SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES
FOR SAFER AVIATION IN ICING ENVIRONMENT

Overview of SENS4ICE project: SENSors and certifiable hybrid architectures FOR safer aviation in ICing Environment

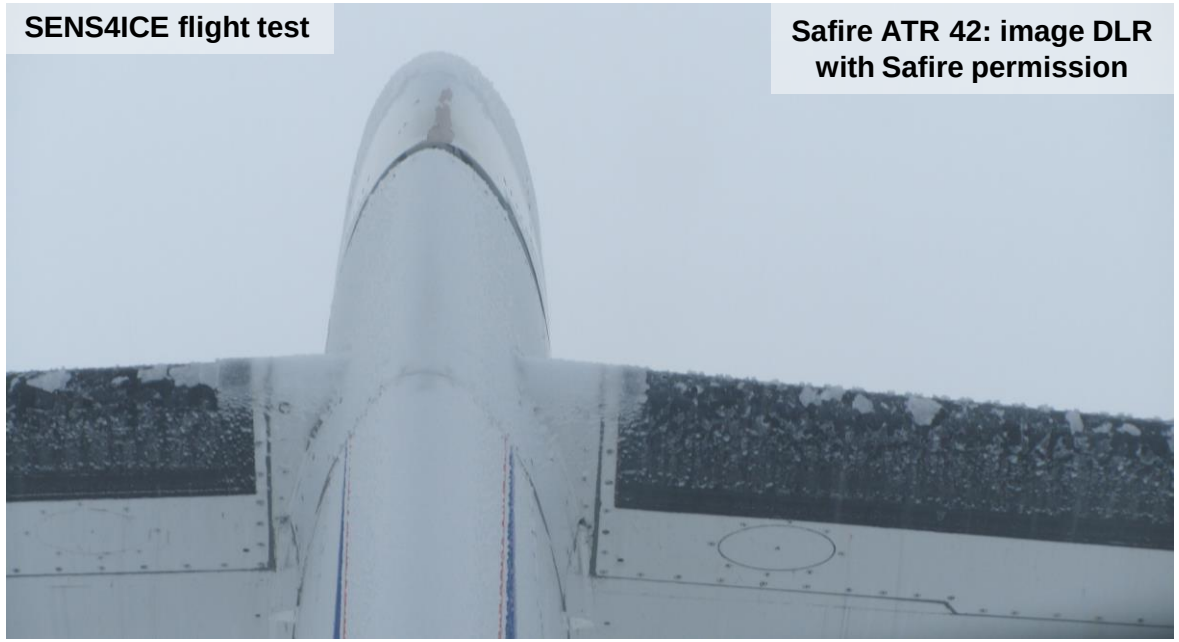
FINAL DISSEMINATION EVENT OF SENS4ICE PROJECT

Carsten Schwarz (DLR)

