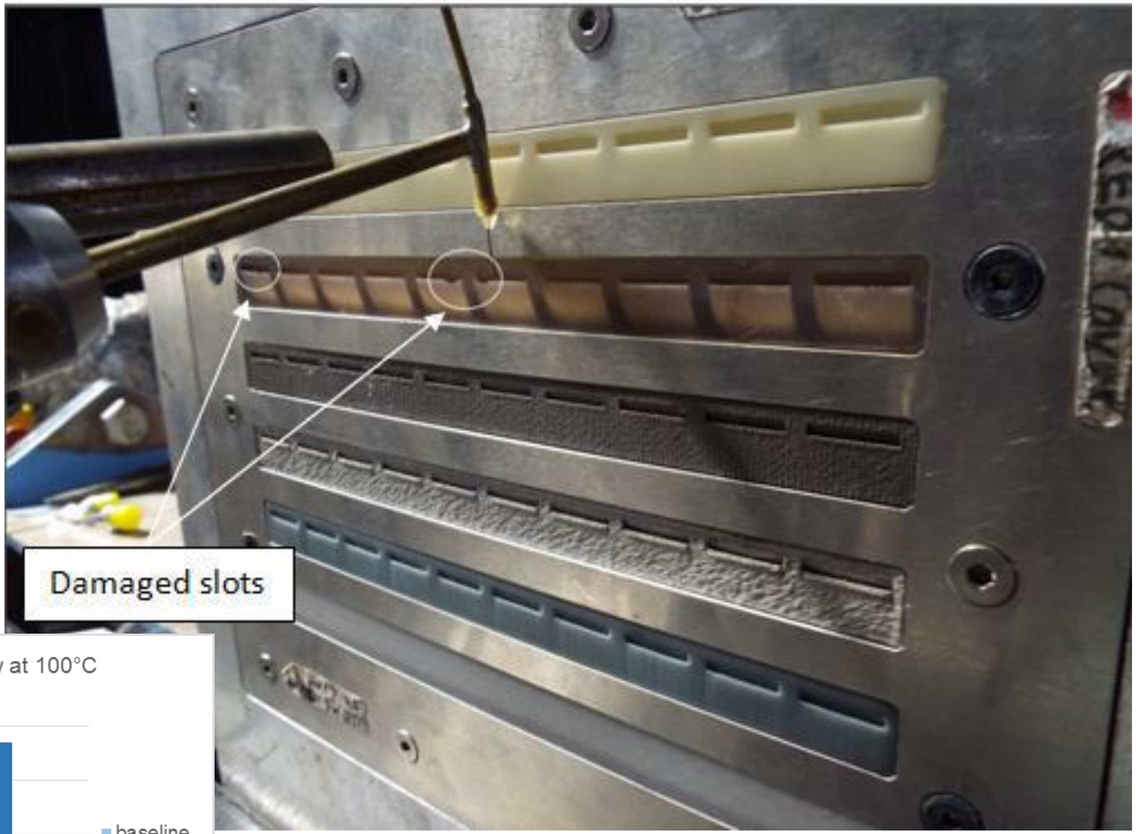
The HJ actuators panel is thoroughly cleaned in order to remove the elements that affect adhesion between ice and its surface (such as oil, grease, dirt).

