SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

LILD – Local Ice Layer Detector

International Conference on Icing of Aircraft, Engines, and Structures

Martin Pohl – German Aerospace Center (DLR)

June 2023

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

Why Icing sensors?

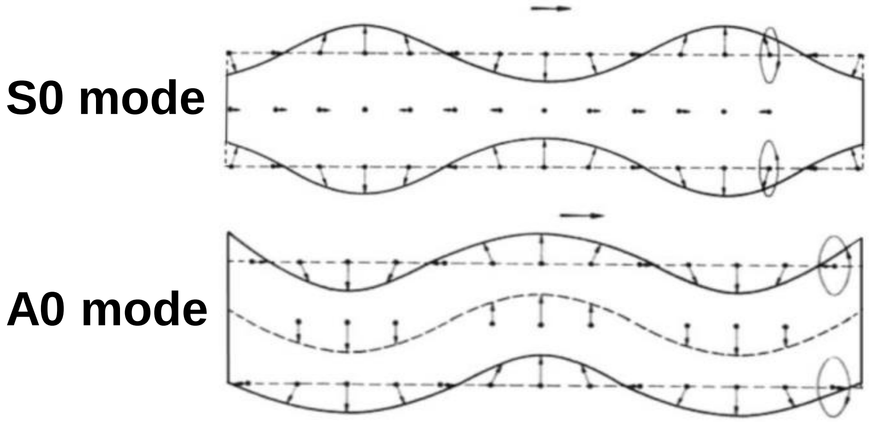
- Ice accretion is alway a risk in aviation
- Weather forecasts do not always correctly predict icing conditions
- Small and medium sized aircraft most prone due to lack of powerful deicing
- German Federal Bureau of Aircraft Accident Investigation (BFU):
  - 15.02.2013 EMB500: Accident because Deicing 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

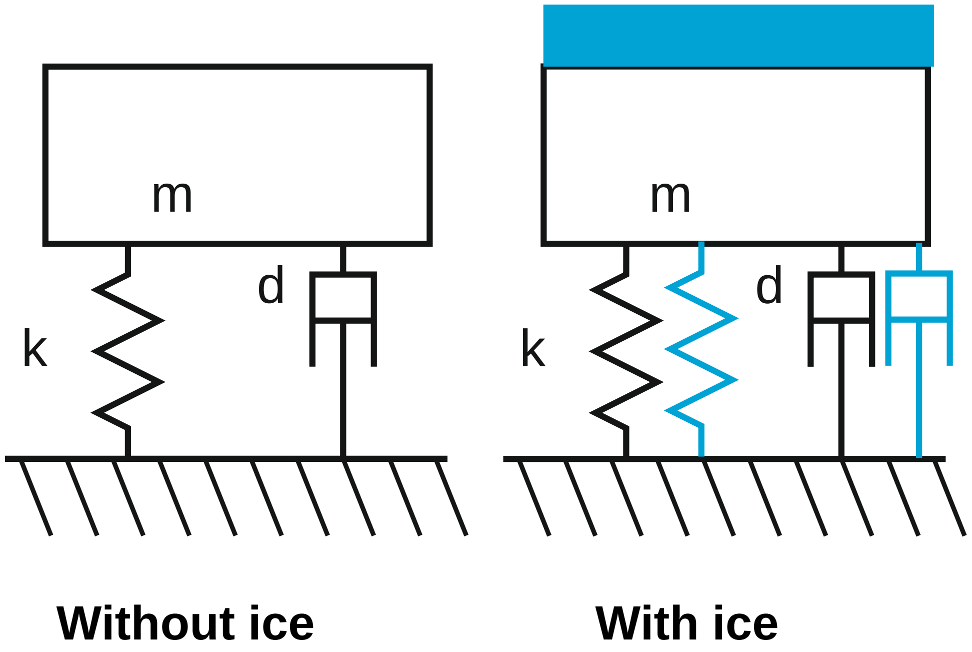
Phenom 100 crash landed due to icing (Source: BFU)

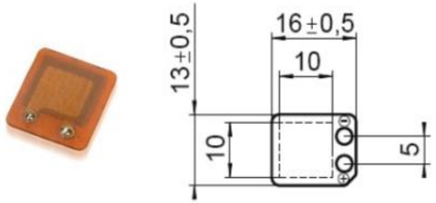
Inflight breakup in thunderstorm with potential icing
Source: BFU

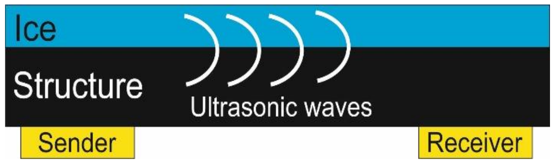
The Local Ice Layer Detector (LILD) principle

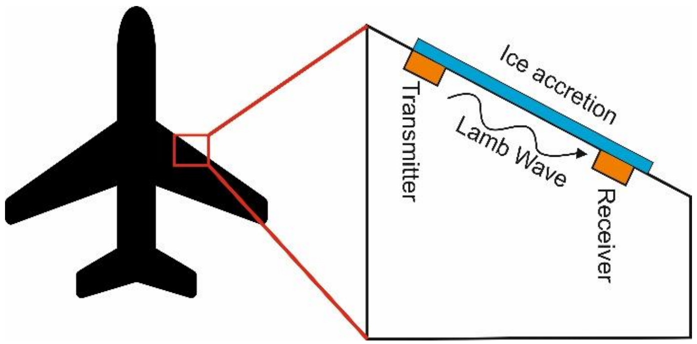
- Ultrasonic structure borne sound (lamb waves) can travel through panel structures
- Transmission behavor of ultrasonic lamb waves in aircraft outside panels changes with the presence of ice
- Ice accretion affects damping, stiffness and mass of panel structure
  - Amplitude and Group velocity of lamb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











Developing LILD Sensor in SENS4ICE

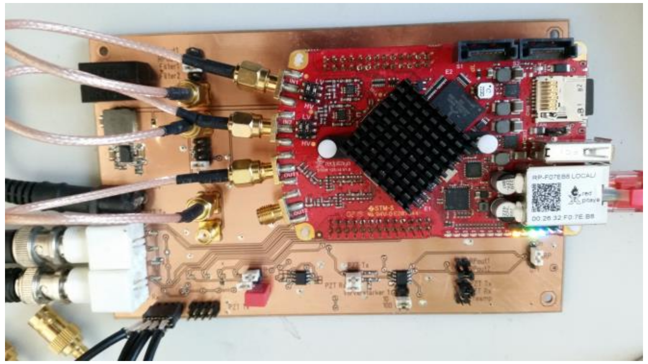
Miniturization and development of flight test capable sensor electronics

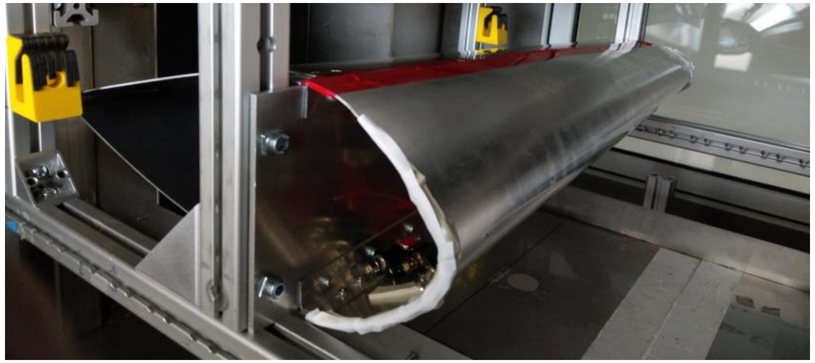
Icing wind tunnel tests

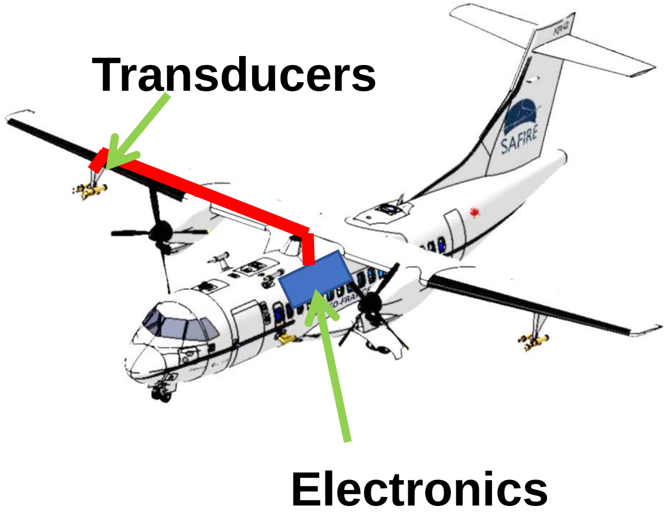
- **Pretests at TU Braunschweig IAF facility**
- **Final test at TU Braunschweig ISM**

