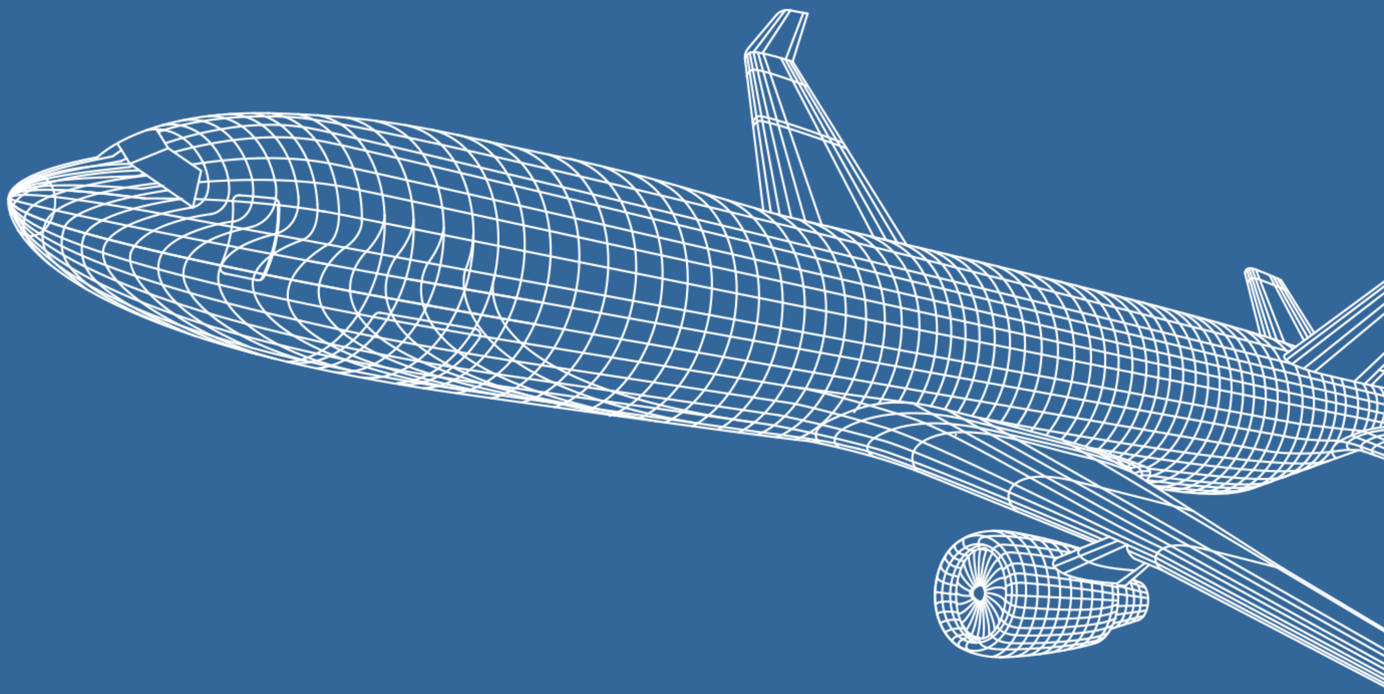

METHODS TO ACCOUNT FOR THE EFFECT OF WATER AND ICE INGESTION ON COMPRESSOR PERFORMANCE

Lars Ellbrant, Hans Mårtensson, Peter Johansson, Ulf Johansson and Fredrik Wallin

Export Control

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GKN TECHNOLOGY: MAKING THINGS FLY

Export control Restriction

Export Control

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Relevance for the aerospace industry

- Accidents due to icing
  - Comair Flight 3272 from Cincinnati (Jan 9, 1997) : "The crash occurred when a "very thin layer of rough ice" accumulated on the wings during descent
  - ATR-72-212 (Nov 4, 2010): "Caused by severe ice build up at 20.000 ft"
  - American Eagle Flight 4181 (Oct 31, 1994): "Loss of control due to ice accretion beyond the deice boots when flying in supercooled cloud and drizzle/rain drops **exceeding icing certification envelope**"

Ref: http://enquirer.com/comair3272/

Ref: http://www.nasa.gov/externalflash/NACA/

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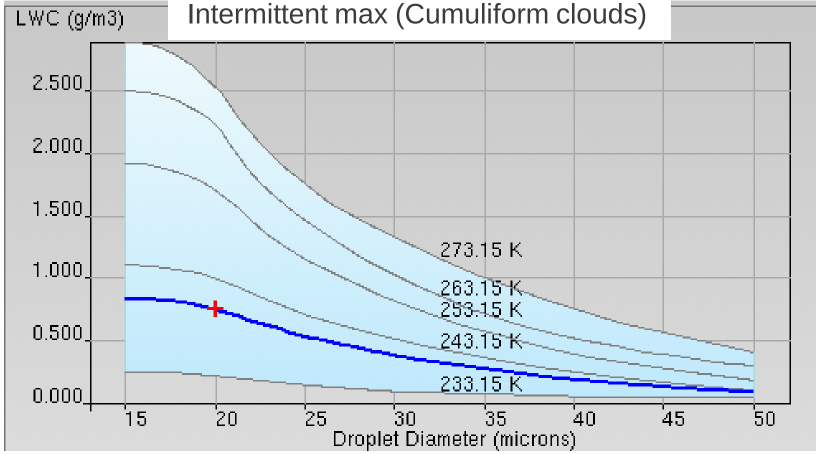
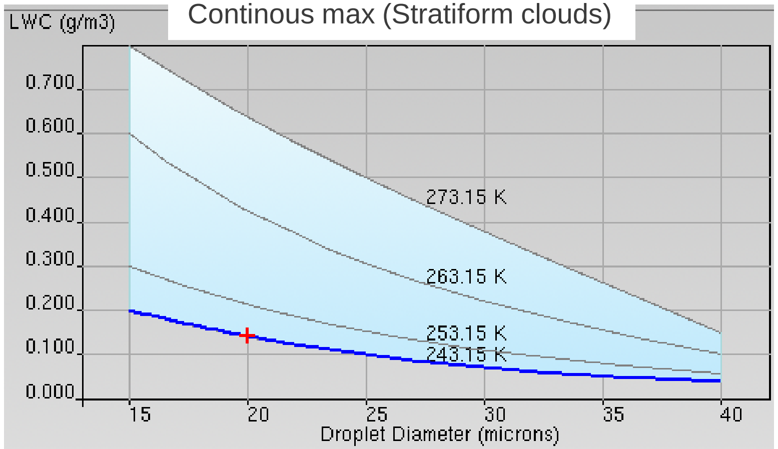
Icing regulations

FAA regulations - Appendix C

The airplane must be able to safely operate in the **continuous maximum** and **intermittent maximum** icing conditions





