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SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

Hybrid & Indirect Ice Detection evaluation

FINAL DISSEMINATION EVENT OF SENS4ICE PROJECT

SAFRAN Aerosystems & 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

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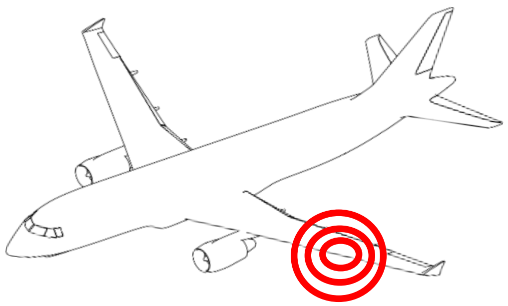
Context and objectives

An overview of Hybrid Detection approach

Direct ice detection

Local detection (ice detector): presence of ice accretion/icing condition.



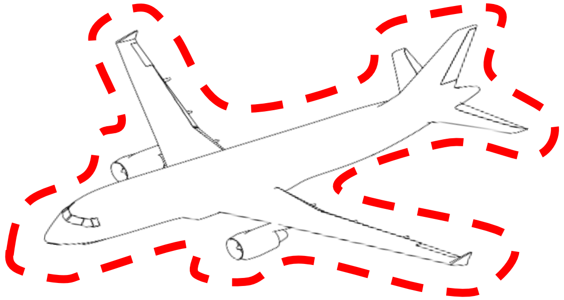
Hybrid ice detection

Combination of Direct and Indirect Detection.

- Flight safety increase.
- Better availability.
- False alarms reduction.
- Detailed information about the icing encounter.
- Continuous monitoring of A/C performance.
- Pilots better reaction.

Indirect ice detection

Global detection: effects of ice accretion.



SENS4ICE goals

- To define the specifications and needs for Hybrid Detection approach
- To develop Hybrid Ice Detection System (HIDS) demonstrator for FT campaign

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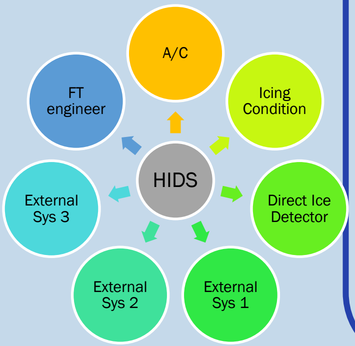
Hybrid Ice Detection System design

HIDS development phases

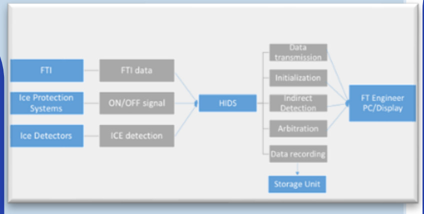
Model Based System Engineering (MBSE) approach

HIDS **environment** and **interfaces** definition

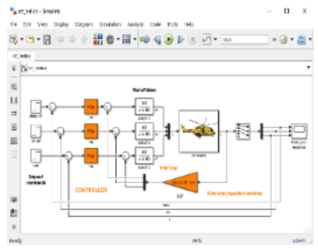


HIDS high-level **specifications**

HIDS **certification guidelines**

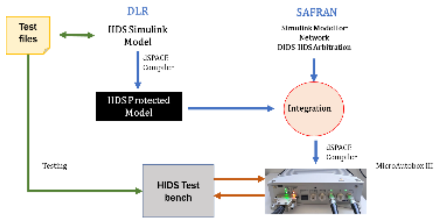


HIDS **architecture** definition



HIDS **modelling** and **software** development

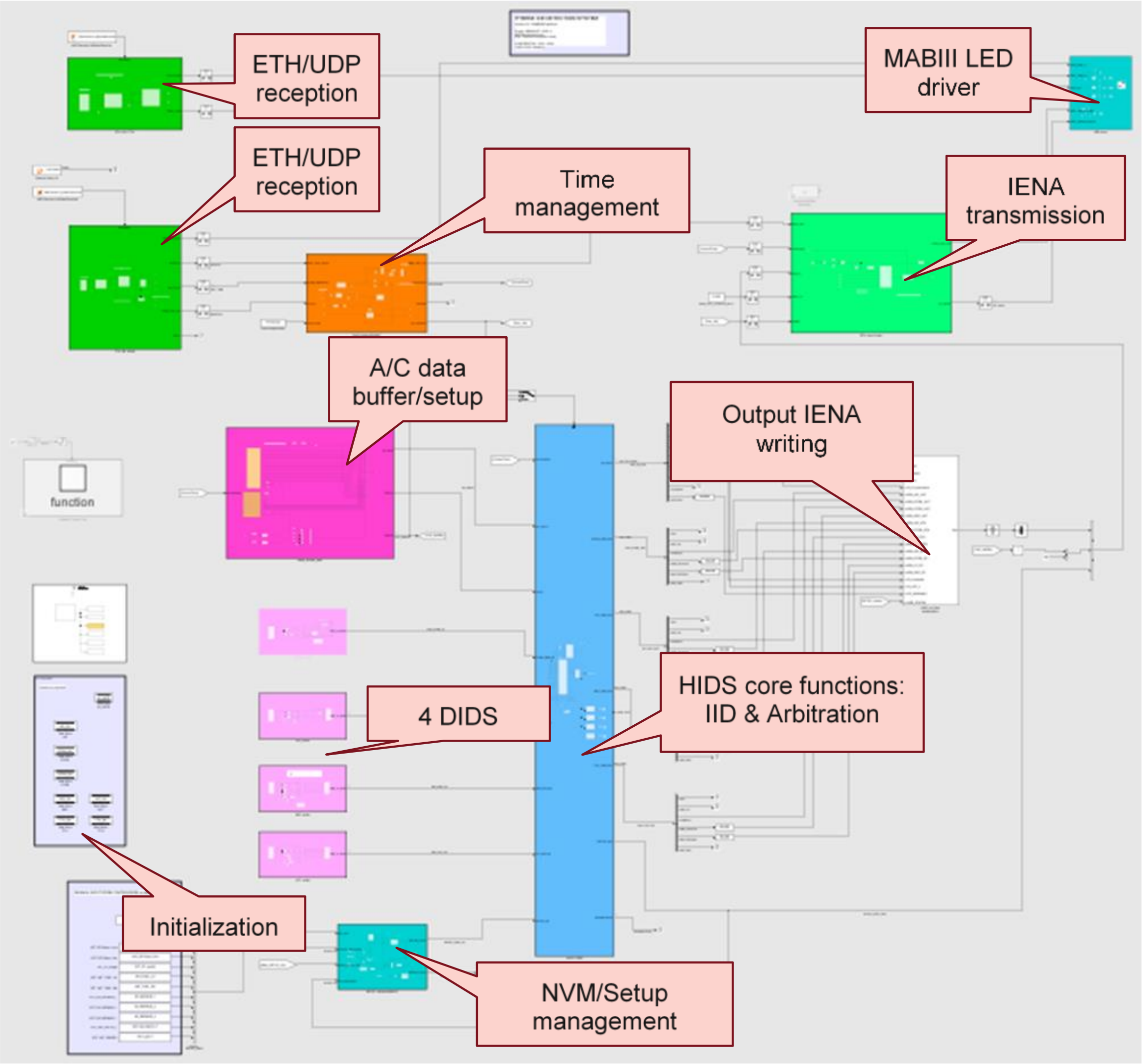
HIDS **hardware** definition



HIDS **validation** and **laboratory tests**

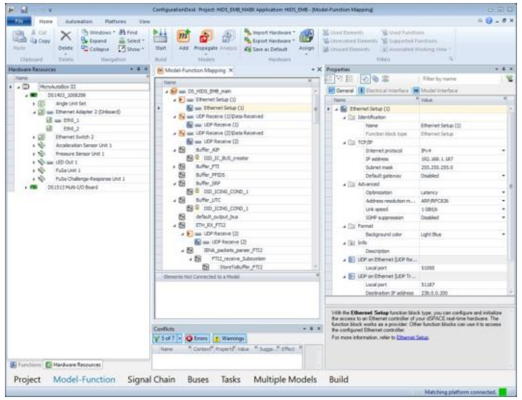
HIDS A/C **installation** and **integration**

HIDS Functions and Simulink model



Why SIMULINK?

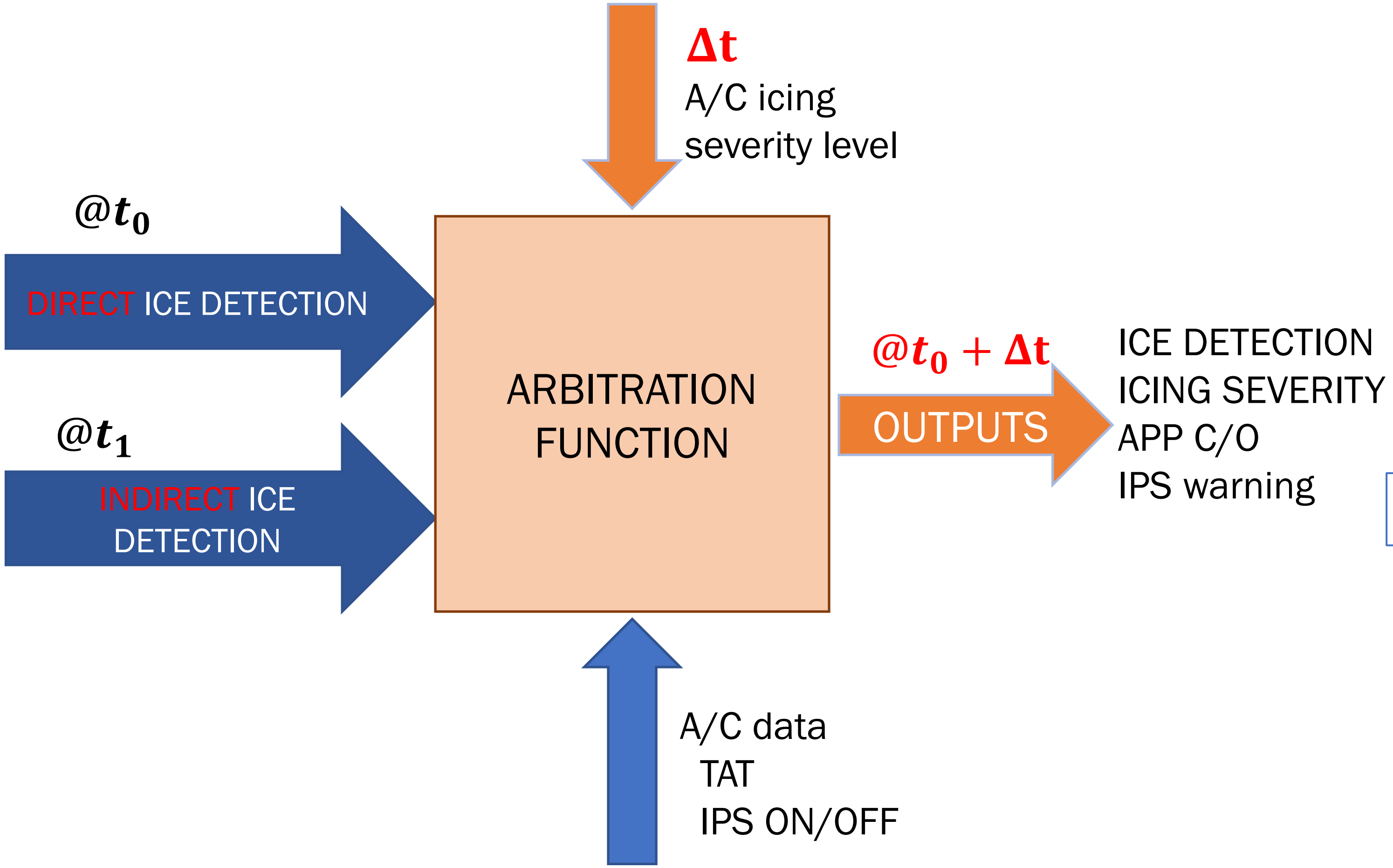
1. **Easy** prototyping environment.
2. The **IID** model provided by DLR is a ***protected* Simulink model**: a compatible execution environment was required.
3. Simulink models are supported by **dSpace MicroAutobox** (hardware chosen for HIDS). **dSpace tools** allow to convert Simulink HIDS model into a ***real-time code*** by adding specific libraries **Ethernet UDP protocol**, chosen for FT data transmission.



dSPACE MAB III and Configuration desk (credit SAFRAN)

Insight on Arbitration function

Aim of Arbitration function: to extract a **single, consistent output** from Direct and Indirect detections!



