SENS4ICE

SENSORS AND CERTIFIABLE HYBRID ARCHITECTURES FOR SAFER AVIATION IN ICING ENVIRONMENT

Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

Design and Testing of an Indirect Ice Detection Methodology

Christoph Deiler, Falk Sachs

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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

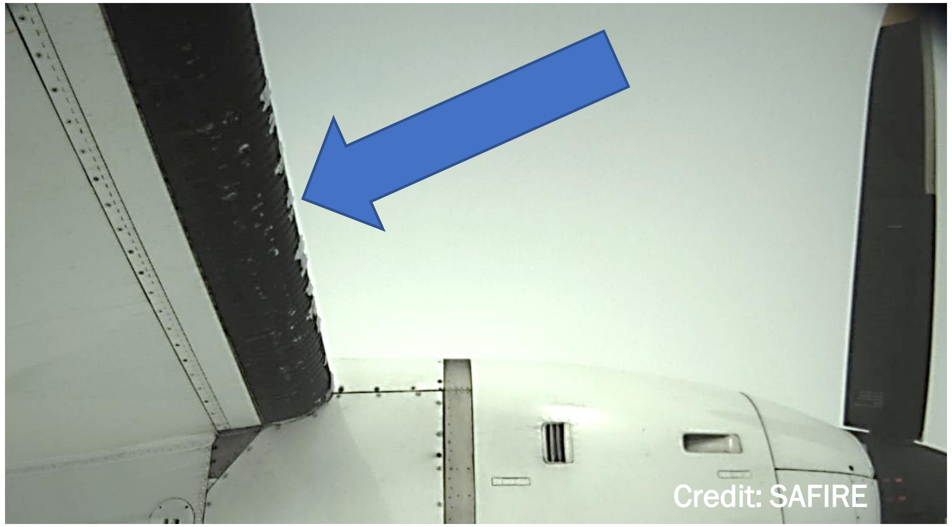
- **Indirect Ice Detection System (IIDS)**
  - software solution for reliable, cost effective and retrofittable ice detection
  - providing necessary information to maintain safe flight conditions
  - potential enabler for more selective activation of anti-ice systems with reduced energy consumption

Credit: DLR

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



Ice Detection System based on the Aircraft Performance: Basic Principle

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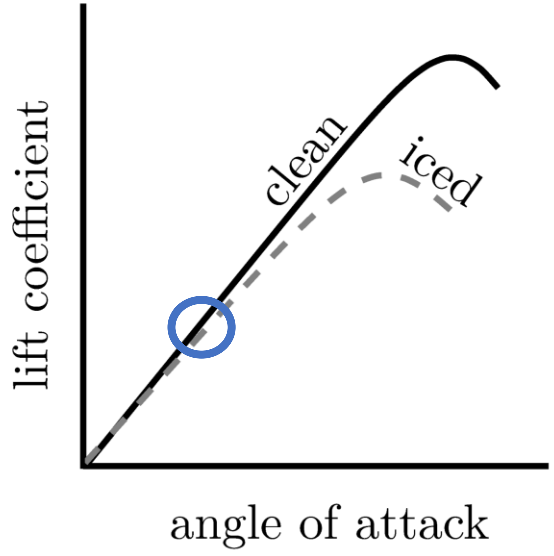

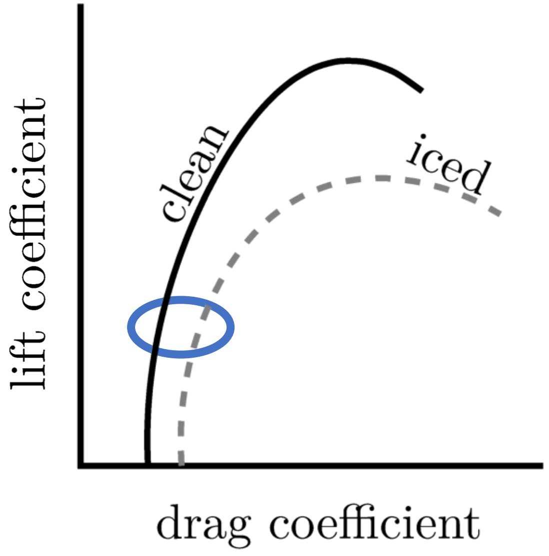

Change of lift resp. pitch coefficient derivatives (C_{L_α} , C_{m_α})

