

# The SENS4ICE EU project – SENSors and certifiable hybrid architectures for safer aviation in ICing Environment – Project Overview and Initial Results ICAS PAPER 2022\_0794



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DLR (German Aerospace Center) - Institute of Flight Systems



# SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES  
FOR SAFER AVIATION IN ICING ENVIRONMENT

## **The SENS4ICE EU project – SENSors and certifiable hybrid architectures for safer aviation in ICing Environment**

### Project Overview and Initial Results

Carsten Schwarz – DLR Institute of Flight Systems

33rd Congress of the International Council of the Aeronautical Sciences (ICAS 2022)

4-9 Sep 2022, Stockholm, Sweden

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

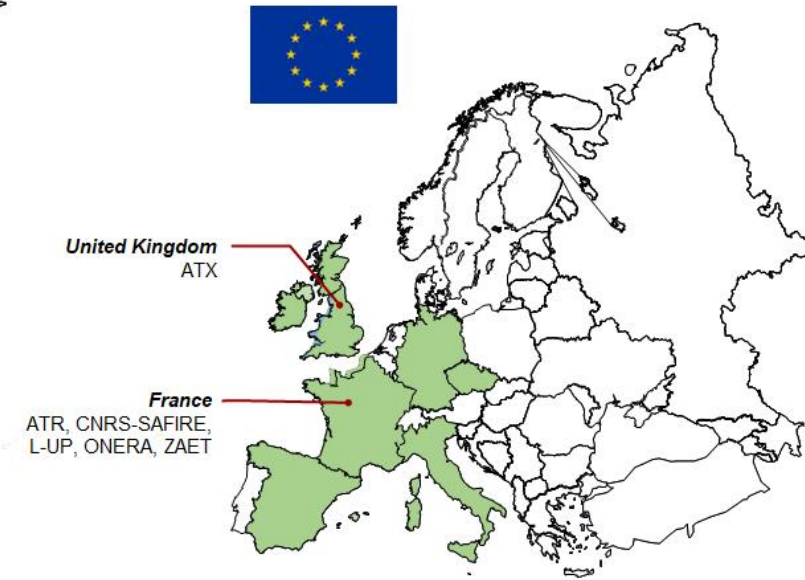


National Research Council Canada

Conseil national de recherches 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





# 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. 0)
    - 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



# Expected impact

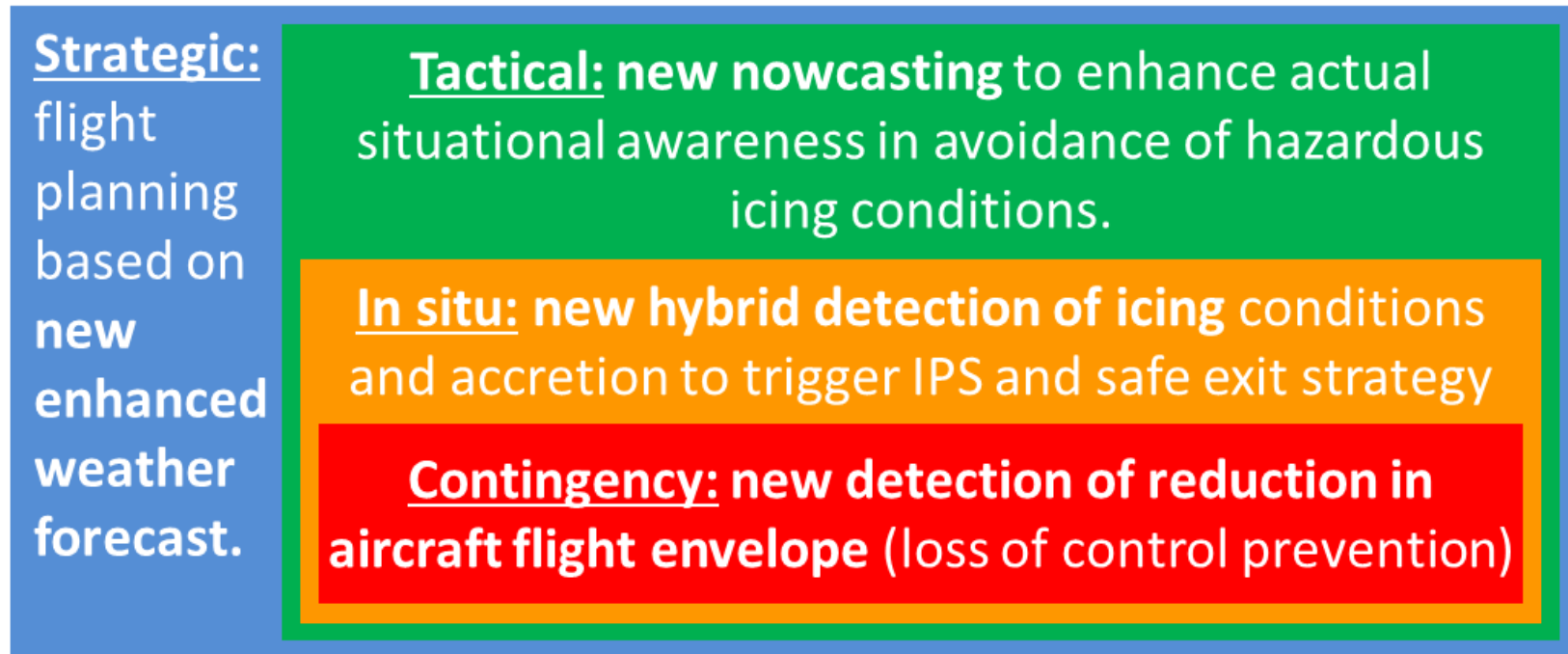
- 💧 Contribute to **increased flight safety**  
by fewer accidents and less in-flight events worldwide
- 💧 Contribute to **reduce costs** for all stakeholders  
by improved and internationally accepted certification rules, standards and means of compliance, covering all types of icing hazards
- 💧 Contribute 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. 0 SLD conditions with a unique layered safety approach:

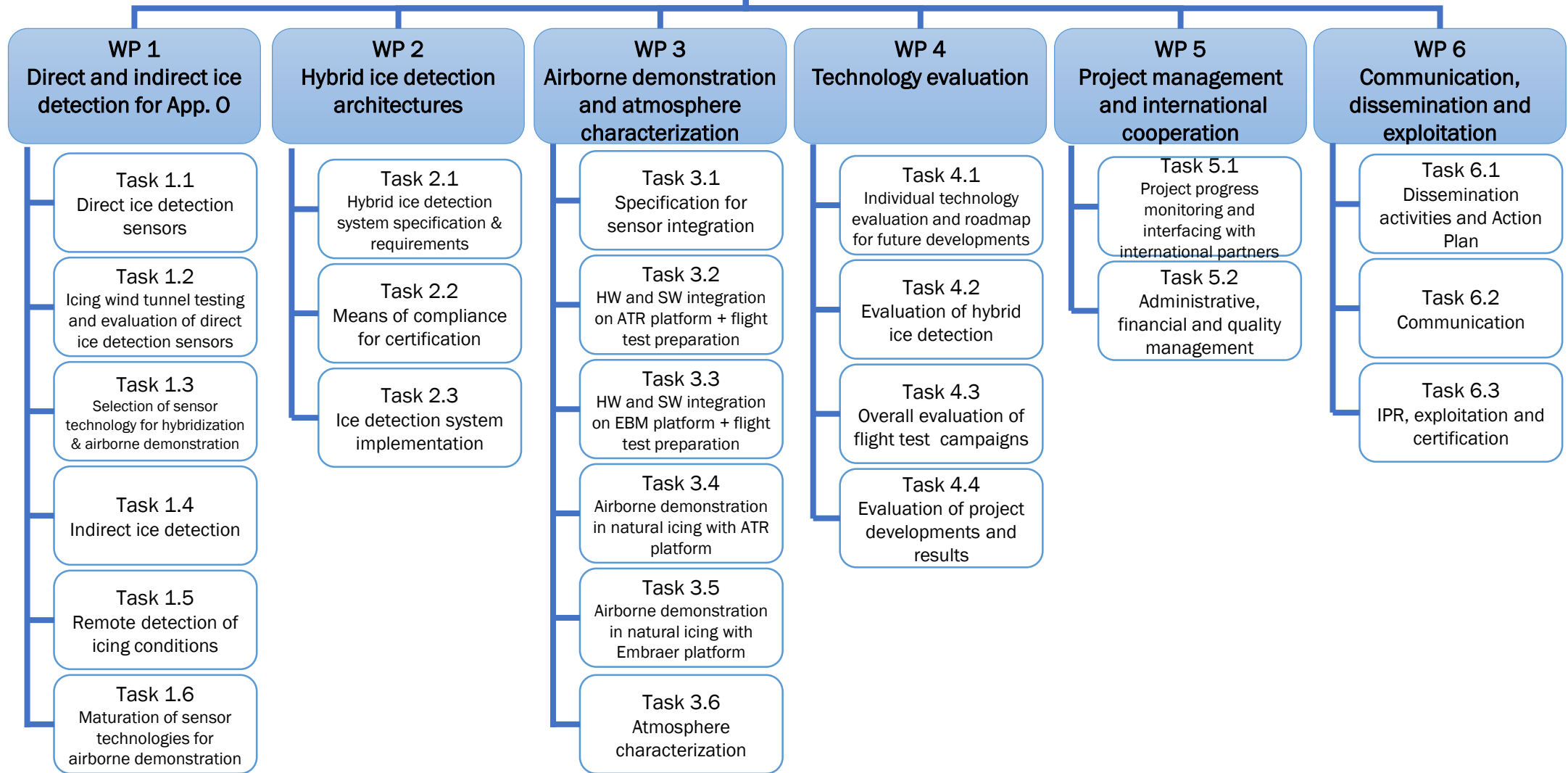


→ Hybrid ice detection is central technology and key to this approach

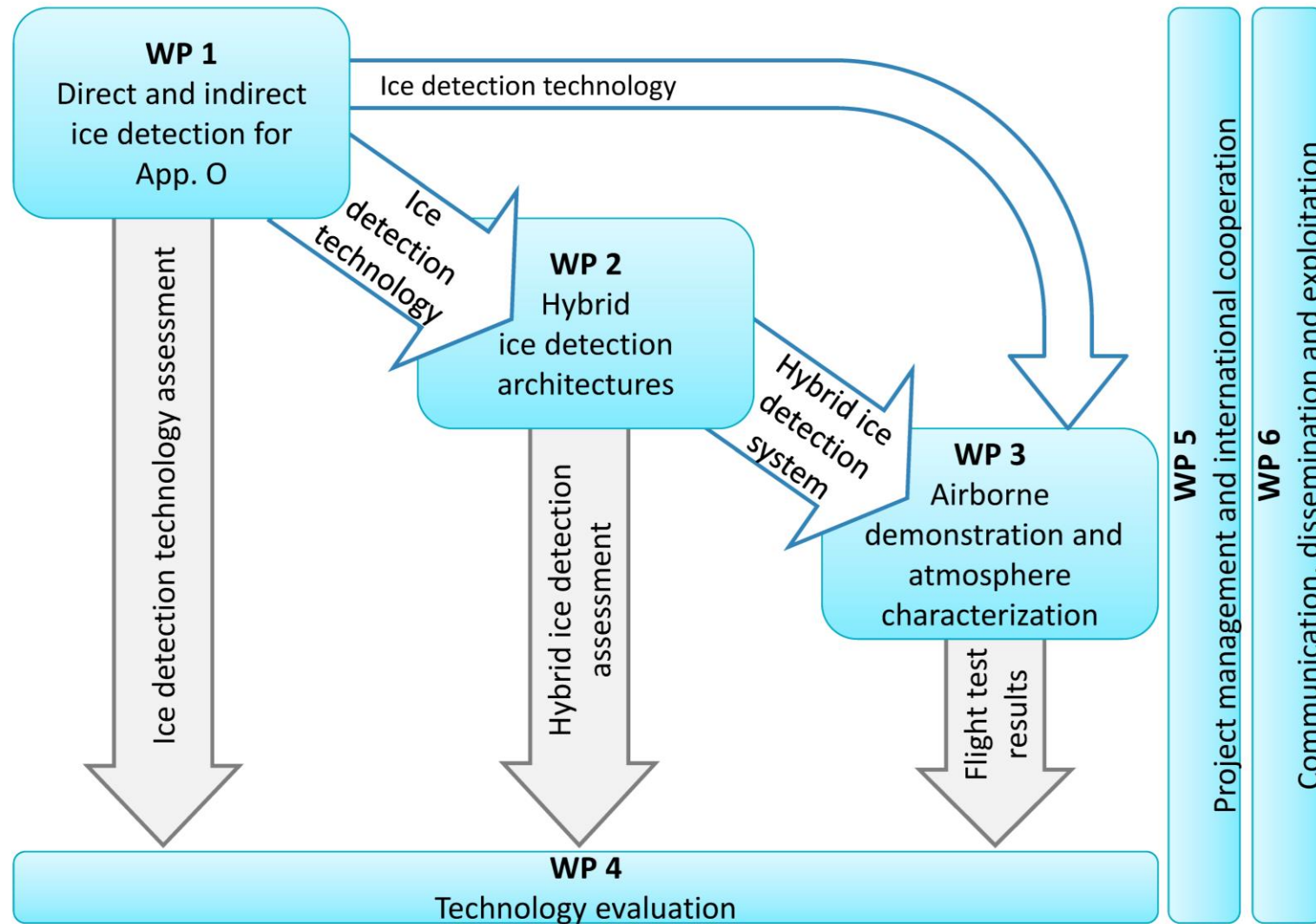


# SENSors and certifiable hybrid architectures for safer aviation in ICing Environment

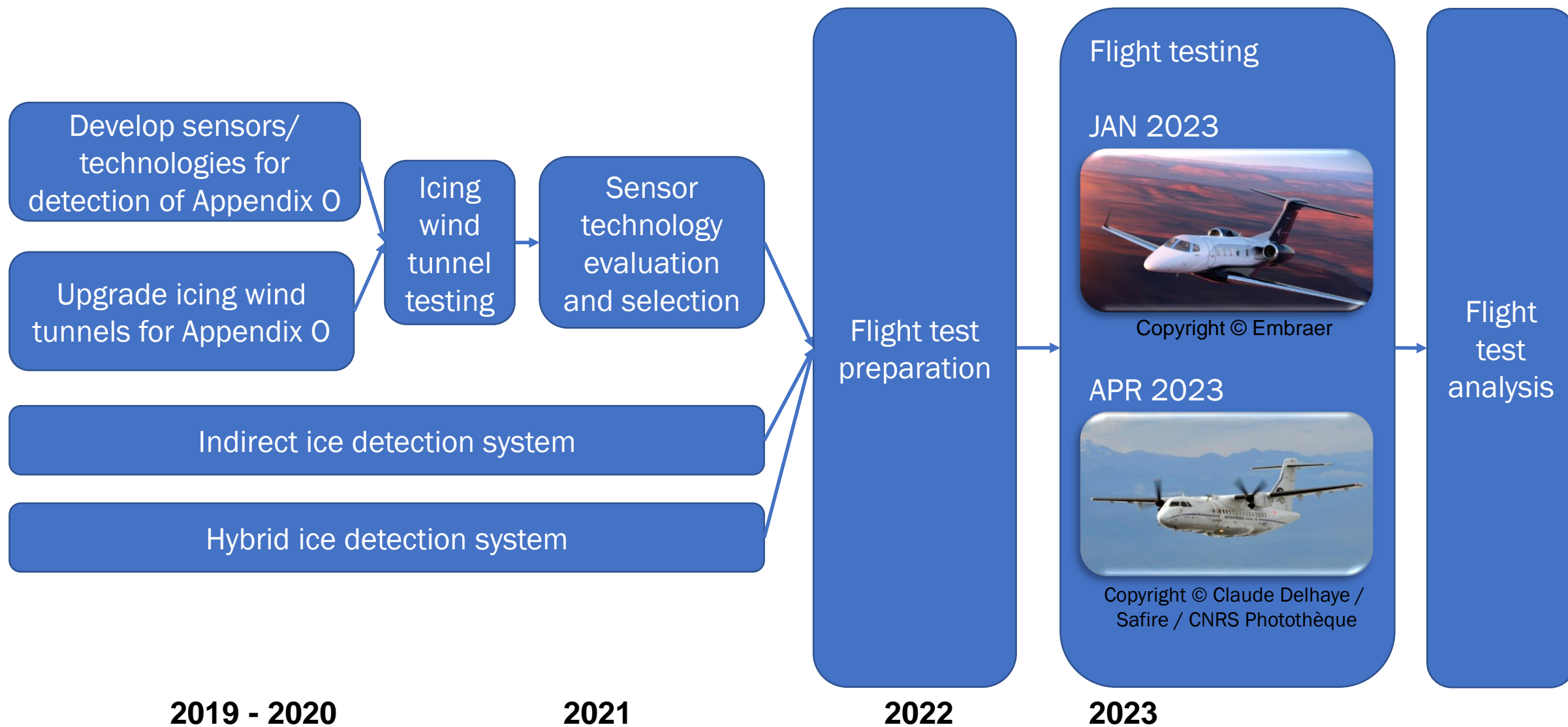
## SENS4ICE



# Technical Work Packages Interrelation



# SENS4ICE Timeline – focus flight testing



# WP1: Direct and indirect ice detection for App. 0

## High Level Objectives

Main Objective: Develop technologies capable of detecting App. 0 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. 0 conditions – four tunnel facilities/total of 28 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. 0 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. 0 conditions
  - 💧 Polarimetric weather radar: development of algorithms to classify icing threats and identify App. 0 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	Atmospheric	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





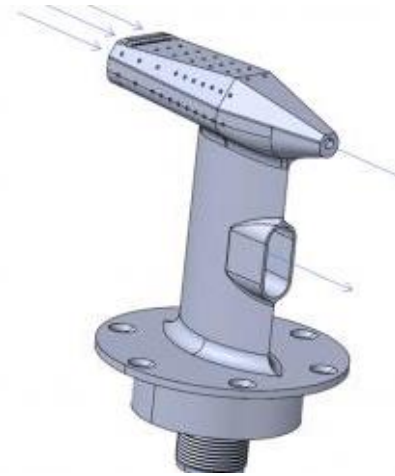
# SENS4ICE sensor technologies for direct sensing of atmospheric icing conditions or ice accretion detection (1/2)



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



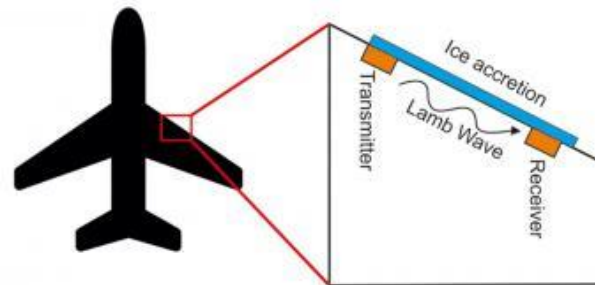
Name: *Collins Ice Detection System (IDS)*  
Project partner: *Collins Aerospace*



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



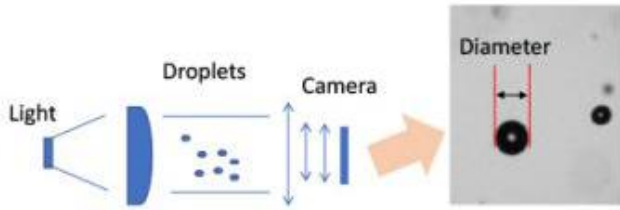
Name: *AMPERA*  
Project partner: *French Aerospace Lab (ONERA)*  
Copyrights: © French Aerospace Lab (ONERA)