DIDS → early detections

IID → need of a certain ice accretion on the airframe

Arbitration outputs provided after a certain delay Δt and if $TAT \leq TAT_{cr}$

Definition of Δt

1. Fixed value
2. $\Delta t = \frac{(\tau_{MAX} - X\% \, \tau_{MAX})}{IAR_{DIDS}}$

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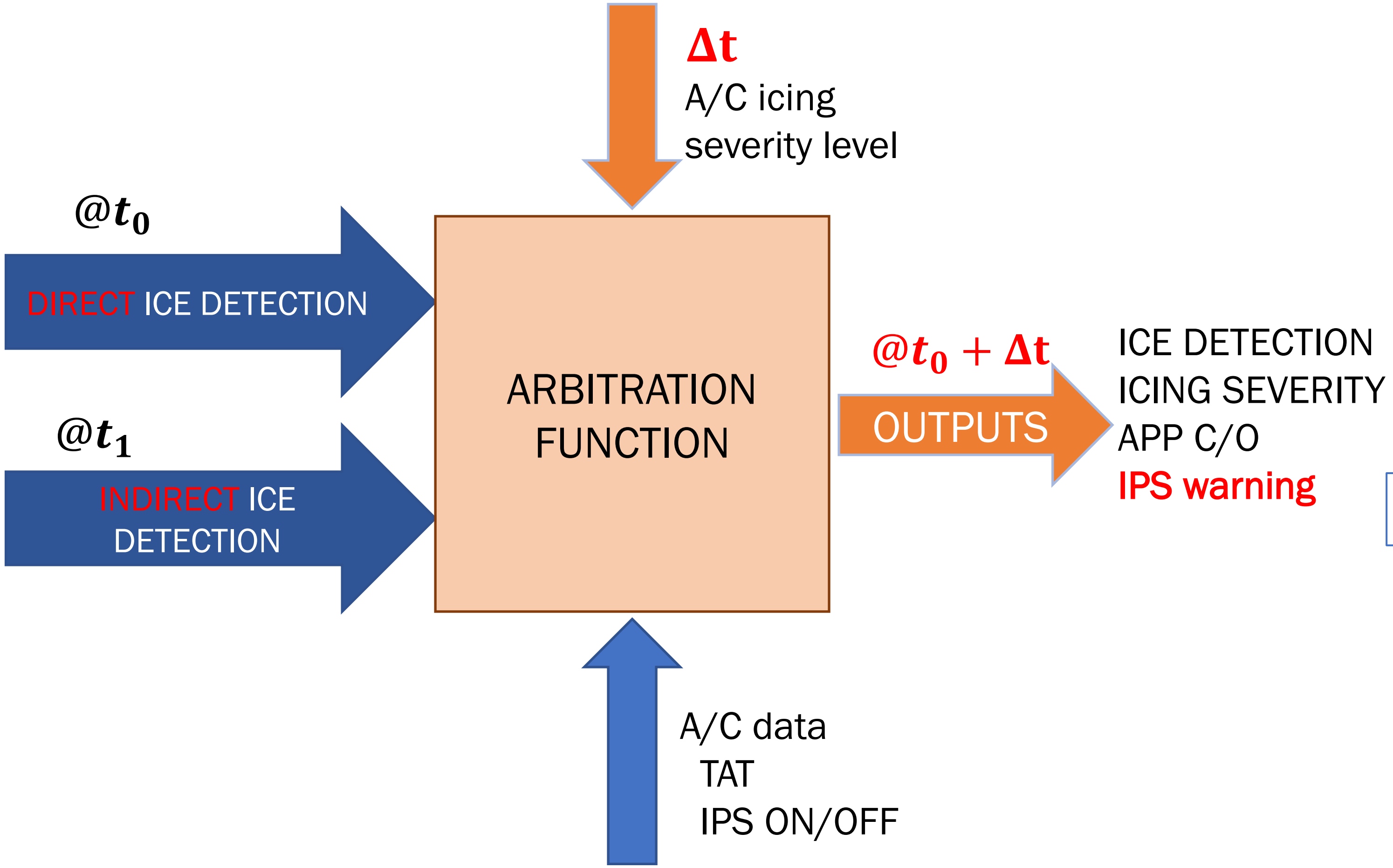

DIDS ➔ **early detections**

IID ➔ need of a certain **ice accretion** on the airframe

Arbitration outputs provided after a certain delay Δt and if $TAT \leq TAT_{cr}$

Definition of Δt

1. Fixed value
2. $\Delta t = \frac{(\tau_{MAX} - X\% \, \tau_{MAX})}{IAR_{DIDS}}$

IPS warning if IID detects after IPS activation

Residual ice accretion

- Runback ice
- App O condition

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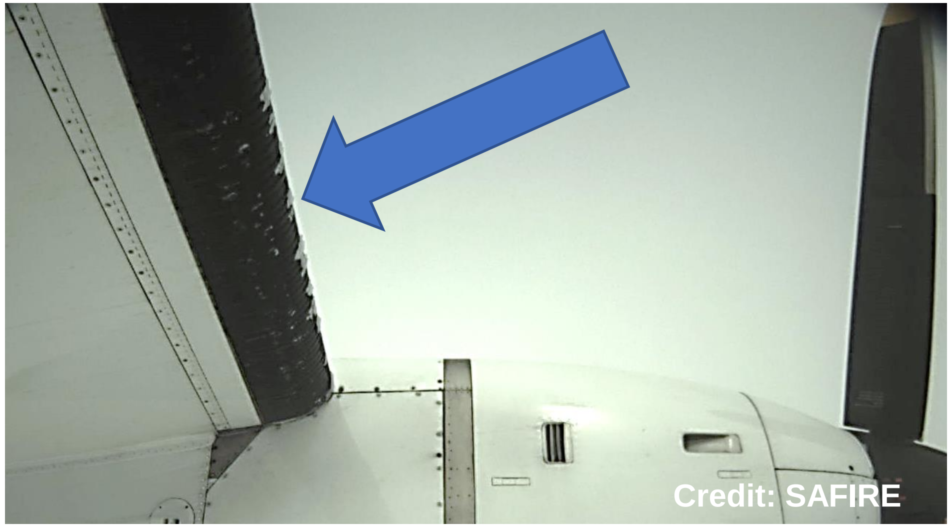
Indirect Ice Detection function design

Performance-Based Ice Detection

- Core of the SENS4ICE Indirect Ice Detection (IID)

Flight Performance = Nominal Aircraft Performance

- "*Expectable Variation*":
  - production tolerances
  - aircraft skin repairs
  - aircraft skin contamination, e.g., dirt
  - engine aging causing reduced efficiency
  - or engine contamination
- "**Variation to be detected**":
  → subject to the indirect ice detection approach



Performance Based (Indirect) Ice Detection

Abnormal Aircraft Performance Monitoring:

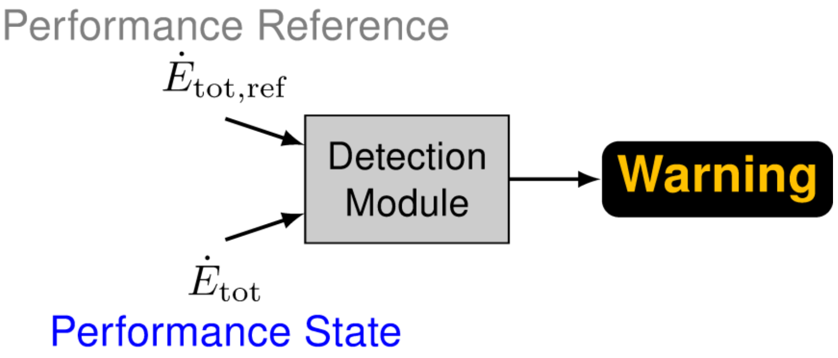
- Total Energy:

$$E_{tot} = \frac{1}{2} \cdot m_{AC} \cdot V_{TAS}^2 + m_{AC} \cdot g \cdot H$$

- Power Imbalance:

$$\dot{E}_{tot} = V_{TAS} \cdot \dot{V}_{TAS} \cdot m_{AC} + \frac{1}{2} \cdot V_{TAS}^2 \cdot \dot{m}_{AC} + g \cdot \dot{H} \cdot m_{AC} + g \cdot H \cdot \dot{m}_{AC}$$

- Detection Principle



- Performance variation as equivalent drag coefficient

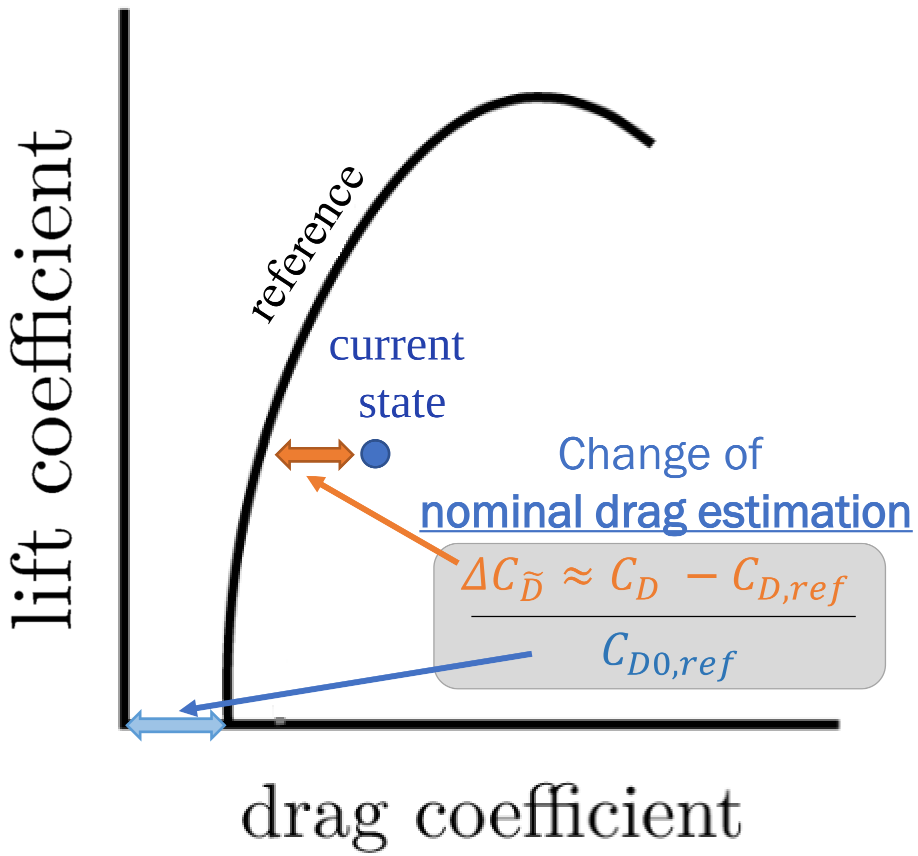
$$\Delta C_{\tilde{D}} \approx \frac{\dot{E}_{tot,ref} - \dot{E}_{tot}}{V_{TAS} \cdot \overline{q} \cdot S}$$

with $\dot{E}_{tot,ref}$ subject to further corrections

Credit: DLR

Flight Performance Reference Data Base

- Reference data required to compute the reference power imbalance $\dot{E}_{tot,ref}$
- Must include the aircraft performance
  - e.g., via multi-dimensional model for $\dot{E}_{tot,ref}$ (e.g. table)
  - aerodynamic reference and engine thrust model → used for SENS4ICE
- Reference could be based on flight data or only preliminary design data for new aircraft
- For SENS4ICE flight test:
  - Specific adaption of reference required due to significant aircraft modifications