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

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

Aircraft Icing Phenomena
Natural Ice Shapes



SENS4ICE flight test

Safire ATR 42: image DLR with Safire permission

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

Credit: **BFU**, Interim Report BFU CX001-13

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

Safety Risks of Icing in Flight

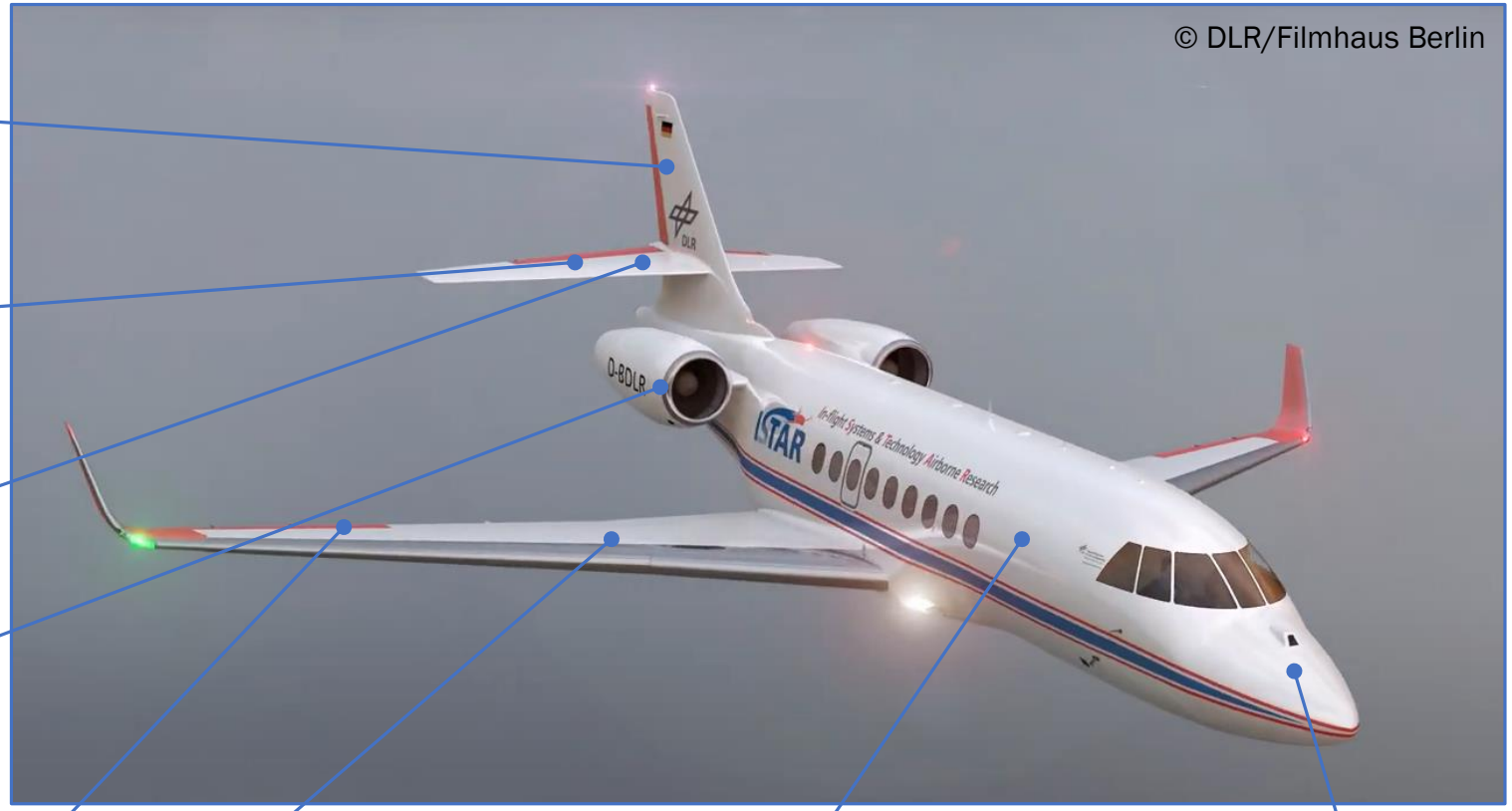
Vertical Tail Plane
- Control degradation
- Drag increase

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

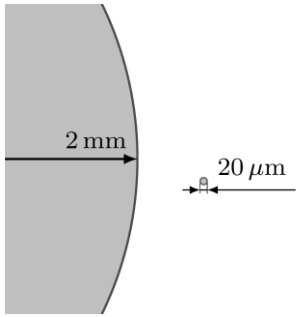
Fuselage
- Drag increase
- Collected contaminant ice layer

