SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES
FOR SAFER AVIATION IN ICING ENVIRONMENT

Public Project Overview

April 2023

Christoph Deiler (DLR – German Aerospace Center)

NATO STO AVT – 388 Meeting, Online – April 27th, 2023

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

SENS4ICE Project Overview

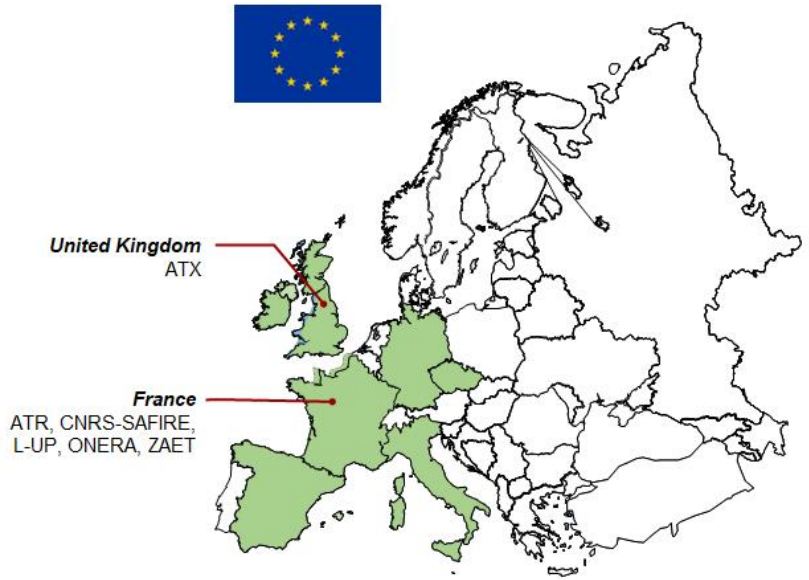
SENSors and certifiable hybrid architectures for safer aviation in ICing Environment

- JAN 2019 - DEC 2023 (extended, originally DEC 2022)
- Coordinator: DLR
- Budget:
  - total estimated eligible costs 8.7 M EUR
  - max. EU contribution 6.6 M EUR
  - project effort in person-months approx. 800 PM
- https://www.sens4ice-project.eu
- #sens4iceproject on LinkedIn

SENS4ICE Consortium Partners

1) DEUTSCHES ZENTRUM FUER LUFT - UND RAUMFAHRT e.V. (DLR)
2) AVIONS DE TRANSPORT REGIONAL (ATR)
3) AEROTEX UK LLP
4) CENTRO ITALIANO RICERCHE AEROSPAZIALI SCPA (CIRA)
5) CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE (CNRS)
6) EMBRAER SA
7) HONEYWELL INTERNATIONAL SRO
8) INSTITUTO NACIONAL DE TECNICA AEROESPACIAL ESTEBAN TERRADAS (INTA)
9) LEONARDO - SOCIETA PER AZIONI
10) L-UP SAS
11) OFFICE NATIONAL D'ETUDES ET DE RECHERCHES AEROSPATIALES (ONERA)
12) TECHNISCHE UNIVERSITAET BRAUNSCHWEIG
13) COLLINS AEROSPACE IRELAND, LIMITED
14) SAFRAN AEROSYSTEMS
15) HONEYWELL INTERNATIONAL INC
16) COLLINS AEROSPACE
17) NATIONAL RESEARCH COUNCIL CANADA

SENS4ICE international collaboration and cooperation



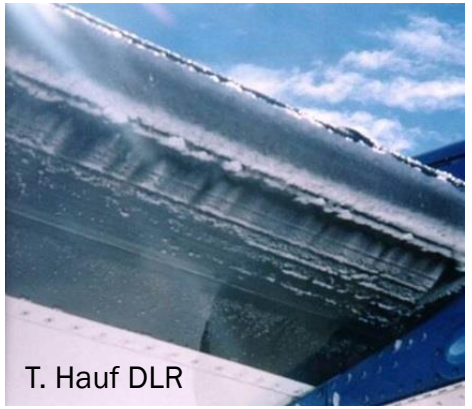
- InCo – international cooperation flagship: Aviation International Cooperation Flagship "Safer and Greener Aviation in a Smaller World"
- 17 project parties (10 countries)
  - 13 European/4 international
  - 6 research centers, 1 university, 9 industrial partners (OEMs and system developers and one SME), 1 SME consultancy partner
- Advisory Board (9 members)
  - aviation certification authorities (EASA, FAA, ANAC)
  - manufacturing (Bombardier, Gulfstream, Airbus DS, DAHER)
  - research (ITA, NLR)
  - operations (VC - *Vereinigung Cockpit*, German Pilot's Association)
- Coordination with EU icing projects ICE GENESIS and MUSIC-haic
- Cooperation with SAE AC-9C Aircraft Icing Technology Committee

Aircraft Icing Phenomena
Natural Ice Shapes

Credit: BFU, Interim Report BFU CX001-13

Credit: NASA (GRC), general permission for usage for educational and informational purposes (NASA Media Usage Guidelines), https://www.nasa.gov/sites/default/files/thumbnails/image/36_anti_icing_technology.jpg

- hazardous effects on aircraft
  - performance
  - dynamic behavior and
  - controls
- adaptation of operational limits required



Dangers of Icing in Flight

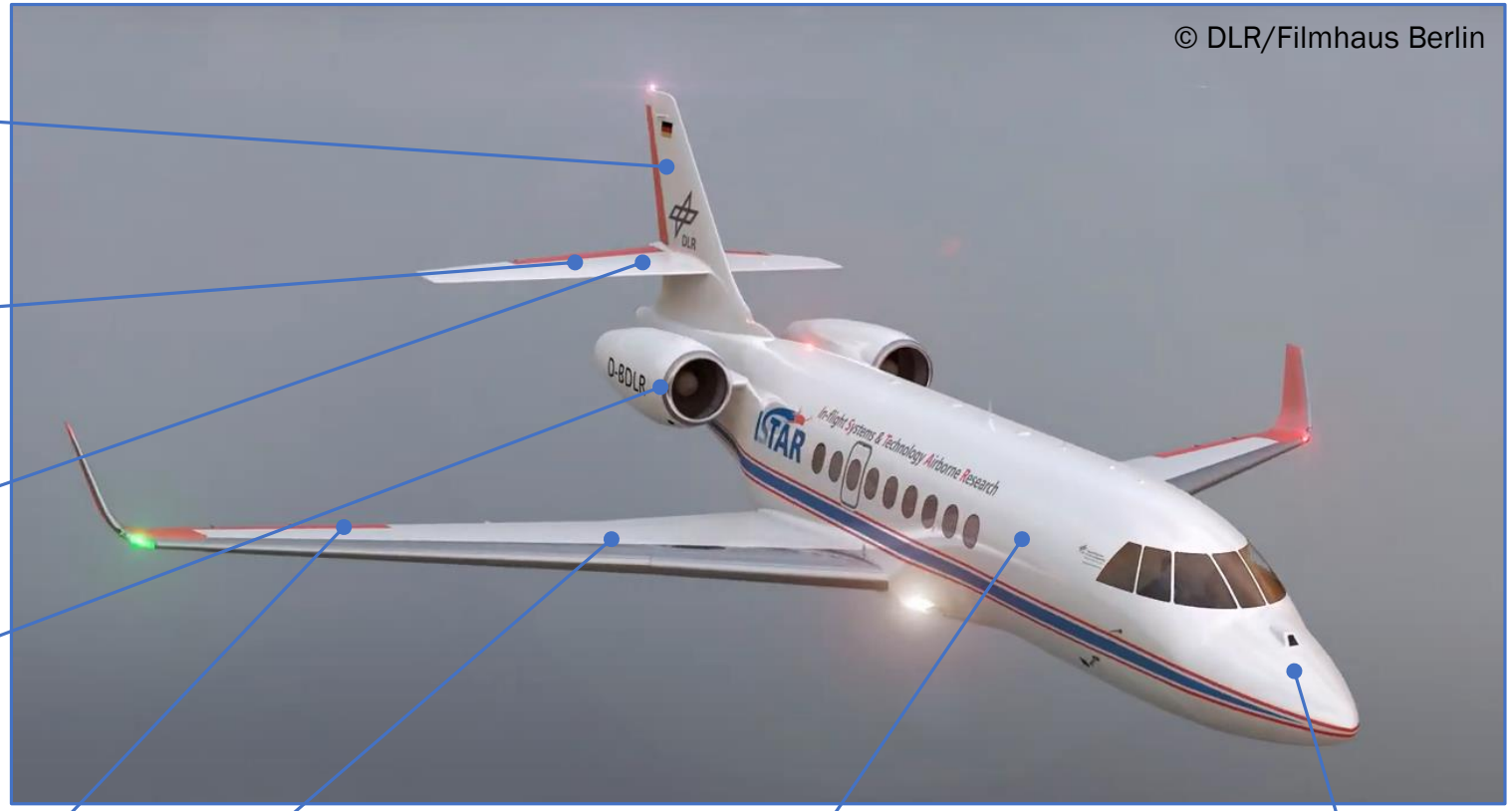
Vertical Tail Plane
- Control degradation
- Drag increase