Flight Test

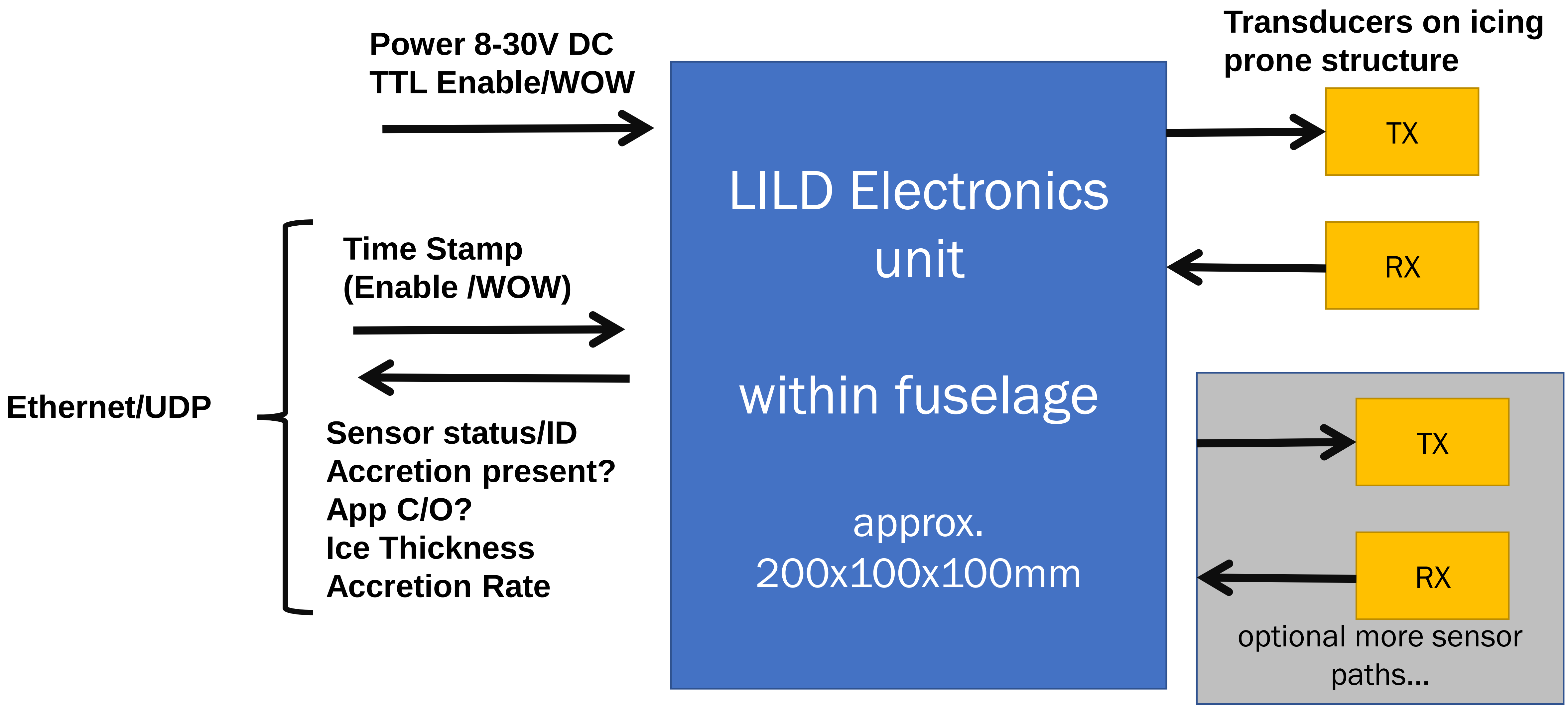
- **Safire ATR42**
- **Planned for 2023**







Overview of LILD sensor electronics

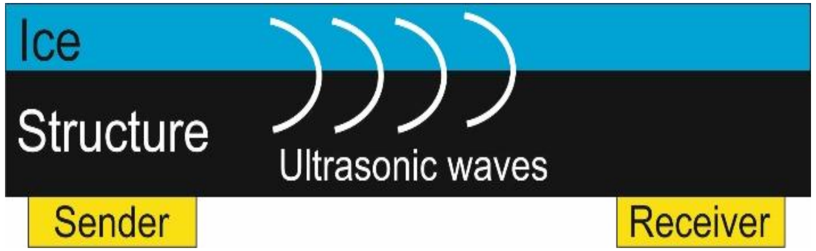


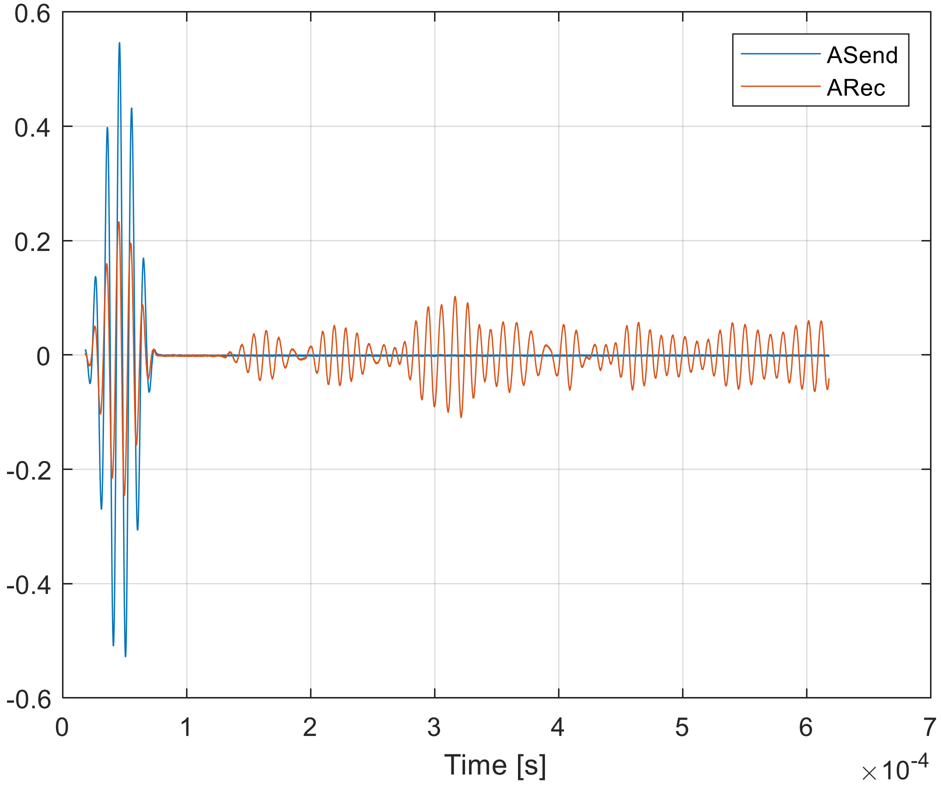
LILD Electronics characteristics

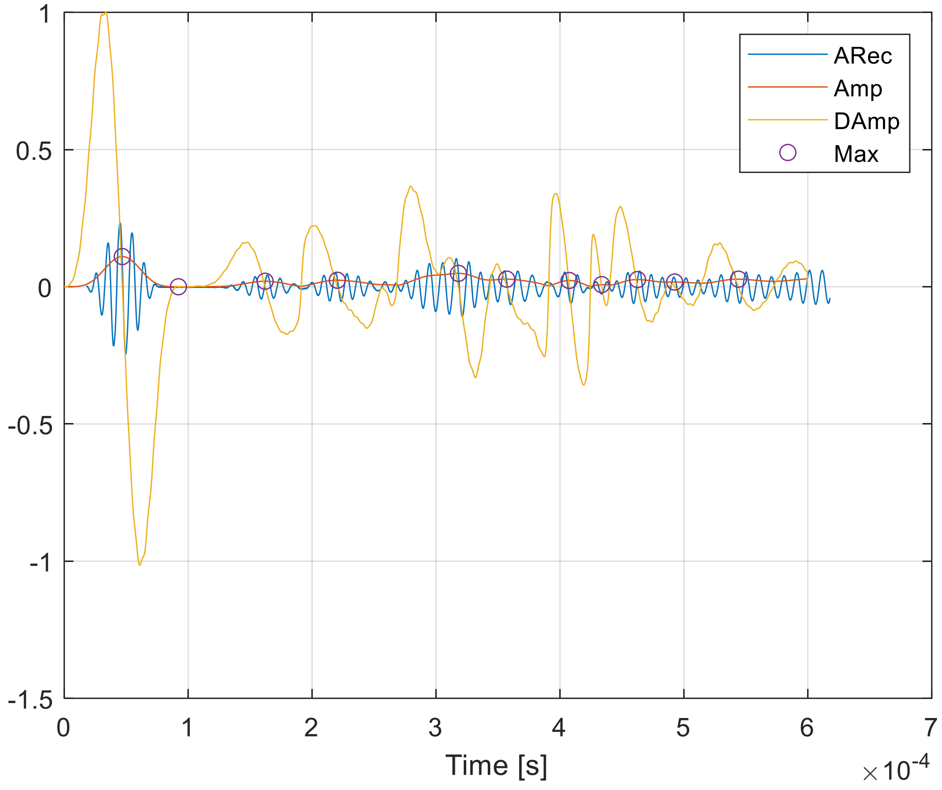
- Xilinx ZYNQ XC7Z01 FPGA and dual core microcontroller for signal aquisition and generation
- Output amplifier for max. 15V amplitude of lamb waves up to 1MHz
- Input bandpass filter 30kHz to 1MHz
- Sampling frequencies of 16.6MHz and 1.95Mhz, up to 125MHz possible
- Synchronous temperature measurement at transmitter locations
- 4 Tx and 4 Rx multiplexers
- Data storage on USB device
- Ethernet on board

