TESTING OF AN INDIRECT ICE DETECTION METHODOLOGY IN THE HORIZON2020 PROJECT SENS4ICE

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Christoph Deiler, DLR, DLRK, September 20th, 2023 | This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N° 824253

Introduction

- Hazardous effects of ice accumulations caused various accidents in the past despite the availability of countermeasures (anti-ice, deice)
- Resulting effects related to type and location of corresponding ice accretion, which have dependency on, e.g., atmospheric conditions, flight condition, aircraft geometry, …
- Goal: early detection of ice accretion and icing conditions
  →SENS4ICE Hybrid Ice Detection Approach

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

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

Tactical: new nowcasting to enhance 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)

Indirect Ice Detection System (IIDS)
- software solution for reliable, cost effective and retrofittable ice detection
- providing necessary information to maintain safe flight conditions
- potential enabler for more selective activation of anti-ice systems with reduced energy consumption

Credit: DLR

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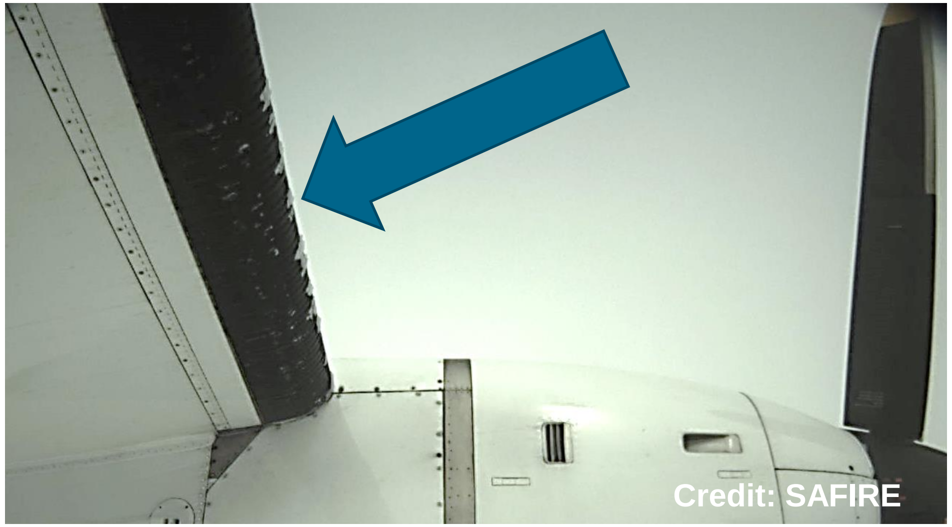
Performance-Based Ice Detection

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



Credit: DLR

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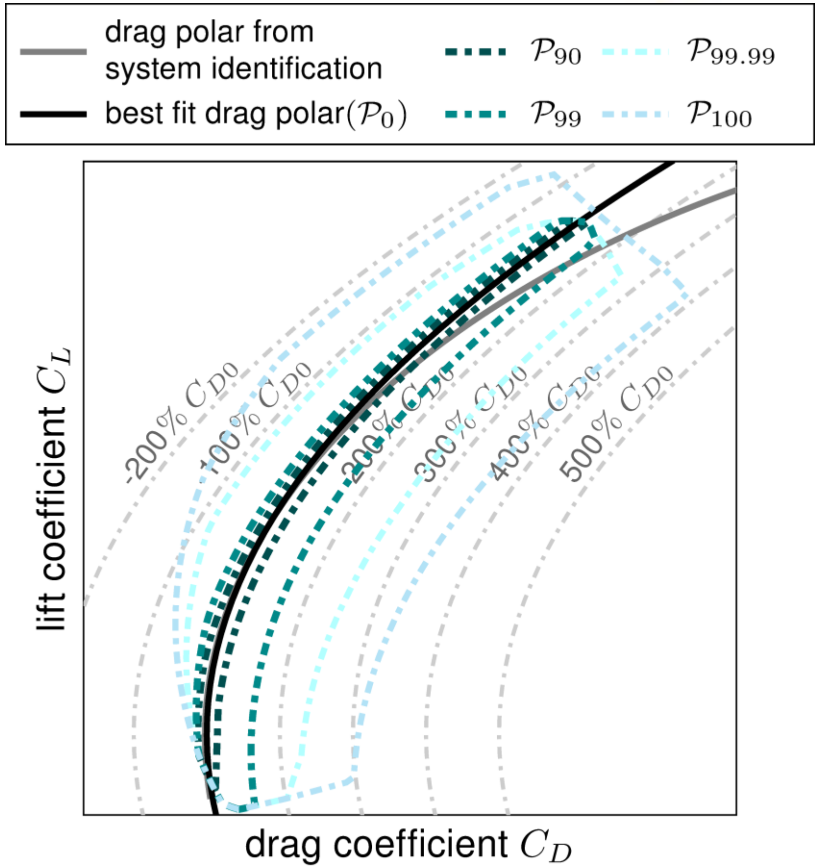
Performance Variation of SENS4ICE Flight Test Bench Embraer Phenom 300 Prototype