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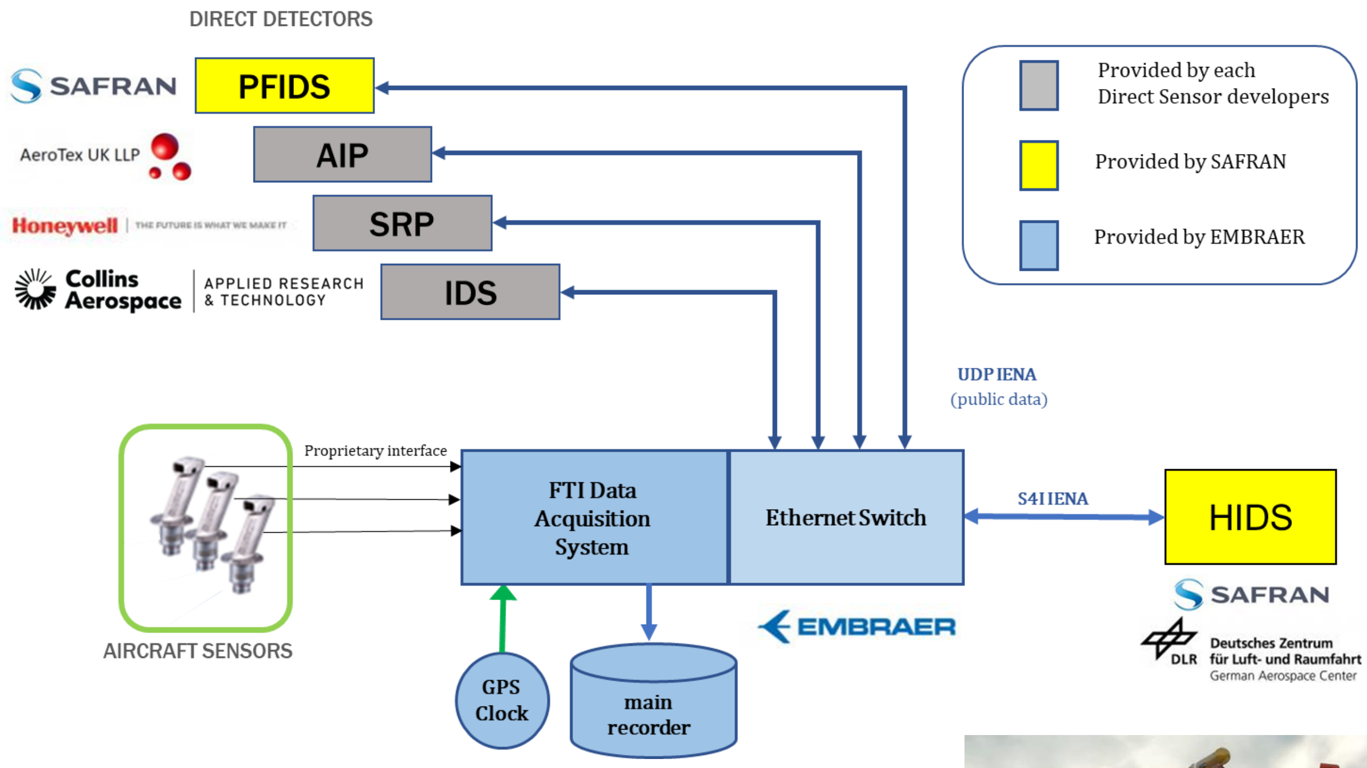
HIDS Flight Test Architectures

Embraer Phenom300 - HIDS FT architecture



Aircraft data provided by

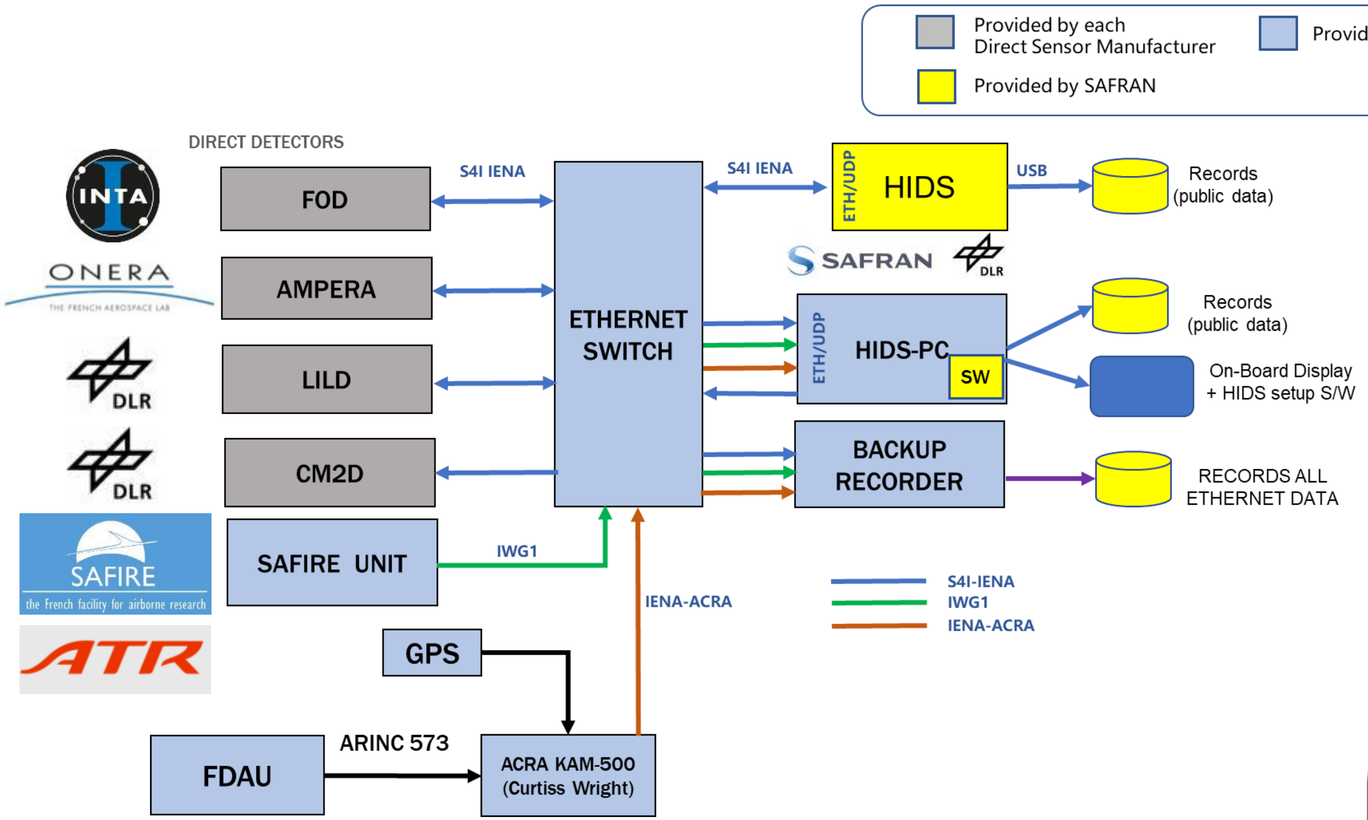
- FTI System (ETH/UDP, IENA S4I format)

Direct Ice Detectors

- PFIDS (SAFRAN)– Ice Accretion Detector
- AIP (AEROTEX) – Icing Condition Detector
- SRP (HONEYWELL) – Icing Condition Detector
- IDS (COLLINS) – Icing Condition Detector

Embraer Phenom 300 used for US Flight Test campaign
(credit Embraer)

SAFIRE ATR42 - HIDS FT architecture



Operator working with HIDS PC.
(credit SAFRAN)

Aircraft data provided by

- SAFIRE FTI (IWG1 format)
- ATR FDAU (ARINC 573 converted into ETH/UDP by ACRA equipment)

Direct Ice Detectors

- FOD (INTA) – Ice Accretion Detector
- AMPERA (ONERA) – Icing Condition Detector
- LILD (DLR) – Ice Accretion Detector
- CM2D (DLR reference probe)

HIDS PC functions (*HIDS_ATR_FT* tool)

- To translate ACRA and IWG1 frames to S4I IENA format
- To enable HIDS/IIDS Initialization
- To monitor/display HIDS and DIDSs outputs
- To record all public data on network (backup)

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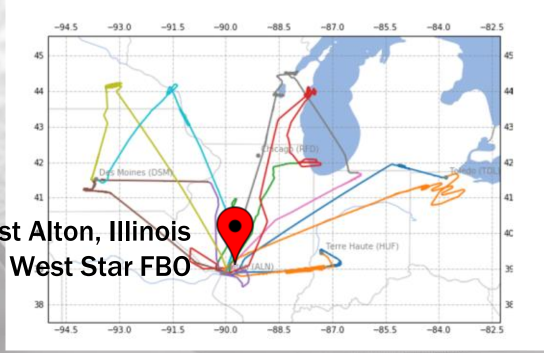
Flight Test Results

Quicklook on HIDS/IID behaviour

US FT campaign

Location:



Period: Winter 2023 (February/March)

Flight hours: about 25

HIDS Communication:

HIDS/IID Initialization:

HIDS Ice Detection:

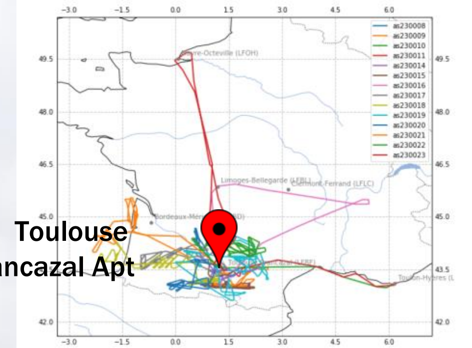
HIDS Recording: N/A

HIDS Monitoring: EMB FT Engineers

Credit Embraer

European FT campaign

Location:



Period: Spring 2023 (April)

