SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES
FOR SAFER AVIATION IN ICING ENVIRONMENT

Local Ice Layer Detector (LILD)

FINAL DISSEMINATION EVENT OF SENS4ICE PROJECT

Martin Pohl – DLR

Directorate General for Research and Innovation, Brussels, Belgium – 29 November 2023

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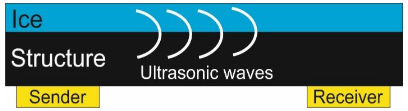
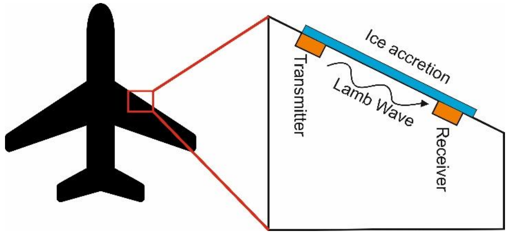
Local Ice Layer Detector (LILD)

A short overview and future challenges

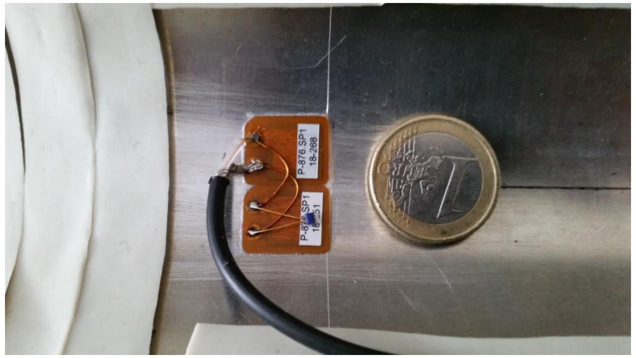
Martin Pohl (DLR)

LILD – Local Ice Layer Detector
German Aerospace Center





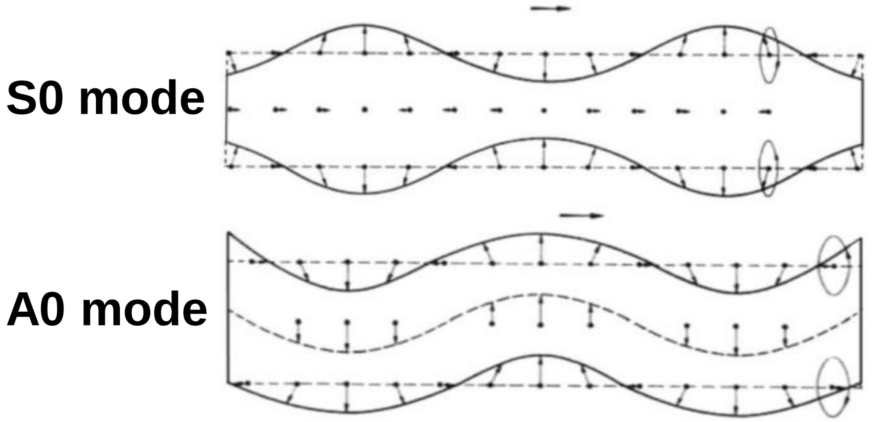
- Detection type: Accretion
- Physical principle: Measuring the change in the Lamb wave guide behaviour in case of ice accretion
- Sensor high-level output description: Ice present, ice thickness, ice accretion rate (planned App C / O discrimination)
- main sensor specifications: Electronics 160x100x60mm, 5W power consumption at 5-30V, 300g. Min. 2 Transducers 16x16x0.5mm 1g at approx. 30cm distance
- Tested in TU Braunschweig icing wind tunnel and European ATR42 flight test campaign
- TRL at project start 2-3, TLR now 6 for ice detection, 3 for App C / App O discrimination

