SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES
FOR SAFER AVIATION IN ICING ENVIRONMENT

Public Project Overview

July 2023

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

SENS4ICE Project Overview

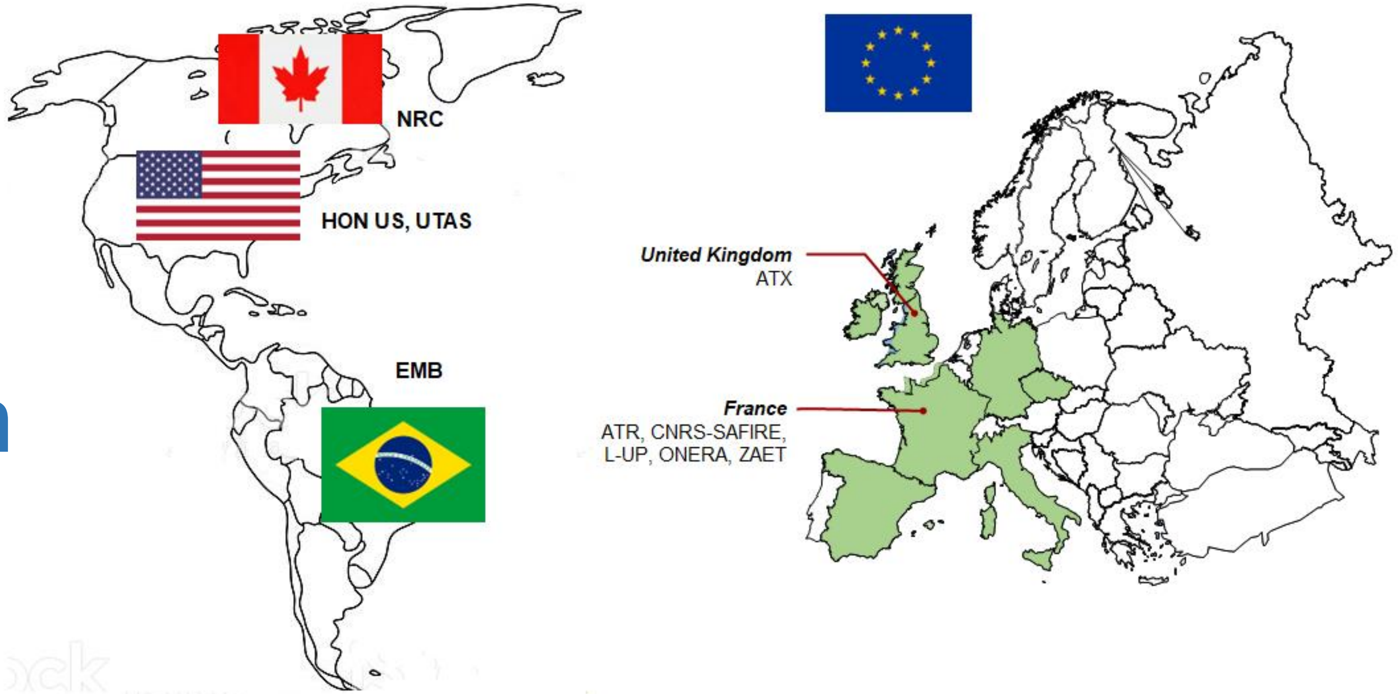
SENSors and certifiable hybrid architectures for safer aviation in ICing Environment

- 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



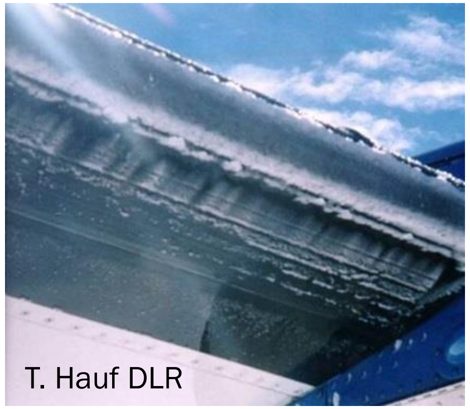
- InCo – international cooperation flagship: Aviation International Cooperation Flagship "Safer and Greener Aviation in a Smaller World"
- 17 project parties (10 countries)
  - 13 European/4 international
  - 6 research centers, 1 university,
    9 industrial partners (OEMs and system developers and 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



T. Hauf DLR

Dangers of Icing in Flight

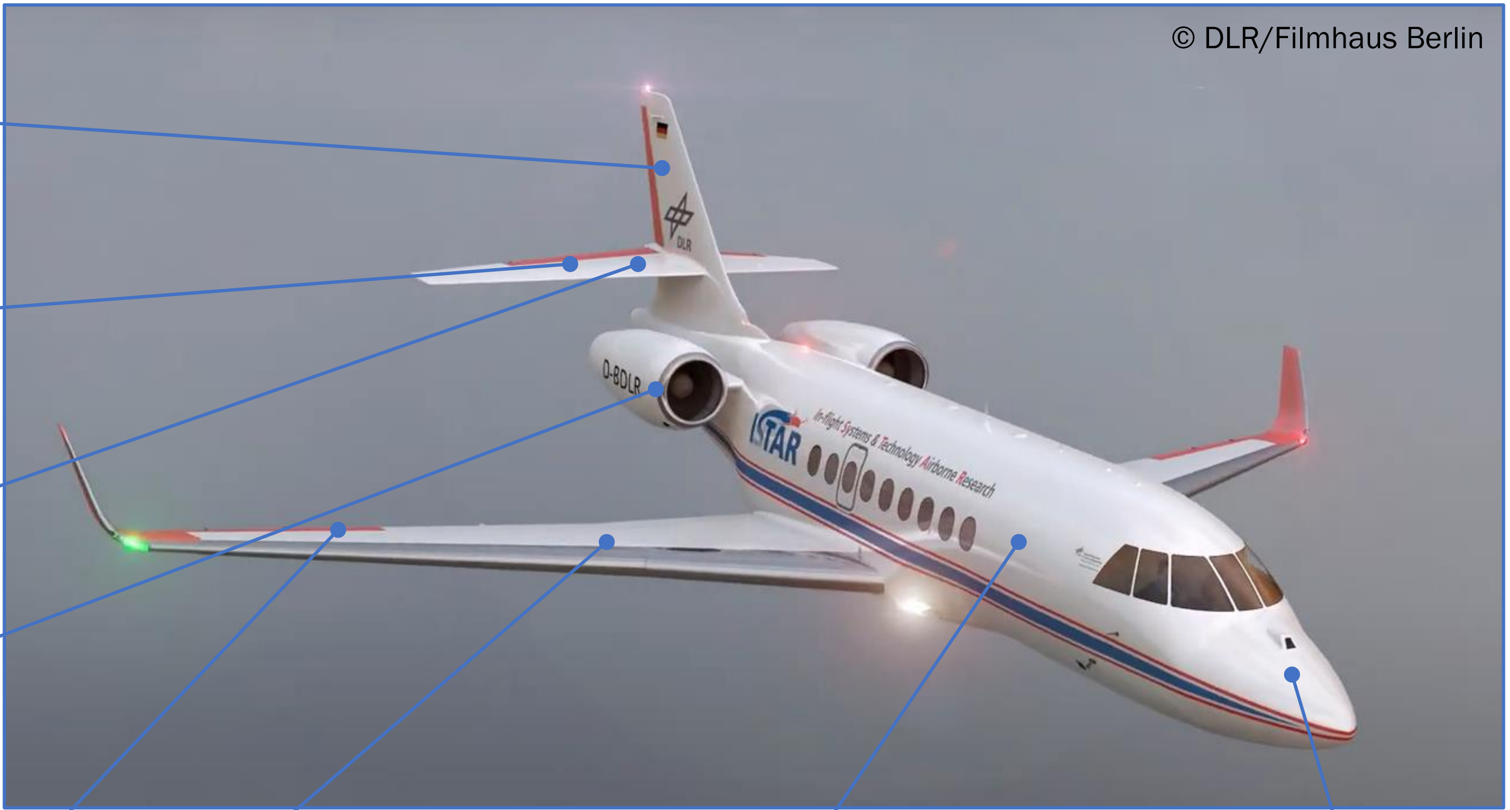
Vertical Tail Plane
- Control degradation
- Drag increase

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:

Strategic: flight planning based on **new enhanced weather forecast.**

Tactical: new nowcasting to enhance actual situational awareness in avoidance of hazardous icing conditions.

In situ: new hybrid detection of icing conditions and accretion to trigger IPS and safe exit strategy

Contingency: new detection of reduction in aircraft flight envelope (loss of control prevention)

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

SENSors and certifiable hybrid architectures for safer aviation in ICing Environment
SENS4ICE

WP 1 – Direct and indirect ice detection for App. O
- Task 1.1 – Direct ice detection sensors
- Task 1.2 – Icing wind tunnel testing and evaluation of direct ice detection sensors
- Task 1.3 – Selection of sensor technology for hybridization & airborne demonstration
- Task 1.4 – Indirect ice detection
- Task 1.5 – Remote detection of icing conditions
- Task 1.6 – Maturation of sensor technologies for airborne demonstration

WP 2 – Hybrid ice detection architectures
- Task 2.1 – Hybrid ice detection system specification & requirements
- Task 2.2 – Means of compliance for certification
- Task 2.3 – Ice detection system implementation

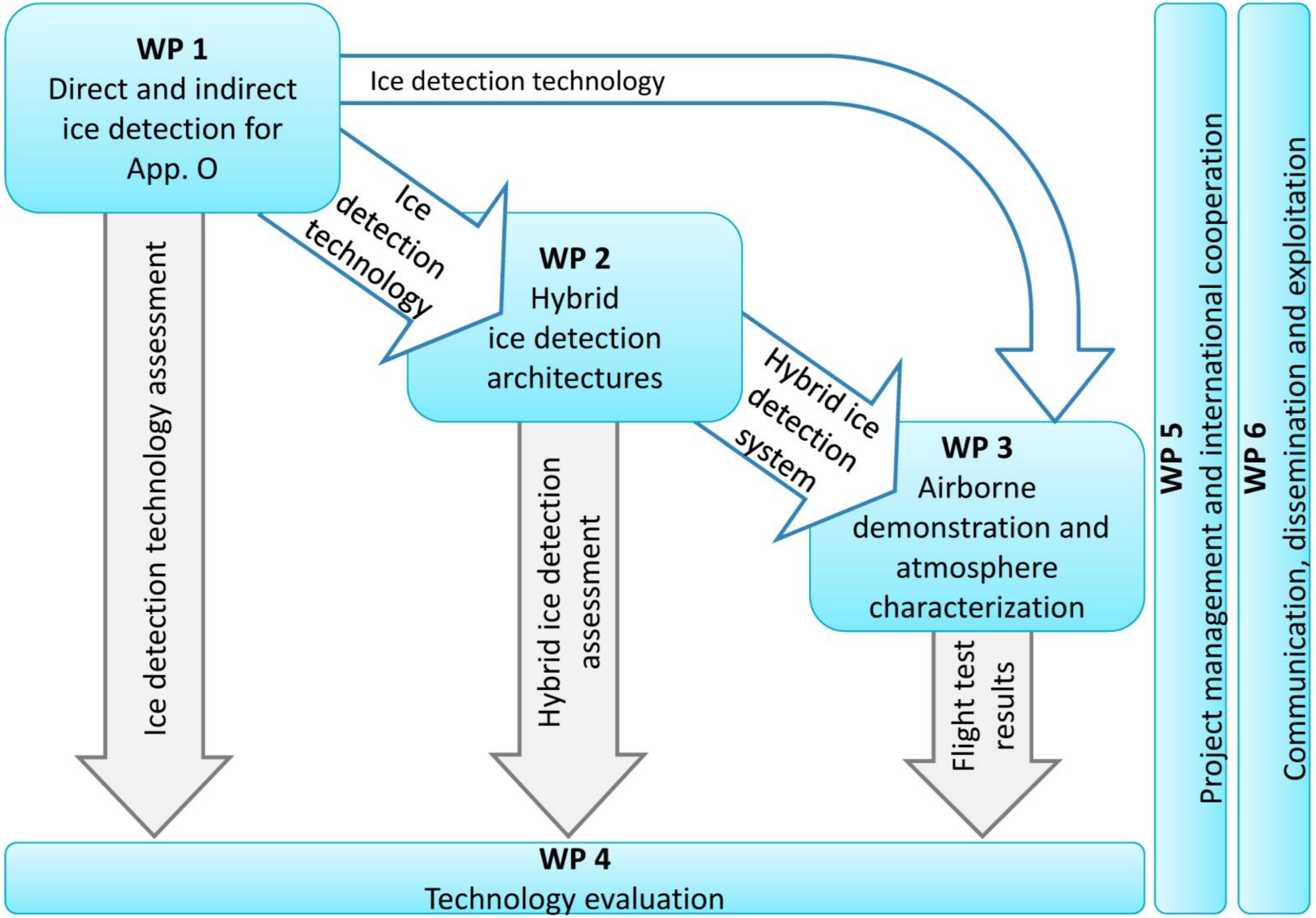
WP 3 – Airborne demonstration and atmosphere characterization
- Task 3.1 – Specification for sensor integration
- Task 3.2 – HW and SW integration on ATR platform + flight test preparation
- Task 3.3 – HW and SW integration on EBM platform + flight test preparation
- Task 3.4 – Airborne demonstration in natural icing with ATR platform
- Task 3.5 – Airborne demonstration in natural icing with Embraer platform
- Task 3.6 – Atmosphere characterization

WP 4 – Technology evaluation
- Task 4.1 – Individual technology evaluation and roadmap for future developments
- Task 4.2 – Evaluation of hybrid ice detection
- Task 4.3 – Overall evaluation of flight test campaigns
- Task 4.4 – Evaluation of project developments and results

WP 5 – Project management and international cooperation
- Task 5.1 – Project progress monitoring and interfacing with international partners
- Task 5.2 – Administrative, financial and quality management

WP 6 – Communication, dissemination and exploitation
- Task 6.1 – Dissemination activities and Action Plan
- Task 6.2 – Communication
- Task 6.3 – IPR, exploitation and certification

Technical Work Packages Interrelation



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/MAR 2023

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Flight test analysis

Commu-nication, Dissem-ination, Exploi-tation

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

WP1: Direct and indirect ice detection for App. O
High Level Objectives

Main Objective: Develop technologies capable of detecting App. O icing conditions using a three-pronged approach:

- Direct detection: development of *in situ* sensors capable of ice detection
  - 10 technologies under EU-funded development representing a variety of physical detection principles
  - Evaluation in icing wind tunnel tests under simulated App. O conditions – three tunnel facilities/total of 16 weeks testing time
  - Two-stage evaluation/selection process to ensure most promising sensors advance to flight test (WP3)
- Indirect detection: utilising existing sensor information and aircraft performance reference data for early detection of airframe icing
- Remote detection: development of methods to detect App. O conditions before the aircraft enters the hazard area
  - Detection and Nowcasting: development of algorithms that combine meteorological factors retrieved from satellite data to detect and forecast (very short-term range) icing threats in App. O conditions
  - Polarimetric weather radar: development of algorithms to classify icing threats and identify App. O conditions

SENS4ICE sensor technologies overview, sensor types and principles

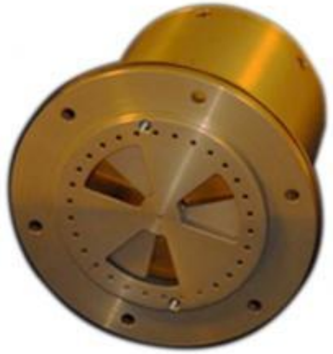
Developer	Sensor	Sensor Type	Sensor Principle
AeroTex	AIP - Atmospheric Icing Patch	Atmospheric	Isothermal with inertial separation at different sensors along aircraft
Collins	IDS - Ice Detection System	Atmospheric	Thermal response to heat impulse
DLR	LILD - Local Ice Layer Detector	Accretion	Ultrasonic wave attenuation / phase change
Honeywell	SRP - Short Range Particulate	Atmospheric	Collecting backscattered light from particles
INTA	FOD - Fiber Optic Detector	Accretion	Latent heat measured with fiber optic
ONERA	AHDEL - Atmospheric Hydrometeor Detector based on Electrostatics	Atmospheric	Particle charging and subsequent measurement of the charge
ONERA	AMPERA - Atmospheric Measurement of Potential and ElectRic field on Aircraft	Atmospheric	Measurement of aircraft electric potential
SAFRAN	AOD - Appendix O Discriminator	Atmospheric	Shadowgraphy
SAFRAN	PFIDS - Primary in-Flight Icing Detection System	Accretion	Optical reflection from accretion
DLR	CM2D - Cloud Multi-Detection Device [BCPD - Backscatter Cloud Probe with Polarization Detection]	Atmospheric	Single particle optical backscatter
DLR	CM2D - Cloud Multi-Detection Device [Nevzorov]	Atmospheric	Isothermal measurement of water content

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

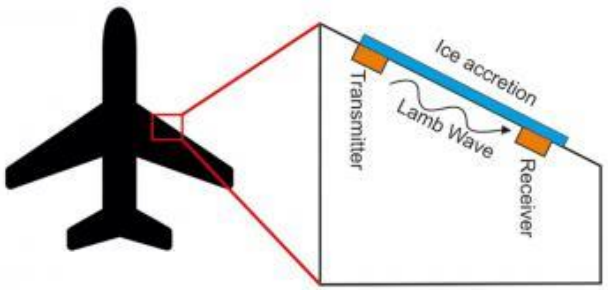
Name: *Short Range Particulate (SRP)*
Project partner: *Honeywell*