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



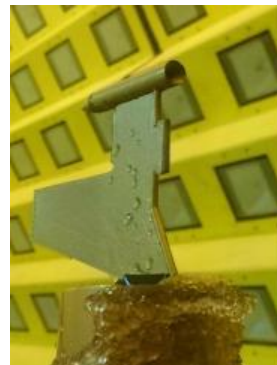
Name: *Atmospheric Icing Patch (AIP)*  
Project partner: *AeroTex UK*  
Copyrights: © AeroTex UK LLP



Name: *Fiber Optic Bragg (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

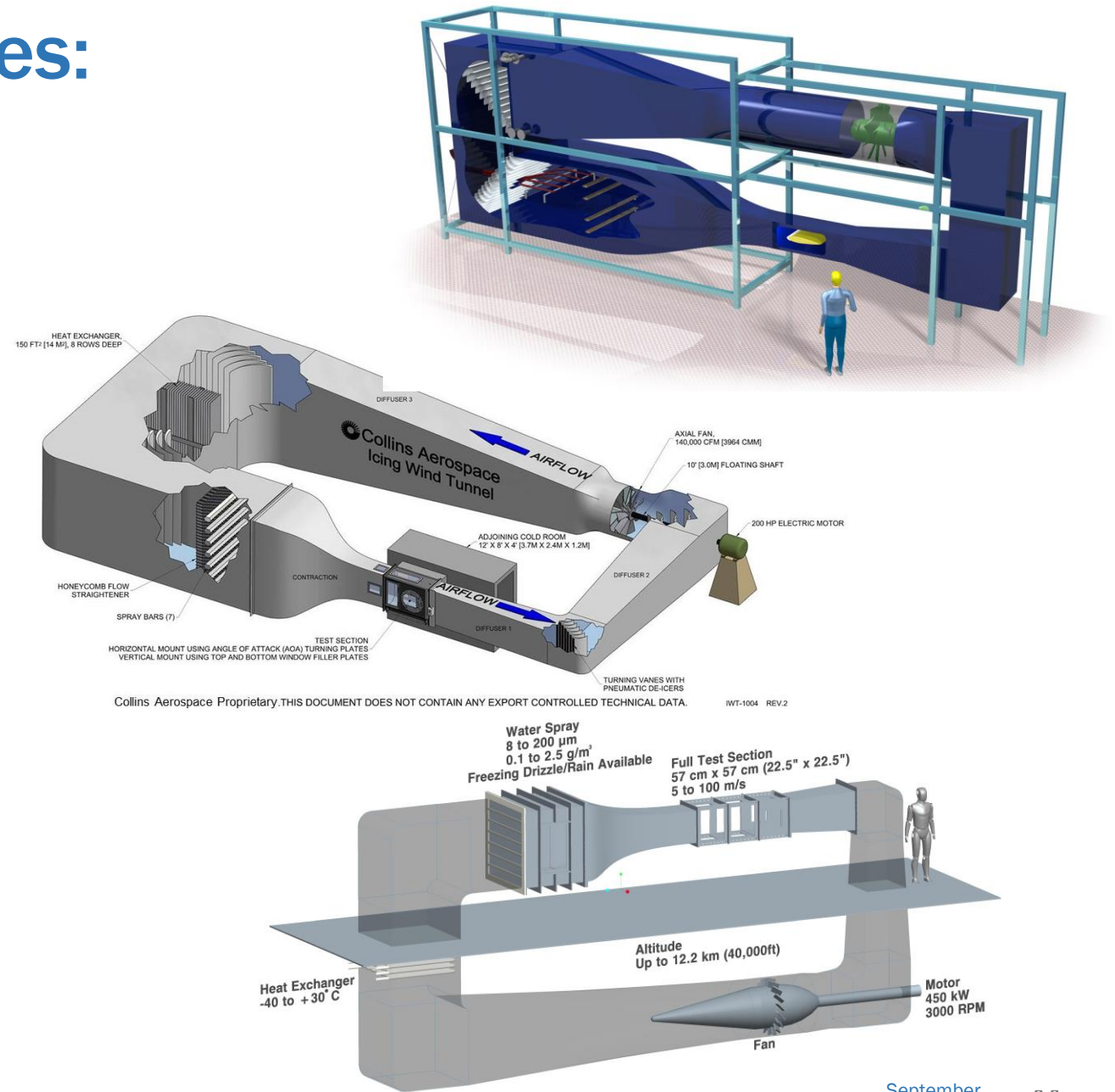
💧 SLD capabilities available and enhanced during SENS4ICE

💧 National Research Council Canada

💧 SLD capabilities available

💧 Total testing time: 16 weeks

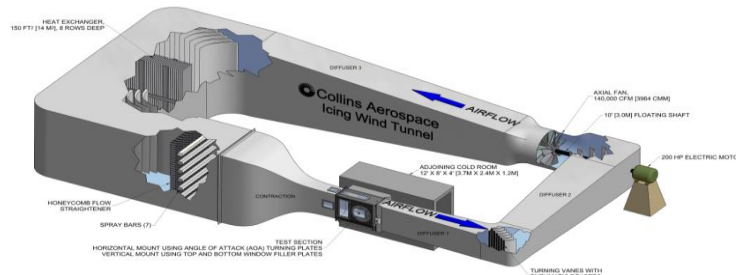
💧 Planned time frame: NOV 2020 – MAR 2021





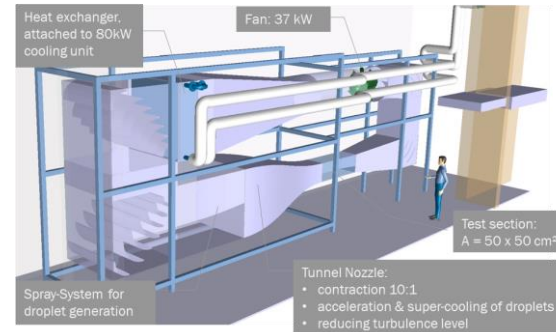
# Overview of SENS4ICE IWT Capabilities

## Collins Aerospace, USA



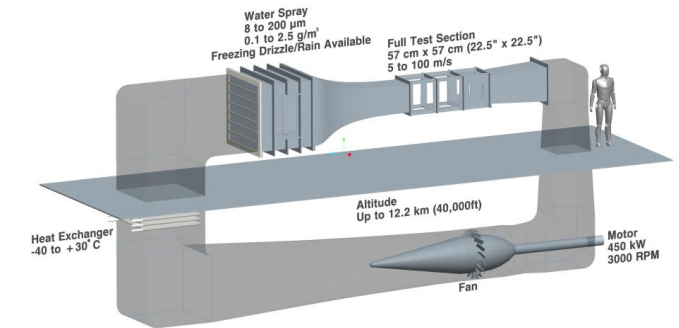
- 5-147 micron droplets
- LWC between 0.1 and 3 g/m<sup>3</sup>
- Temperature 0°C to -30°C
- Sustained speed 13-103 m/s
- Test section: 152x56x112 cm<sup>3</sup>
- Calibrated per SAE ARP 5905
- Compliant with AS9100C
- Controls and power supplies can simulate aircraft controls

## TU Braunschweig, Germany



- MVD 9-60 micron droplets
- LWC between 0.1 and 1.5 g/m<sup>3</sup>
- Temperature 30°C to -20°C
- Sustained speed 10-40 m/s
- Test section: 150x50x50 cm<sup>3</sup>
- Calibrated per SAE ARP 5905
- Short spray transients ~ 15s
- Bi-modal SLD and mixed phase capability

## NRC, Canada

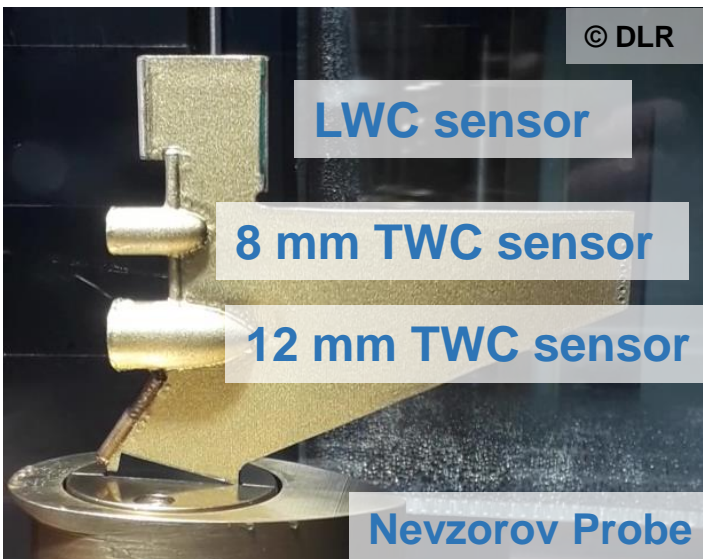
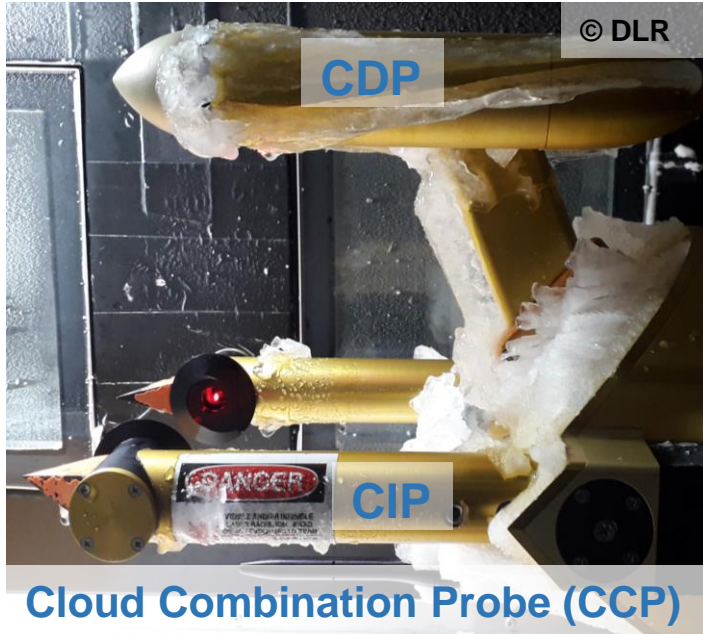