\+ Almost fully conserved within linear dynamic models
➔ direct use of the tools from linear control theory possible

\- Also significantly impacted by other phenomena
➔ not specific enough

\- Excitation needed for proper detection (steady flight is an issue)

Change of drag polar (glide ratio)

Remark: Information lost during linearization

\+ Seems to characterize very well the effects of ice accretion

\+ Detection during steady flight conditions

Credit: DLR

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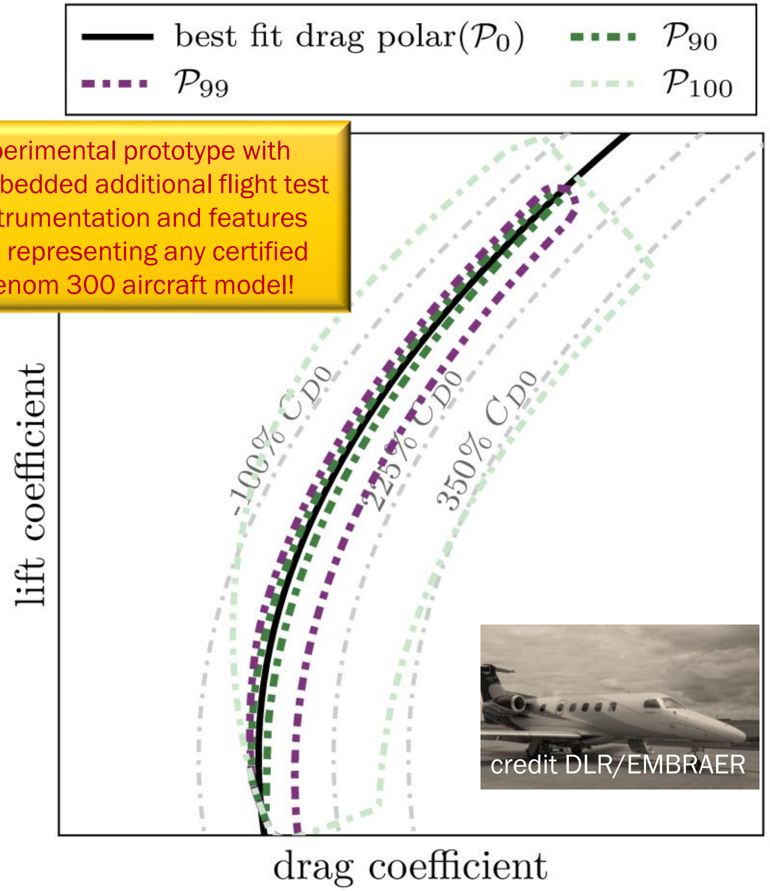
Performance Variation of SENS4ICE Flight Test Benches