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

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

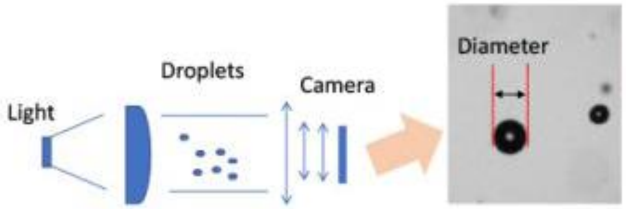


Name: *AMPERA*
Project partner: *French Aerospace Lab (ONERA)*



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

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

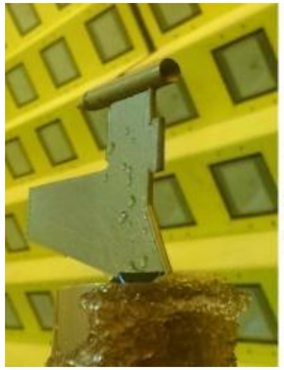


Name: *Appendix O Discriminator (AOD)*
Project partner: *SAFRAN*

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

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

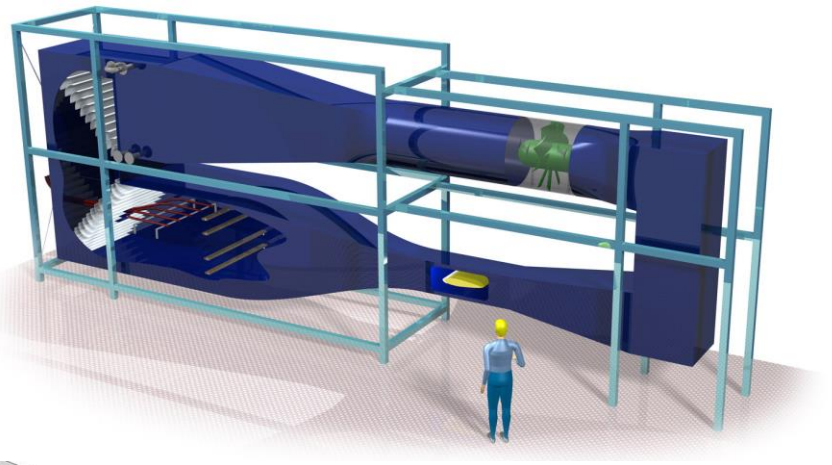
Name: *PFIDS (Primary in-Flight Icing Detection System)*
Project partner: *SAFRAN*

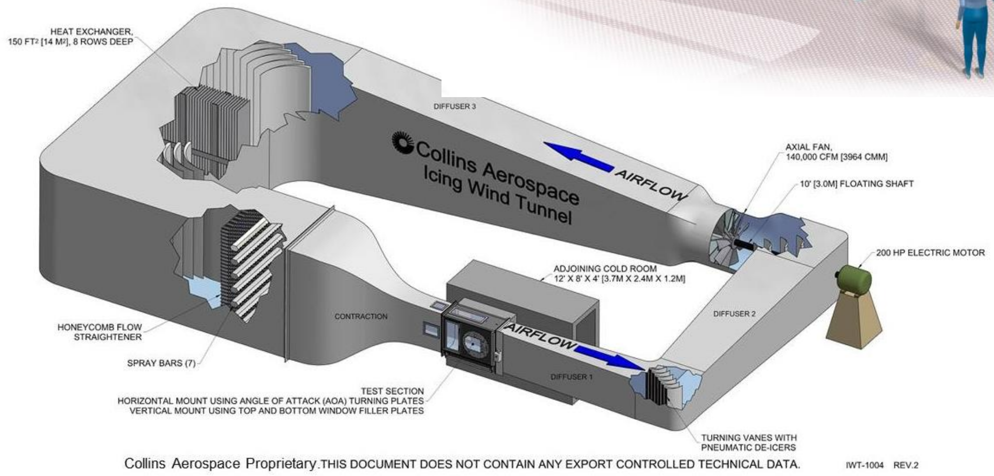


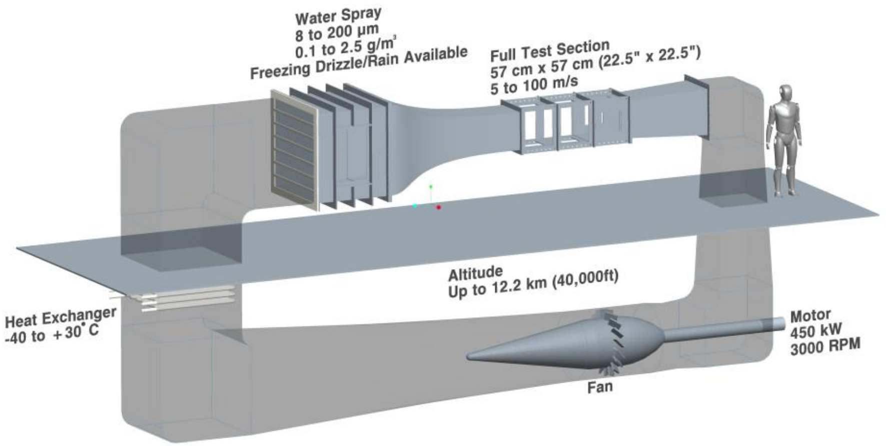
Name: *Nevzorov Probe and Backscatter Cloud Probe with Polarization Detection (BCPD)*
Project partner: *DLR (German Aerospace Center)*

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

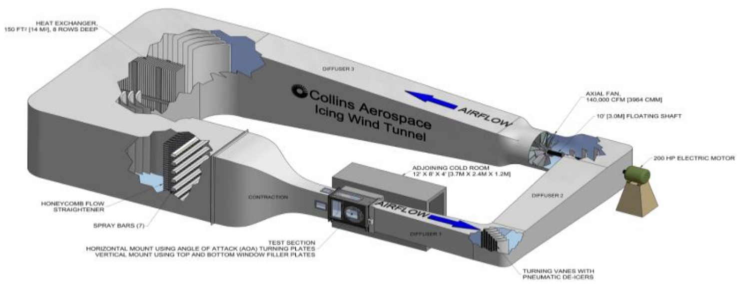






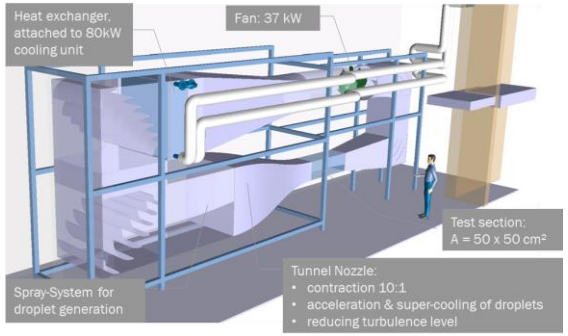
Overview of SENS4ICE IWT Capabilities

Collins Aerospace, USA



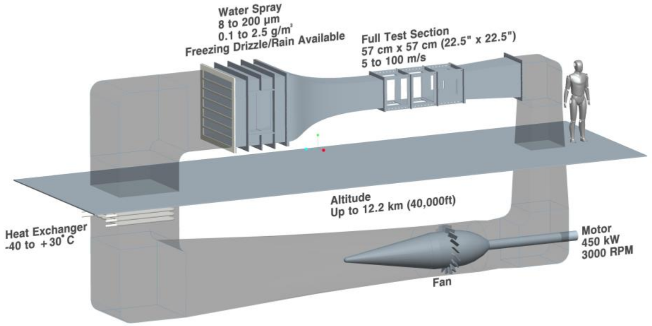
- 5-147 micron droplets
- LWC between 0.1 and 3 g/m3
- Temperature 0°C to -30°C
- Sustained speed 13-103 m/s
- Test section: 152×56×112 cm3
- Calibrated per SAE ARP 5905
- Compliant with AS9100C
- Controls and power supplies can simulate aircraft controls

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

Common test points between IWT facilities TUBS, Collins and NRC

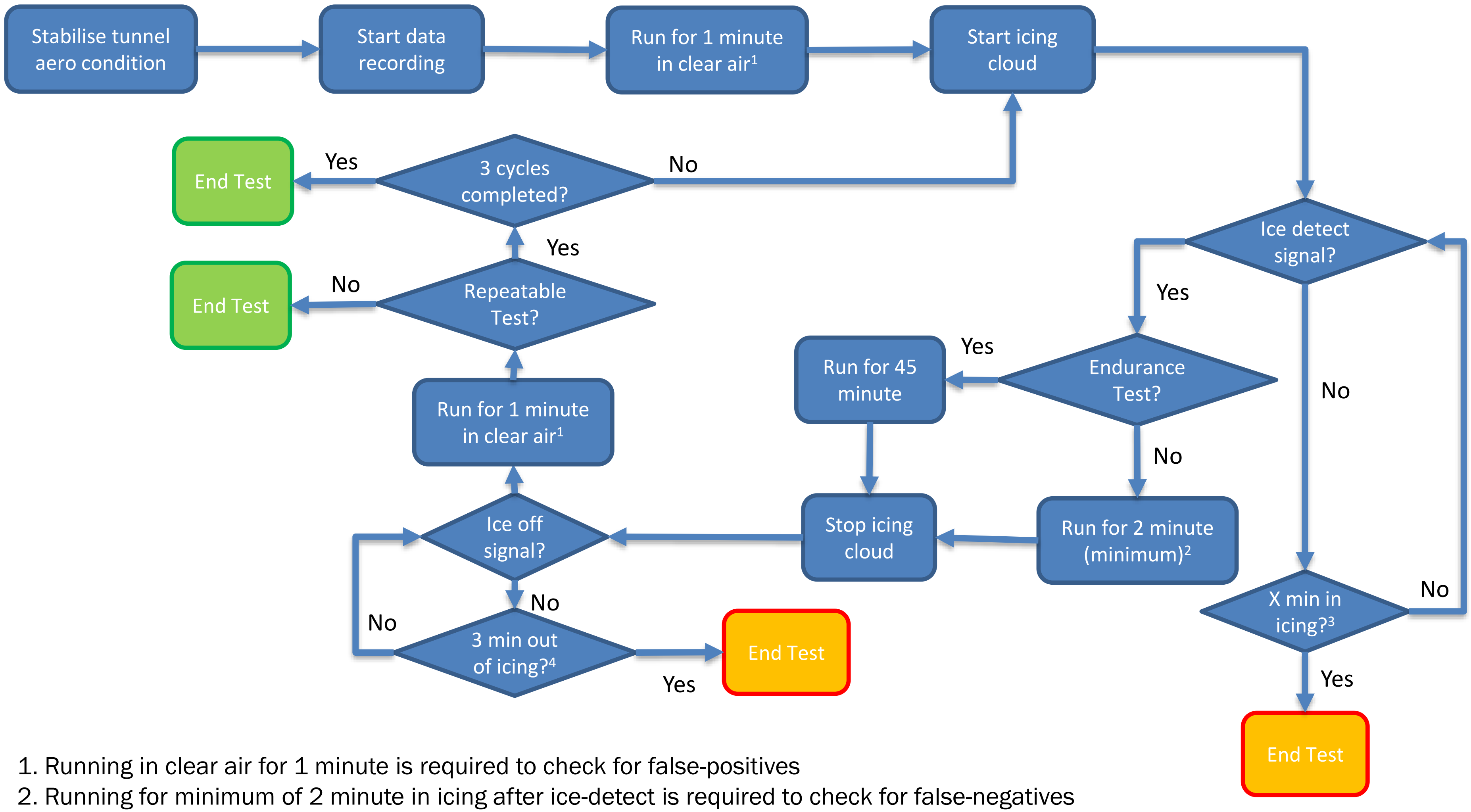
IWT	App C					
	Total Test Points	Common with 3 IWT	Common with 2 IWT	Only at 1 IWT	CM Test Points	IM Test Points
TUBS	19	4	1	14	10	9
Collins	18	4	3	10	9	9
NRC	19	4	4	11	9	10
	App O					
	Total Test Points	Common with 3 IWT	Common with 2 IWT	Only at 1 IWT	Total Points [unimodal]	Total Points [bimodal]
TUBS	18	0	1	17	0	18
Collins	6	0	1	5	6	0
NRC	17	0	2	15	4	13

Collins IWT SENS4ICE Test Matrix

Case	Condition	Airspeed	Static Temp.	MVD	LWC
[-]	[-]	[m/s]	[deg. C]	[µm]	[g/m^3]
1	LW-C CM	40	-20	15	0.30
2	LW-C CM	40	-10	20	0.42
3	LW-C CM	40	-1	23	0.54
4	LW-C CM	67	-2	15	0.80
5	LW-C CM	67	-20	18	0.25
6	LW-C CM	67	-10	20	0.42
7	LW-C CM	85	-30	17	0.17
8	LW-C CM	85	-20	15	0.30
9	LW-C CM	85	-10	23	0.34
10	LW-C IM	40	-20	22	1.50
11	LW-C IM	40	-1	20	2.50
12	LW-C IM	40	-10	28	1.20

Case	Condition	Airspeed	Static Temp.	MVD	LWC
[-]	[-]	[m/s]	[deg. C]	[µm]	[g/m^3]
13	LW-C IM	67	-2	23	2.00
14	LW-C IM	67	-20	30	0.80
15	LW-C IM	67	-10	25	1.40
16	LW-C IM	85	-30	20	1.00
17	LW-C IM	85	-20	23	1.30
18	LW-C IM	85	-10	32	0.80
19	unimodal	76	-17.7	122.3	0.46
20	unimodal	76	-17.7	189.5	0.56
21	unimodal	76	-17.7	169.1	0.78
22	unimodal	76	-17.7	183.8	0.78
23	unimodal	76	-17.7	155.4	0.94
24	unimodal	76	-17.7	163.5	0.82

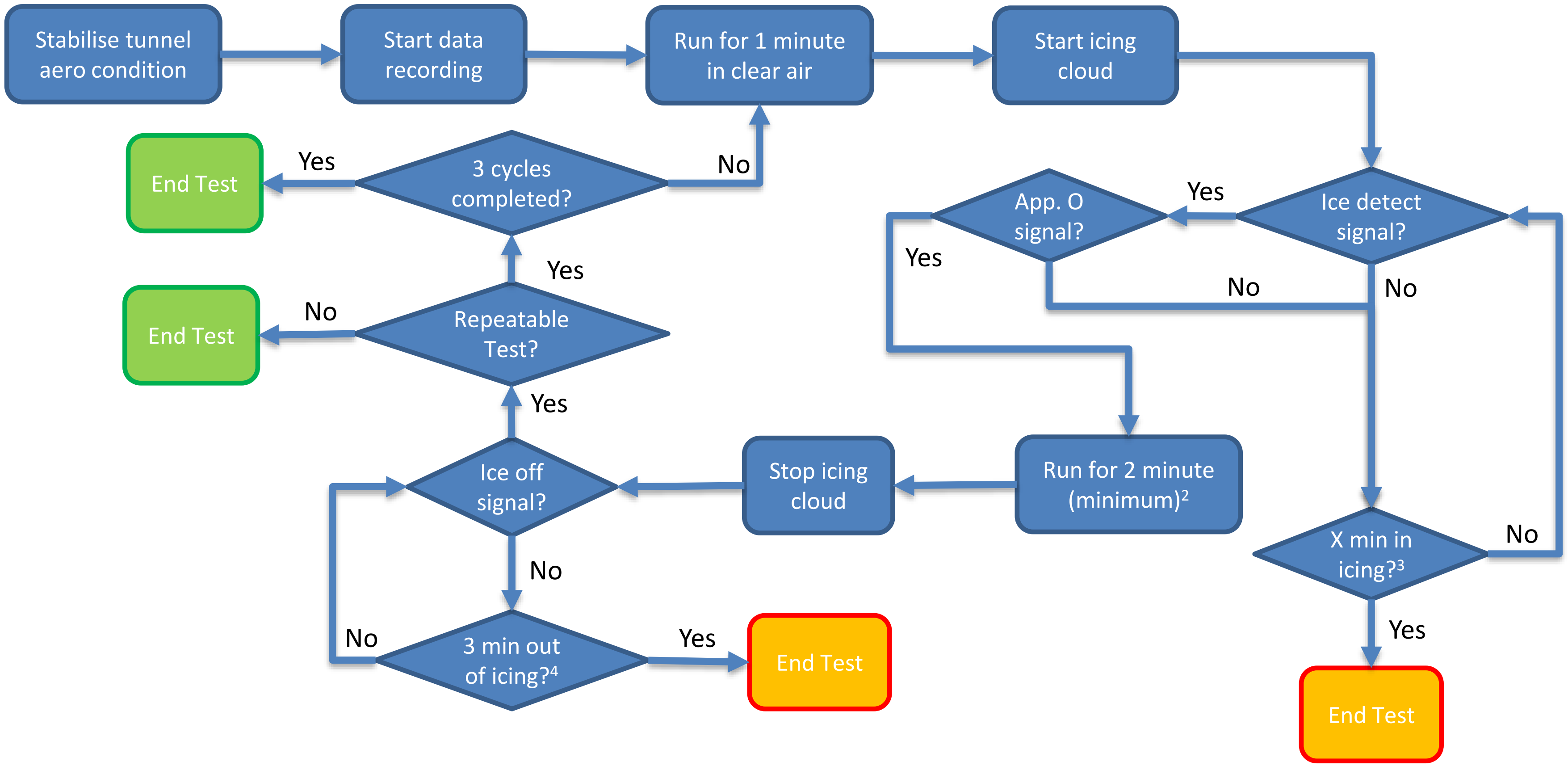
IWT Test Procedures – App C Conditions



Notes:

1. Running in clear air for 1 minute is required to check for false-positives
2. Running for minimum of 2 minute in icing after ice-detect is required to check for false-negatives
3. X is the target calculated detection time + 1 minute
4. Based on AS5498A time to detect exit being a maximum of 3 minutes

IWT Test Procedures – App O Conditions



Notes:

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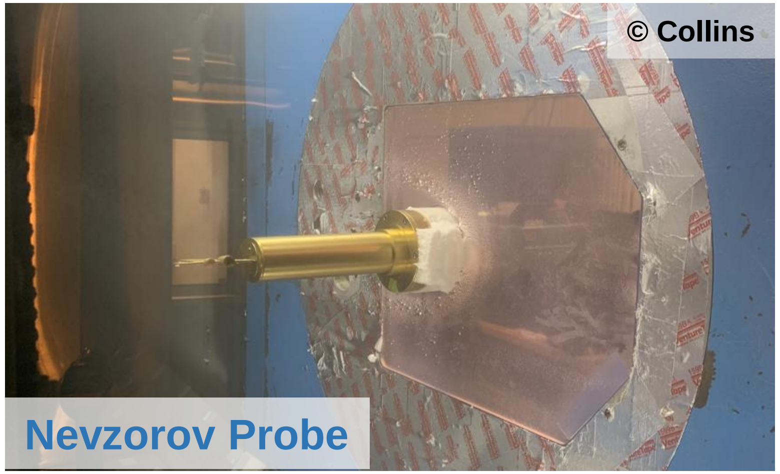
2. Running for minimum of 2 minute in icing after ice-detect is required to check for false-negatives
3. X is the target calculated detection time + 1 minute
4. Based on AS5498A time to detect exit being a maximum of 3 minutes

SENS4ICE Reference Measurements
CCP & Nevzorov Probes at Collins Icing Wind Tunnel

- Nevzorov probe
  2 days of testing at Collins
  - Completed entirety of App C and App O test matrices



- Cloud Combination Probe (CCP) probe
  3.5 days of testing at Collins
  - Completed entirety of App. C and App O. test matrices
  - During test only one of CCP probe's measurement volumes could be positioned in tunnel centerline at a time
  - For that reason, many test conditions were repeated in two configurations so that data could be collected with each measurement volume centered in the tunnel.