Big data analysis using fundamental engineering knowledge (**<u>smart data approach</u>**):

- operational flights similar to SENS4ICE target application
- only standard instrumentation as source of information

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



→ 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

Credit: DLR/ Embraer

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Performance-Based (Indirect) Ice Detection

Abnormal Aircraft Performance Monitoring:

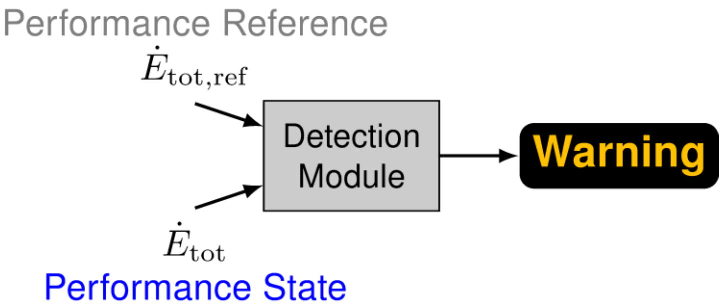
- Total Energy:

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

- 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



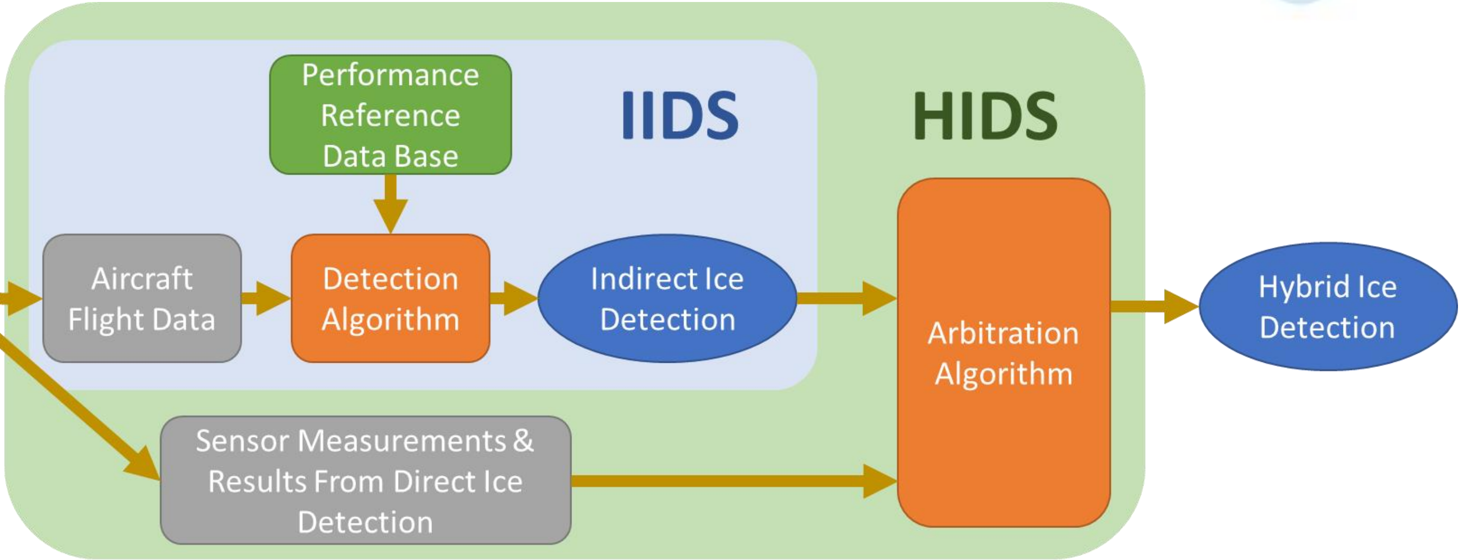
- Performance variation as equivalent drag coefficient