Flight hours: about 50

HIDS Communication:

HIDS/IID Initialization:

HIDS Ice Detection:

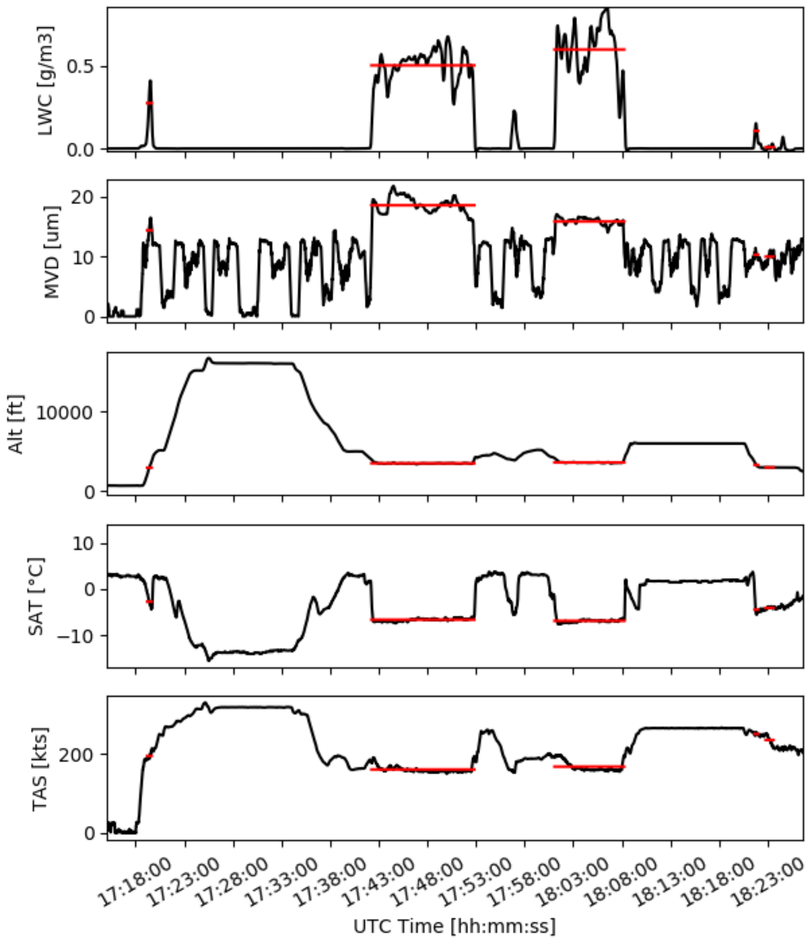
HIDS Recording:

HIDS Monitoring: SENS4ICE partners

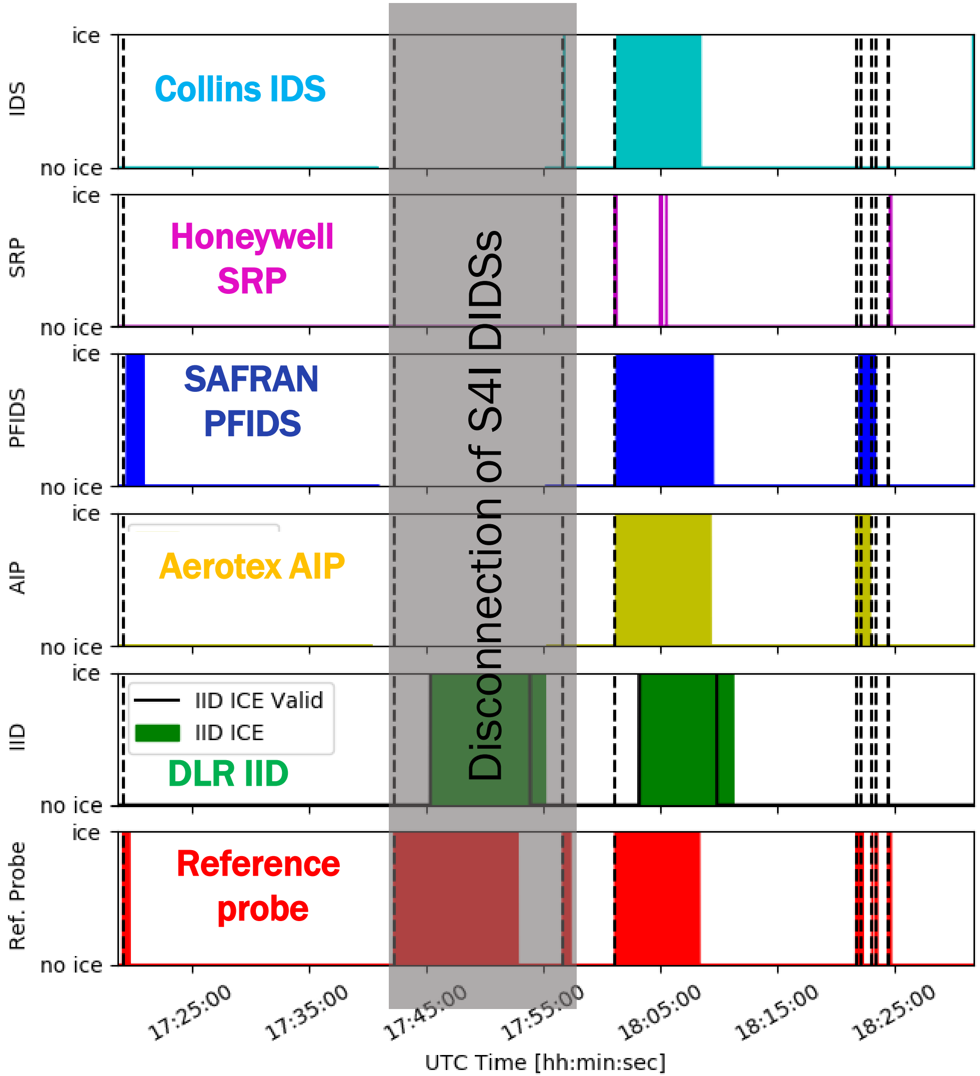
Credit SAFRAN

HIDS results for US FT campaign

Flight 1475 – 2: DIDS & IID detection in **App C conditions**



Reference probes and A/C data



HIDS results for US FT campaign

Flight 1475 – 2: HIDS arbitration results for each DID/IID couple

HIDS Arbitration (only if WoW = 0):

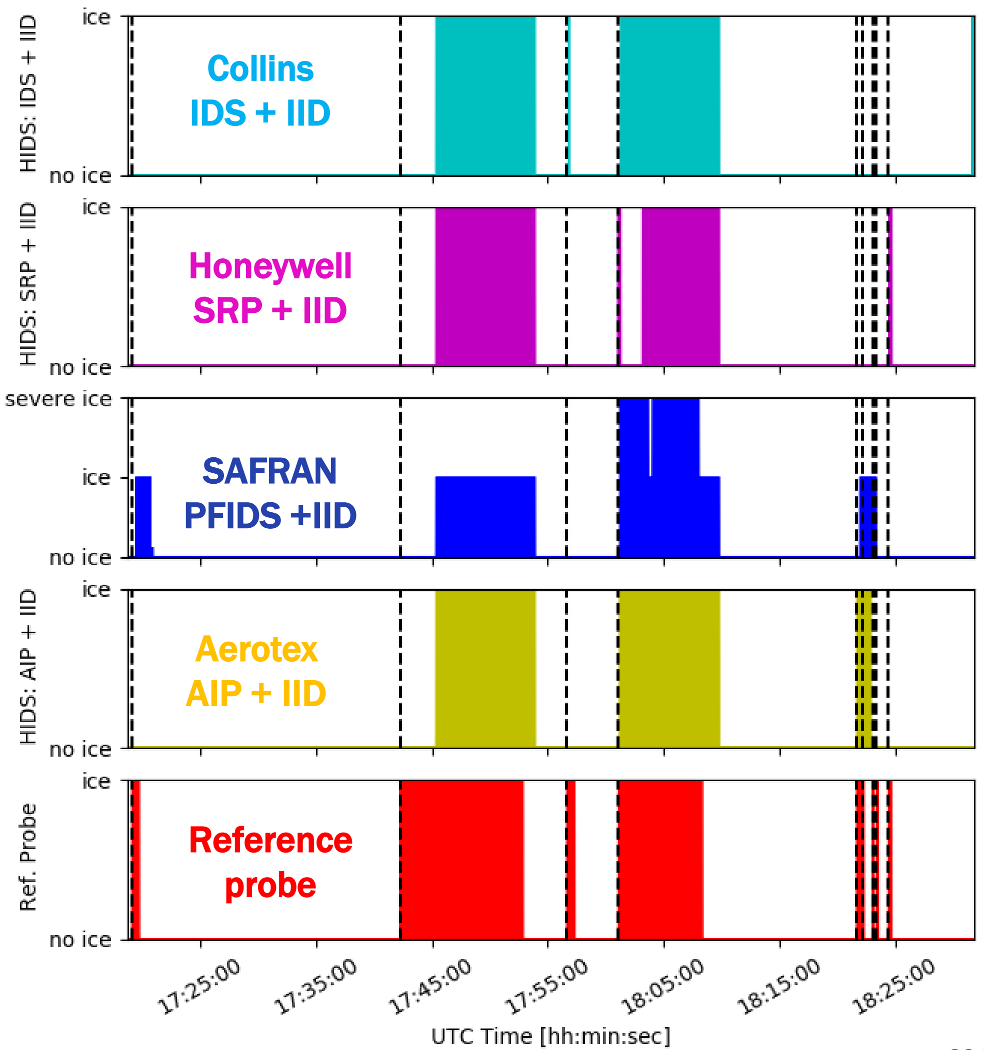
Synthetic output obtained by combining DIDS outputs with IID_ICE_V

IID ICE Valid = IID reliable + TAT<5°C

Possible Outputs:

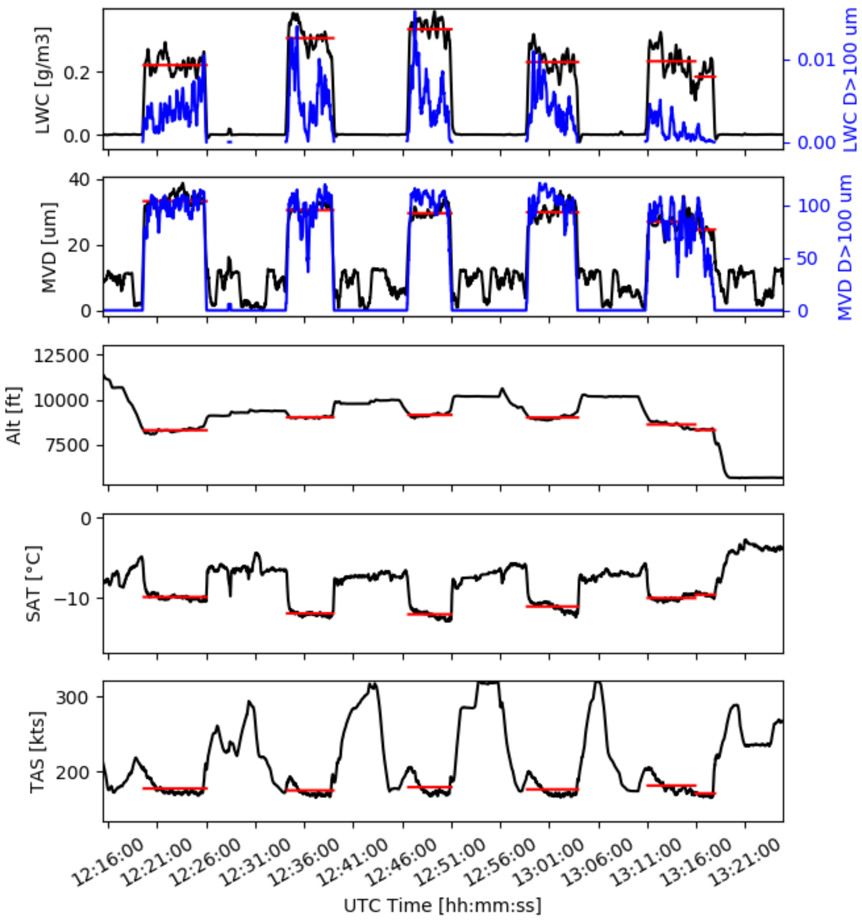
- 2: SEVERE ICE
  - IAR_{DIDS} > 1.25 mm/min
  - LWC_{DIDS} >1.2 kg/m3
- 1: ICE
- 0: NO ICE
- <0: APP 0