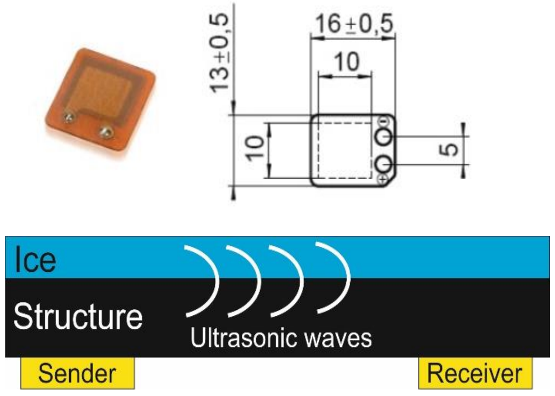


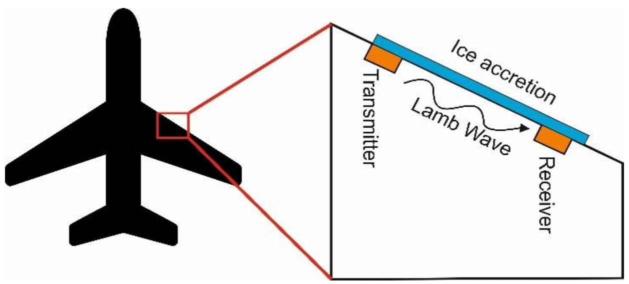
LILD – Local Ice Layer Detector

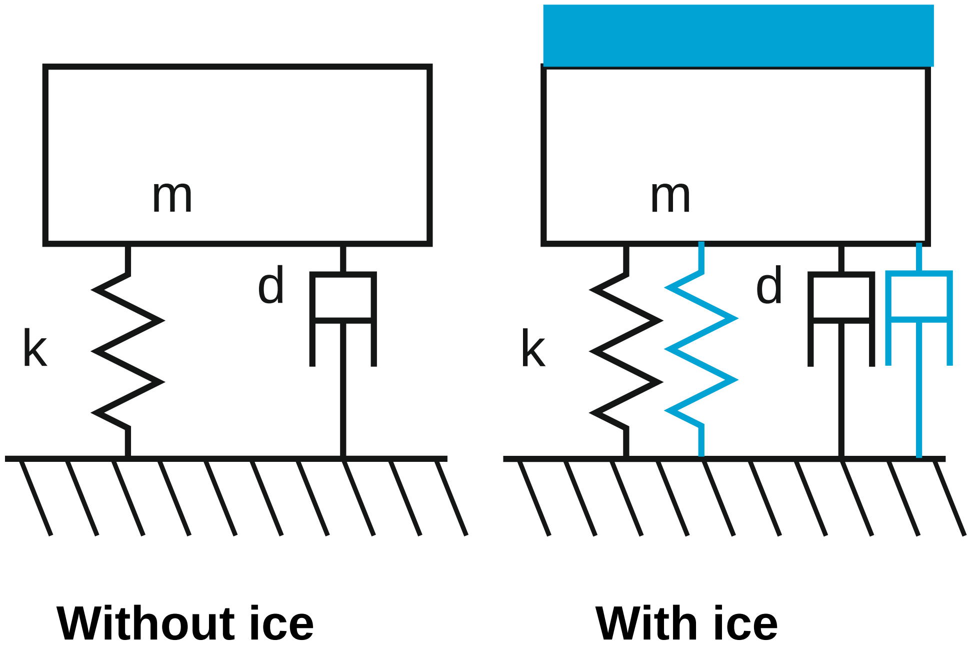
Where we came from…

- 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





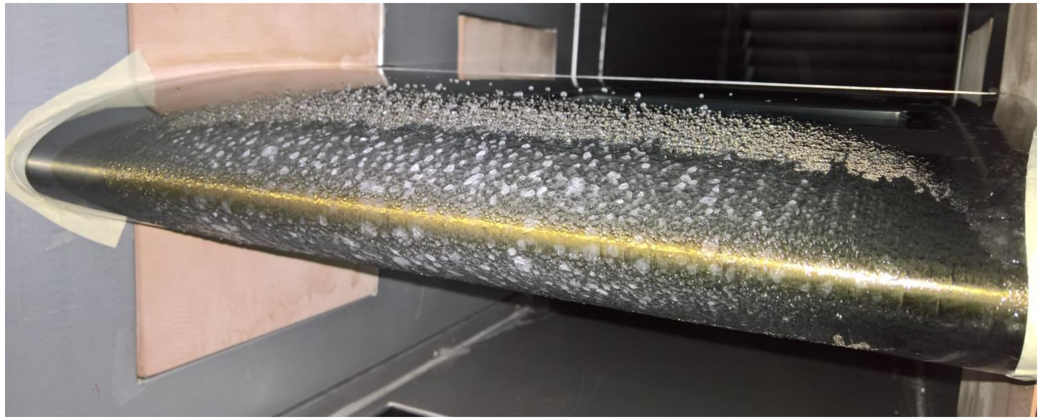


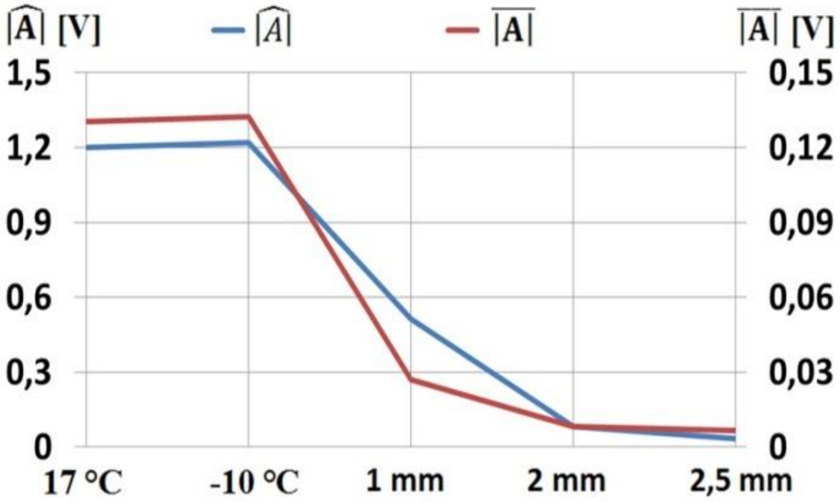


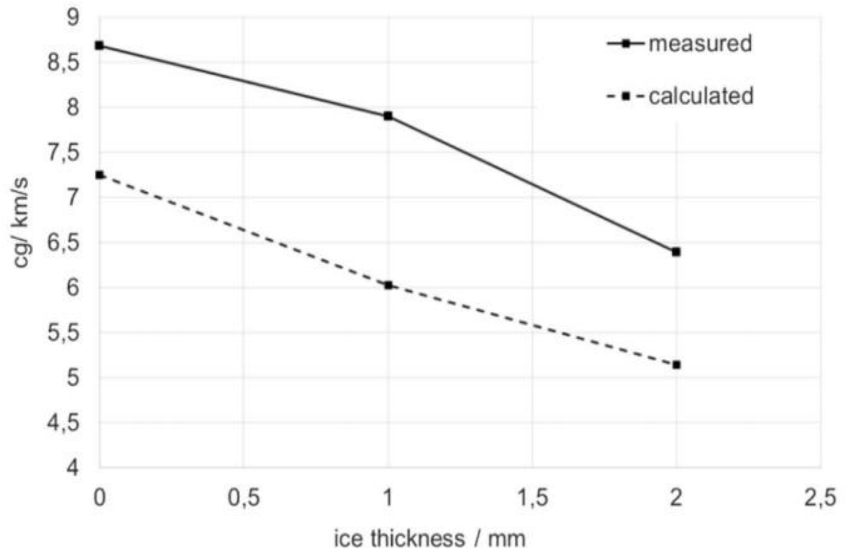
LILD – Local Ice Layer Detector

Where we came from…

- Some preliminary work on panel structures
