SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES
FOR SAFER AVIATION IN ICING ENVIRONMENT

LILD – Local Ice Layer Detector

Deutscher Luft- und Raumfahrtkongress

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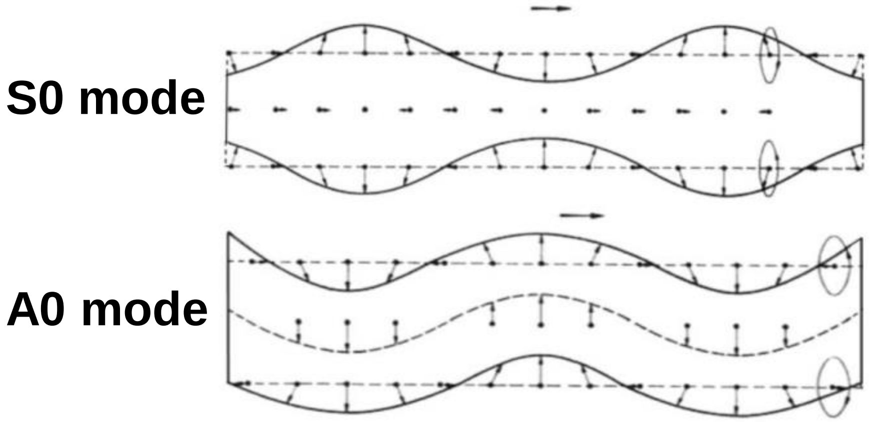
Why Icing sensors?

- 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

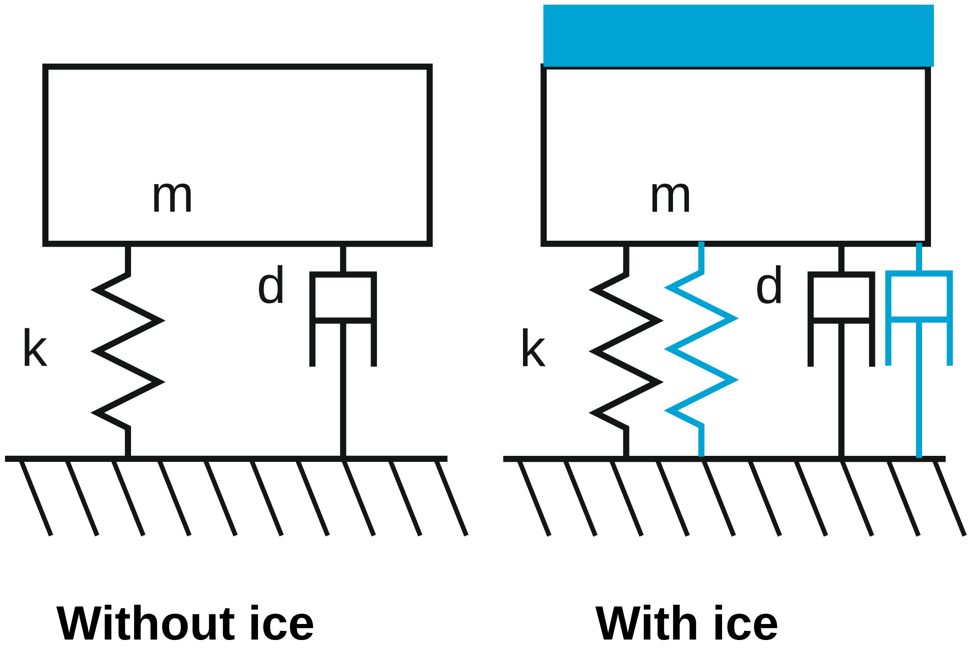
Phenom 100 crash landed due to icing (Source: BFU)

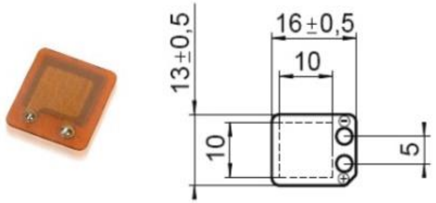
Inflight breakup in thunderstorm with potential icing
Source: BFU

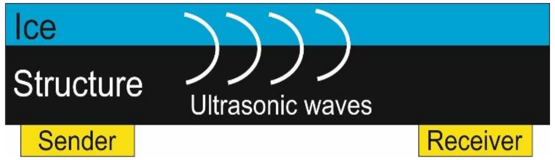
The Local Ice Layer Detector (LILD) principle

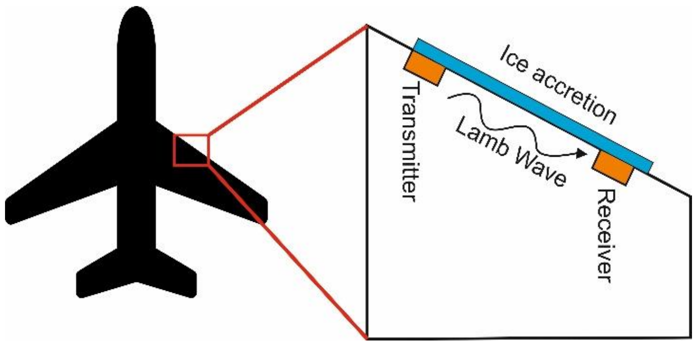


- Ultrasonic structure borne sound (lamb waves) can travel through panel structures
- Transmission behavor of ultrasonic lamb waves in aircraft outside panels changes with the presence of ice
- Ice accretion affects damping, stiffness and mass of panel structure
  - Amplitude and Group velocity of lamb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









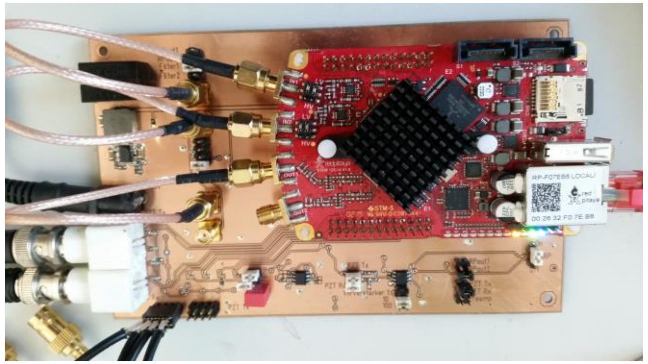
Developing LILD Sensor in SENS4ICE

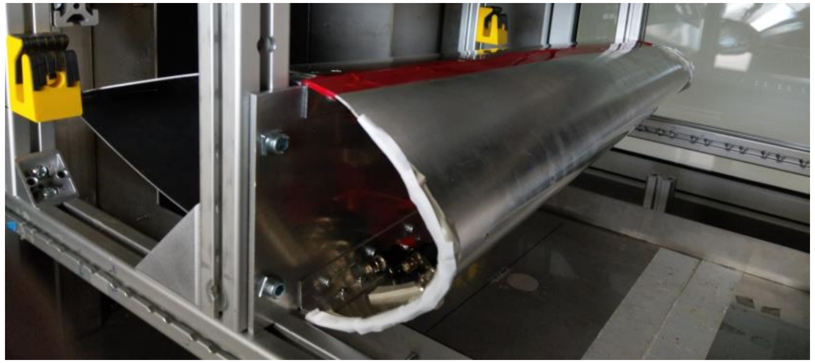
Miniturization and development of flight test capable sensor electronics → **Icing wind tunnel tests**

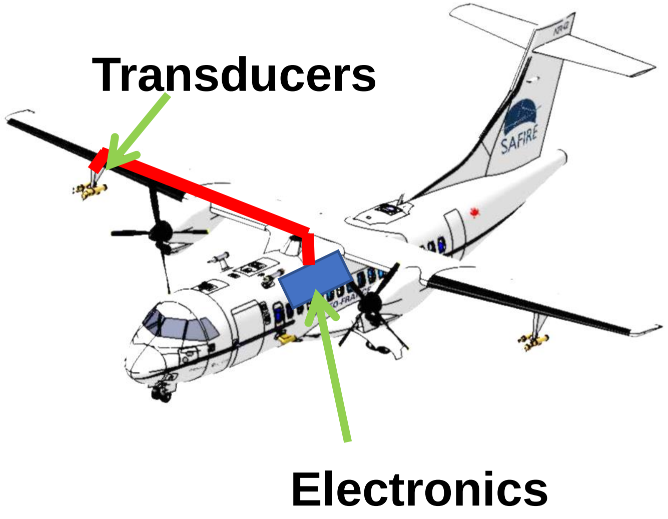
- Pretests at TU Braunschweig IAF facility
- Final test at TU Braunschweig ISM