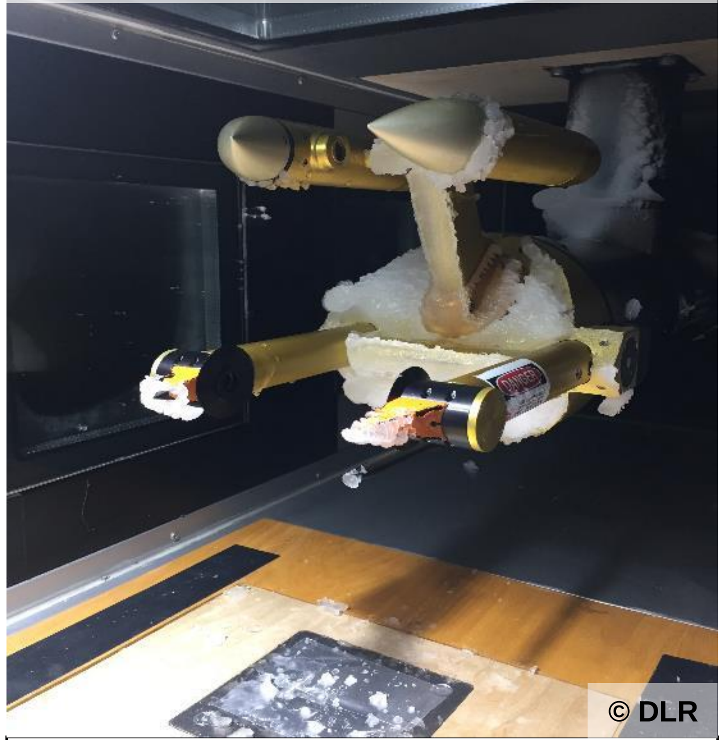
[El Hassan Ridouane (Collins), SENS4ICE Icing Wind Tunnel Capabilities and Test Procedures, SENS4ICE first public project symposium, SAE AC-9C Aircraft Icing Technology Committee Meeting 22 OCT 2020]

SENS4ICE Reference Measurements

CCP (CDP & CIP) & Nevzorov Probes at TUBS Icing Wind Tunnel

Reference measurement wind tunnel testing in Appendix C and O conditions was conducted during three weeks in January and July 2020

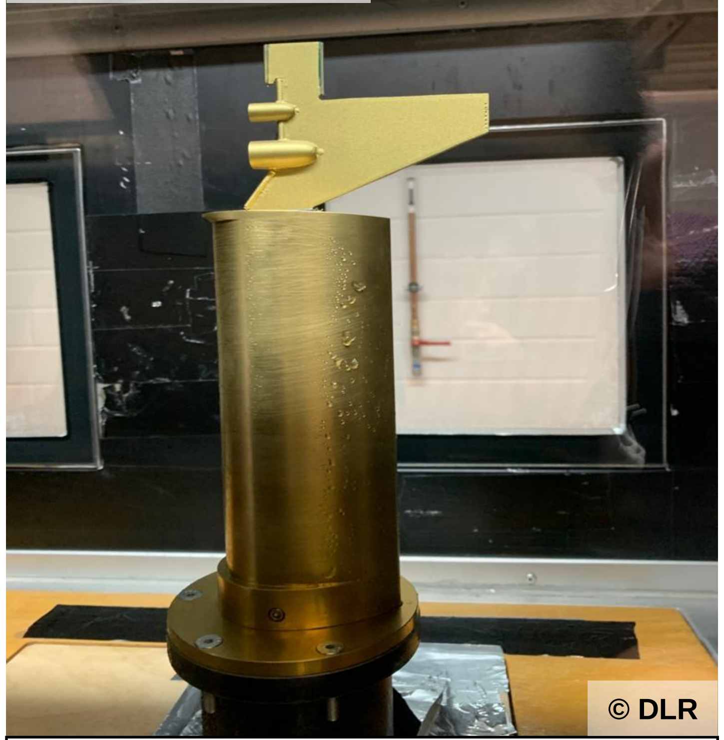
Cloud Combination Probe (CCP)



© DLR

CDP size range : 2 – 50 µm
CIP size range: 15 – 950 µm

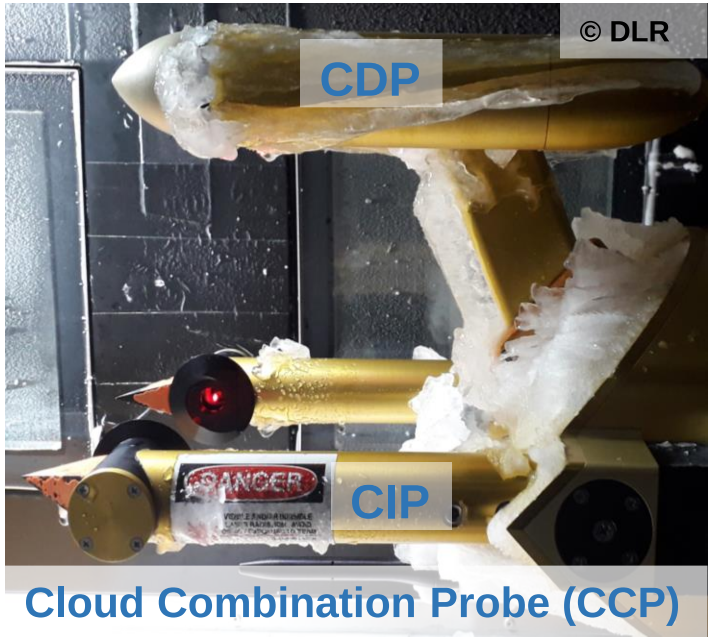
Nevzorov Probe

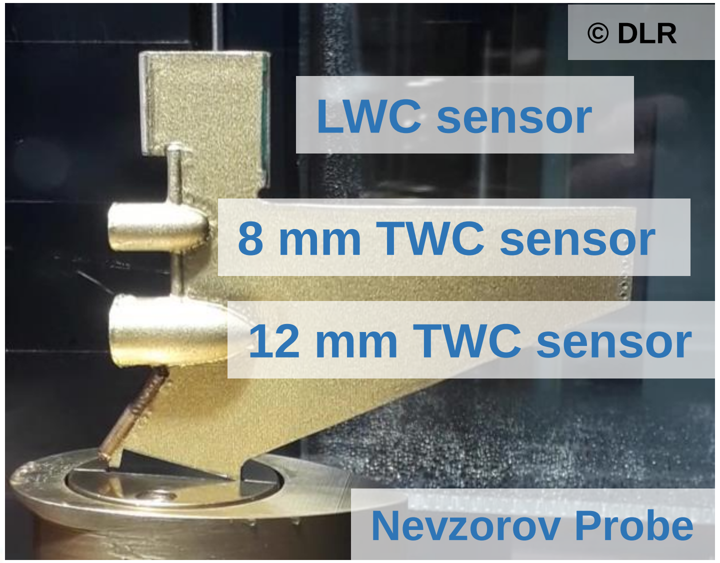


© DLR

LWC sensitivity: 0.003 g/m³
Air speed range: 10 – 180 m/s

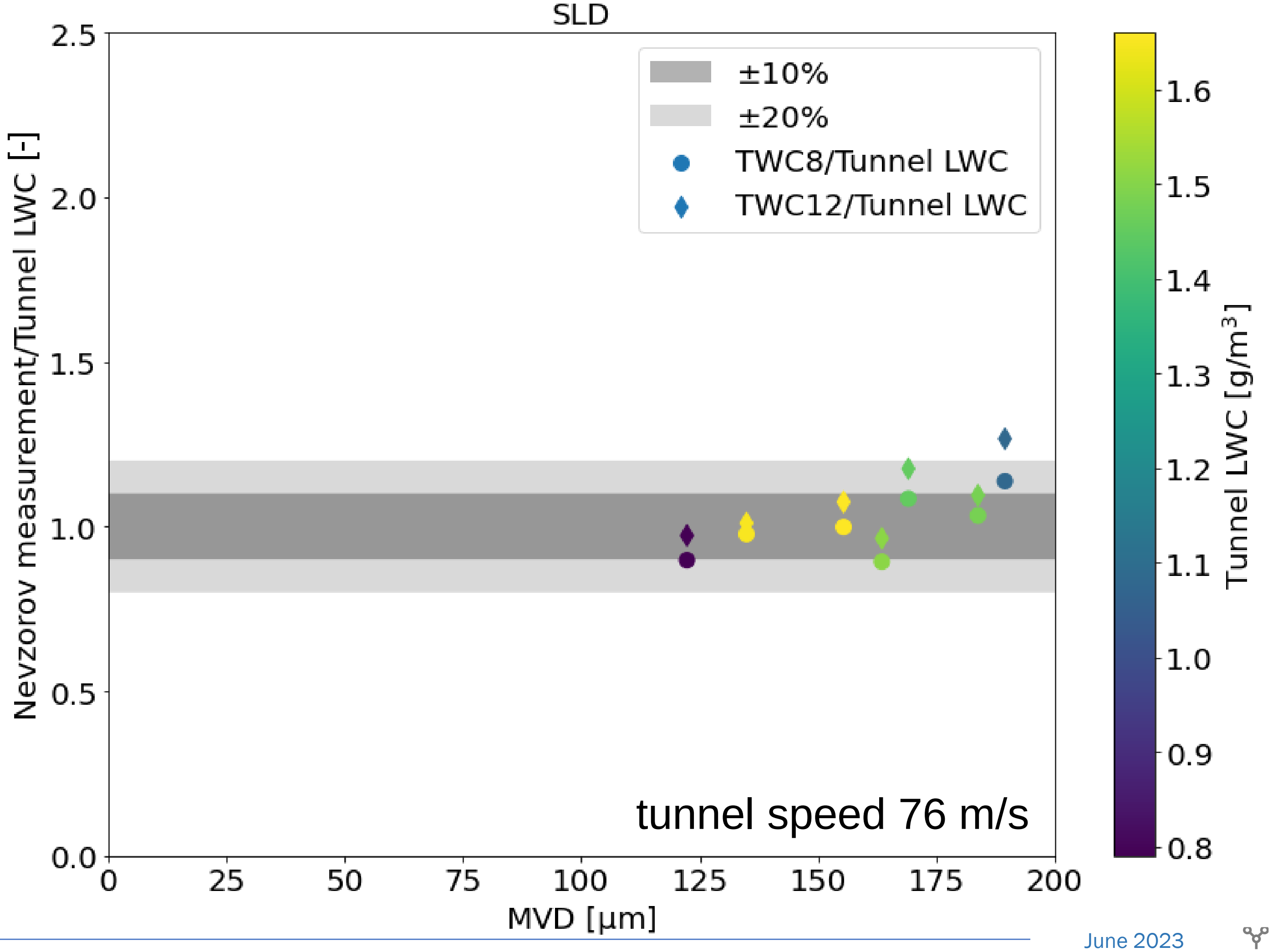
Reference Instrumentation & Measurements





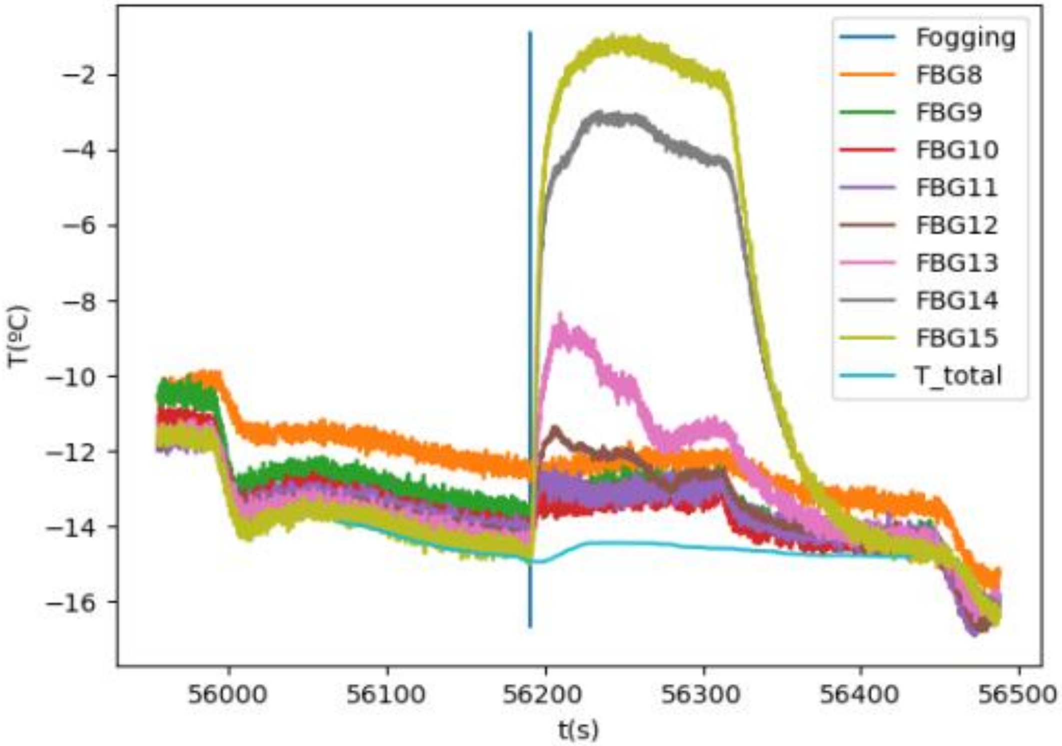
Reference measurements (Nevzorov probe) in SLD conditions

- generally good agreement with tunnel LWC data (SEA probe)
- for MVDs < 180 µm, Nevzorov and SEA probe agree within 20%



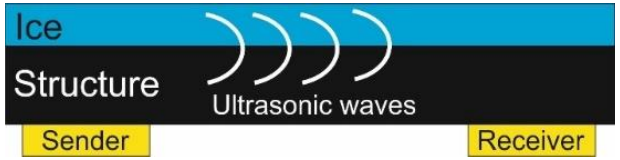
FOD (Fiber Optic Detector) – using Fiber Bragg Grating Sensors (FBGSs)

- FBGS are integrated in the surface of an airfoil to provide temperature measurements over the chord.
- Measurements are compared with a heat and mass balance model.
- Based on this a prediction for liquid water content (LWC) and ice accretion rate (IAR) is generated.
- IWT results show a good correlation with theoretical calculations. The following capabilities have been demonstrated: detect beginning and end of ice accretion, LWC and IAR quickly and with good precision.
- The different measurement locations over the cord of the airfoil allow to clearly distinguish the temperature distribution.

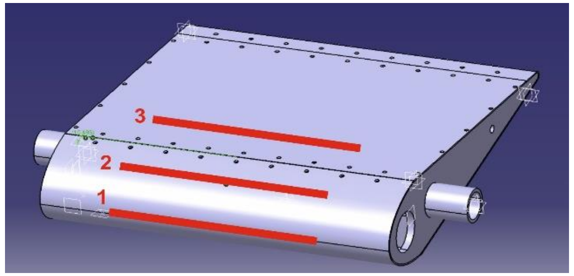


FOD temperature time histories at NRC AIWT for different measurement locations over the airfoil chord ("FBG 8 – 15") and the total temperature for Appendix O conditions (LWC = 0.82 g/m^3, MVD = 163.5 µm; V = 76 m/s, start time of icing cloud marked by a vertical line "Fogging")

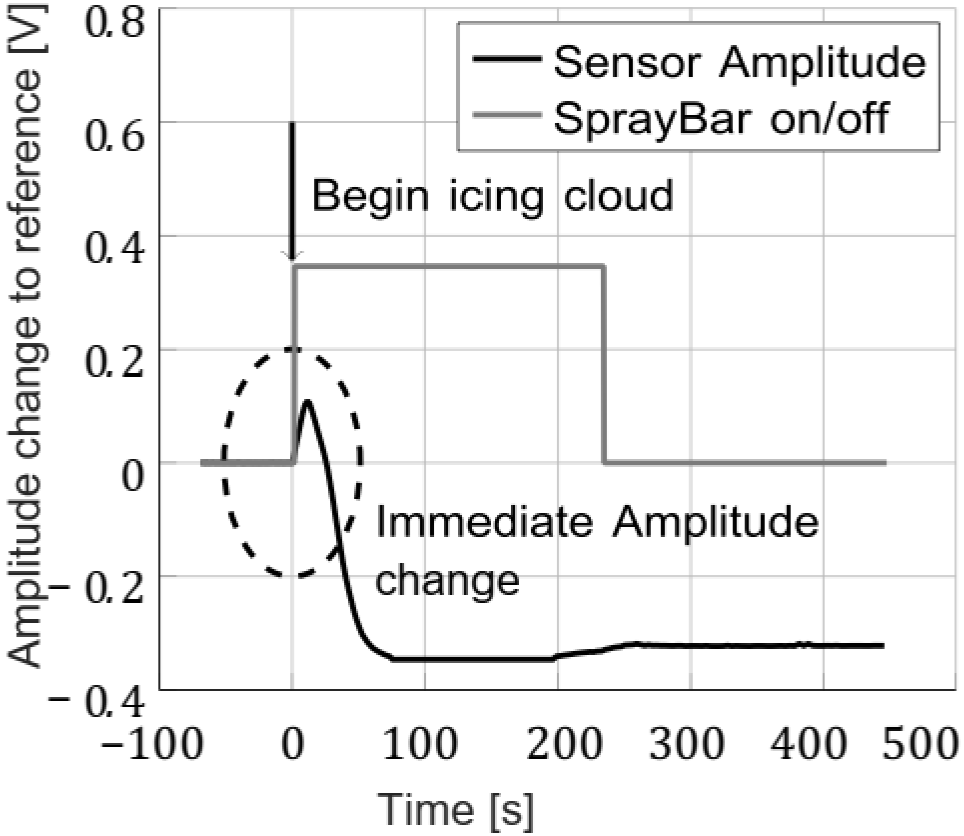
Local Ice Layer Detector (LILD)