- Ice layers reduce amplitude and group velocity
- Lamb waves only need minor power ->potential for a small and lightweight sensor is seen







LILD – Local Ice Layer Detector
What we did in SENS4ICE

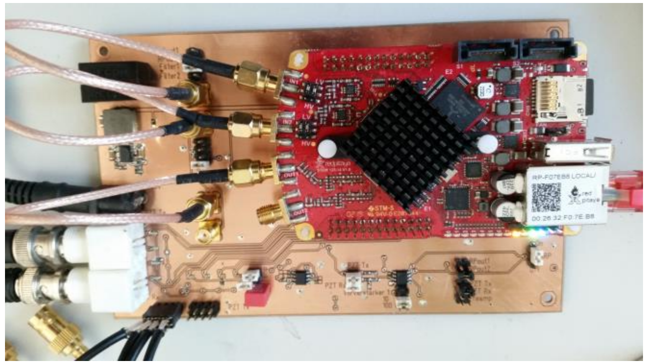
Miniturization and development of flight test capable sensor electronics

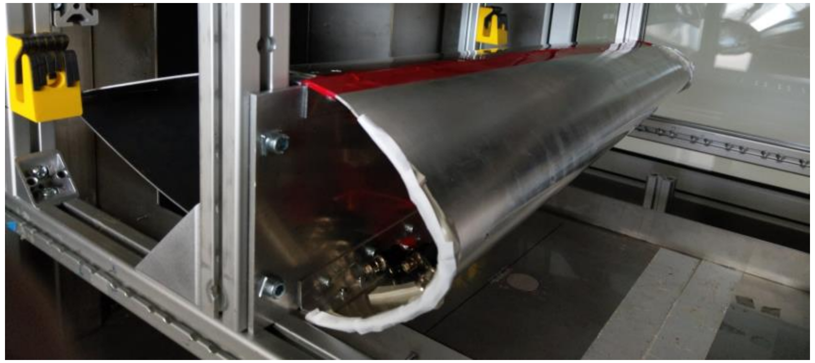
Icing wind tunnel tests

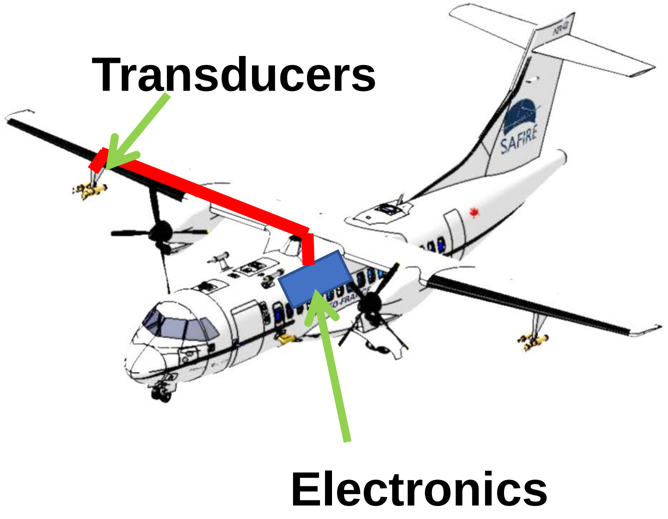
- **Pretests at TU Braunschweig IAF facility**
- **Final test at TU Braunschweig ISM**