Analyzing the signals

- Finding the lag time and amplitude of lamb wave pulses

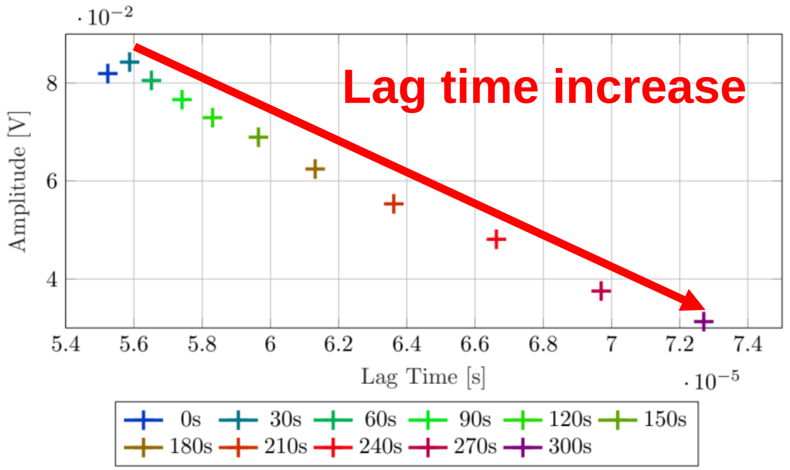


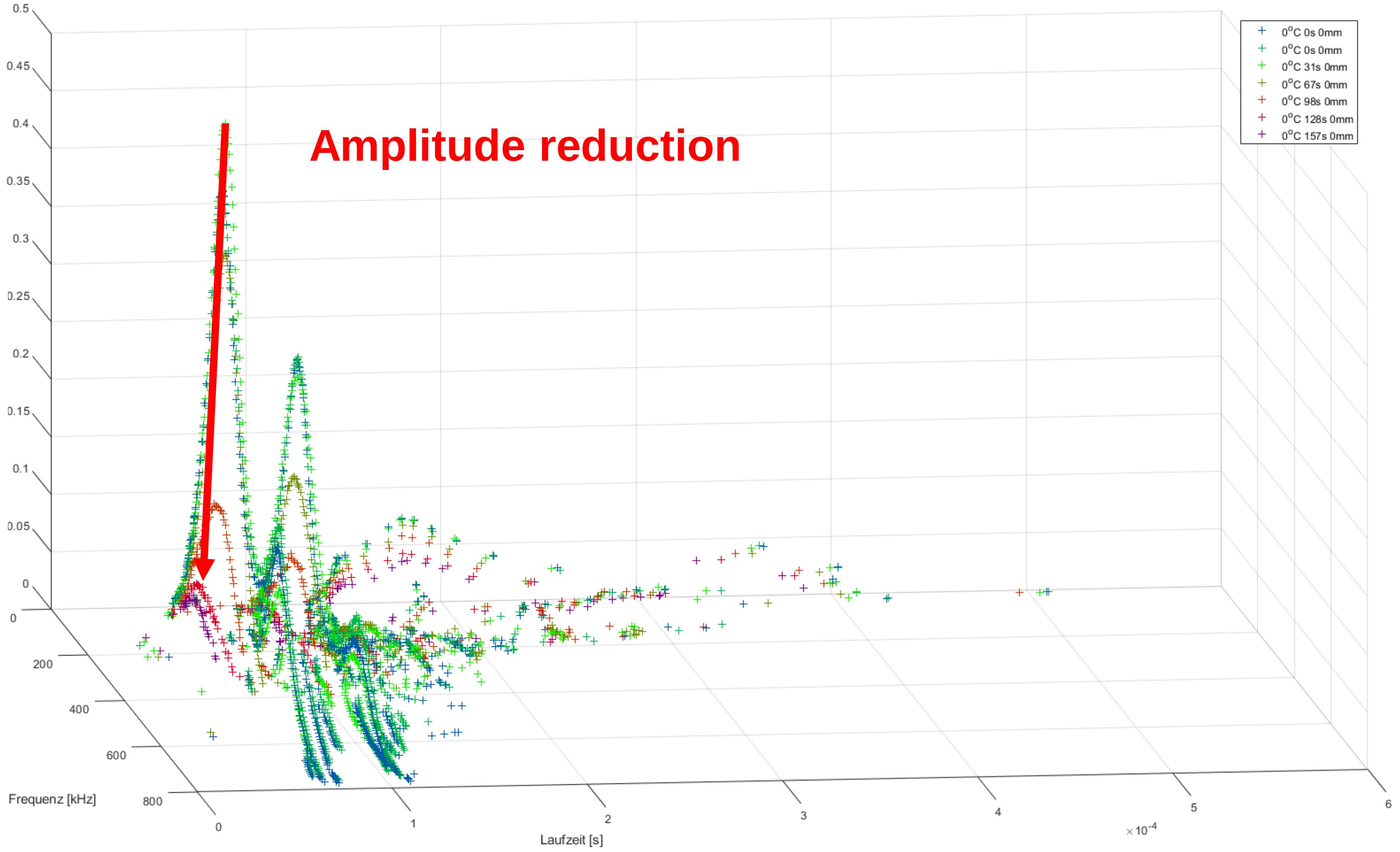




Analyzing the influence of ice on the signals

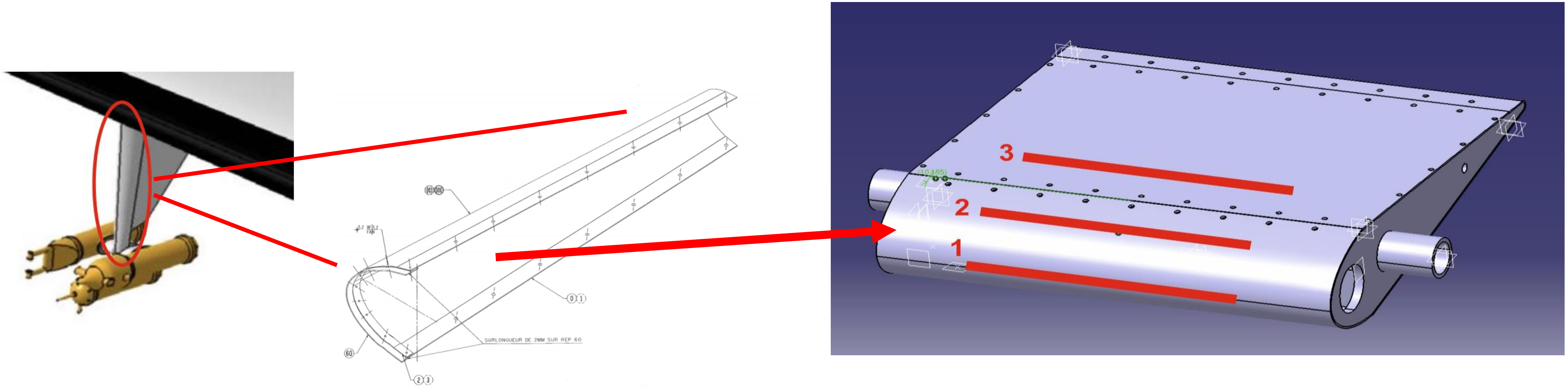
- Finding the pulses, which are susceptible to ice
- Frequency sweep
- 30s ice accretion
- Ice layer reduces amplitude





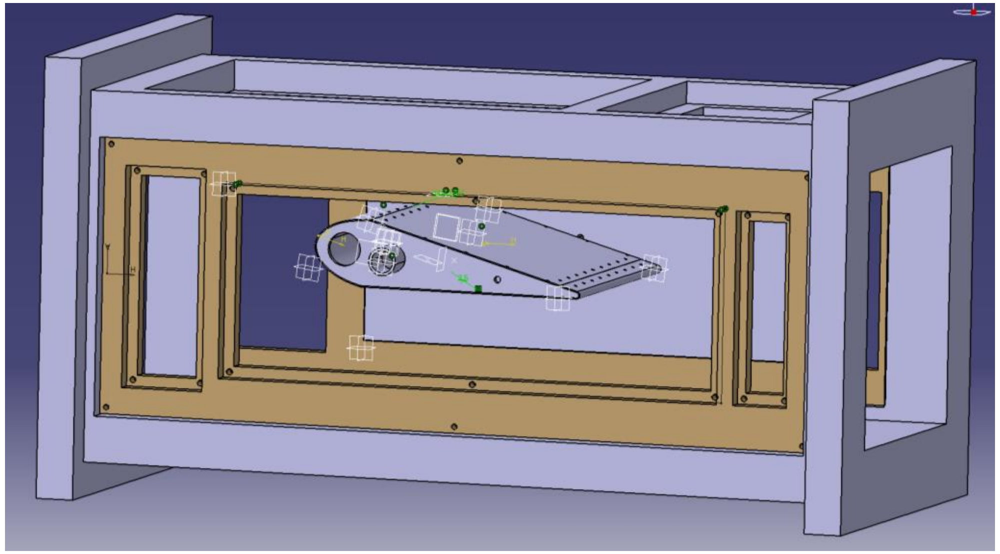
Icing wind tunnel tests

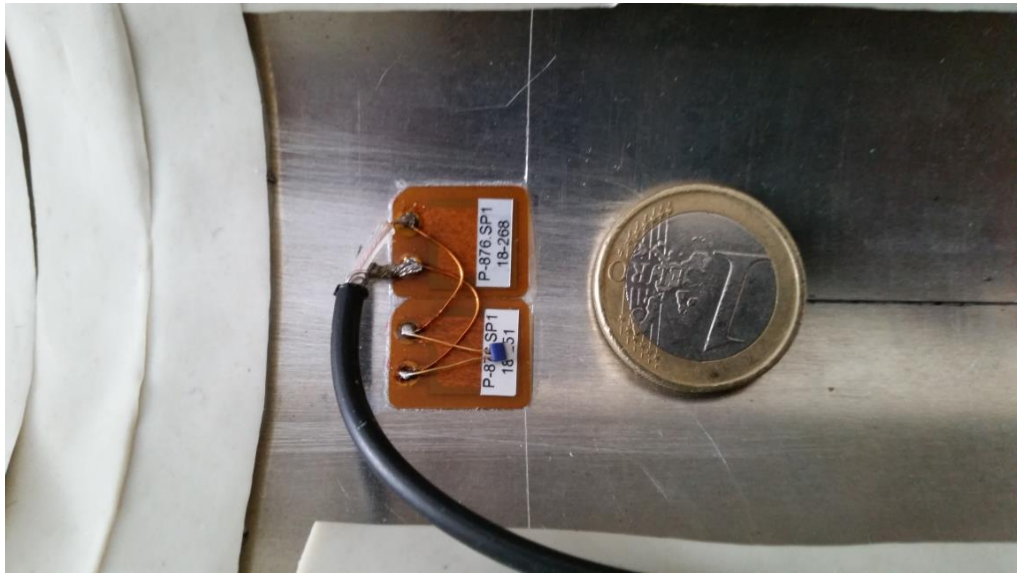
- Finding the pulses, which are susceptible to ice
- Build and airfoil demonstrator according to ATR42 pylon leading edge airfoil

