Validation of Droplet Size in the VTT Icing Wind Tunnel Test Section

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Wind Power
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Outline

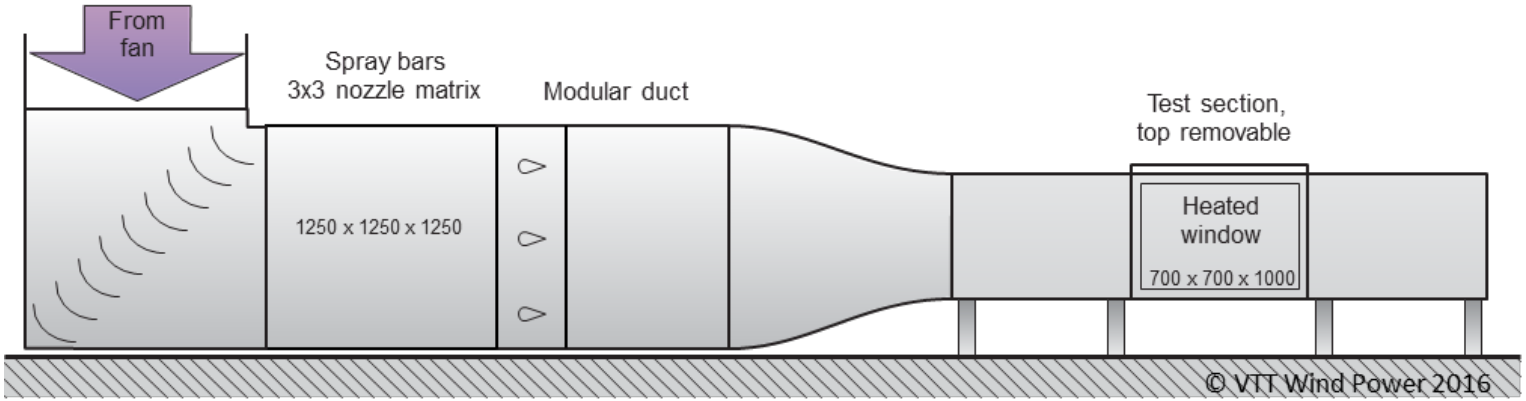
Purpose of Validation Campaign

- Need for improving the knowledge of operating conditions in the icing wind tunnel (IWT) test section:
  - Median Volume Diameter – MVD [µm] and Droplet Size Distribution – DSD [µm]
  - Liquid Water Content – LWC [g/m^3]
- The main target was to improve the tests repeatability and accuracy
- Operating the VTT icing wind tunnel in the validated conditions:
  - enables precise inputdata for the R&D work (ice accretion models)
  - gives more valuable measurement data or solutions for customer needs
- Validation measurements executed in summer 2018. The following partners enabled this measurement campaign:
  - The Finnish Meteorological Institute (FMI)
  - University of Oulu
  - Technical University of Denmark (DTU)

Icing Wind Tunnel Validation Conditions

Comparable validation conditions:

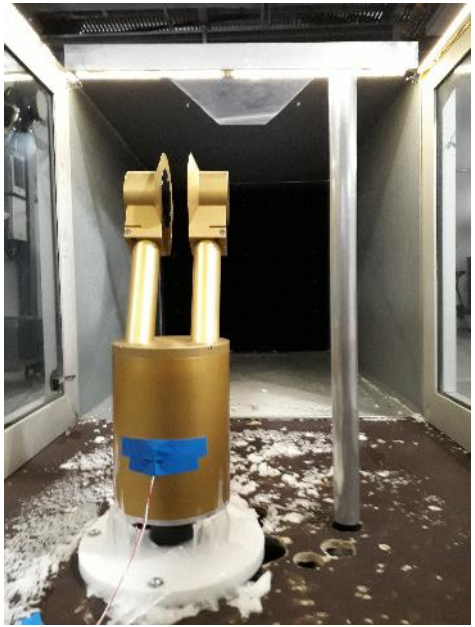
- Temperature -5°C
- Relative humidity (90…95) %
- Flow Velocity 7 m/s & 10 m/s
- 3 x different water spraying levels
- 2 x different atomizing air levels