Flight Test

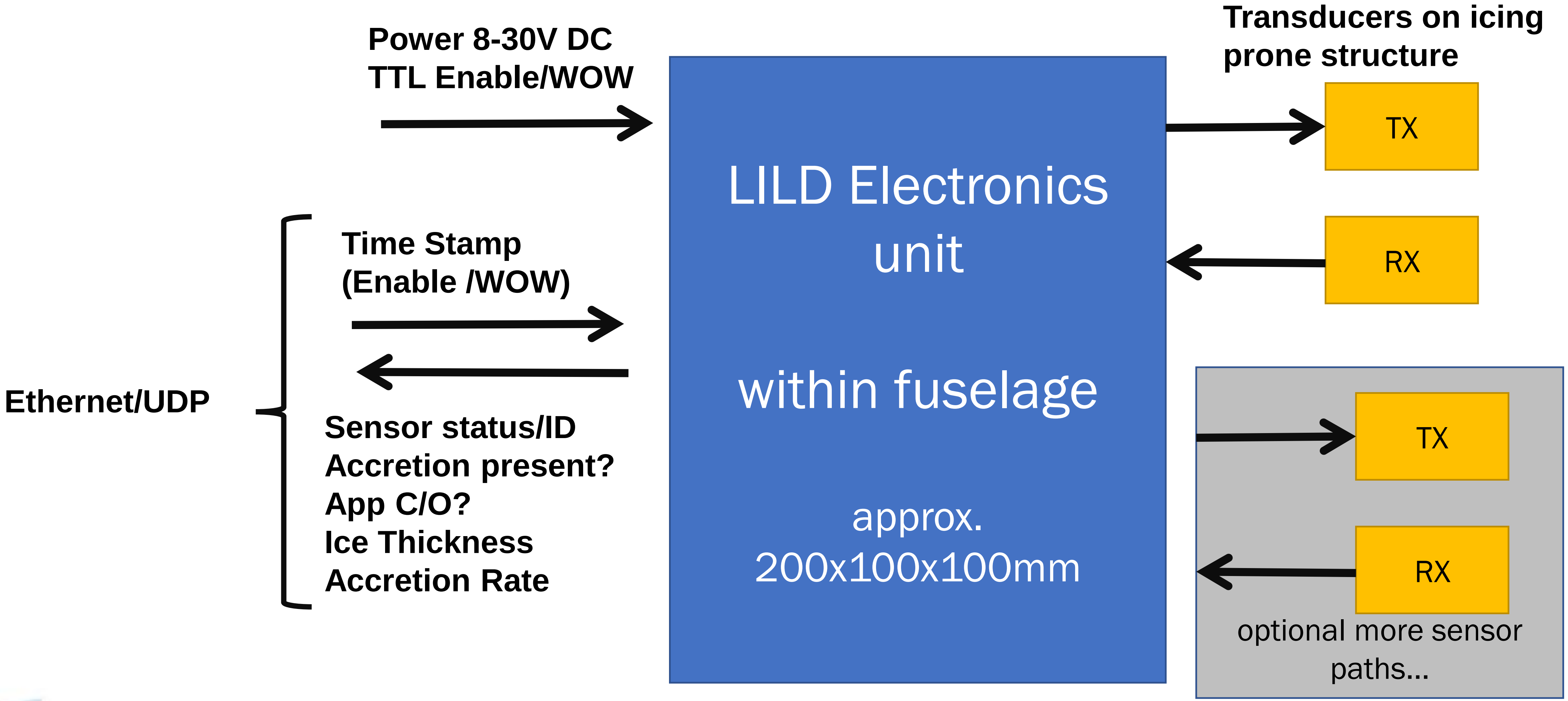
- **Safire ATR42**
- **Performed in 2023**







LILD – Local Ice Layer Detector
What we did in SENS4ICE

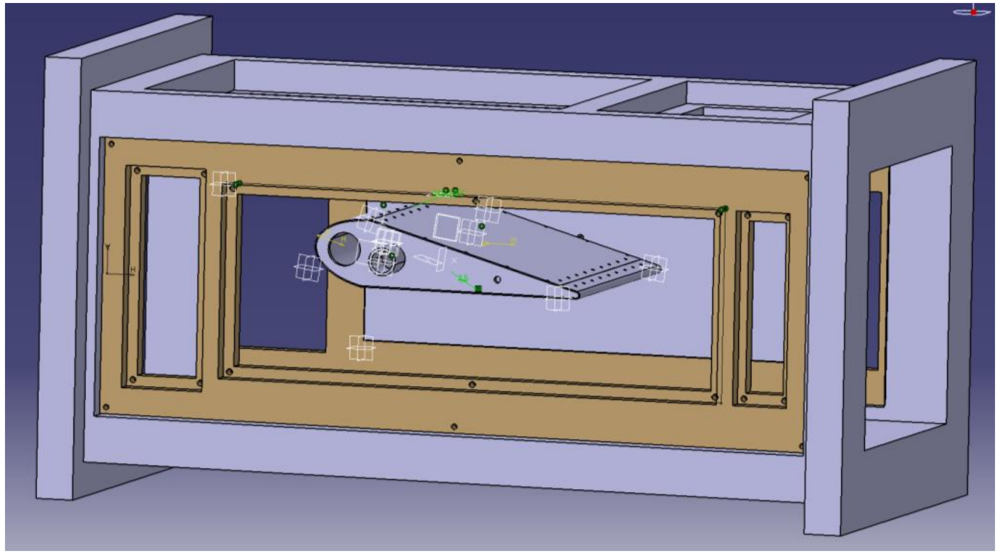


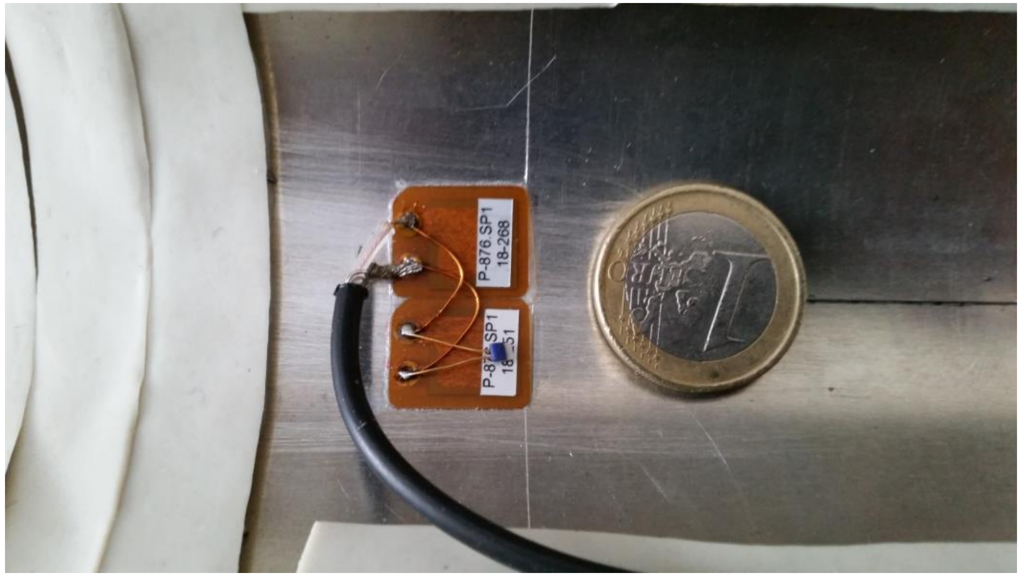
LILD – Local Ice Layer Detector
What we did in SENS4ICE