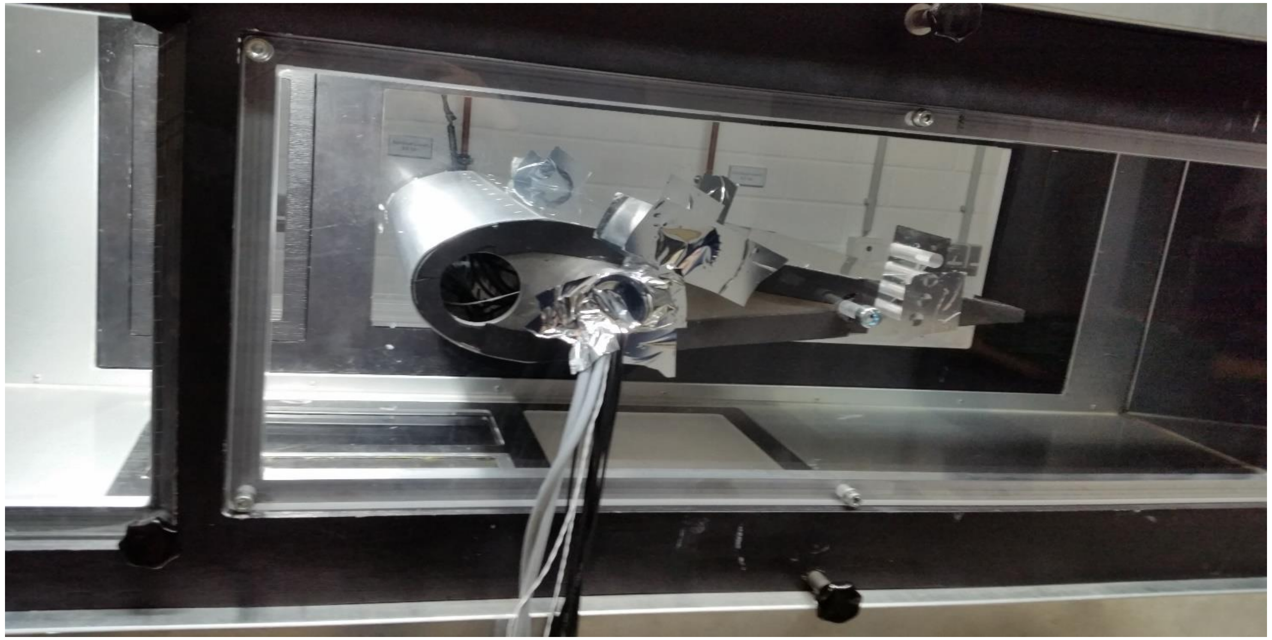


IWT test at TU BS ISM tunnel

- 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

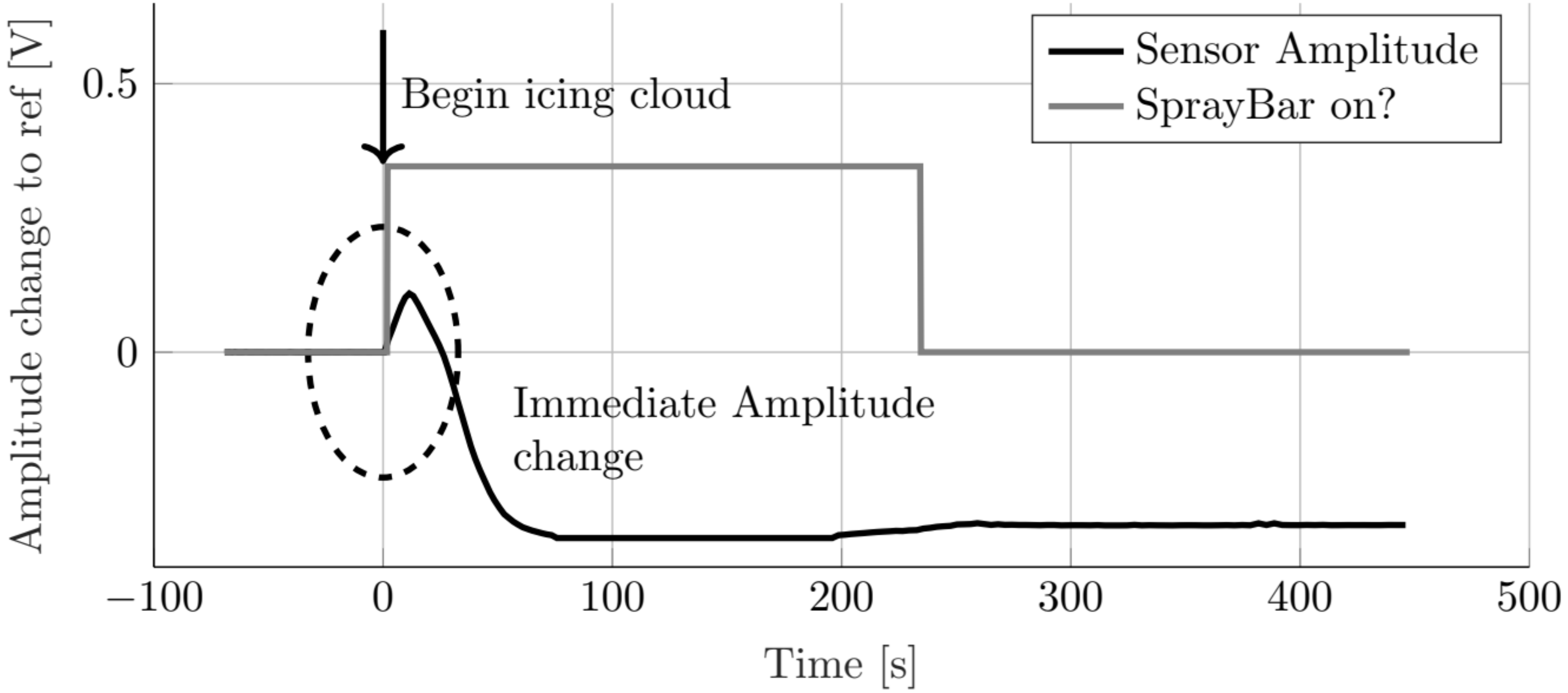






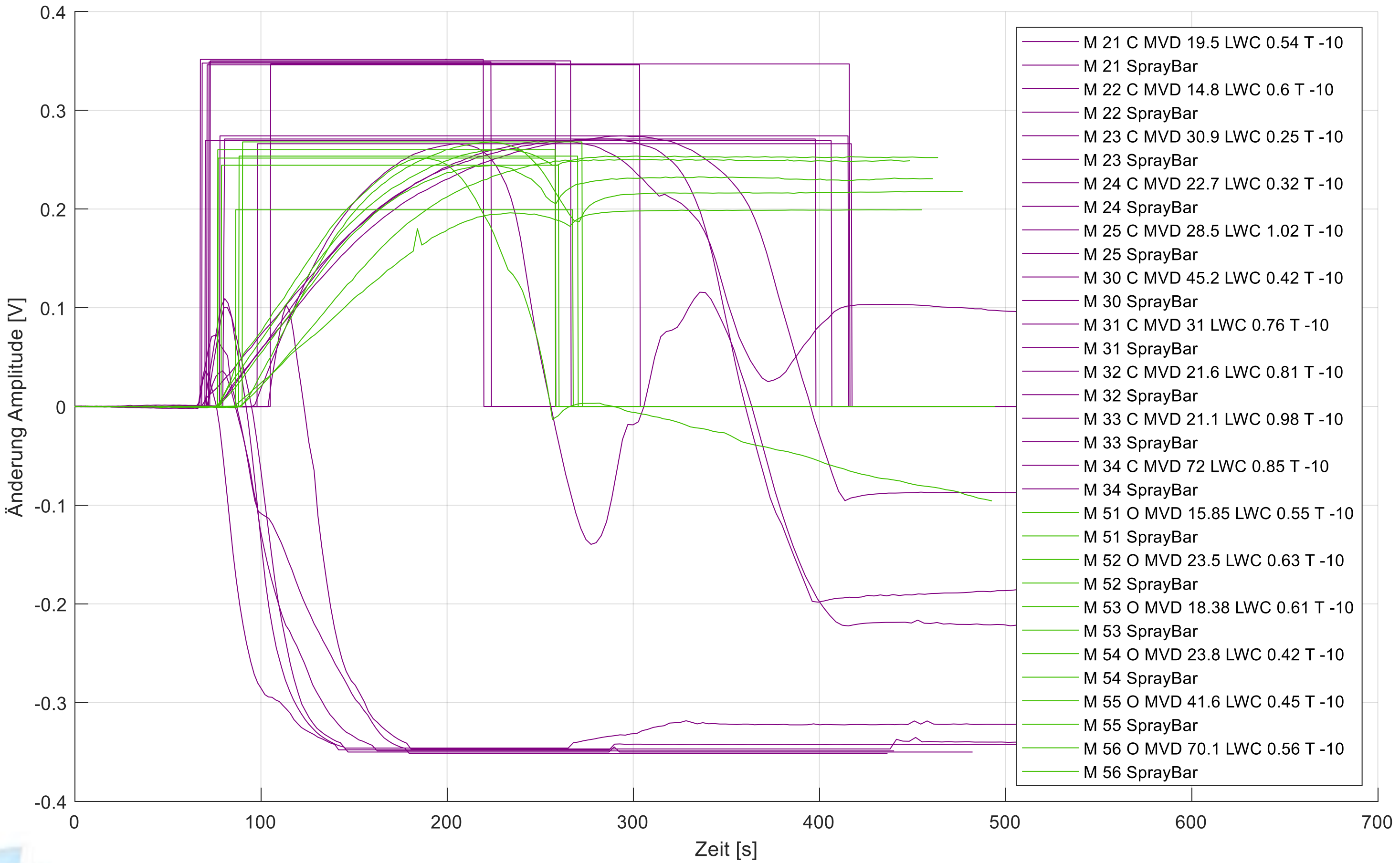
IWT test at TU BS ISM tunnel

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

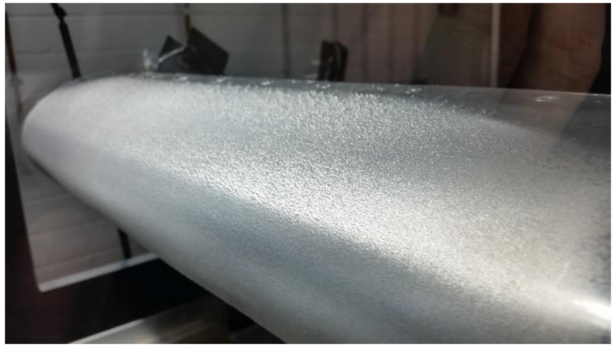


IWT at TU BS ISM tunnel