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

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

Credit: DLR

Indirect Ice Detection System (IIDS)

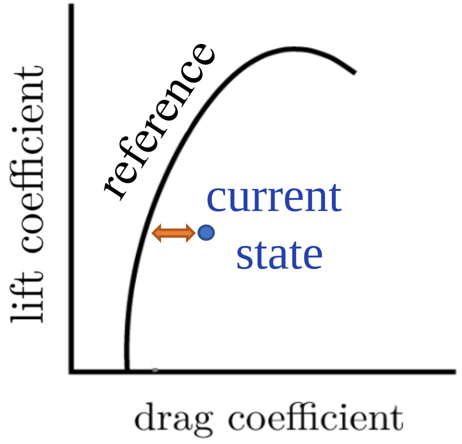


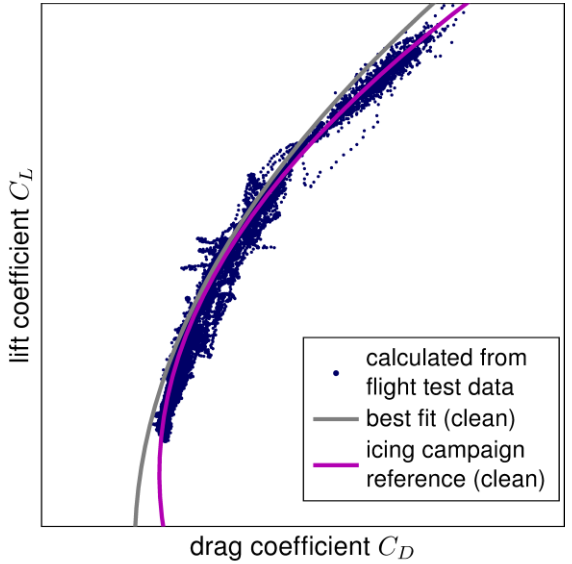
- Core part of the hybrid ice detection system (HIDS)
- Integration of DLR's IIDS in HIDS implementation made by SAFRAN Aerosystems
- IIDS for a specific aircraft type, which concern
  - the flight data preprocessing: information about the current aircraft state
  - the flight performance reference data base
  - the indirect ice detection threshold and confirmation times
  - the detection reliability conditions

Credit: DLR / Embraer / SAFIRE

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





Credit: DLR

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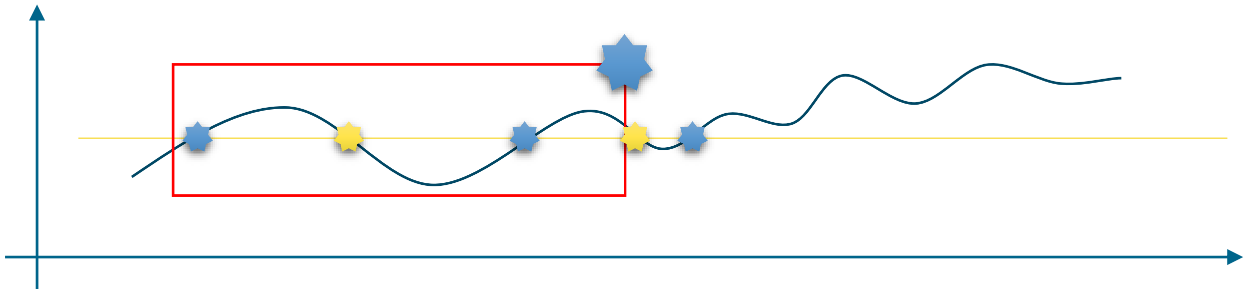
Detection Threshold and Confirmation Time

- 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 threshold as relative drag coefficient increase	10%
confirmation timeframe for detection (threshold exceeded more than 50%)	20 s
confirmation time for reset (threshold undershot more than 50%)	180 s

