MODELING, IDENTIFICATION AND DETECTION OF AIRCRAFT ICING

Challenges of Transferring Recent Achievements to (Fixed-Wing) UAV

Christoph Deiler

DLR – German Aerospace Center, Institute of Flight Systems, Braunschweig

The Problem with Airplane Icing

- 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, …

Credit: BFU, Interim Report BFU CX001-13

- App. O to CS-25 issued to address Supercooled Large Droplets (SLD) (in addition to App. C)
- Better understanding and prediction of icing impact on aircraft characteristics

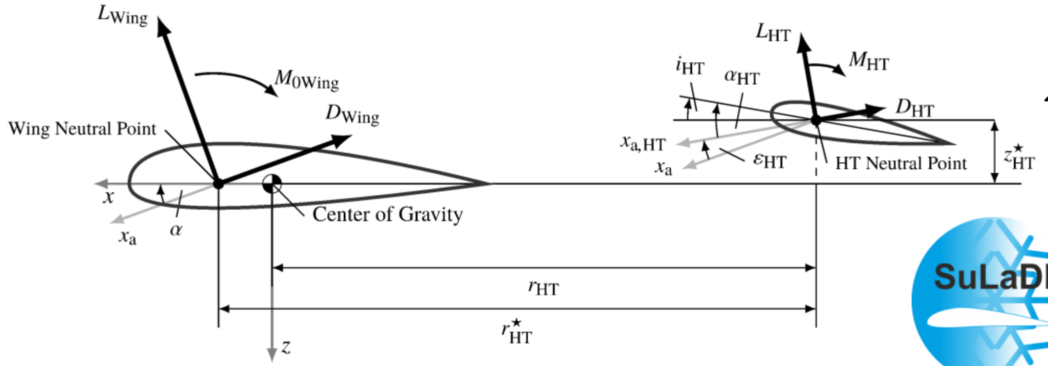
Novel Research Applications: Small Aerial Vehicle Configurations

- Different requirements for small (**fixed-wing**) aerial vehicles than for large transport aircraft
- Complex sensor technologies or protection measures not applicable (e.g., weight, size, energy consumption)
- Shift of impact severity: weight increase, propeller icing, vehicle dynamics
- Icing management highly important for long endurance missions of smaller vehicles in harsh environments, e.g. search, surveillance, or urgent medication delivery in remote locations

- New field for icing research
- Tailoring of application of icing detection technologies and countermeasures for UAV

Credit: DLR

Modelling of Icing Effects

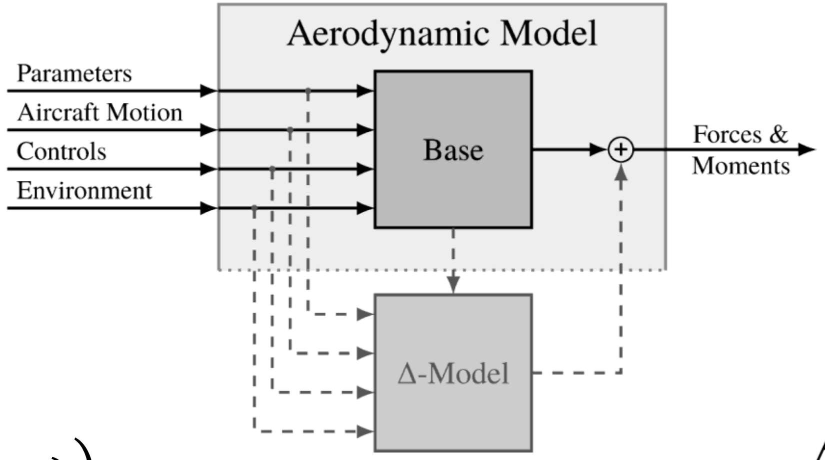


Supercooled Large Droplets Icing

Basic aircraft model formulation:

- longitudinal aerodynamics → two-point model formulation
- lateral aerodynamics → nonlinear derivative model

Iced aircraft model extension:

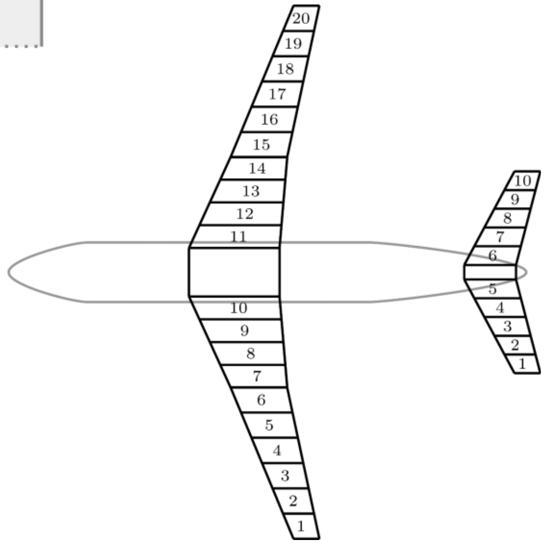


- Δ-model coefficients analytically derived from basic model
- linear parameter extension:

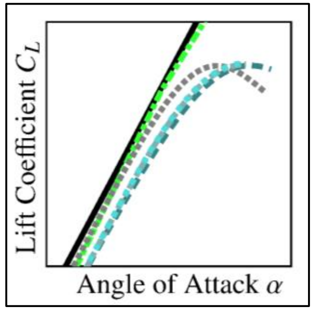
$$P = (1 + k_P)\, P_{\text{base}} + d_P = P_{\text{base}} + \Delta P_{\text{ice}}$$

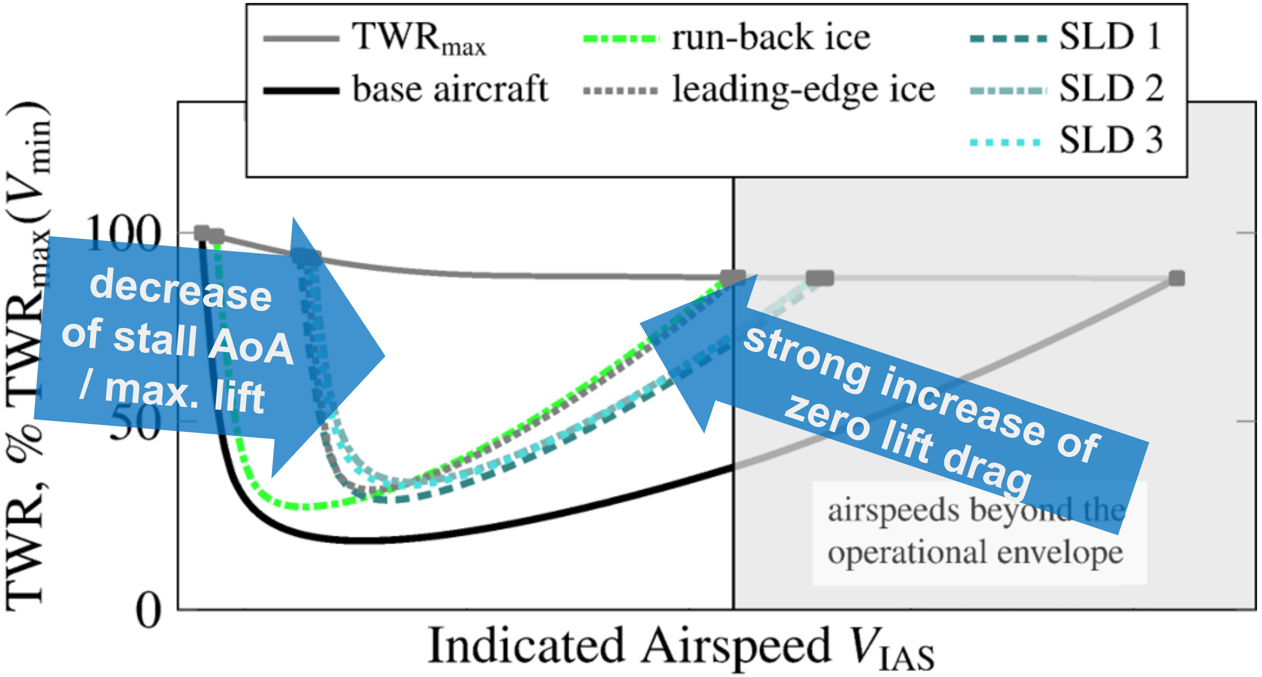
$$C_{(\cdot)}(P) = \Big(C_{(\cdot)}(P_{\text{base}})\Big)_{\text{base}} + \Delta\Big(C_{(\cdot)}(P_{\text{base}} + \Delta P_{\text{ice}})\Big)_{\text{ice}}$$