→ **Flight Test**

- Safire ATR42
- Planned for 2023







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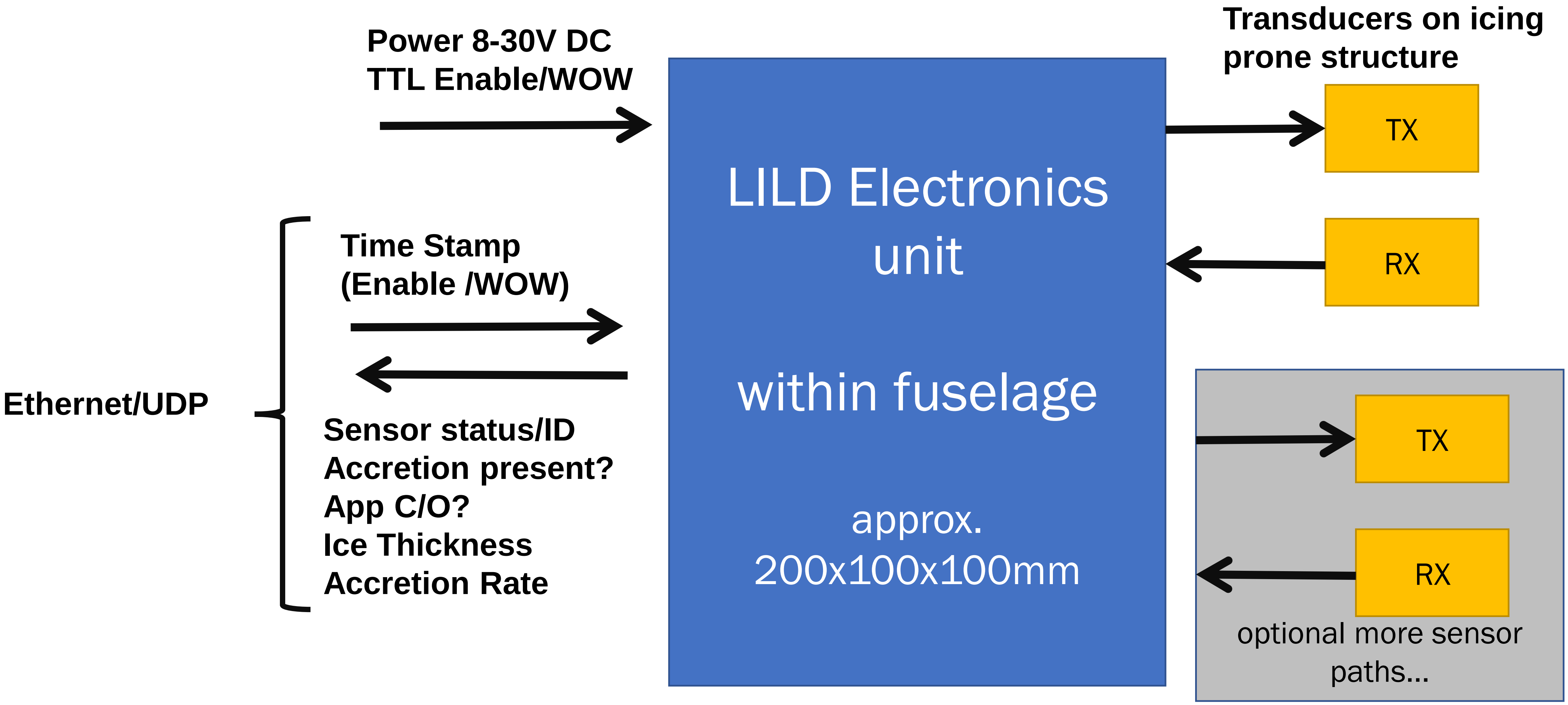
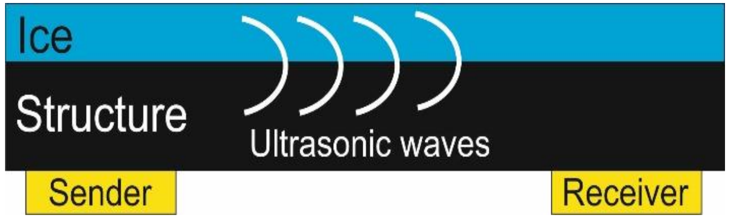
Overview of LILD sensor electronics