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

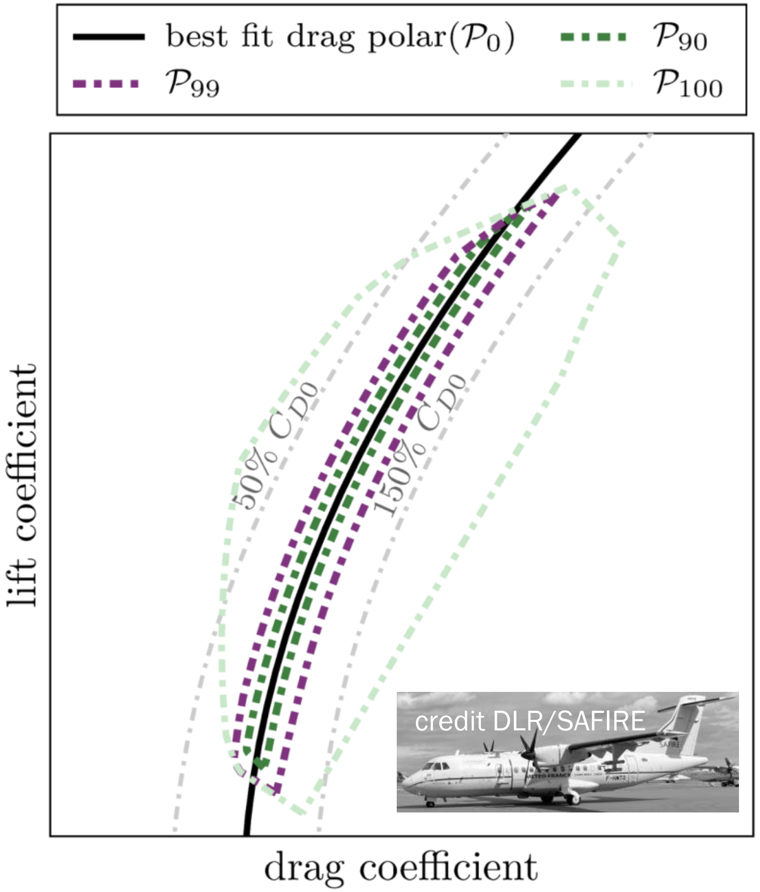
- operational flights similar to SENS4ICE target application
- only standard instrumentation as source of information
- **Conclusions:**
  → monitoring of aircraft flight performance using the regular sensors possible
  → level of precision allows detection of performance degradation induced by ice accretion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

Performance Based (Indirect) Ice Detection

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Abnormal Aircraft Performance Monitoring:

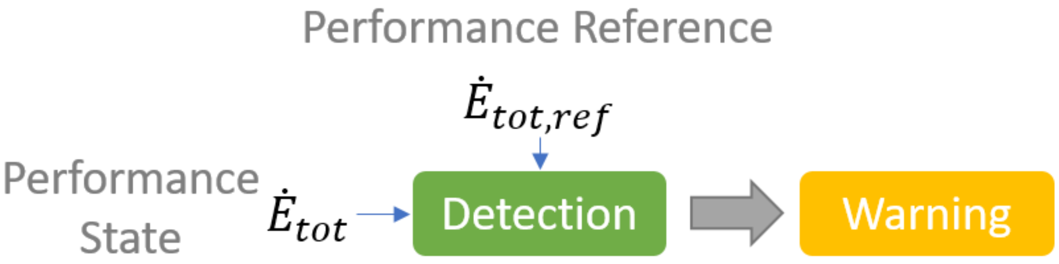
- Total Energy:

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

- 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

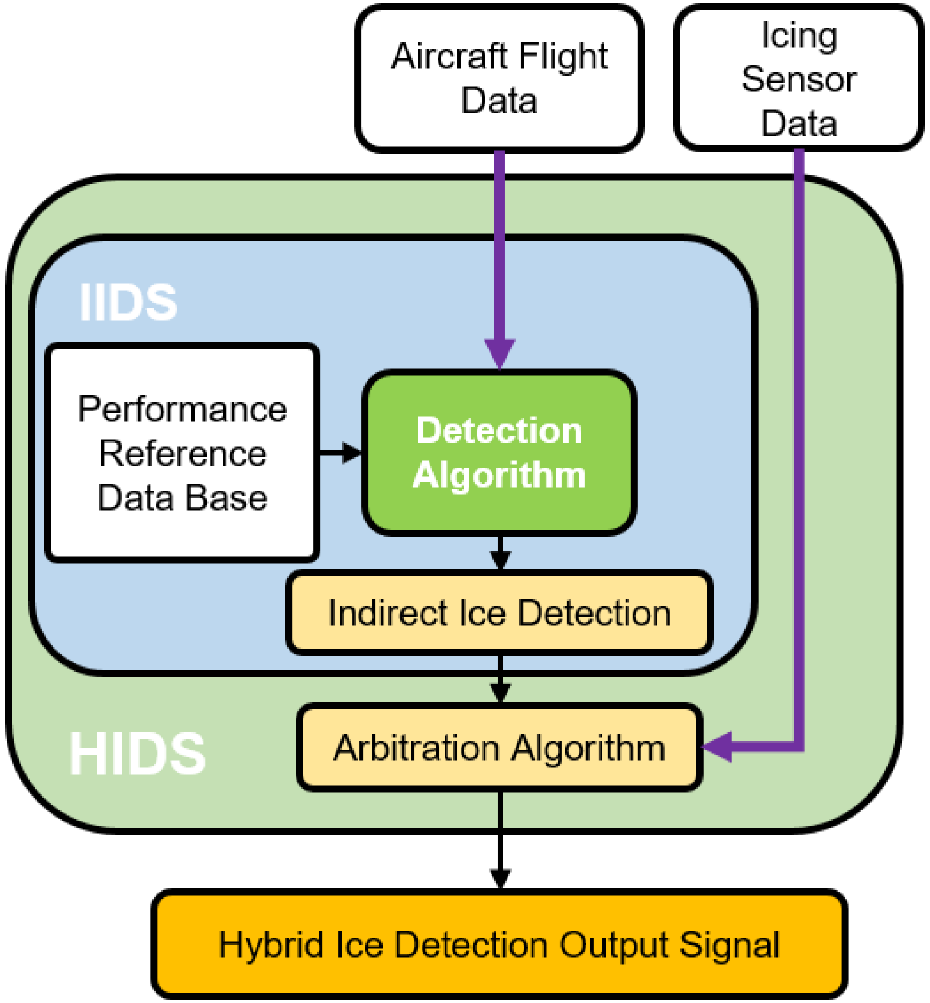
$$\Delta C_{\tilde{D}} \approx \frac{\dot{E}_{tot,ref} - \dot{E}_{tot}}{V_{TAS} \cdot \overline{q} \cdot S}$$

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

Credit: DLR

Indirect Ice Detection System (IIDS)

- core part of the HIDS
- IIDS for a specific aircraft type, which concern
  - the flight data preprocessing: information about the current aircraft state
    - acceleration, rotational rates and attitude
    - atmospheric conditions, altitude, airspeed, inflow angles
    - engine (and propeller) state
    - aircraft configuration and weight and balance
  - the flight performance reference data base
  - the indirect ice detection threshold and confirmation times
  - the detection reliability conditions