Elevator Gap
- Control degradation

Stabilizer
- Control degradation
- Drag increase

Engines
- Danger of flameout or damage due to contaminants

Aileron Gap
- Control degradation



Wing
- Performance loss
- Control degradation

Fuselage
- Drag increase
- Collected contaminant ice layer

Sensors
- Malfunction
- Blockage

SENS4ICE Goal/ Impact

Problem

- Detect icing conditions
- Including SLD (supercooled large droplets) / App. O (CS-25 / 14 CFR Part 25) icing
- Detection very challenging

Solution

- 10 direct detection technologies
- Hybrid approach – fusion of input data: sensor(s) and indirect detection

Benefits

- Operational benefits:
  - activate anti-/de-icing
  - avoid/ leave icing conditions
- Certification process benefits – flights in App. O/ SLD icing
  - safety risk due to severe and unknown aircraft icing
  - online evaluation of safety margins during flight tests/ certification flights

SENS4ICE
Scope and positioning

- SENS4ICE fills the gap of SLD icing detection (App. O)
  → hybridisation of different detection techniques
- Technology development, test, validation and maturation with specific regards to integration of hybrid system architectures
  → TRL 5 of hybrid system at the end of SENS4ICE
- Technology demonstration in relevant icing conditions:
  - icing wind tunnels
  - flight test

  → SENS4ICE will provide large data base of icing conditions
- Close cooperation with regulation authorities for development of new certifiable hybrid ice detection system
  → SENS4ICE will provide an acceptable means of compliance

→ SENS4ICE contributes to increase aviation safety in SLD icing conditions

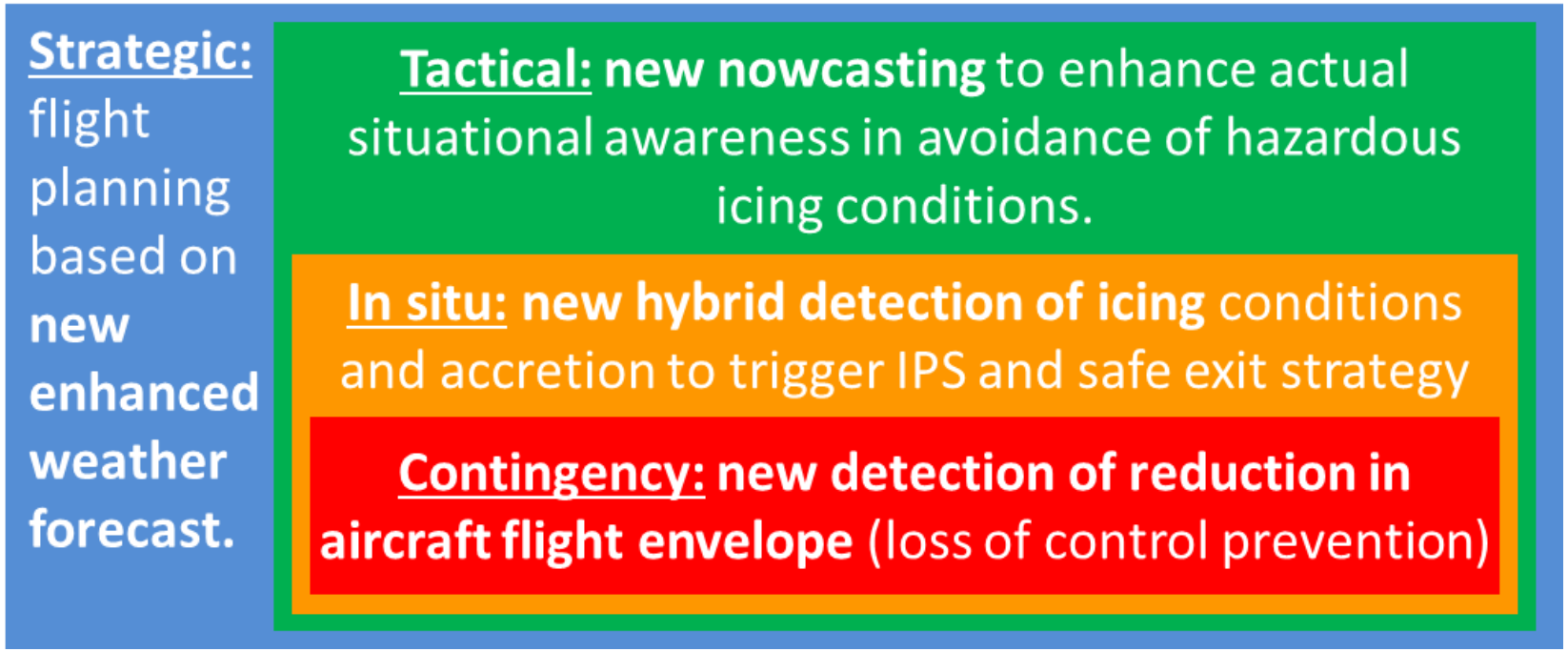
TRL: Technology readiness level

Expected impact

- Contribute to **increased flight safety**
  by fewer accidents and less in-flight events worldwide
- Contribute to **reduce costs** for all stakeholders
  by improved and internationally accepted certification rules, standards and means of compliance, covering all types of icing hazards
- Contribute to **decrease delays** in operations
  thanks to more efficient avoidance of icing hazards and to fewer damages in need of inspection and repair

Layered Approach on Ice Detection

SENS4ICE will address this challenge of reliably detecting and avoiding App. O SLD conditions with a unique layered safety approach:



→ Hybrid ice detection is central technology and key to this approach

SENS4ICE Timeline – focus flight testing

Develop sensors/ technologies for App. O detection

Upgrade icing wind tunnels for App. O

Icing wind tunnel testing

Sensor technology evaluation and selection

Indirect ice detection system

Hybrid ice detection system

Flight test preparation

Flight testing

FEB 2023

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APR 2023

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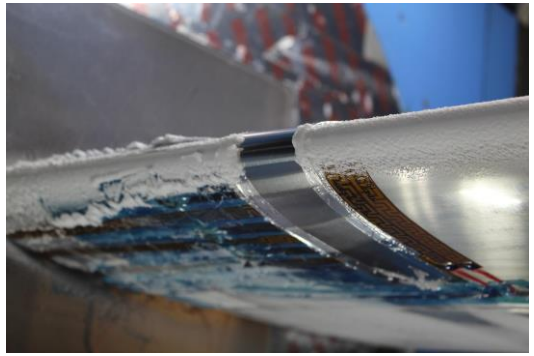
Flight test analysis

Commu-nication, Dissem-ination, Exploi-tation

2019 - 2020 **2021** **2022** **2023**

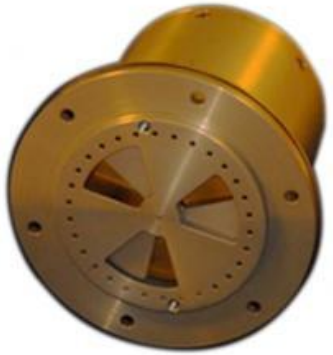
SENS4ICE sensor technologies for direct sensing of atmospheric icing conditions or ice accretion detection (1/2)

Name: *Short Range Particulate (SRP)*
Project partner: *Honeywell*
Copyrights: © Honeywell



Name: *Collins Ice Detection System (IDS)*
Project partner: *Collins Aerospace*

Name: *Atmospheric Hydrometeor Detector based on Electrostatics (AHDEL)*
Project partner: *French Aerospace Lab (ONERA)*
Copyrights: © French Aerospace Lab (ONERA)



Name: *AMPERA*
Project partner: *French Aerospace Lab (ONERA)*
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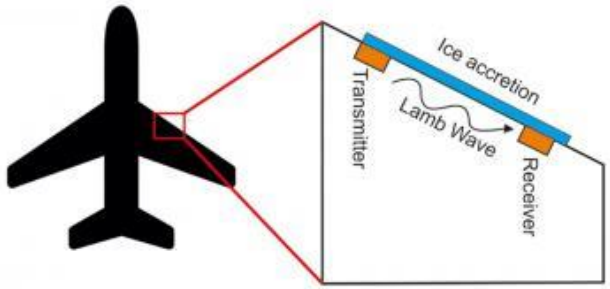
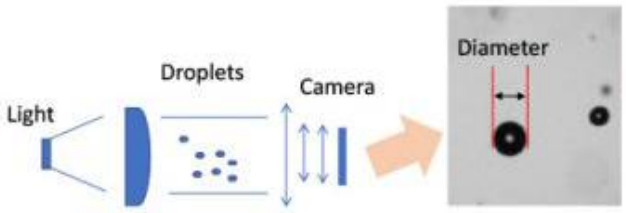