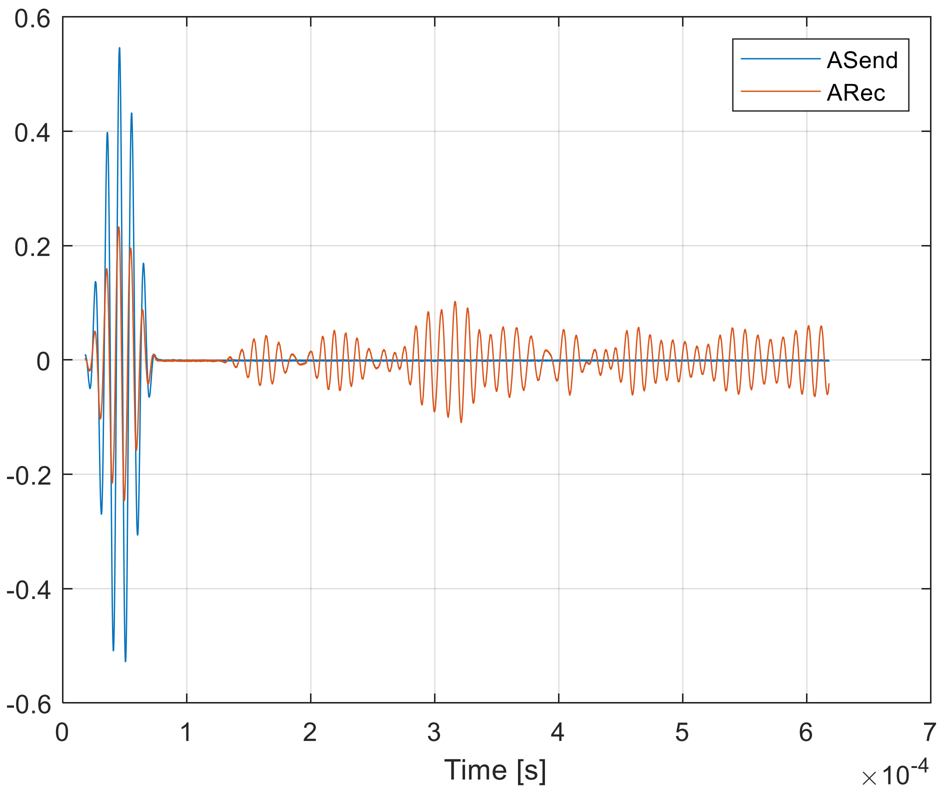
LILD Electronics characteristics

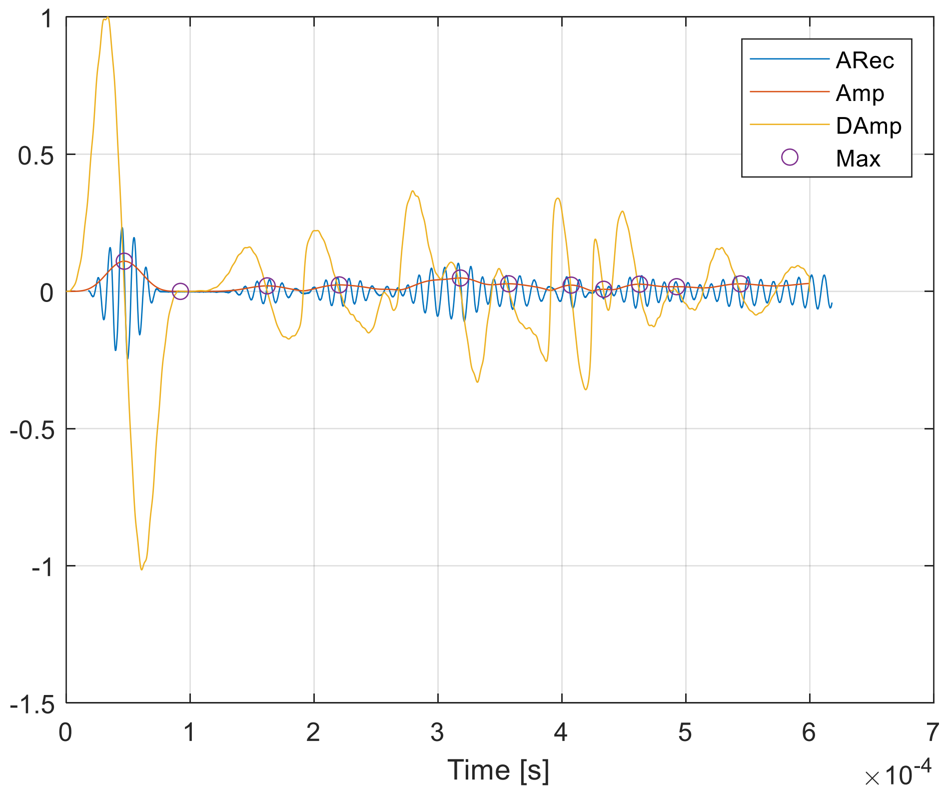
- Xilinx ZYNQ XC7Z01 FPGA and dual core microcontroller for signal aquisition and generation
- Output amplifier for max. 15V amplitude of lamb waves up to 1MHz
- Input bandpass filter 30kHz to 1MHz
- Sampling frequencies of 16.6MHz and 1.95Mhz, up to 125MHz possible
- Synchronous temperature measurement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

Analyzing the signals



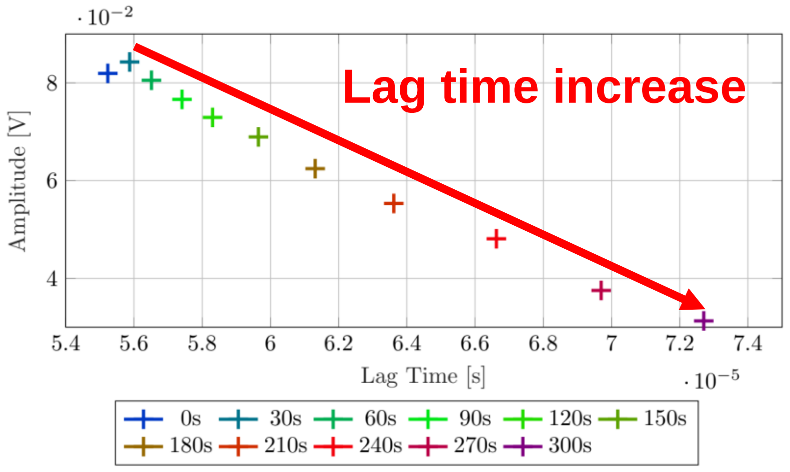
- Finding the lag time and amplitude of lamb wave pulses

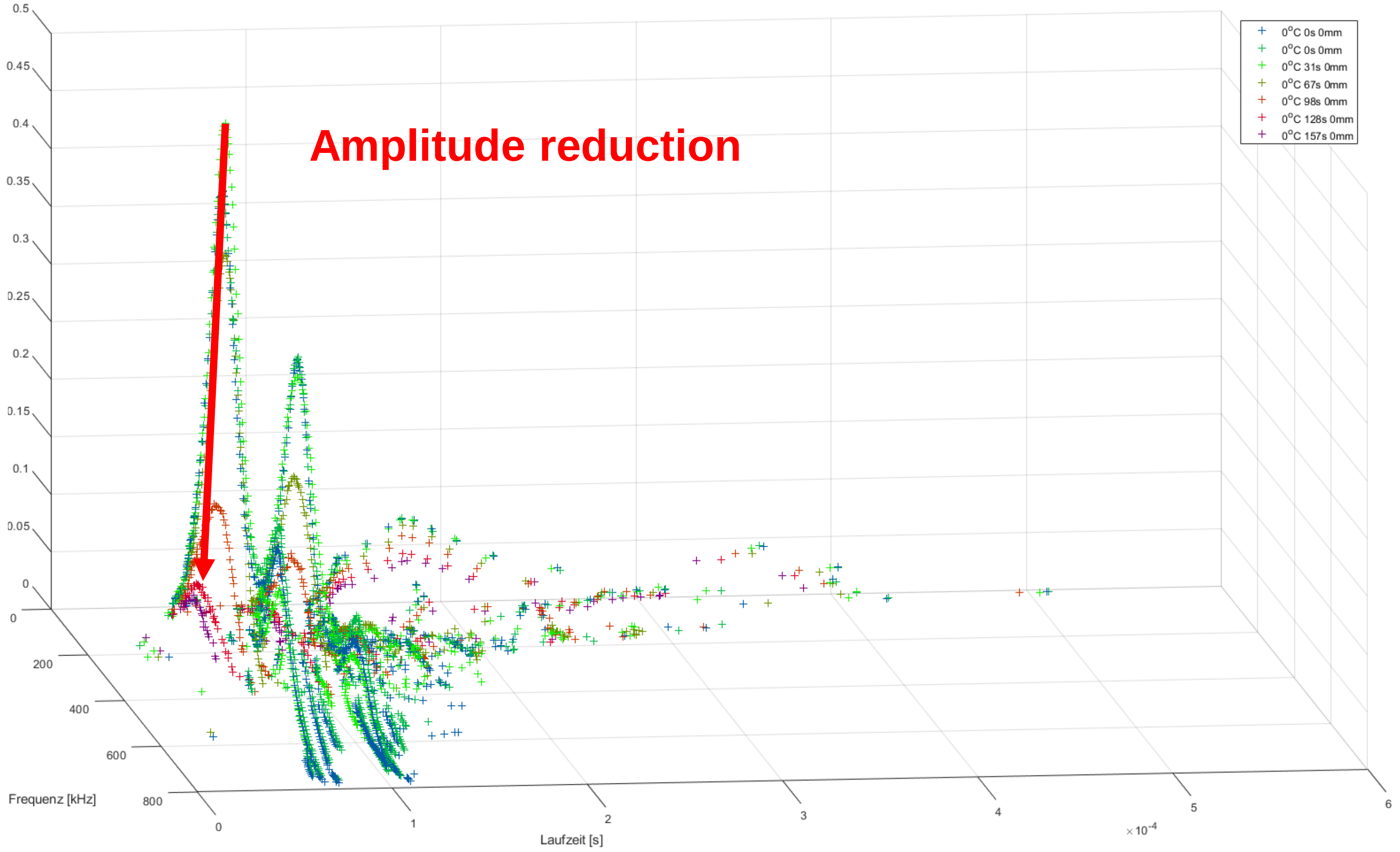




Analyzing the influence of ice on the signals

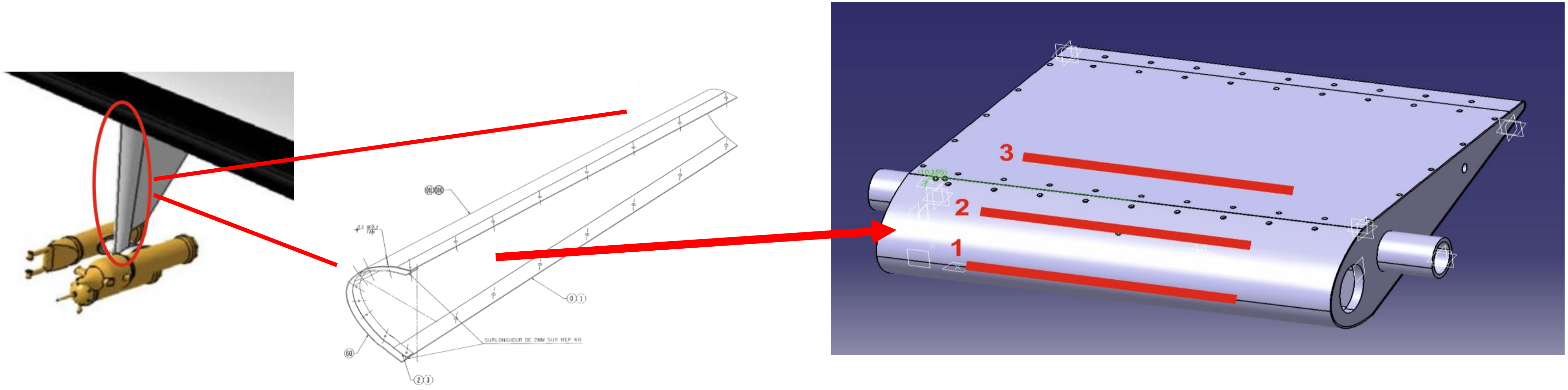
- Finding the pulses, which are susceptible to ice
- Frequency sweep
- 30s ice accretion
- Ice layer reduces amplitude