FAA regulations - Appendix O

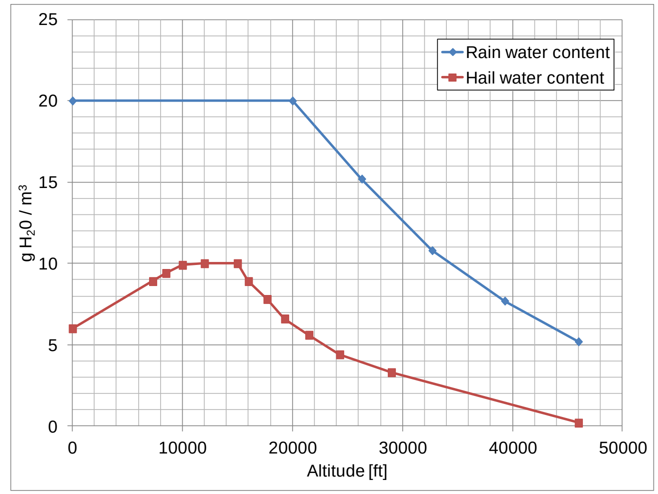
Expands certification to include super large droplets (SLD) which includes freezing drizzle and freezing rain

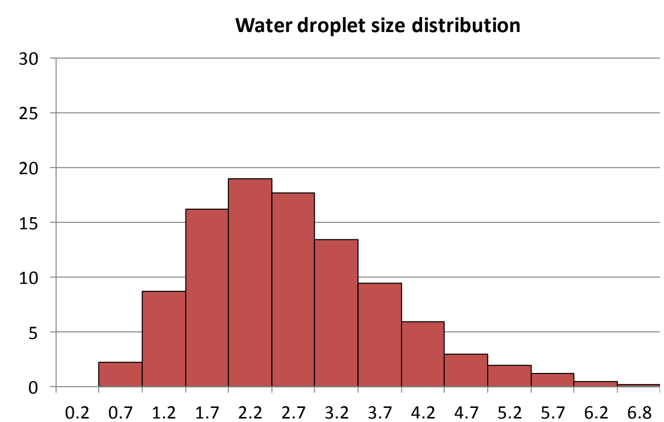
<u>Choices for certification</u>

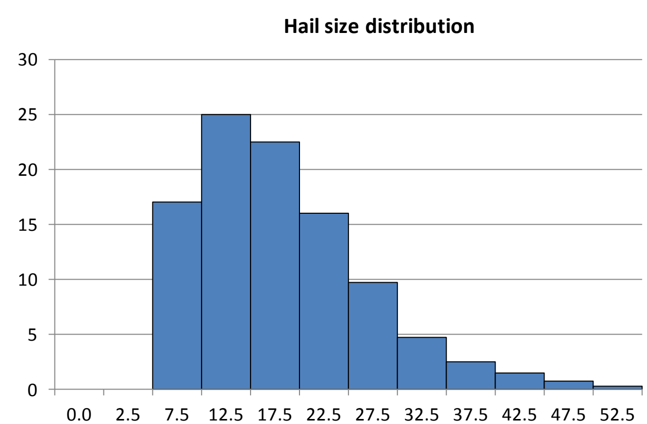
1. Certify only with Appendix C
    - Aircraft must detect and exit all SLD conditions safely
2. Certify with Appendix C and O
    - Aircraft allowed to operate in envelopes including in App. O and C

AIA Rain/Hail requirements for certification tests

- Rain/Hail certification
  - Liquid water content versus altitude
  - Rain droplet size distribution (0 – 8 mm)
  - Hail size distribution (up to 55 mm)
- Rain/hail ingestion can cause:
  - Compressor stall
  - Flame out
  - Fan blade degradation

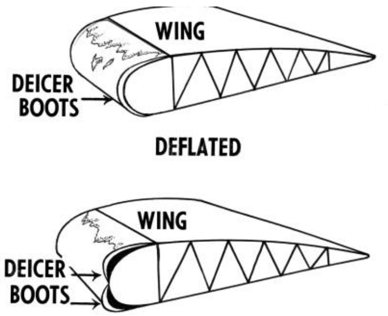




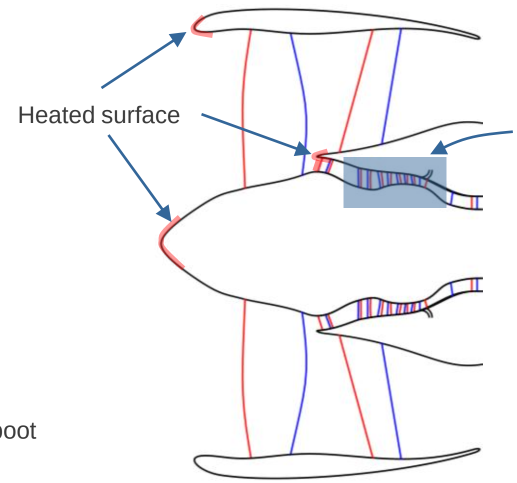


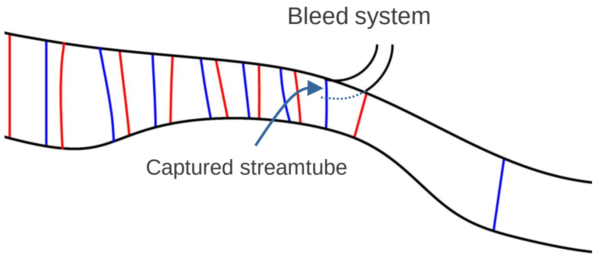
Technologies to avoid failure due to icing/water

- To ensure safe operation in icing conditions:
  - Anti-icing: Protections system used to ensure that no ice is accreted on surfaces
  - De-icing systems: Protection system that removes ice from surfaces
  - Engine bleed system: Removes ingested water/particles to prevent engine failure such as flame-out, compressor stall