- 8-200 micron droplets
- LWC between 0.1 and 2.5 g/m<sup>3</sup>
- Supercooled Water: 10 to > 200 µm (incl. SLD bi-modal)
- Temperature +30°C to -40°C
- Sustained speed 5-100 m/s
- Test section: 57x57 cm<sup>2</sup> (52x33 cm<sup>2</sup> with insert)
- Sea level < Altitude < 40,000ft
- Calibrated per SAE ARP 5905

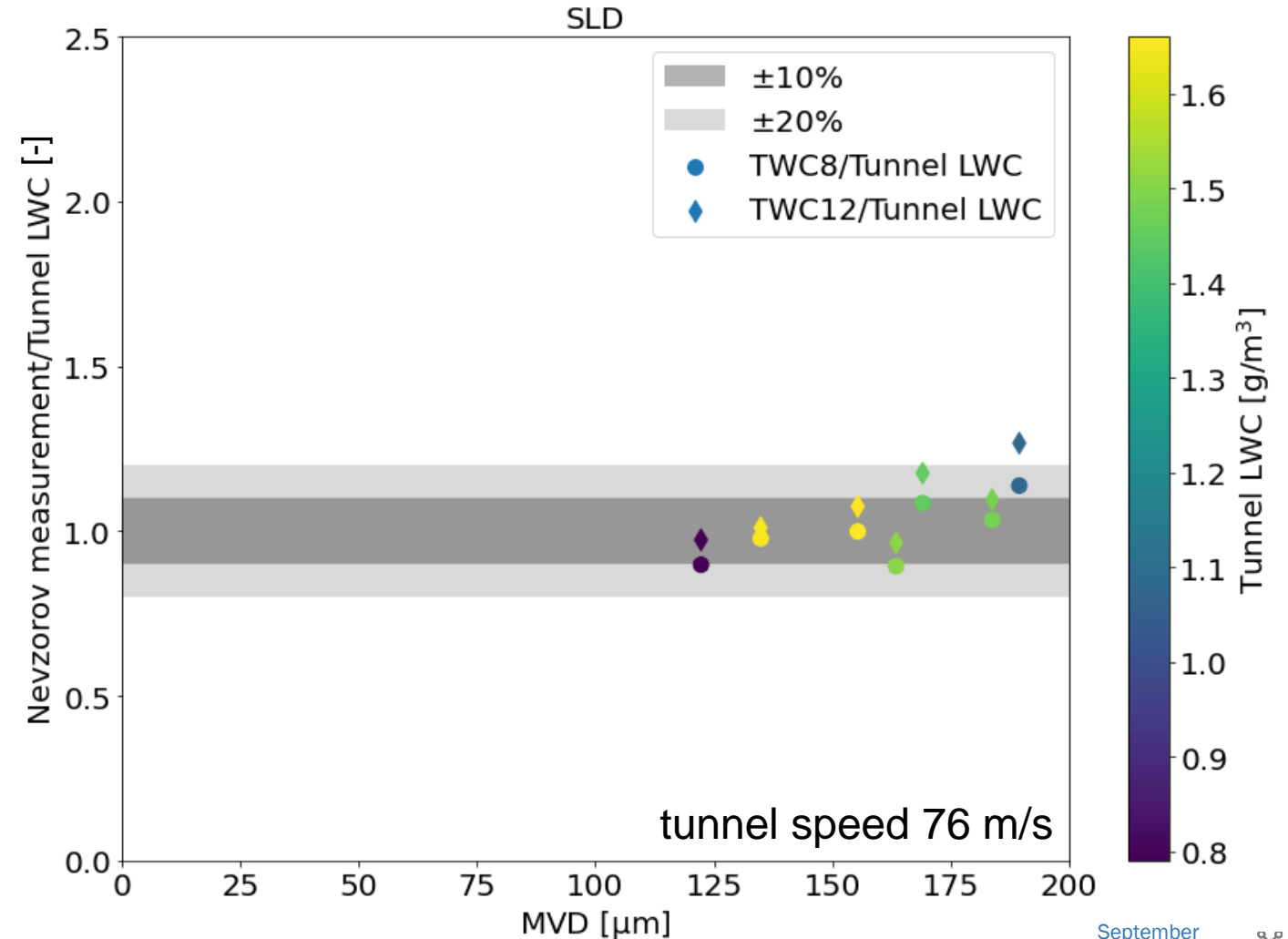
💧 Dedicated common test points defined for all involved SENS4ICE IWT



# Reference Instrumentation & Measurements

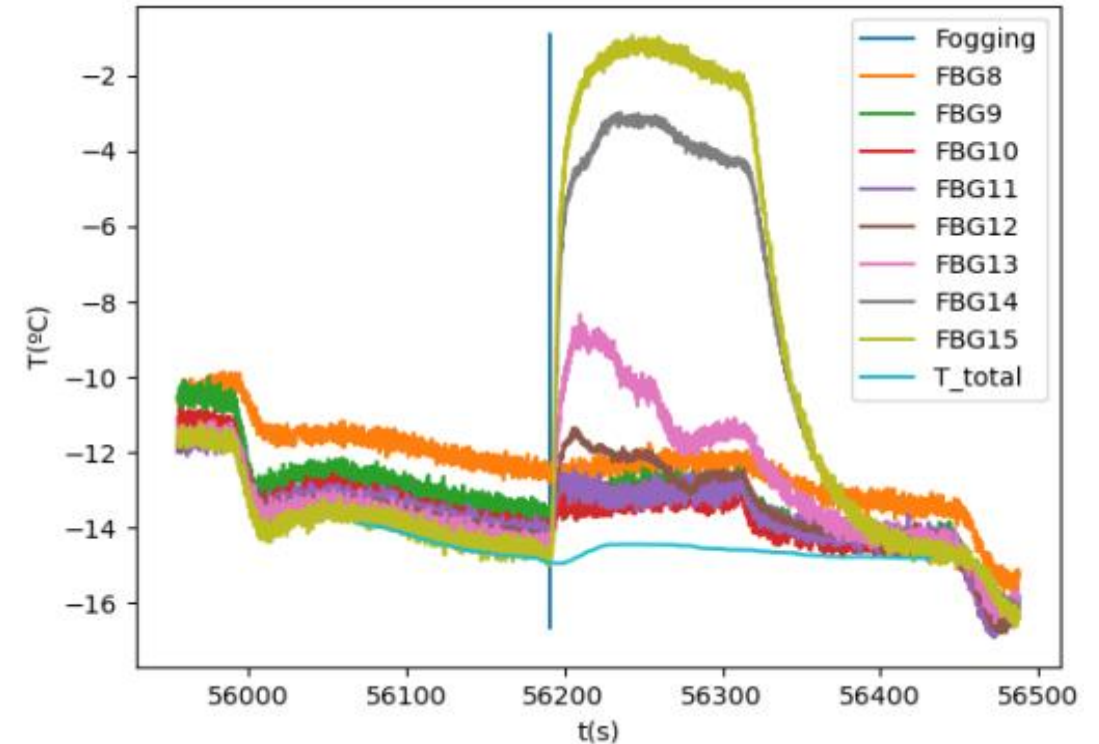


- Reference measurements (Nevzorov probe) in SLD conditions
- 💧 generally good agreement with tunnel LWC data (SEA probe)
  - 💧 for MVDs  $< 180 \mu\text{m}$ , Nevzorov and SEA probe agree within 20%



# FOD (Fiber Optic Bragg) – using Fiber Bragg Grating Sensors (FBGs)

- 💧 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.

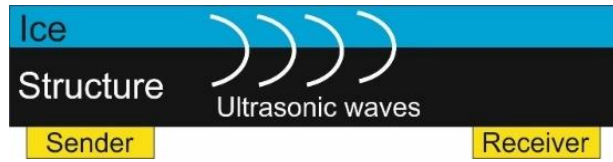


FOD temperature time histories at NRC AIWT for different measurement locations over the airfoil chord (“FBG 8 – 15”) and the total temperature for Appendix O conditions (LWC = 0.82 g/m<sup>3</sup>, MVD = 163.5 μm; V = 76 m/s, start time of icing cloud marked by a vertical line “Fogging”)