Credit: DLR

Flight Performance Reference Data Base

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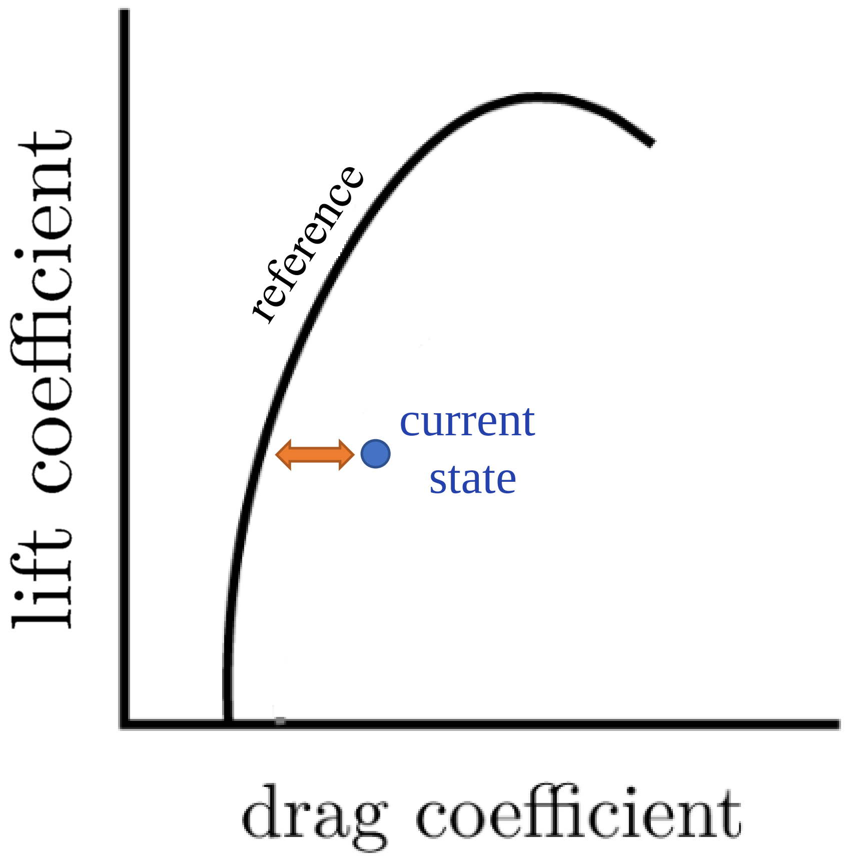
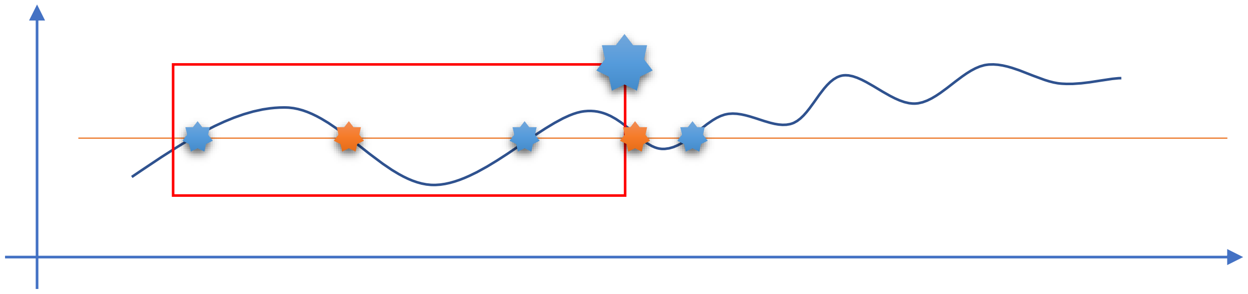
- Reference data required to compute the reference power imbalance $\dot{E}_{tot,ref}$
- Must include the aircraft performance
  - e.g., via multi-dimensional model for $\dot{E}_{tot,ref}$ (e.g. table)
  - aerodynamic reference and engine thrust model → used for SENS4ICE
- Reference could be based on 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

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 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

	SAFIRE ATR 42-320	Embraer Phenom 300
detection threshold as relative drag coefficient increase	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

