SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

LILD – Local Ice Layer Detector

SAE AC9C meeting

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October 2021

This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement n° 824253

Why Icing sensors?

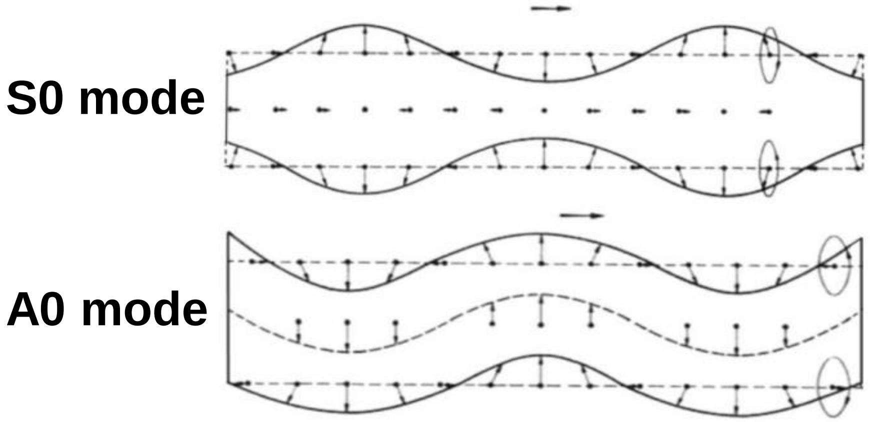
- Ice accretion is alway a risk in aviation
- Weather forecasts do not always correctly predict icing conditions
- Small and medium sized aircraft most prone due to lack of powerful deicing
- German Federal Bureau of Aircraft Accident Investigation (BFU):
  - 15.02.2013 EMB500: Accident because Deicing system was not active
  - 14.12.2017 Cessna 510: Loss of control on final approch
  - 08.08.2017 PA46: Loss of control in icing and turbulence over Bodensee
- Sensing ice accretion could prevent accidents by activating deicing systems or evading icing conditions
- Small and low cost sensor especially suited for small and medium sized aircraft
- Applicability at icing prone surfaces is advantageous

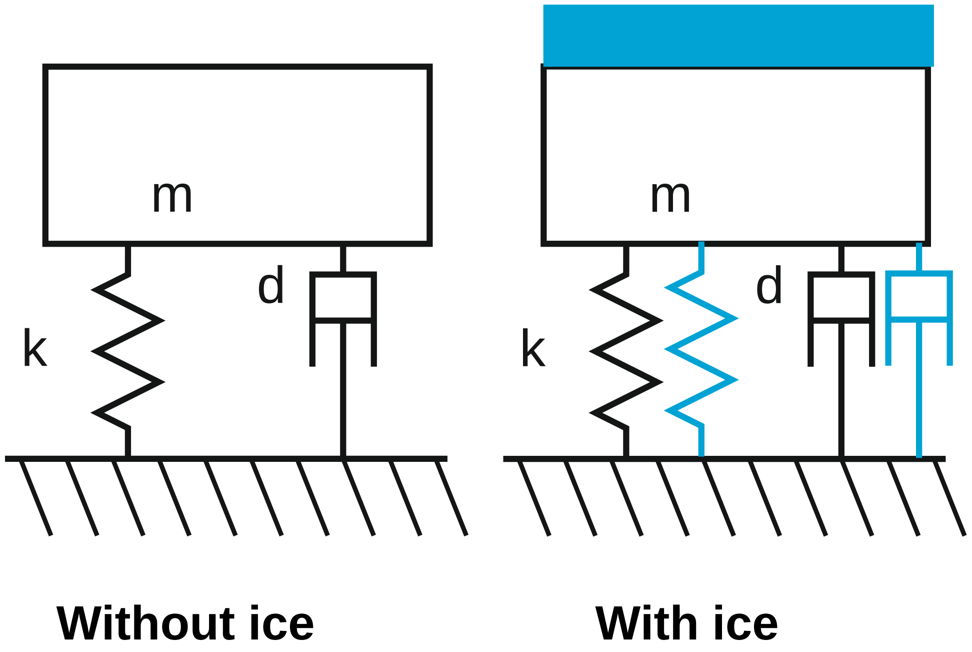
Source: AOPA

Source: BFU

The Local Ice Layer Detector (LILD) principle

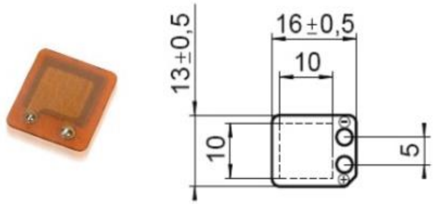
- Ultrasonic structure borne sound (lamb waves) can travel through panel structures
- Transmission behavor of ultrasonic lamb waves in aircraft outside panels changes with the presence of ice
- Ice accretion affects damping, stiffness and mass of panel structure
  - Amplitude and Group velocity of lamb wave are altered with presence of ice



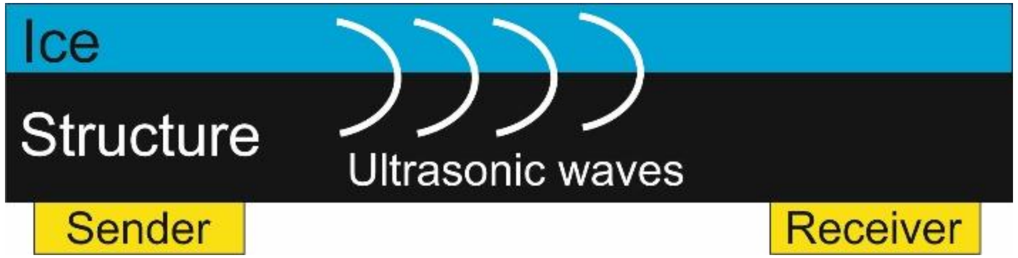


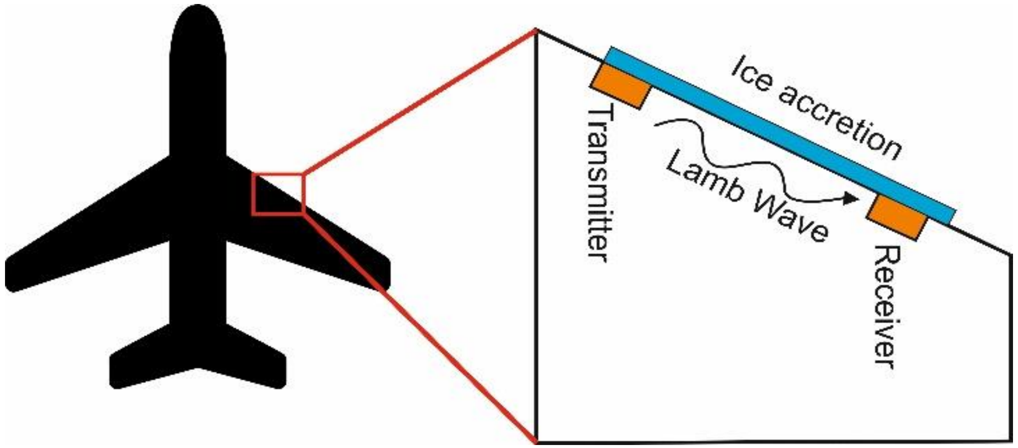
How to build a LILD sensor

- Application of piezoelectric transducers on the back side of icing prone structure as transmitter and receiver
- Transducer small in size