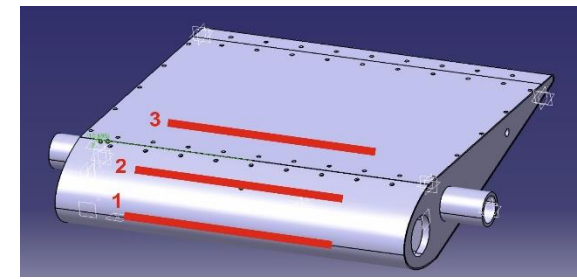




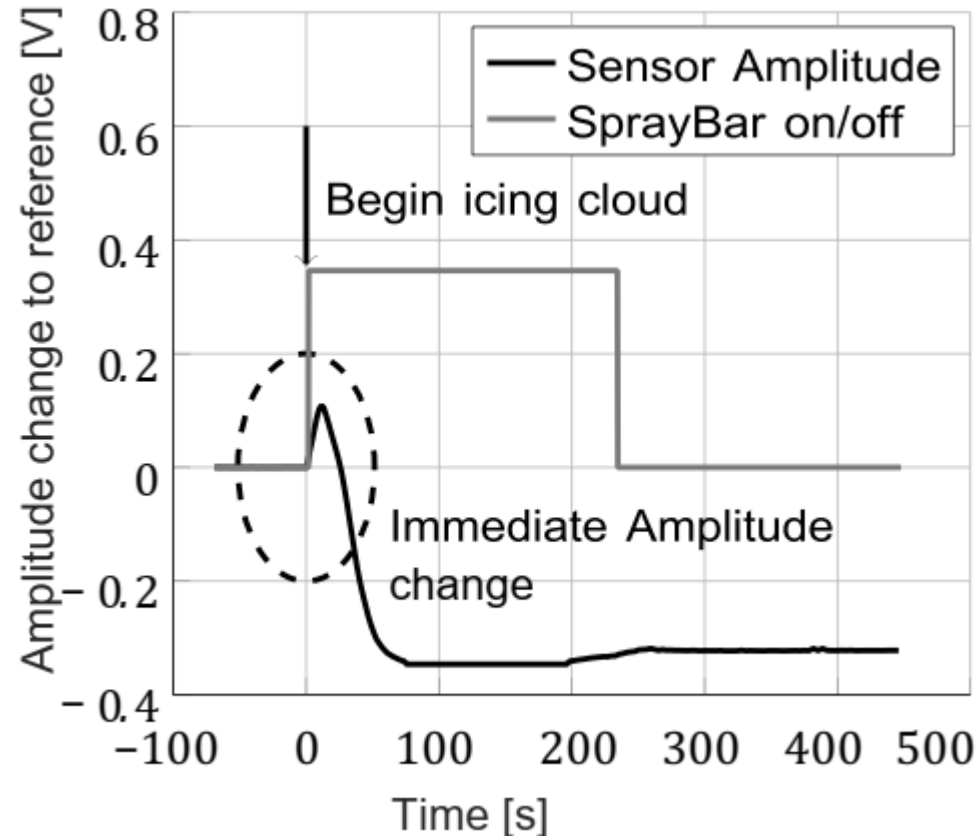
# Local Ice Layer Detector (LILD)



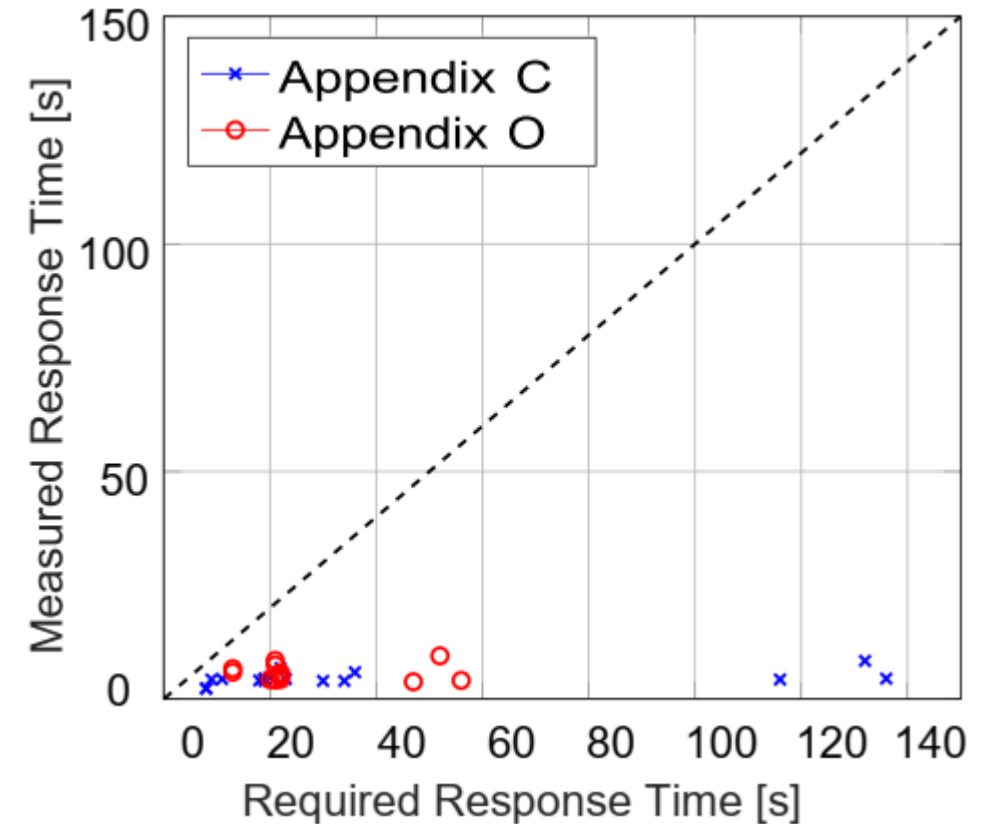
LILD principle of travelling ultrasonic lamb waves



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  $\mu\text{m}$ , LWC = 0,98  $\text{g}/\text{m}^3$ , T = -10°C)

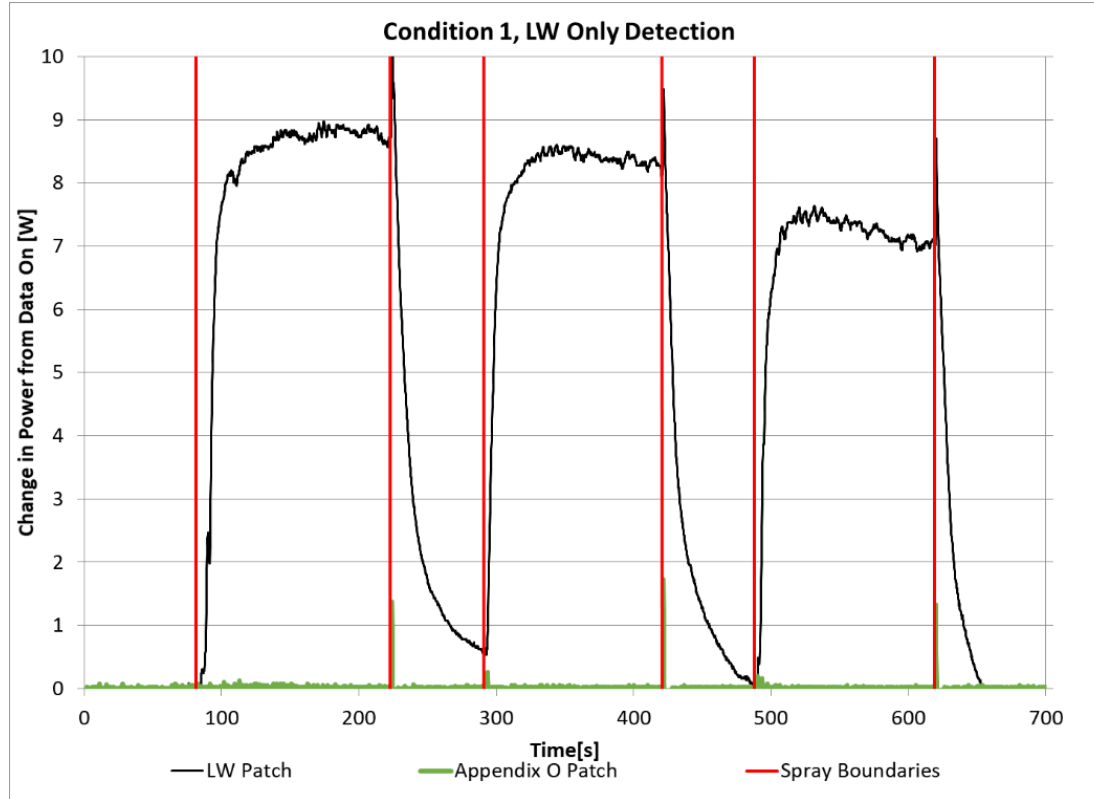


LILD response times for Appendix C and O conditions measured at BIWT compared to the required response time

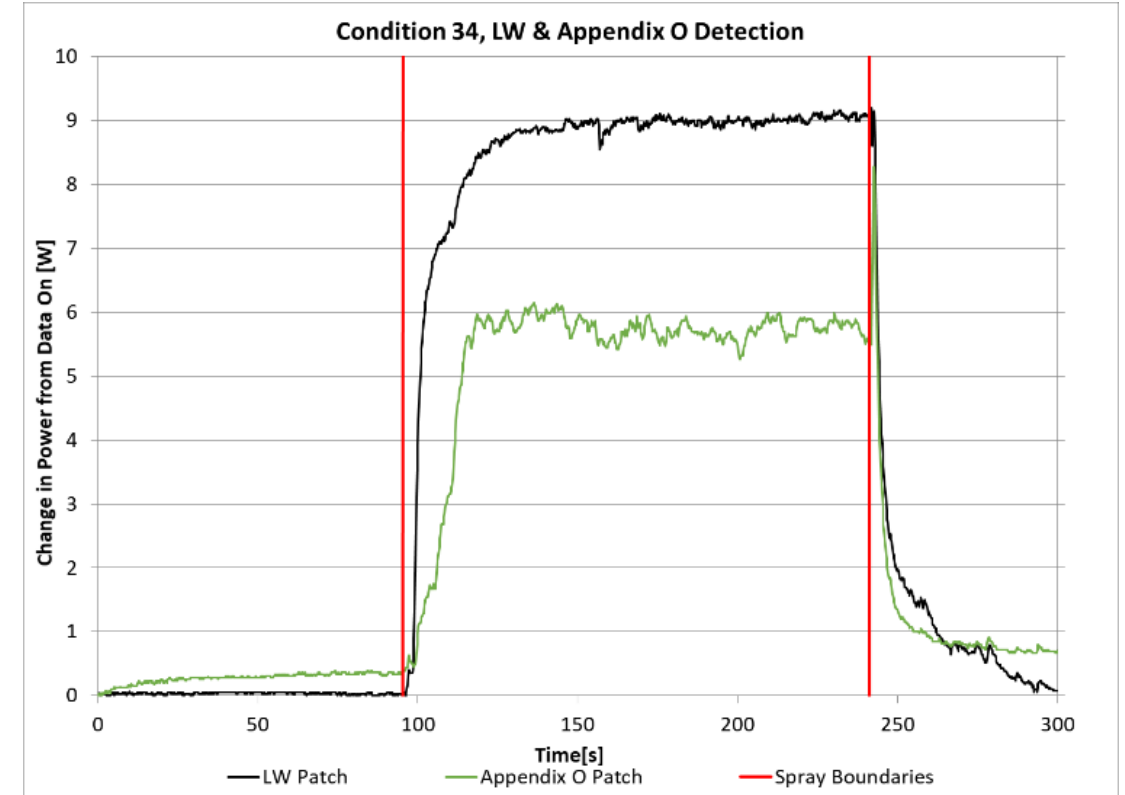


# Atmospheric Icing Patch – AIP

consisting of an array of low power ( $< 28\text{W}$ ) iso-thermal ice detection sensors