Icing wind tunnel tests

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



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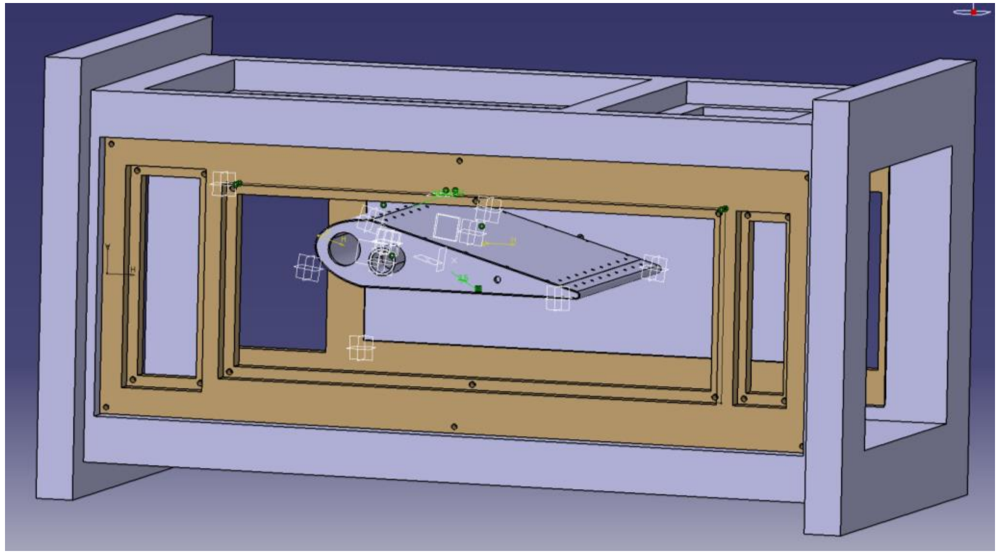
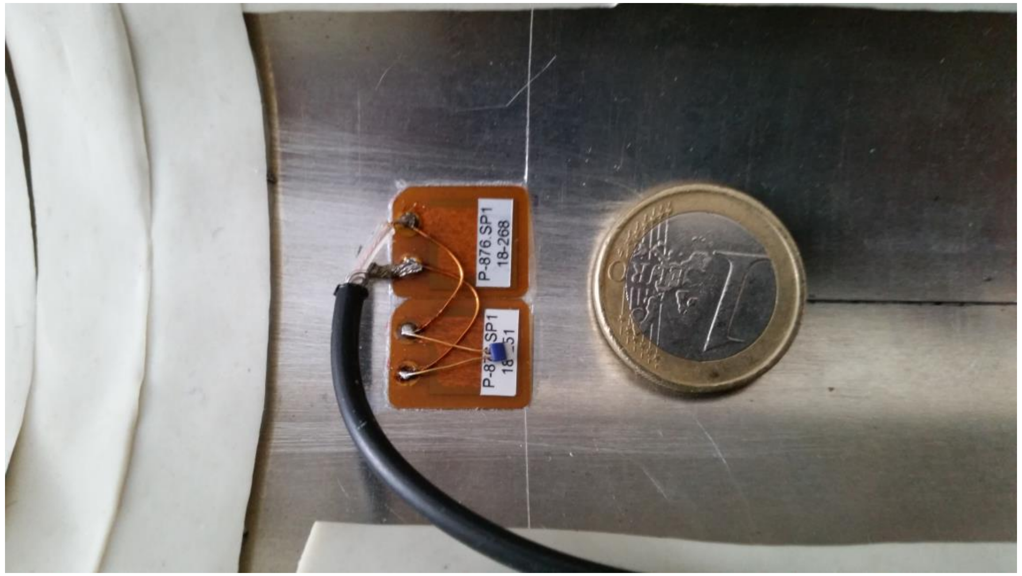
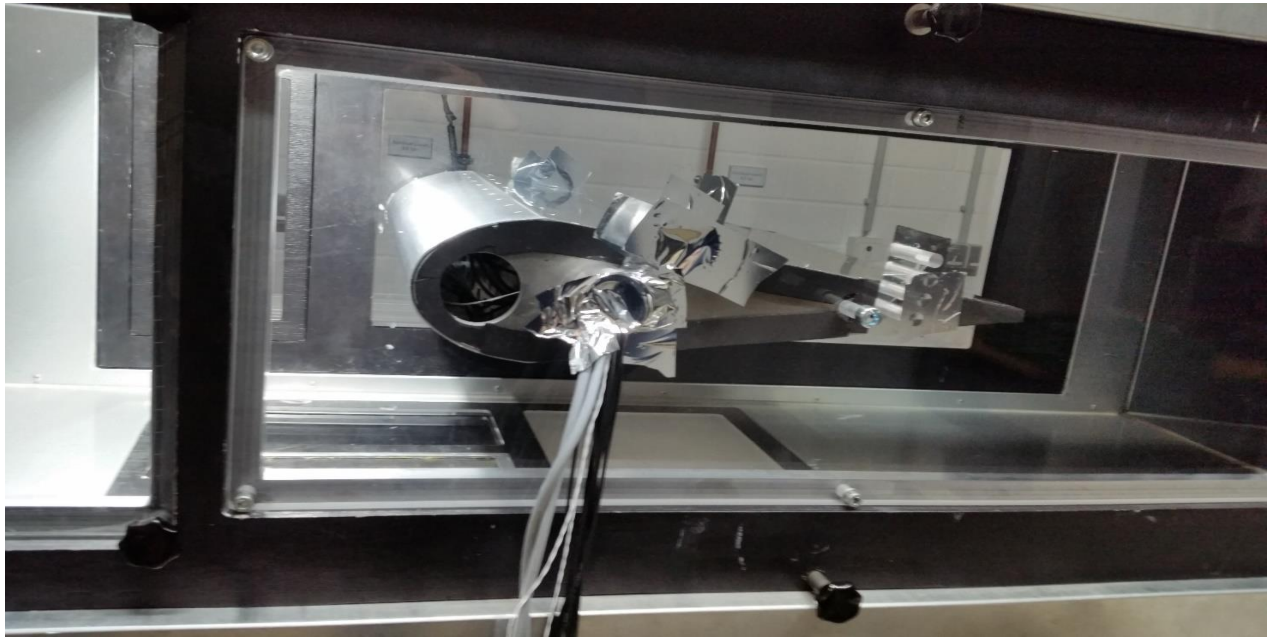
IWT test at TU BS ISM tunnel