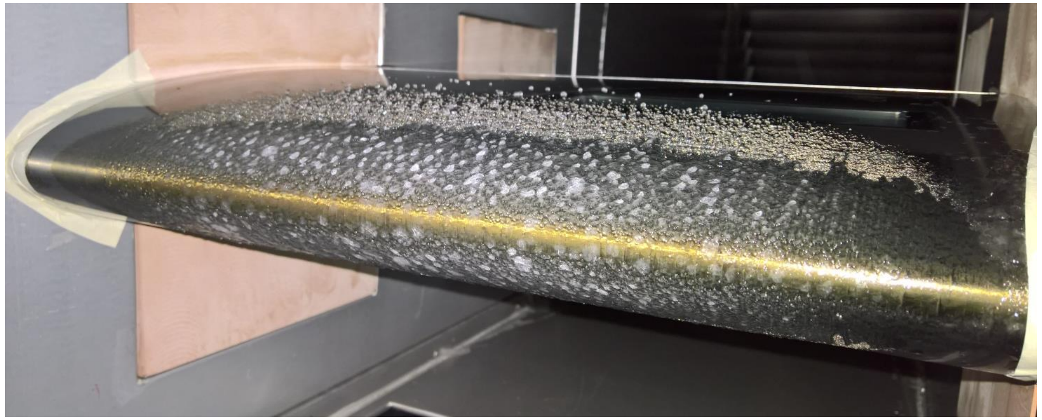
- Aircraft structure acts as wave guide
- Distance between transmitter and receiver approx. 30-50cm
- Sensor can be applied on leading edges of wings, empennage or other icing prone surfaces

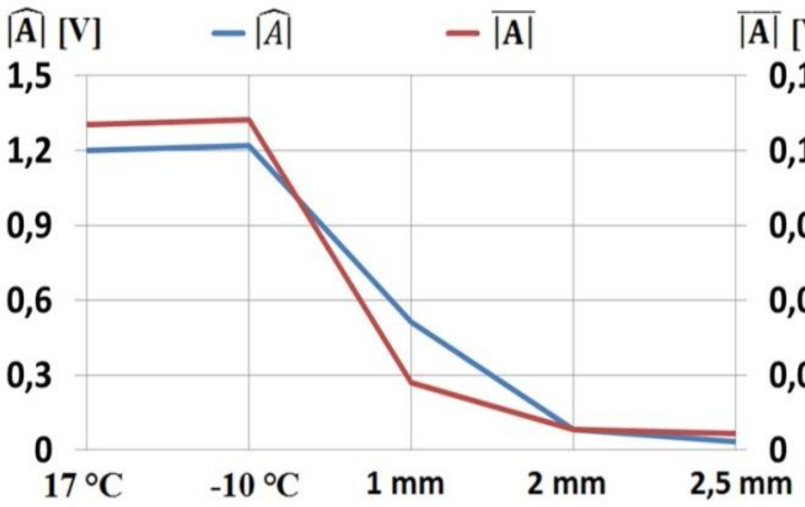


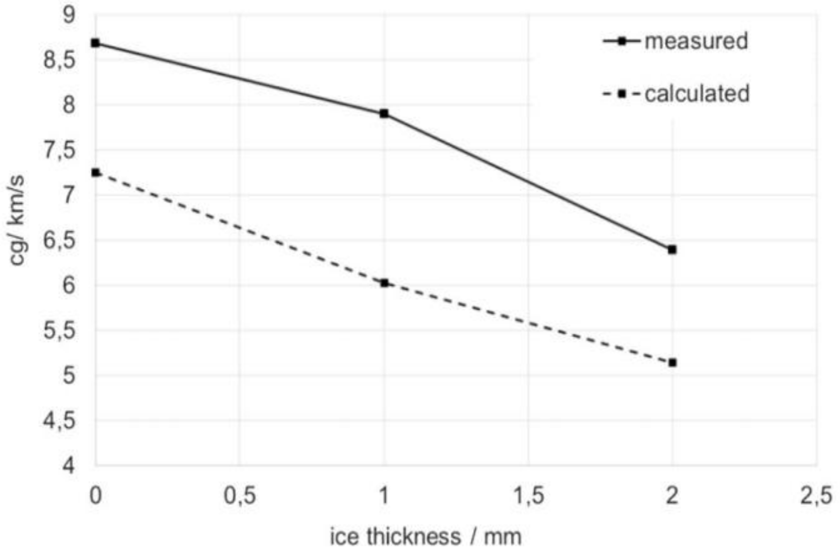


How to build a LILD sensor

- Preliminary investigations of LILD principle by Christian Mendig
- Ice layer reduces amplitude and group velocity of lamb waves







Developing LILD Sensor in SENS4ICE

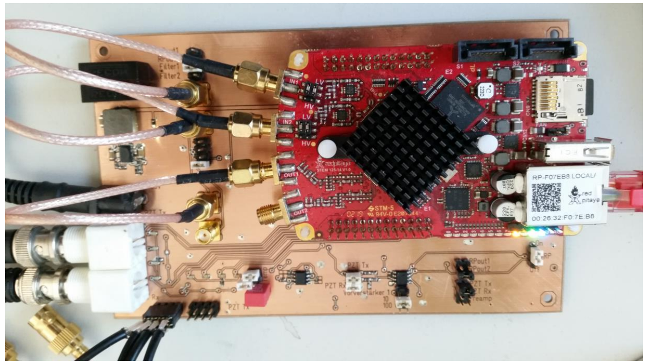
Miniturization and development of flight test capable sensor electronics

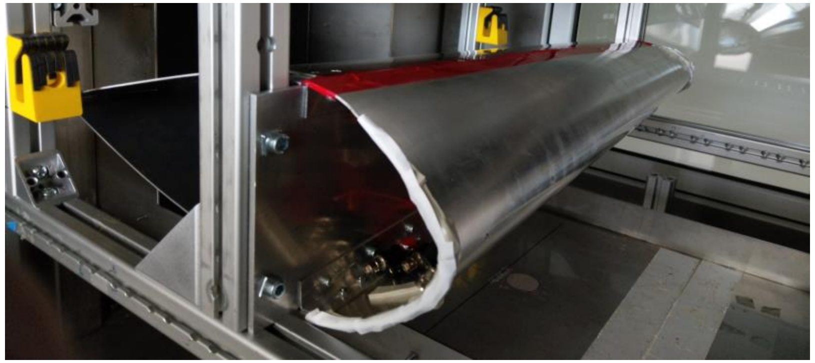
Icing wind tunnel tests

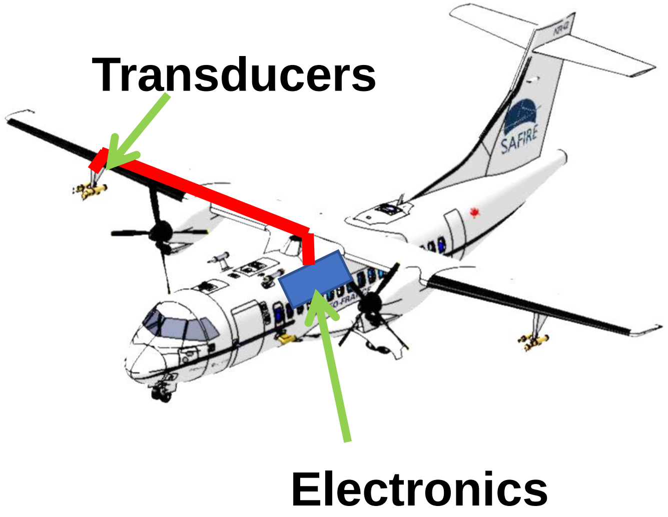
- **Pretests at TU Braunschweig IAF facility**
- **Final test at TU Braunschweig ISM**