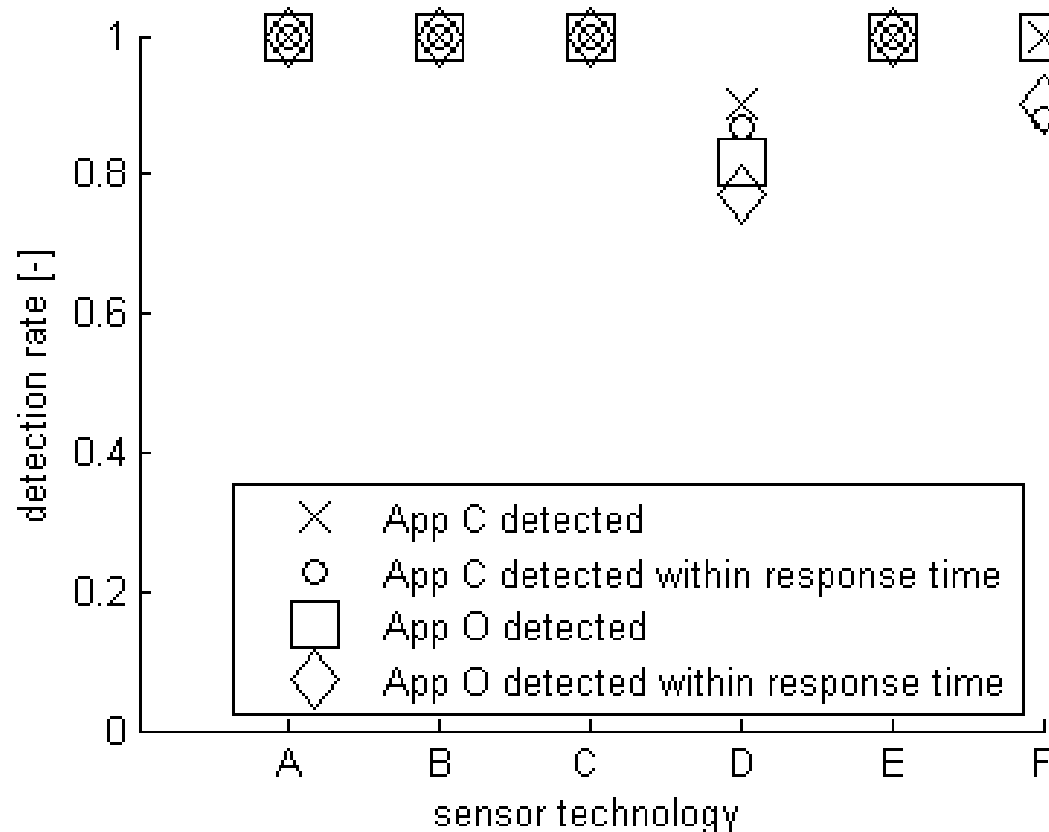
Example of AIP patch power response in small droplet icing conditions (note Appendix O patch shows no response)



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 and another sensor with 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

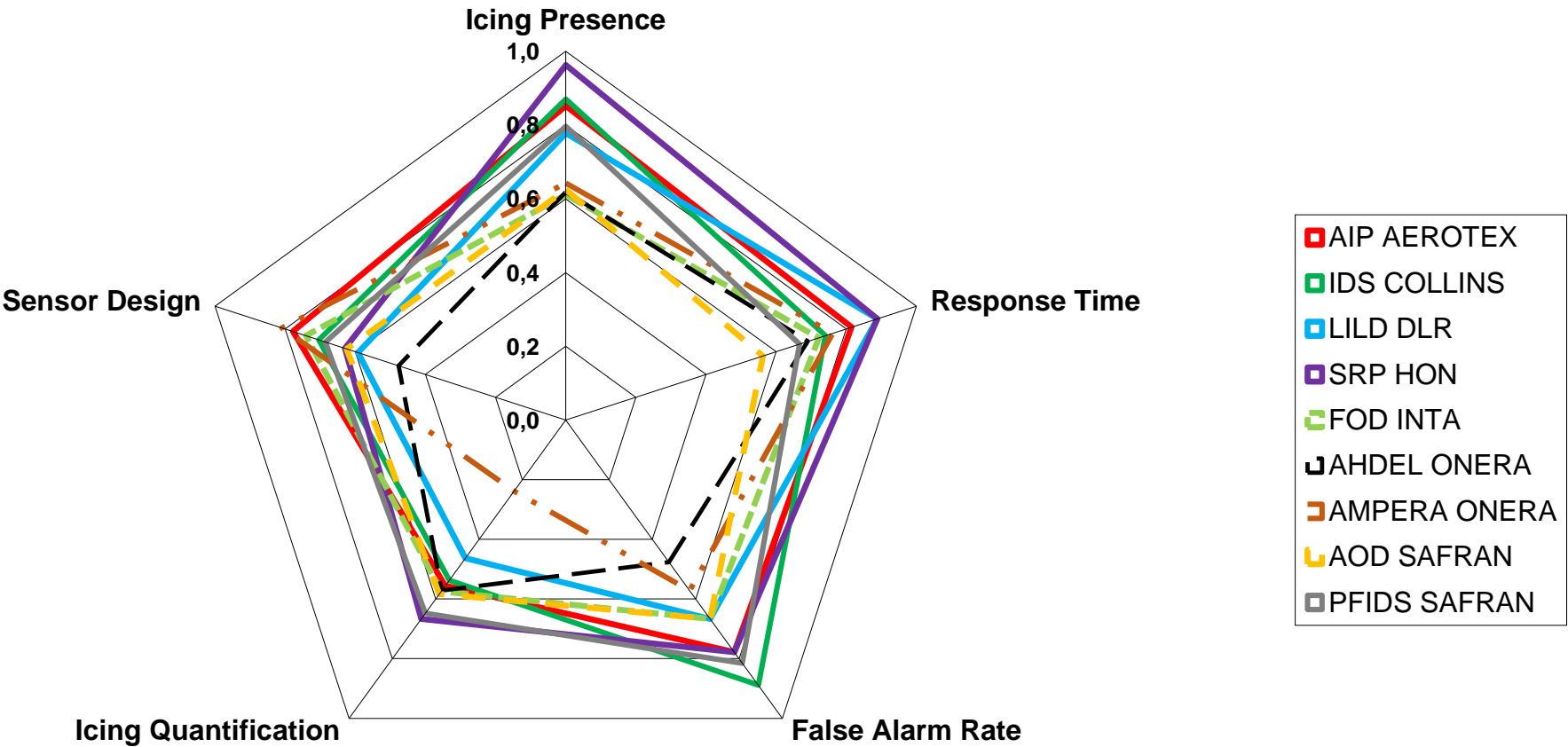


# Technology evaluation criteria and weighting factors

Technology evaluation criteria	Weighting factor
<b>Icing (ice accretion) / Icing condition presence detection capability</b> (for App. C (required) and App. O (primary project goal, hence App. O capabilities are more relevant))	0.35
<b>Response time</b> (for providing Icing/Icing Condition Presence)	0.20
<b>False alarm rate</b> (i.e., detection of icing in non-icing conditions)	0.10
<b>Icing quantification and contributing factors for severity determination</b> , 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
<b>Sensor design</b> : weight/integration/power (expected once technology is matured)	0.05



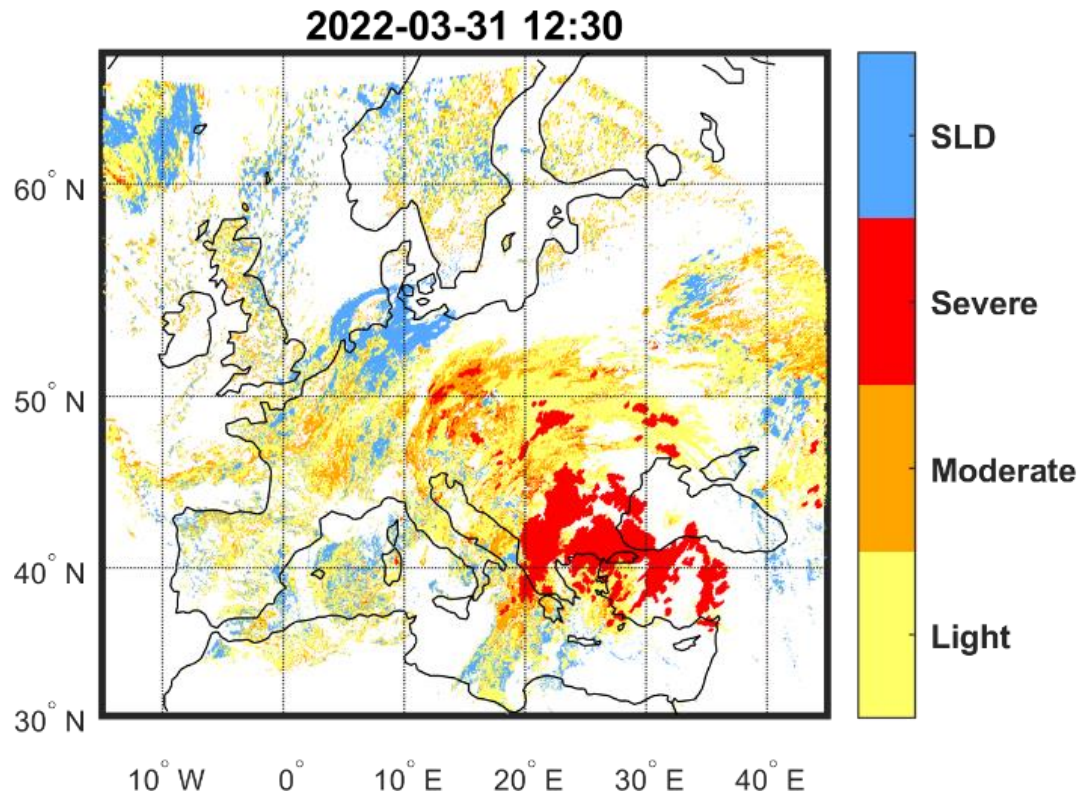
# SENS4ICE Advisory Board evaluation ratings for sensor technologies averaged for all Advisory Board members for evaluation criteria (averaged ratings between 0 and 1, normalised, best rating 1)