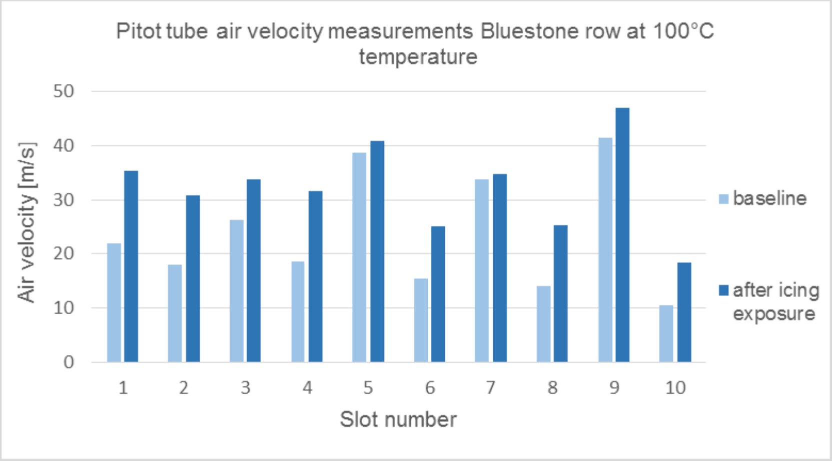




Test No 5.
Icing Exposure

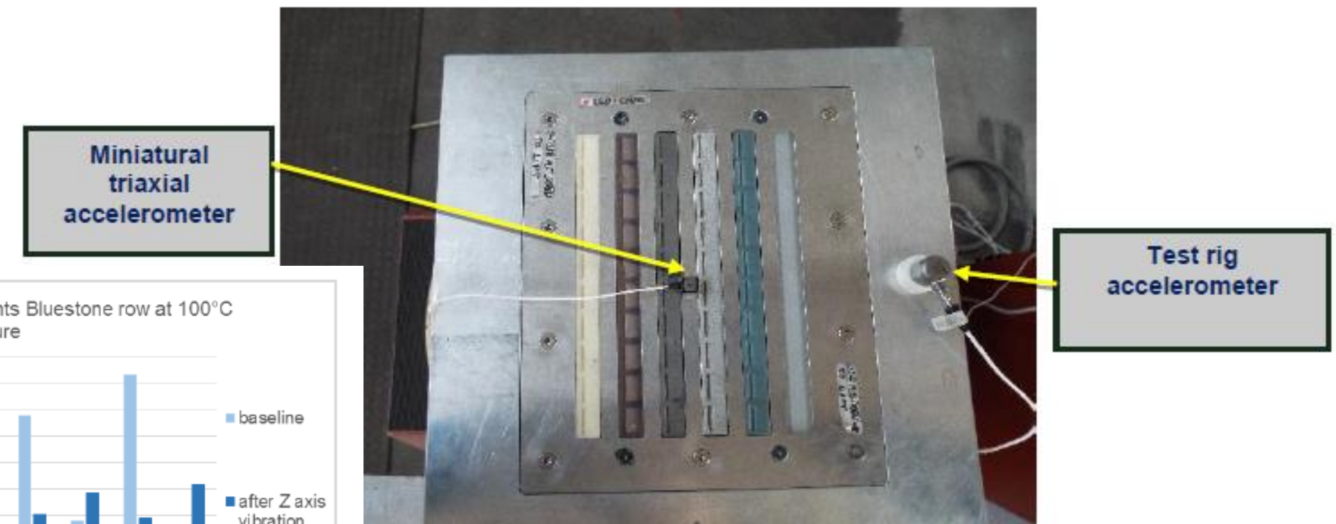
Observation: After visual inspection, this test has reveal the fact that plastic material is influenced by the icing accretion on the thinnest side of the actuators nozzle wall**.**

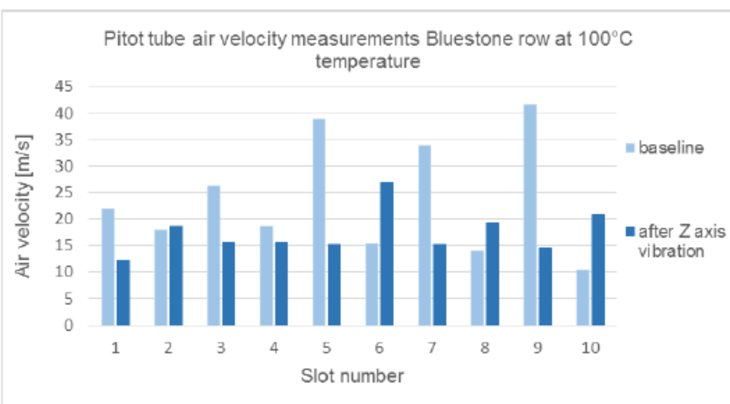




Test No 6.
Mechanical Vibrations - OK

- The actuators panel was tested in the frequency domain 5-2000 Hz, with a sweep rate not greater than 1 octave/min. The accelerometers signal recorded a level of accelerations
- Also, the actuators panel was NOT “operational” during the mechanical shock test.