Sensors
- Malfunction
- Blockage

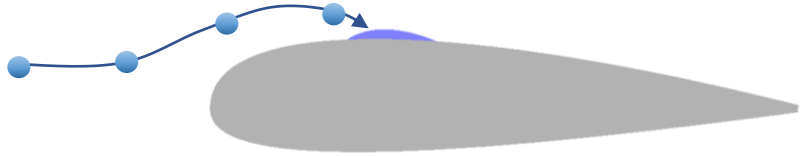
[Falk Sachs (DLR), Indirect ice detection for the hybrid ice detection system, SENS4ICE first public project symposium, SAE AC-9C Aircraft Icing Technology Committee Meeting 22 OCT 2020]

Supercooled Large Droplet (SLD) Icing - Challenges

Supercooled **Large** Droplets: > 50 µm



- Impingement behind the leading edge



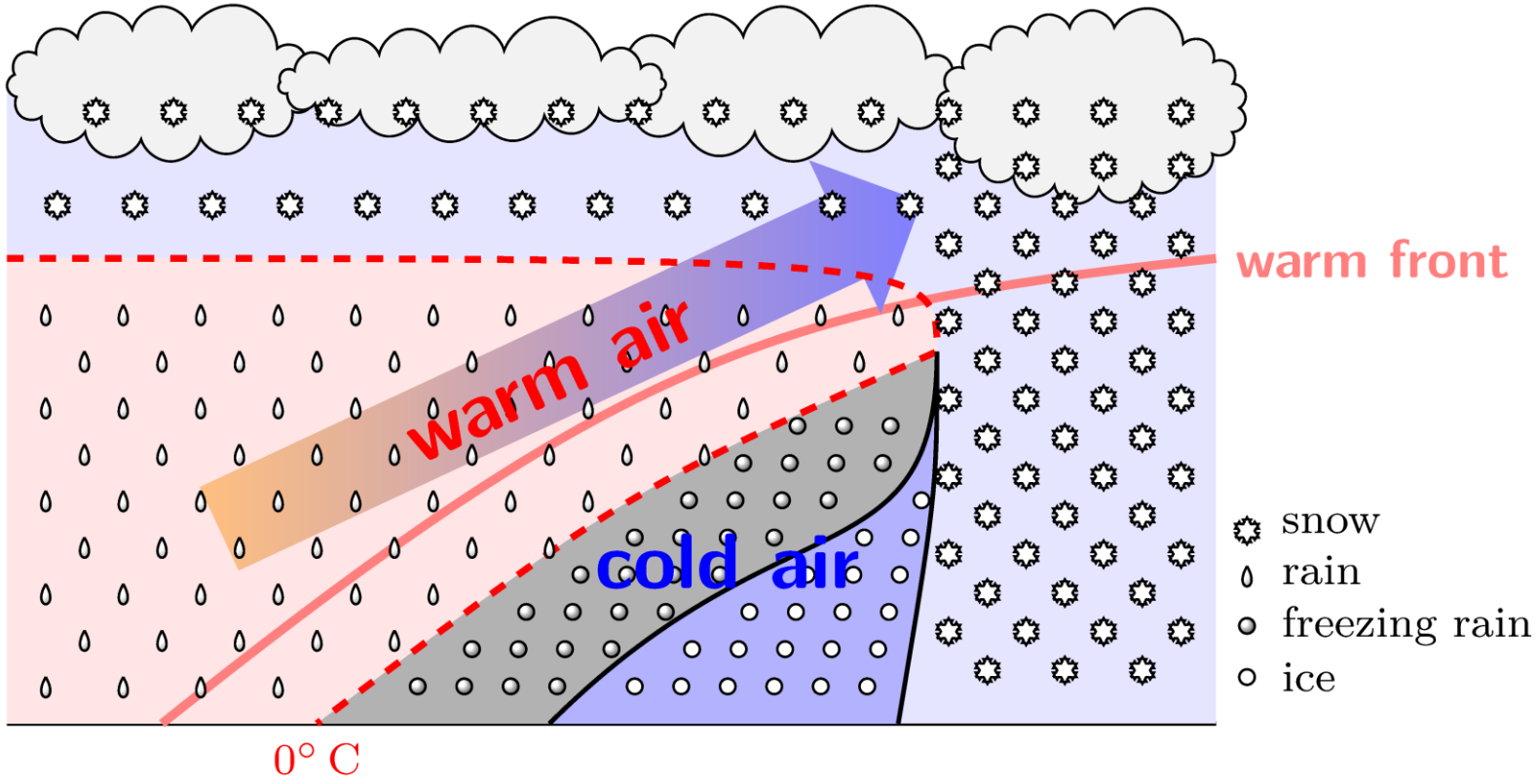
- Supercooled water running downstream

