Prepared by:

Gerard Duprat / Nick Dart
Aerodynamics Dept
Airbus

Presented by

Nick Dart

Use of 3-D Ice Accretion Simulation Software for Certification

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Outline:

- Introduction
- 2D ice shapes calculation process
- The need for 3D icing codes
- Current use of 3D ice accretion codes
- Issues for acceptance by the regulatory authorities
- Additional issues for acceptance by users
- Way forward
- Conclusions

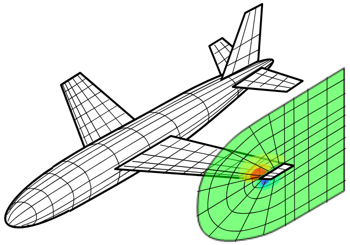
Introduction

- The ice accretion prediction and wing ice protection system design for Airbus products are currently based on 2D icing tools, wind tunnel tests and flight tests.
- In order to reduce the limitations associated with the 2D simplifications an effort has been made to capture the 3D flow features by using 3D flow solvers.
- However, the highly three dimensional nature of some components of the aircraft precludes the use of 2D and 2.5D methodologies (air intake ducts, windshields, etc).
  - Without the 3D icing codes, certification would only be possible using icing wind tunnel tests or natural icing trials.

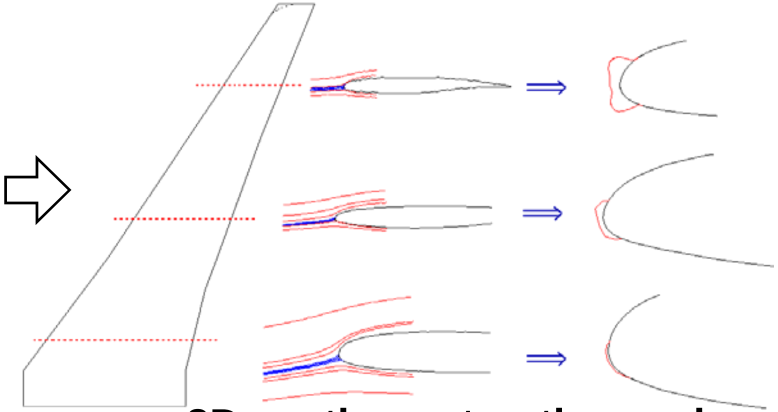
Introduction

- **General needs:**
  - JAR 25 App C
  - Glaciated, mixed phase and SLD (App X, D)
- **Other Business:**
  - Flush air intakes (APU, HHX, ventilation,…)
  - Actuator disk & slipstream
  - Detached ice blocks trajectories
  - Condensation in heat exchangers
  - Cockpit / Comfort of the pilots (humidity nozzle)
- **Windshield:**
  - Protected area definition
  - Water catching
  - AI & DI system performance
  - Ice accretion
  - Ice shedding
- **Fuselage, protuberances (Internet antenna, TAC,…) & specific instruments (F/T,…):**
  - Water catching
  - Ice accretion
  - Ice shedding
- **Wing (clean and high-lift configurations)/HTP/VTP:**
  - Protected area definition
  - Water catching
  - AI & DI system performance
  - Ice accretion
  - Ice shedding
  - Performance degradation
- **Rotating components (fan & compressor blades, RAT, propeller):**
  - Protected area definition
  - Water catching
  - AI & DI system performance
  - Ice accretion
  - Ice shedding
- **Instruments (anemometry, clinometry, ice detector, visual icing indicator,…:**
  - Water catching
  - Ice accretion
  - AI system performances
- **Nacelles:**
  - Protected area definition
  - Water catching
  - AI & DI system performance
  - Ice accretion
  - Ice shedding