Comparison between baseline and post vibration test for distances z=1mm ; y=10mm

Test No 7.
Mechanical Shock - OK

- The test is performed on a mechanical shocks testing-machine. The actuators panel is fitted with the same gripping as on the aircraft, in a device that allows it's positioning so that the force resulting from the shock exposure manifests in one of the 6 directions derived from movements in planes parallel to the coordinate axes planes of the airplane. This test is based on EUROCAE ED-14G standard, Section 7.

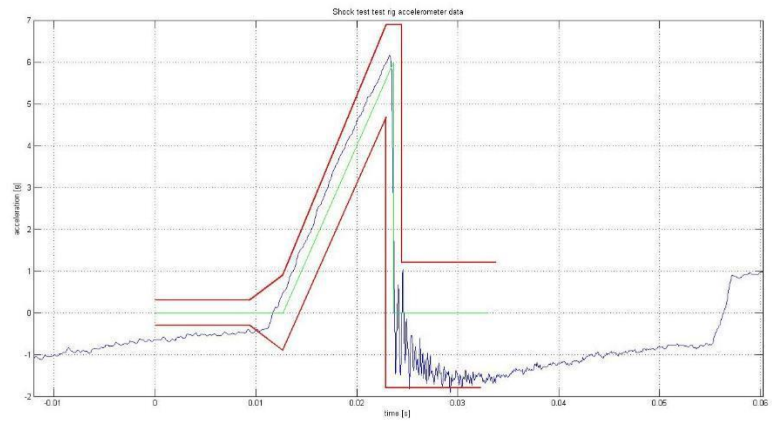
- The input shock is measured by an accelerometer, placed as close as possible to the actuators panel attachment point, with an accuracy of ±10% of standard reading.

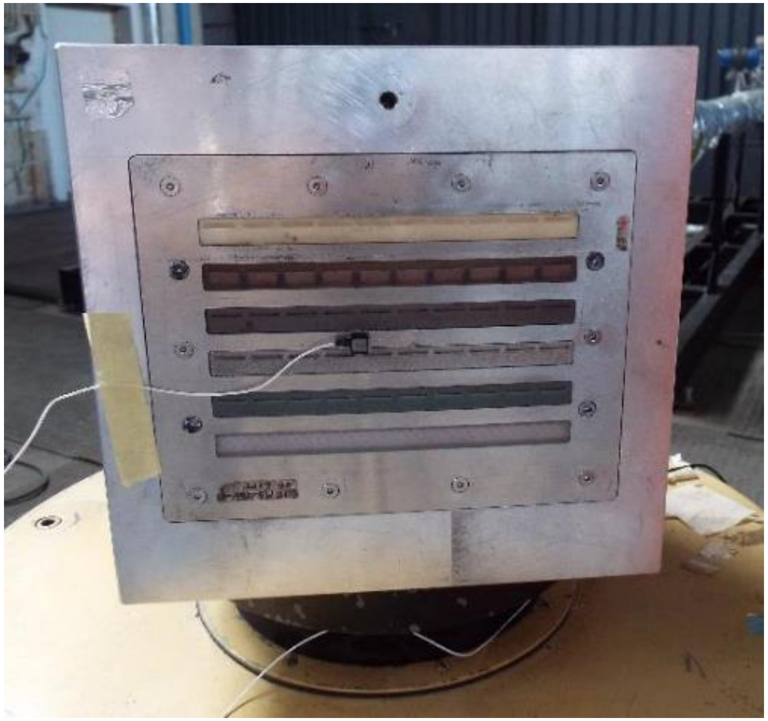
- TIRA SHOCK 4110:
  - ✓ Frequency range: 0-5000 Hz;
  - ✓ Maximum load: 100 kg;
  - ✓ Maximum acceleration: 570 m/s^2;
  - ✓ Maximum stroke: 20 mm;

Test No 7.
Mechanical Shock

- Recommendation: “The test is performed on a mechanical shocks testing-machine. The actuators panel is fitted in a device that allows it’s positioning so that the force resulting from the shock exposure manifests in one of the 6 directions derived from movements in planes parallel to the coordinate axes planes of the airplane”. This test is based on EUROCAE ED-14G standard, Section 7.

- The input shock was measured by an accelerometer, placed as close as possible to the actuators panel attachment point, with an accuracy of ±10% of standard reading.