Name: *Local Ice Layer Detector (LILD)*
Project partner: DLR (*German Aerospace Center)*
Copyrights: © DLR (German Aerospace Center)

SENS4ICE sensor technologies for direct sensing of atmospheric icing conditions or ice accretion detection (2/2)



Name: *Appendix O Discriminator (AOD)*
Project partner: *SAFRAN*
Copyrights: © SAFRAN

Name: *Atmospheric Icing Patch (AIP)*
Project partner: *AeroTex UK*
Copyrights: © AeroTex UK LLP

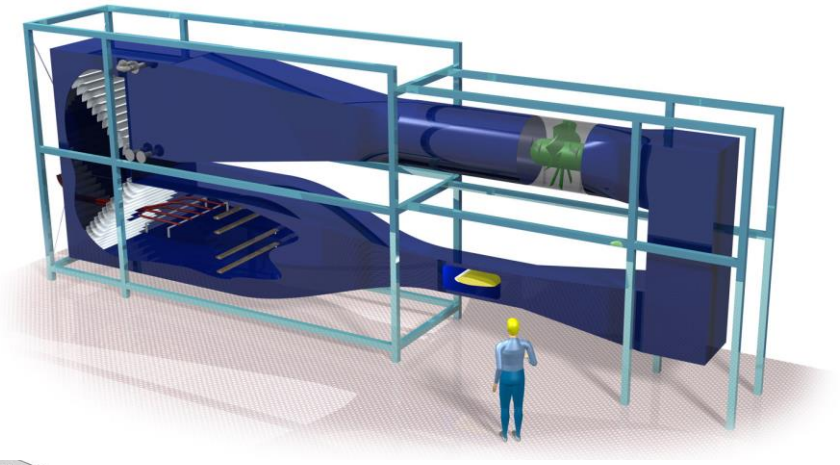
Name: *Fiber Optic Detector (FOD)*
Project partner: *INTA*
Copyrights: © INTA

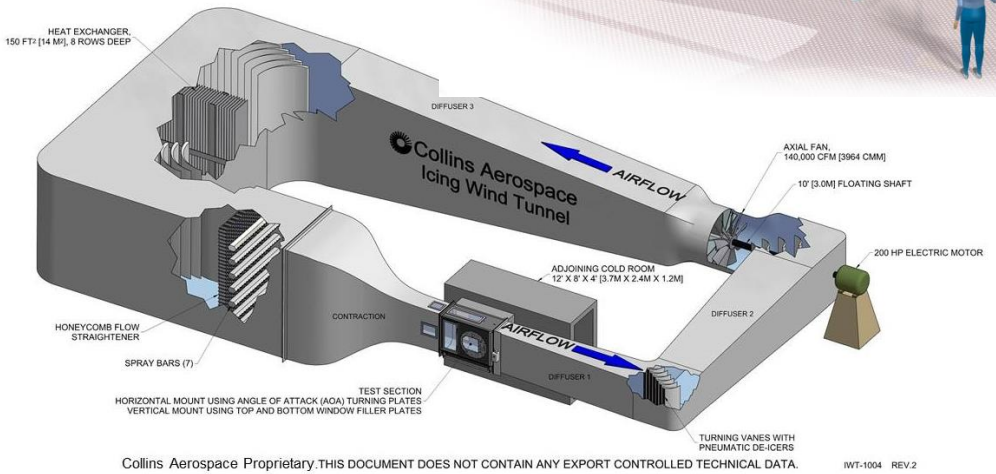
Name: *PFIDS (Primary in-Flight Icing Detection System)*
Project partner: *SAFRAN*
Copyrights: © SAFRAN

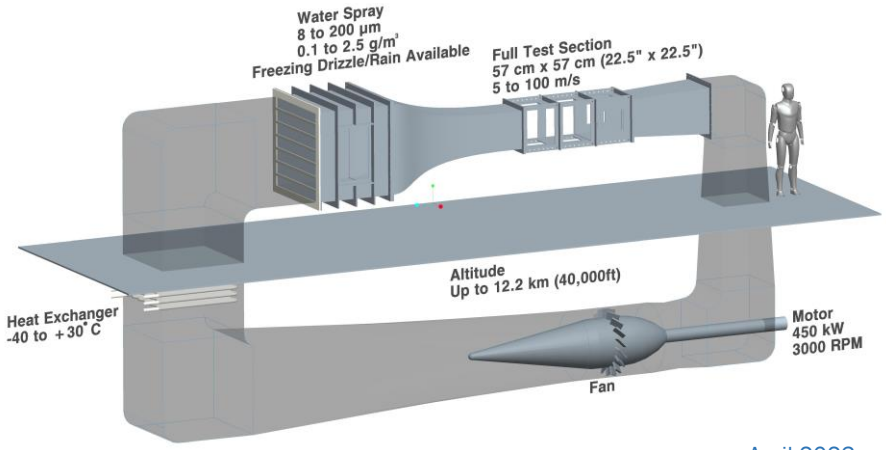
Name: *Nevzorov Probe and Backscatter Cloud Probe with Polarization Detection (BCPD)*
Project partner: *DLR (German Aerospace Center)*
Copyrights: © Skytech and © DMT

SENS4ICE research facilities: Icing Wind Tunnels

- TU Braunschweig
  - SLD capabilities available and enhanced during SENS4ICE
- Collins Aerospace
  - SLD capabilities available and enhanced during SENS4ICE
- National Research Council Canada
  - SLD capabilities available
- Total testing time: 16 weeks
- Planned time frame: NOV 2020 – MAR 2021

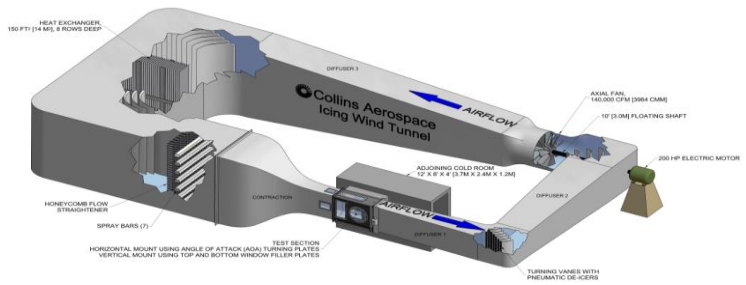






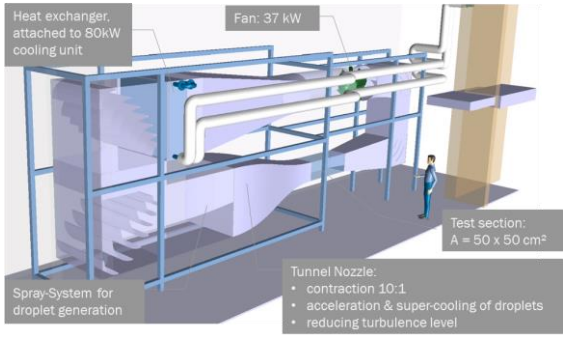
Overview of SENS4ICE IWT Capabilities

Collins Aerospace, USA



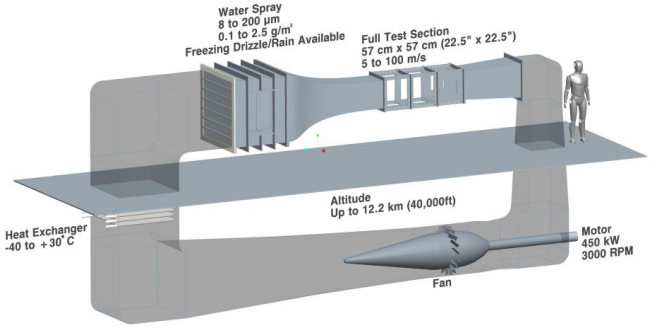
- 5-147 micron droplets
- LWC between 0.1 and 3 g/m3
- Temperature 0°C to -30°C
- Sustained speed 13-103 m/s
- Test section: 152×56×112 cm3
- Calibrated per SAE ARP 5905
- Compliant with AS9100C
- Controls and power supplies can simulate aircraft controls

TU Braunschweig, Germany



- MVD 9-200 micron droplets
- LWC between 0.1 and 1.5 g/m3
- Temperature 30°C to -20°C
- Sustained speed 10-40 m/s
- Test section: 150×50×50 cm3
- Calibrated per SAE ARP 5905
- Short spray transients ~ 15s
- Bi-modal SLD and mixed phase capability