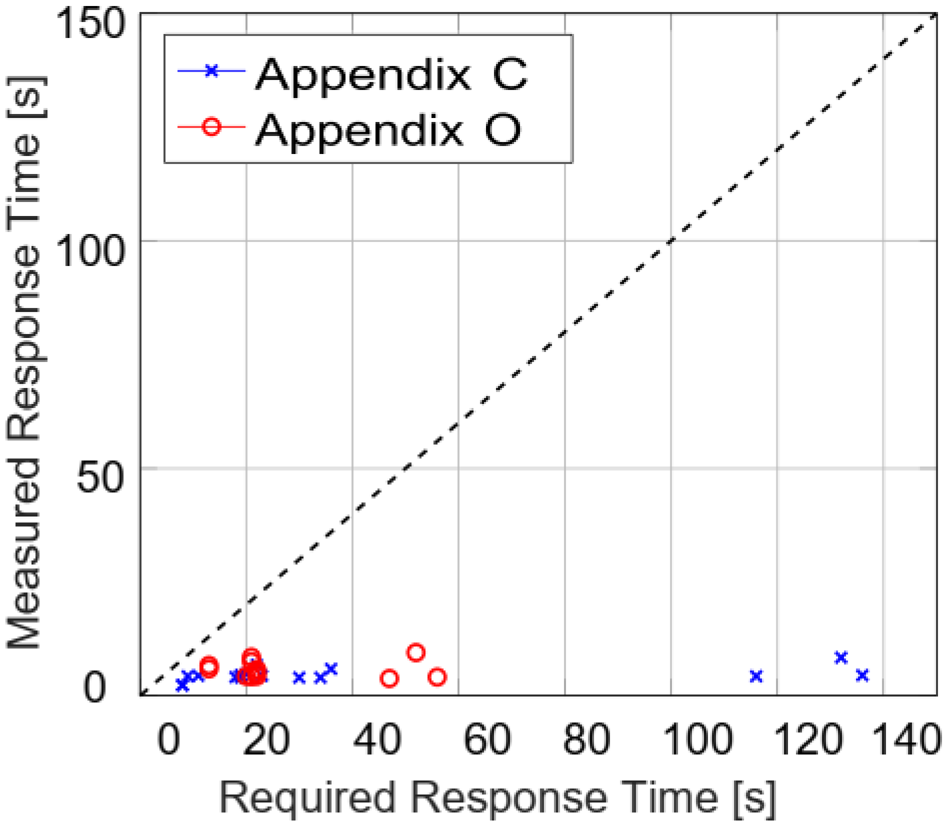
LILD principle of travelling ultrasonic lamb waves



Lamb wave measurement channels marked in red for IWT test



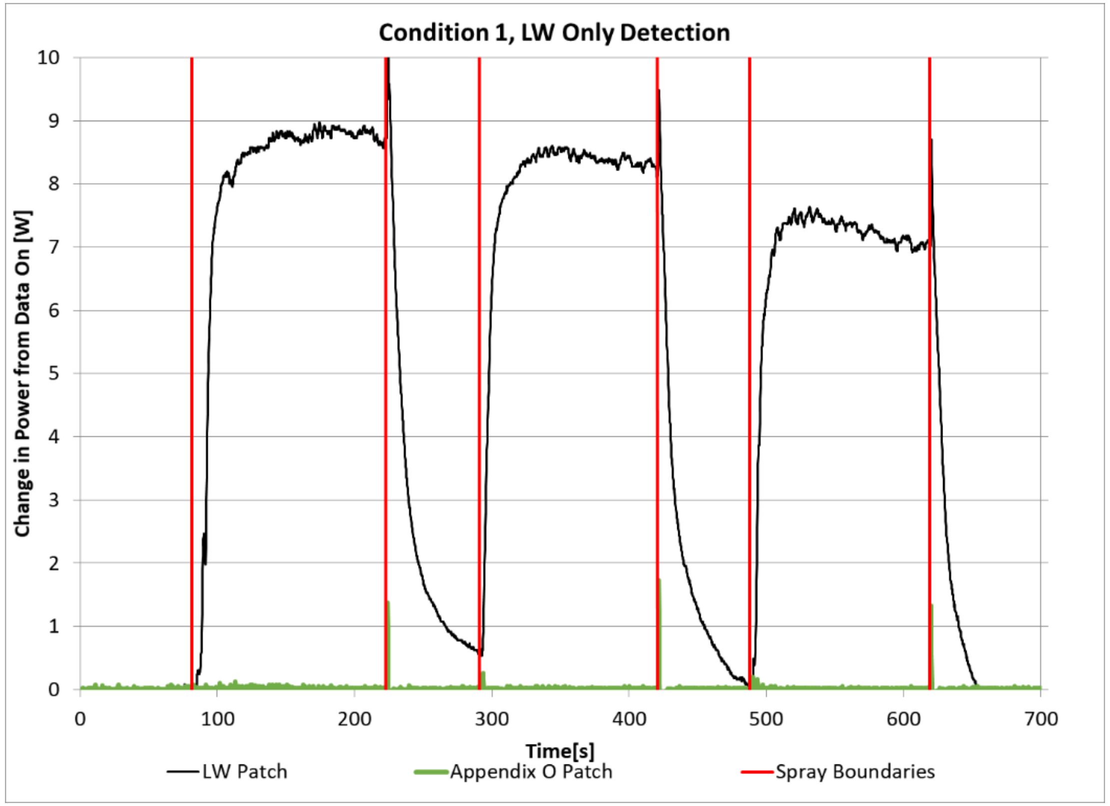
LILD immediate lamb wave amplitude reaction of the received pulse upon icing conditions start for exemplary Appendix C test case (MVD = 21.1 µm, LWC = 0,98 g/m^3, T = -10 °C)



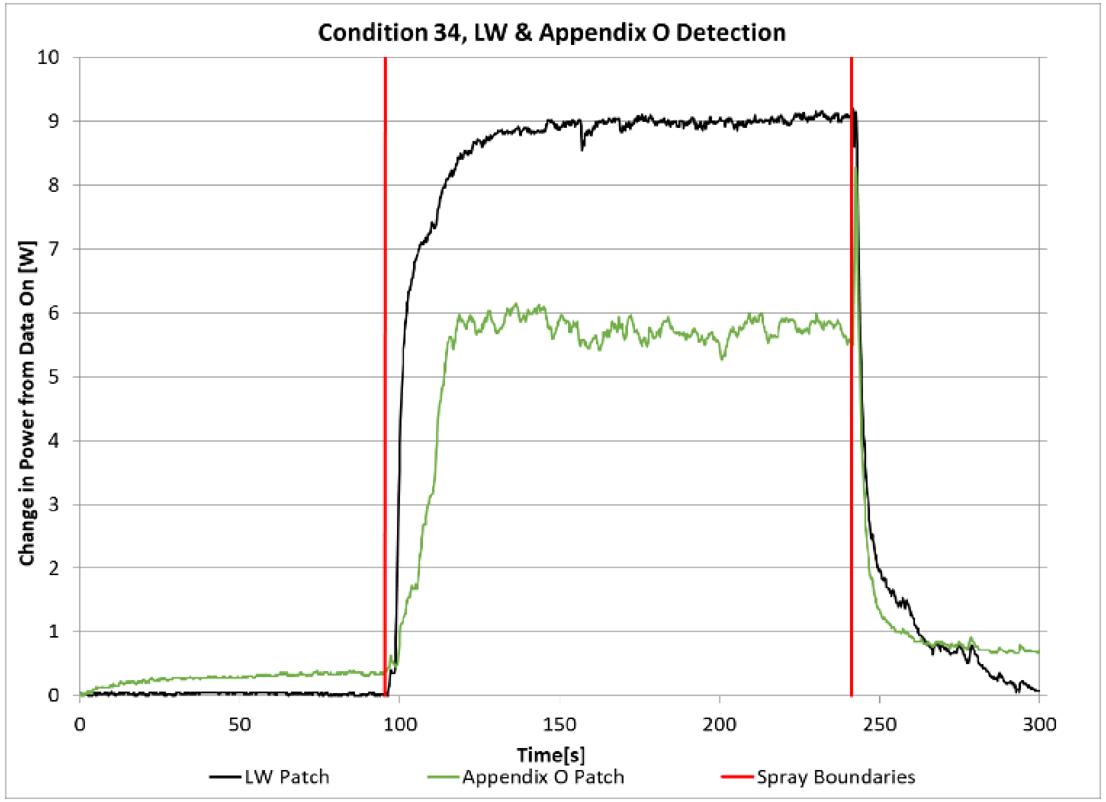
LILD response times for Appendix C and O conditions measured at BIWT compared to the required response time

Atmospheric Icing Patch – AIP

consisting of an array of low power (< 28W) iso-thermal ice detection sensors

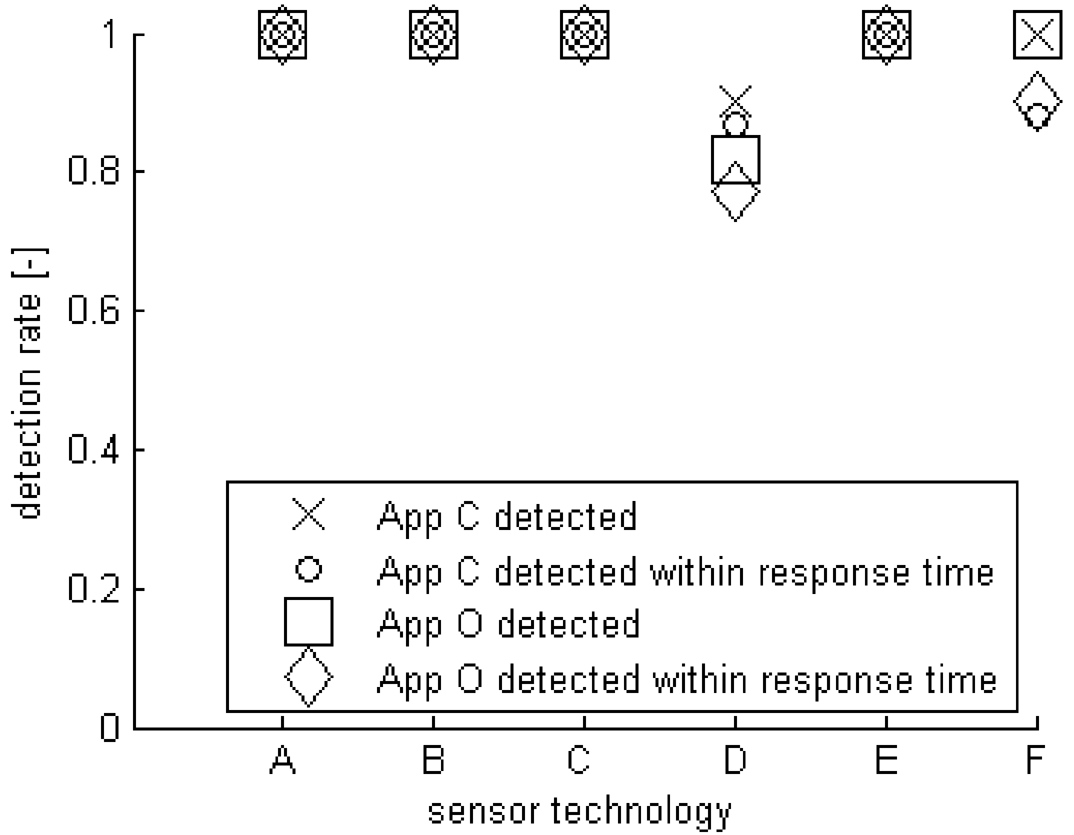


Example of AIP patch power response in small droplet icing conditions (note Appendix O patch shows no response)



Example of AIP patch power response in large droplet icing conditions (note Appendix O patch response)

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

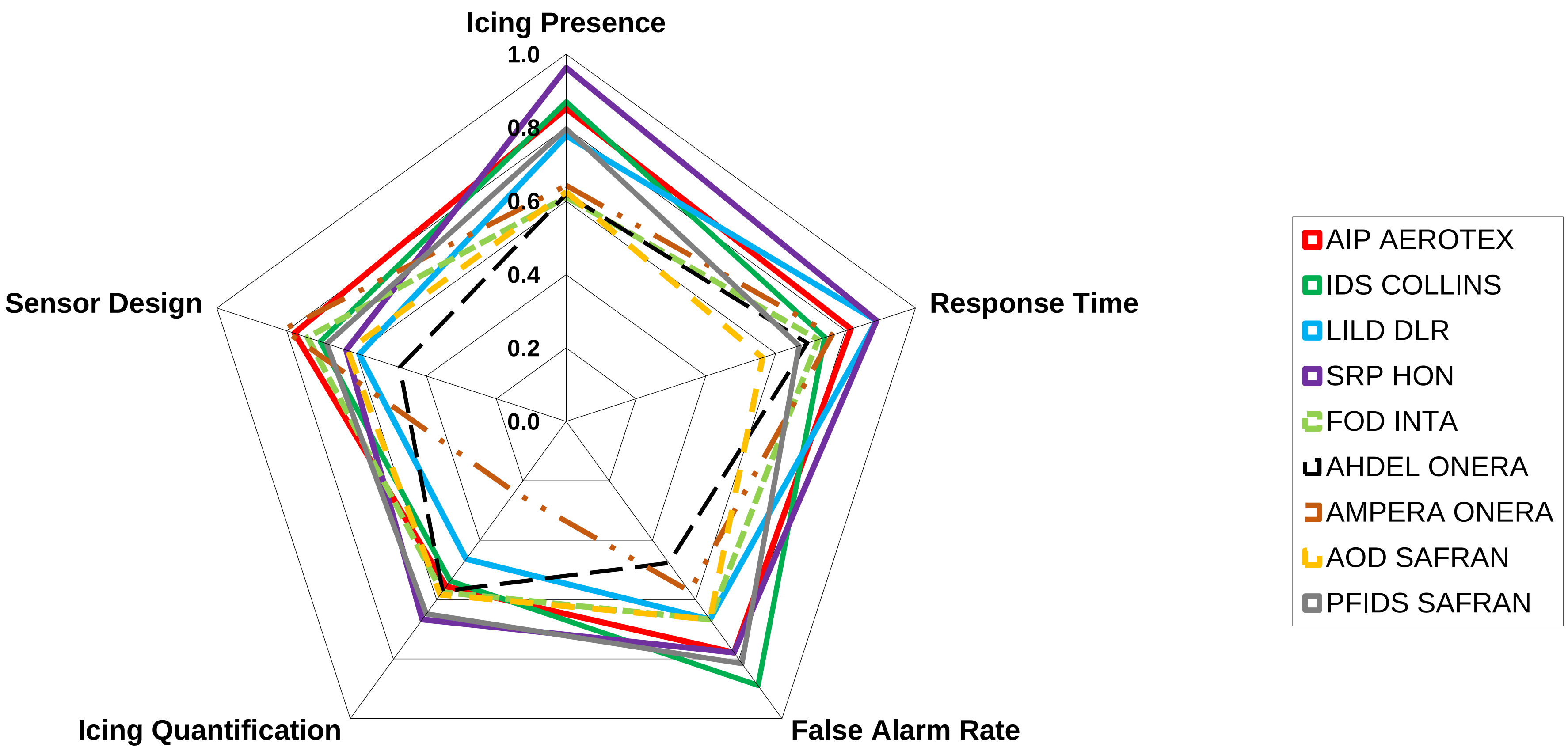
Technology evaluation criteria and weighting factors

Technology evaluation criteria	Weighting factor
Icing (ice accretion) / Icing condition presence detection capability (for App. C (required) and App. O (primary project goal, hence App. O capabilities are more relevant))	0.35
Response time (for providing Icing/Icing Condition Presence)	0.20
False alarm rate (i.e., detection of icing in non-icing conditions)	0.10
Icing quantification and contributing factors for severity determination, mainly with regard to App. O (discrimination App. C/O, icing, icing condition characteristics, either of those outputs can contribute to a good rating, while not all are required)	0.30
Sensor design: weight/integration/power (expected once technology is matured)	0.05

SENS4ICE Advisory Board evaluation ratings for sensor technologies

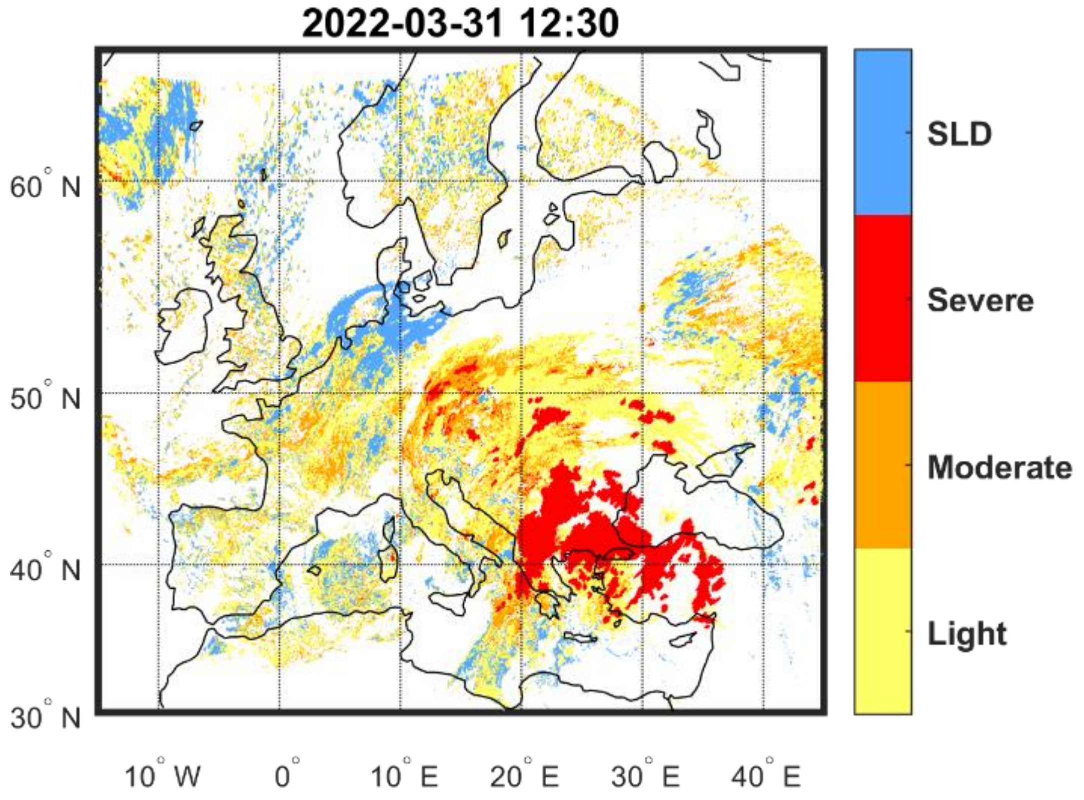
averaged for all Advisory Board members for evaluation criteria