Cloud Droplet Measurement Probes

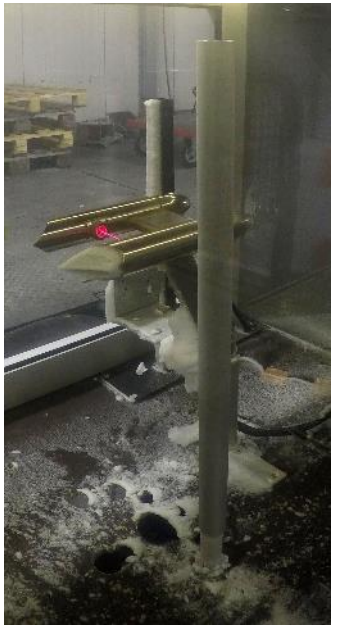
FINNISH METEOROLOGICAL INSTITUTE

CDP



UNIVERSITY OF OULU

ICEMET



DTU Technical University of Denmark

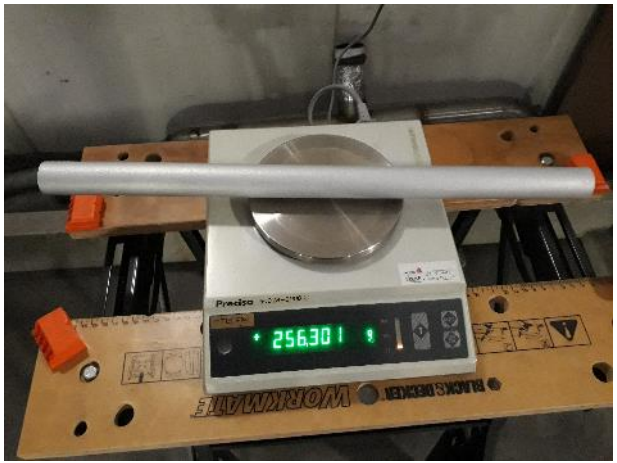
CDP

Methods in the Validation Measurements

Calibrated parameter:
Temperature [°C]
Relative humidity [RH %]
Wind Speed [m/s]
Water [kg/h]

IWT test section:
Droplet size, MVD [µm]
Validated with FMI CDP, ICEMET & DTU CDP measurements

More accurate LWC value:
Calculation is based on ISO12494 (Atmospheric icing of structures)



Results of Validation Measurements

Differences between cases ?

Case 1. vs. Case 3.

- Effected by sprayed water [kg/h] ~ 2 x higher
- LWC [g/m^3] value ~ 2 x higher

Case 1. vs. Case 4

- Effected by atomizing air [l/min] ~ 2 x higher
- MVD [µm] – value decreases

Case 4. & Case 5.