- Detection based on relative value with based zero-lift drag coefficient
  → nominal case: relative value 100% with additional drag coefficient is zero
- Confirmation time for detection required to prevent false alarms by measured performance fluctuations
- Weighted moving averages used for filtering and confirmation

Credit: DLR

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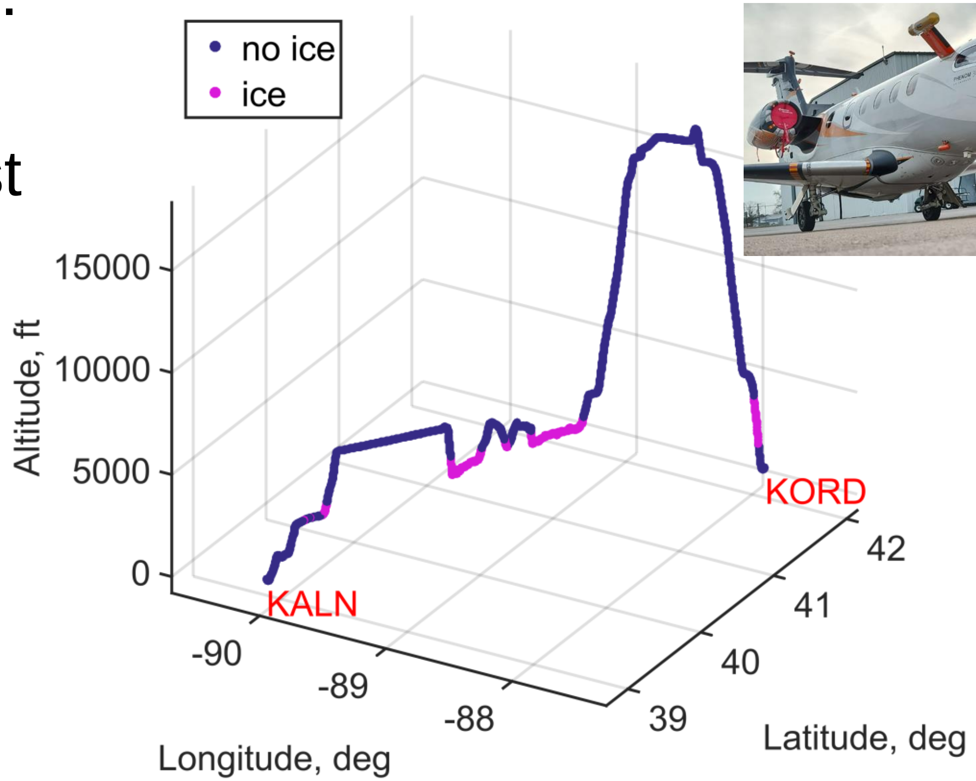
Example Test Flight – North America Campaign

- Flight from Chicago O’Hare to Alton / St. Louis on 23rd Feb. 2023
- Two icing encounters as SENS4ICE test points (App. C):
- Test Procedure:
  - Dive into icing clouds with clean aircraft (free of any ice)
  - Icing encounter with ice formation on unprotected surfaces
  - Climb out of cloud and de-icing of airframe with higher speed in warmer air



- for IIDS testing during SENS4ICE and HIDS interaction mainly airframe ice accretion with a detectable performance degradation is required!
- successful test if IIDS reliably detects ice formation / performance degradation

Credit: DLR / Embraer

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Typical Icing Encounter during SENS4ICE North America Campaign