- 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

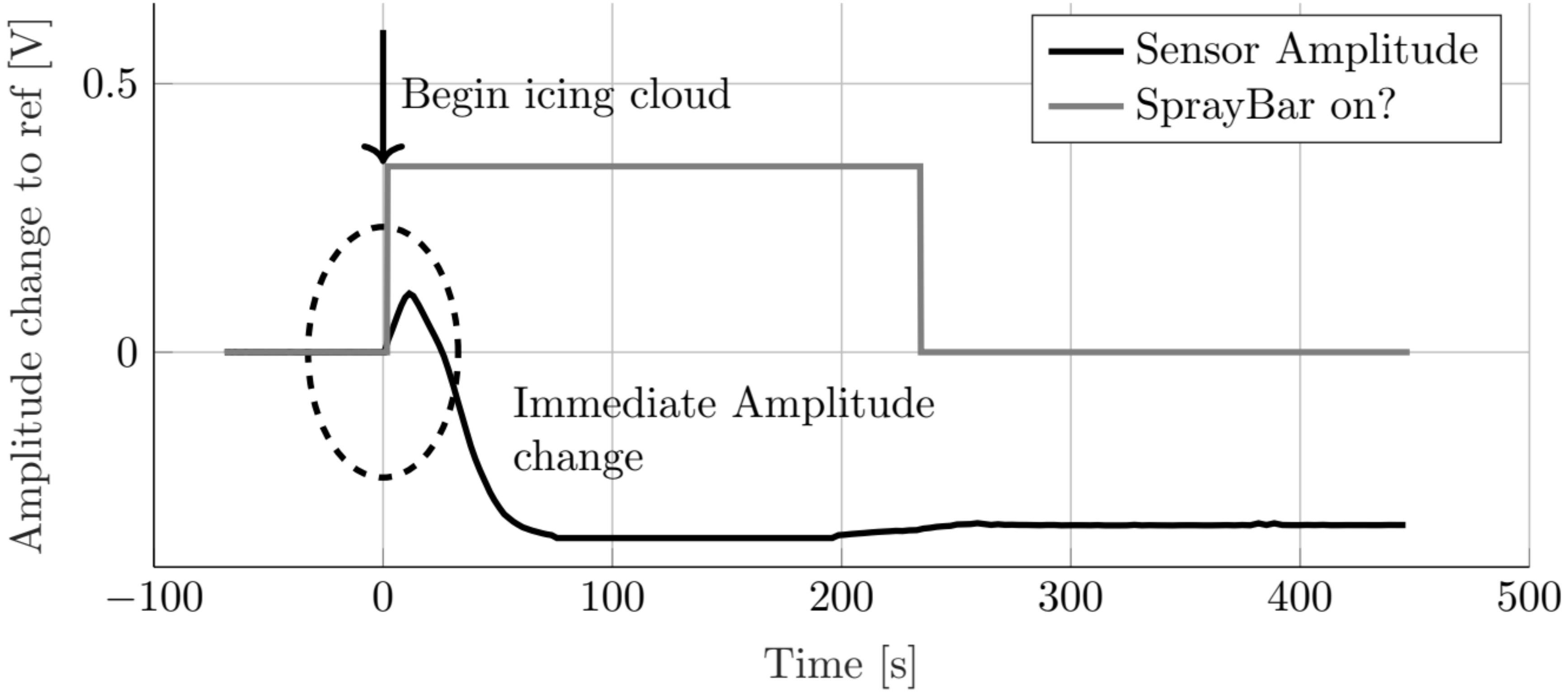






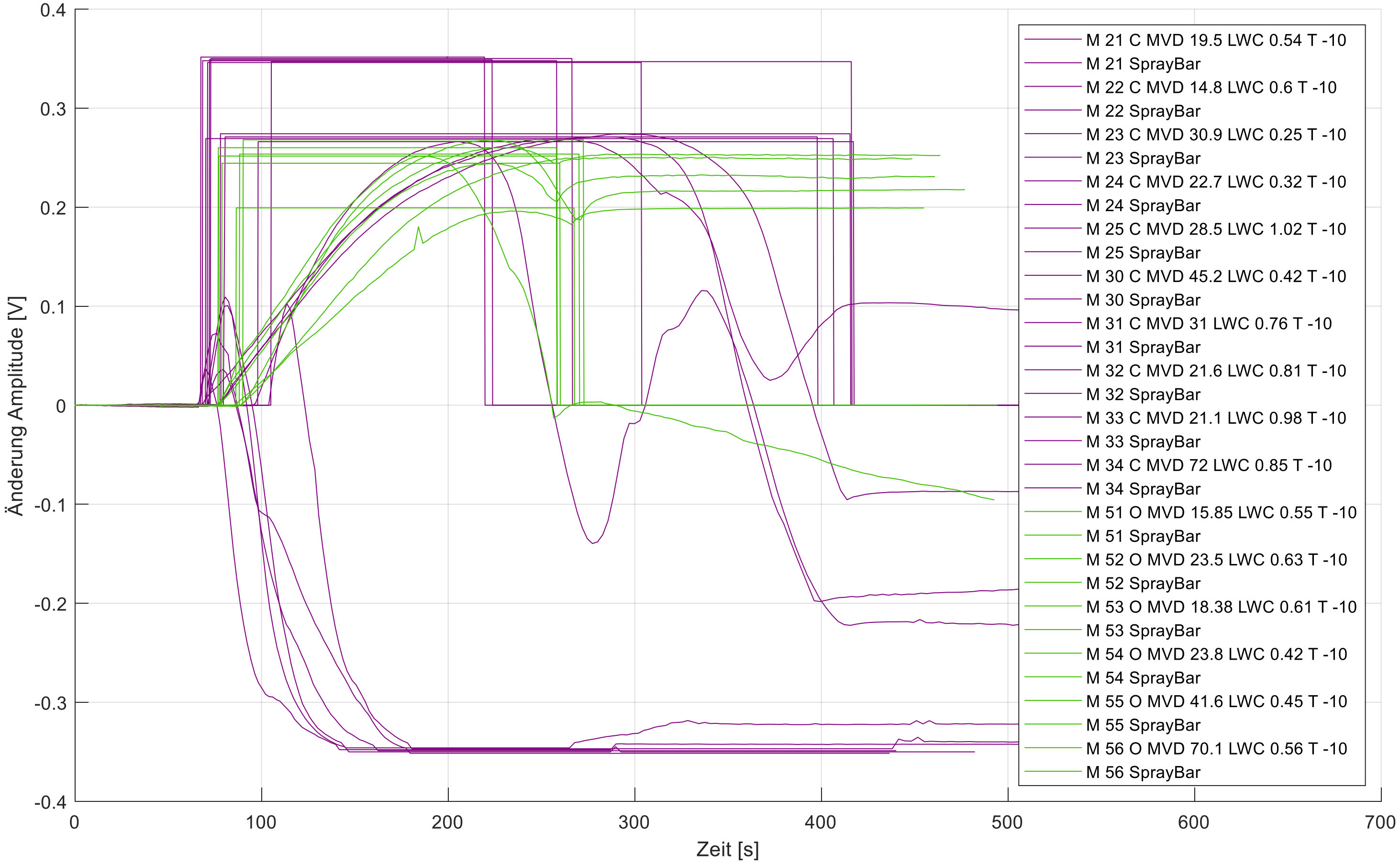
IWT test at TU BS ISM tunnel

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

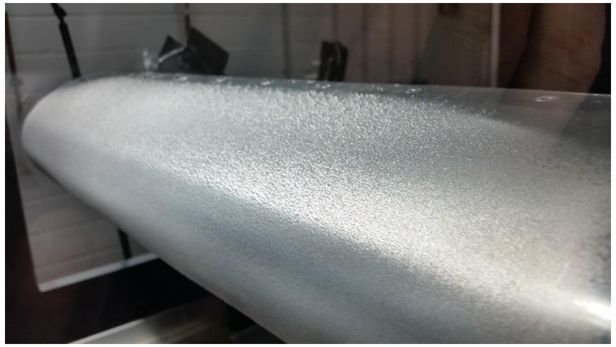


IWT at TU BS ISM tunnel

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



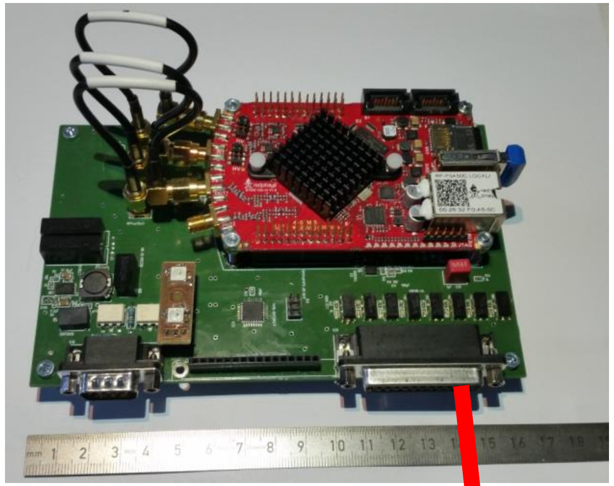
App C MVD 45.2µm
LWC 0.42g/m^3 -10°C

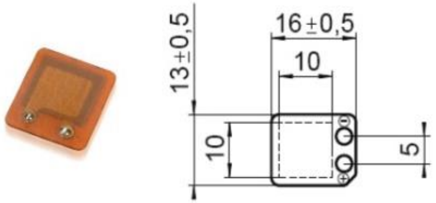