- Effected by sprayed water [kg/h] ~ 2 x higher
- LWC [g/m^3] value ~ 2 x higher

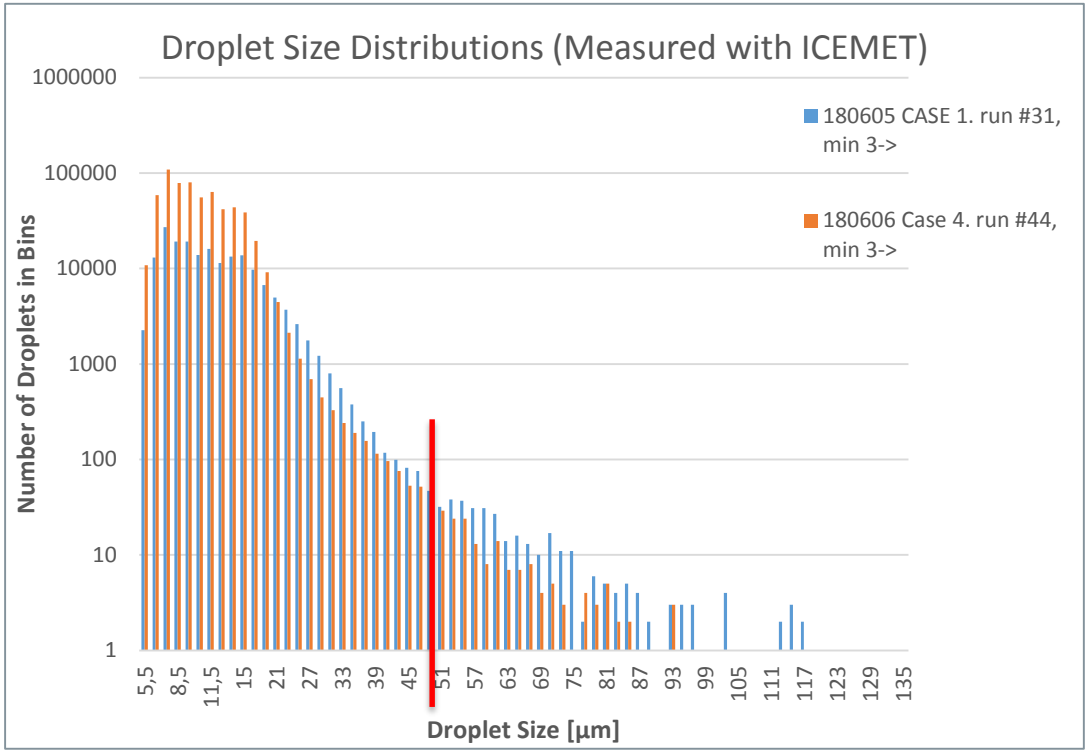
	Case 1.	Case 2.	Case 3.	Case 4.	Case 5.
VTT IWT $LWC_{Theoretical}$ [g/m3]	0,25	0,44	0,44	0,25	0,44
ICEMET					
MVD [µm]	25,5±0,7	24,3±0,4	25,7±0,5	16,1±0,3	16,6±0,2
LWC [g/m^3]	0,27±0,03	0,42±0,03	0,48±0,02	0,22±0,03	0,46±0,05
CDP FMI					
MVD [µm]	18,5±1,7	17,8±1,4	-	13,5±0,4	14,1±1,0
LWC [g/m^3]	0,45±0,06	0,81±0,12	-	0,56±0,14	0,84±0,33
CDP DTU					
MVD [µm]	18,5±1,6	18,8±1,7	-	13,8±0,8	-
LWC [g/m^3]	0,34±0,05	0,74±0,13	-	0,52±0,10	-

Comparison of MVD [µm] & LWC [g/m^3] case by case:

- MVD: ICEMET measured higher values than both CDP probes
- MVD: CDP (FMI) probe measured almost equal values compared to CDP (DTU) probe
- LWC: The calculated $LWC_{Theoretical}$ values are almost identical compared to measured ICEMET values!
- LWC: Both CDP probes measured higher values than ICEMET probe
- LWC: Between CDP probes small differences in measured values can be seen

Results of Validation Measurements

- **MVD range:**
  - CDP (2…50) µm
  - ICEMET (5…200) µm
- **Observed during the tests:**
  - ICEMET detected droplets with MVD [µm] value higher than 50 µm!
  - Therefore ICEMET results were used to evaluate the new IWT operating conditions.
- **DSD comparison example:**
  - Case 1. - The bigger droplets are highlighted (lower atomizing air were used)
  - Case 4. - The smaller droplets are highlighted (higher atomizing air were used)