No delay applied to DIDS detection (Δt= 0)

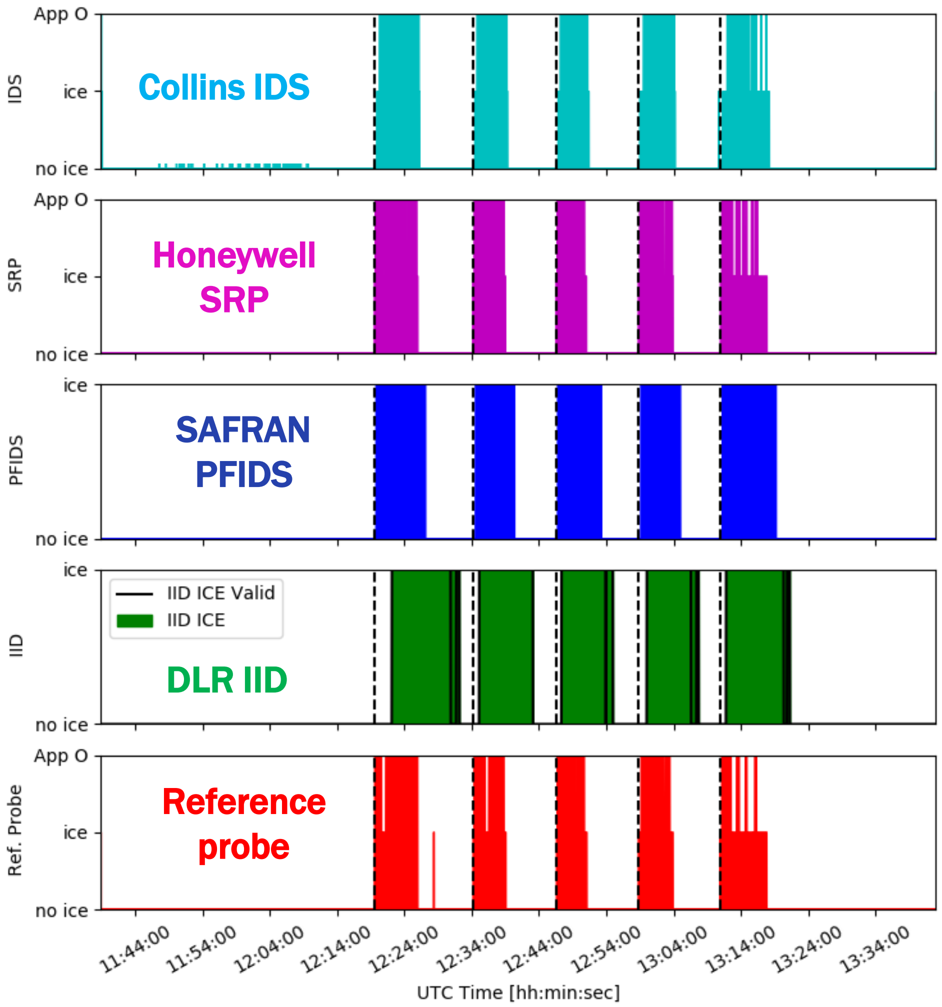


HIDS results for US FT campaign

Flight 1476 – 1: DIDS & IID detection in **App O conditions**

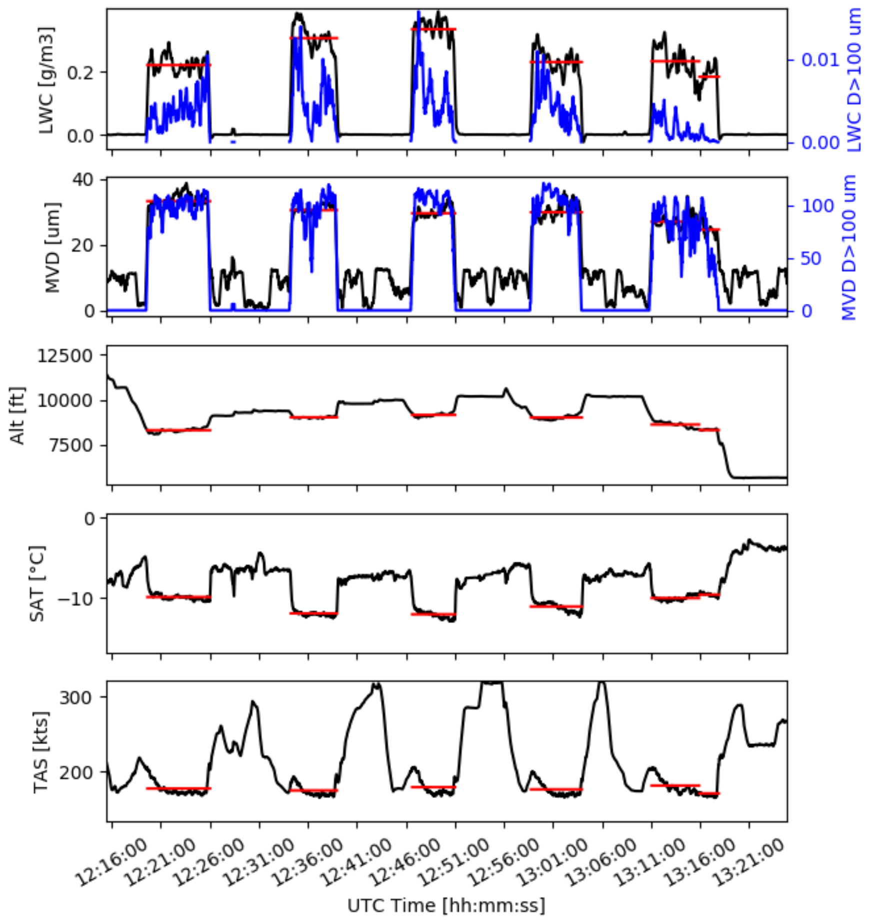


Reference probes and A/C data

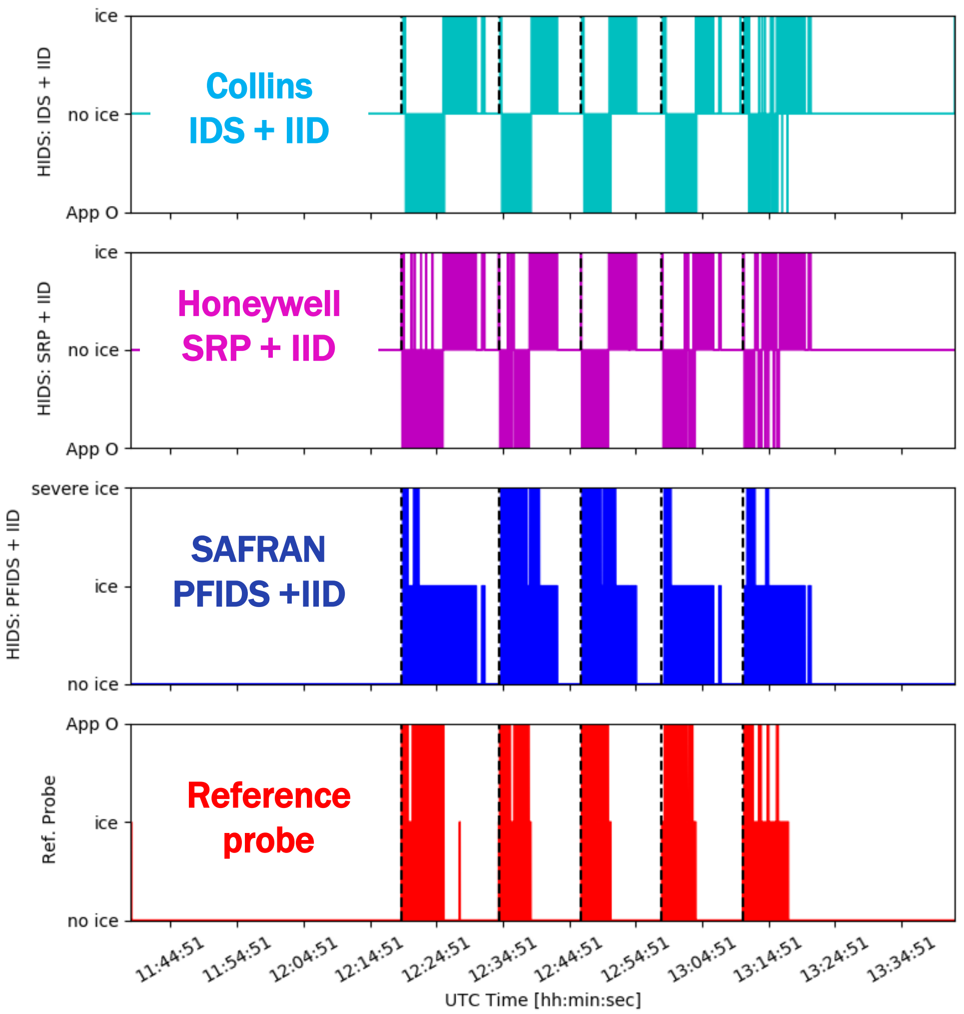


HIDS results for US FT campaign

Flight 1476 – 1: HIDS arbitration results for each DID/IID couple