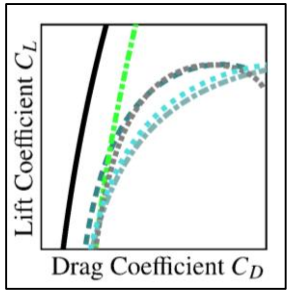
- strip model formulation for wing and horizontal tail



Example of Ice-Induced Limitations of Aircraft Flight Performance: Change of Thrust-to-Weight Ratio (App. C & O)







run-back ice case

leading-edge ice case

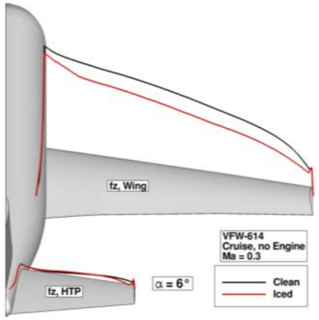
SLD-ice case

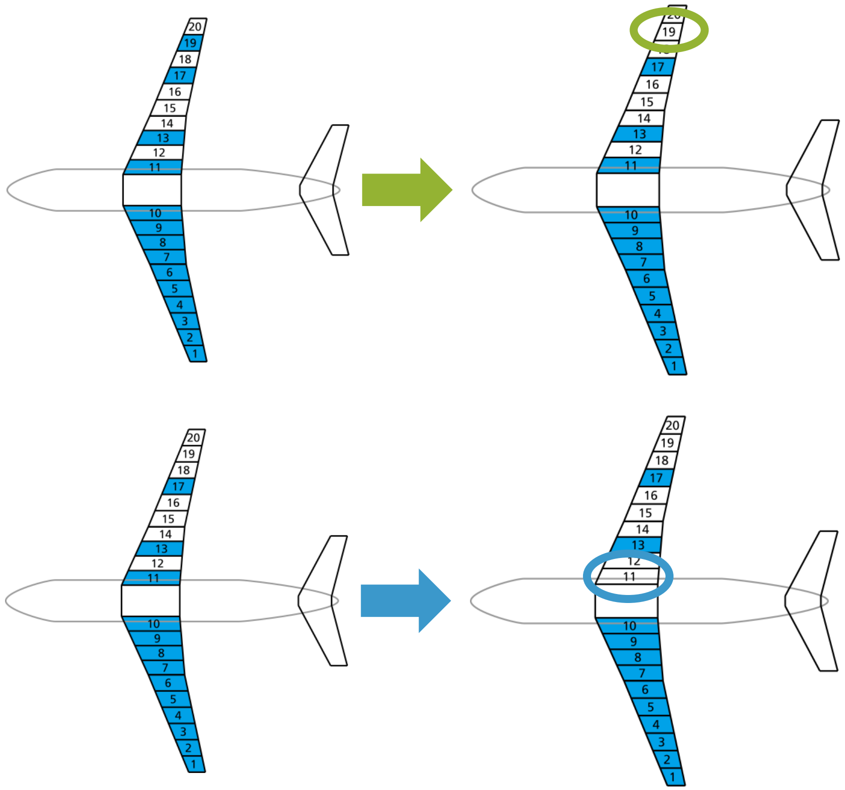
- Significant difference of aerodynamic impact directly affecting flight performance
- Nonlinear models identified from flight test data, trimmed and evaluated