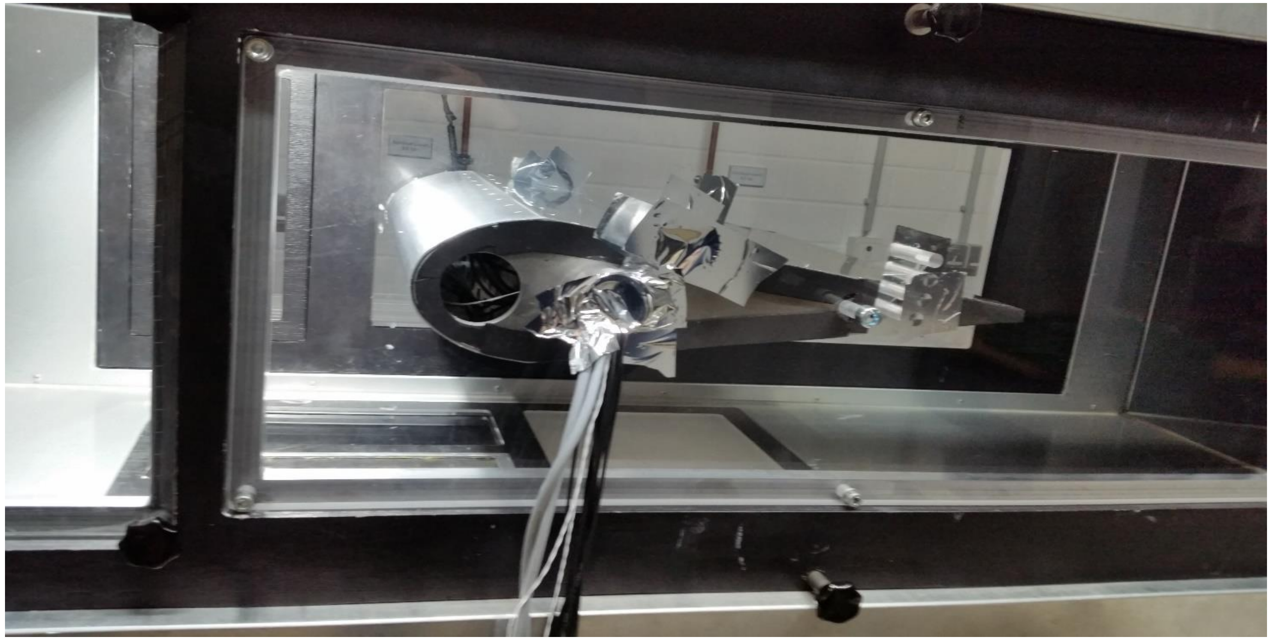
- Xilinx ZYNQ XC7Z01 FPGA and dual core microcontroller for signal aquisition and generation
- Output amplifier for max. 15V amplitude of lamb waves up to 1MHz
- Input bandpass filter 30kHz to 1MHz
- Sampling frequencies of 16.6MHz and 1.95Mhz, up to 125MHz possible
- Synchronous temperature measurement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