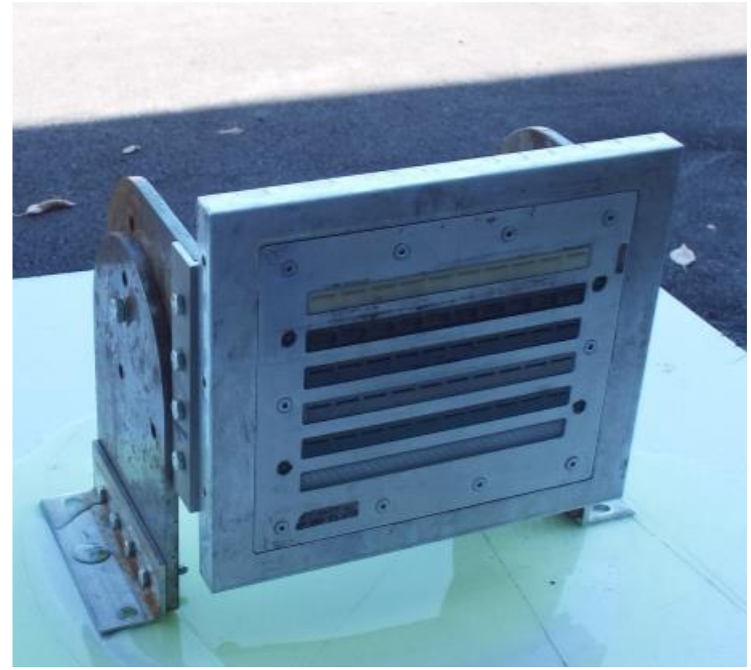


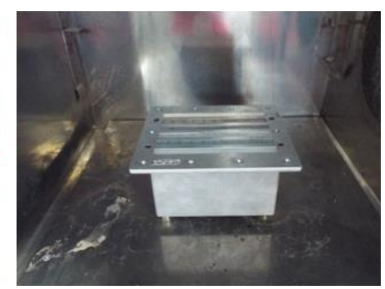
Test No 8.
De-Icing Fluid

- This test determine whether the materials used in the construction of the equipment can withstand the un-wanted effects of fluid contamination. This test was based on EUROCAE ED-14G standard, Section 11. The actuators panel was installed on a specialized test bench and the equipment was not required to operate during this test and the test was performed at ambient temperature.

- The actuators panel is sprayed for minimum 15 minutes to the entire surface with De-Icing fluid Safewing MP II FLIGHT, a propylene glycol based SAE type II aircraft deicing / anti-icing fluid, which meets or exceeds the current revision of SAE specification AMS 1428. The flow of De-Icing fluid for spraying the actuators panel was Q = 200g/min.

- The surfaces were maintained in a wetted condition for 8 hours followed by a drying period of 16 hours at 65°C.





Test No 9.
Solid Elements Contamination

- Half of the output windows of the actuators panel was completely blocked and the tests were performed wrt EUROCAE ED-14G standard.
- Bodies of A type were placed in all active rooms of the actuators panel final stage through the exit slots. Then the actuators panel was supplied by pressure. It was kept running for 30 minutes or until the complete elimination of the elements inserted into the actuators panel.
- This step was repeated by replacing Type A bodies with Type B and Type C.

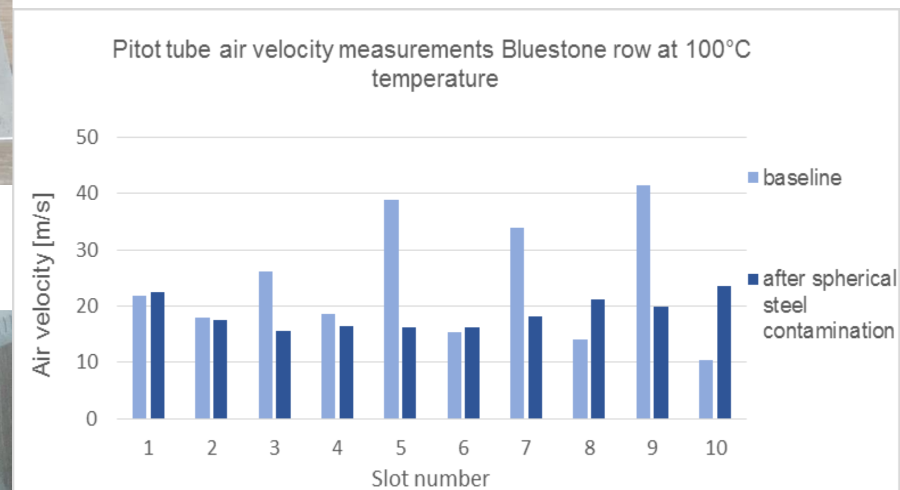
Body	Shape	Material	Diameter [mm]
A	Non-uniform	Quartz	-
B	Spherical	Steel	0.3 – 0.4 mm
C	Spherical	Glass	0.3 – 0.4 mm