Ref: https://en.wikipedia.org/wiki/Deicing_boot





- To support technologies method development and validation is needed

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Initiatives

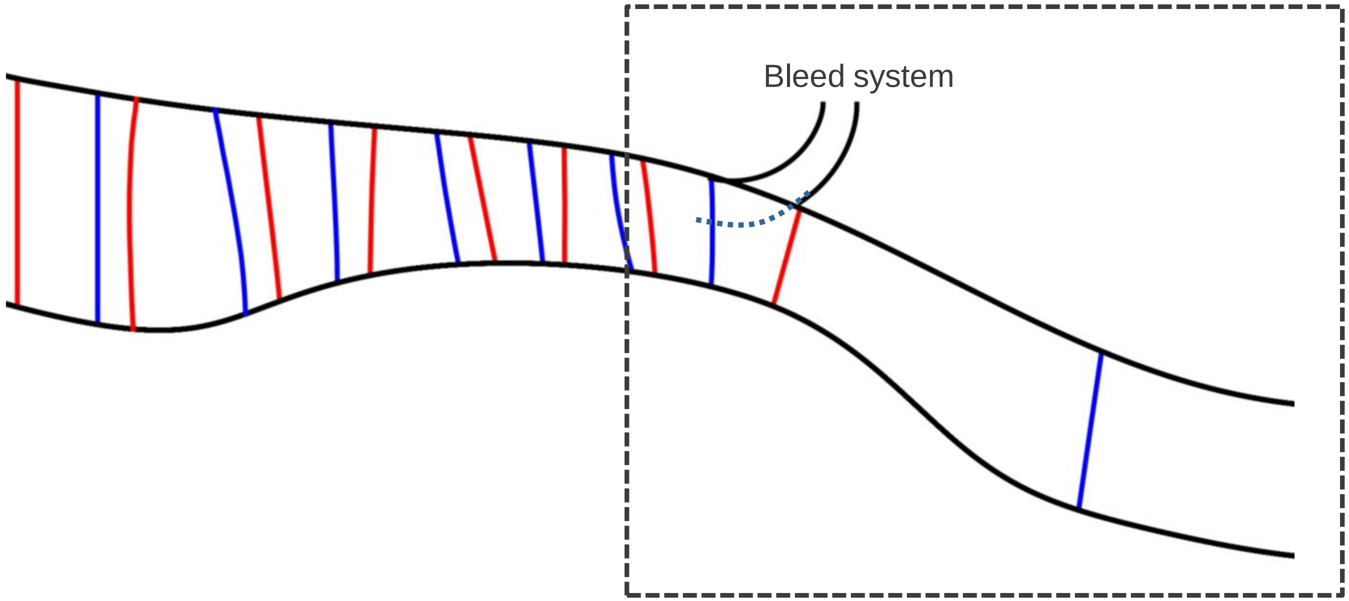
Clean Sky

STORM

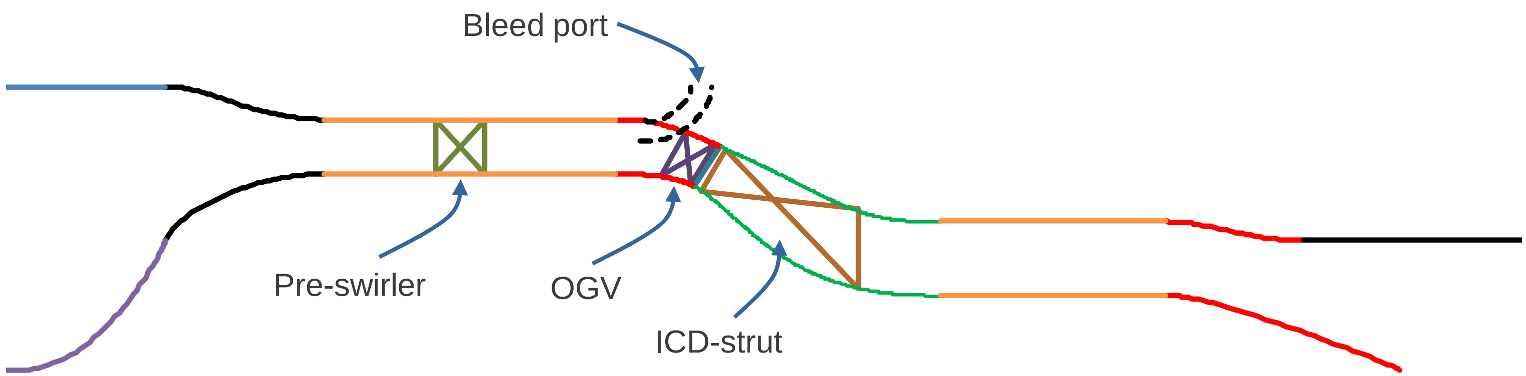
SYSTEMS AND SIMULATION TECHNIQUES OF ICE RELEASE ON PROPULSIVE SYSTEMS

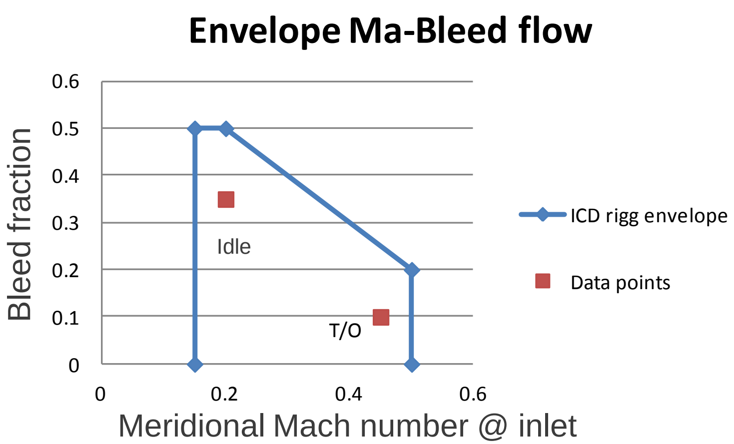
GKN water injection rig – meridional view

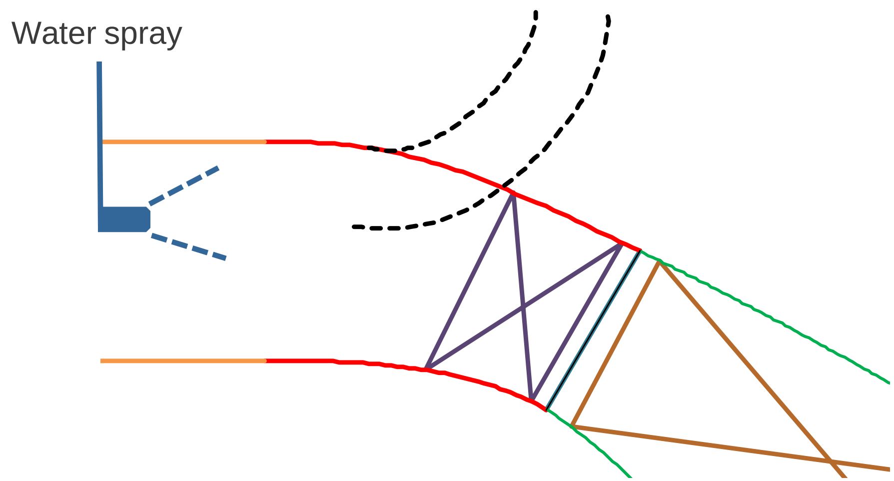
- Financed through CleanSky2
- Objectives
  - Study bleed functionality downstream the Low Pressure Compressor with regards to:
    - Aerodynamics
    - Water extraction
    - Generate experimental data for validation of analysis methods



GKN water injection rig – meridional view







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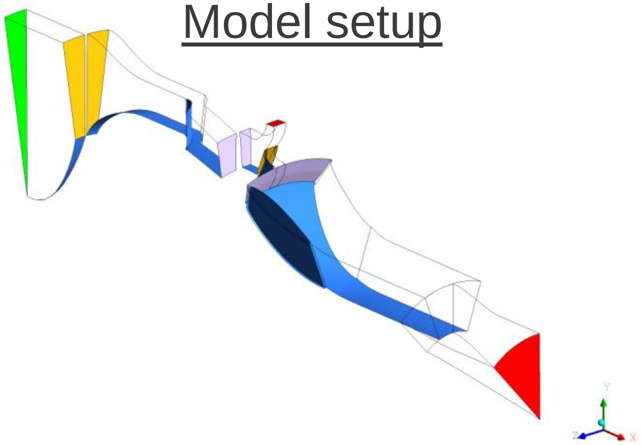
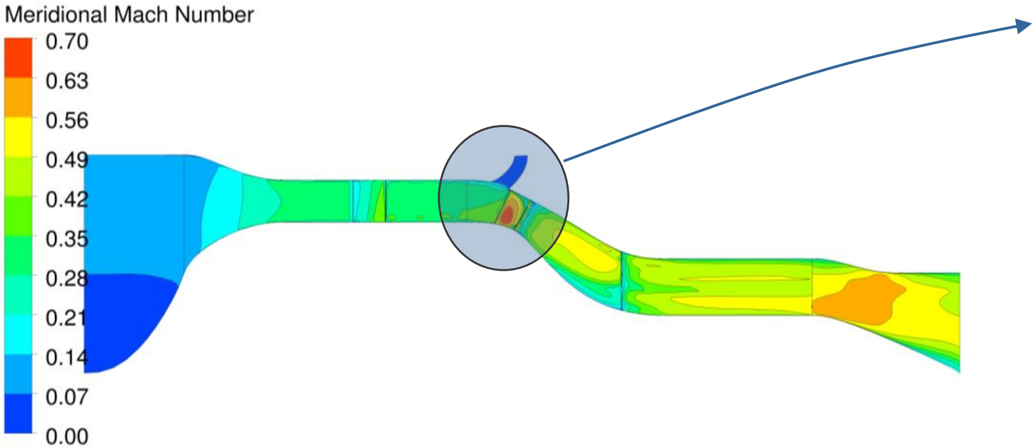
GKN water injection rig – CFD analysis