Time-lapse video from cockpit camera in Phenom 300 prototype test aircraft

Credit: Embraer

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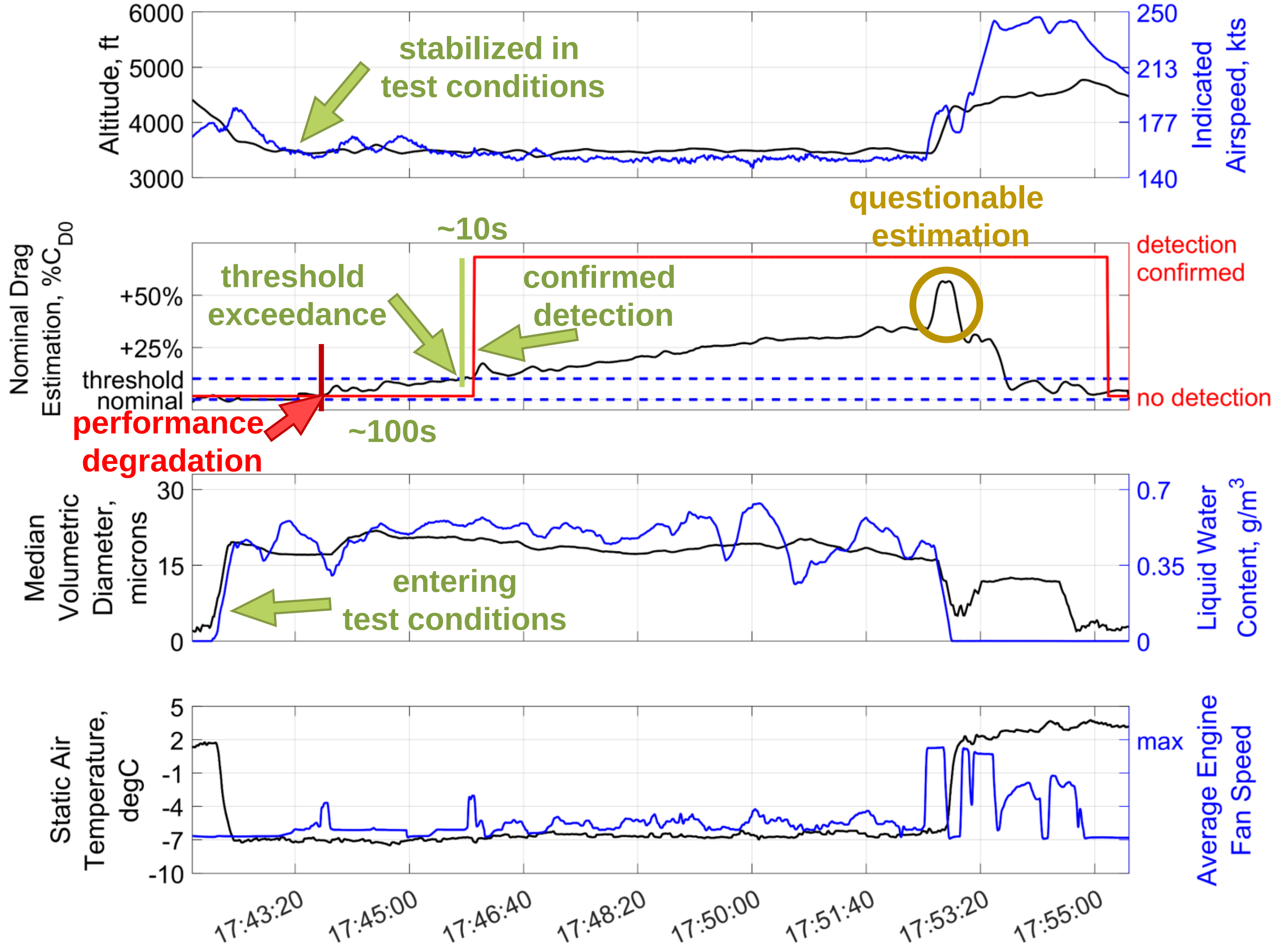
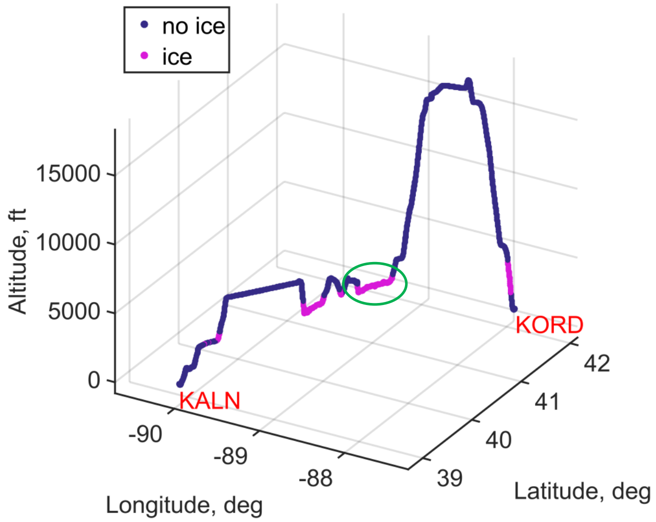
Example encounter