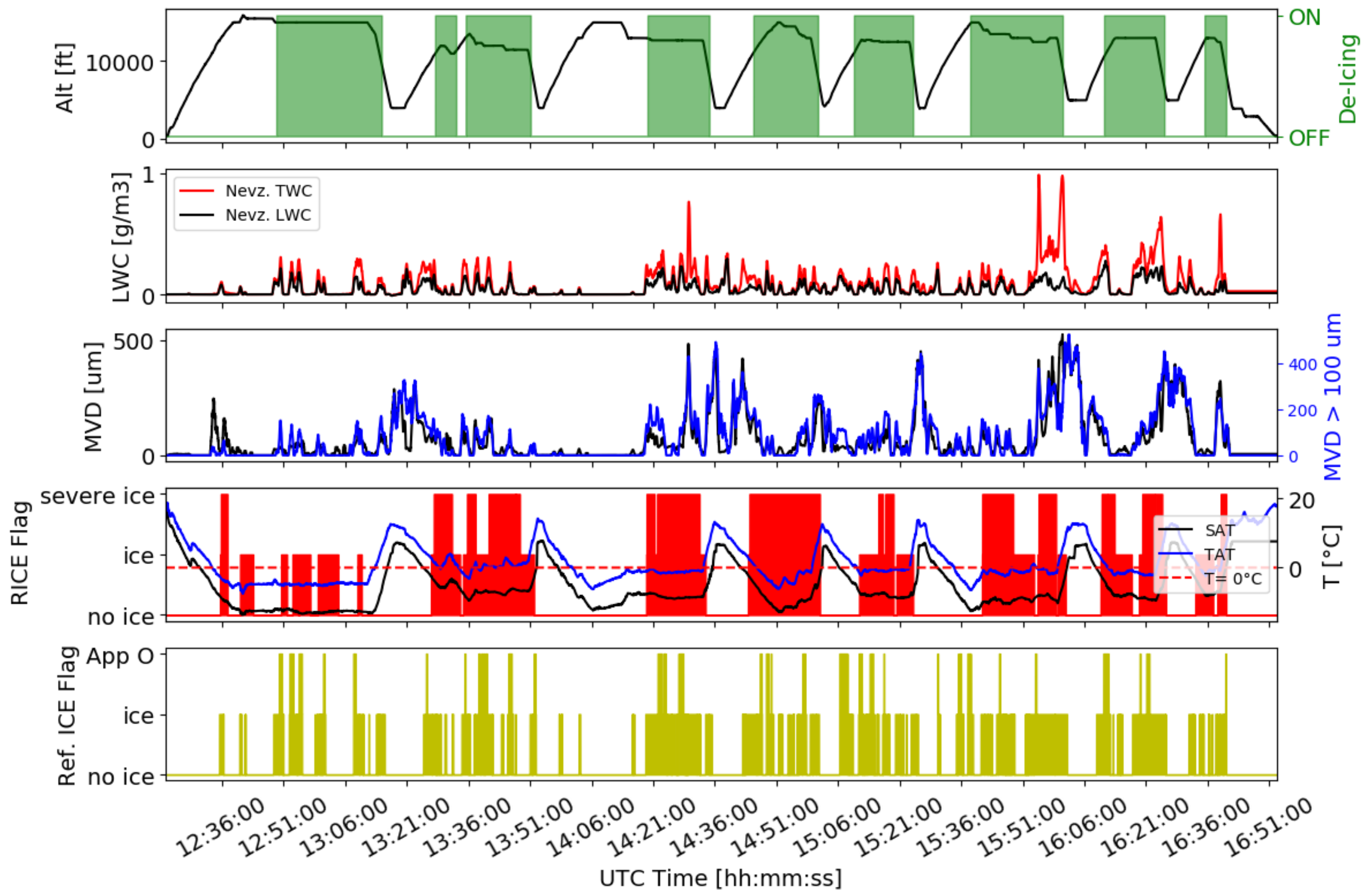


Reference probes and A/C data



HIDS results for EU FT campaign

Flight as230018: reference probes and A/C data



Several icing conditions encountered

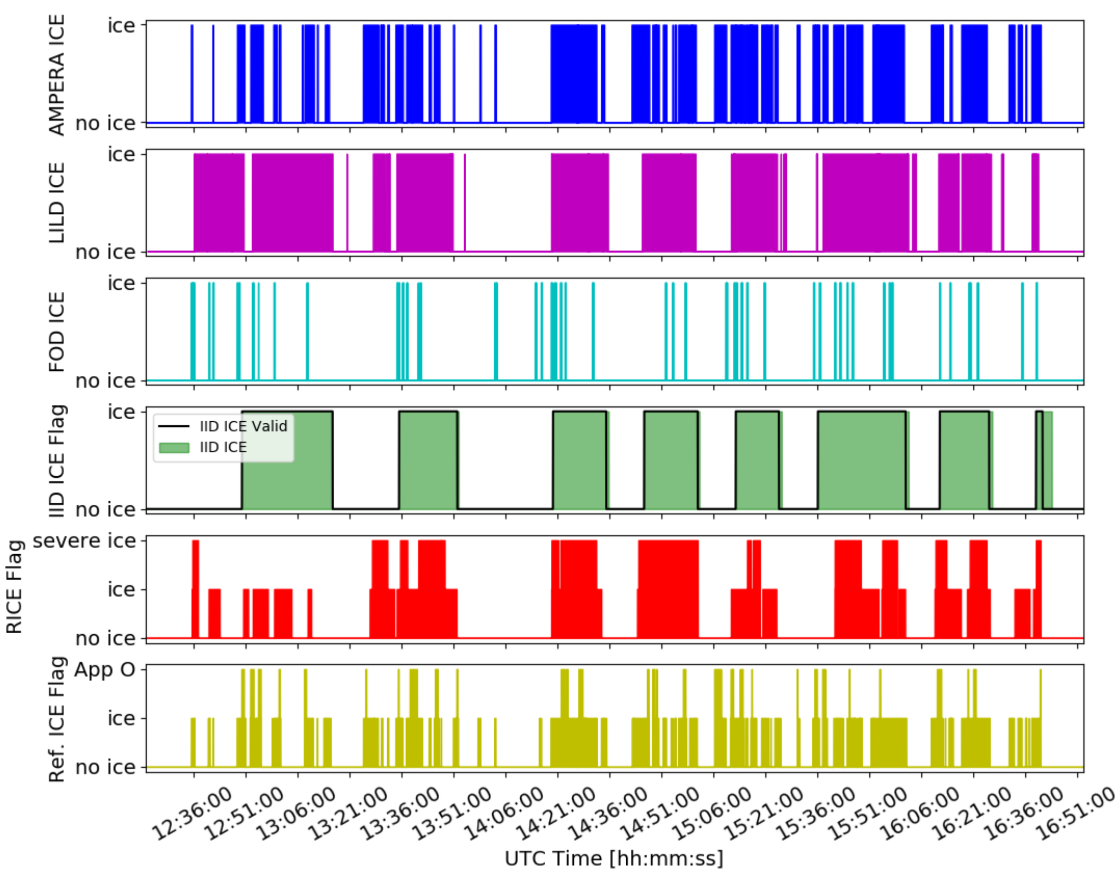
- 9 activations of IPS
- 20 RICE detections
- 251 Ref. probes detections
  - SLD presence
  - Ice Crystals presence
  - Lower LWC w.r.t. US FT campaign

Difficult characterization of Icing Conditions!