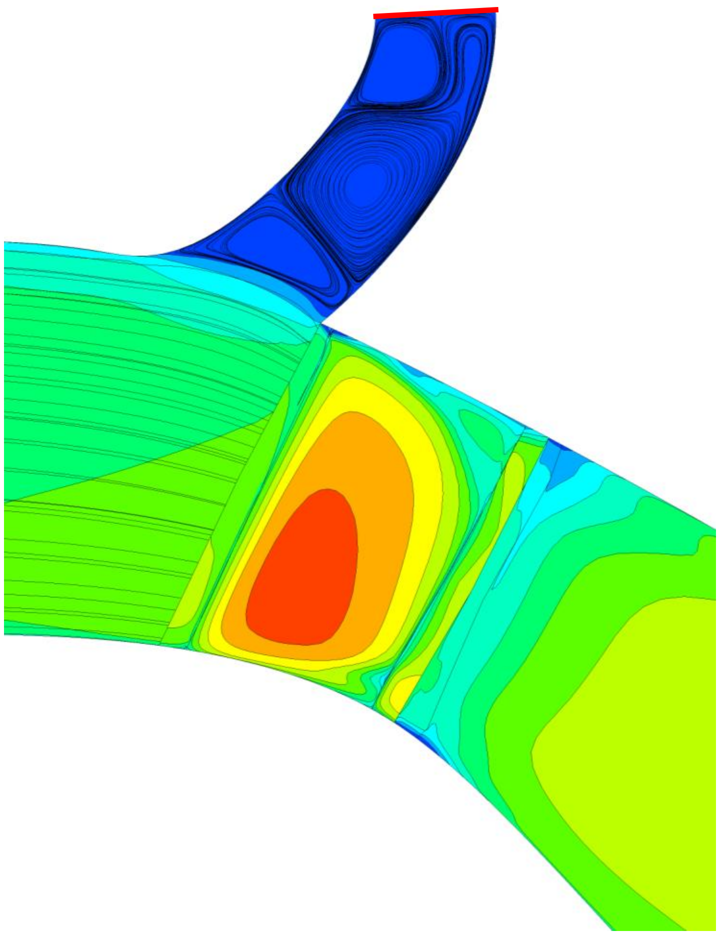
Model setup



CFD analysis on the rig



Design point: Bleed pipe closed



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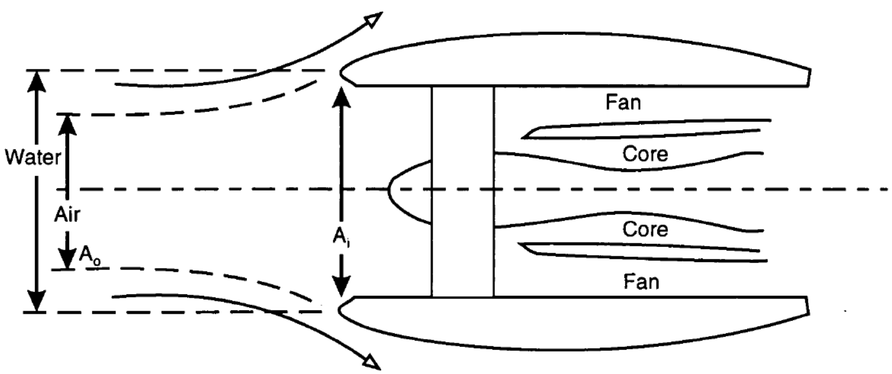
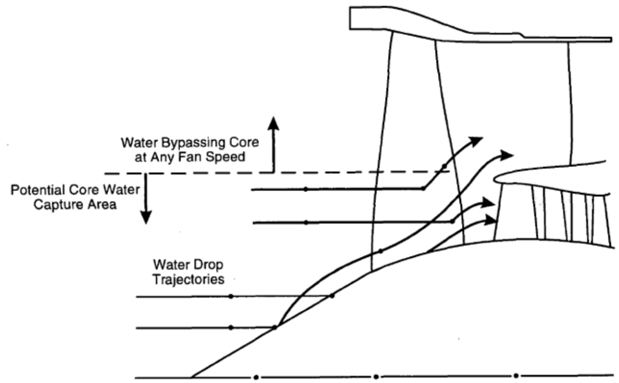
GKN water injection rig - amount of water

REF AGARD 322, "Recommended practices for the assessment of the effects of atmospheric water ingestion on the performance and operability of gas turbine engines", sept 1995

- On engine intake 5% WAR should be covered at all conditions
  - Citing FAR Part 33: Water and Hail Ingestion Standard 4% airflow by weight
  - Citing US mil std 5%
- Core WAR = 5% assumed giving some margin
  - Capture area (Scoop factor) increases war compared to ambient
  - Centrifuging and coverage by fan hub decreases core war





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Droplet sizes & Films

What distributions to aim for

- Some film forms on the end walls
- Max Droplet size to enter LPC 8mm
- Simple Post break-up models indicate smaller droplets reaches core <100 µm
- Hail will be substantially larger.
- Need to simulate rain ingestion through LPC to formulate requirement on drops, and distribution at LPC back-end.

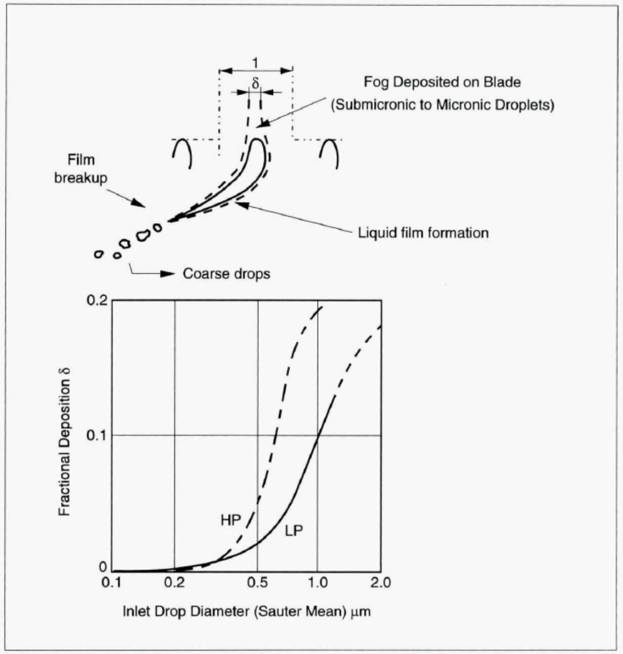

Figure 5-5

Micronic Droplet Deposition and Coarse Drop Formation
(Reference 7.8)