relatively fast and reliable detection





Credit: DLR/ Embraer

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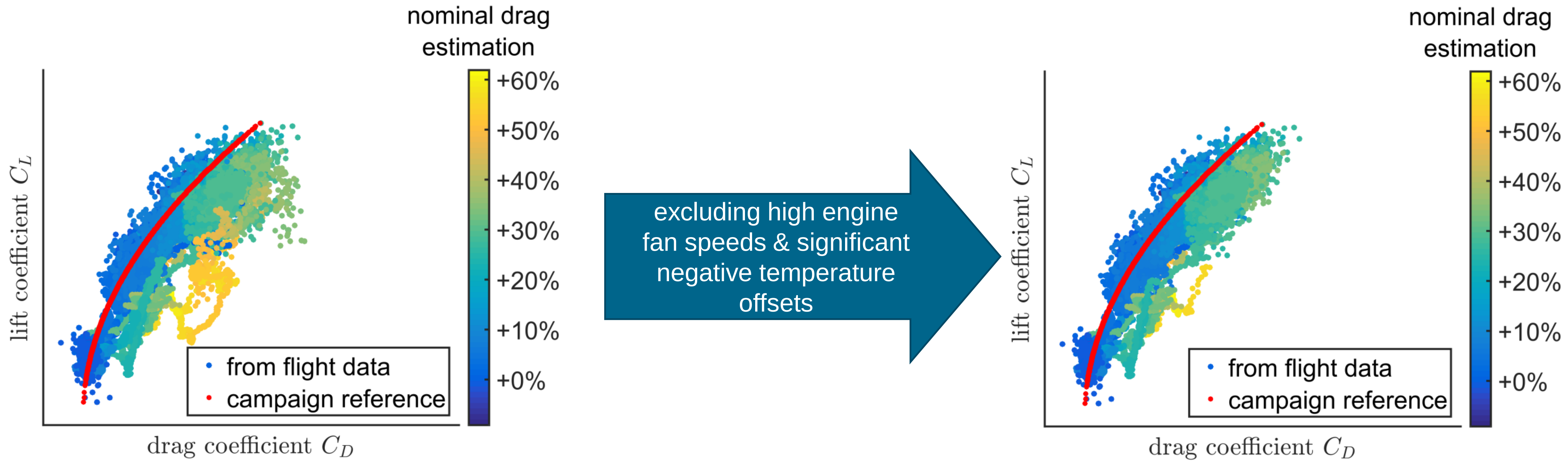
Aerodynamic Degradation due to Icing
Example Flight (23rd Feb. 2023)



Credit: DLR/ Embraer

- Engine thrust model shows deficiencies for high fan speeds at low temperatures in lower altitudes (neg. temperature offsets to standard atmosphere)