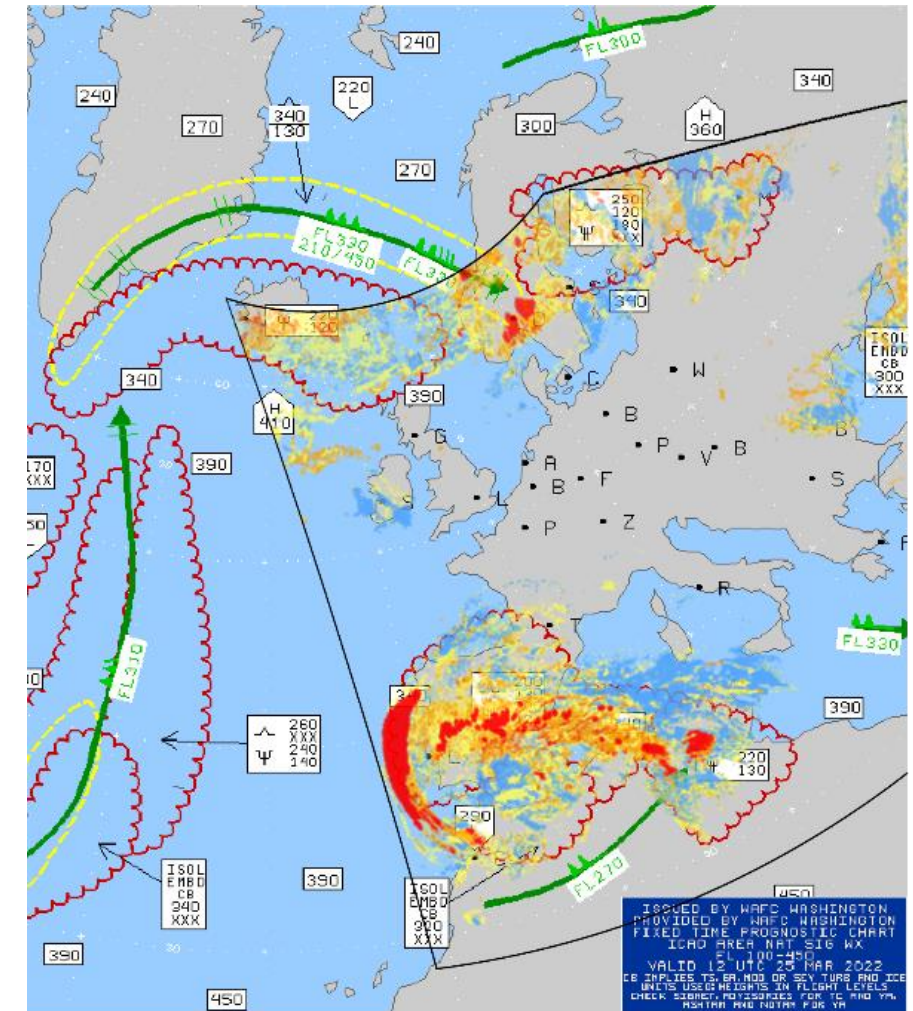


# Remote Ice Detection

- ❖ 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

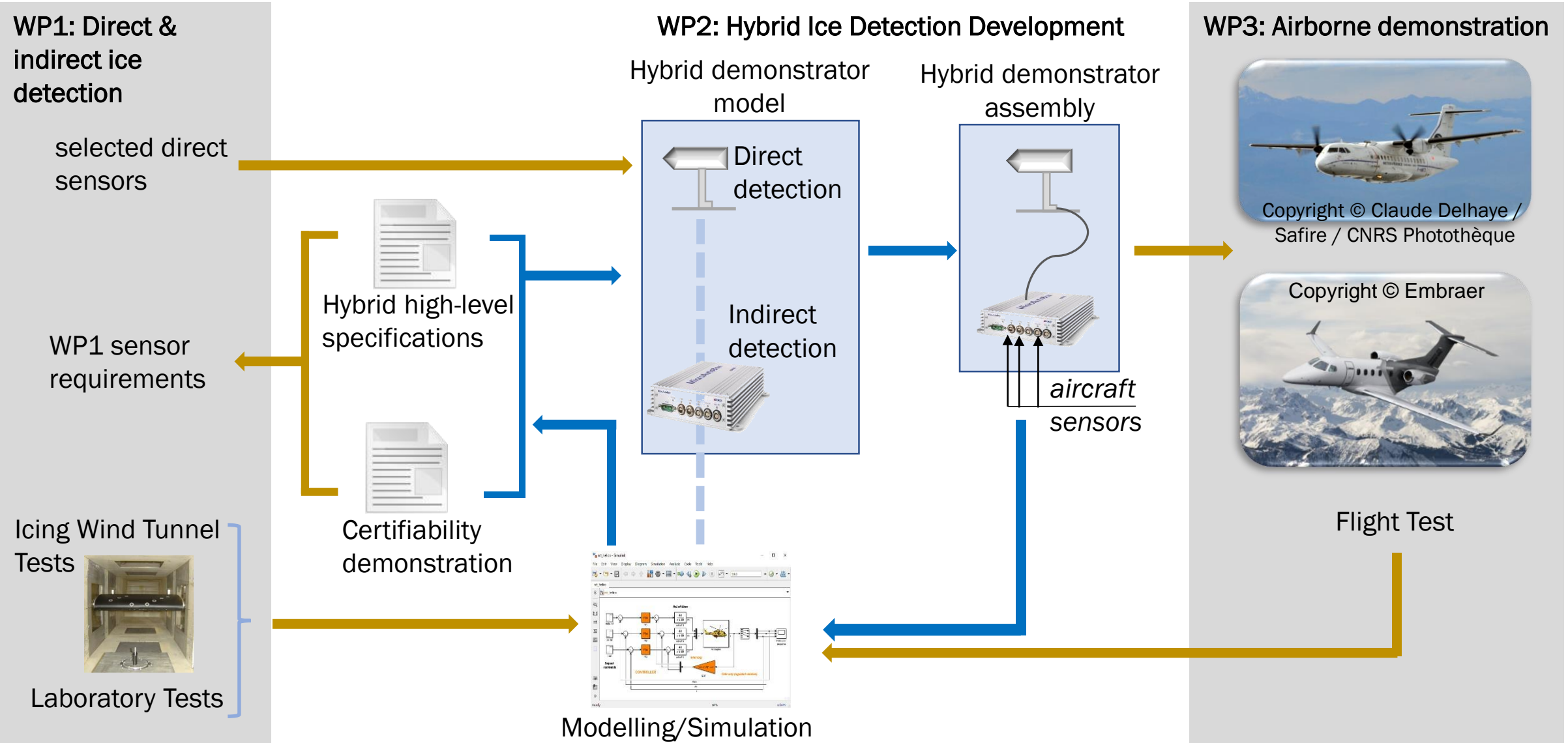
### Objectives for hybrid ice detection

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)

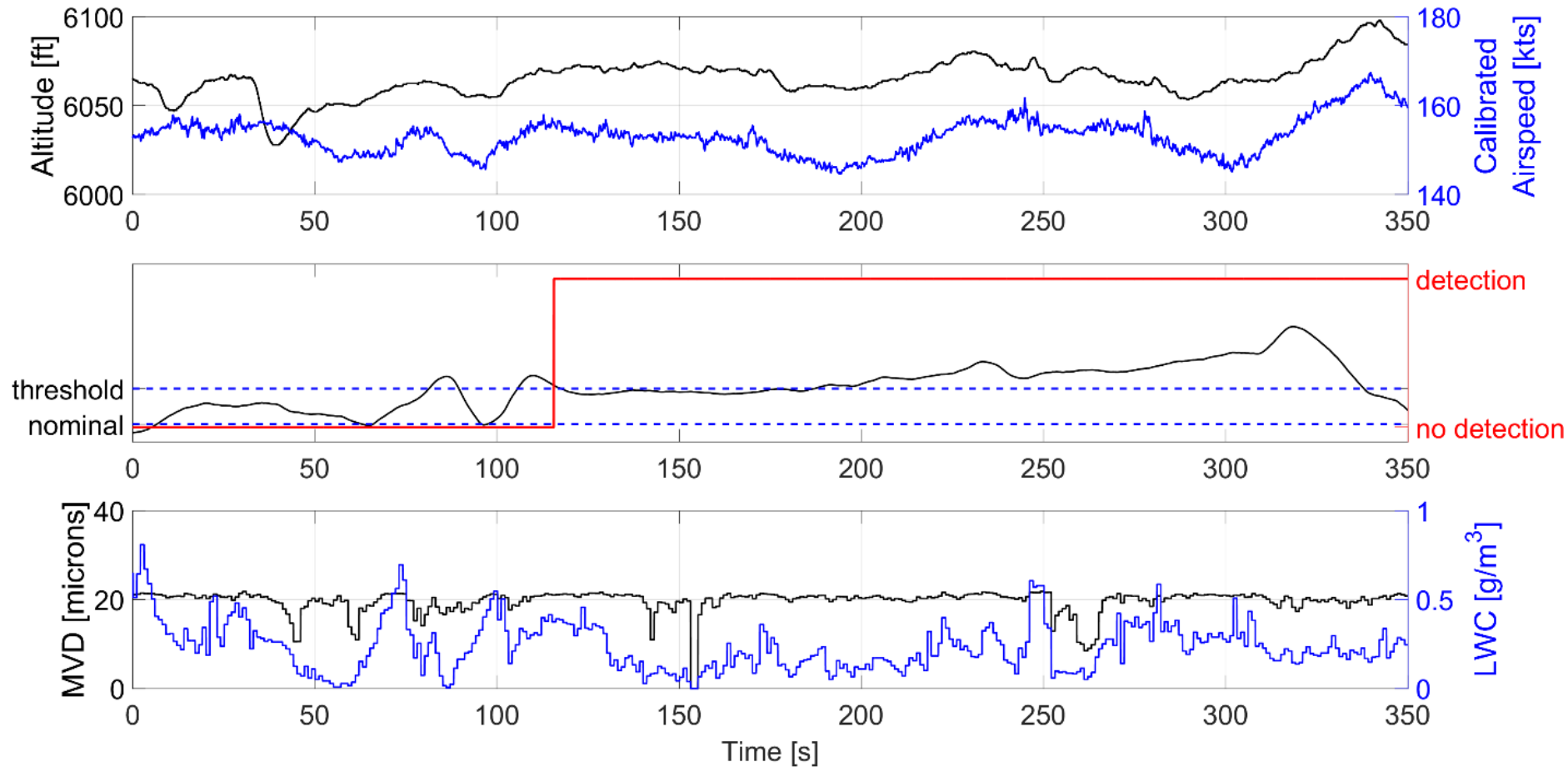
in close cooperation with OEMs and certification authorities during SENS4ICE