(averaged ratings between 0 and 1, normalised, best rating 1)

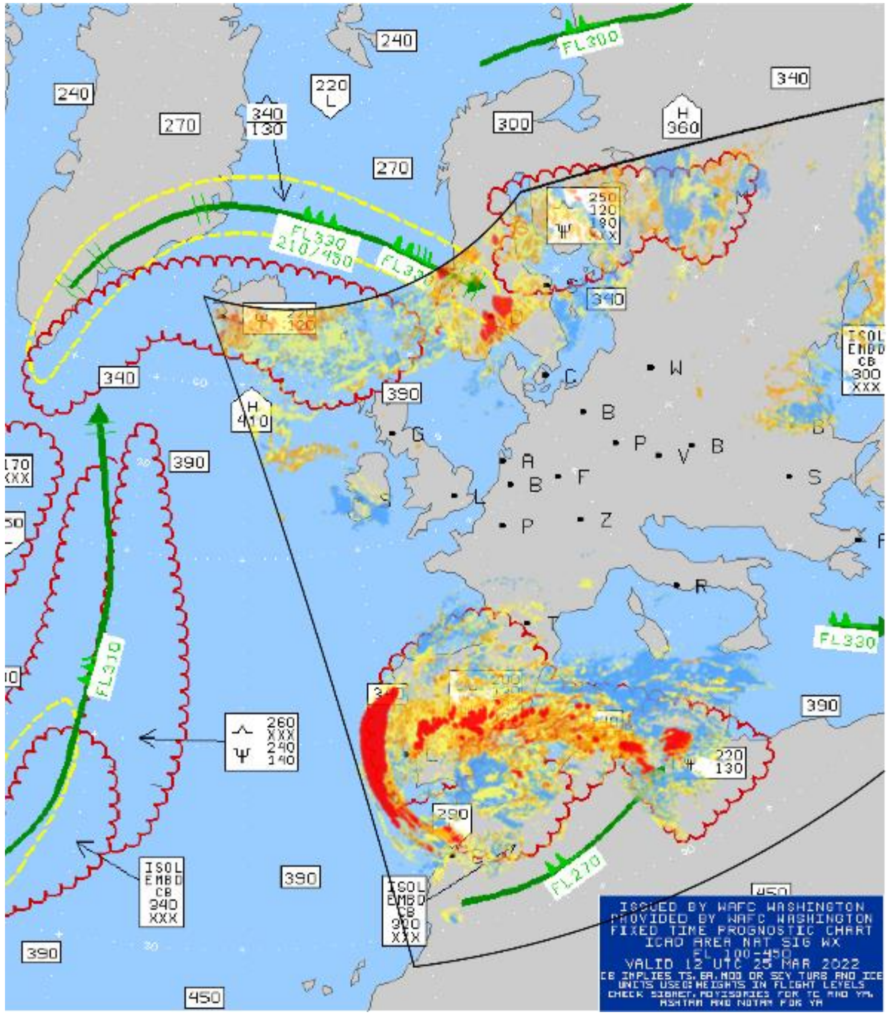


Remote Ice Detection

- CIRA enhanced and matured existing satellite data based icing detection algorithm to consider SLD icing conditions
- main factors: liquid water content (LWC), temperature, droplet size and cloud type



CIRA remote icing detection algorithm output for 31 MAR 2022 12:30 UTC



CIRA remote icing detection validation example (comparison with SIGWX chart)

WP2: Hybrid Ice Detection

Robust Hybrid Ice Detection:

different techniques for **direct sensing** of atmospheric conditions and/or ice accretion

\+

indirect techniques to detect change of aircraft characteristics with ice accretion on airframe

Development, test, validation and maturation of different technologies for

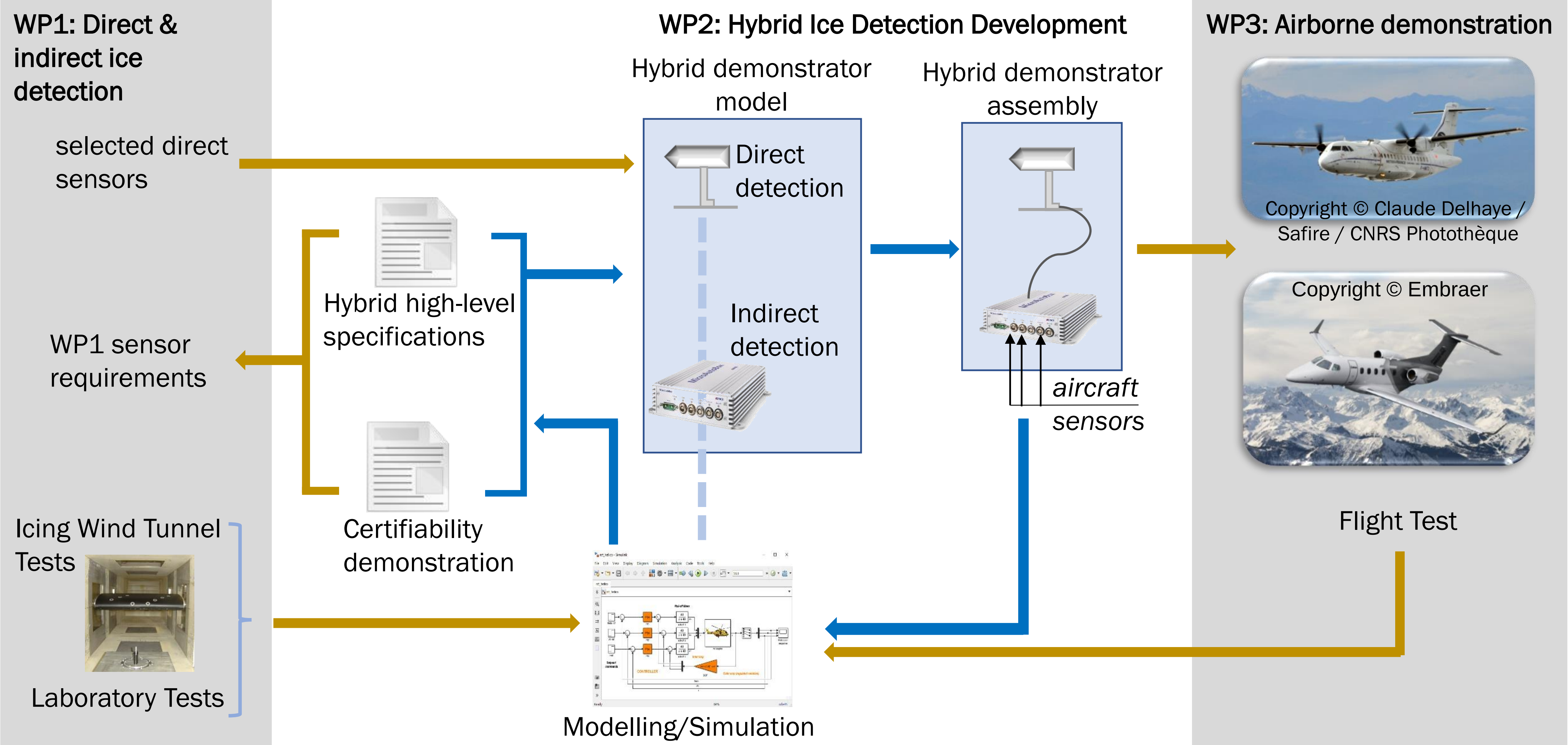
- direct ice detection
- indirect ice detection

Objectives for hybrid ice detection

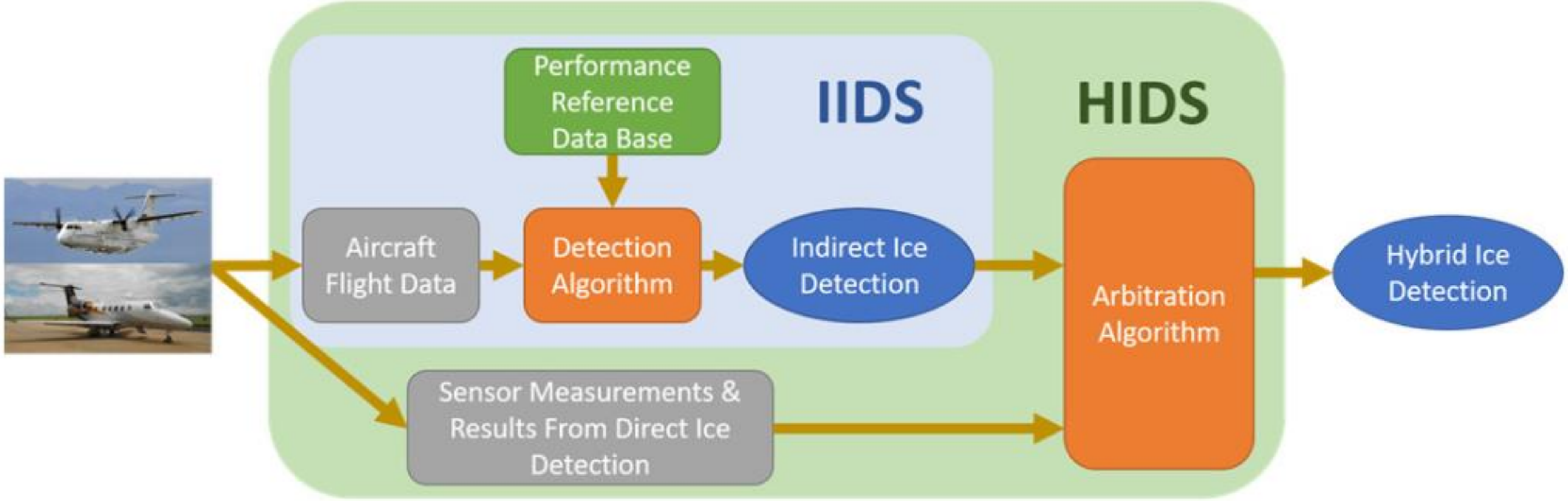
1. Hybrid ice detection system specification
2. Certification programme for hybrid ice detection system
3. Hybrid ice detection system modelling
4. Hybrid ice detection design, build & assembly (+ TRL 5 review)

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

WP2: Hybrid Ice Detection – Development Workflow



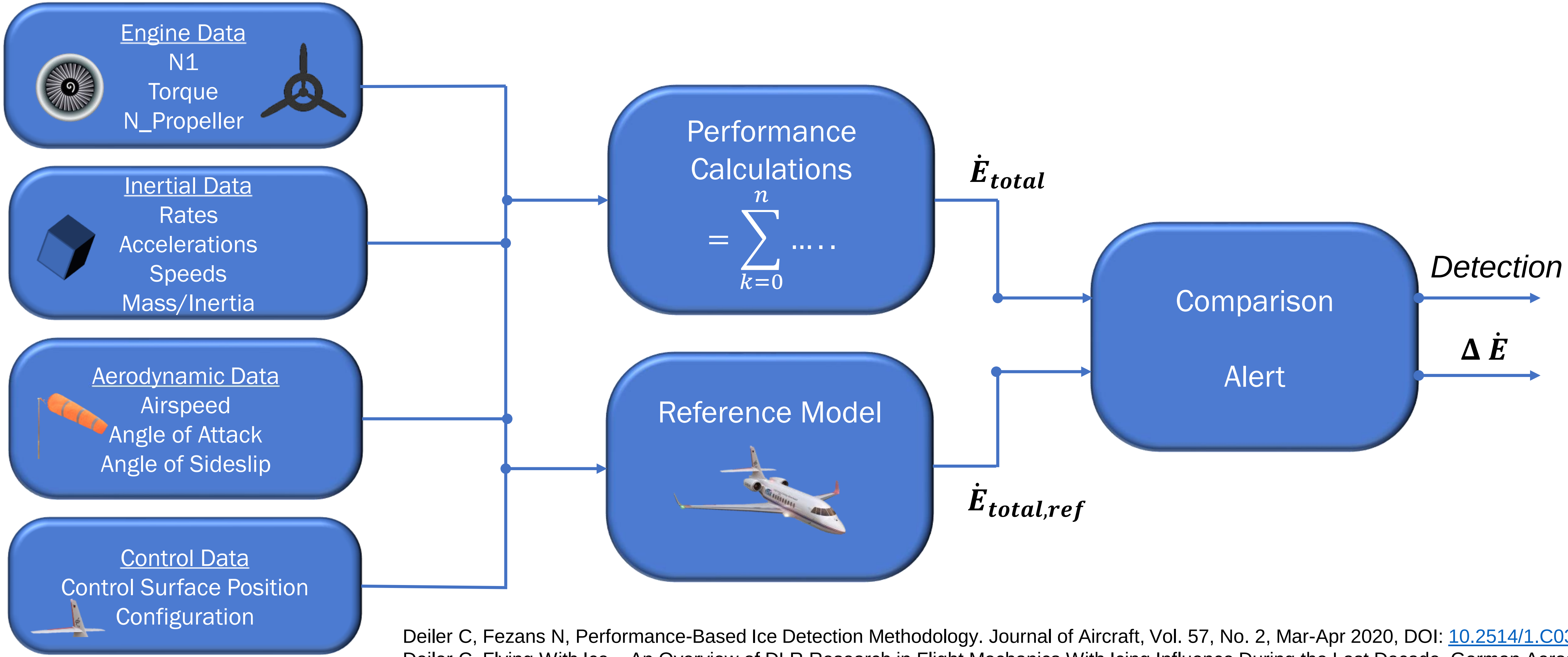
Hybrid Ice Detection System (HIDS) concept including Indirect Ice Detection System (IIDS)



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.

Image Credit DLR/EMBRAER/SAFIRE

DLR's Indirect Ice Detection – based on aircraft performance System Design



Deiler C, Fezans N, Performance-Based Ice Detection Methodology. Journal of Aircraft, Vol. 57, No. 2, Mar-Apr 2020, DOI: 10.2514/1.C034828
Deiler C, Flying With Ice – An Overview of DLR Research in Flight Mechanics With Icing Influence During the Last Decade. German Aerospace Conference DLRK 2021, Bremen and online, DOI: 10.25967/550008

Indirect Ice Detection – System Performance

Conflicting demands

Detection time ⟵ Trade-Off ⟶ **Detection accuracy/reliability**

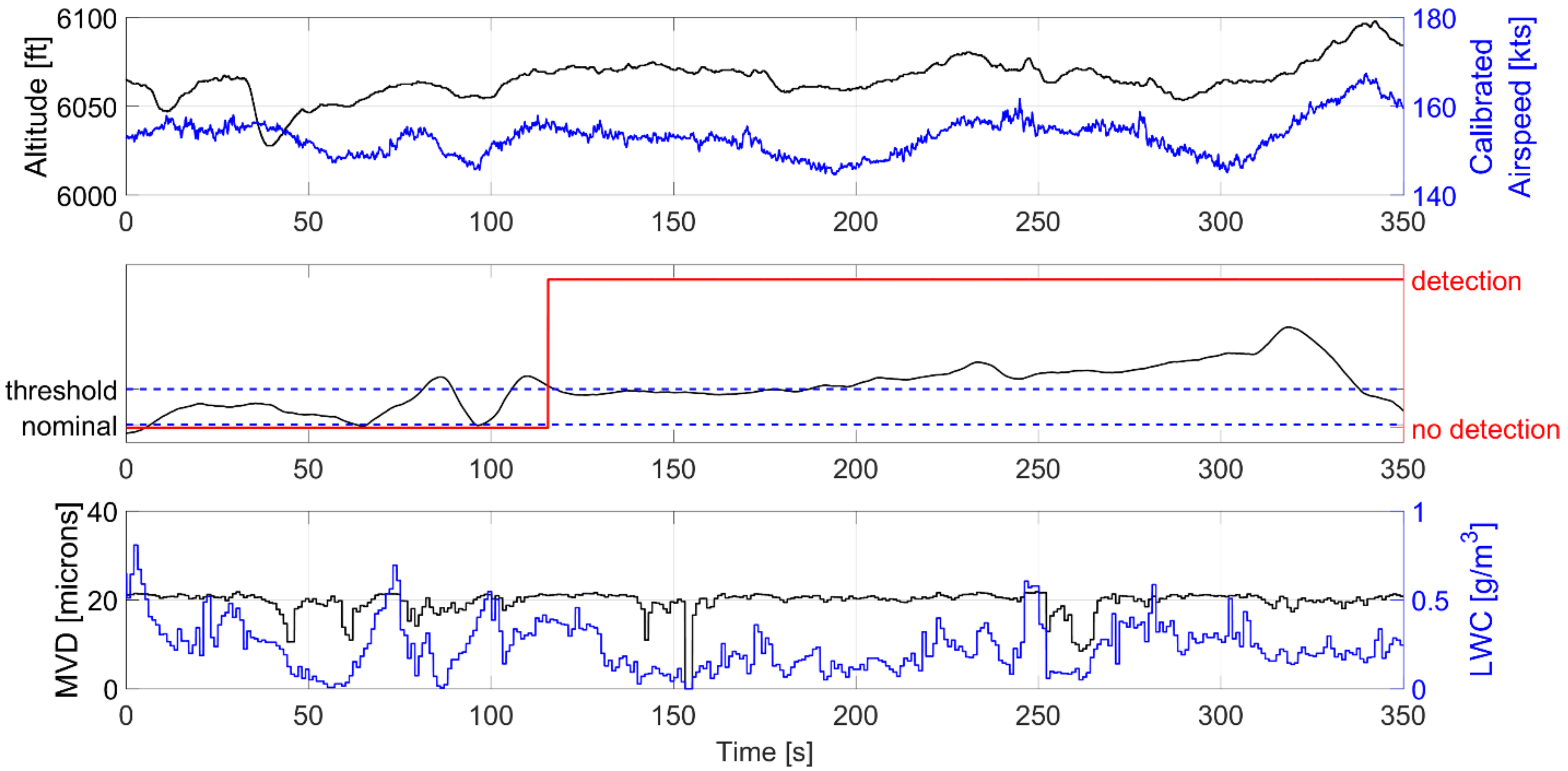
- Early detection information
- Enable early countermeasures
- Faster than any hazardous effects could occur