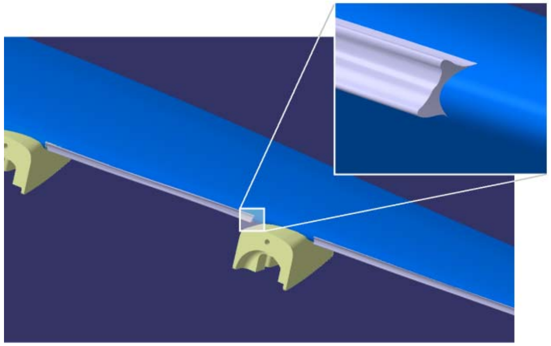
2D ice shape calculation process



3D CFD modelling

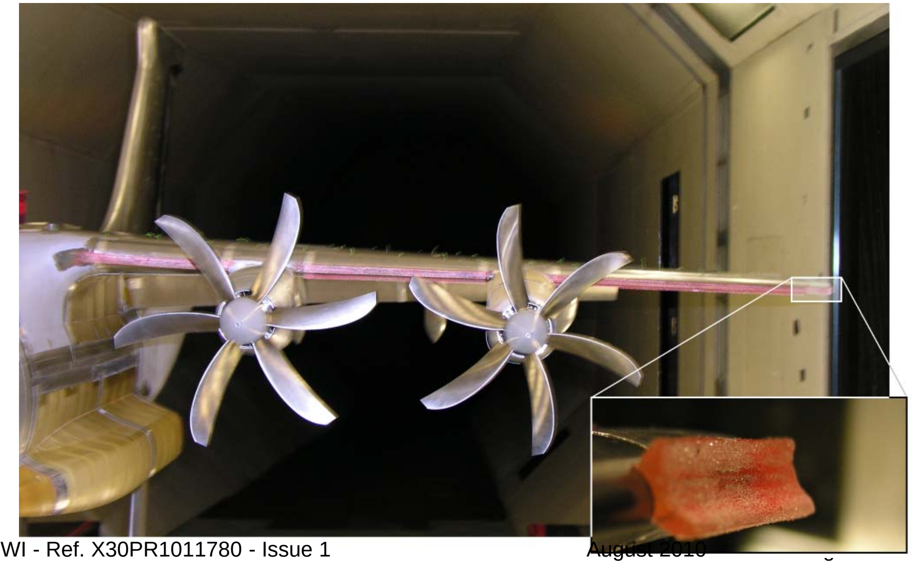


2D section extraction and 2D ice shape prediction



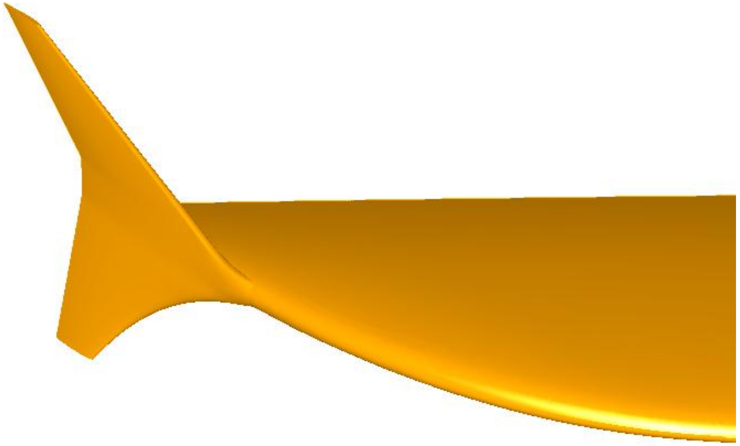
Creation of 3D CATIA solids for wind tunnel testing of stereo-lithographic artificial ice

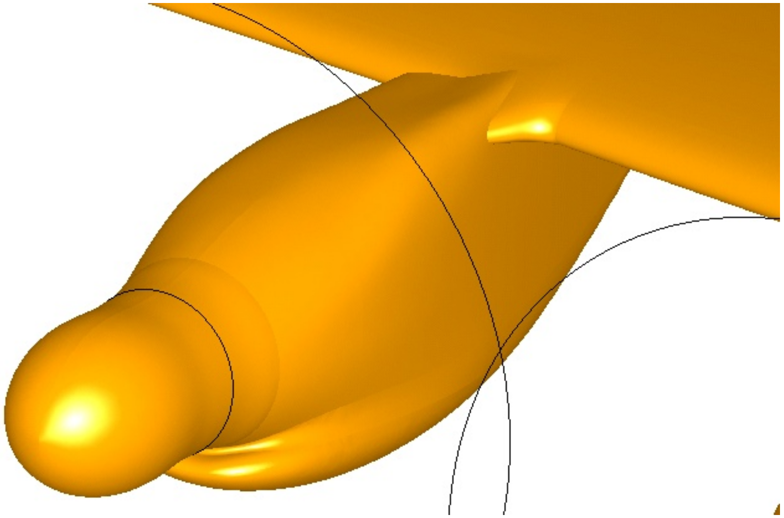
The 3D ⇒ 2D ⇒ 3D process is time consuming.