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

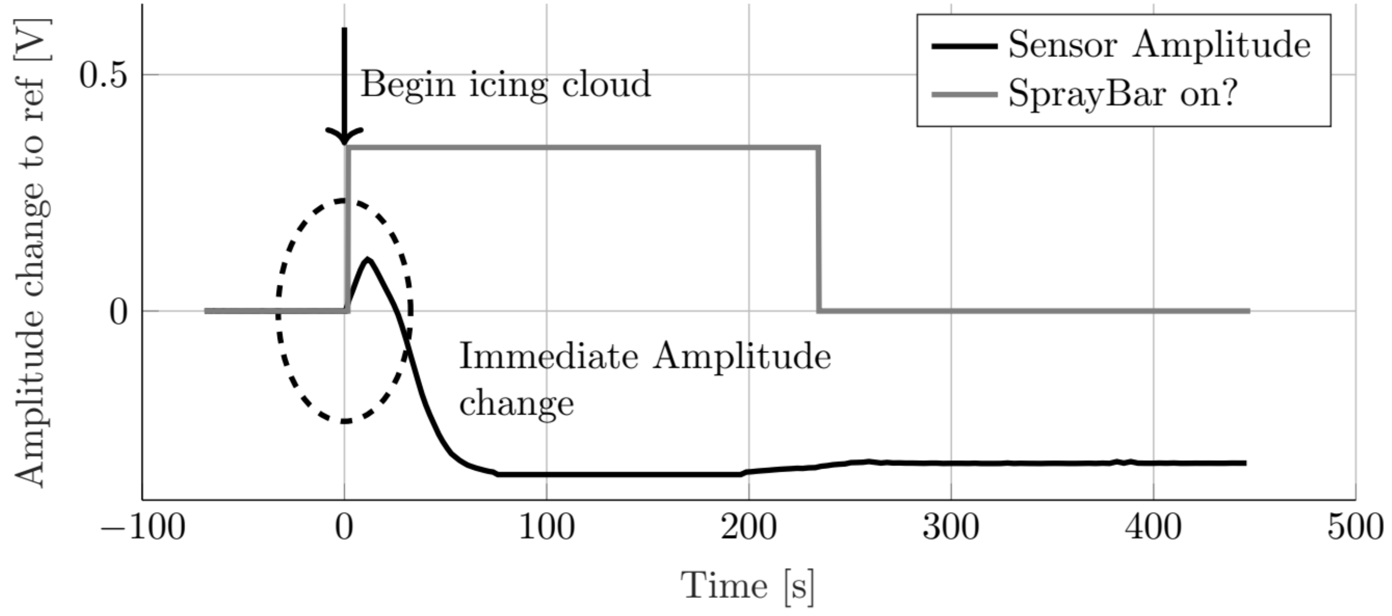


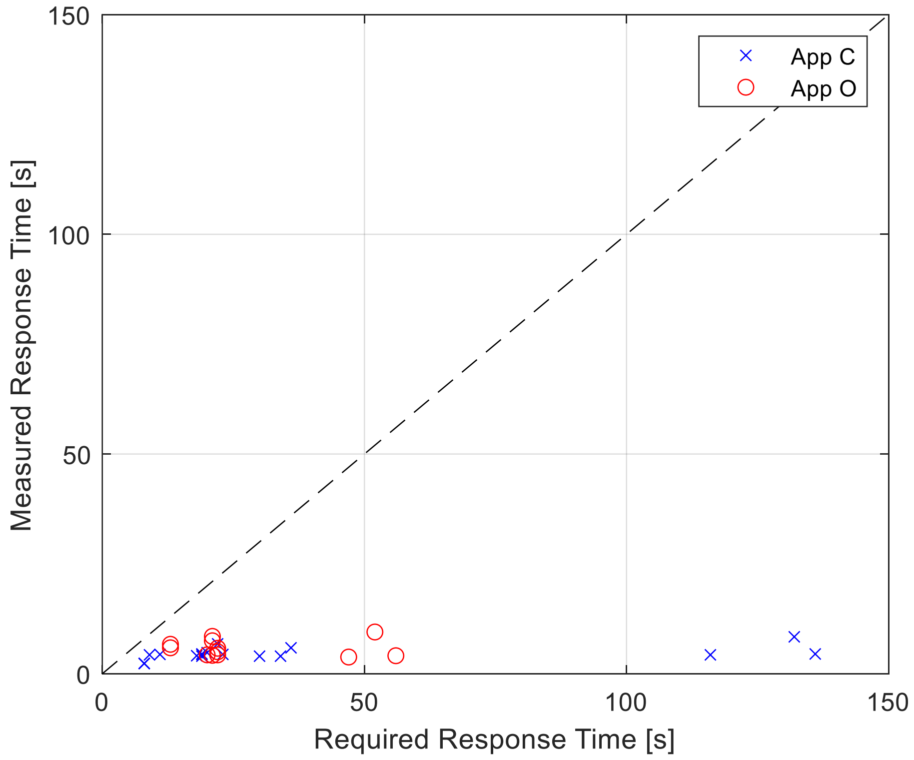




IWT test at TU BS ISM tunnel

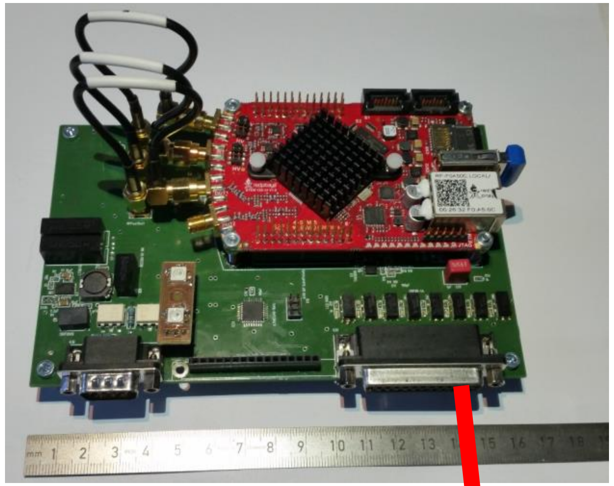
- Response time is very low
- Amplitude changes instantly with ice accretion when airfoil is clean before
- All testpoints detected with minor delay