→ SLD icing conditions > safety of flight > certification

Credit: DLR (C. Raab)

Supercooled Large Droplets (>50 µm)

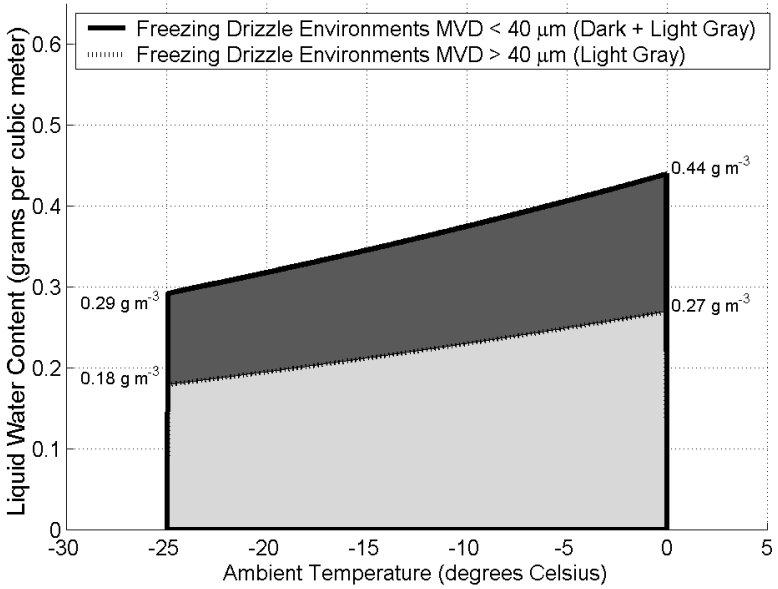
- High reaching clouds containing snow, which is melting in the warm air to large drops
- Part of large droplets falling down being supercooled in cold air
- Without nucleus for crystallization, SLD from freezing drizzle or freezing rain



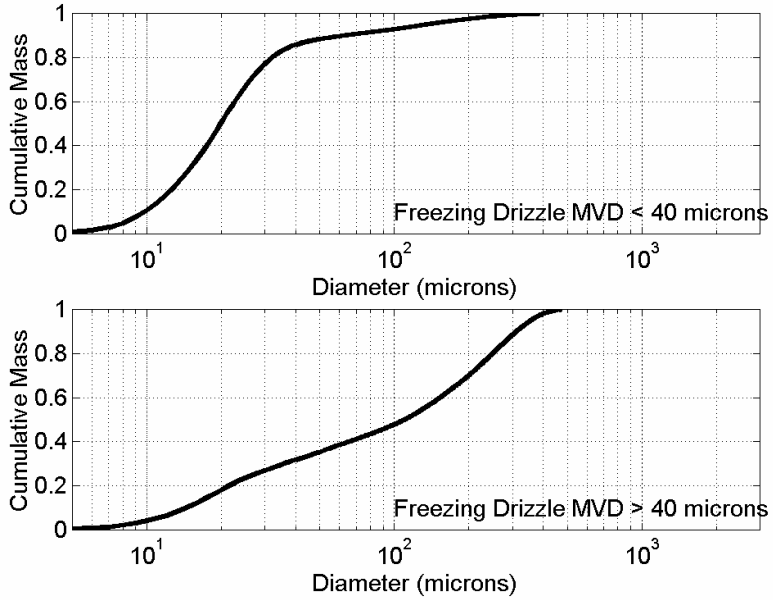
EASA/FAA Certification Specifications Appendix O envelope