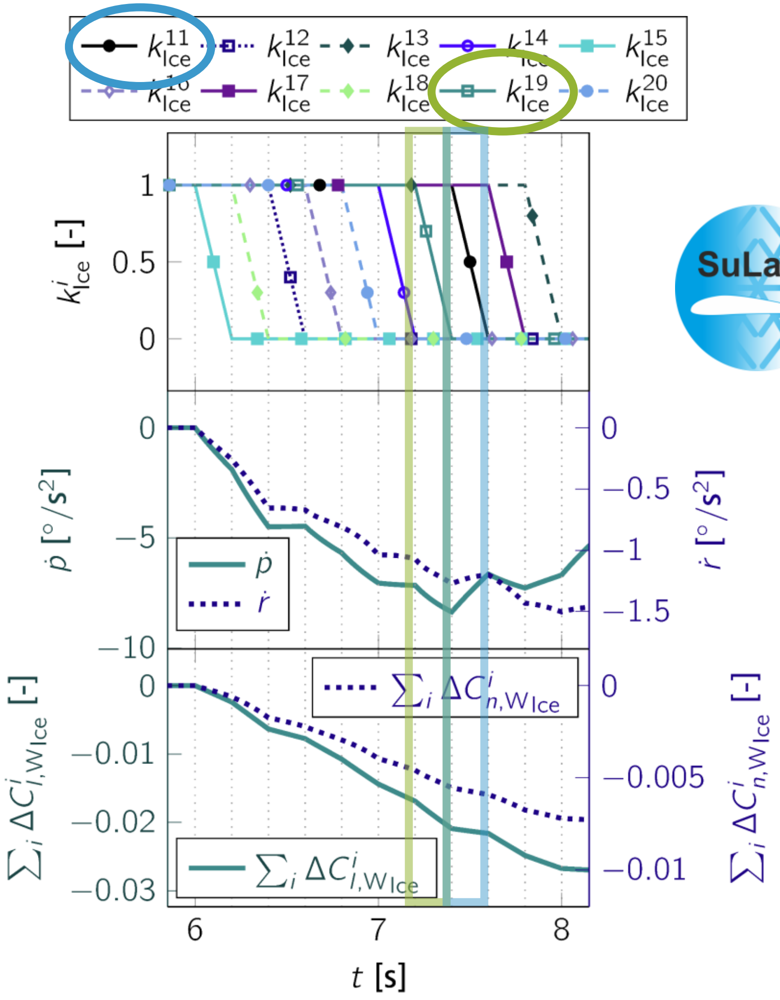
Christoph Deiler (2021), Flight Characteristics with Different Supercooled Large Droplet Ice Configurations. The Aeronautical Journal. Cambridge University Press. doi: 10.1017/aer.2021.98

Credit: DLR / Embraer

Example of Ice Shedding Effects on Aircraft (Aero-)Dynamics







Supercooled Large Droplets Icing

- Additional moments during right wing deicing with random pattern
- Individual strip influence, no aerodynamic interaction considered
  → presumably worsening effects

Deiler, C., Kilian, T. Dynamic aircraft simulation model covering local icing effects. *CEAS Aeronaut J* **9**, 429–444 (2018). https://doi.org/10.1007/s13272-018-0291-6

Credit: DLR

Application of Results to UAV Icing?

- Modelling approach transferable to different aircraft, but
  - different effects of icing on small fixed-wing airplanes due to airfoil size and ice formation
  - aerodynamic degradation might cause more hazardous effects on UAV dynamics due to smaller vehicle size, weight and inertia
- Basic icing effects on flight performance similar respectively worse for small size vehicles → faster degradation of performance with significantly reduced capabilities and remaining envelope
- Discrimination of atmospheric icing conditions required for UAV?
  → dependency on specific conditions or icing as overall problem?

- Research required to determine the specific effects of icing on smaller size UAV
- Flight test based approach for determination of iced aircraft characteristic preferable

Horizon 2020 Project SENS4ICE

SENSors and certifiable hybrid architectures for safer aviation in ICing Environment

- SENS4ICE fills the gap of SLD icing detection (App. O)
- Technology development, test, validation & maturation
  → TRL 5 of hybrid system at the end of SENS4ICE
- Technology demonstration in relevant icing conditions: testing facilities & flight test
  → SENS4ICE will provide large database 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**

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

- JAN 2019 – DEC 2023
- Coordinator DLR + 16 project partners
- 11.9 M€ including 6.6 M€ EU contribution
- https://www.sens4ice-project.eu
- #sens4iceproject on LinkedIn

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824253.