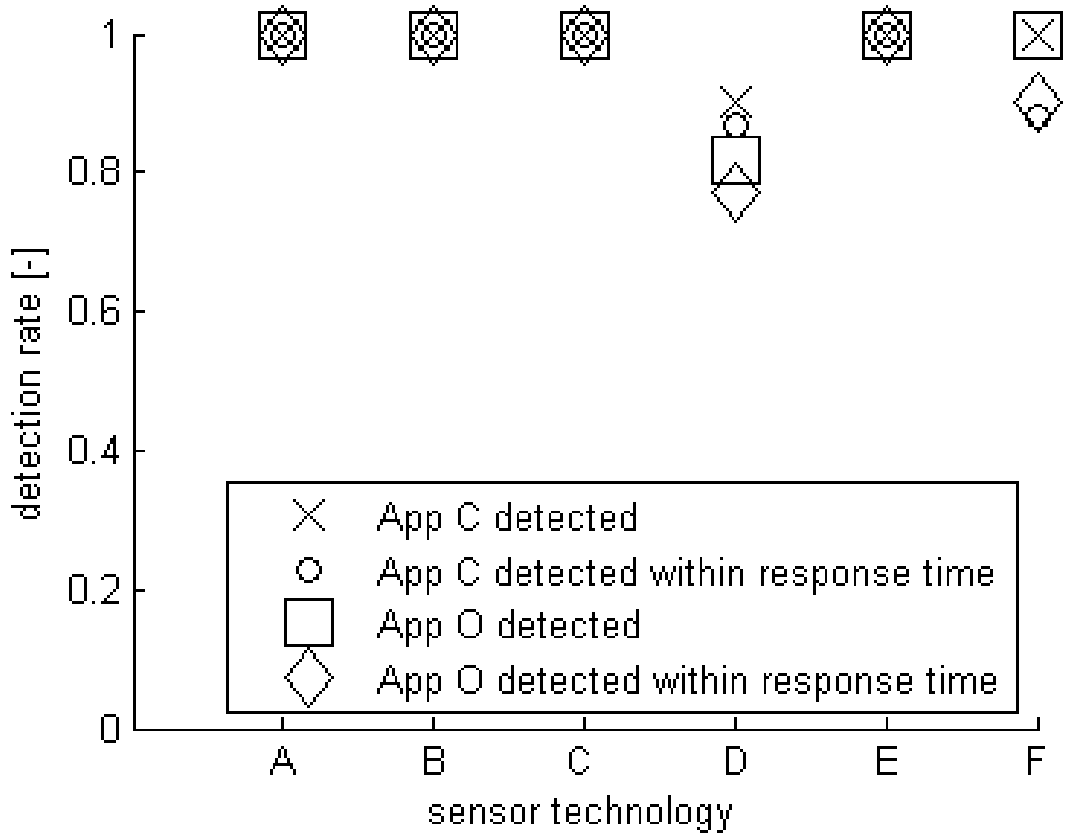
NRC, Canada



- 8-200 micron droplets
- LWC between 0.1 and 2.5 g/m3
- Supercooled Water: 10 to > 200 µm (incl. SLD bi-modal)
- Temperature +30°C to -40°C
- Sustained speed 5-100 m/s
- Test section: 57×57 cm2 (52x33 cm2 with insert)
- Sea level < Altitude < 40,000ft
- Calibrated per SAE ARP 5905

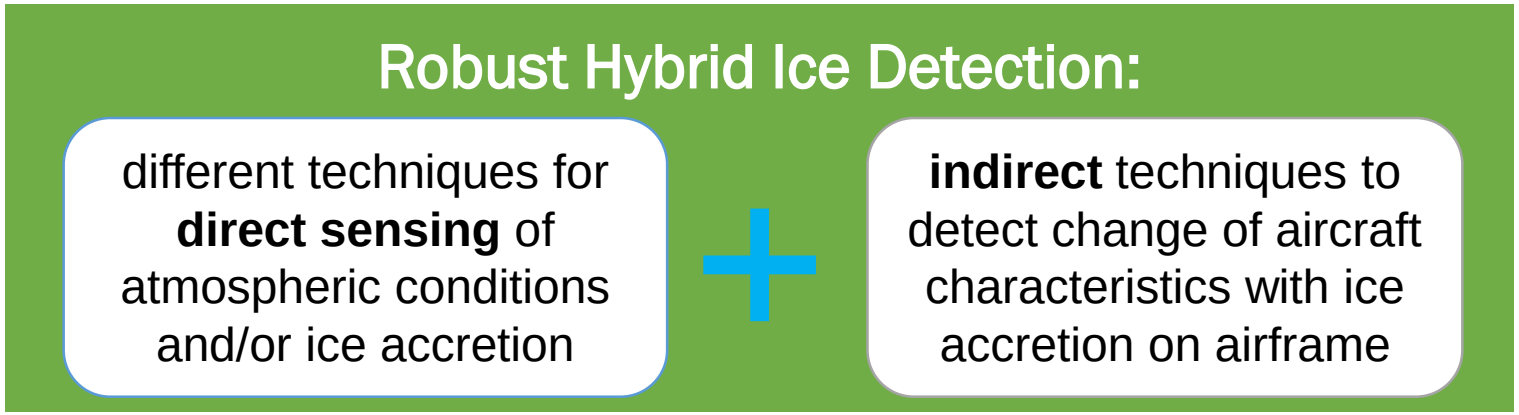
- Dedicated common test points defined for all involved SENS4ICE IWT

SENS4ICE sensor technologies IWT testing detection rates for App. C and O icing condition test points



- anonymised overview of detection rates
  - test cases successfully detected related to total number of test cases
  - excluding DLR's CM2D scientific/reference sensor / results subject to export control restrictions
- several sensors have correctly detected 100% of test points for Appendix C and also for Appendix O
- also within required maximum response time
  - as per EUROCAE inflight icing systems standard ED-103
  - maximum response time depending on icing condition

WP2: Hybrid Ice Detection



Development, test, validation and maturation of different technologies for

- direct ice detection
- indirect ice detection

Objectives for hybrid ice detection

1. Hybrid ice detection system specification
2. Certification programme for hybrid ice detection system
3. Hybrid ice detection system modelling
4. Hybrid ice detection design, build & assembly (+ TRL 5 review)

in **close cooperation with OEMs and certification authorities** during SENS4ICE

WP2: Hybrid Ice Detection – Development Workflow

WP1: Direct & indirect ice detection

selected direct sensors

WP1 sensor requirements

Icing Wind Tunnel Tests

Laboratory Tests

Hybrid high-level specifications

Certifiability demonstration

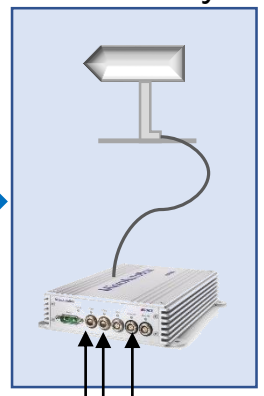
WP2: Hybrid Ice Detection Development

Hybrid demonstrator model

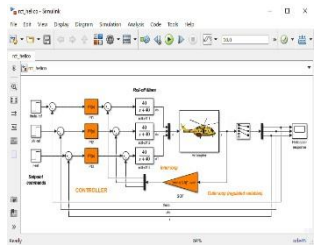
Direct detection

Indirect detection

Hybrid demonstrator assembly



aircraft sensors



Modelling/Simulation

WP3: Airborne demonstration

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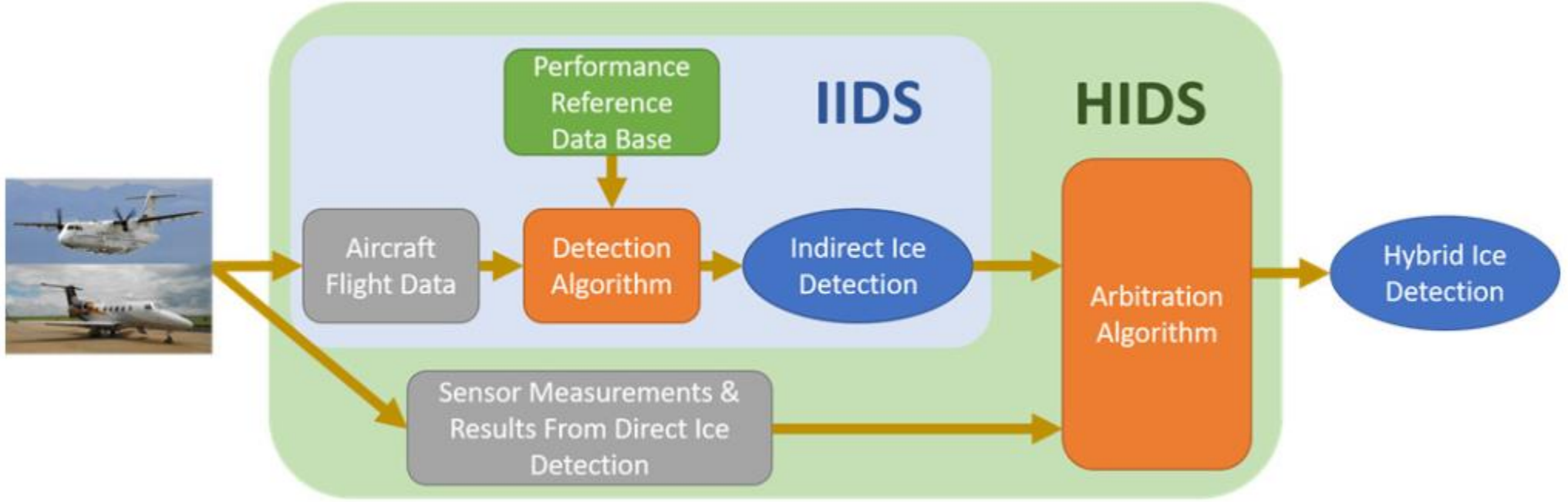
Flight Test

Hybrid Ice Detection System (HIDS) concept including Indirect Ice Detection System (IIDS)



Christoph Deiler, Falk Sachs (2023) Design and Testing of an Indirect Ice Detection Methodology. SAE International Conference on Icing of Aircraft, Engines, and Structures 2023, 20-22 June 2023, Vienna, Austria (submitted).