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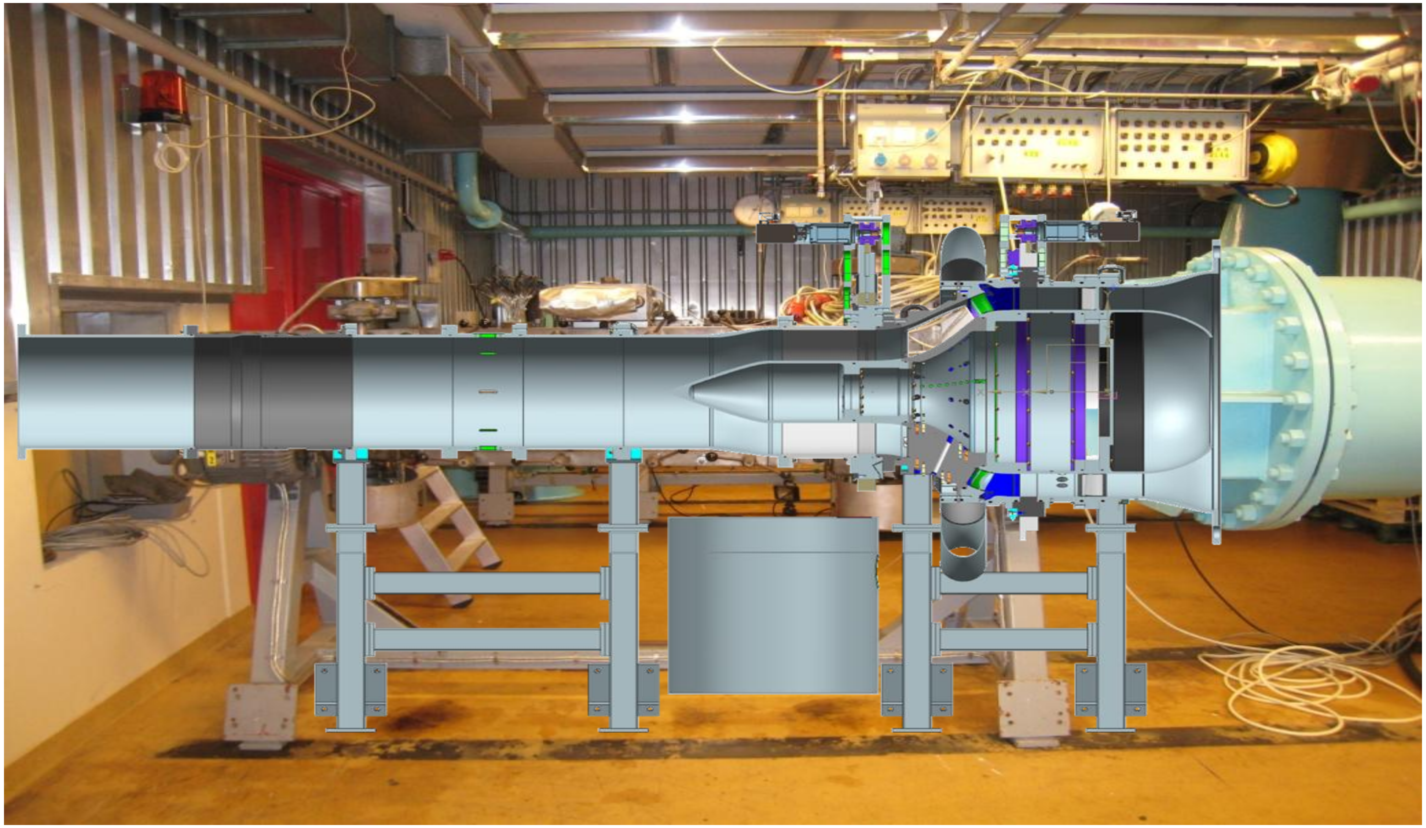
GKN water injection rig – Current status

- Plan to start test in December 2016



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STORM

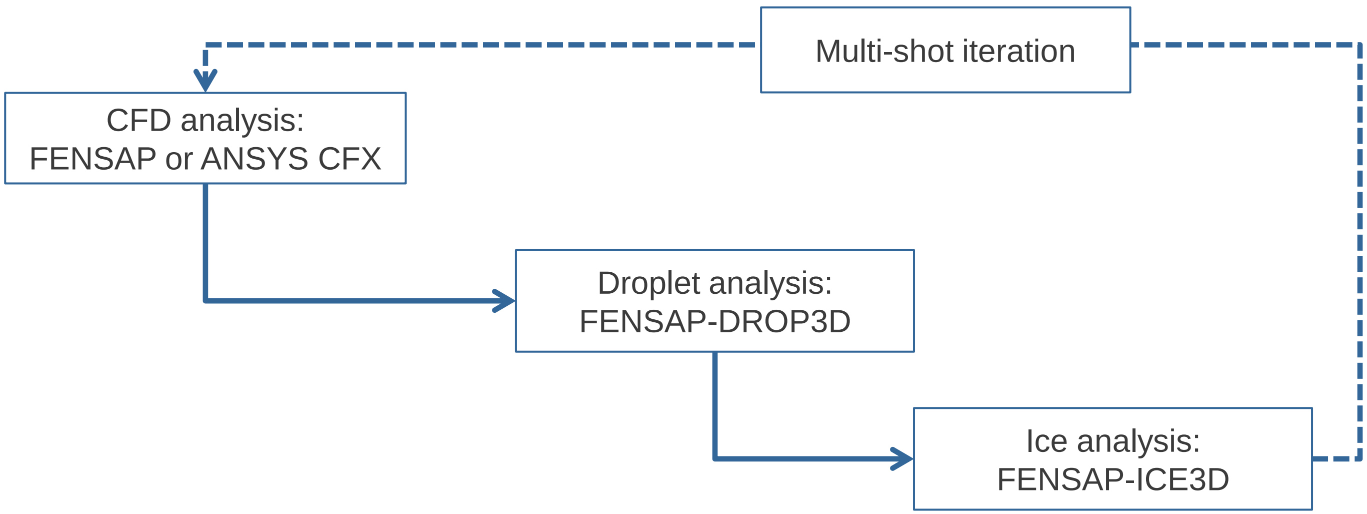
Efficient ice protection Systems and simulation Techniques Of ice Release on propulsive systeMs

GKN STORM

- Objectives
  - The STORM project will provide new advanced simulation methodologies in three specific fields:
    - Ice release
    - Ice accretion with runback aspects
    - Ice trajectory for aero propulsive systems
  - STORM will also increase the maturity (TRL) of innovative technologies for ice protection
    - Develop and test technologies for engine and nacelle components (electrical, mechanical and coatings)