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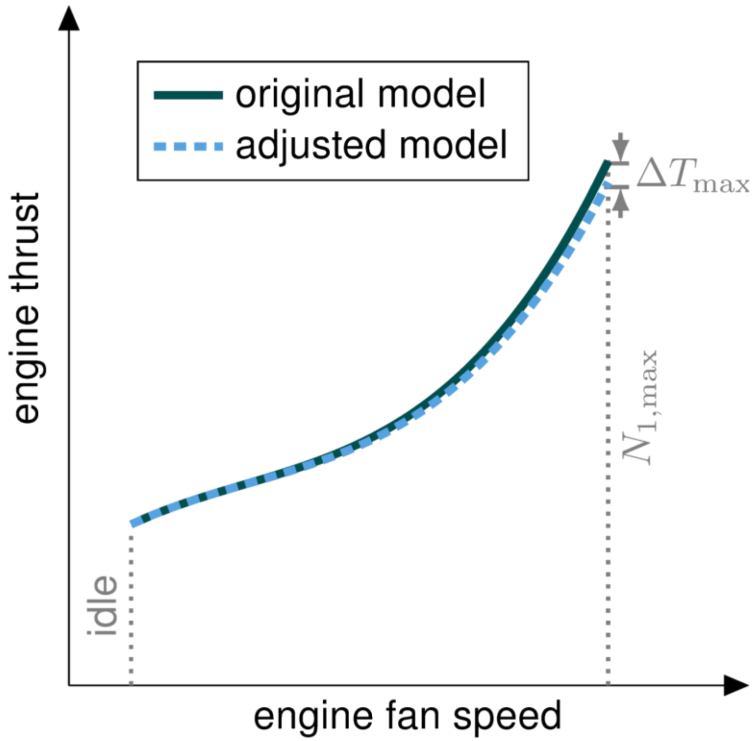
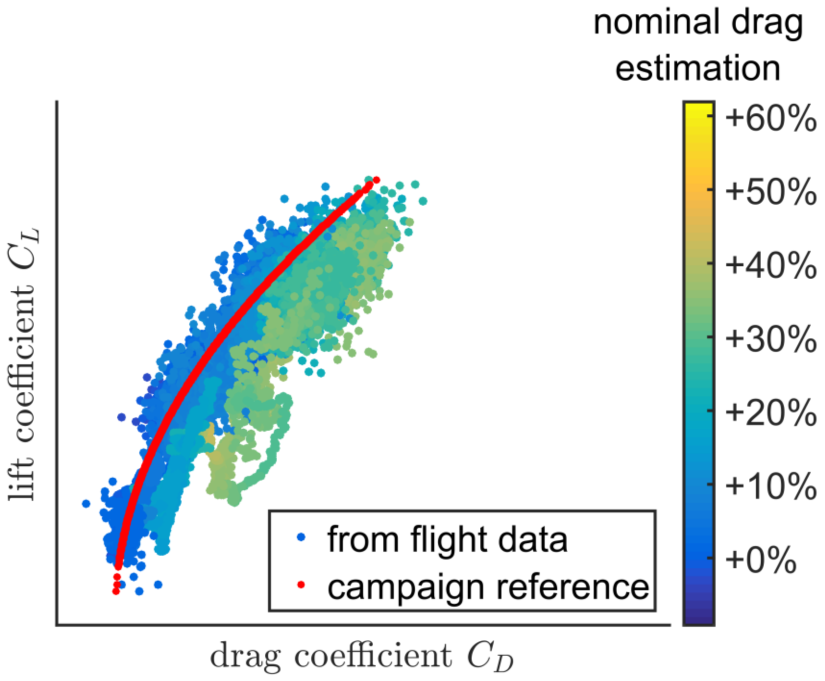
Thrust model adjustment
Example Flight (23rd Feb. 2023)



aerodynamic calculation and IIDS simulation after engine model modification



Credit: DLR/ Embraer

- Model adjustment reduces questionable drag estimation
- Advantage of split implementation in SENS4ICE with modified aerodynamics for flight test implementation and engine thrust model