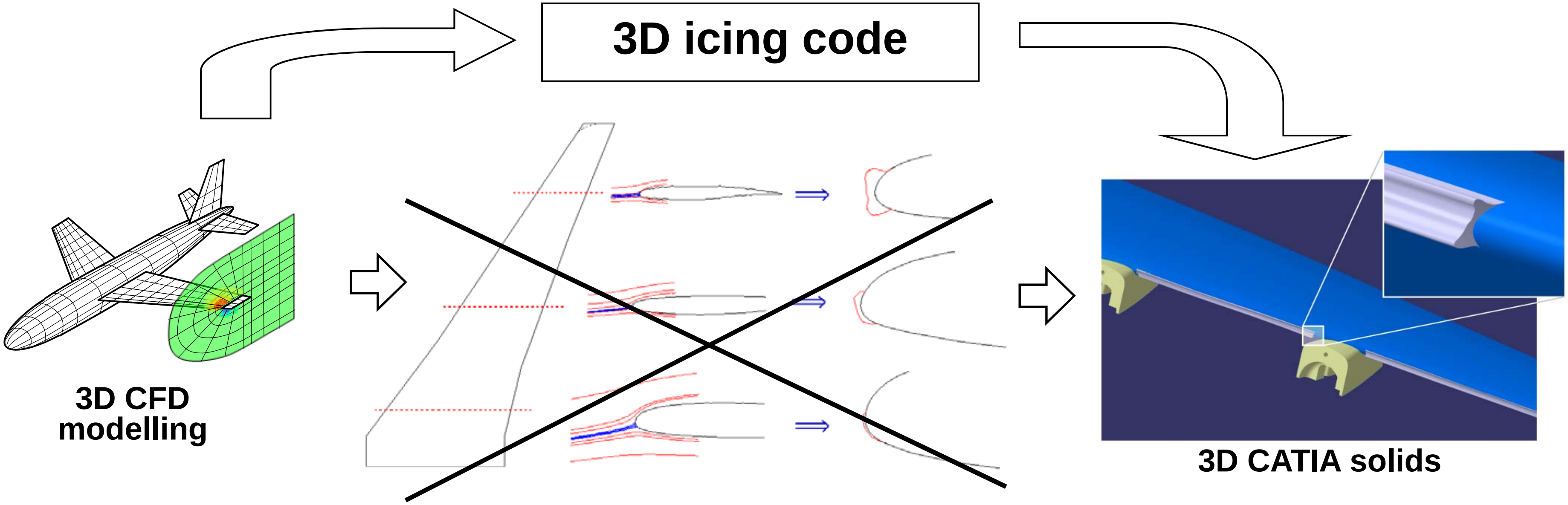
2D ice shape calculation process

- The accuracy of 2D codes is questionable in regions of complex 3D flow.
- 2D icing codes are not able to model the absence of ice in ‘shadow areas’.





3D icing code concept



3D icing code

3D CFD modelling

3D CATIA solids

- 3D icing code post-processes the CFD flow solution.
- 3D ice shapes are created directly.
  - **Improved process efficiency**
  - **Improved accuracy, especially around highly 3D features**