- Freezing Drizzle
- Freezing Rain

Appendix O, Freezing Drizzle, Liquid Water Content

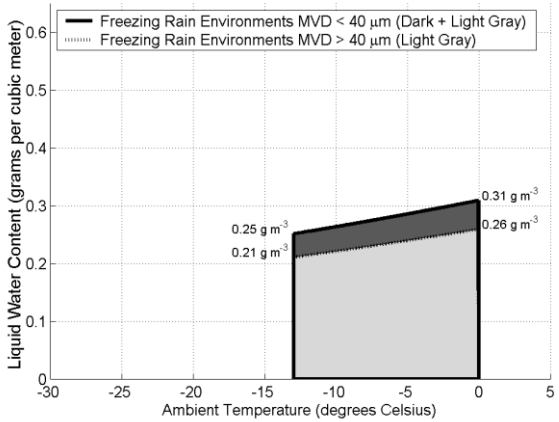


Appendix O, Freezing Drizzle, Drop Diameter Distribution

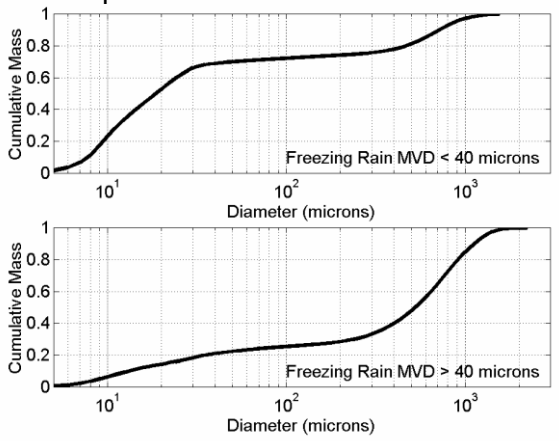


CS-25 BOOK 1 (CS-25 Amendment 21, Annex to ED Decision 2018/005/R), Appendix O, Figure 1 & 2

Appendix O, Freezing Rain, Liquid Water Content



Appendix O, Freezing Rain, Drop Diameter Distribution



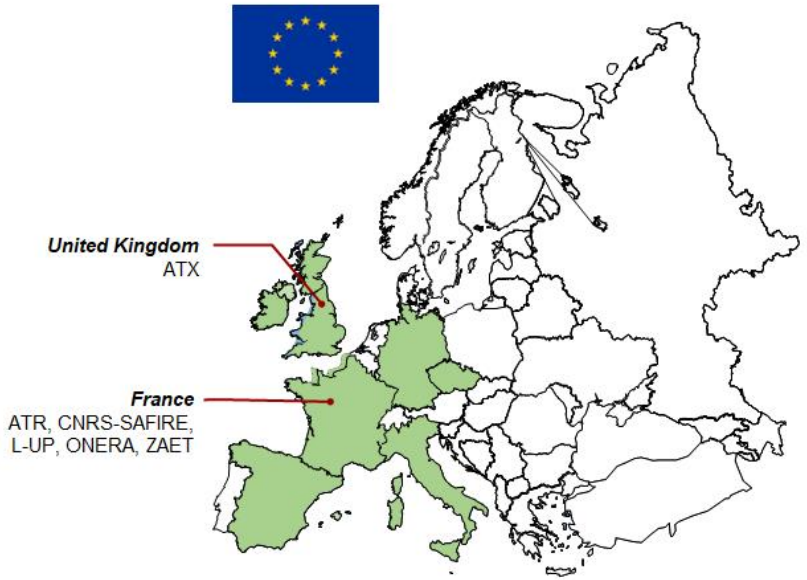
CS-25 BOOK 1 (CS-25 Amendment 21, Annex to ED Decision 2018/005/R), Appendix O, Figure 4 & 5