Image Credit DLR/EMBRAER/SAFIRE

Indirect Ice Detection – System Performance

Conflicting demands

Detection time ⟷ Trade-Off ⟷ **Detection accuracy/reliability**

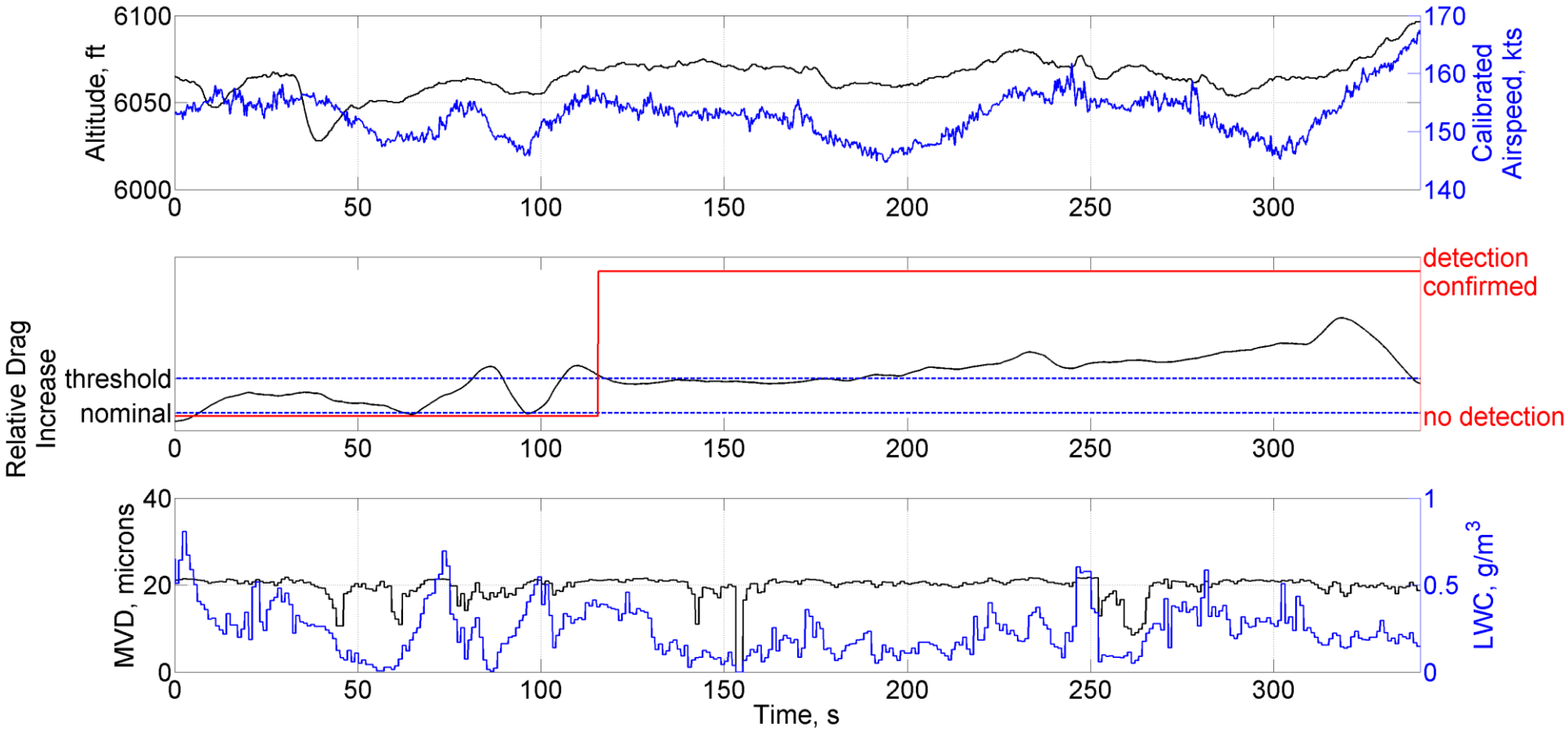
- Early detection information
- Enable early countermeasures
- Faster than any hazardous effects could occur

- Prevent false alarms
- Increase reliability of detection information
- Increase situational awareness
- Basis for automatic system response

System is based on ice accretion effects on performance (continuous change, no significant step)

→ Determine a threshold that represents the necessary compromise

Indirect Ice Detection – flight test data initial results



Indirect ice detection results based on pre-existing natural icing flight test data exhibiting relative drag increase above detection threshold [Embraer flight test data]

WP3: Airborne demonstration and atmosphere characterisation

dedicated to airborne technology demonstration in relevant icing conditions

Objectives

- Issue main requirements and constraints
  for integration of sensors and probes on flight test platforms
- Release flight test program
  for testing new individual and hybrid technologies in distinct icing conditions
- Perform airborne demonstration in natural icing conditions:
  - in Europe with CNRS/SAFIRE ATR-42
  - in North America with Embraer Phenom 300
- Characterisation of atmosphere from flight test campaigns in App. O conditions

Guidance by special Flight Test Committee (FTC) formed by platform providers and leaders of WP1, WP2 and WP4 to ensure harmonised preparation and execution of individual flight test campaigns

SENS4ICE research facilities: Flight Test Platforms

- total flight test time: 75h in natural icing conditions
- North America: FEB 2023
- Europe: APR 2023

Embraer Phenom 300

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SAFIRE ATR-42

Copyright © SAFIRE/JC Canonici

North America Flight Test Campaign

Copyright © Embraer

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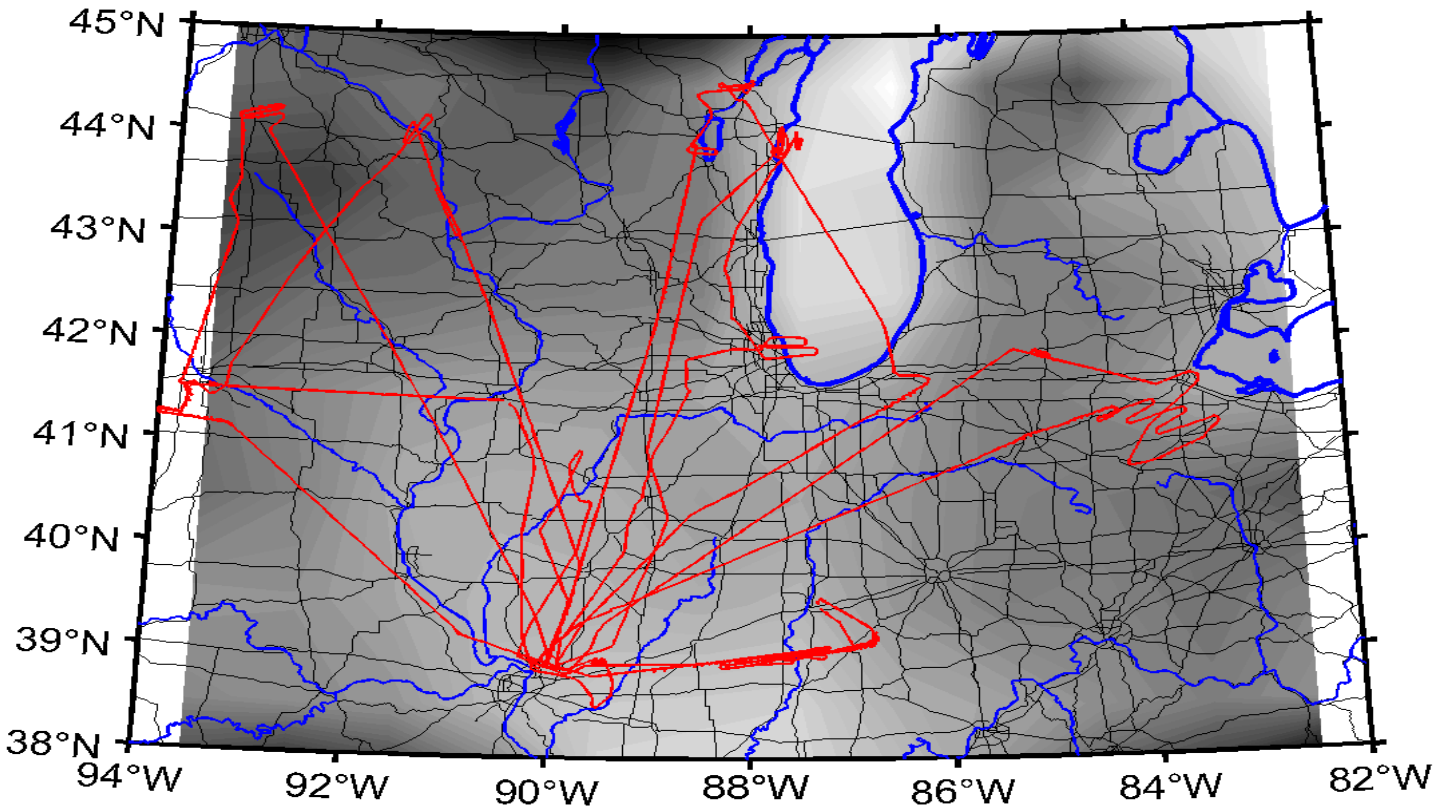
North America Flight Test Campaign