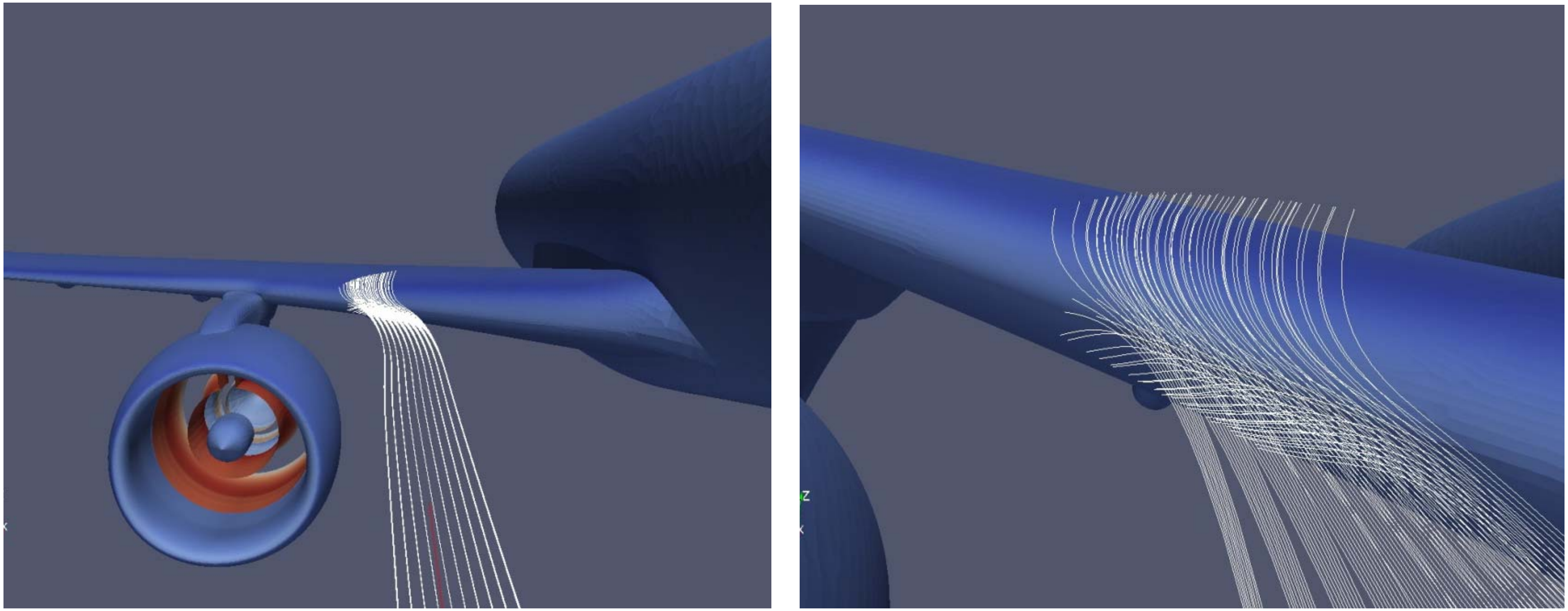
Current use of 3D ice accretion codes

3D codes are currently used for the following applications:

- Droplet trajectories, impingement area, cloud-over concentration and cloud depletion layer definition for nacelles, probes, windshield, protuberances (internet antenna,..) and intakes.
- Ice shape prediction on highly 3D components (e.g. NACA ducts).
- Supplementing/supporting the 2D process where 2D codes have limitations in terms of capability and accuracy:
  - Determining the shape and extent of ice close to wing/fuselage junctions, wing/pylon junctions, wing tip.
  - Ice accretion on deployed high lift configurations, where 2D codes are restricted to modelling single element aerofoils.