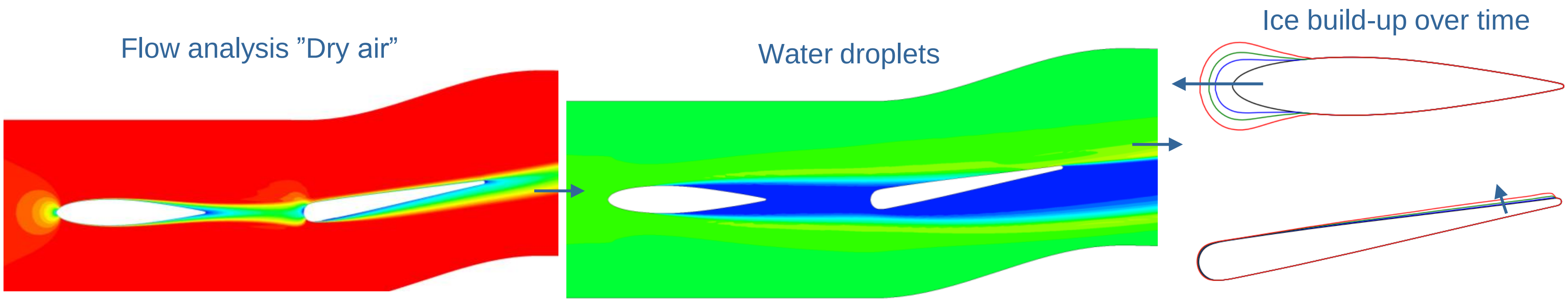
- GKN focuses on method development and validation for predicting ice accretion on engine components
- Work includes benchmarking methods with project partners (ONERA, CIRA)

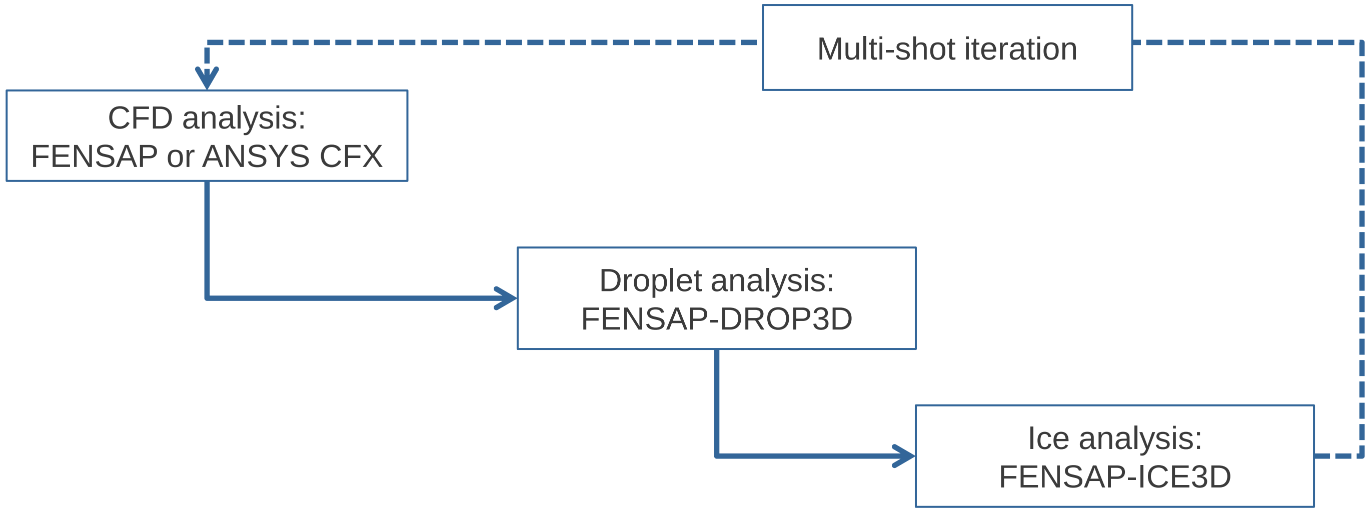
Methodology for water/ice analysis



FENSAP/CFX analysis

Methodology for water/ice analysis





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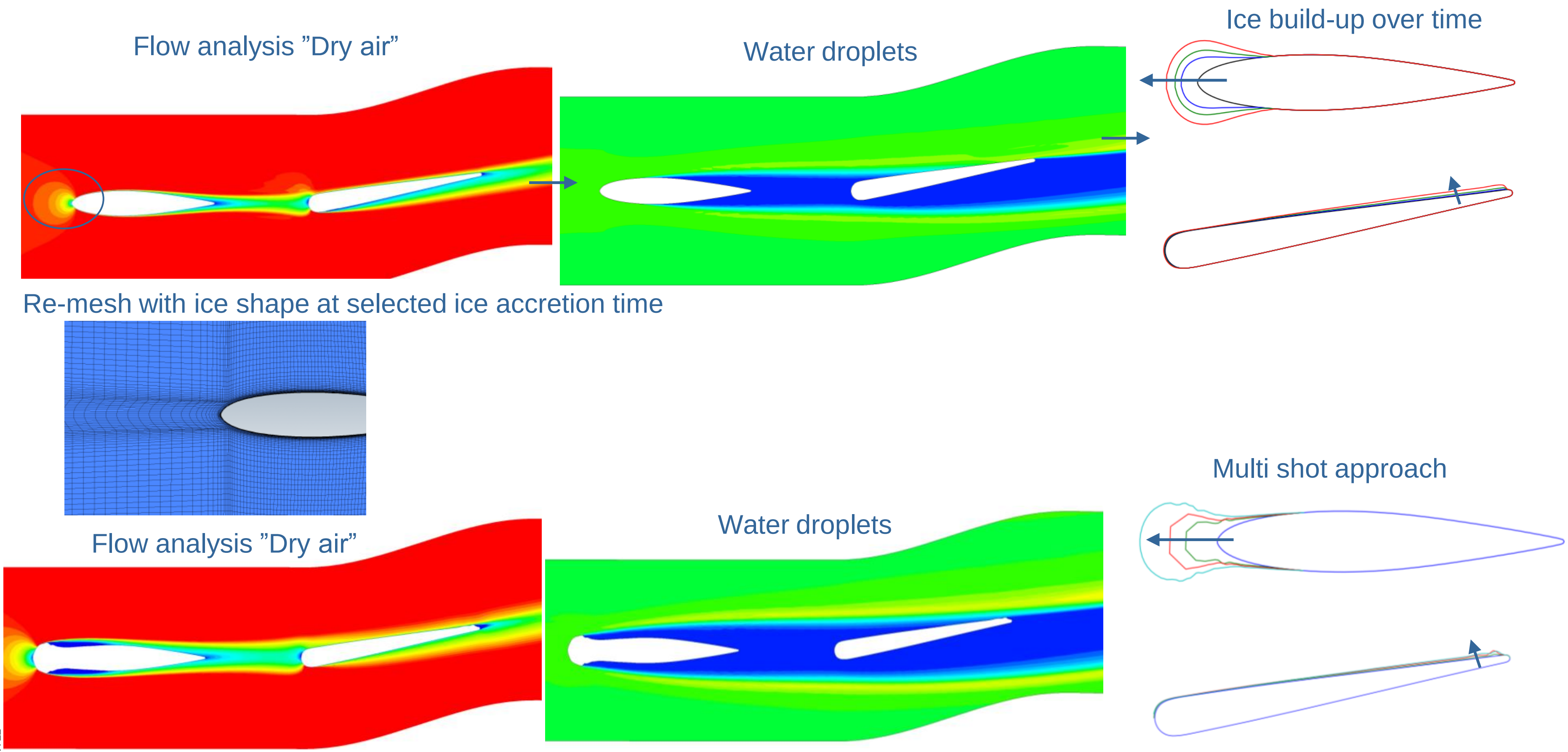
FENSAP/CFX analysis