Flight Test

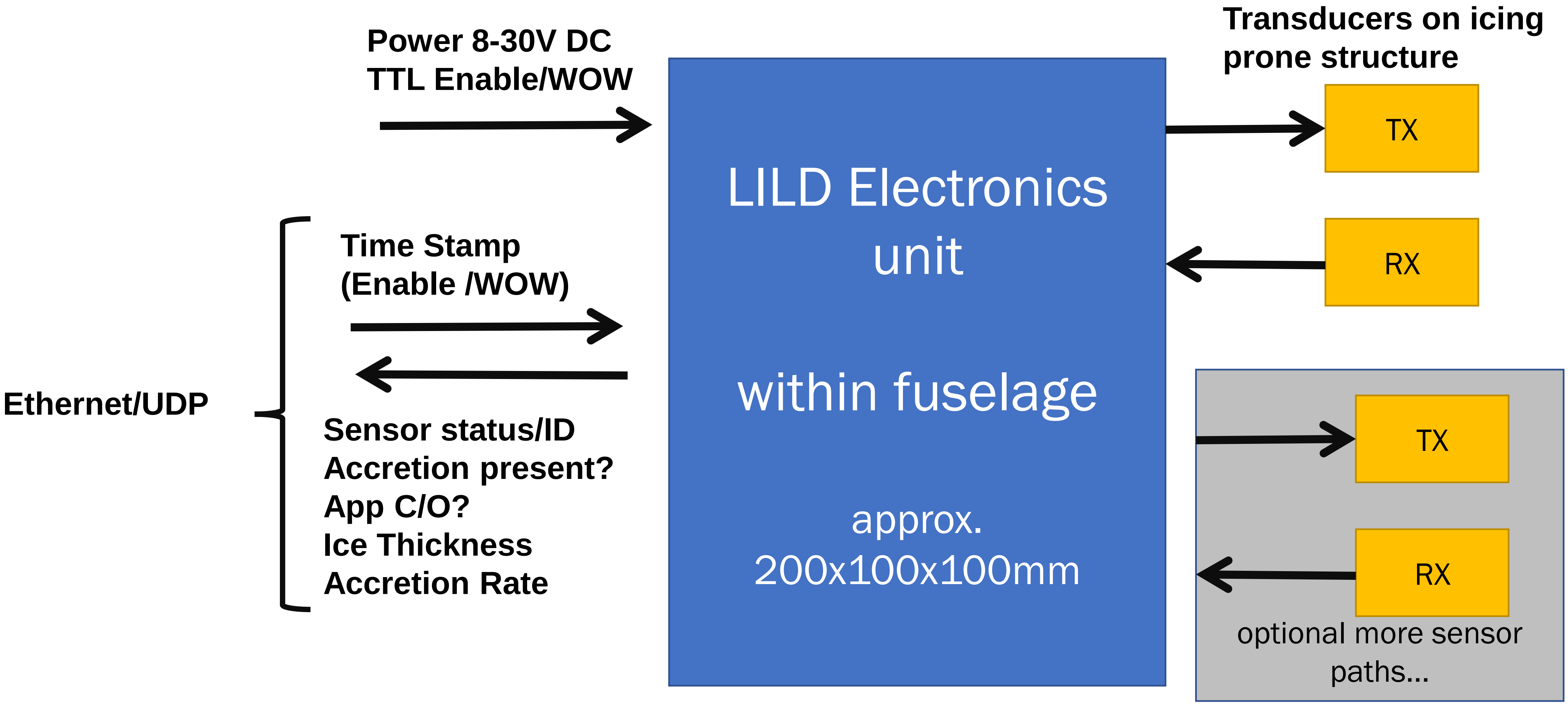
- **Safire ATR42**
- **Planned for 2023**