SENS4ICE Layered Safety Concept for Liquid Water Icing

may not be possible for (small) UAV

relevant for UAV

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

required for UAV

Contingency: new detection of reduction in aircraft flight envelope (loss of control prevention)

important for UAV

- Significant safety improvements provided by the SENS4ICE ice detection architecture especially for SLD icing conditions
- Enabler for more targeted use of energy-consuming anti-ice systems

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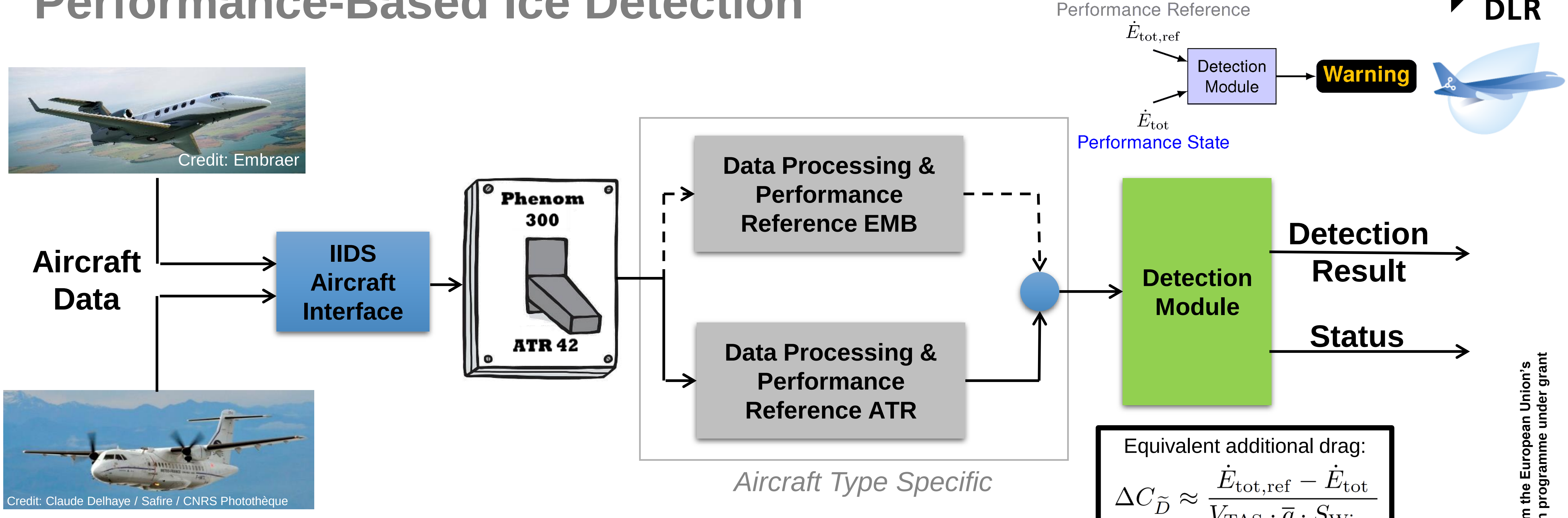
Indirect Ice Detection System (IIDS) in SENS4ICE
Performance-Based Ice Detection