IIDS Test Results on Icing Flight Data

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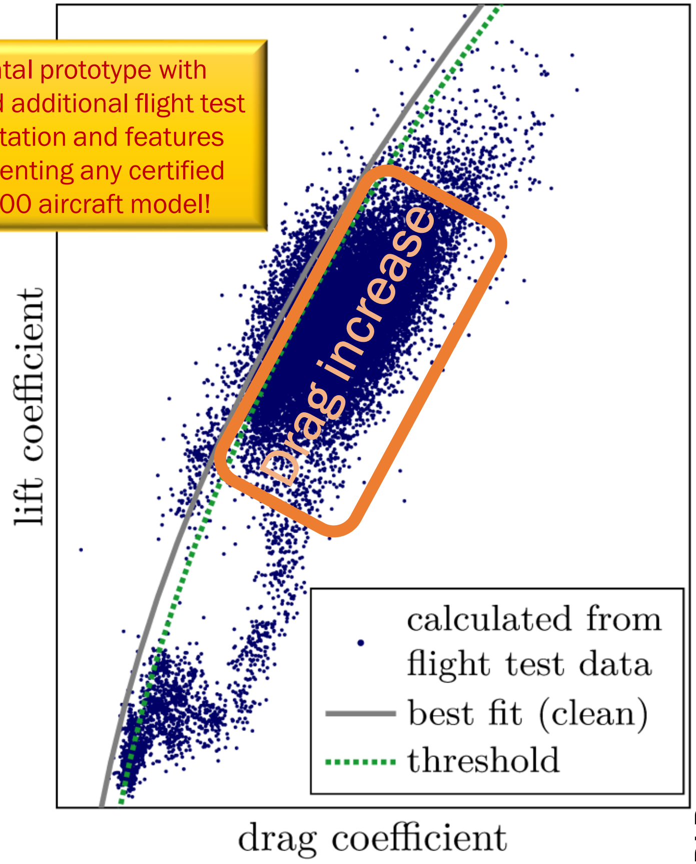
- IIDS implementation in Matlab®/Simulink
- IIDS validation for SENS4ICE flight test campaign with existing App. C icing flight data for EMB Phenom 300 prototype
- Flight Data contain measurements of
  - translational accelerations
  - rotational rates
  - aircraft attitude
  - true airspeed, angle of attack, and angle of sideslip
  - geographic position and altitude
  - control surface deflections
- Relevant icing encounters extracted for IIDS validation

<u>NOTE</u>: specific flight test data excluding other sources of performance degradation!

App. C icing encounter
(flight data from before SENS4ICE)