SPHERICAL STEEL
(Ø 0.3 – 0.4 mm)

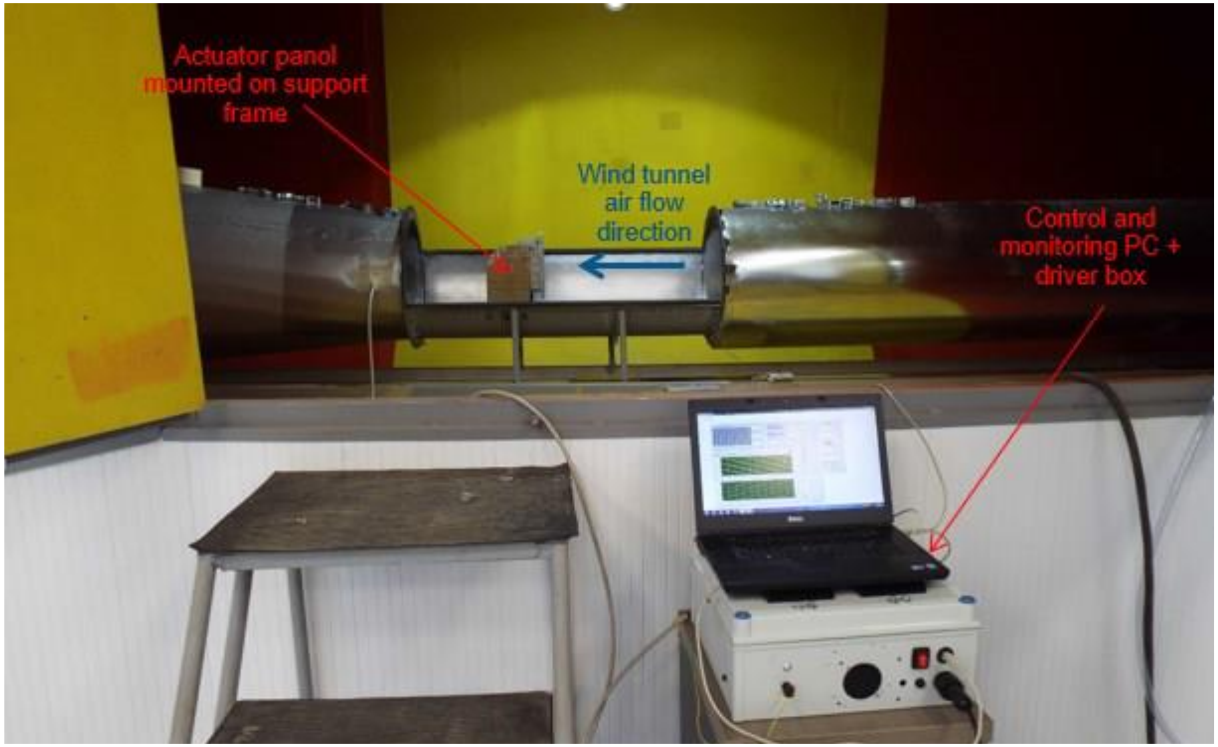

SPHERICAL GLASS
(Ø 0.3 – 0.4mm)


VOLCANIC – SILICONE QUARTZ
(non-uniform)