SENS4ICE Project Overview

SENSors and certifiable hybrid architectures for safer aviation in ICing Environment

- JAN 2019 - DEC 2023 (extended, originally DEC 2022)
- 17 Consortium partners including 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 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

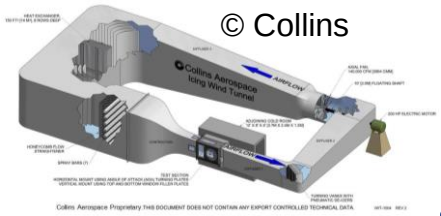
Benefits

- 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

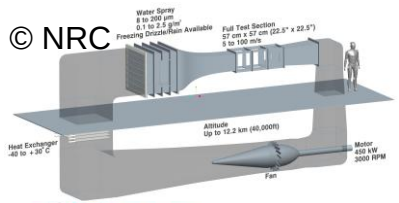
SENS4ICE Timeline / Summary / Achievements

Upgrade icing wind tunnels for App. O

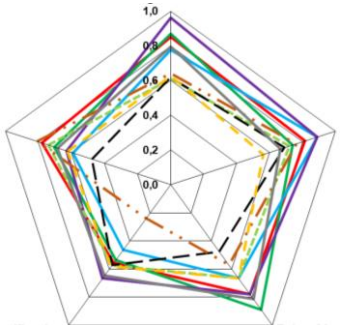
Develop sensors/ technologies for App. O detection



Icing wind tunnel testing



Sensor technology evaluation and selection



Hybrid ice detection

Indirect ice detection

Flight test preparation

Flight testing

FEB/MAR 2023

Copyright © Embraer

APR 2023

Copyright © Claude Delhaye / Safire / CNRS Photothèque

Flight test analysis/ techno-logy evalua-tion

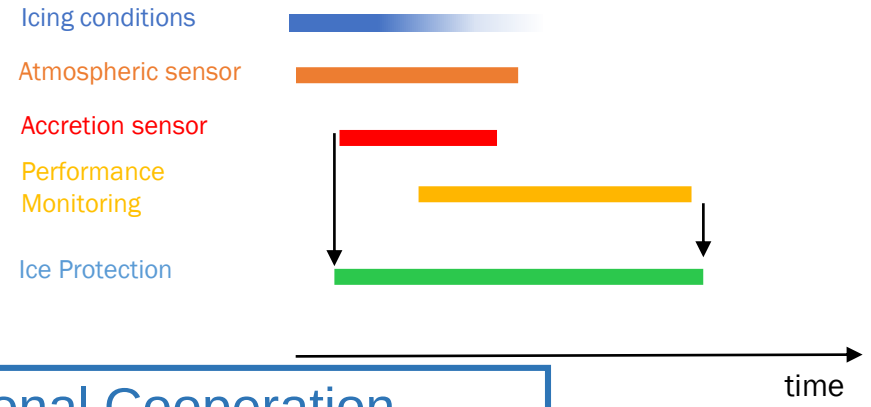
Commu-nication, Dissem-ination, Exploi-tation

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

EU Project SENS4ICE - Results

SENSors and certifiable hybrid architectures for safer aviation in ICing Environment