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



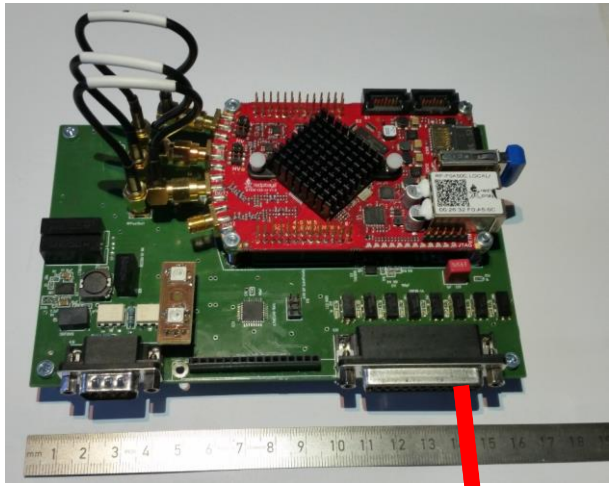
App C MVD 45.2µm
LWC 0.42g/m^3 -10°C

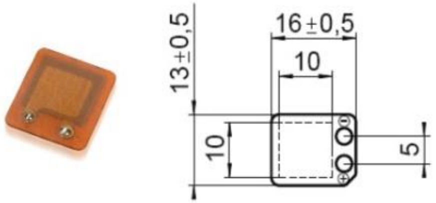


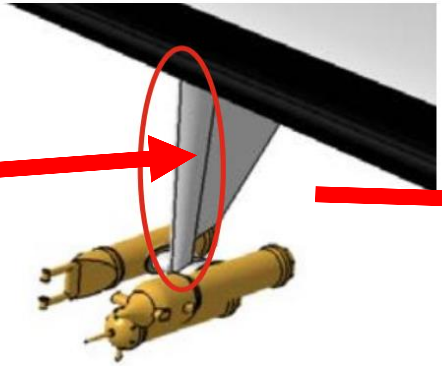
App O MVD 41.6µm
LWC 0.45 g/m^3 -10°C

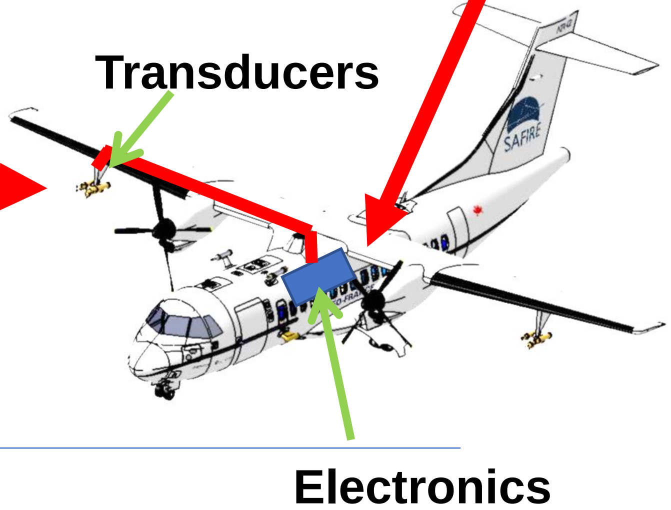
Preparing the flight test

- Sensor integration and test flights March 2023



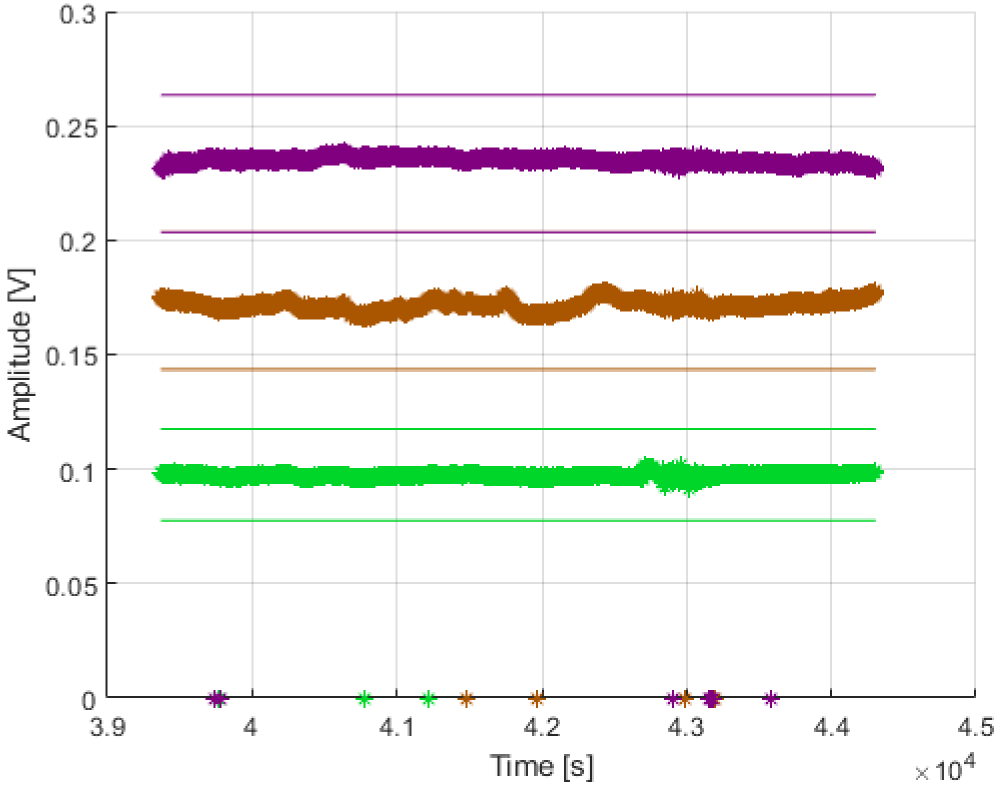