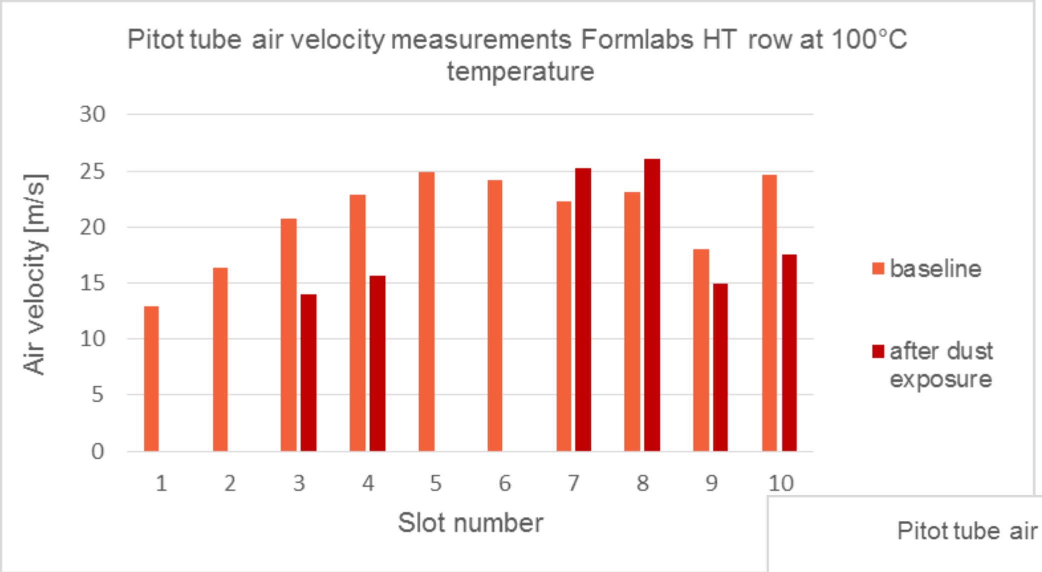
Test No 9.
Solid Elements Contamination nOK

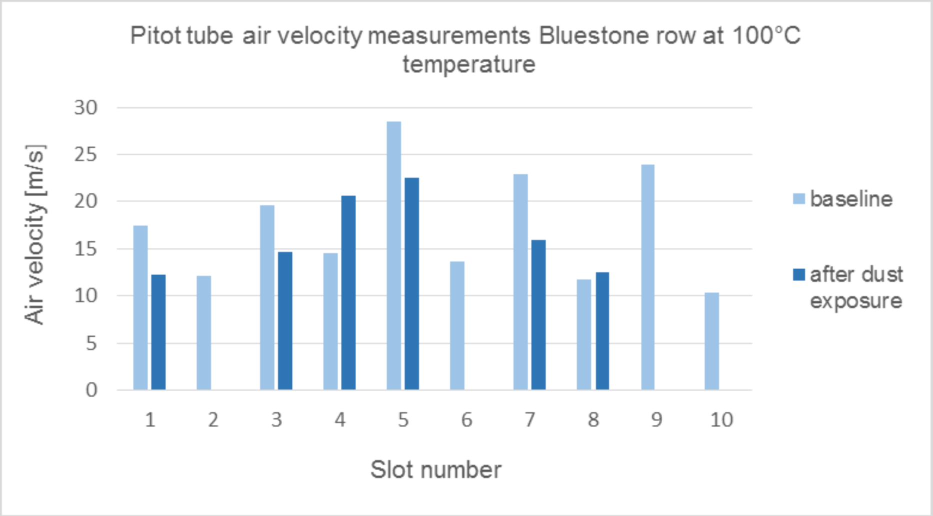


Test No 10.
Sand and Dust Exposure



Test No 10.
Sand and Dust Exposure





Conclusions and Outlook

- In general the harsh environmental testing went well, some problems were encountered during the solid contamination/sand and dust tests;

- Specific care might be necessary for sand and dust conditions, since the essential feature of the active flow approach is a powerful control jets expelled out of a small orifice. Any blocking and/or remaining material inside the chamber could impact the functionality.

- We can conclude in general that the harsh environmental testing provided very valuable and detailed data sets, to compare the SJA /HJ properties before and after exposure to harsh conditions.

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Thank you!

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This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement No 604013, AFLONEXT project.