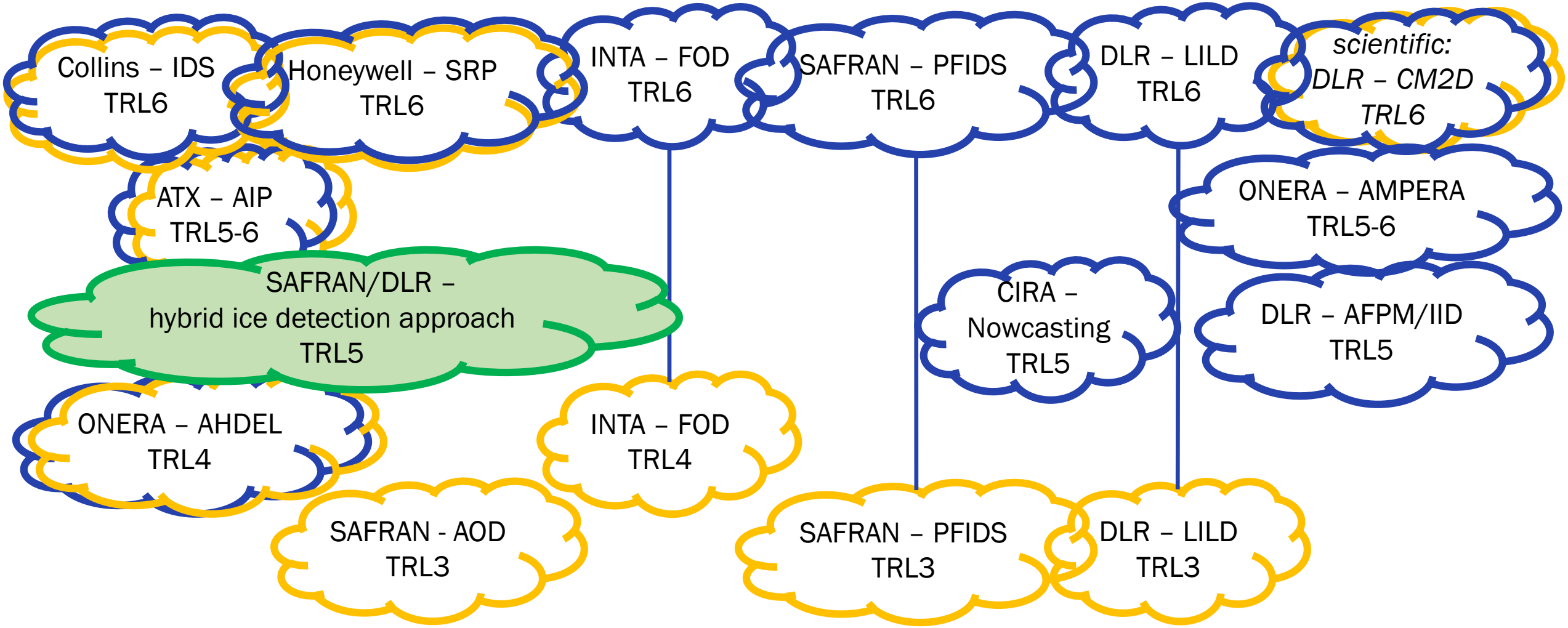
- **Direct, indirect and remote ice detection technologies particularly for SLD** (Supercooled Large Droplets) icing developed, considerably matured and successfully demonstrated in IWT (icing wind tunnel) and natural icing conditions in flight campaigns
- Intense and significant coverage of **relevant icing conditions** achieved for IWT (icing wind tunnels) and flight campaigns including valuable SLD encounters
  → while certification envelope is multi-dimensional and much larger
- **Broad and promising technology application** for different purposes/vehicles
  → many innovative technologies low size/ low weight/ low power or even a software solution (indirect detection)
- Game changer **hybrid solution** for challenging task of SLD detection
  - combining dissimilar technologies into a hybrid solution combining both direct and indirect technologies > TRL5 reached
  - successfully tested/demonstrated in two flight campaigns
  - benefits of quick warnings and continuous ice accretion and flight performance monitoring
  - IPS efficiency optimisation



- Excellent Fruitful International Cooperation
- Outstanding Communication and Dissemination

SENS4ICE – Technology readiness levels TRL reached

App 0 detection and App 0 discrimination

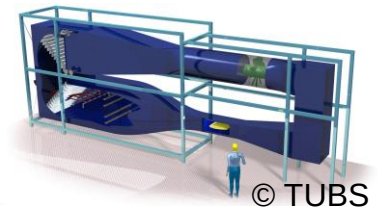


- Exploitation: patents for most technologies filed/ underway, relationships with supply/OEM industry established