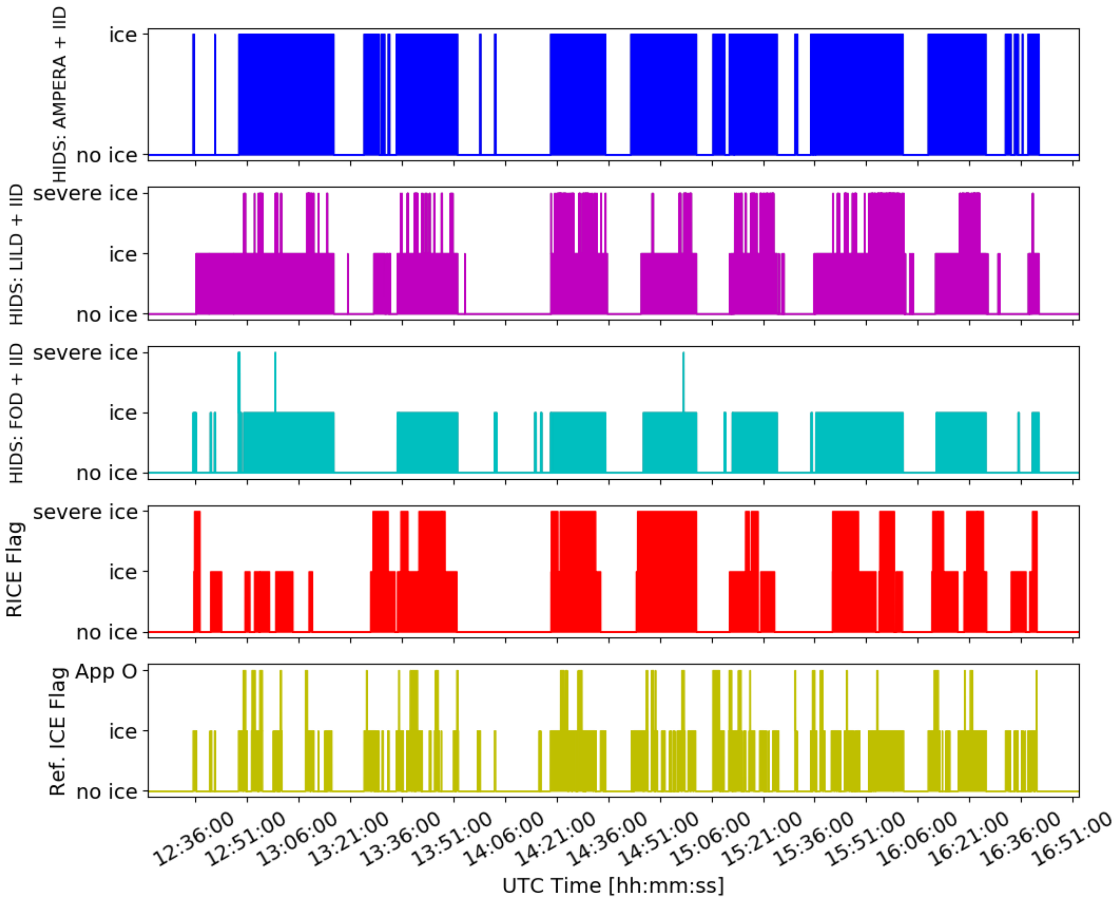
HIDS results for EU FT campaign

ONERA AMPERA
DLR LILD
INTA FOD
DLR IID
RICE probe
Ref. Probes

Flight as230018: ice detection results



DIDSs and IID Ice Detection

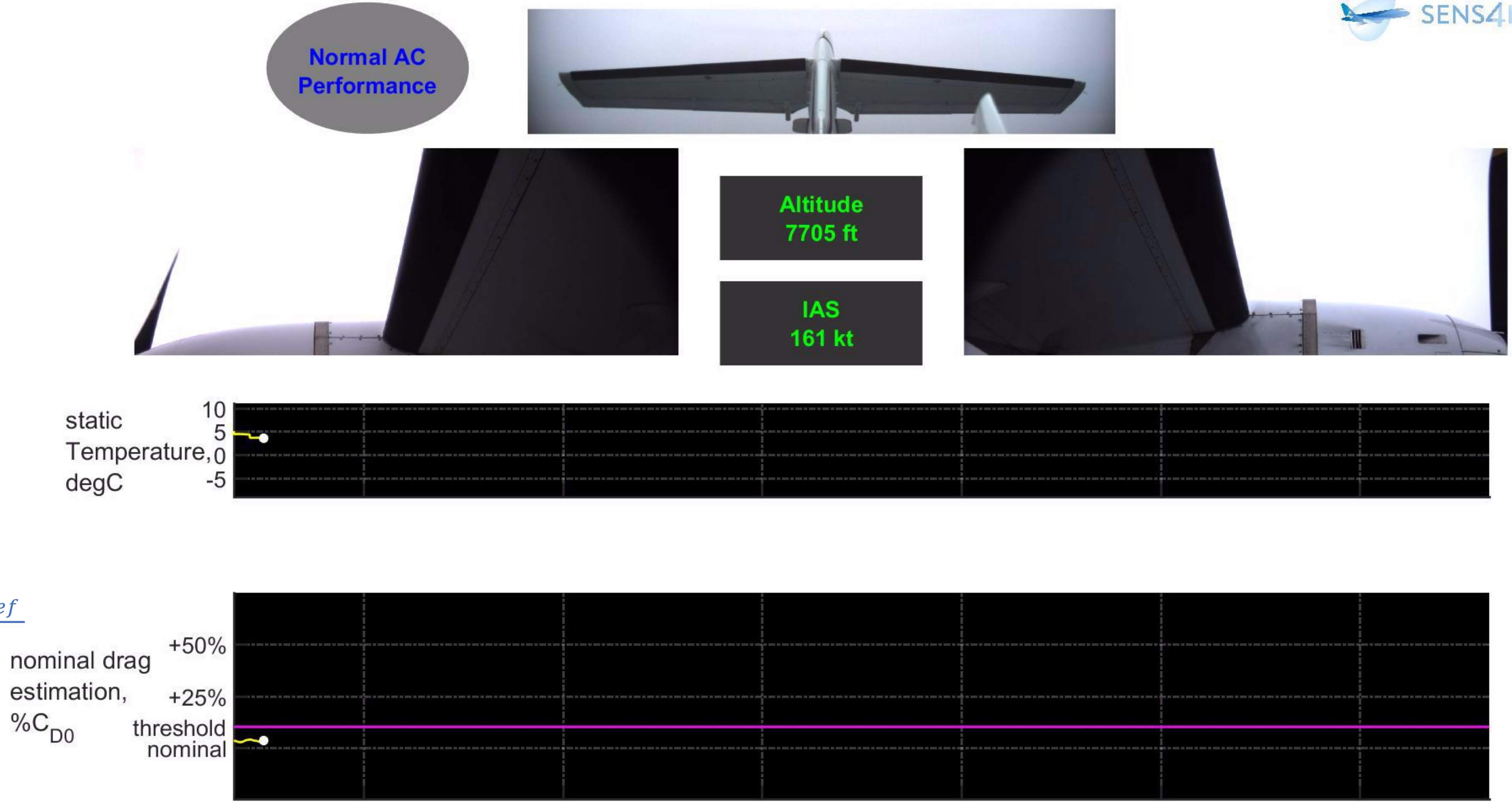


HIDS arbitration results

Example on detailed indirect ice detection results

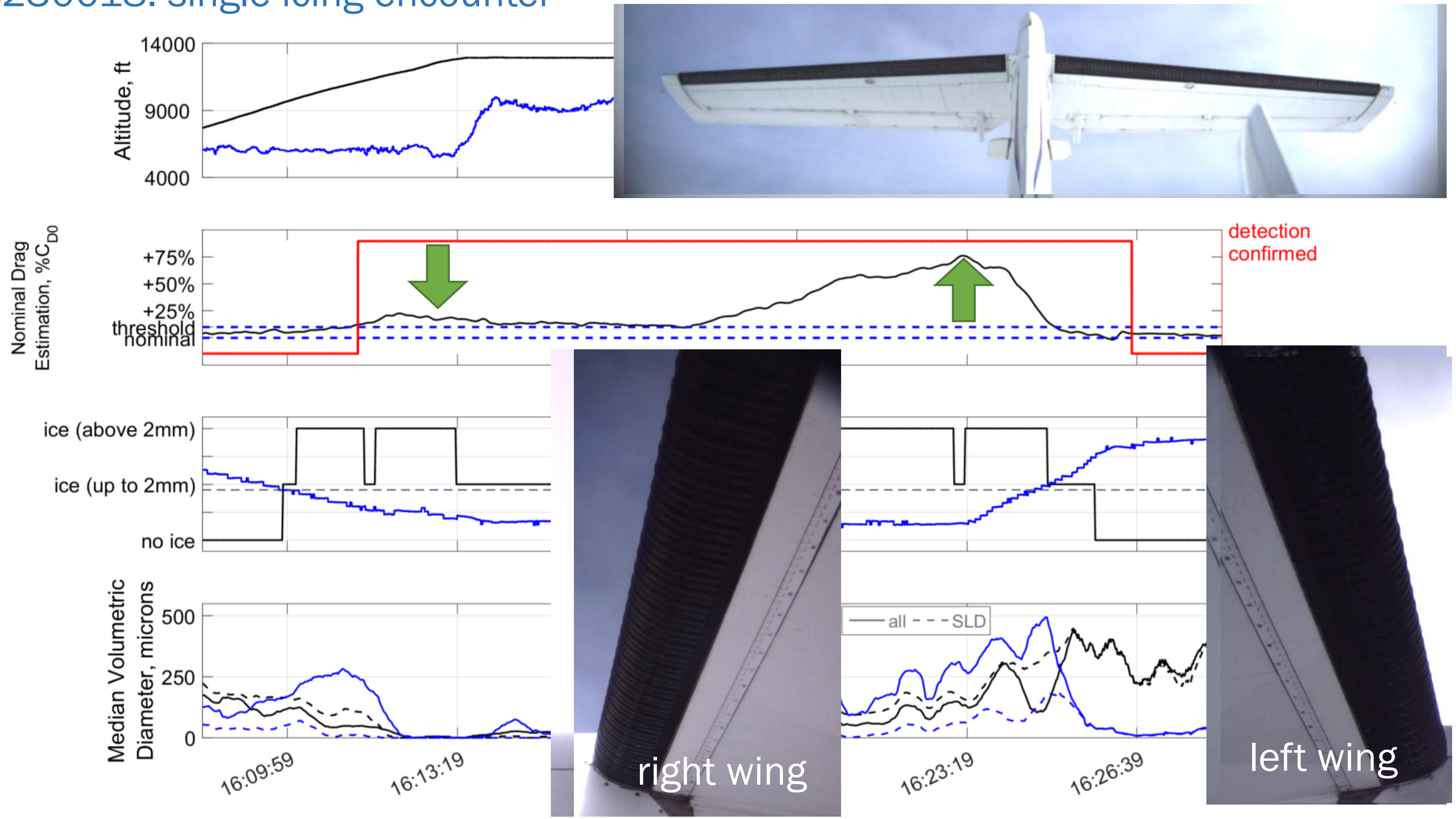
Flight as230018: single icing encounter

$$\frac{C_D - C_{D,ref}}{C_{D0,ref}}$$



Example on detailed indirect ice detection results

Flight as230018: single icing encounter



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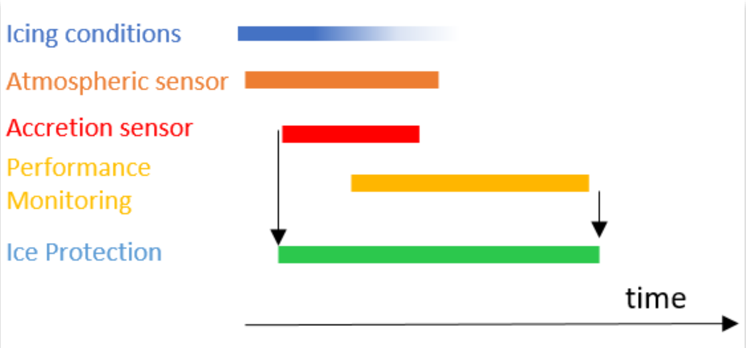
Conclusions and Outlook

Conclusions and Outlook (1)

- HIDS challenging development and testing, with large amount of different data to process and dependency on the aircraft type and architecture
- Very promising flight tests results: Good system behaviour during FT
- Benefits of hybridization:
  - Early detection and continuous performance monitoring (residual ice),
  - Potential optimization of Ice Protection.



→ **Hybrid Ice Detection approach achieved a TRL5**

Ways forward:

- **Flight Testing**: understanding actual SLD appearance during flight and specific impact on aircraft flight characteristics → more complete assessment of technologies and definition of required acceptable means of compliance for potential certification.
- **Approach**: investigation of HIDS enhancements with an optimize selection of direct sensors and exploitation of HIDS data in tight collaboration with aircraft manufactures
- **Airworthiness**: a new certification approach to be developed in collaboration with certification authorities.

Conclusions and Outlook (2)

- Indirect ice detection methodology based on an aircraft performance degradation
  → one key to success for SENS4ICE
- several advantages compared to direct detection (mainly complementary), e.g.,
  - retrofit capabilities (simple software solution)
  - highly beneficial information about the remaining aircraft capabilities → safe exit strategy
- Indirect ice detection provides redundancy for ice detection when hybridized
  → reduced risk for common cause failures
- Novel ice detection and chance for treatment of icing hazard in aviation including small-size vehicles of general aviation or drones

Ways forward:

- **Flight Testing:** further investigation of specific icing characteristics for using indirect detection output for icing severity assessment
- **System:** technology transfer to other vehicles operating in different icing environments
- **Airworthiness:** definition of certification strategy for indirect ice detection as stand-alone system

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.

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Indirect Ice Detection function design

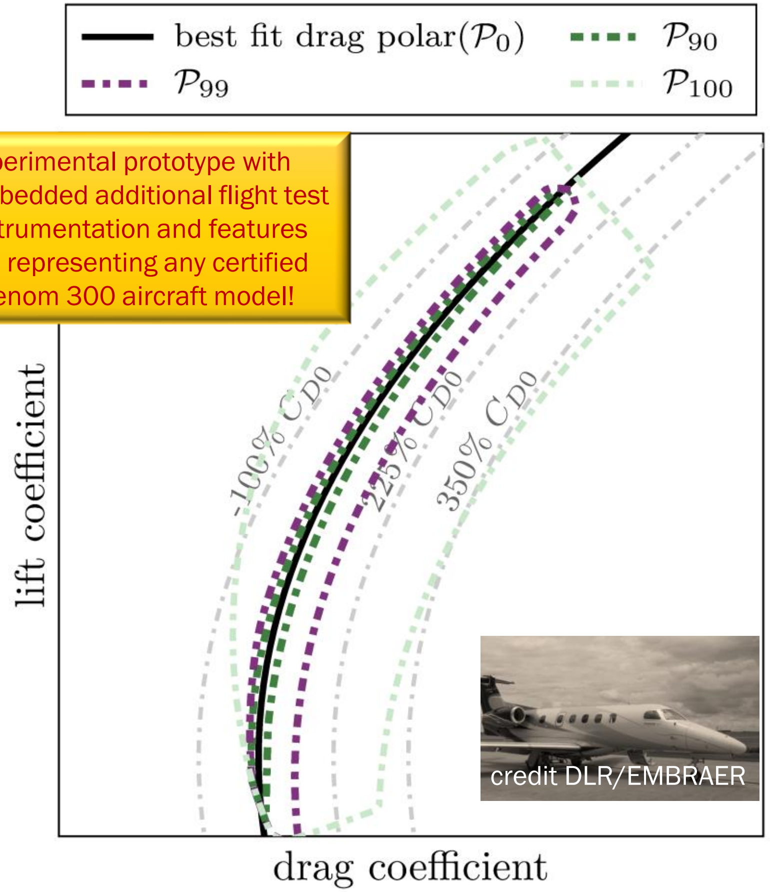
29 November 2023

Performance Variation of SENS4ICE Flight Test Benches

Big data analysis using fundamental engineering knowledge (**smart data approach**):