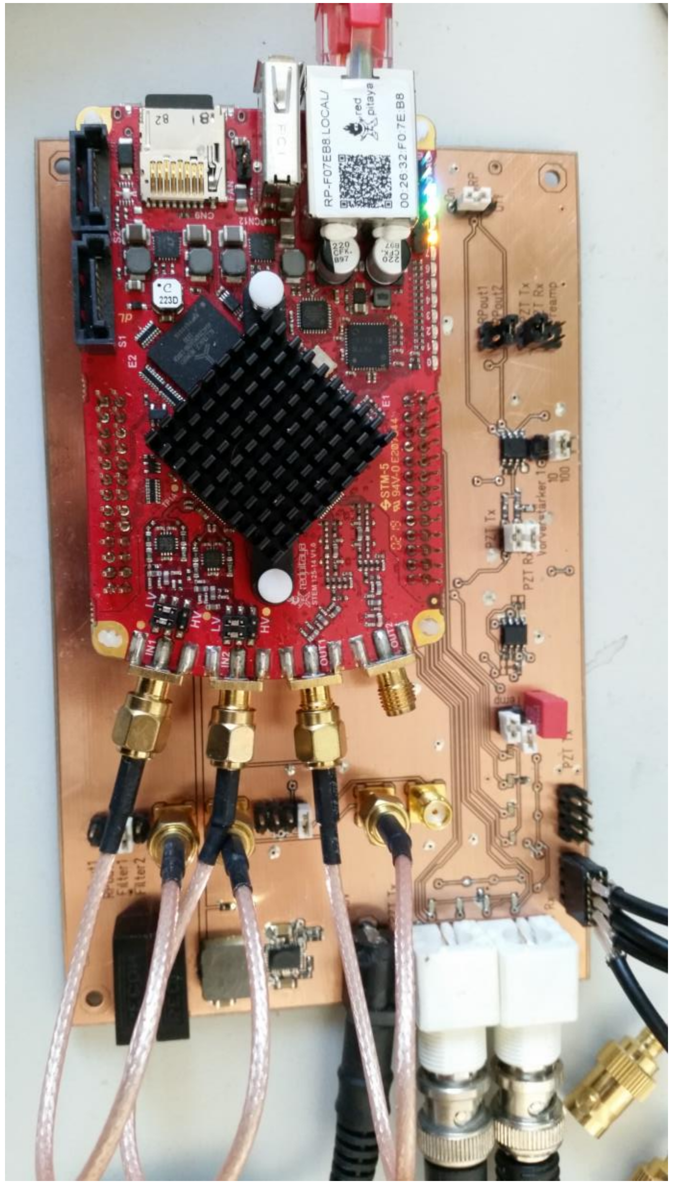


Overview of LILD sensor electronics



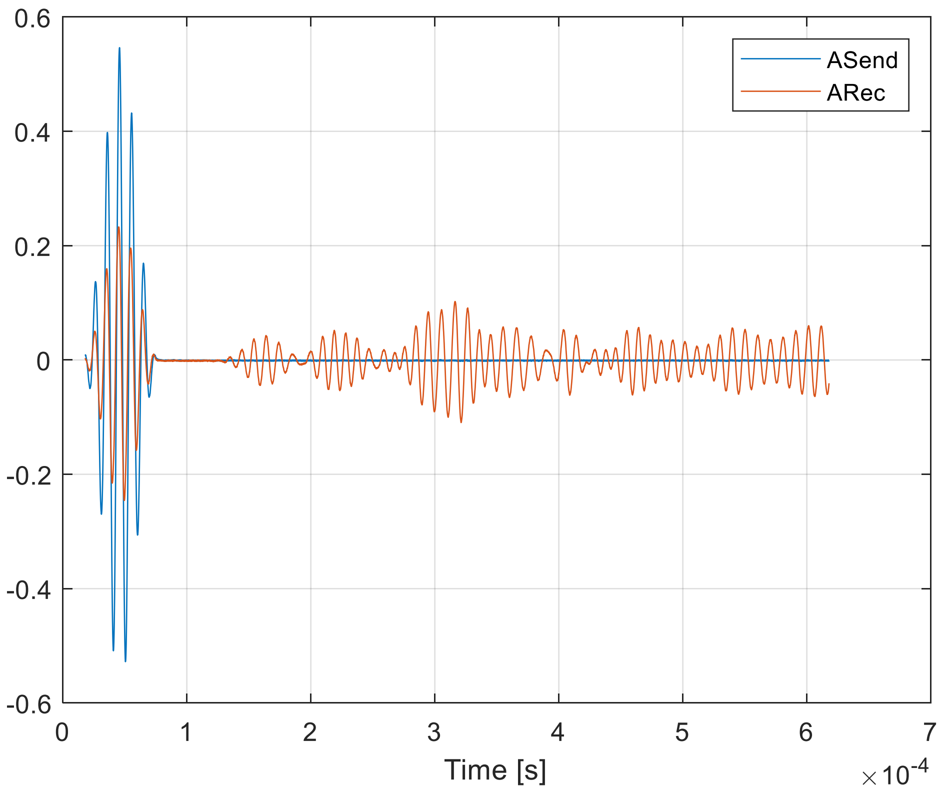
LILD Electronics characteristics

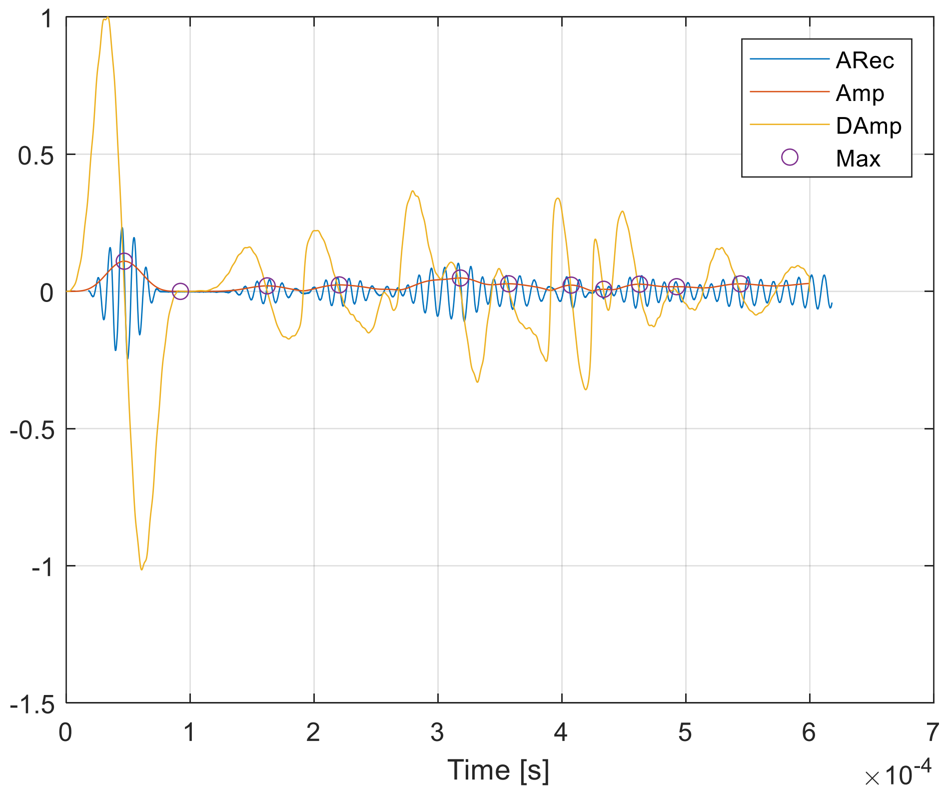
- Xilinx ZYNQ XC7Z01 FPGA and dual core microcontroller for signal aquisition and generation
- Output amplifier for max. 15V amplitude of lamb waves up to 1MHz
- Input bandpass filter 30kHz to 1MHz
- Sampling frequencies of 16.6MHz and 1.95Mhz
- Synchronous temperature measurement at transmitter location
- Data storage on USB device
- Ethernet on board



Analyzing the signals

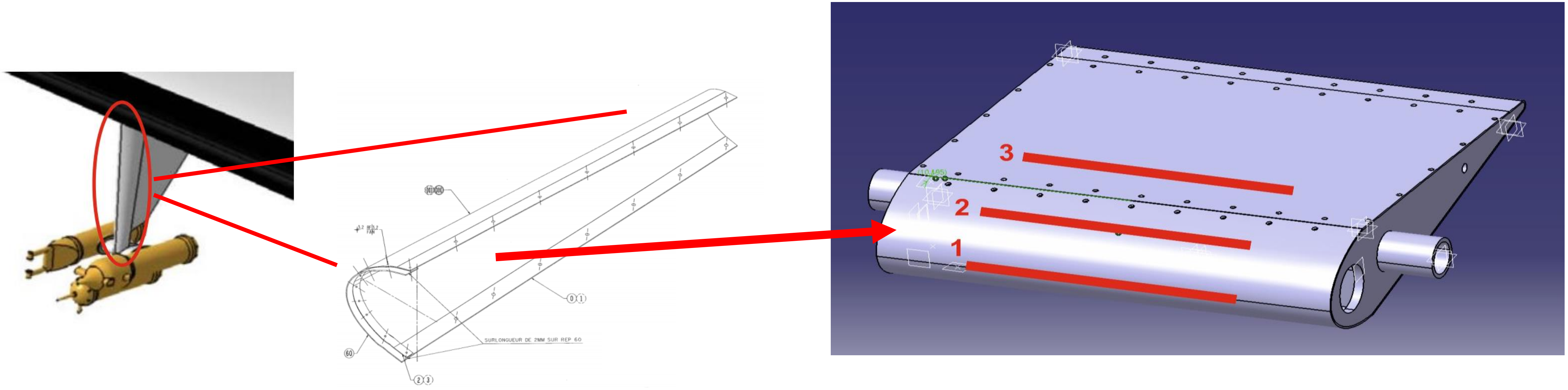
- Finding the lag time and amplitude of lamb wave pulses