Methodology for water/ice analysis



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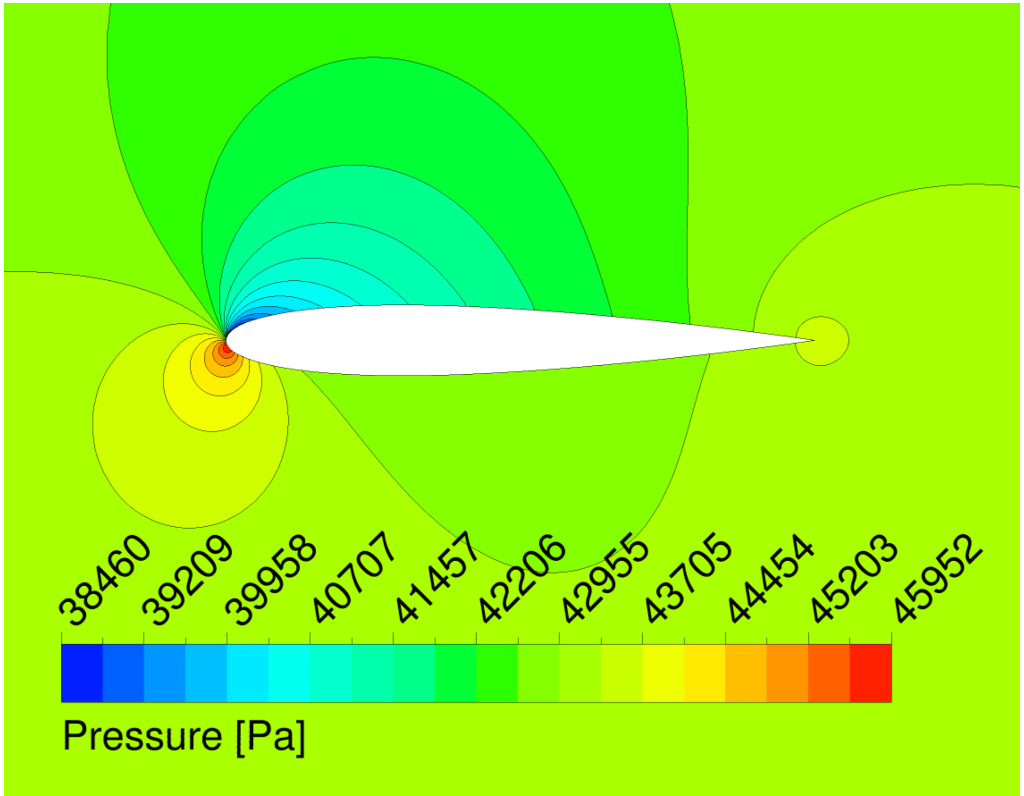
Test cases within STORM

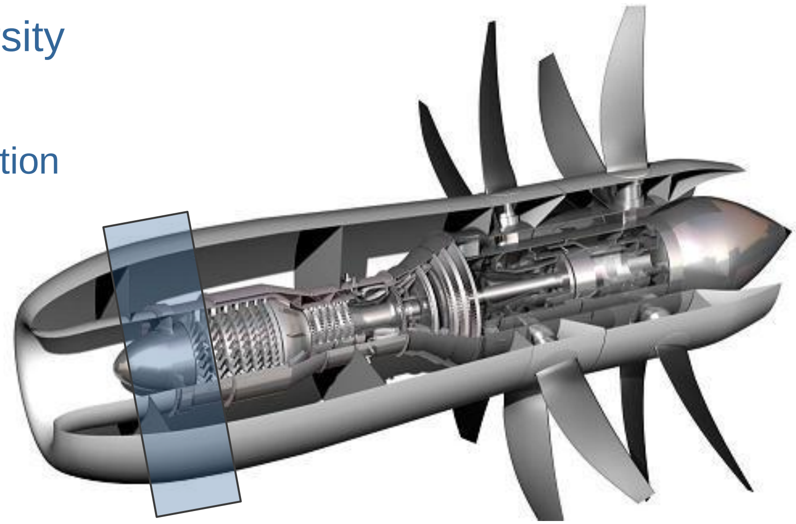
Test cases – 2D wing in freestream

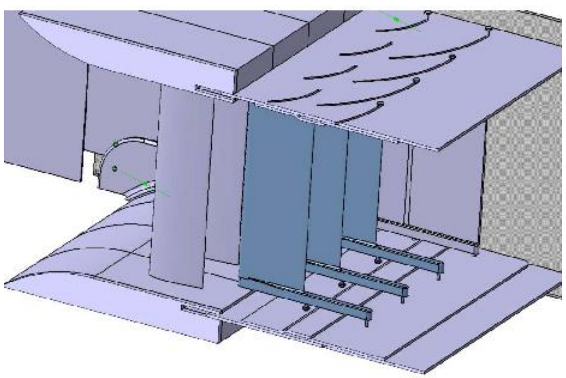
- 2D wing in freestream (NACA0012)
  - Low TRL test case
  - Chord 0.53 m
  - Angle of attack 4°
  - Mach number 0.177
  - Liquid water content 1.3 g/m^3
  - Mean droplet diameter 20 microns
  - Ice accretion time 480s.

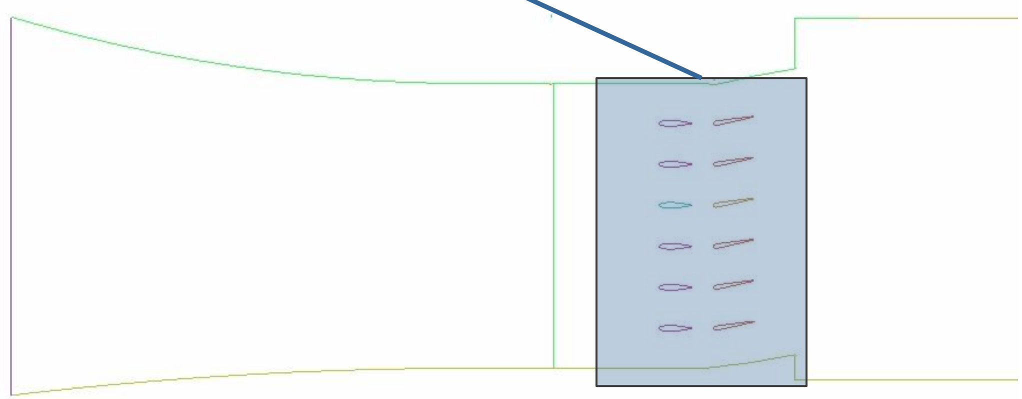


Test cases – Strut + VGV cascade rig

- Cascade rig test in icing tunnel at Cranfield University
  - Strut and variable guide vane (VGV)
  - Represents an inlet section for an Open rotor configuration
  - Testing include different types of ice accretion:
    - Rime ice
    - Glaze ice
    - Unheated versus heated struts