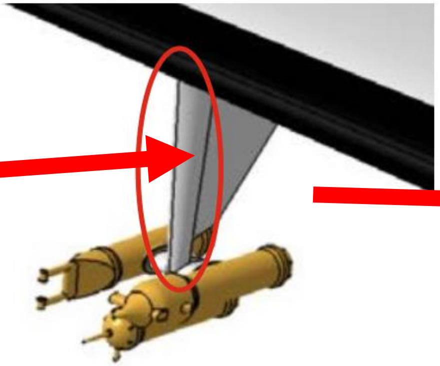
App O MVD 41.6µm
LWC 0.45 g/m^3 -10°C

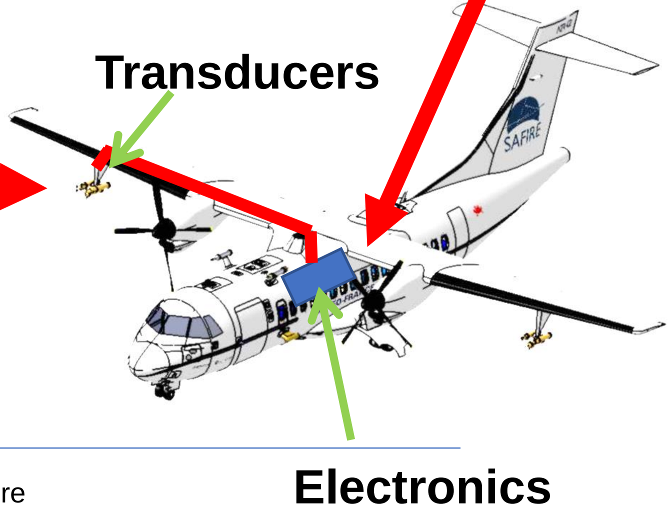
Preparing the flight test

- Sensor integration and test flights March 2023









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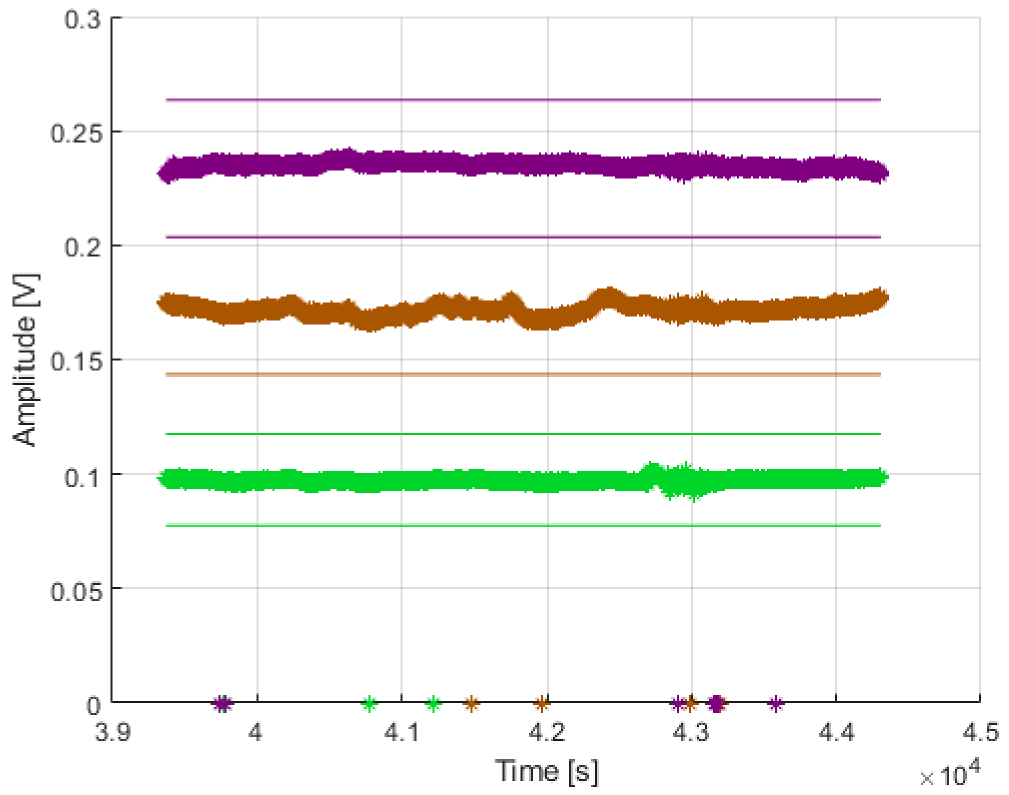
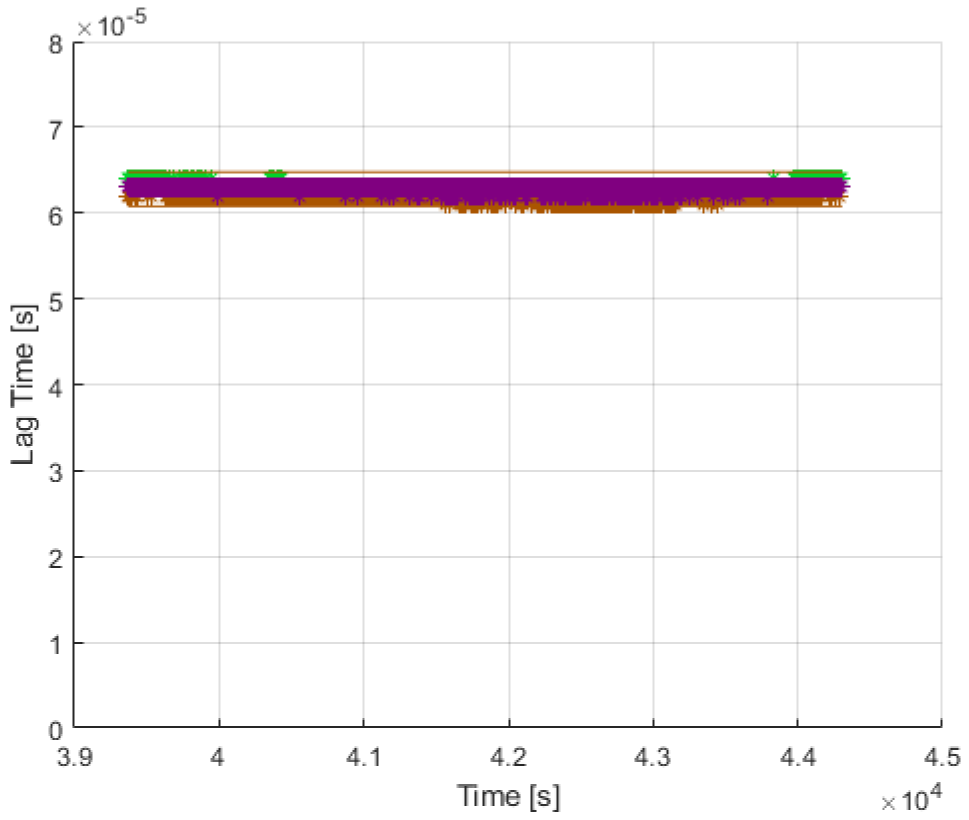
Flight test results

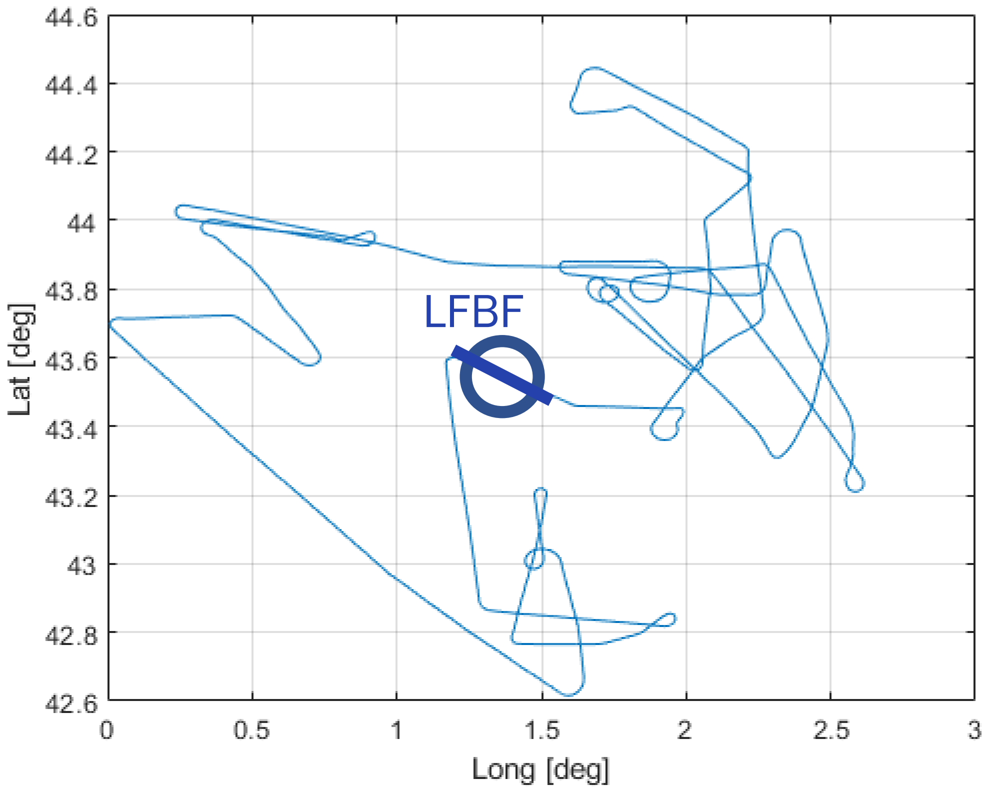
- Clean air test flight 22.03.2023 (up to FL170)
- Amplitude and Lag time between detection limits