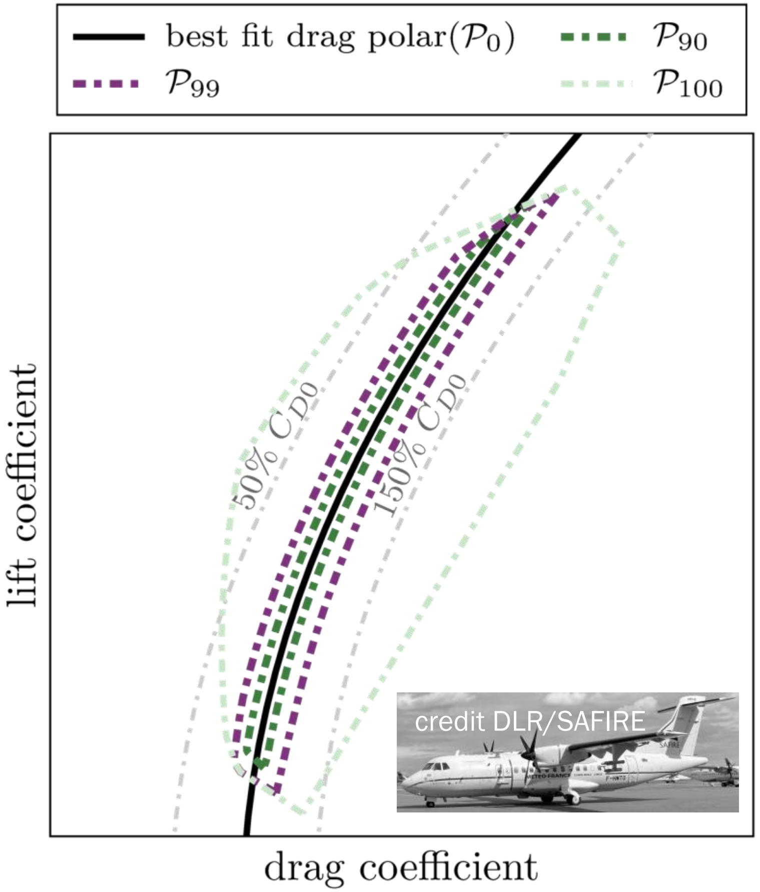
- operational flights similar to SENS4ICE target application
- only standard instrumentation as source of information
- **Conclusions:**
  → monitoring of aircraft flight performance using the regular sensors possible
  → level of precision allows detection of performance degradation induced by ice accretion at a very early stage

Embraer Phenom 300 prototype
(North America flight test campaign)



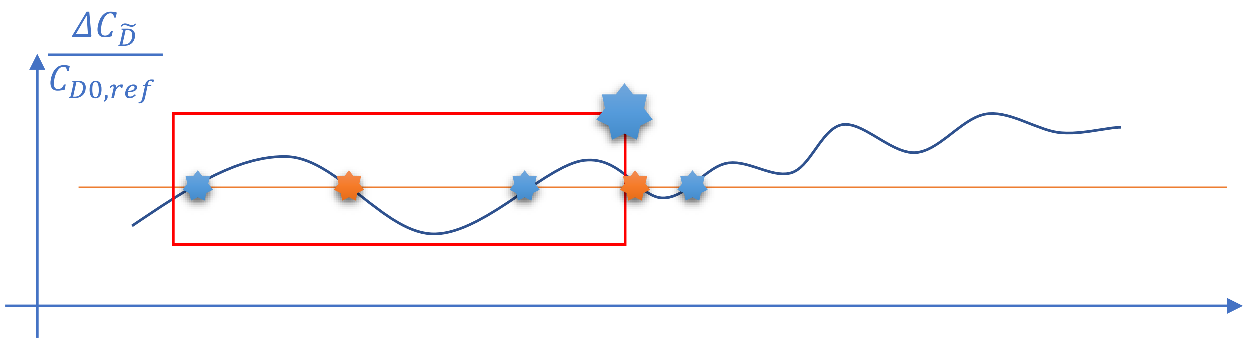
Experimental prototype with embedded additional flight test instrumentation and features not representing any certified Phenom 300 aircraft model!

ATR 42-320 flight test bench
(European flight test campaign)



Credit: DLR / Embraer / Safire

Detection Threshold and Confirmation Time



- Abnormal flight performance
  - airframe ice accretion persistent,
  - degradation constantly increasing
    → indirect ice detection
- Detection threshold on the equivalent drag coefficient
  → significant degradation and critical for safe flight
  → earlier if possible
- Detection based on relative value with based zero-lift drag coefficient
  → nominal case: relative value with no additional drag
  → estimated drag increase $\Delta C_{\tilde{D}}$ in % $C_{D0,ref}$
- Confirmation time for detection required to prevent false alarms by measured performance fluctuations
- Weighted moving averages used for filtering and confirmation

	SAFIRE ATR 42-320	Embraer Phenom 300
detection threshold as relative drag coefficient increase	10% (15%)	10%
confirmation timeframe for detection (threshold exceeded more than 50%)	20 s	20 s
confirmation time for reset (threshold undershot more than 50%)	180 s	180 s

Credit: DLR

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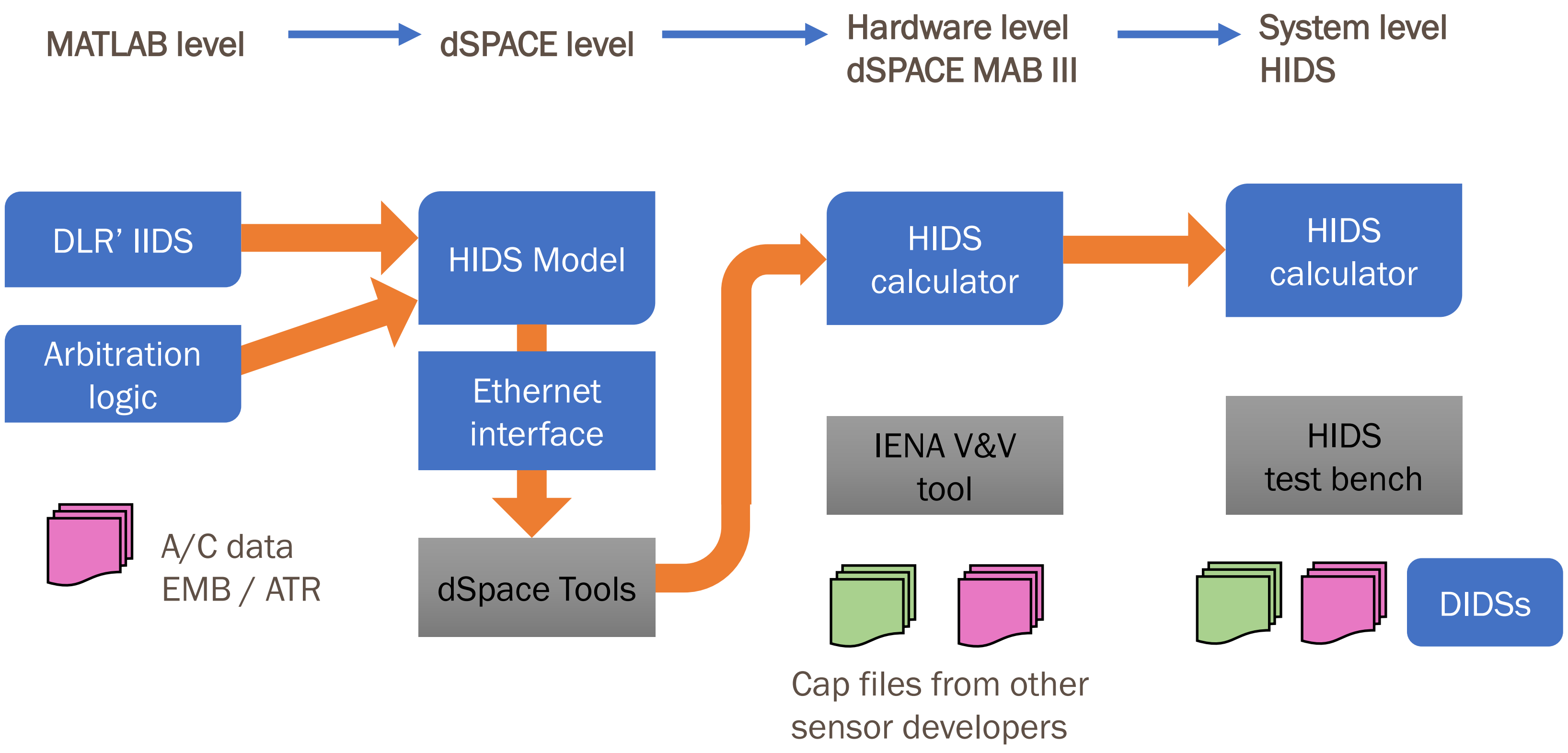
HIDS validation and laboratory tests

29 November
2023

HIDS validation and laboratory tests



Main testing phases

1. Validation of HIDS/IIDS Simulink model
2. Integration of HIDS Simulink model into dSPACE environment
3. Validation of HIDS Calculator Ethernet interfaces
4. Validation of the whole HIDS demonstrator

Development of a specific **test bench**: the **HIDS Monitor** PC application!

(CVI, National Instrument)

HIDS validation and laboratory tests

Test .mat file (provided by DLR)

Flight data

Ref. data

Flight Data

HIDS/IIDS initialization data

A/C Network Simulator

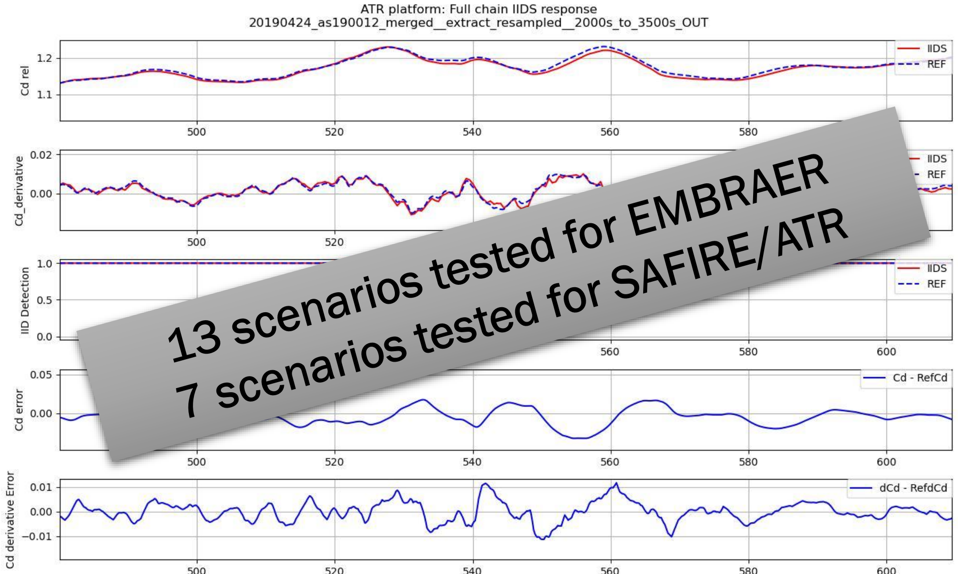
HIDS Monitor application

HIDS/IIDS (MAB III)

ETH/IENA protocol

Python post-processing tool

HIDS outputs compared to reference data



Results example

13 scenarios tested for EMBRAER

7 scenarios tested for SAFIRE/ATR

HIDS

Ref.