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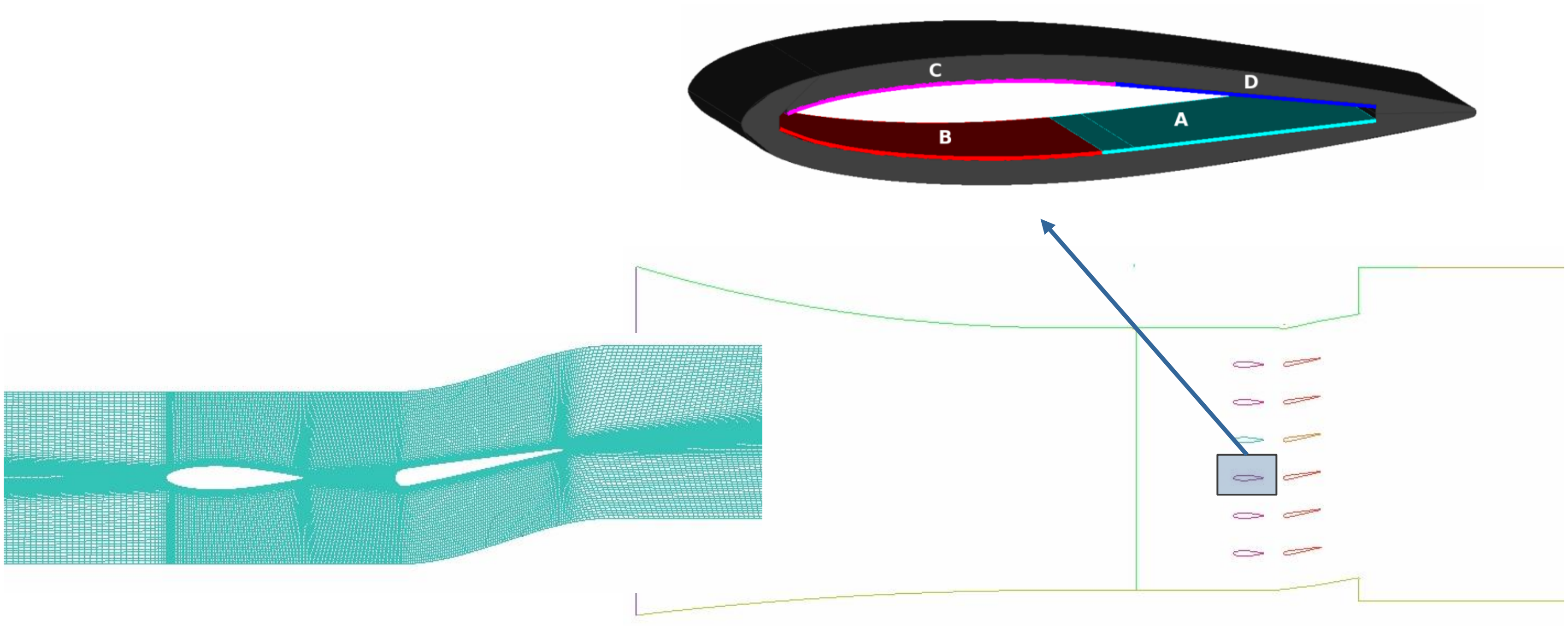
Test cases – Strut + VGV cascade rig

- Cascade rig test in icing tunnel at Cranfield University
  - Heated strut
  - Regions A, B, C and D can be heated with different power to control the anti-icing function

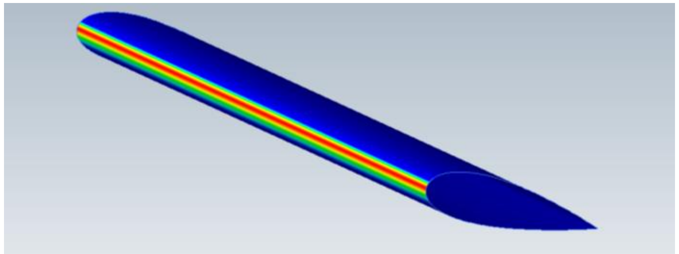


Results

Results – NACA12

- NACA12 in freestream, ice accreation 480s

Mass of water caught on surface



Ice shape after 480s compared to experiment: Single shot vs. Multishot

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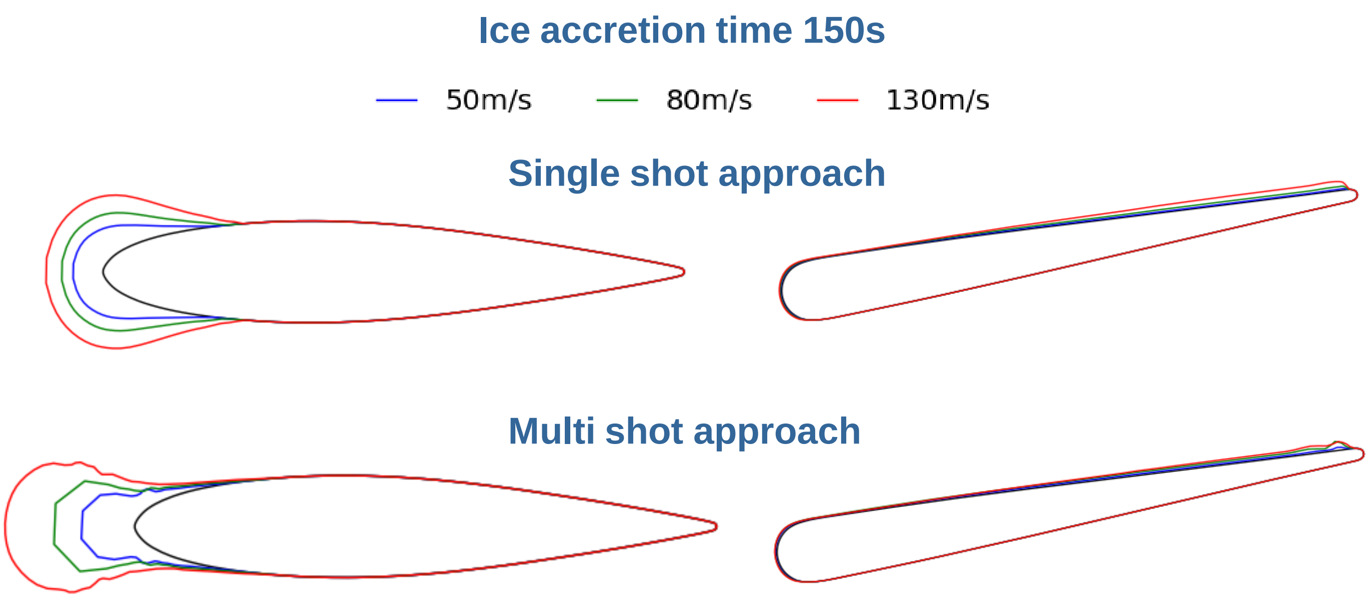
Results – Cascade rig

- Cascade rig – Unheated



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Conclusion and future work

- Bleed functionality is being tested at GKN Aerospace through the EU project CleanSky2
  - Methods to account for water and particle ingestion will be developed and validated
- GKN builds capability to predict ice accretion through the EU project STORM
  - Methodology will be validated with engine representative test cases
  - This include validation of methods to predict anti-ice technology performance

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