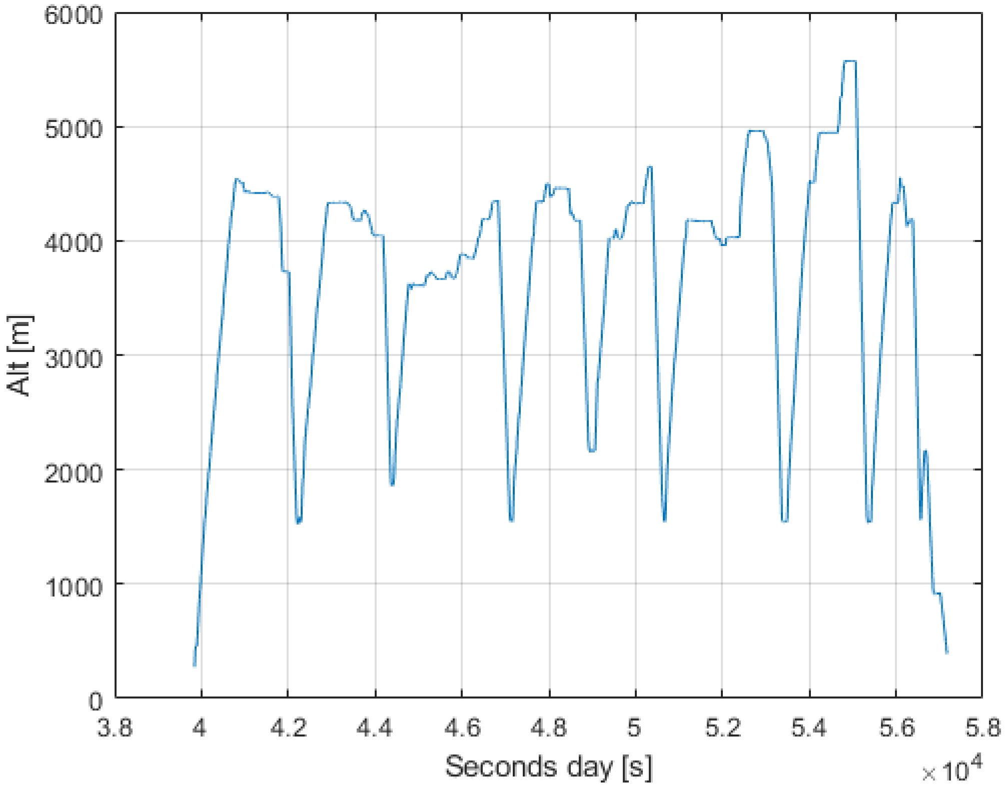




Flight test results

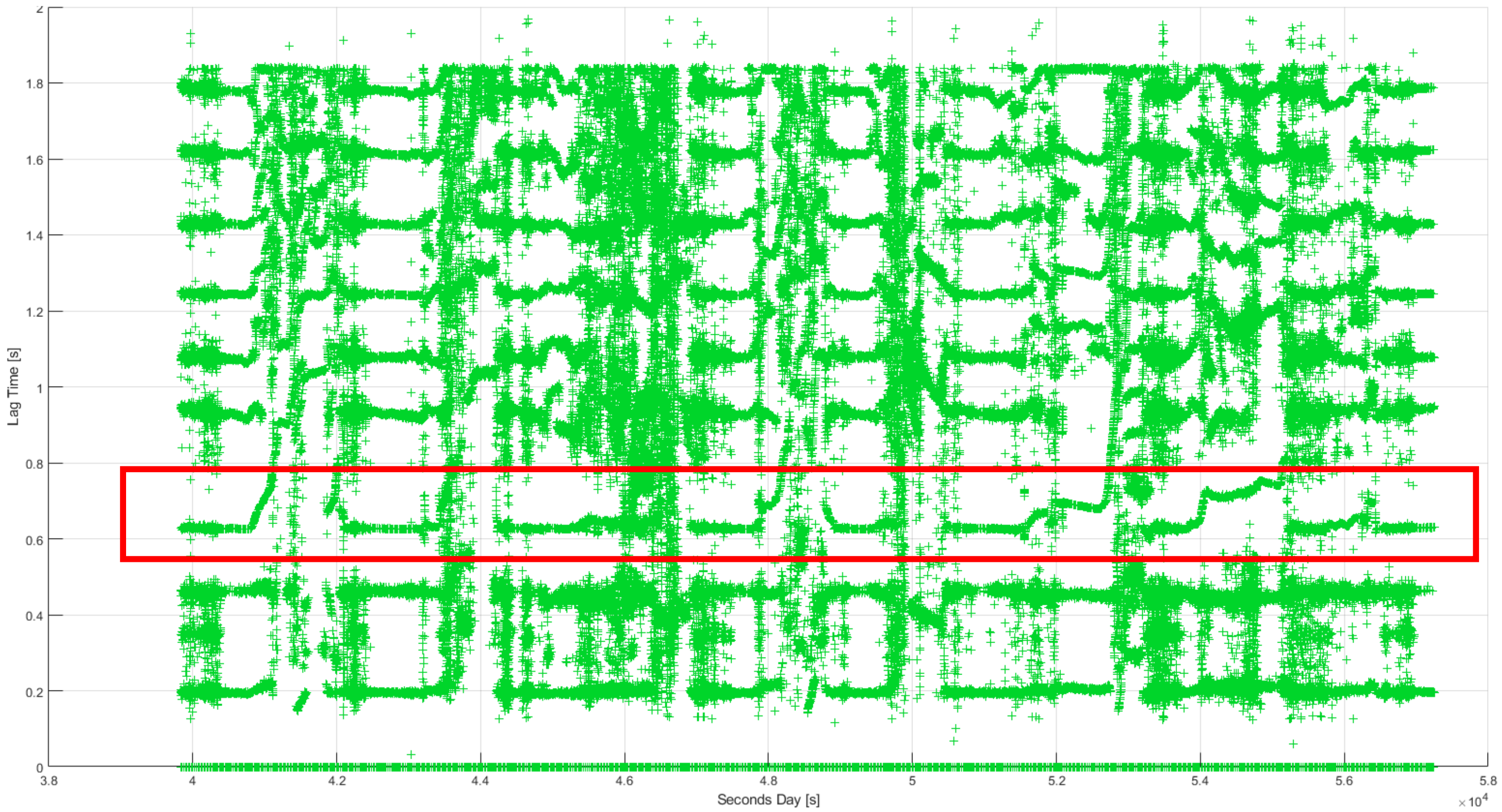
- One exemplarily test flight: 24.04.2023 in the vicinity of LFBF