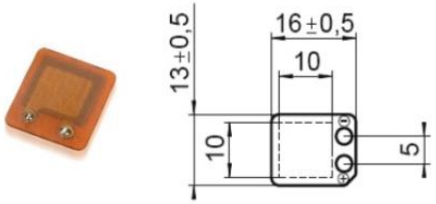


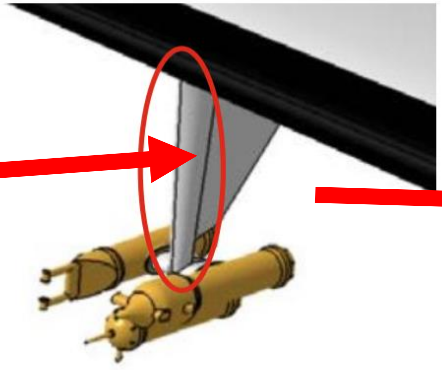


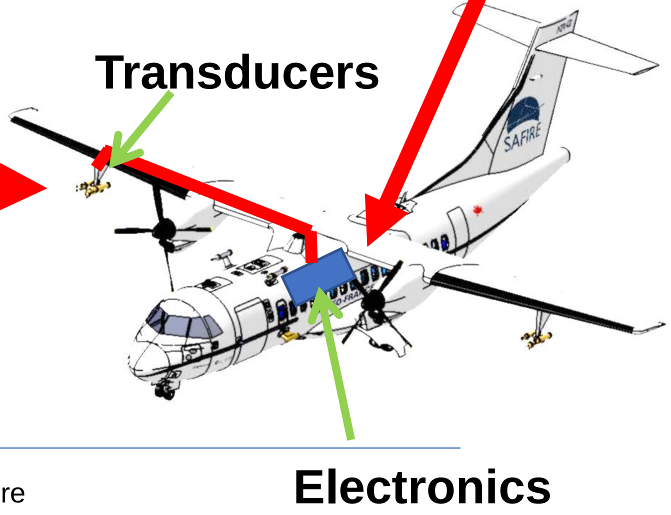
Preparing the flight test

- Sensor integration and clean air flights March 2023









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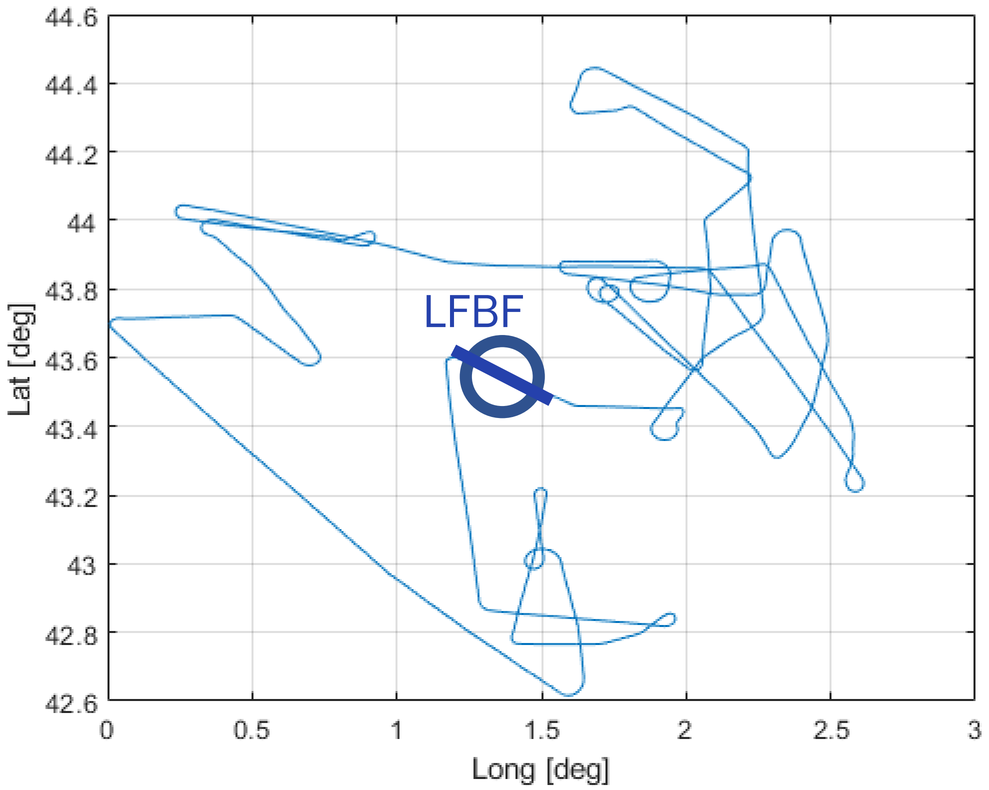
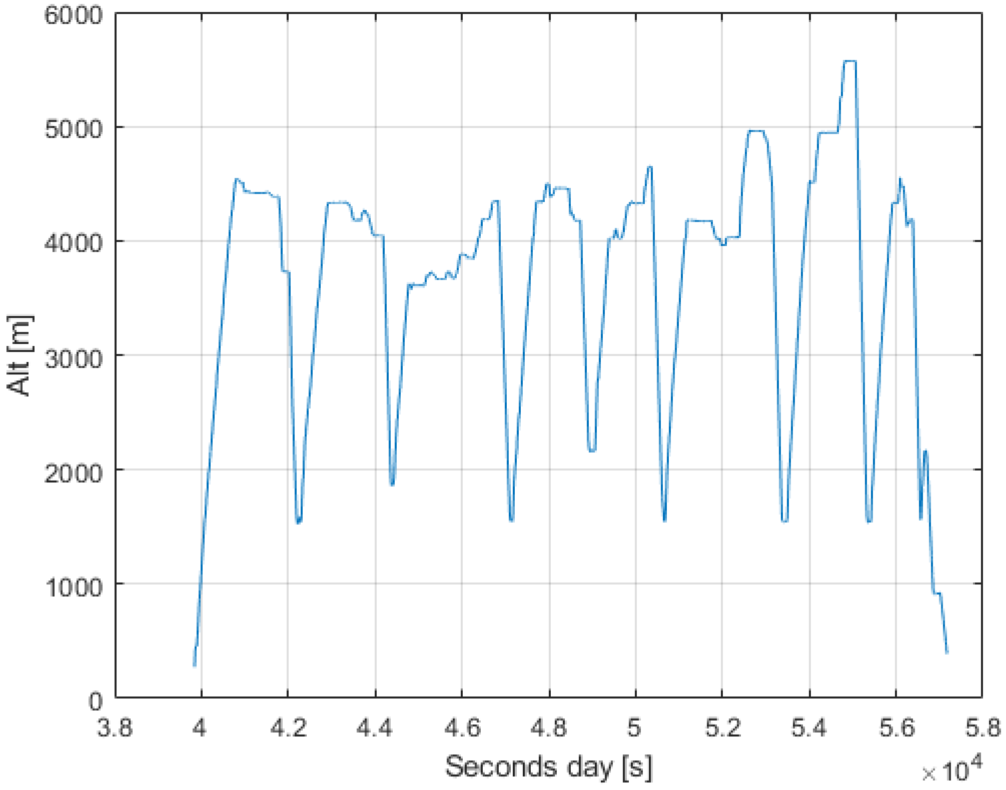
Flight test results