- 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 the French ATR 42 environmental research aircraft of Safire
  - 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

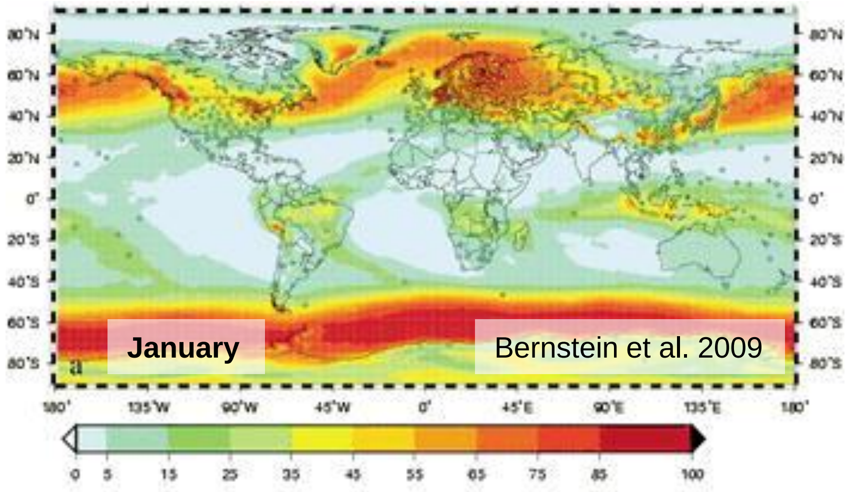
SENS4ICE Flight Campaigns

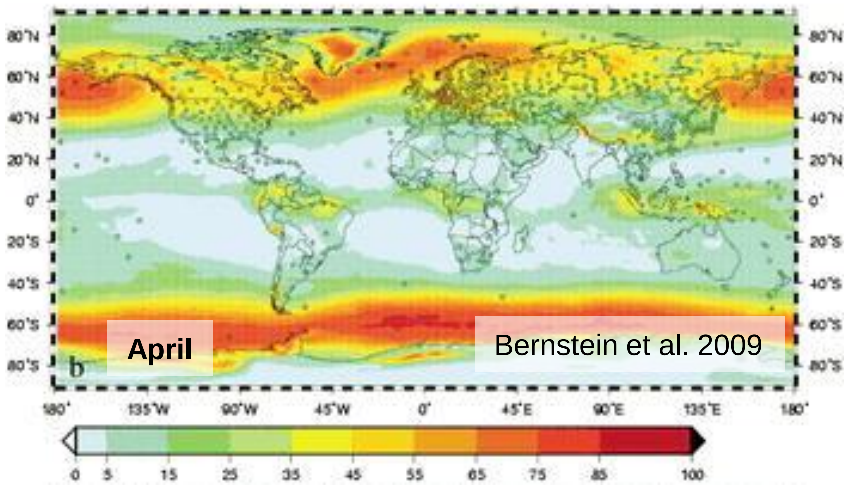
- Total flight test time: 75h in natural icing conditions
- North America
  - February/March 2023
  - Embraer Phenom 300 operated by Embraer
  - **15 flights** with a total of **25 flight hours** (including ferry and check flights) successfully conducted targeting natural liquid water icing conditions and in particular SLD conditions
- Europe
  - April 2023
  - French ATR 42 environmental research aircraft of Safire
  - **15 flights** with a total of **about 50 flight hours** successfully conducted targeting natural liquid water icing conditions and in particular SLD conditions

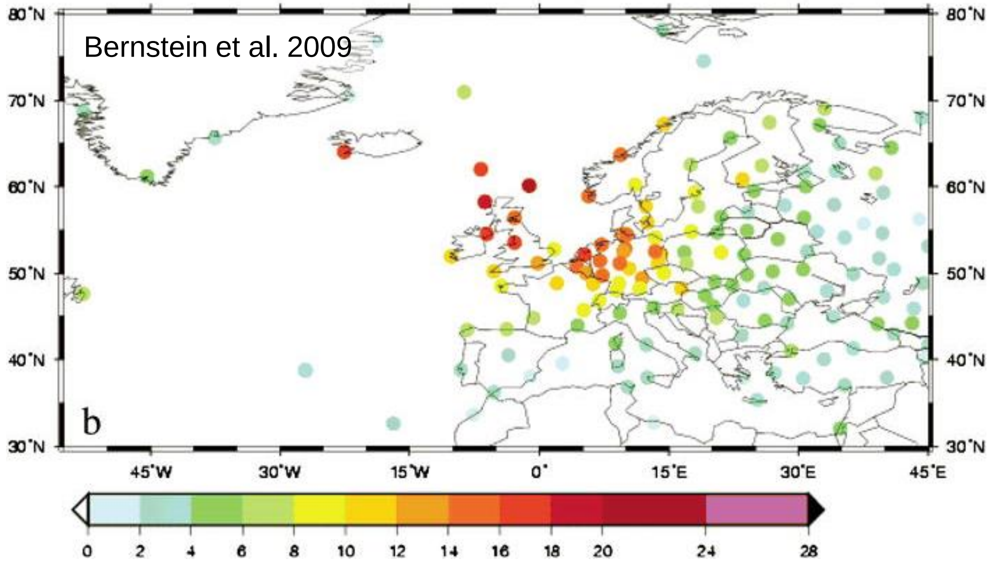
Embraer Phenom 300

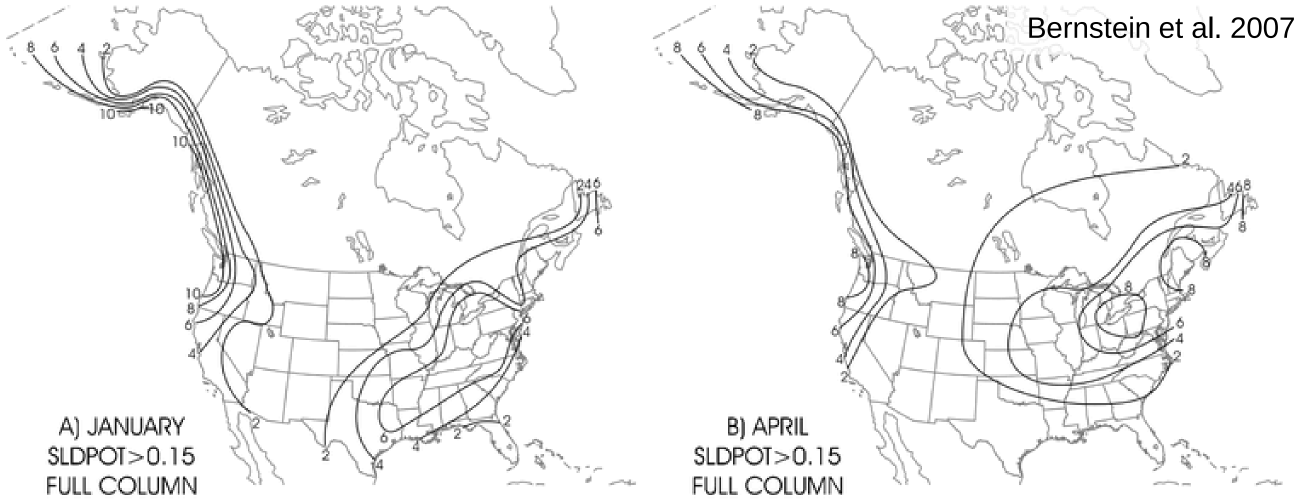
SAFIRE ATR 42

Icing Frequencies Analysis





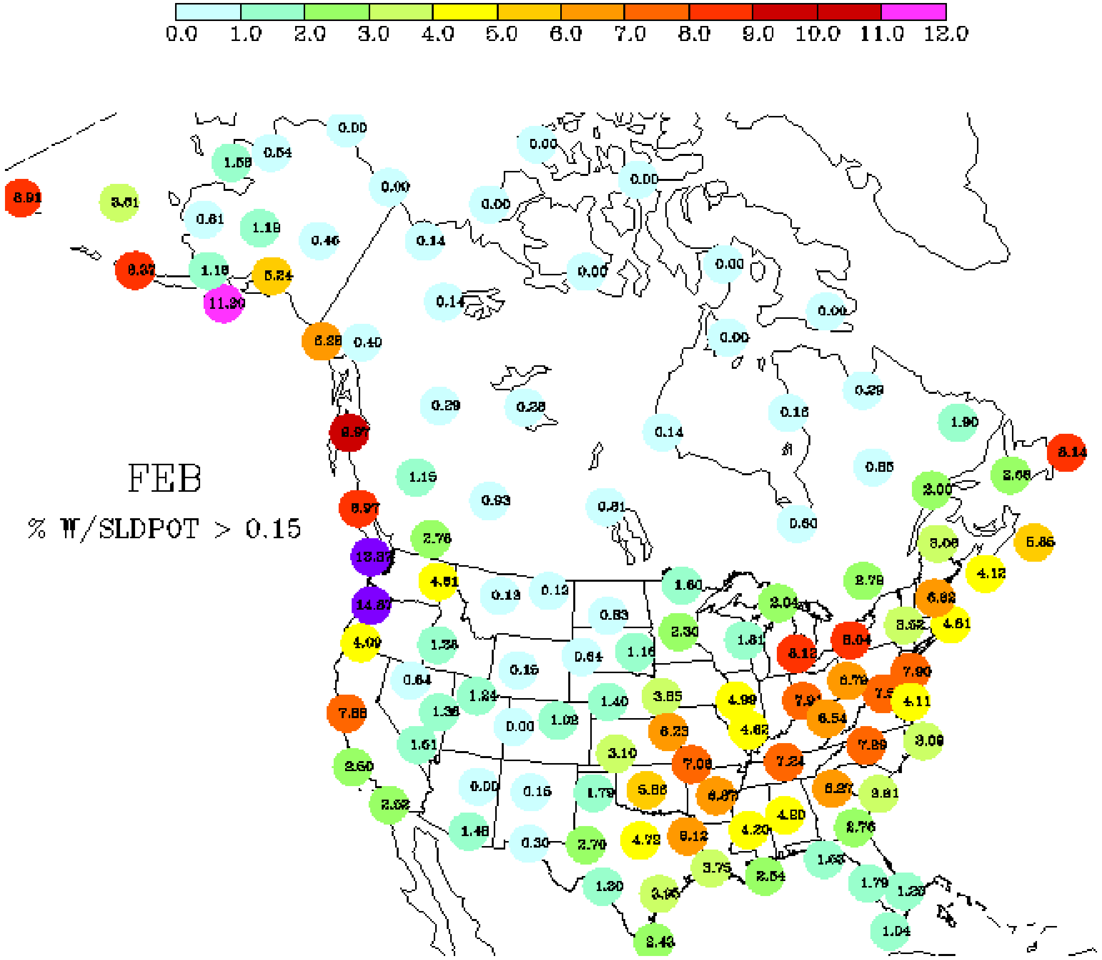


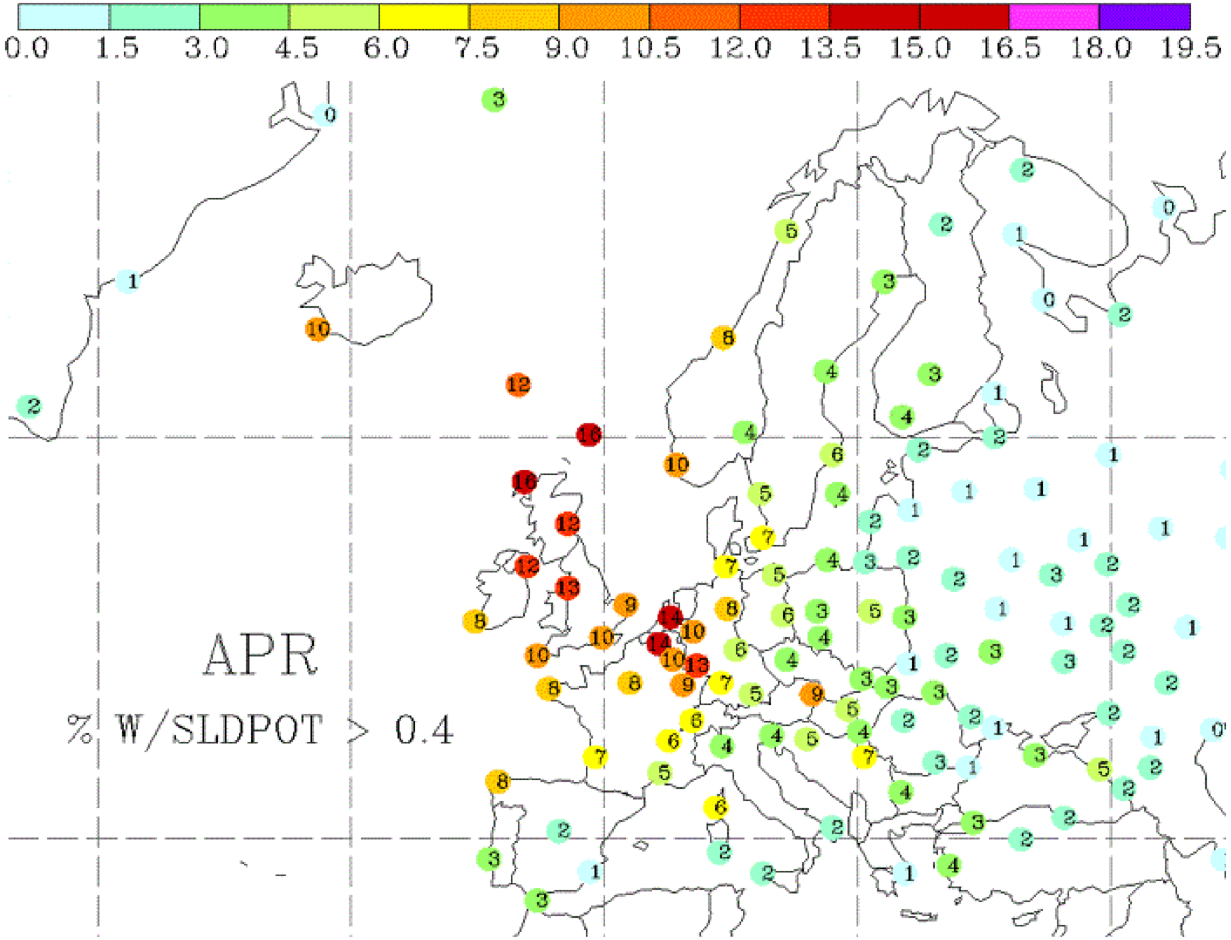


Bernstein et al. 2007: Bernstein, B. C., Wolff, C. A., & McDonough, F. (JAMC 2007). An Inferred Climatology of Icing Conditions Aloft, Including Supercooled Large Drops. Part I: Canada and the Continental United States. DOI: 10.1175/2007JAMC1607.1, **Bernstein et al. 2009**: Bernstein, B. C., & Le Bot, C. (JAMC 2009). An Inferred Climatology of Icing Conditions Aloft, Including Supercooled Large Drops. Part II: Europe, Asia, and the Globe, DOI: 10.1175/2009JAMC2073.1

Icing Frequencies Analysis

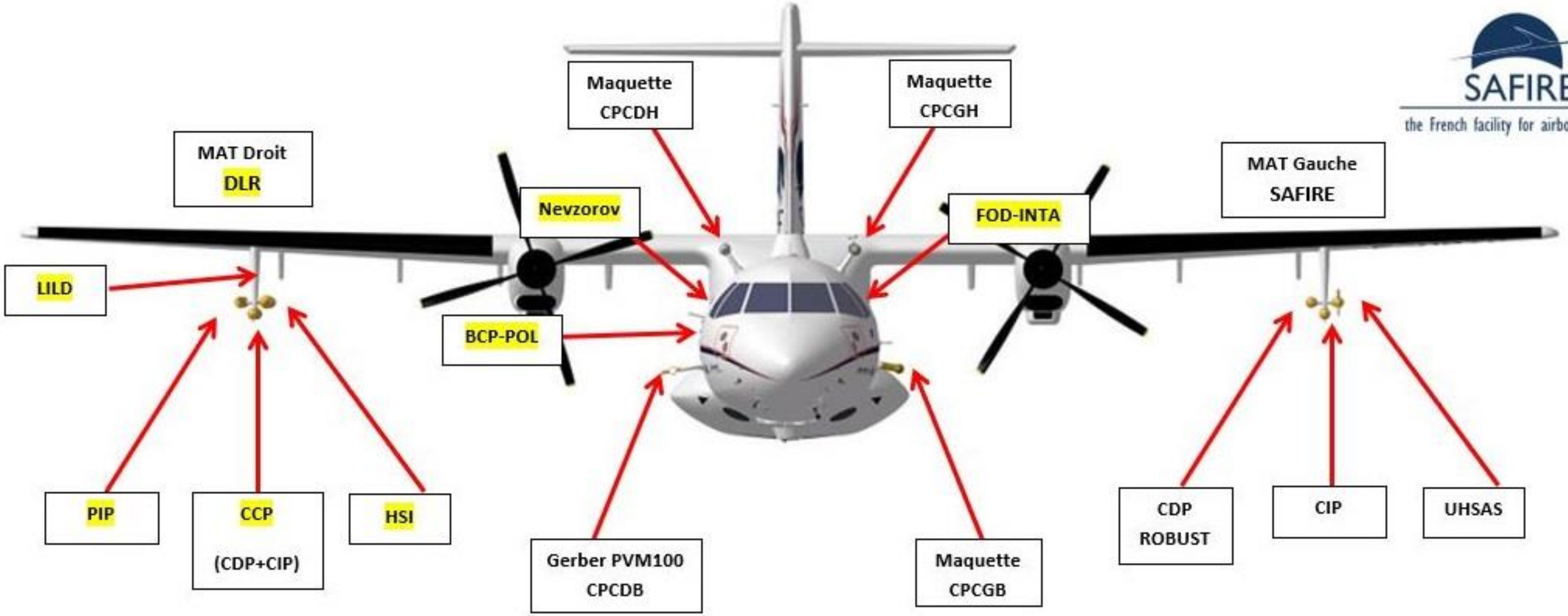
Full column frequencies of days with SLD potential [Ben Bernstein]