SENS4ICE - Impact

- *Contribute to **increase passenger safety** by fewer accidents and less in-flight events worldwide.*
  - Detection technologies for early detection and annunciation to flight crew were developed, matured and demonstrated successfully
  - Aircraft flight performance monitoring was developed, matured and demonstrated successfully allowing to monitor criticality of ice accretion and effectiveness of ice protection systems
  - SENS4ICE technologies contribute to considerably reduce safety risk of sever icing conditions including Appendix O conditions
- *Contribute to **decrease costs** for all parties (e.g. industry, authorities, research & test centres) by improved and internationally accepted certification, standards and means of compliance, covering all types of icing hazards.*
  - SENS4ICE ice detection technologies particularly for Appendix O conditions significantly support feasibility, effectiveness and safety of certification flight test and open a path for certification of future novel aircraft types in general. SENS4ICE technologies were developed in close contact with aviation authorities involved in SENS4ICE via Advisory Board or dedicated support contract.
- *Contribute to **decrease delays** in operations thanks to more efficient avoidance of icing hazards and to fewer damages in need of inspection and repair.*
  - SENS4ICE onboard ice detection technologies can serve to collect in-situ real-time information about detailed icing situations, that may be centralized and used to increase safety and efficiency of air traffic operations in harsh environments.
  - SENS4ICE satellite-based icing conditions nowcasting in particular for Appendix O conditions allow to include short term information for aviation weather tools and information service to ensure safety and efficiency of air traffic operations.

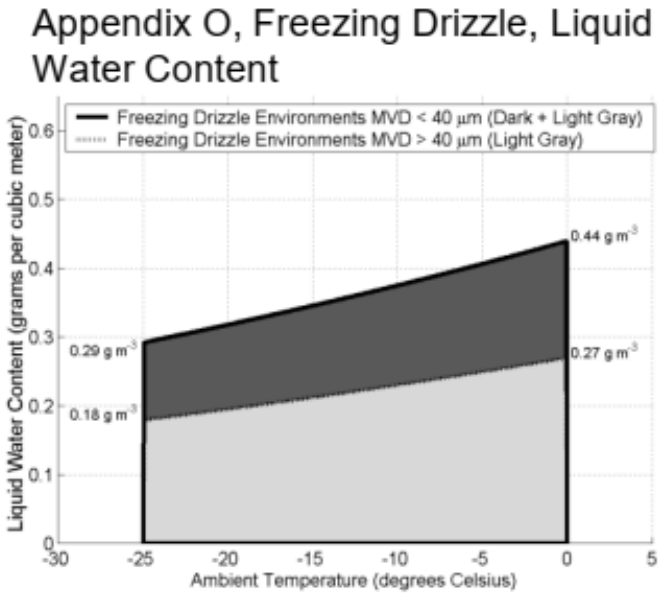
SENS4ICE
Conclusion & Outlook - Research Gaps


© TUBS

- further research/ development/ testing in enhanced icing wind tunnels and in natural icing conditions in flight required covering the full range of App O, specifically freezing rain, for maturing icing detection and discrimination technologies and identifying path for certification

Safire ATR 42: image DLR with Safire permission

- dedicated research and development for smart ice protection technologies with high efficiency required e.g. for greener aviation high aspect ratio aircraft and small/ low speed/ low altitude/ unmanned vehicles



- Improve understanding of icing effects on aircraft for rare and safety/certification relevant icing conditions (Appendix O/ SLD) to enable certification and safe operations for new aircraft/vehicle designs

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

If not acknowledged, images courtesy of the consortium partners.

SENS4ICE

Visit our website www.sens4ice-project.eu
and Linkedin #sens4iceproject