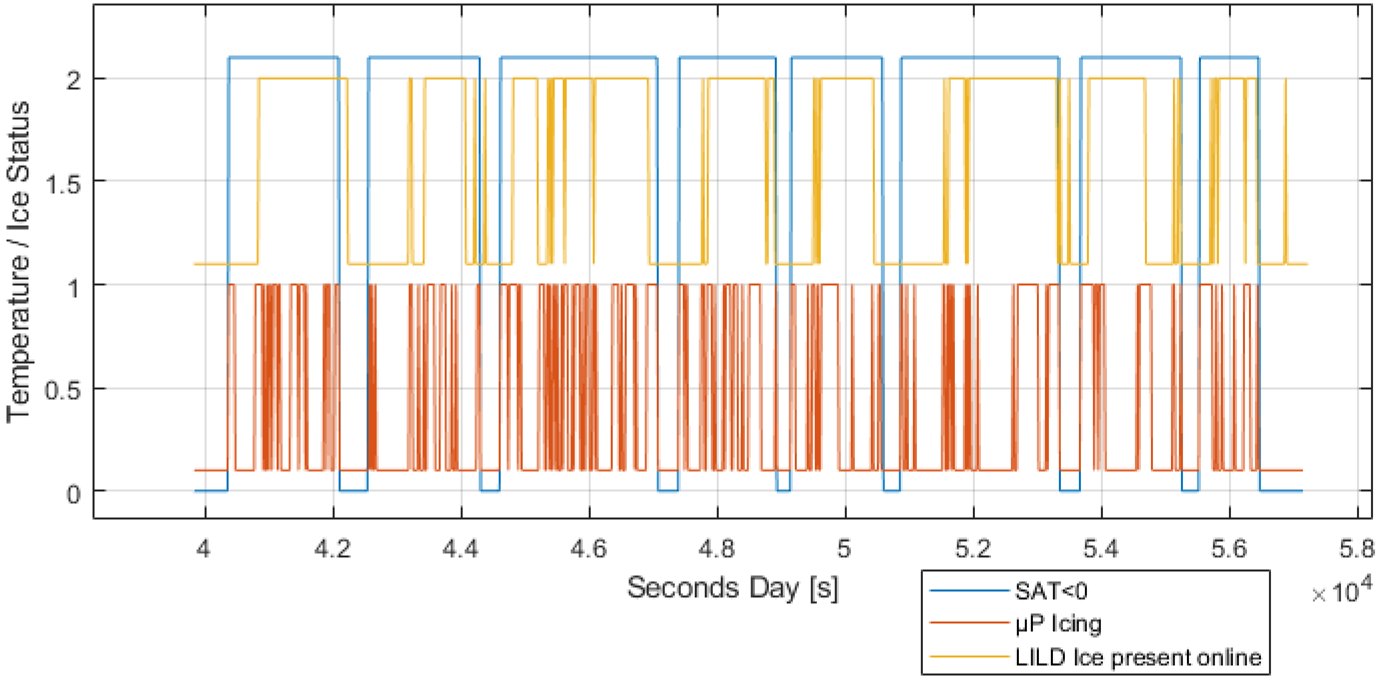
- One exemplary test flight: 24.04.2023 in the vicinity of LFBF





Flight test results

- One exemplary 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
- All icing encounters detected when beginning with ice-free airfoil



LILD – Local Ice Layer Detector

What we achieved…

- Development of lightweight and low port sensor electronics
- Successful wind tunnel test: All testpoints detected
- Successful flight test: Ice was detected in coincidence with the other sensors
- Sensor hard- and software worked flawlessly

LILD – Local Ice Layer Detector

Where we want to go…

- Open issues

- Lamb wave vs. ice accretion is very complex physical phenomenon:
  - Estimating the characteristics of accreted ice and icing conditions is an inverse problem with limited knowledge
  - Ice thickness estimation is currently inconsistent due to cross sensitivities to temperature, ice shape and accretion rate
  - Discrimination between App C and App O (supercooled large droplets) could not be demonstrated with test setup
- Sensor requires prior calibration to mounting structure and icing
  - In SENS4ICE this was done in icing wind tunnel tests

LILD – Local Ice Layer Detector

Where we want to go…

- Research requirements for LILD sensor industrialization:
  - Understanding ice lamb wave interaction
    - Extended experimental campaign to provide sufficient data base
    - AI implementation on signal analysis to correlate lamb wave pattern with icing conditions
  - App C/App O discrimination
  - Maturation of sensor electronics
    - Enhancement of measurement rate by use of FPGA technology
    - More measurement channels at different places at the aircraft
    - Combination of LILD with anti-icing and de-icing technologies
    - Miniaturization and signal adaptation to environmental conditions
  - Follow-up flight test?

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If not acknowledged, images courtesy of the consortium partners.

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