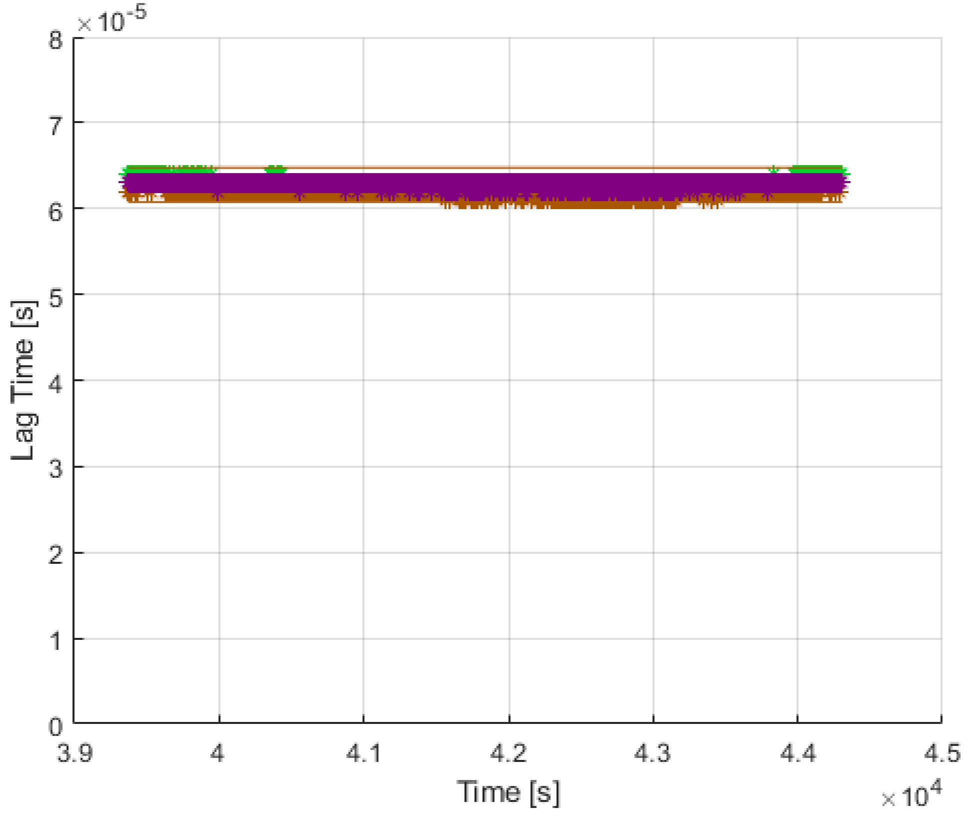




Flight test results

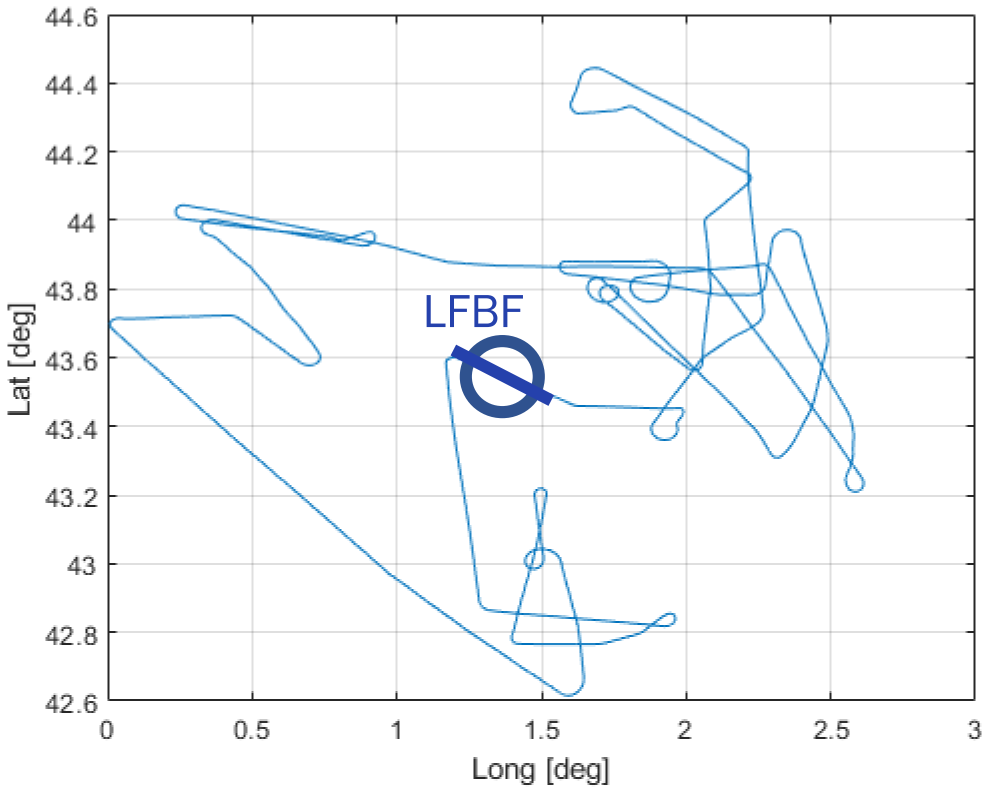
- Clean air test flight 22.03.2023 (up to FL170)
- Amplitude and Lag time between detection limits

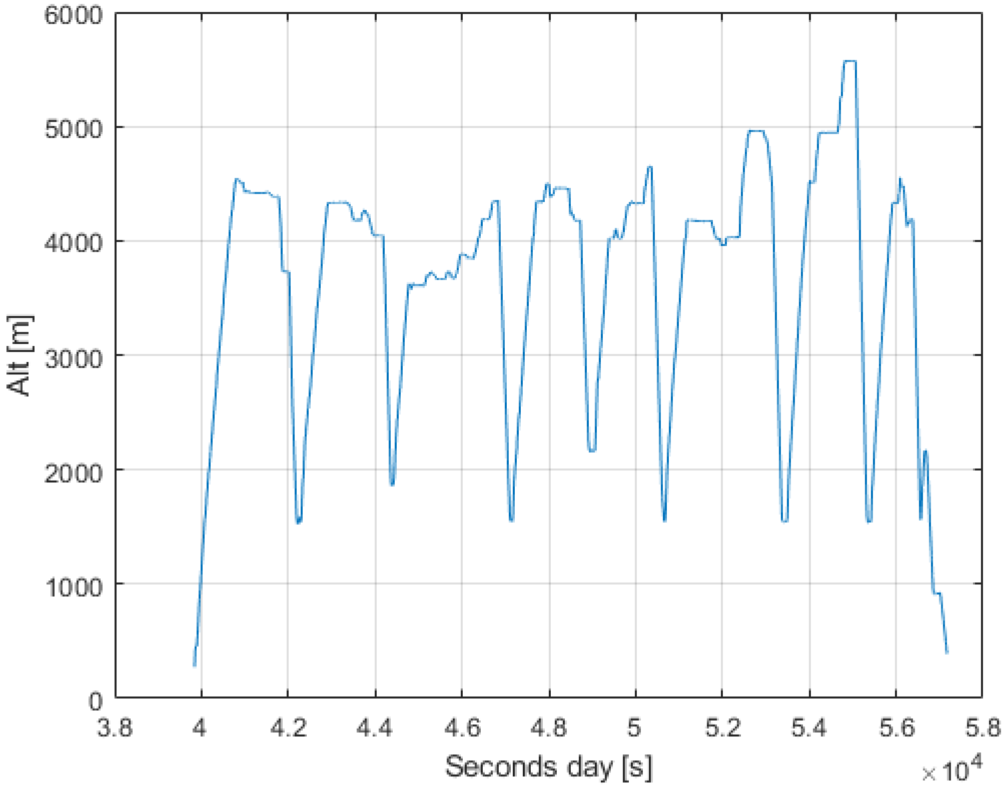




Flight test results

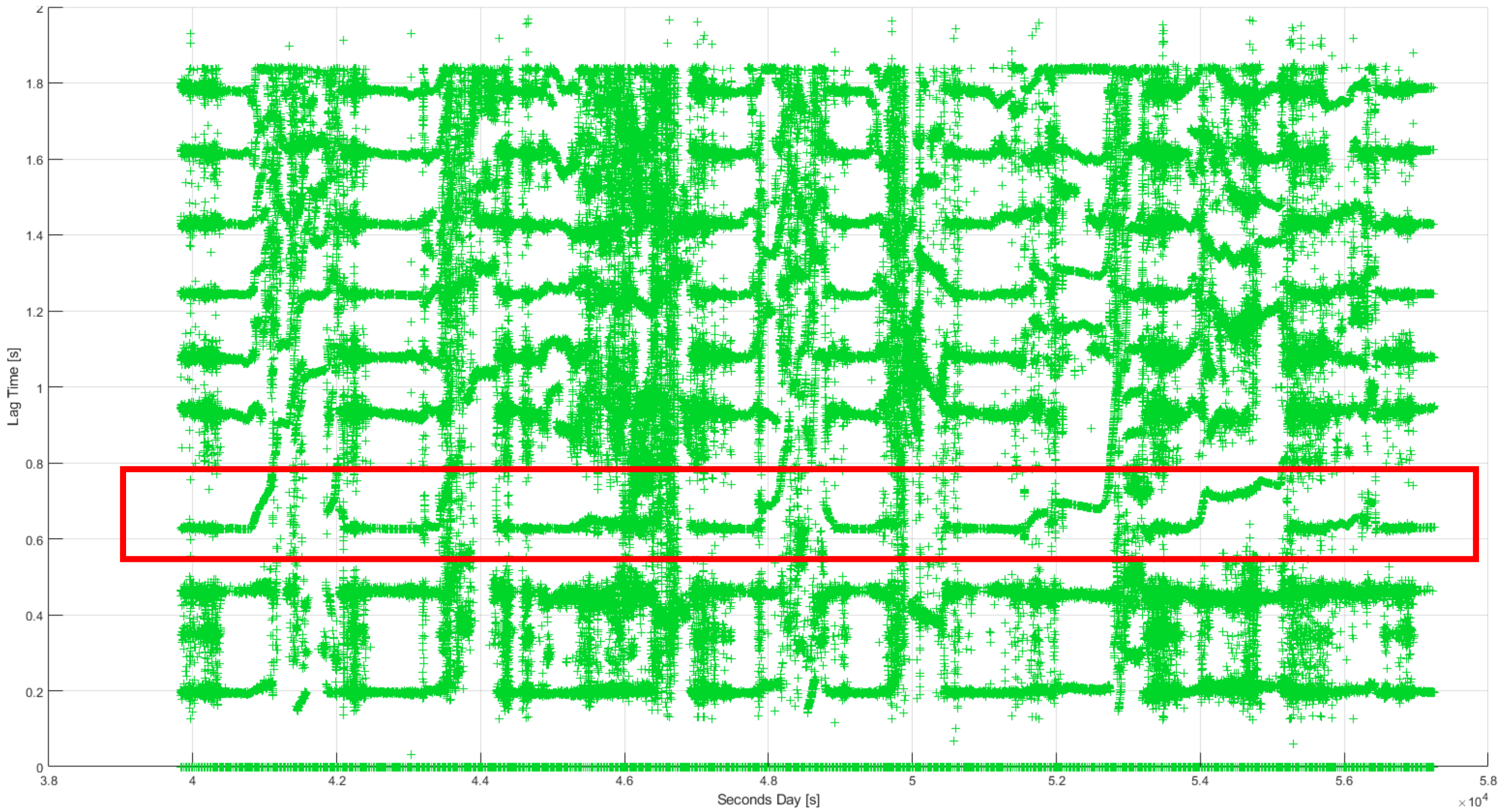
- One exemplarily test flight: 24.04.2023 in the vicinity of LFBF