Data analysis process (SLD Potential "SLDPOT" calculated using "CIP-Sonde") based on: Bernstein, B. C., Wolff, C. A., & McDonough, F. (JAMC 2007). An Inferred Climatology of Icing Conditions Aloft, Including Supercooled Large Drops. Part I: Canada and the Continental United States. DOI: 10.1175/2007JAMC1607.1, Bernstein, B. C., & Le Bot, C. (JAMC 2009). An Inferred Climatology of Icing Conditions Aloft, Including Supercooled Large Drops. Part II: Europe, Asia, and the Globe, DOI: 10.1175/2009JAMC2073.1

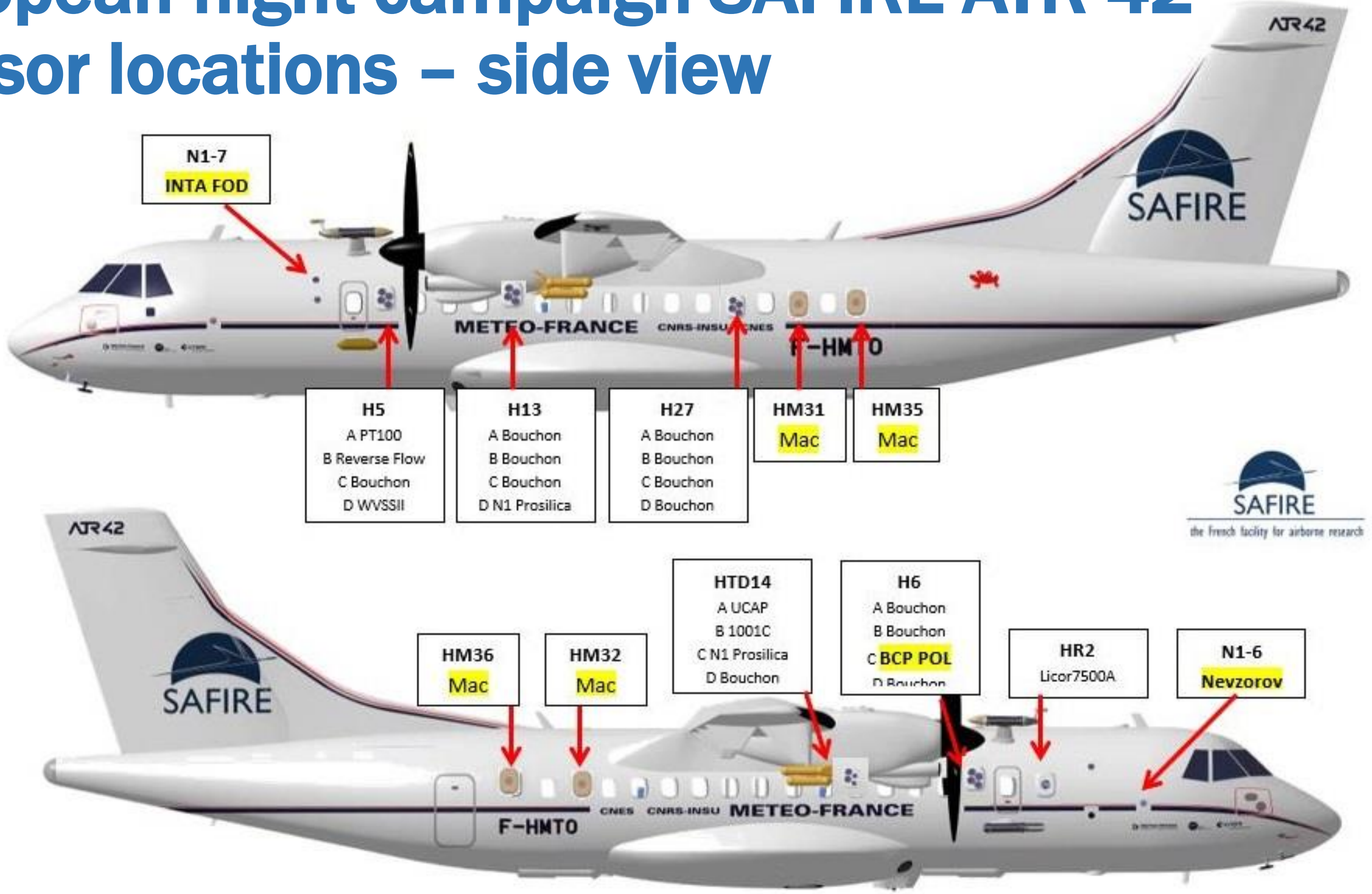
European flight campaign SAFIRE ATR 42
Sensor locations – front view



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

SENS4ICE Airborne Reference Instruments for Icing Atmosphere Characterisation

Nevzorov Probe installed on SAFIRE ATR 42

Precipitation Imaging Probe (PIP), Cloud Combination Probe (CCP) and High Speed Imager (HIS) installed on SAFIRE ATR 42

European flight campaign SAFIRE ATR 42 Sensor installations

- SENS4ICE ice detection technologies tested with SAFIRE ATR 42
  - **FOD** - Fiber Optic Detector (INTA)
  - **AMPERA** - Atmospheric Measurement of Potential and ElectRic field on Aircraft (ONERA)
  - **LILD** - Local Ice Layer Detector (DLR)
  - **CM2D** - Cloud Multi-Detection Device (DLR)
  - **HIDS** - Hybrid Ice Detection System (Safran)
  - **IIDS** - Indirect Ice Detection System (DLR)
- SAFIRE ATR 42 with test sensors and reference instruments

North America flight campaign Embraer Phenom 300

with sensors installed during the SENS4ICE flight test campaign in North America, February-March 2023

- SENS4ICE ice detection technologies tested with Embraer Phenom 300
  - AIP - Atmospheric Icing Patch (AeroTex)
  - PFIDS - Primary in-Flight Icing Detection System (Safran)
  - IDS - Ice Detection System (Collins)
  - SRP - Short Range Particulate (Honeywell)
  - HIDS - Hybrid Ice Detection System (Safran)
  - IIDS - Indirect Ice Detection System (DLR)

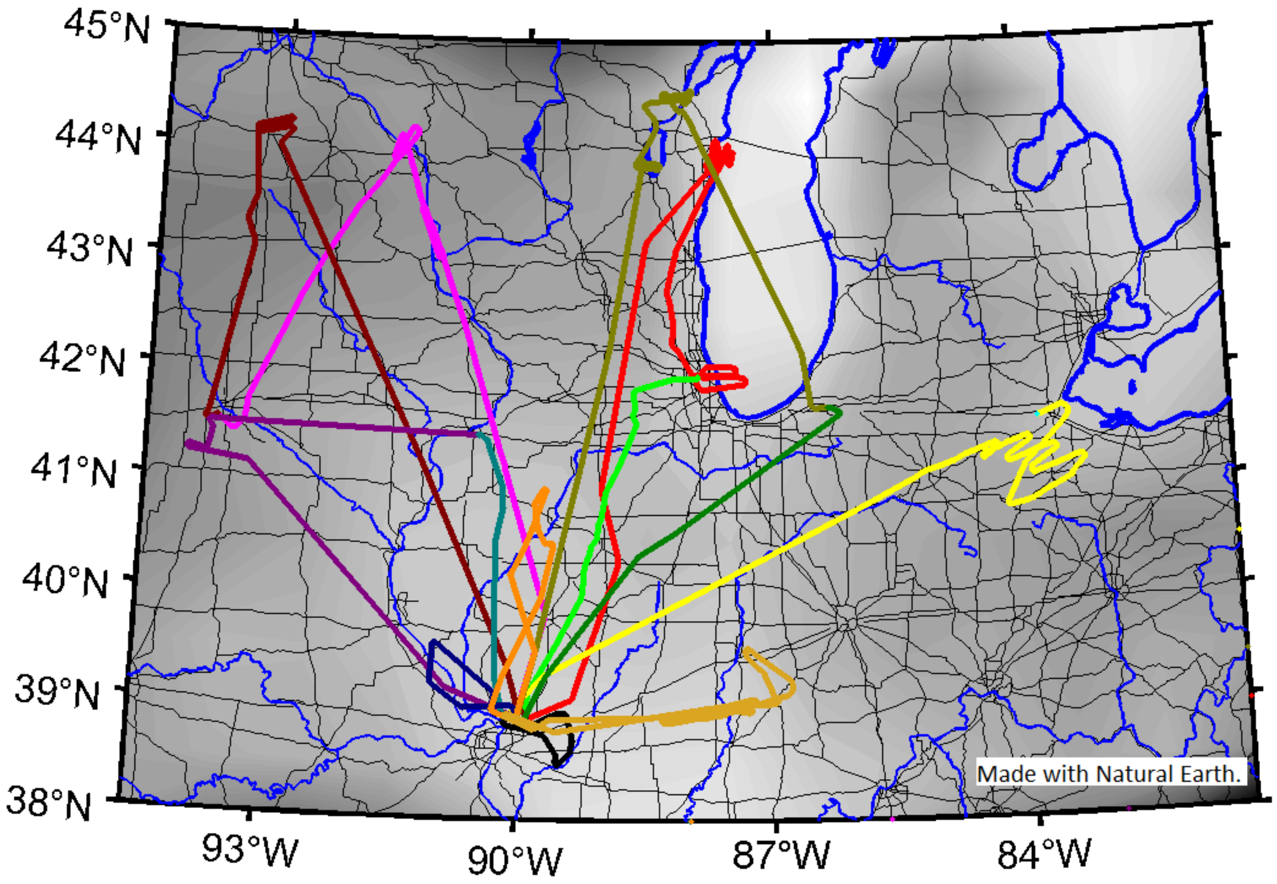
SENS4ICE Flight Campaign North America

- February/March 2023
- Embraer Phenom 300 operated by Embraer
- **15 flights** with a total of **25 flight hours** (including ferry and check flights) successfully conducted targeting natural liquid water icing conditions and in particular SLD conditions
- total of **55 encounters** with icing clouds flown, ranging from about 2 min to about 7 min duration
- the higher the LWC the lower the exposure time
- icing encounters intended to be relatively short for safety reasons
- preliminary analysis:
  about 20% of flight time in icing conditions
- initial detailed analysis: 264 min in icing conditions, 37 min Appendix O conditions

No	Date	Flight duration [hrs]	Comment
1	22 FEB 2023	0:39	Check flight
2	23 FEB 2023	2:45	Appendix O
3	23 FEB 2023	1:12	Appendix C
4	25 FEB 2023	2:03	Appendix O
5	25 FEB 2023	1:37	Appendix C
6	01 MAR 2023	2:45	Appendix O
7	01 MAR 2023	2:12	Appendix O
8	06 MAR 2023	1:07	Appendix C
9	06 MAR 2023	-	Dry Air
10	08 MAR 2023	2:21	Appendix O
11	08 MAR 2023	0:40	Return to base
12	08 MAR 2023	-	Check flight
13	09 MAR 2023	1:23	Appendix C
14	10 MAR 2023	2:15	Appendix O
15	10 MAR 2023	1:08	Appendix C

SENS4ICE Flight Campaign North America Ground Tracks

- Aircraft located in Alton, Illinois, along the border between Illinois and Missouri
- Operating in regions of flat terrain to the west and south of the Great Lakes



SENS4ICE Flight Campaign North America

- Ice accreted on windshield after leaving clouds with supercooled liquid water

Image Credit Embraer

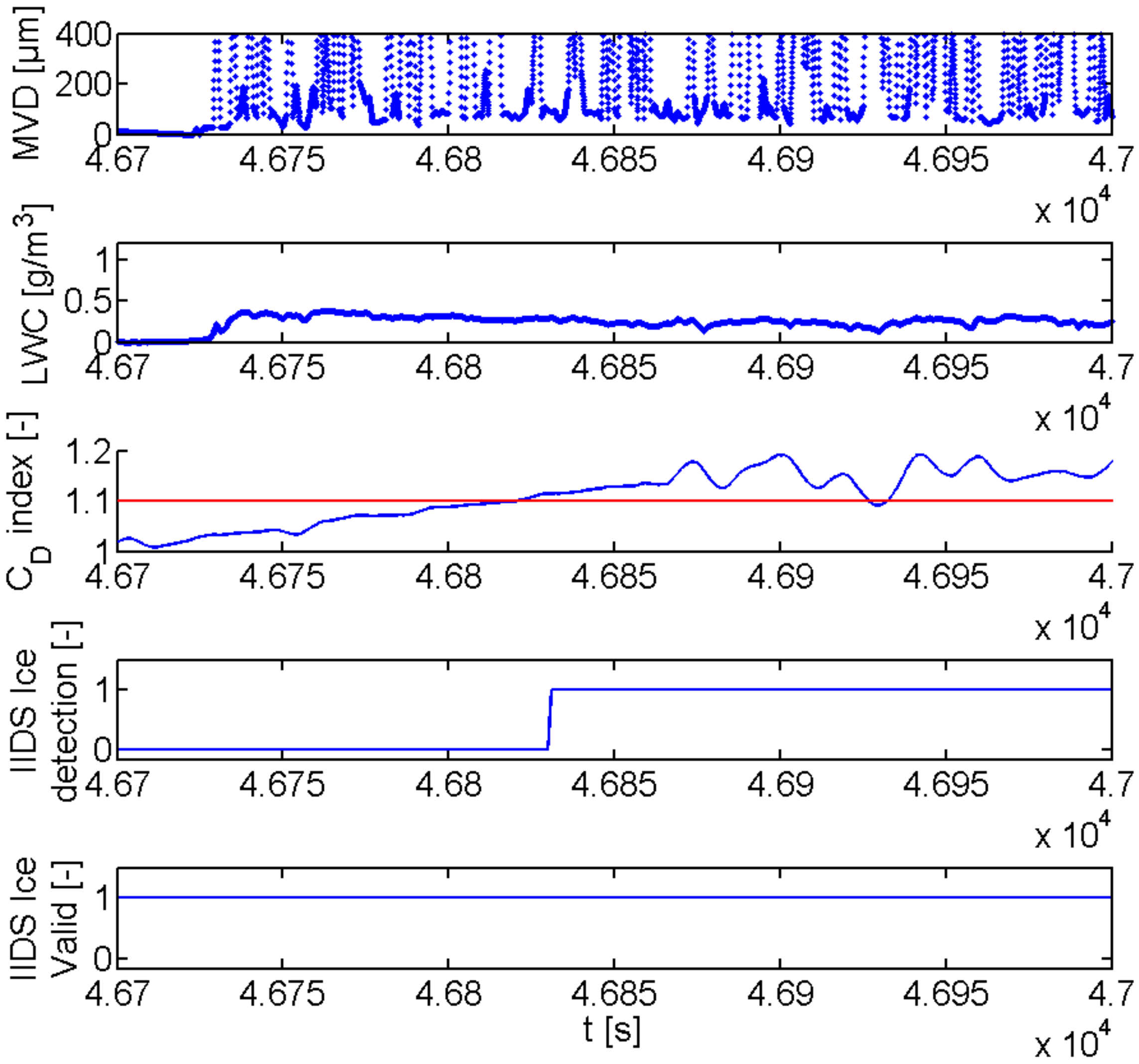
SENS4ICE Flight Campaign North America

- Ice accretion on windshield during SLD cloud encounter

time-lapse video - Credit Embraer

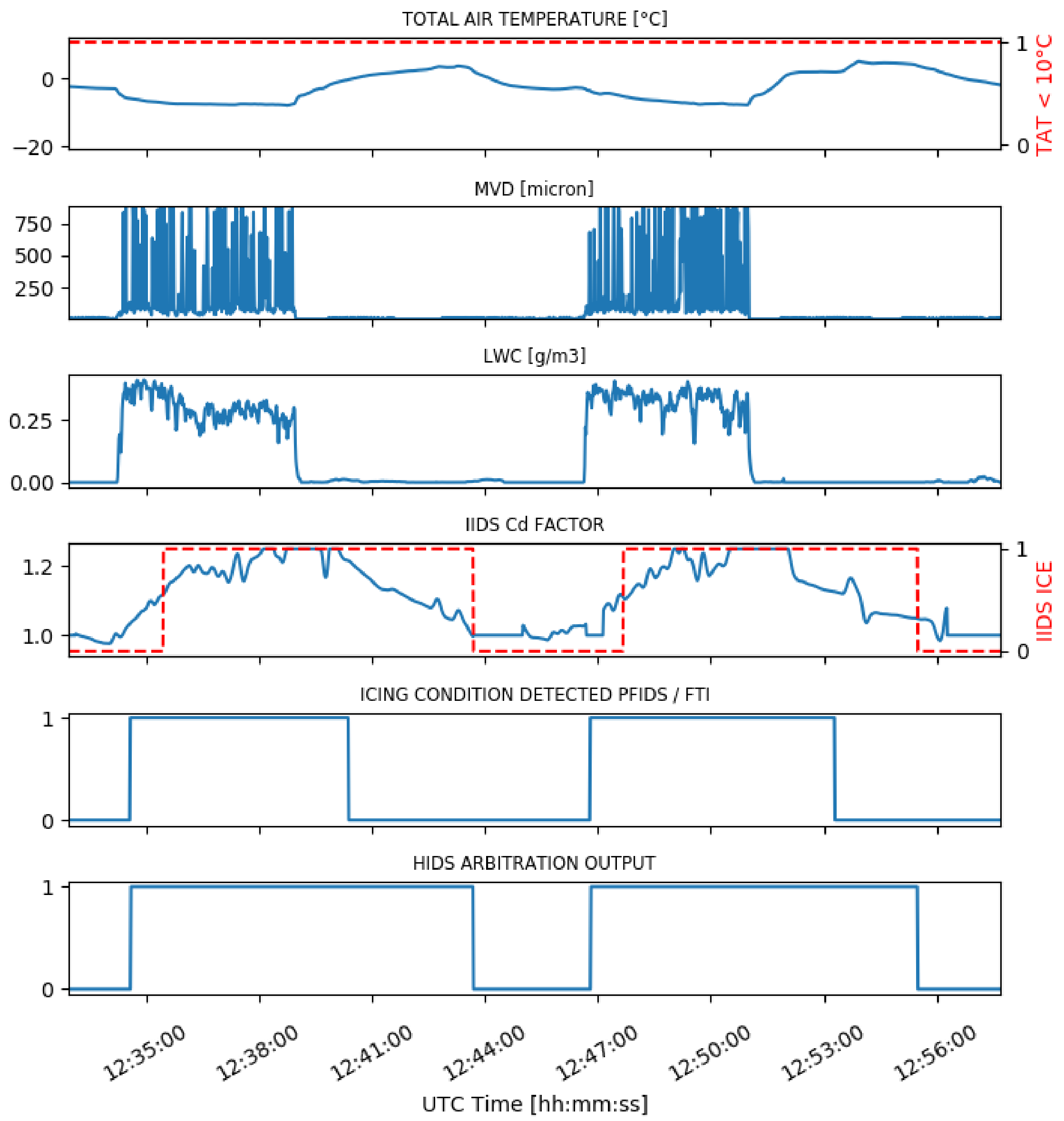
SENS4ICE Flight Campaign North America
Indirect Ice Detection