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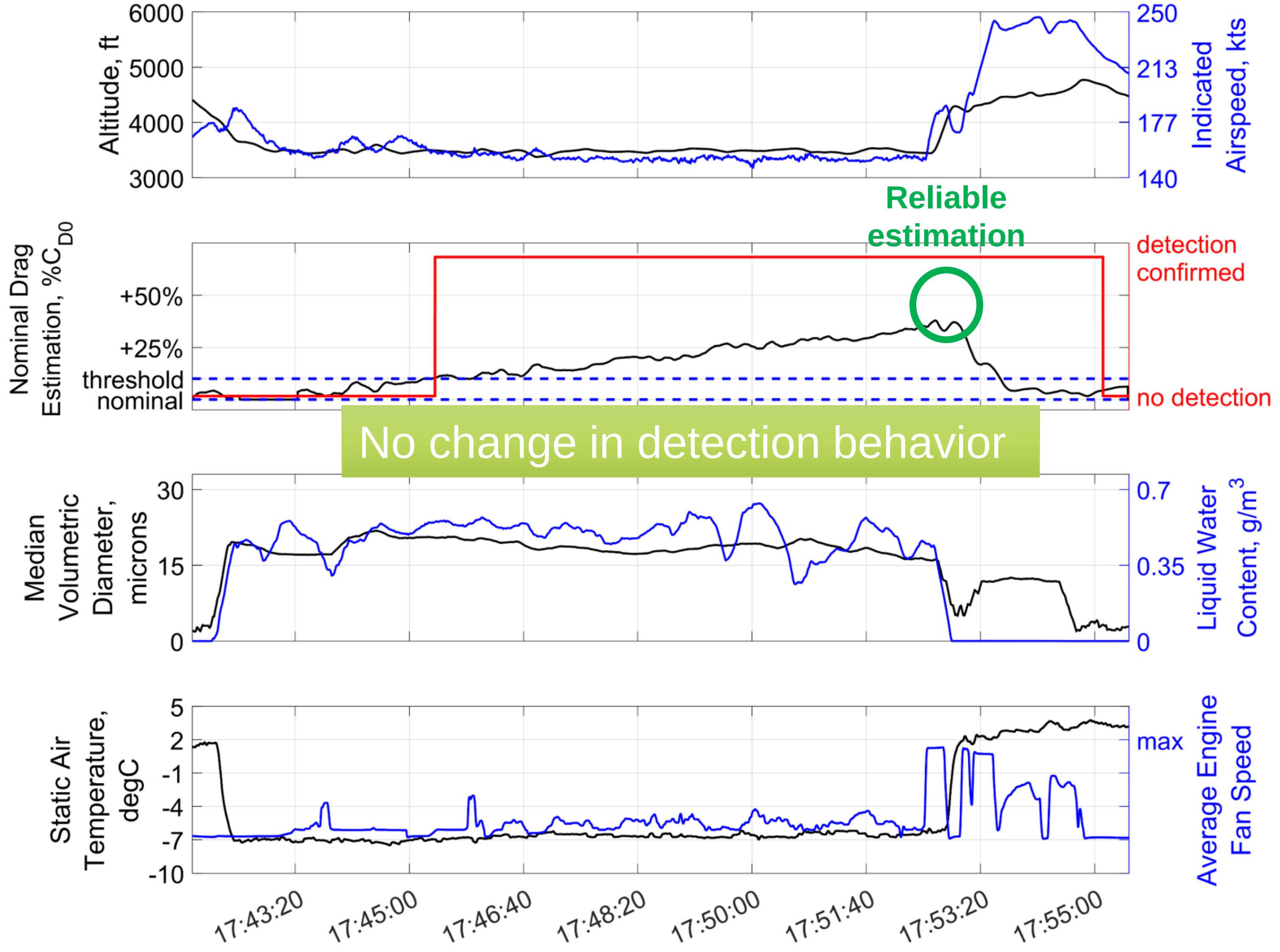
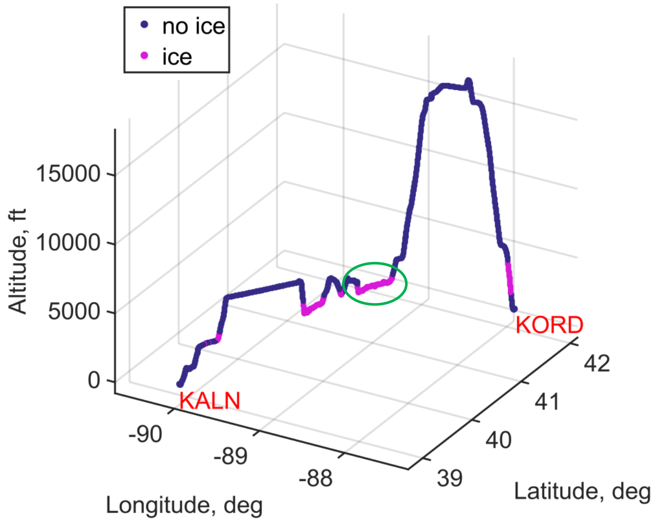
Example encounter – Adjusted Engine Thrust Model



No change in detection behavior



Credit: DLR/ Embraer

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Summary: Indirect Ice Detection System in SENS4ICE

- 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
- IIDS provides redundancy for ice detection when hybridized → reduced risk for common cause failures
- Validation of IIDS during SENS4ICE US Campaign in icing conditions
- Novel ice detection and chance for treatment of icing hazard in aviation including small-size vehicles of general aviation or drones
- Next step: Comprehensive evaluation of SENS4ICE flight test campaigns regarding IIDS performance

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Impressum

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Credits: iced wing: credit SAFIRE; EMB Phenom 300 prototype: credit Embraer; remaining pictures „DLR (CC BY-NC-ND 3.0)“

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