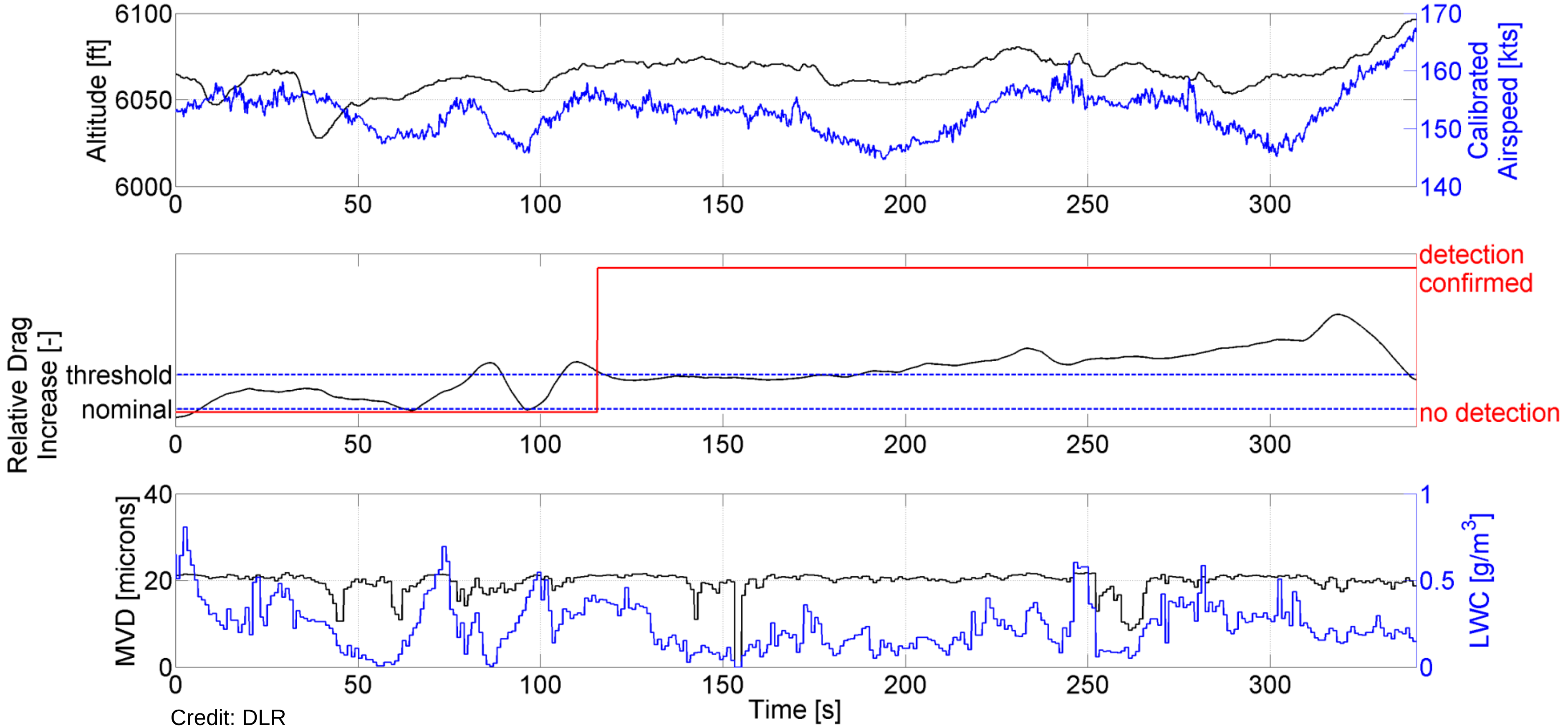
Equivalent additional drag:

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

- Designed to easily cope with specific aircraft requirements and characteristics, e.g., configuration, propulsion system, avionics, operational requirements
- Retrofittable and high potential for smaller aircraft

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824253.

Example of IIDS Validation Results (App. C Flight Test Data)



Credit: DLR

- Indirect ice detection results based on pre-existing natural icing flight test data exhibiting relative drag increase above detection threshold [Embraer flight test data]

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824253.

Challenges for Application of Performance-Based Ice Detection to UAV Icing

- 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
- Differences to large transport aircraft
  - Shorter detection times required due to possibly faster hazardous ice accretion with significant degradation
  - Propeller degradation due to ice accretion potentially faster than aerodynamic degradation
    → discrimination of engine malfunction and ice accretion required for performance-based detection method

- Transfer of methodology to UAV icing requires additional (vehicle specific) research, but provides a significant potential for (low cost / effort) ice detection

Summary

- Icing hazard for aviation generally under control
- Challenges for ice management on new aircraft configurations like small-size (fixed-wing) UAVs
- New specific needs for reliable ice detection
- Demands for research to better understand the specific effects of icing on small-size UAV configurations

Impressum

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Author:	Christoph Deiler (christoph.deiler@dlr.de)
Institute:	Institute of Flight Systems

Credits:

BFU, (Interim) Report BFU CX001-13; Embraer; Claude Delhaye / Safire / CNRS Photothèque;

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