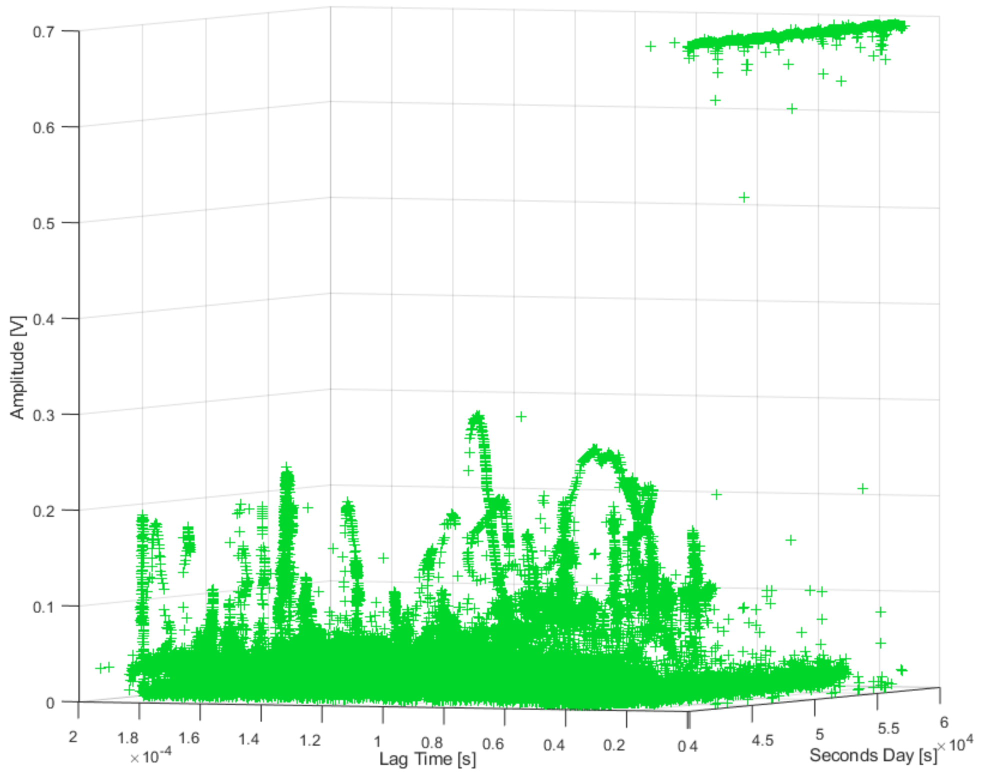




Flight test results

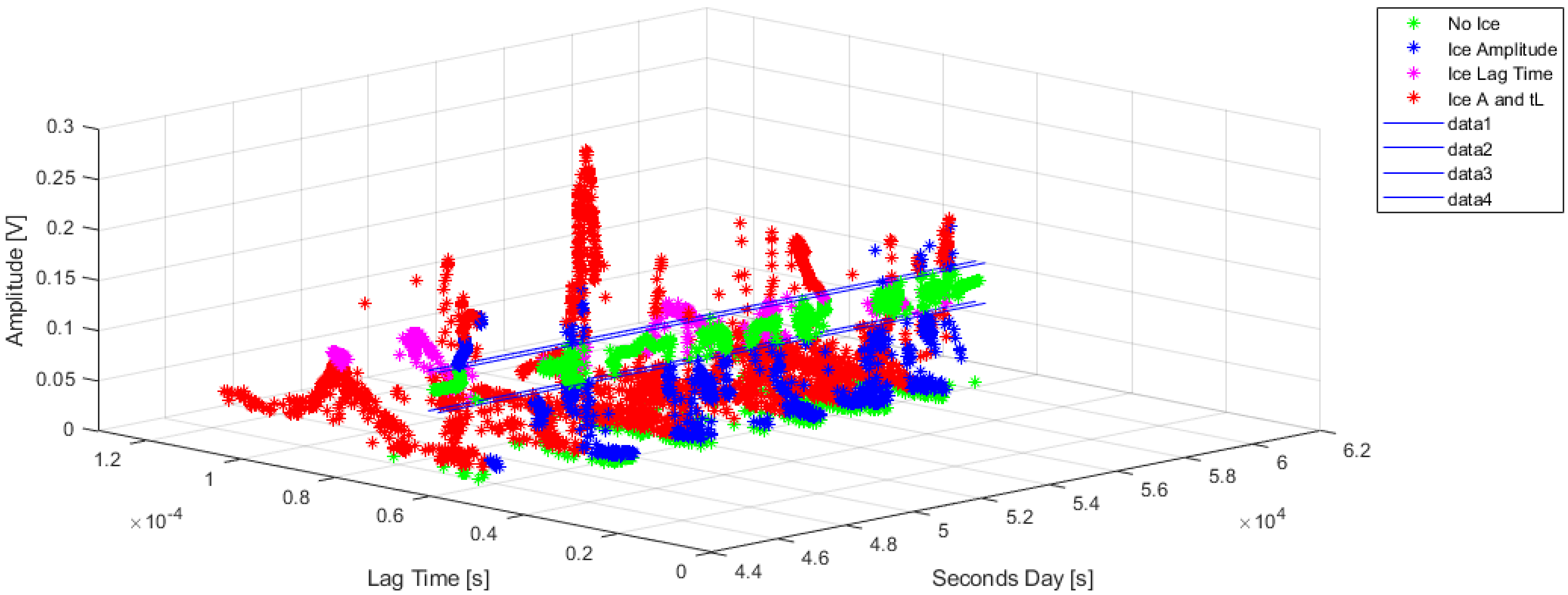
- One exemplarily test flight: 24.04.2023 in the vicinity of TLS
- LILD raw data: A literal mess of lag time and amplitude pairs of received pulses





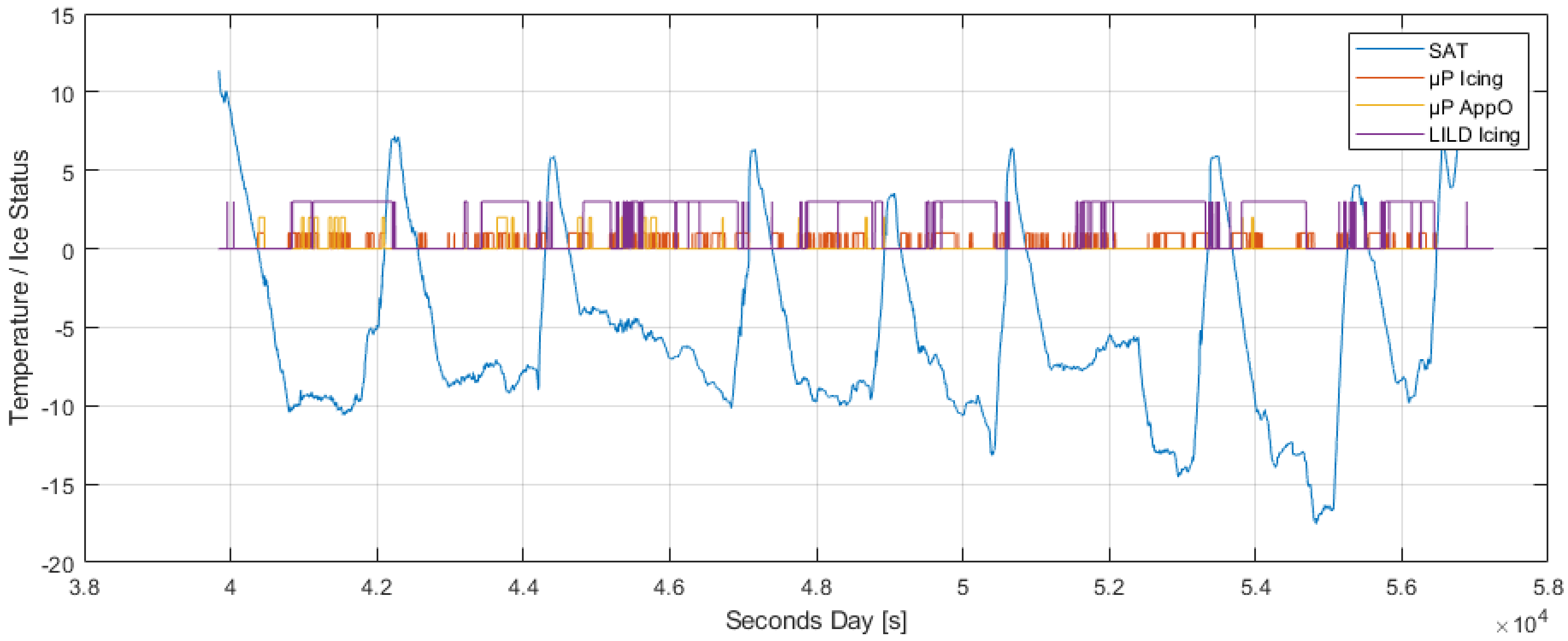
Flight test results

- One exemplarily test flight: 24.04.2023 in the vicinity of TLS
- LILD raw data: Filtering the relevant pulse and analyzing lag time and amplitude



Flight test results

- One exemplarily test flight: 24.04.2023 in the vicinity of TLS
- Ice Status: LILD and Microphysics with static temperature
- LILD detects icing slightly later than Microphysics



Conclusion and outlook

- 3 test flights and 14 campaign flights performed
- Sensor hardware worked flawlessly with minor user interaction. Standalone system that only needed to be switched on before takeoff and off after landing
- Pulse data, online analysis data and raw time data logged for analysis
- A first look into the results:
  - Raw ice detection data correlate well with begin of icing (slightly delayed to Microphysics since ice accretion is measured. Coincident with Ampera and faster than HIDS)
  - End of ice accretion harder to detect. LILD output signal is an „ice present on structure“ signal that turns to 0 when the ice is removed e.g. by descending
  - Some signal disturbances detected that did not happen in wind tunnel experiments. Static discharges on aircraft?

Conclusion and outlook

- Outlook
  - Continuing data analysis…
  - Improving ice detection on measured pulses: Can we use all pulses instead of only one? Neuronal networks? -> Follow up project planned at DLR to investigate that
  - Adding a heater to deice at least one measurement channel of the sensor for better and faster recognition of the exit of icing conditions and the end of ice accretion