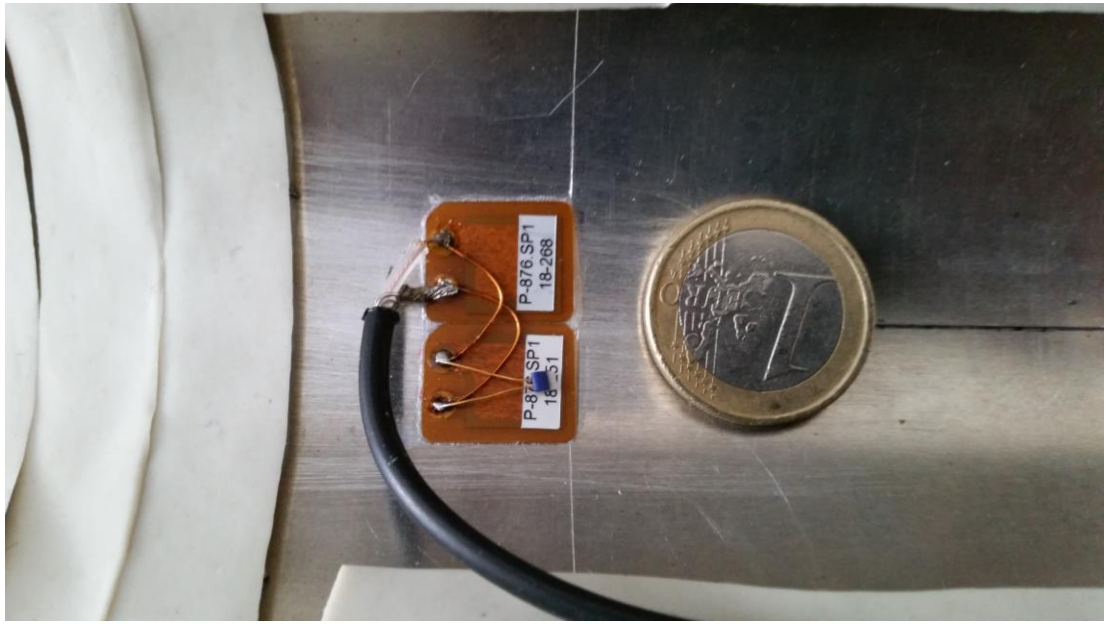
Analyzing the influence of ice on the signals

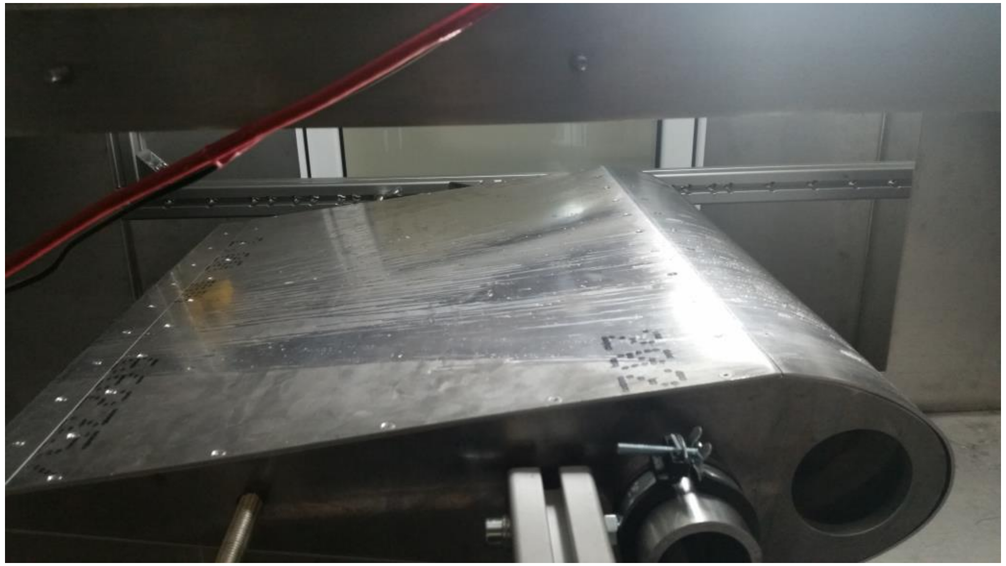
- Finding the pulses, which are susceptible to ice
- Build and airfoil demonstrator according to ATR42 pylon leading edge airfoil



Analyzing the influence of ice on the signals

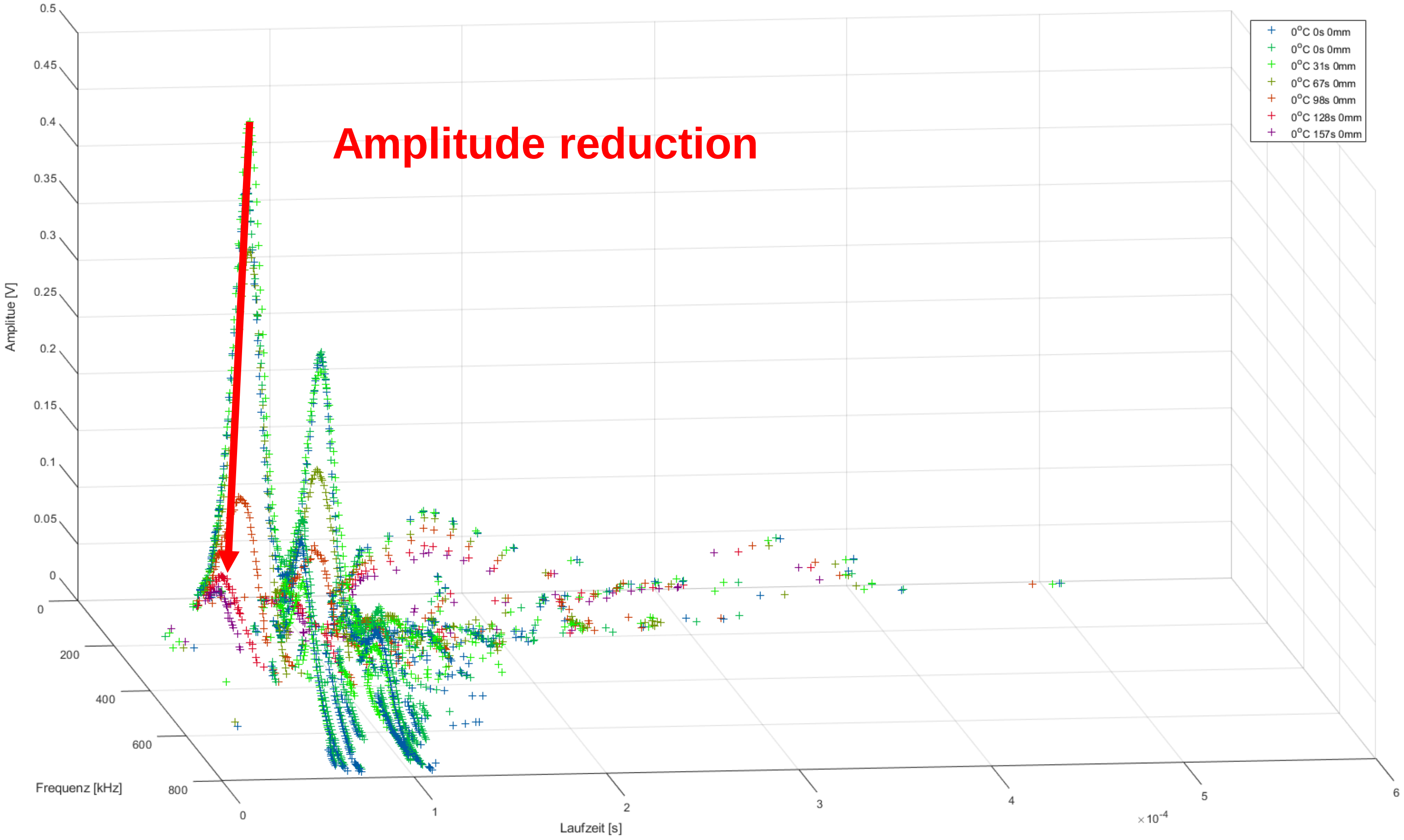
- Finding the pulses, which are susceptible to ice
- Build and airfoil demonstrator
- Application of piezoelectric transducers