# WP2: Hybrid Ice Detection – Development Workflow



# DLR's Indirect Ice Detection – based on aircraft performance



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. 0 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
- planned main time frame: JAN and APR 2023

## **SAFIRE ATR-42**



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## **Embraer Phenom 300**

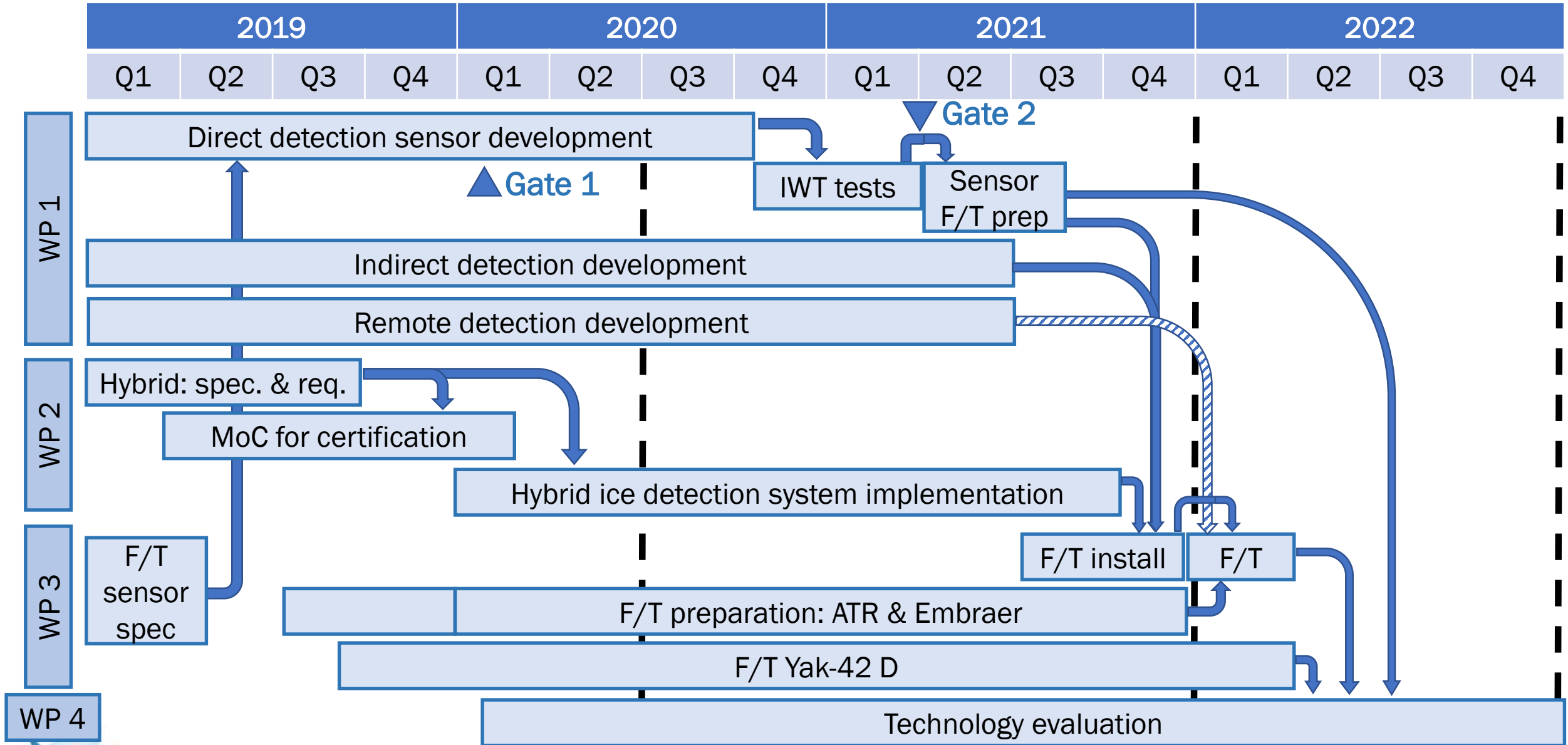


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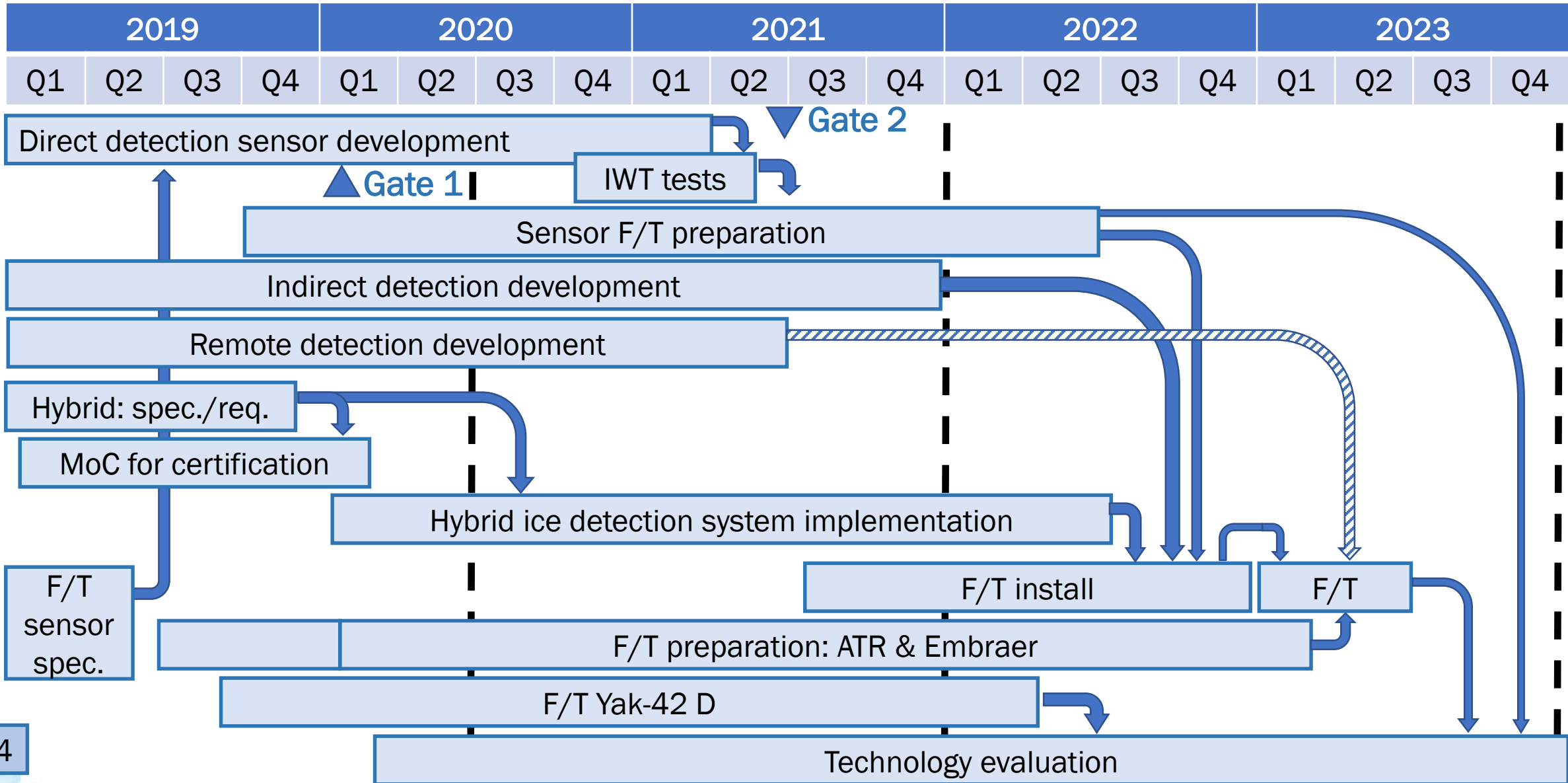




# SENS4ICE Timescale (simplified Gantt – original/ 4 years)



# SENS4ICE Timescale (simplified Gantt – extended/ 5 years)



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>



SENS4ICE