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



Credit: DLR

IIDS Test Results on Icing Flight Data

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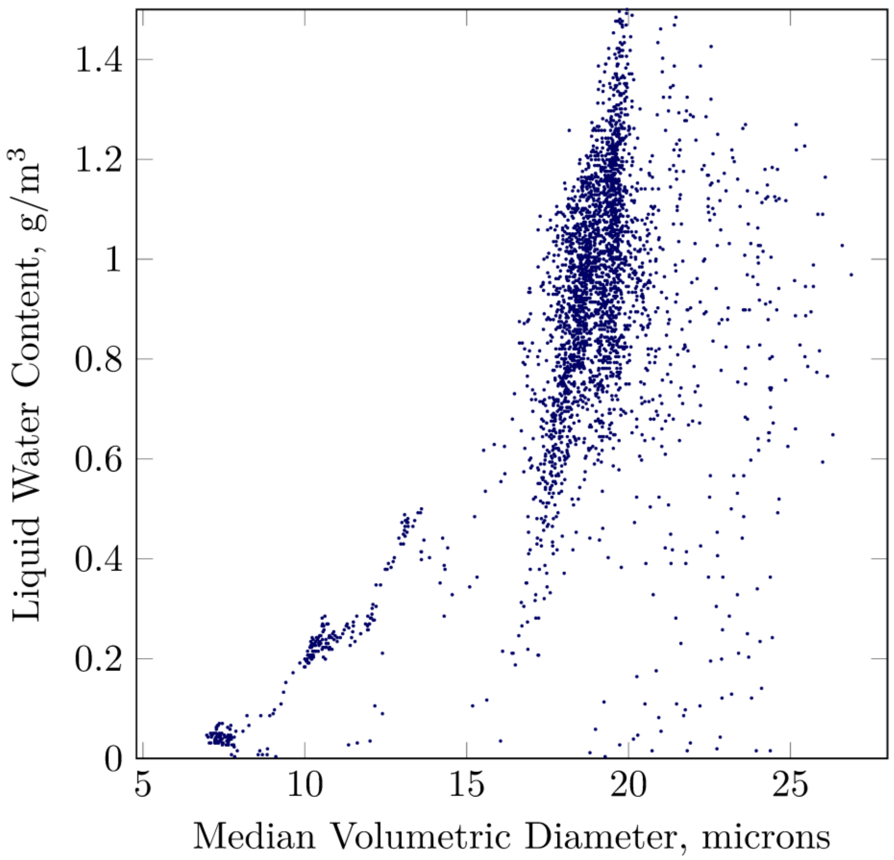
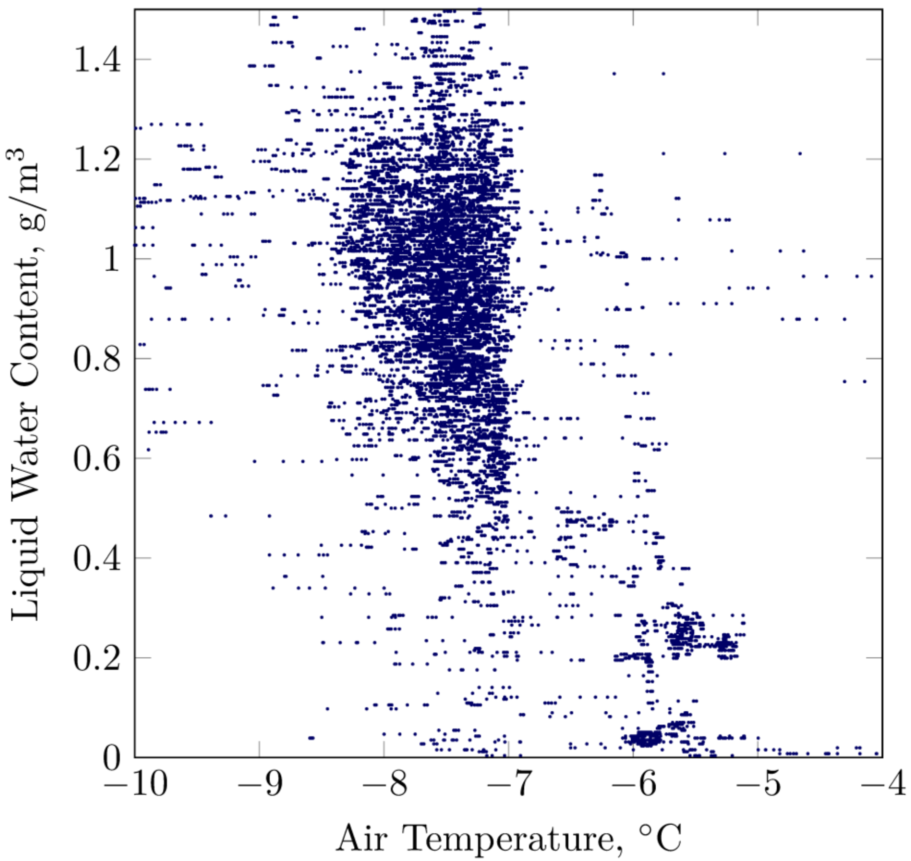
Atmospheric conditions from example flight data → Appendix C icing conditions