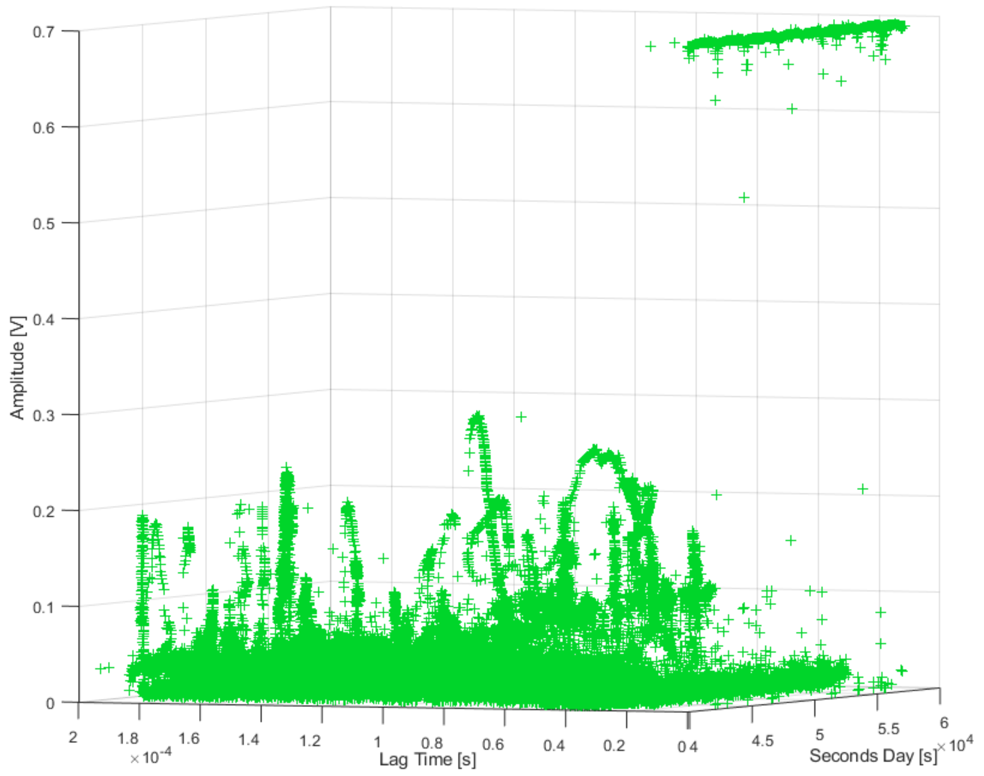




Flight test results

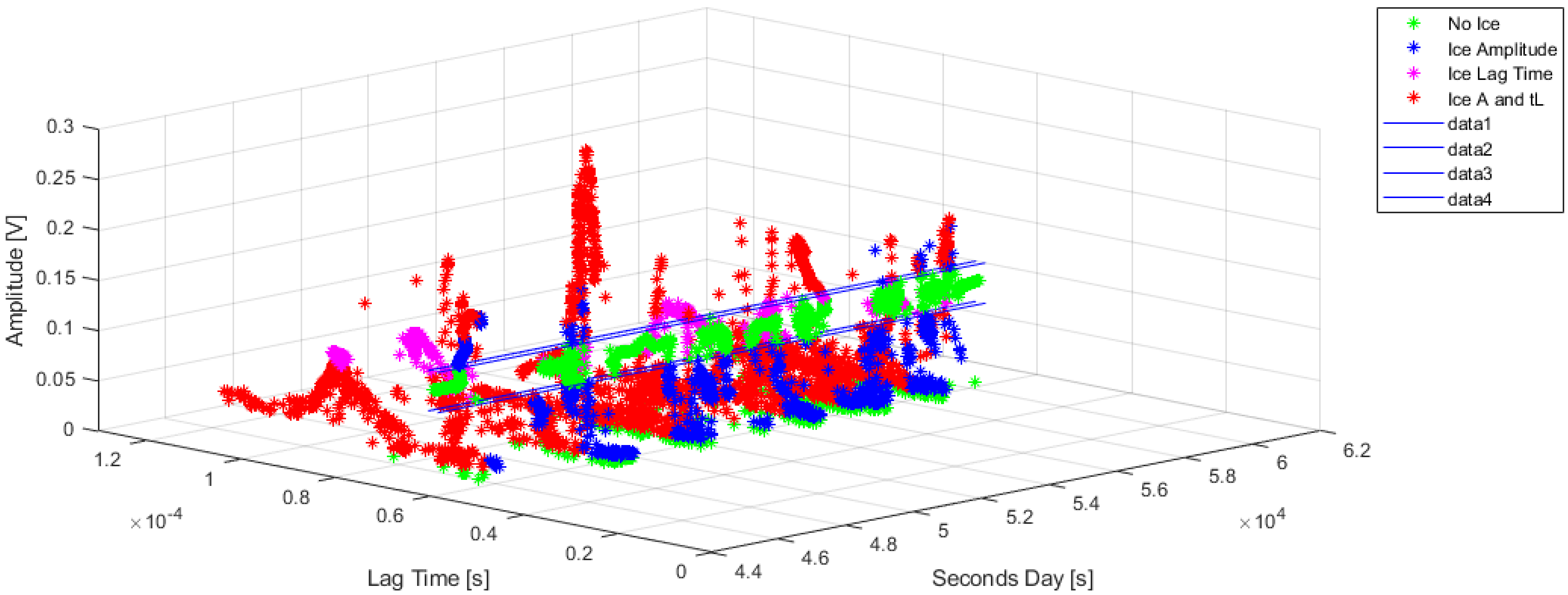
- One exemplarily test flight: 24.04.2023 in the vicinity of TLS
- LILD raw data: A literal mess of lag time and amplitude pairs of received pulses





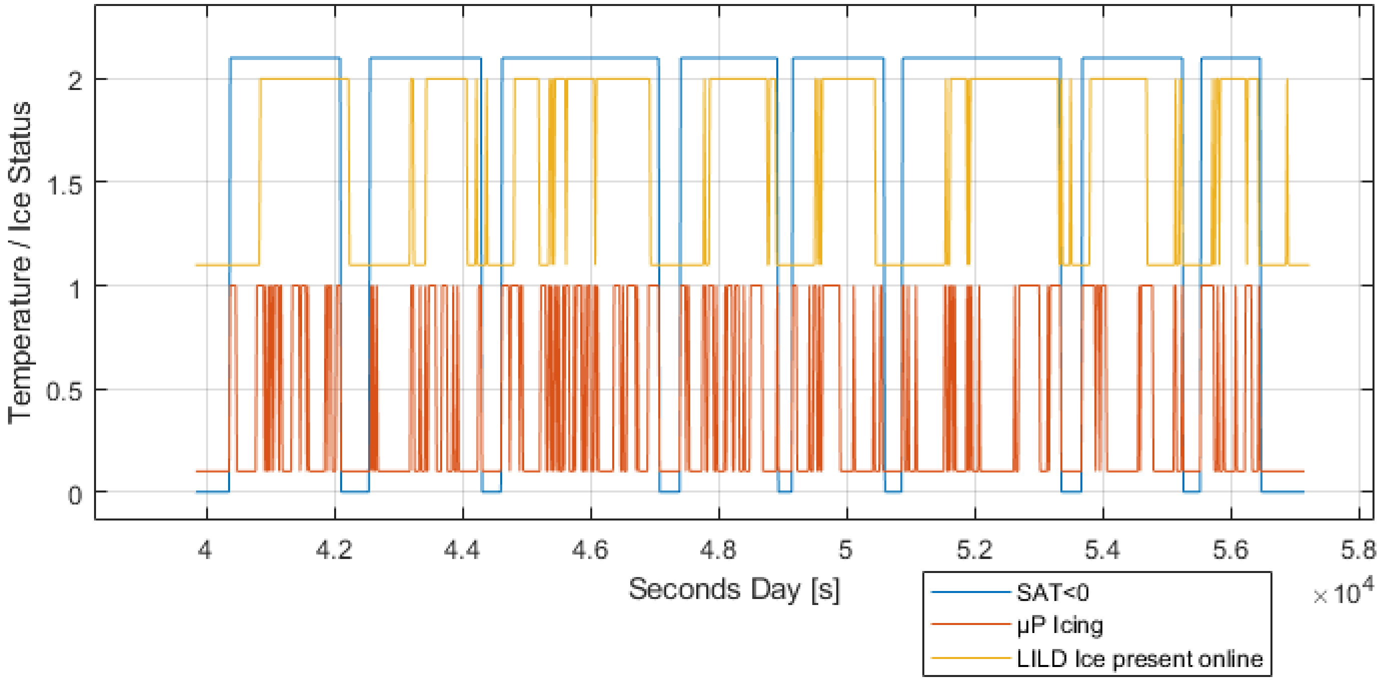
Flight test results

- 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<0°C indication
- 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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Icing wind tunnel tests

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