- IIDS (Indirect Ice Detection System) flight test 25 Feb 2023 outcome example based on preliminary analysis and compared to preliminary results for MVD and LWC



SENS4ICE Flight Campaign North America Hybrid Ice Detection

- HIDS (Hybrid Ice Detection System), including IIDS (Indirect Ice Detection System), flight test 25 Feb 2023 outcome example based on preliminary analysis and compared to preliminary results for MVD and LWC



SENS4ICE Flight Campaign Europe

SENS4ICE Flight No	Safire Flight ID	Date	Takeoff (UTC)	Landing (UTC)
1	as230009	2023-04-03	2023-04-03 at 06:08:24 in Francazal	2023-04-03 at 09:37:52 in Francazal
2	as230010	2023-04-04	2023-04-04 at 11:38:45 in Francazal	2023-04-04 at 12:53:28 in Hyeres
3	as230011	2023-04-04	2023-04-04 at 13:11:38 in Hyeres	2023-04-04 at 14:30:24 in Francazal
4	as230012	2023-04-06	2023-04-06 at 07:14:08 in Francazal	2023-04-06 at 07:40:33 in Francazal
5	as230013	2023-04-14	2023-04-14 at 04:36:47 in Francazal	2023-04-14 at 09:29:43 in Francazal
6	as230014	2023-04-15	2023-04-15 at 06:03:41 in Francazal	2023-04-15 at 08:19:53 in Francazal
7	as230015	2023-04-18	2023-04-18 at 13:56:21 in Francazal	2023-04-18 at 17:05:24 in Francazal
8	as230016	2023-04-20	2023-04-20 at 10:40:09 in Francazal	2023-04-20 at 13:20:12 in Francazal
9	as230017	2023-04-22	2023-04-22 at 06:03:10 in Blagnac	2023-04-22 at 08:52:02 in Blagnac
10	as230018	2023-04-24	2023-04-24 at 12:22:37 in Francazal	2023-04-24 at 16:52:22 in Francazal
11	as230019	2023-04-25	2023-04-25 at 11:03:45 in Francazal	2023-04-25 at 15:54:11 in Francazal
12	as230020	2023-04-26	2023-04-26 at 06:30:55 in Francazal	2023-04-26 at 08:54:07 in Francazal
13	as230021	2023-04-26	2023-04-26 at 13:34:05 in Francazal	2023-04-26 at 17:08:11 in Francazal
14	as230022	2023-04-27	2023-04-27 at 06:33:18 in Francazal	2023-04-27 at 09:58:29 in Francazal
15	as230023	2023-04-27	2023-04-27 at 12:07:20 in Francazal	2023-04-27 at 15:46:36 in Francazal

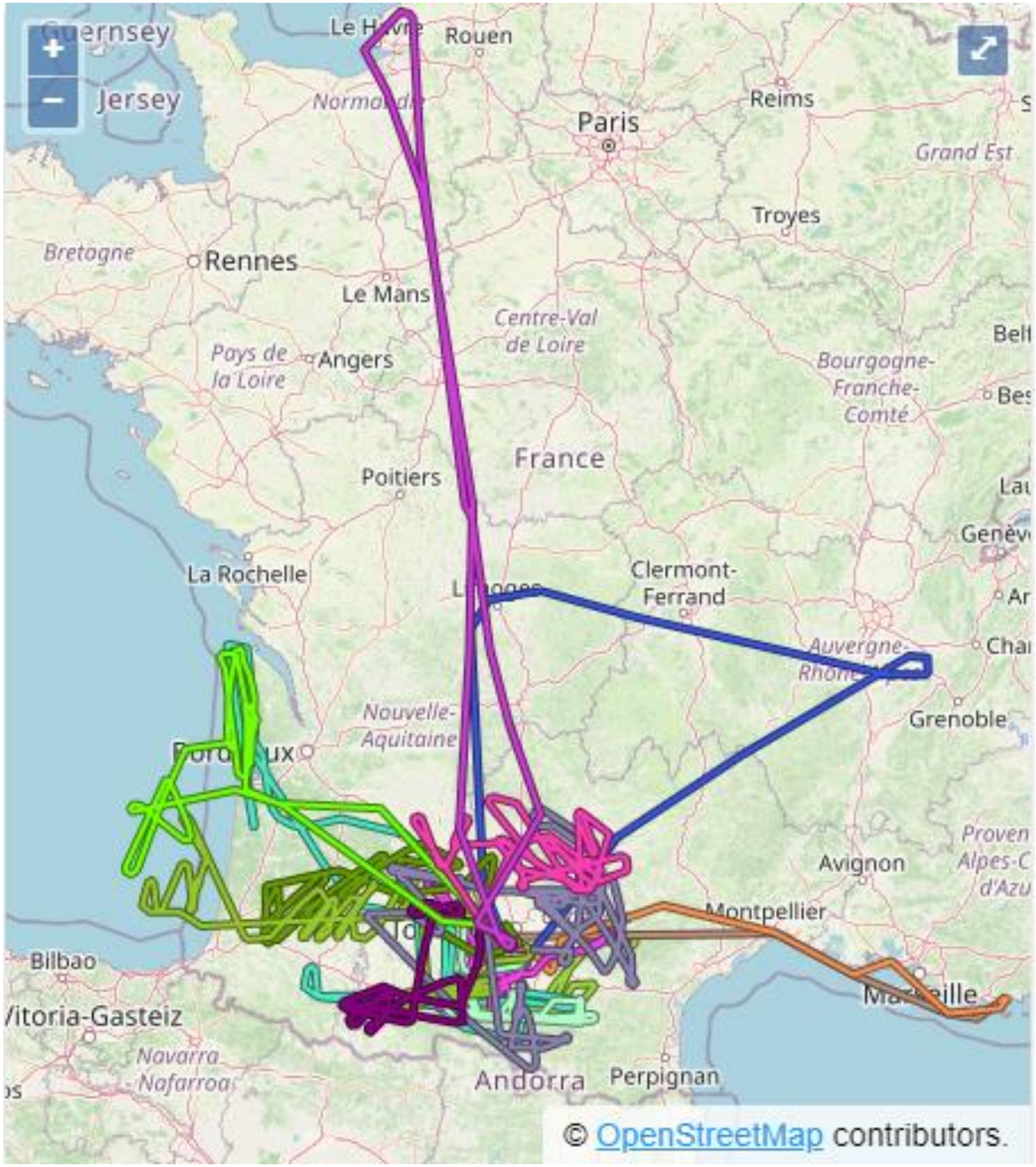
- based on public Safire website https://safireplus.aeris-data.fr/data-access

Airborne data was obtained using the aircraft managed by Safire, the French facility for airborne research, an infrastructure of the French National Center for Scientific Research (CNRS), Météo-France and the French National Center for Space Studies (CNES). Distributed data are processed by SAFIRE.

SENS4ICE Flight Campaign Europe
Ground Tracks

- April 2023
- French ATR 42 environmental research aircraft of Safire
- **15 flights** with a total of **about 50 flight hours** successfully conducted targeting natural liquid water icing conditions and in particular SLD conditions

- Source: https://safireplus.aeris-data.fr/data-access
- Airborne data was obtained using the aircraft managed by Safire, the French facility for airborne research, an infrastructure of the French National Center for Scientific Research (CNRS), Météo-France and the French National Center for Space Studies (CNES). Distributed data are processed by SAFIRE.
- Map Data From OpenStreetMap https://www.openstreetmap.org/copyright/en licensed under the Open Database License



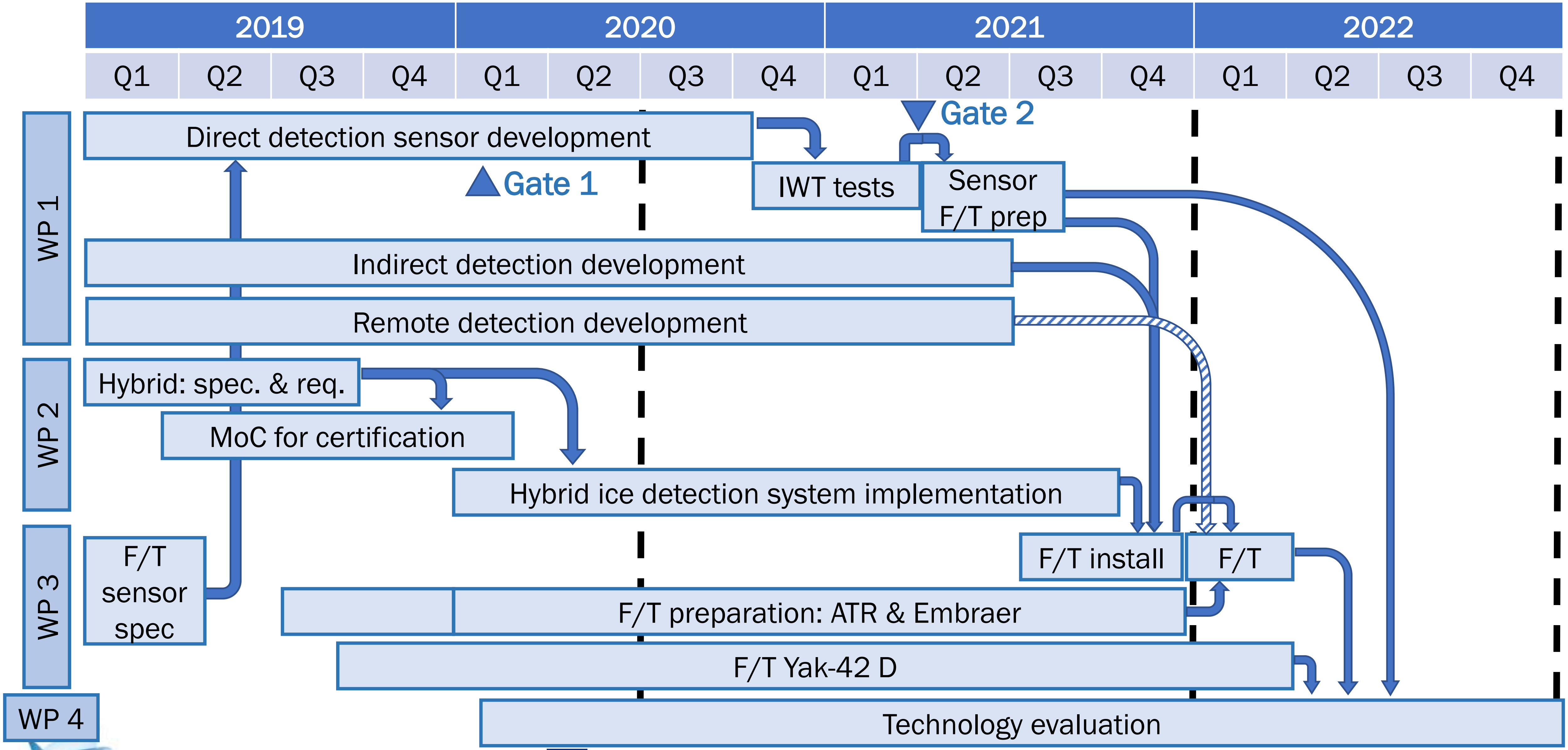
SENS4ICE Flight Campaign Europe

- SAFIRE ATR 42 horizontal tail with ice accretion [image DLR]

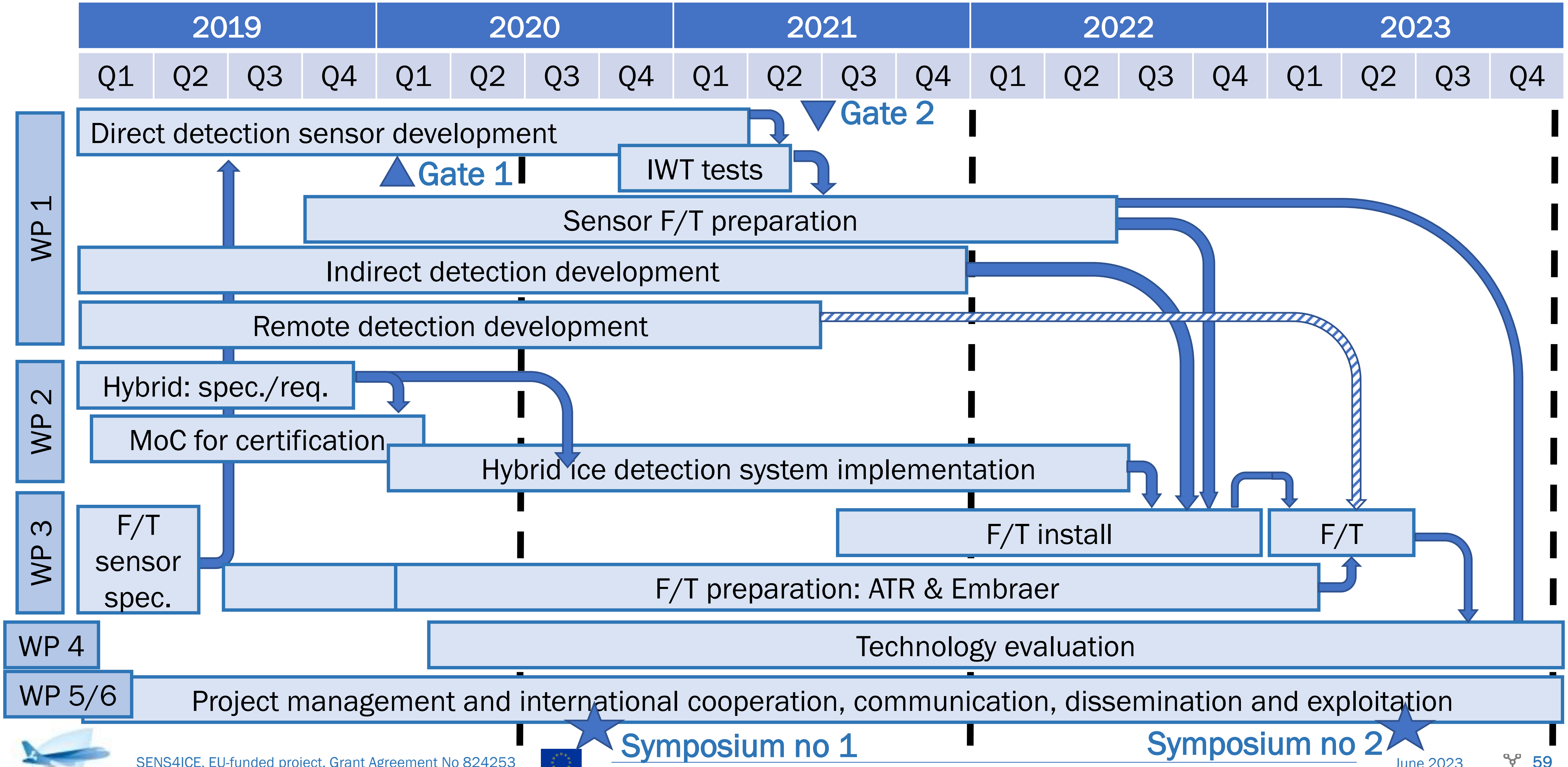
Summary

- EU project SENS4ICE: increase flight safety in icing / especially SLD conditions and enhance knowledge base for Appendix O conditions
- Icing detection technologies developed specifically aiming at Appendix O icing conditions
- Icing wind tunnels enhanced capabilities for representing Appendix O conditions
- Direct ice detection sensors tested successfully in icing wind tunnels under both Appendix O and Appendix C conditions
- Hybrid ice detection system under development, incorporating a performance-based indirect ice detection system
- Two flight campaigns successfully conducted early 2023
  - test ice detection technologies under natural icing conditions
  - focus on Appendix O
  - promising initial results: encountered icing conditions, sensor detection behavior and hybrid ice detection system performance including indirect ice detection system

SENS4ICE Timescale (simplified Gantt – original/ 4 years)



SENS4ICE Timescale (simplified Gantt – extended/ 5 years)



SENS4ICE Final Public Dissemination Event

- 29th of November 2023
- Brussels, Belgium
- Further details will be provided via
  - https://www.sens4ice-project.eu
  - https://www.linkedin.com/company/sens4ice-project

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

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

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