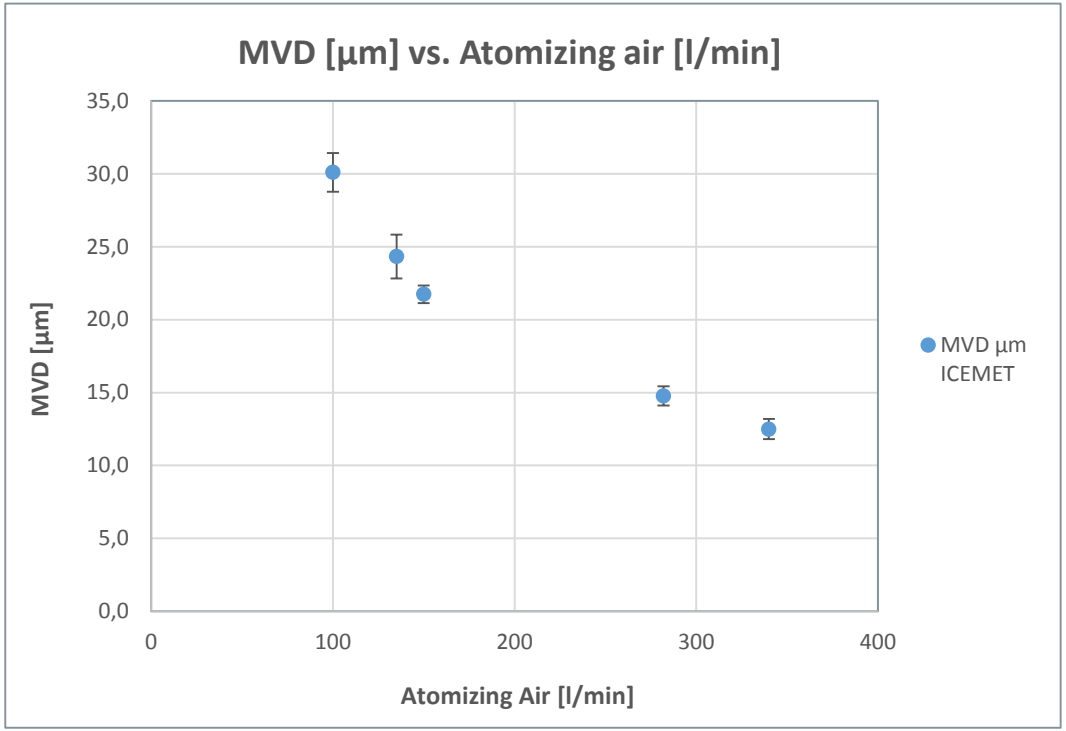
Updated VTT IWT operating parameters

Validated Conditions: **T=-5°C & WS=10 m/s**

- MVD level 1. ~ 25 µm
  - LWC 0,2 … 0,3 g/m^3 Typical Icing
  - LWC 0,5 g/m^3 Severe Icing
- MVD level 1. ~ 16 µm
  - LWC ~ 0,2 g/m^3 Typical Icing
  - LWC ~ 0,5 g/m^3 Severe Icing

Operating regime:

- Wind speed upto 20 m/s
  - Can be operated hours
- Wind speed (20 – 50) m/s
  - Can be operated shorter periods and has to be assessed case by case
- Temp. range: +25°C … -25°C



Summary

- In the planning phase, we considered what could be the suitable size of test matrix…
  - Number of variables to reach enough large scale of operating parameters ?
  - Repeatability
  - Comparability with the three independent devices
- Time consuming, but fruitful project!
  - laboratory work & data-analysis
- We were a bit surprised that small amount of droplets in the test section were higher than 50 µm!
- The calculated $LWC_{Theoretical}$ values are almost identical compared to measured ICEMET probe LWC values
- After this project we have better understanding:
  - about our icing wind tunnel operating regime
  - how to control the droplet characteristics
  - how to improve our test matrix in the future
  - how to rerun some extra tests
- Challenging task to validate the IWT operating conditions!

References

- ICEMET probe (http://www.oulu.fi/icemet/)
- CDP probe (http://www.dropletmeasurement.com/cloud-droplet-probe-cdp-2)
- Atmospheric icing of structures. ISO 12494 International Standard. First edition 2001-08-15. p. 66

Thank You!

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