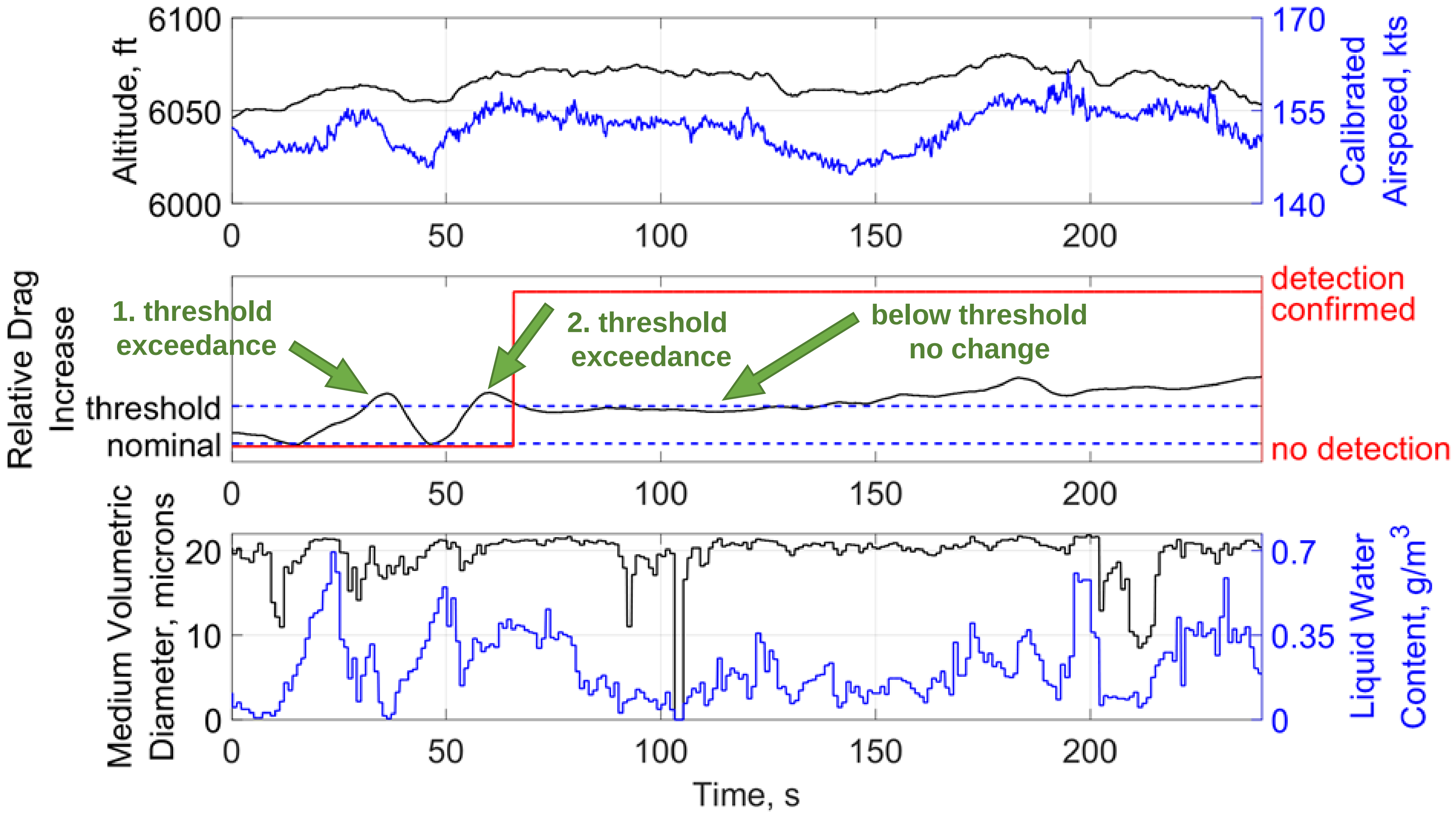




Credit: DLR

Example encounter

App. C icing encounter (flight data from before SENS4ICE)



Credit: DLR

Conclusion

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- 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
- Methodology requires precise measurements of flight condition
  → normally available for modern aircraft
- Verification & validation of IIDS based on ATR 42 and EMB Phenom 300 flight data:
  - IIDS design verification (clean air data)
  - IIDS detection validation with natural icing flight test data (App. C) for Phenom 300
- IIDS tuning for flight test campaigns according to given results
- Next step: SENS4ICE flight test campaign evaluation regarding IIDS performance

Credit: DLR

Further Application of Performance-Based Ice Detection beyond SENS4ICE

- IIDS opens up various new possibilities for the ice detection on smaller aircraft
- Basic icing effects on flight performance similar respectively worse for small size vehicles, e.g., UAV
  → faster performance degradation with significantly reduced capabilities and remaining envelope
- Advantages for UAV ice detection
  - performance degradation due to ice accretion measurable during all flight phases including rapid maneuvering
  - valuable information about flight envelope limitation directly available
- Transfer of methodology to, e.g., UAV icing requires additional (vehicle specific) research, but provides a significant potential for (low cost / effort) ice detection

Credit: DLR

Imprint

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Author: Christoph Deiler (christoph.deiler@dlr.de)

Institute: Institute of Flight Systems

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