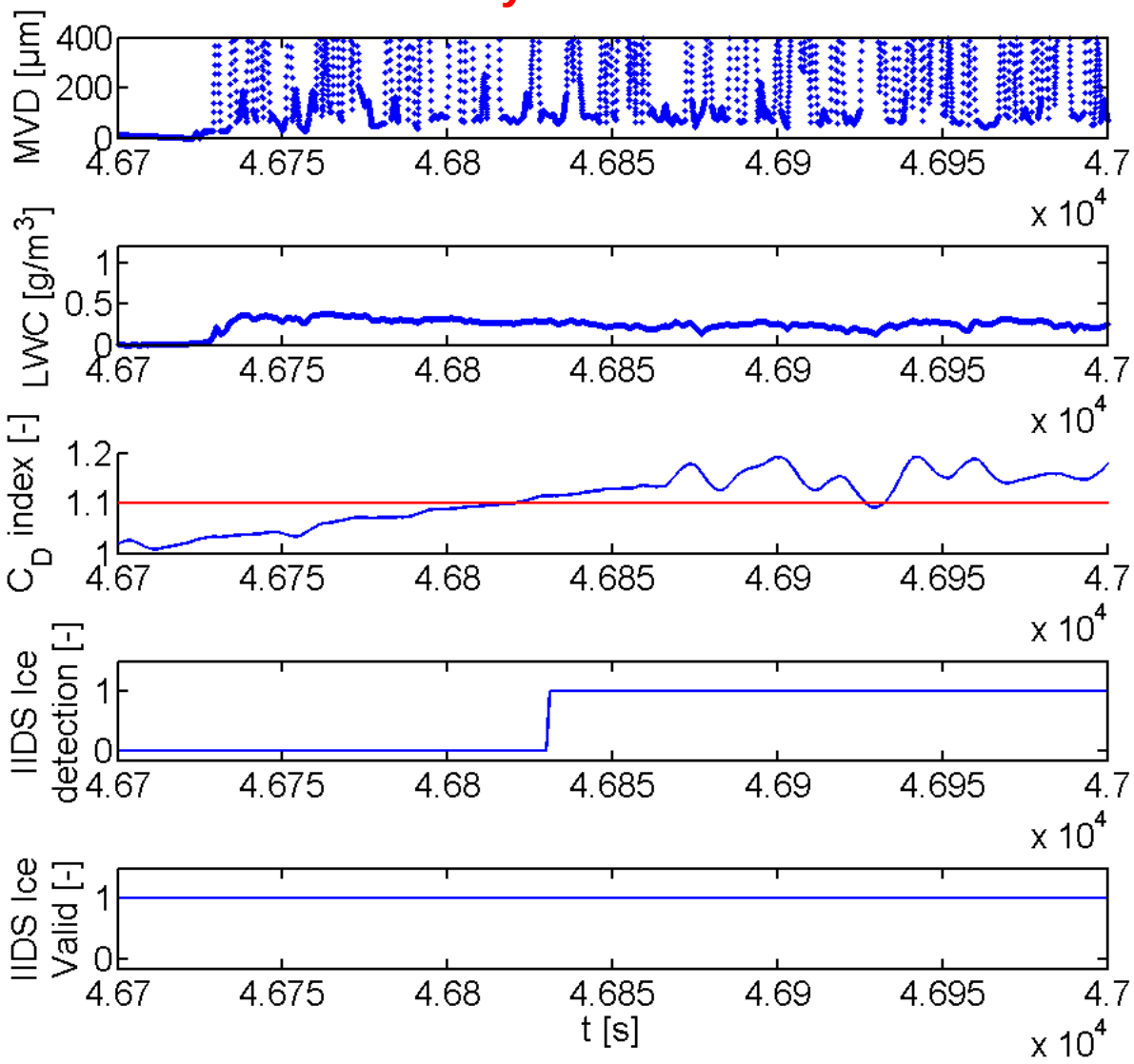
- Flight tracks out of Alton / St. Louis area



Indirect Ice Detection System

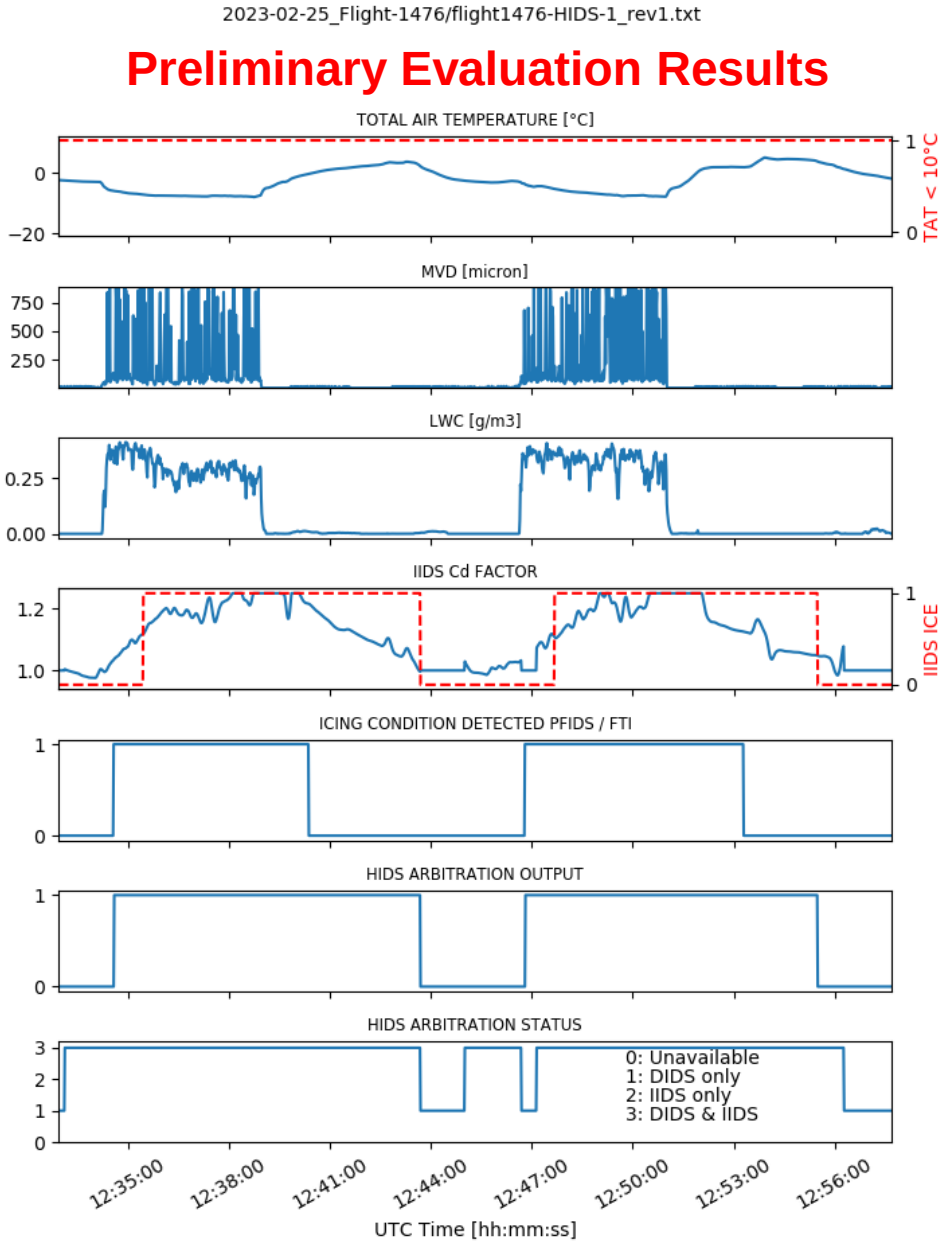
- IIDS performance during flight test in App. O conditions as expected from the design
- IIDS capable of detecting ice accretion on the test aircraft reliable without false alarms within the design envelope
- IIDS performance analysis subject to detailed evaluations during the project