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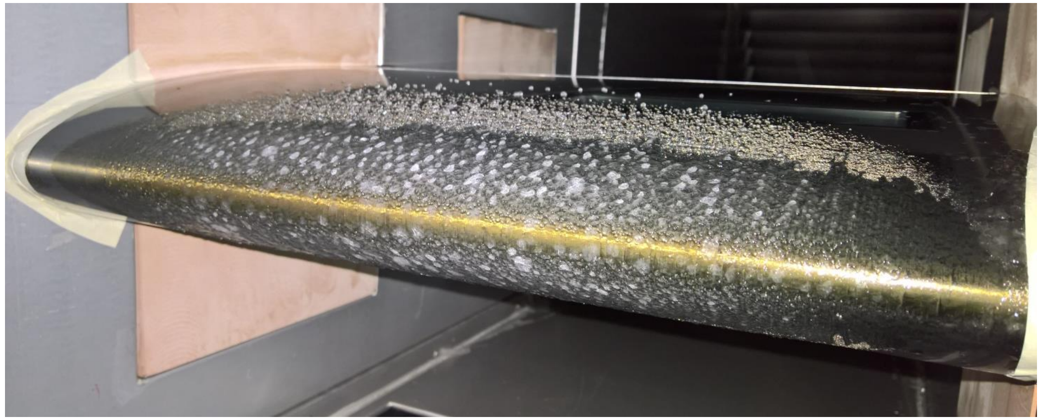
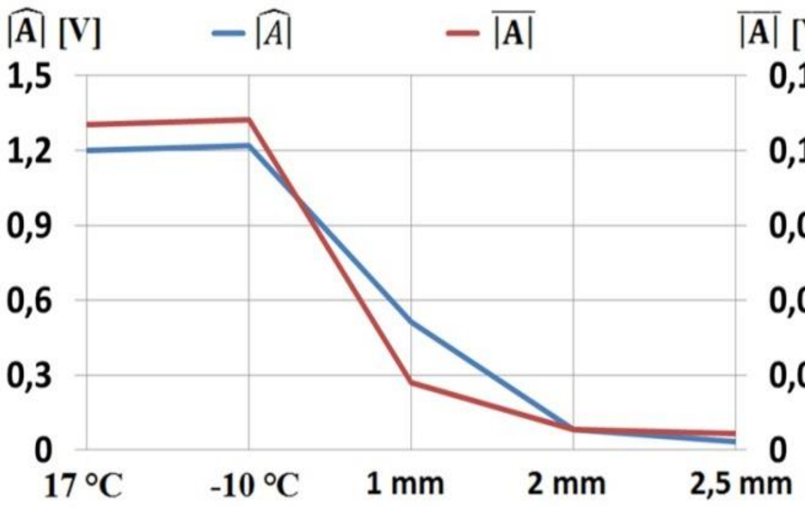
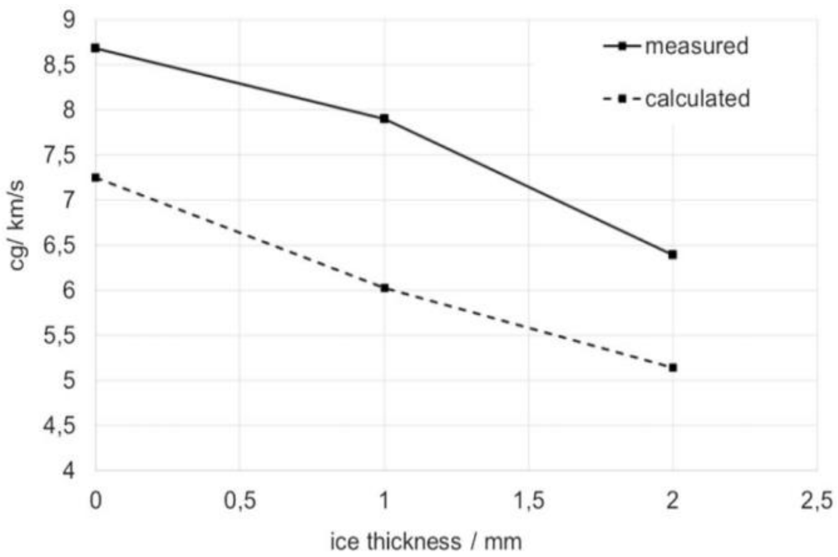
How to build a LILD sensor

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

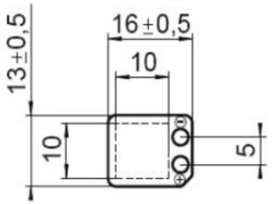




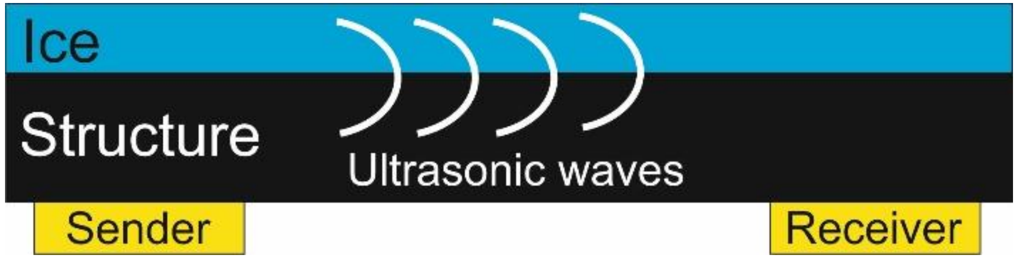


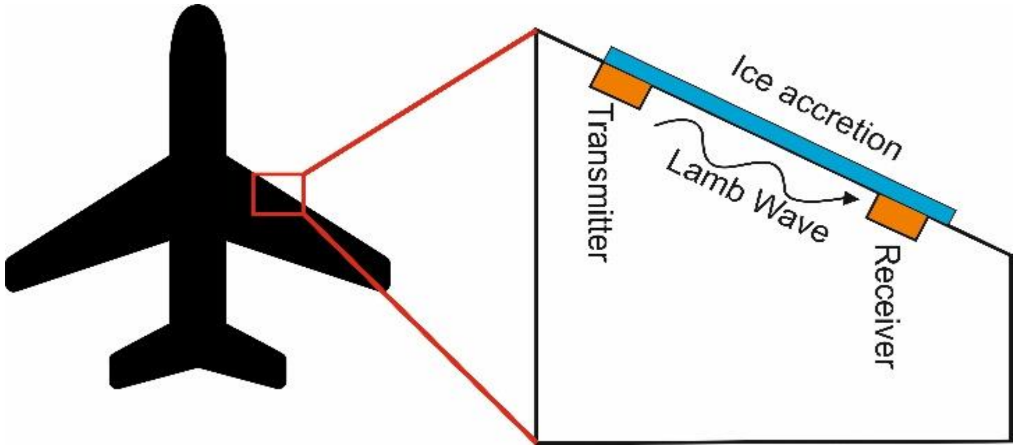
How to build a LILD sensor

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



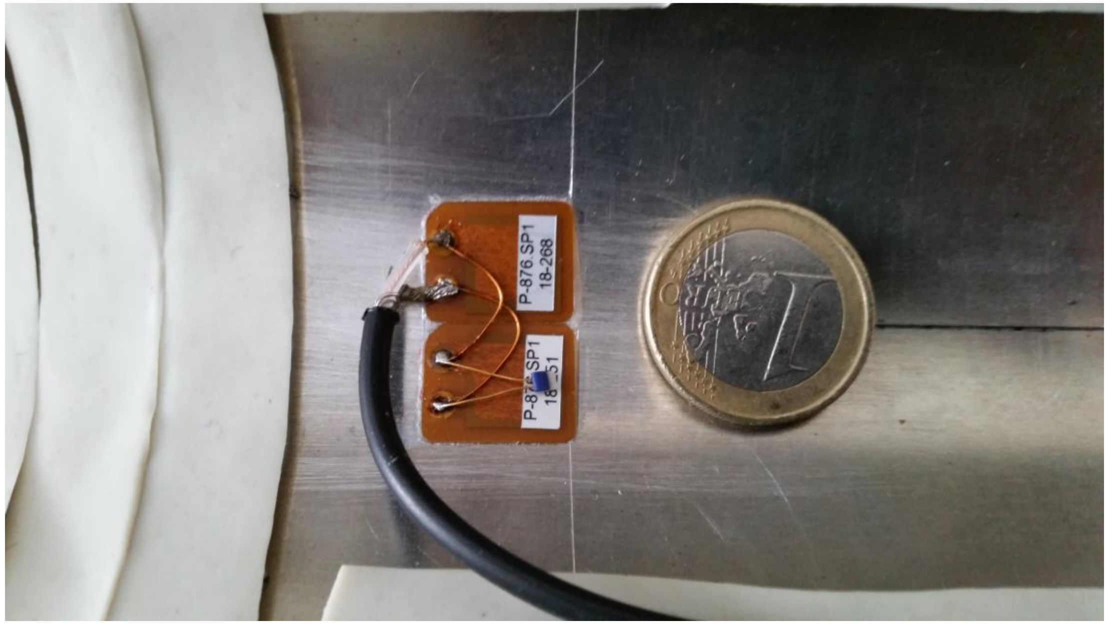
- Aircraft structure acts as wave guide
- Distance between transmitter and receiver approx. 30-50cm
- Sensor can be applied on leading edges of wings, empennage or other icing prone surfaces

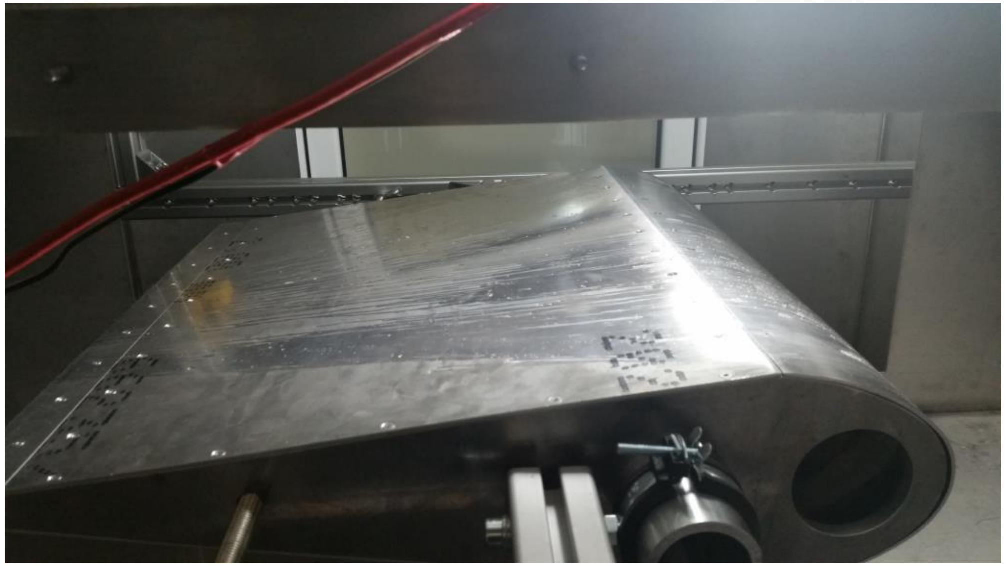




Icing wind tunnel tests

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





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Source: AOPA

Source: BFU