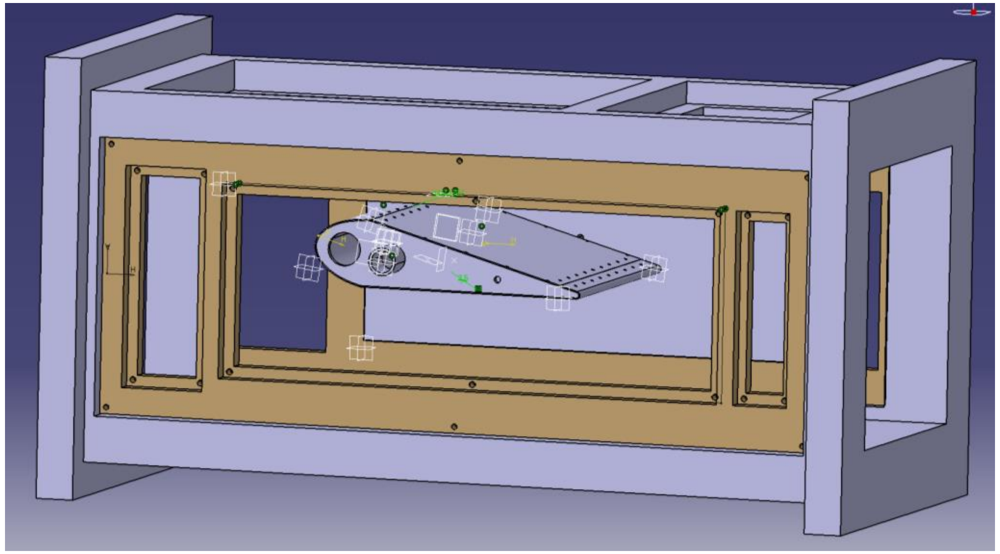
Analyzing the influence of ice on the signals

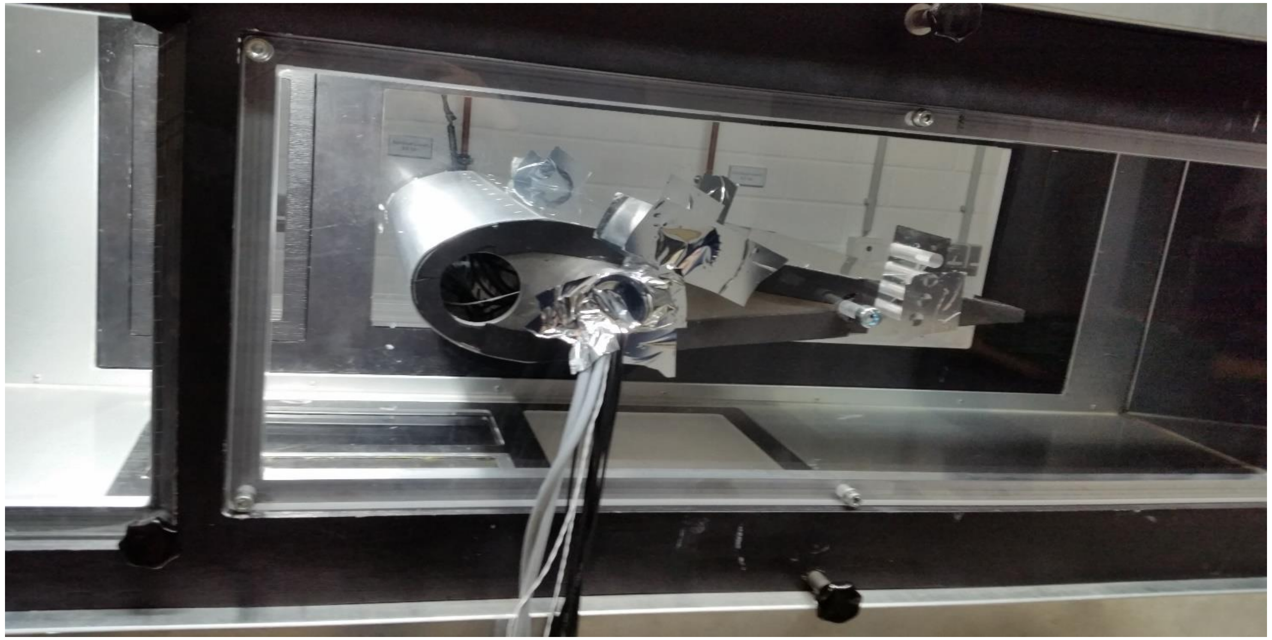
- Finding the pulses, which are susceptible to ice
- Frequency sweep
- 30s ice accretion
- Ice layer reduces amplitude



IWT test at TU BS ISM tunnel

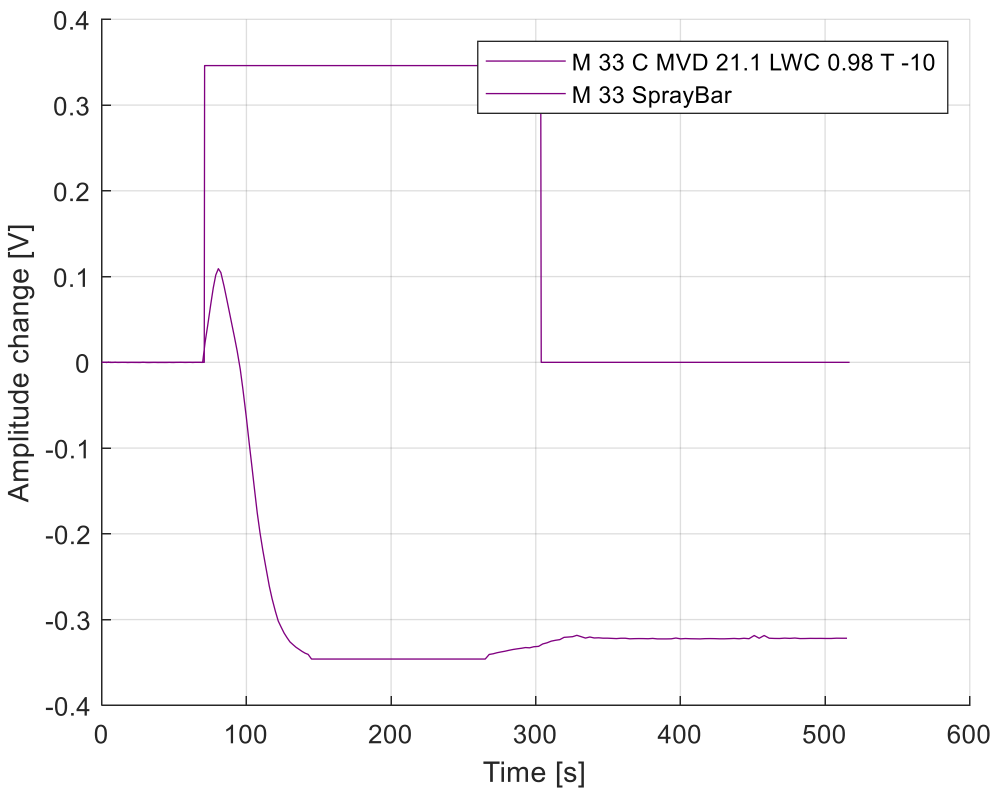
- Fitting the demonstrator to the tunnel
- Plexiglass side panels
- 1min dry time, maximum response time + 2min icing cloud, 3min dry
- 17 App C and 20 App O test cases measured between -2°C and -20°C