Preliminary Evaluation Results



Hybrid Ice Detection System

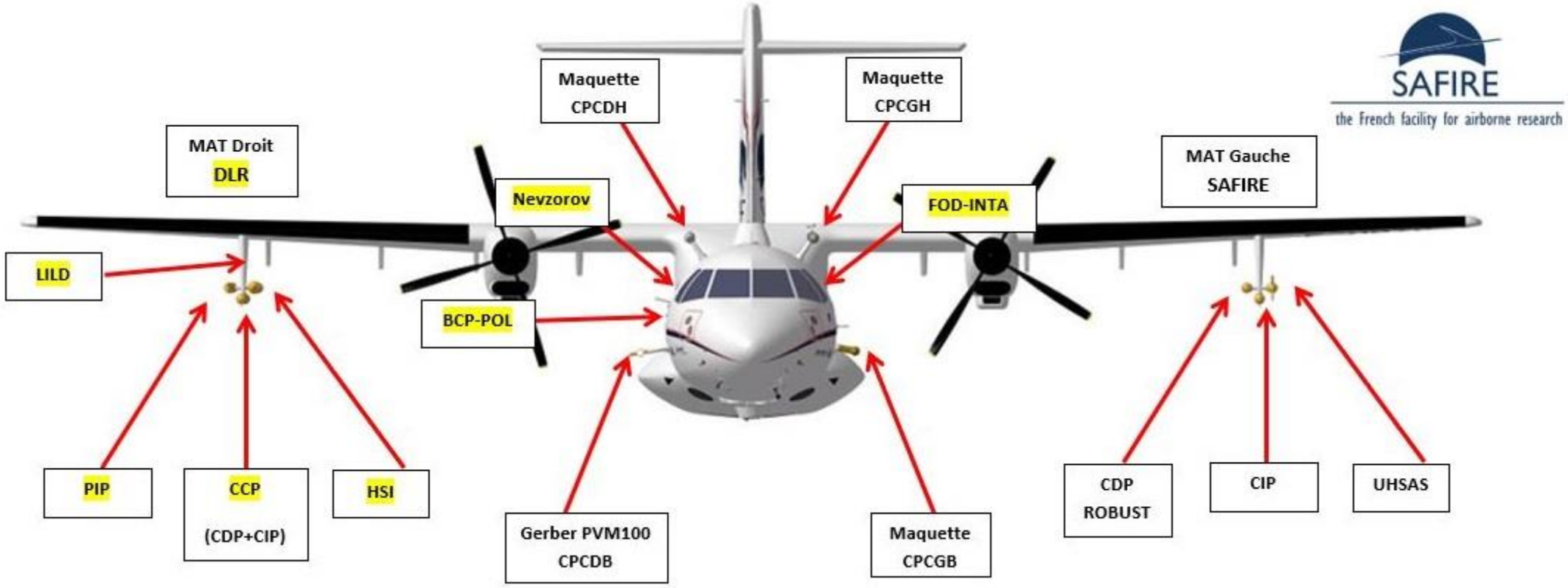
- HIDS performance during flight test in App. O conditions
- HIDS allows to fast and reliably detect icing and also indicate limited AC capabilities after the icing encounter until full de-icing
- HIDS performance analysis subject to detailed evaluations during the project



European Flight Test Campaign

Copyright © DLR

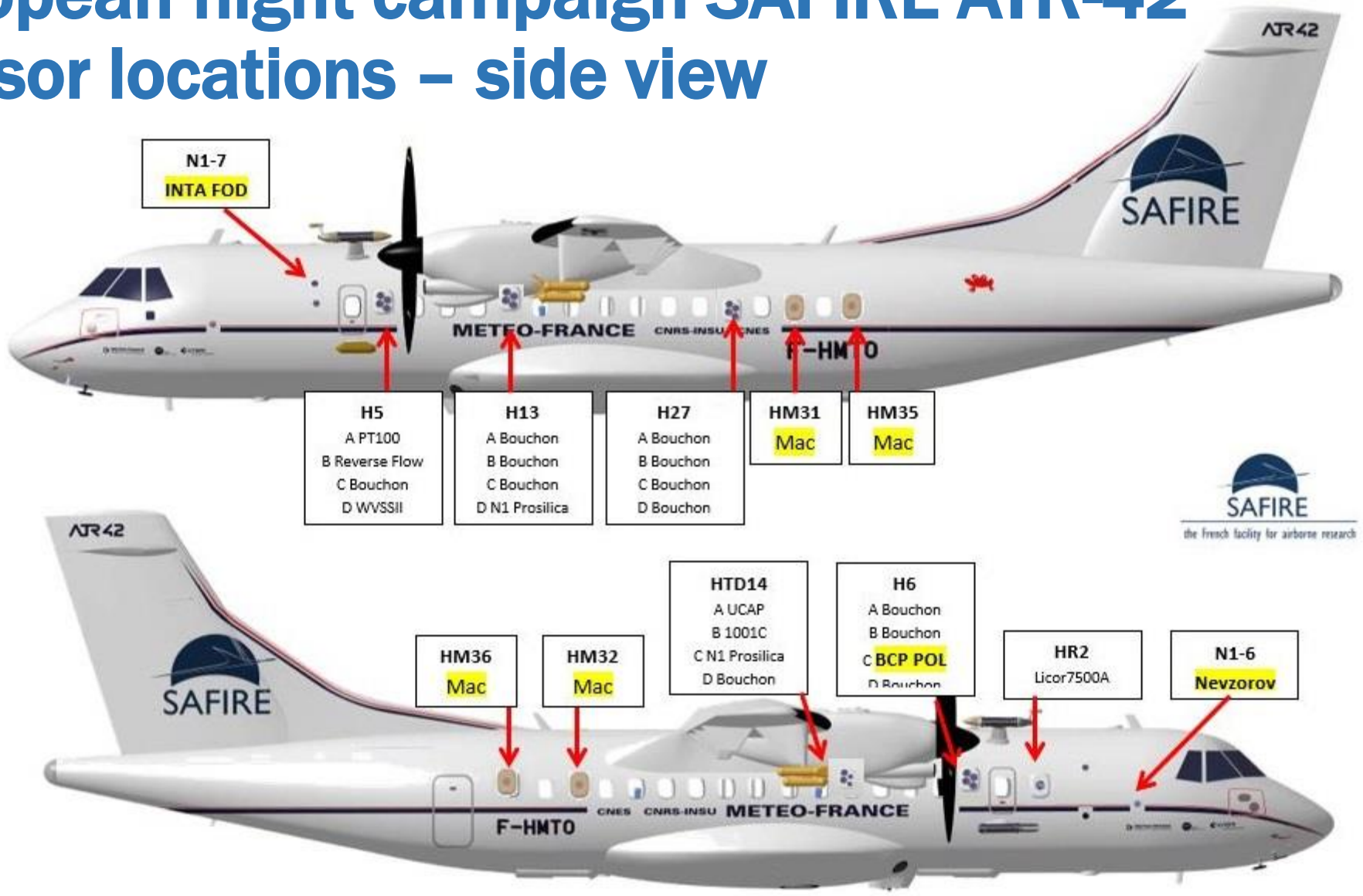
European flight campaign SAFIRE ATR-42
Sensor locations – front view