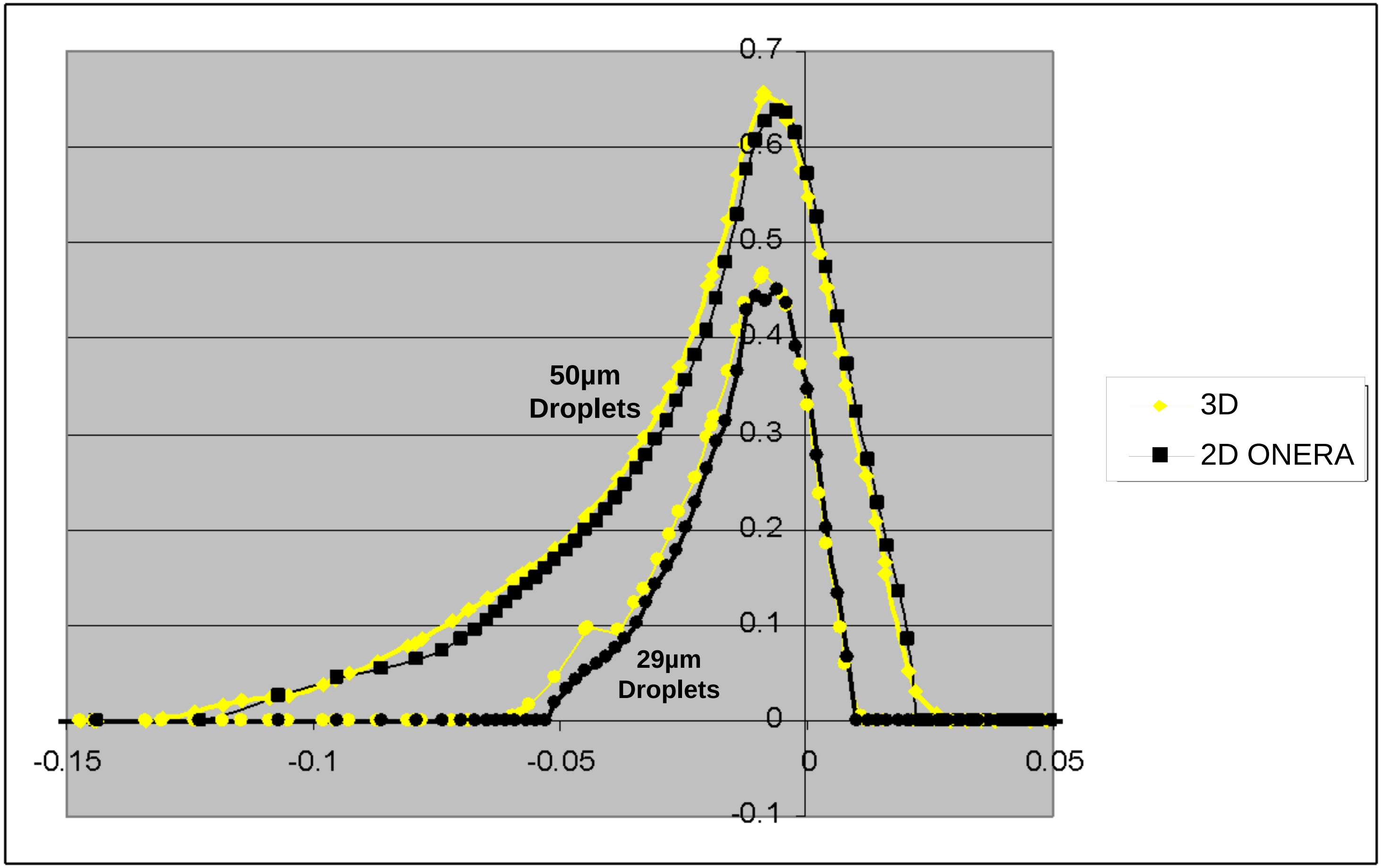
Current use of 3D ice accretion codes - Examples

- Example of droplet trajectories around wing at a specific spanwise location:

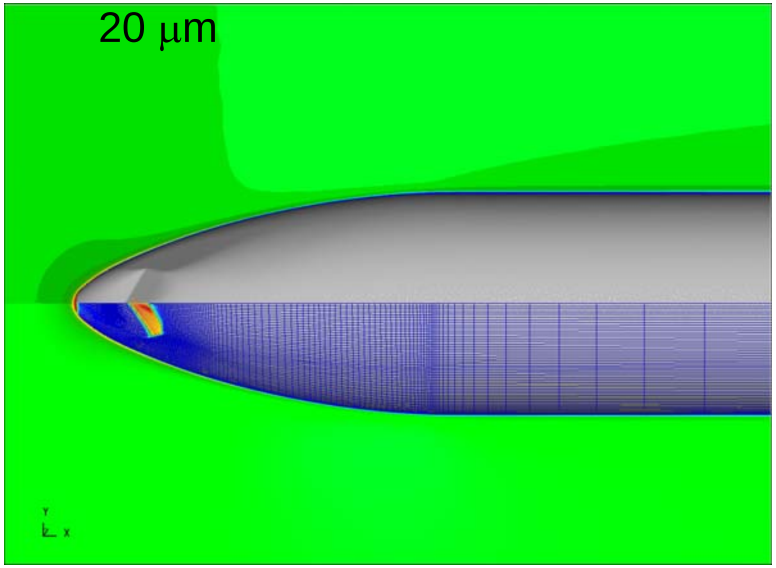


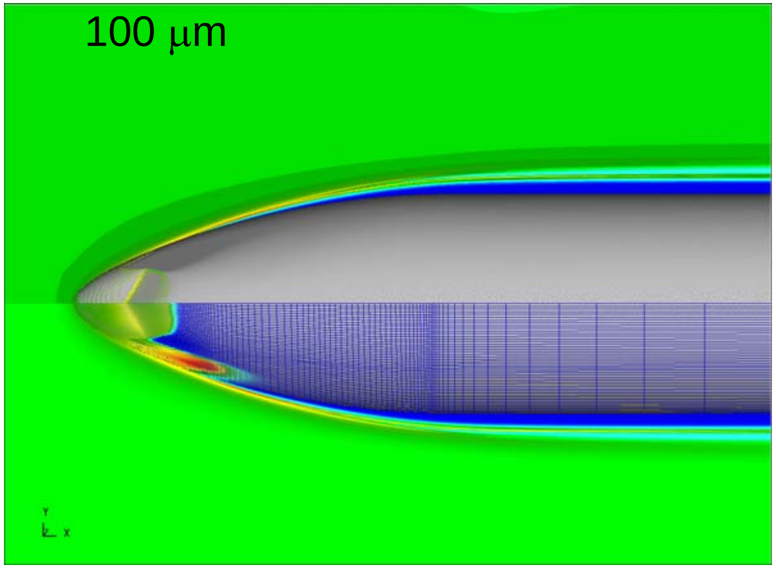
Current use of 3D ice accretion codes - Examples

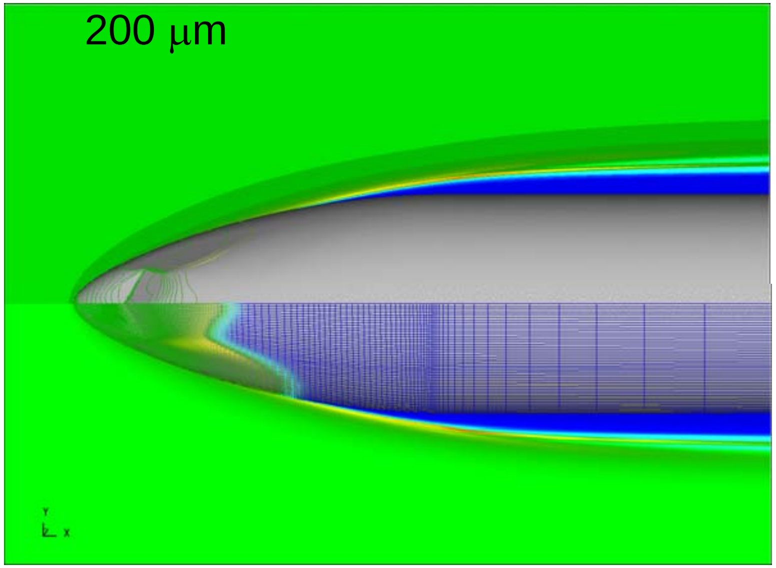
- Example comparison of 2D versus 3D catch efficiencies:

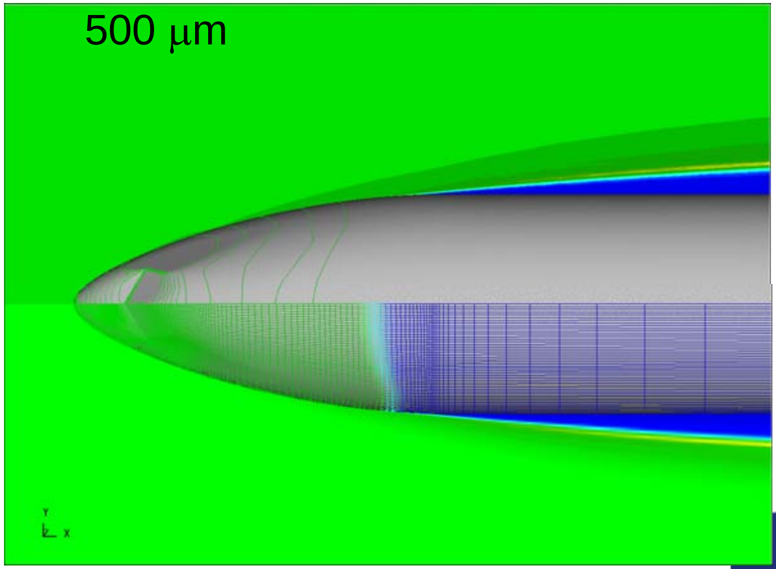


Current use of 3D ice accretion codes - Examples



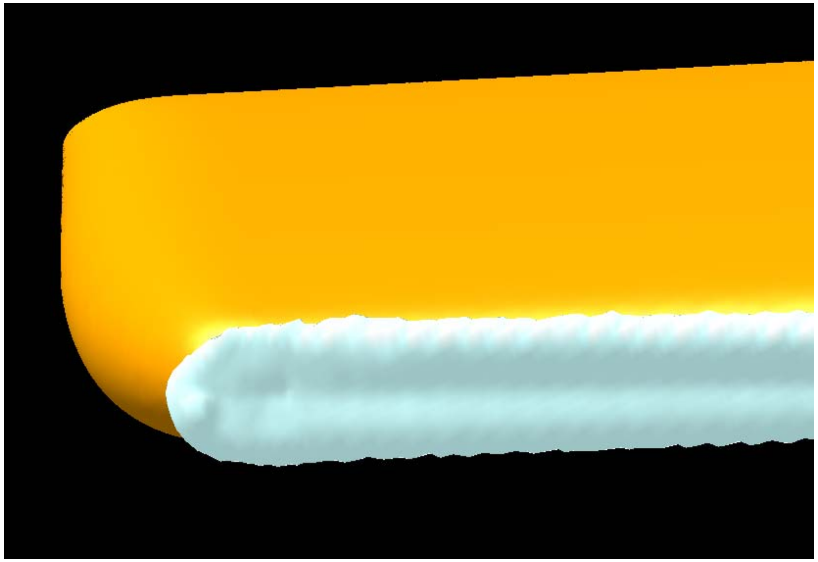


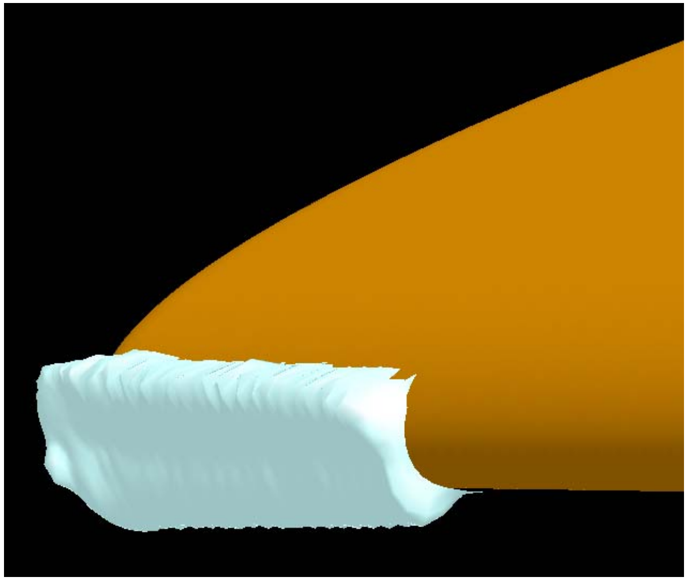




Current use of 3D ice accretion codes - Examples

- Example ice accretion prediction using 3D ice accretion code:





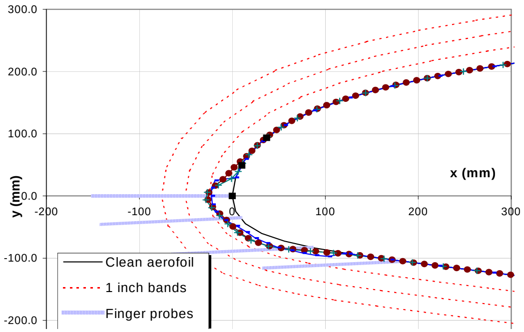
Issues for acceptance by the regulatory authorities

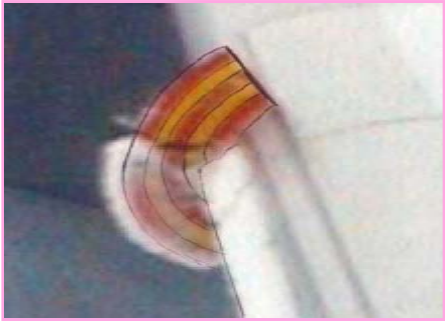
- The users (aircraft manufacturers) and regulators *should* have the same requirements and reservations about the use of 3D icing codes:
    - Demonstrated accuracy, through comprehensive validation.
    - Consistent results (minimal user dependency) through a well defined best practice, code application methodology, software quality assurance etc.

- However, users have an additional requirement that the codes must be practicable to use, in terms of their run time and general efficiency, to make their use feasible within a design and certification environment.

Issues for acceptance by the regulatory authorities

- Firstly, 3D icing codes need to be validated to the same standard as established 2D icing codes.
  - This includes the requirement to model new icing environments such as Appendix X and D.
- Additional validation is needed for 3D geometries, including complex 3D geometries.
  - Lack of experimental 3D data available in open literature.
  - Development of 3D methodology with the aim to keep the same safety level as the ‘historical’ 2D methodology.
  - Partial validation conducted by code prediction /flight test data comparison, but fidelity of flight test data is sometimes poor.





Validation level

- Validation experiences from icing or dry-air tunnel testing required to support code acceptance

  - 2 levels of experiences:

    - Coarse level to allow a first assessment of code capability:
      - Ice shapes database, pressure distribution and global coefficient (CL , CD…)

    - Fine level to allow understanding of physics:
      - Ice growth, heat transfer coefficient, roughness development
      - Boundary layer measurement…

  - Covering App C, X (& D)

Additional issues for acceptance by users

- Run time:
  - 3D icing codes are highly CPU-intensive compared with 2D icing codes.
- Capability improvements sought:
  - Improved ice accretion process, to allow the simpler execution of multistep calculations, for example.
  - Ability to create CAD solids directly from the 3D ice shapes predictions is important to improve the overall process efficiency.
- Development of best practise and application methodology.

Way forward

- Fundamental work needs to be done to develop a comprehensive understanding of the physics:
  - 3D wall/droplet interaction (splashing, bouncing,...)
  - Water film transport
  - Roughness and heat transfer
  - Phase change
  - Ice growing modelling
- Assessment of code capability should be done:
  - Code to code comparison (ref to NATO/RTO WS)
  - Way of improvement and recommendations should be put in place
- 3D methodology needs to be developed
- 3D validation database should be built up:
  - Covering App C, X (and D)

Conclusions

- Airbus currently uses 2D icing codes for ice accretion prediction on lifting surfaces and wing ice protection system design.
  - 3D icing codes are used in a supplementary role.
- Airbus are interested in a more widespread use of 3D icing codes in the future, for ice shape calculations, because potential improvements are foreseen in terms of:
  1) Ice prediction accuracy, especially for highly 3D features.
  2) More efficient process.
- Most of the basics of 3D simulation are put in place.
  - 3D icing codes tend to use the established theory utilised by 2D codes, but within a 3D framework.
  - Improvements are needed to address the gaps in the process:
    - 3D ice shape → CAD

Conclusions

- Validation of the codes and an established user-independent best practise is required.
- Acceptance by airworthiness authorities should be discussed based on:
  - Code to code comparison
  - Code experimental data comparison
  - Development of 3D methodology
- Development of an open validation database and code to code comparisons are highly supported by Airbus.

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