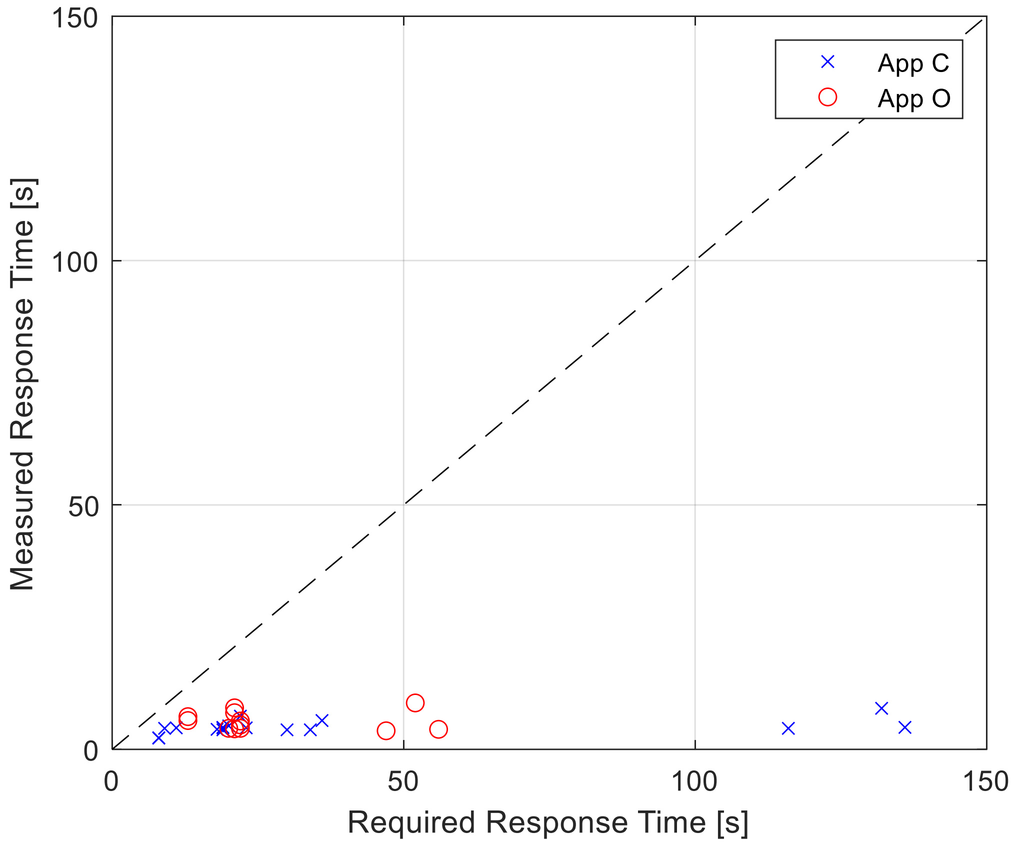




IWT test at TU BS ISM tunnel

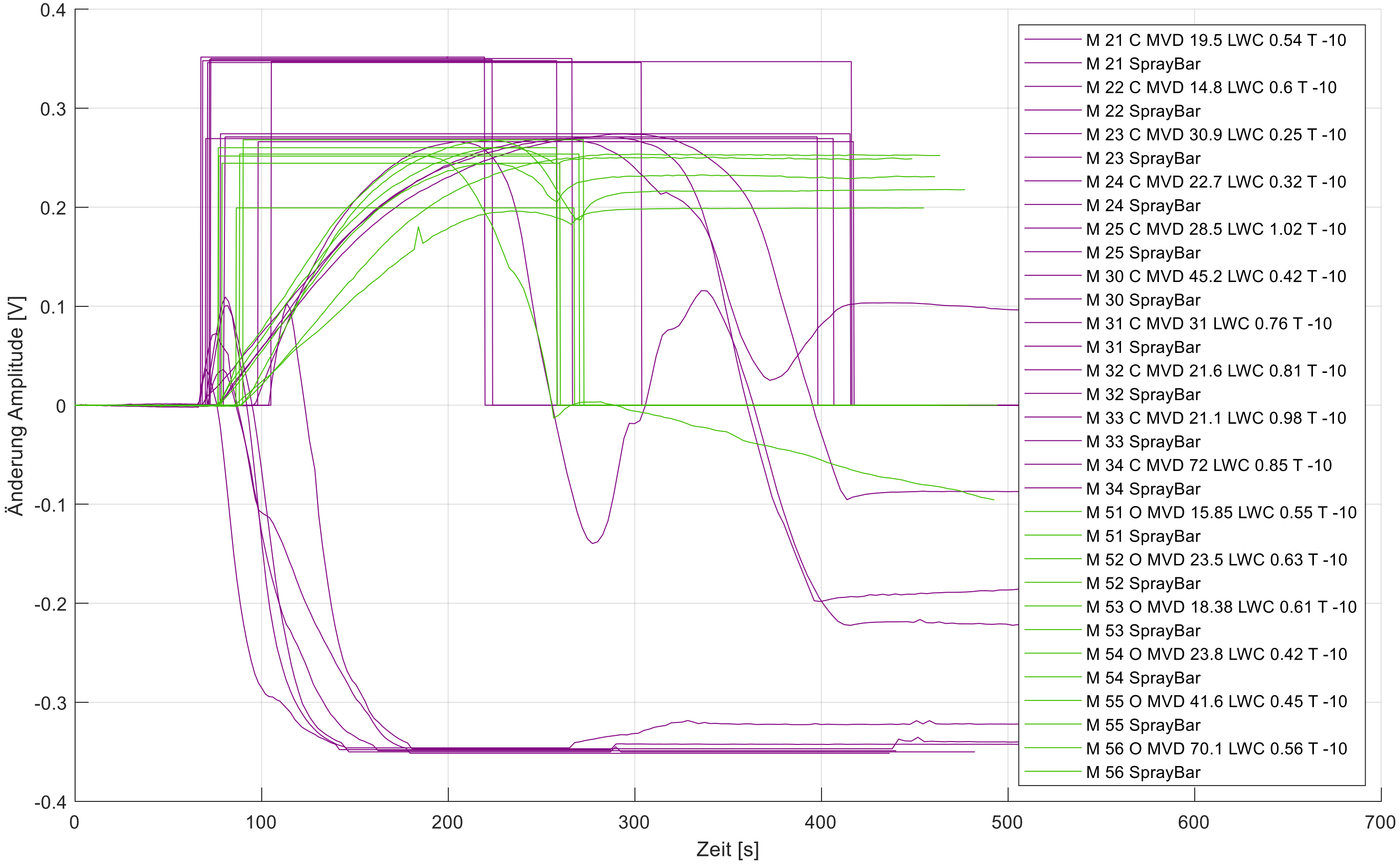
- Response time is very low
- Amplitude changes instantly with ice accretion when airfoil is clean before



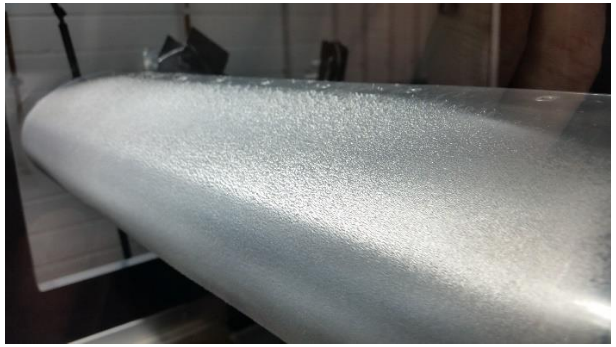


IWT at TU BS ISM tunnel

- No significant difference in amplitude change between App C and App O
- Amplitude may increase or decrease with ice accretion