SENS4ICE equipment highlighted in yellow

Image Credit Safire

European flight campaign SAFIRE ATR-42
Sensor locations – side view

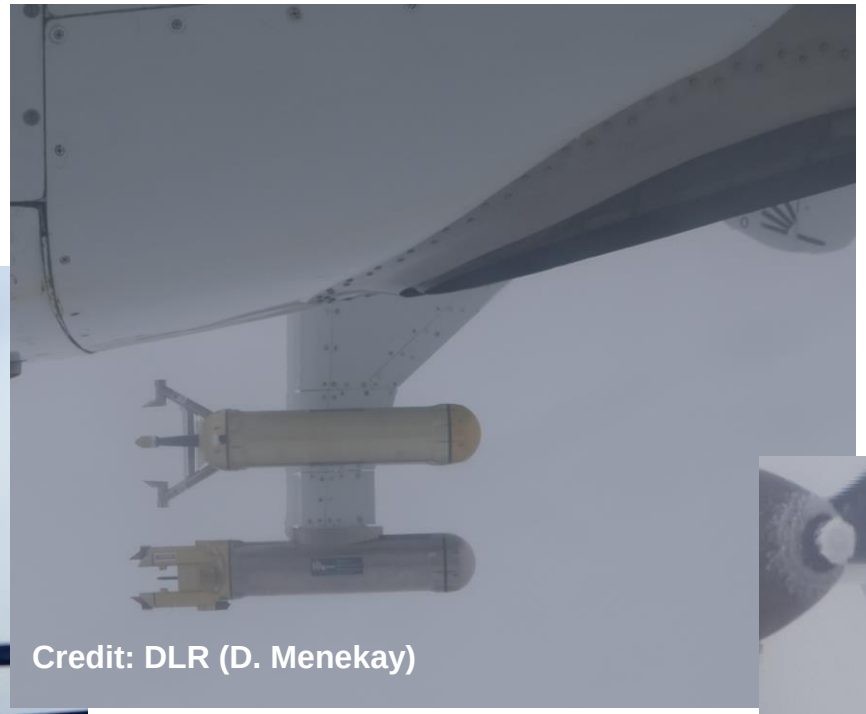


SENS4ICE equipment highlighted in yellow

Image Credit Safire

European Flight Test Campaign Impressions

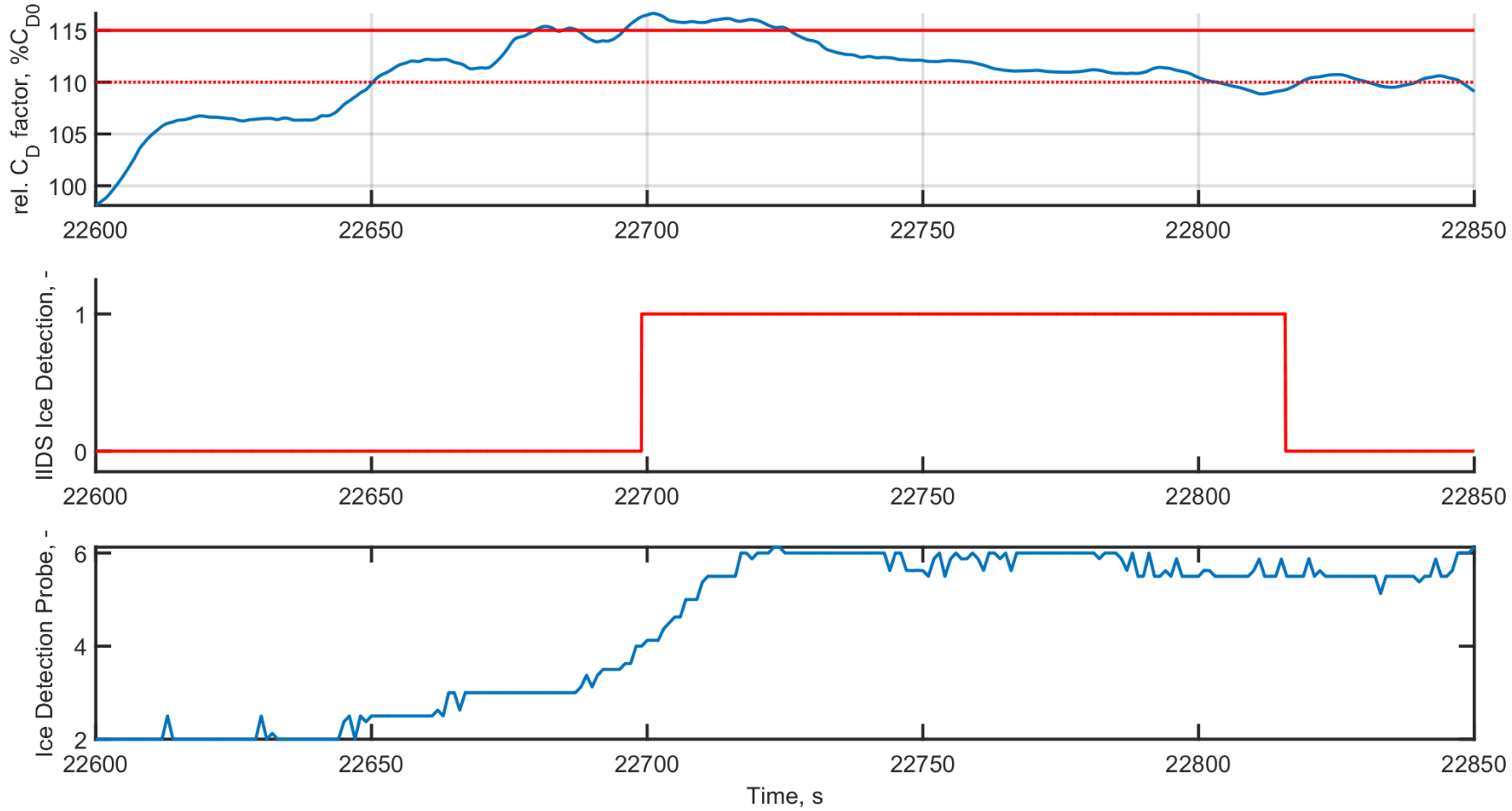

Credit: SAFIRE (J-F. Bourdin)


Credit: DLR (D. Menekay)


Credit: SAFIRE (J-F. Bourdin)

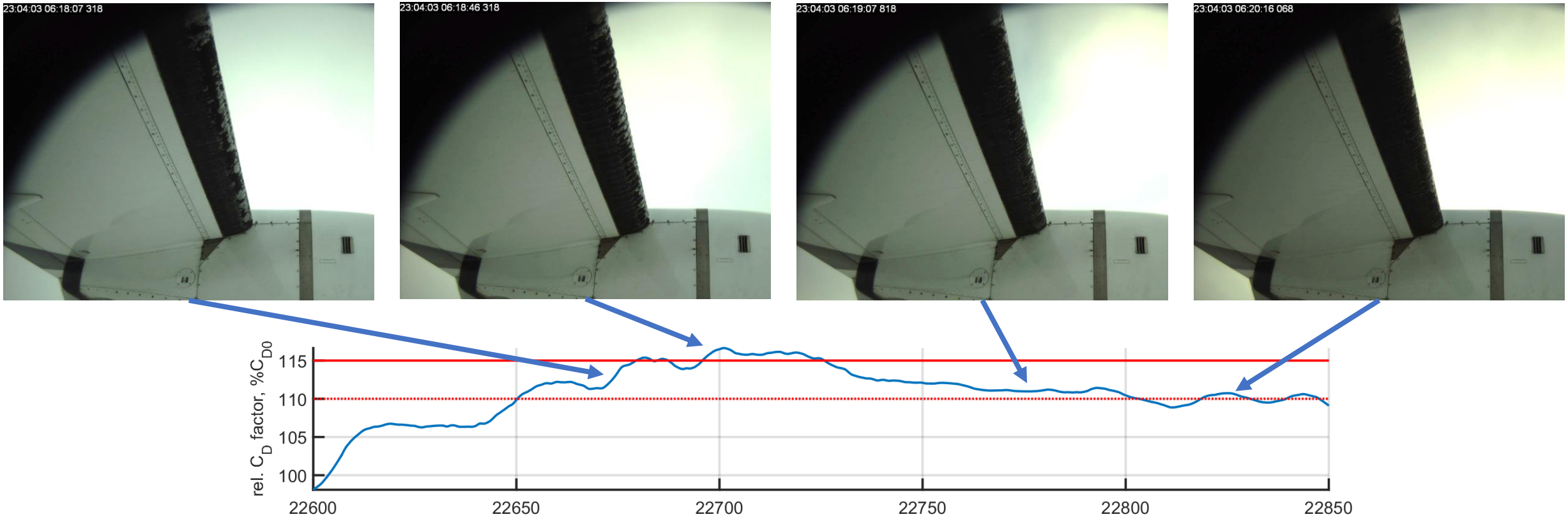
Indirect Ice Detection System

Preliminary Evaluation Results



Indirect Ice Detection System

Preliminary Evaluation Results



Summary

- Final year of the SENS4ICE project
- Technology development and testing on schedule
- Recently very successful flight test campaigns in natural icing conditions:
- Different icing conditions encountered, App. C and App. O !
- Large data source for evaluation of new detection technologies
- Different communication and dissemination events until end of this year:
  - SAE Icing Conference, Vienna, June
  - Final project meeting, Brussels, November

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

https://www.sens4ice-project.eu

https://www.linkedin.com/company/sens4ice-project

SENS4ICE