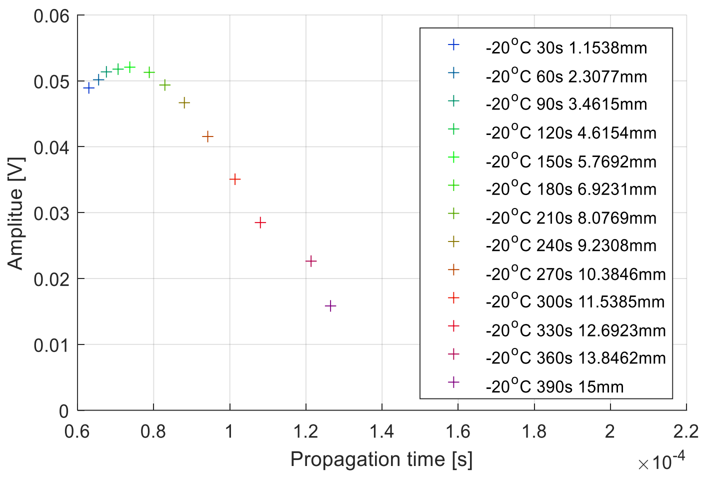
App C MVD 45.2µm
LWC 0.42g/m^3 -10°C



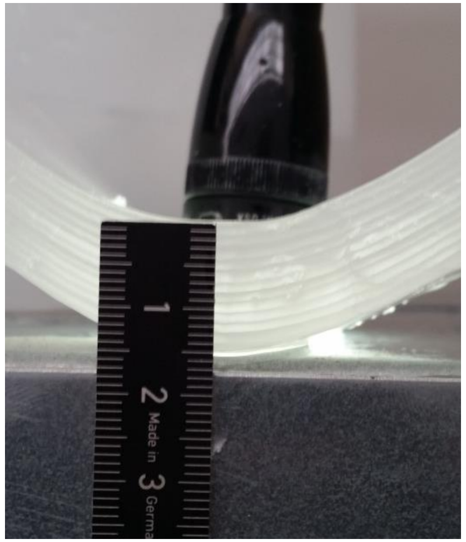
App O MVD 41.6µm
LWC 0.45 g/m^3 -10°C

Conclusion IWT test

- Detection times for beginning ice accretion on clean airfoil are very short in the range of less than 10s for all test points
- Detection of end of positive ice layer growth or new ice layer growth with already present ice requires more time up to 1min
- Ice layers have been detected from <0.3mm up to 15mm
- With the tested App C and App O points, no significant differences in the measured signal were visible with the tested sensor setup and detection algorithms
    - Ice accretion for similar conditions (temperature, LWC, MVD) was comparable between App C and App O in TU BS IWT test
    - Ice accretion chord was more influenced by LWC and temperature than droplet size

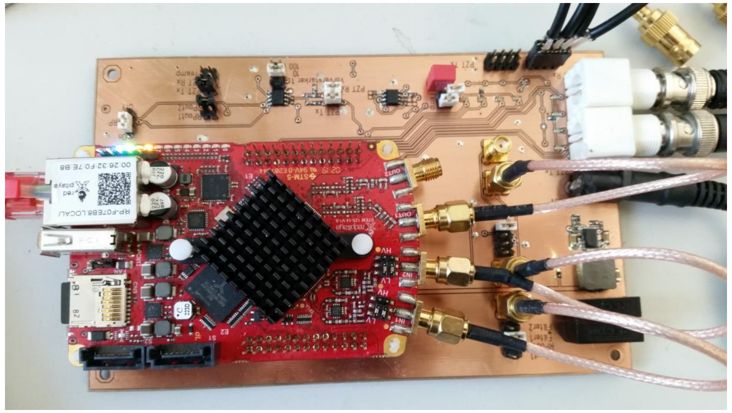


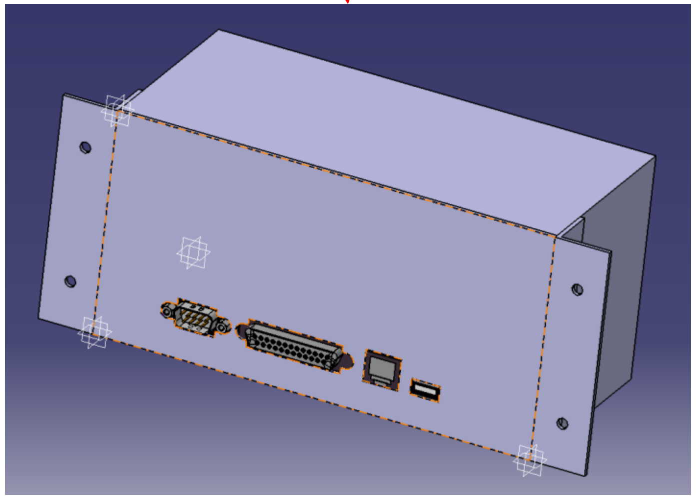
Signals with up to 15mm ice layer (demonstrated in pretests)

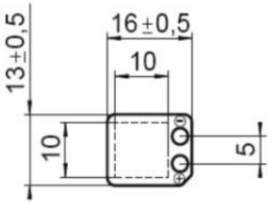


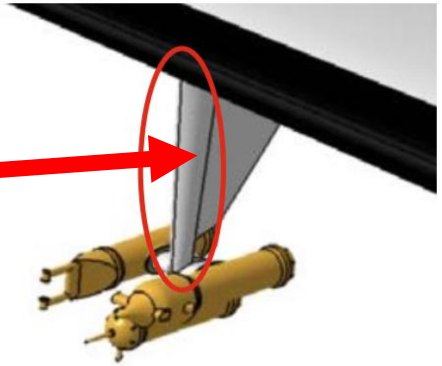
LILD – next steps

- Design and fabrication of flight test electronics
  - Addition of user interface with status supervision and display, real time clock, fitting to 19“ rack
  - Firmware adaptation for online ice detection and data storage
  - Ethernet interface programming for data excange with aircraft and hybrid system
- Instrumentation of ATR42 pylon leading edge
- Characterization of wave transmission behavior of pylon leading edge
- Flight test in 2023 ☺









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LILD – current status

Current TRL: 3-4

IWT Facility: TU BS

Output Data Parameters for flight test:

STATUS, ACC, ACC Rate, ACC Thk, ACC O (planned)

Parameter	Value
LWC (g/m³)	No limitation
MVD (µm)	No limitation
D_{max} (um)	No limitation
Detection Range (cm)	Ice accretion at aircraft surface
Accretion Rate (mm/s)	Up to 10 mm/s
Response Time (s)	< 1 s
Dimensions (cm x cm x cm)	20 x 10 x 10 cm expected for flight test prototype electronic box, Transducers 20 x 20 x 0.5 mm
Weight (kg)	Electronic Box of flight test prototype approx. 1 kg, Transducers approx. 1 g cable: depending of the mounting position
Power (W)	Approx. 10 W for electronic box

Test	Test Points Detected [%]	Test Points detected within Response Time [%]	Test Points detected within 1.5X Response Time [%]	Test Points with ACC Rate measurement [%]	Average ACC Rate Error [%]
Appendix C Test Points	100	100	100	88	60
Appendix C Repeat Points	92	83	83	33	35
Appendix O Test Points	100	100	100	100	41
Appendix O Repeat Points	-	-	-	-	-