

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

VTT TECHNICAL RESEARCH  
CENTRE OF FINLAND LTD

Wind Power

Tuomas Jokela, Mikko Tiihonen &  
Timo Karlsson

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Umeå, Sweden



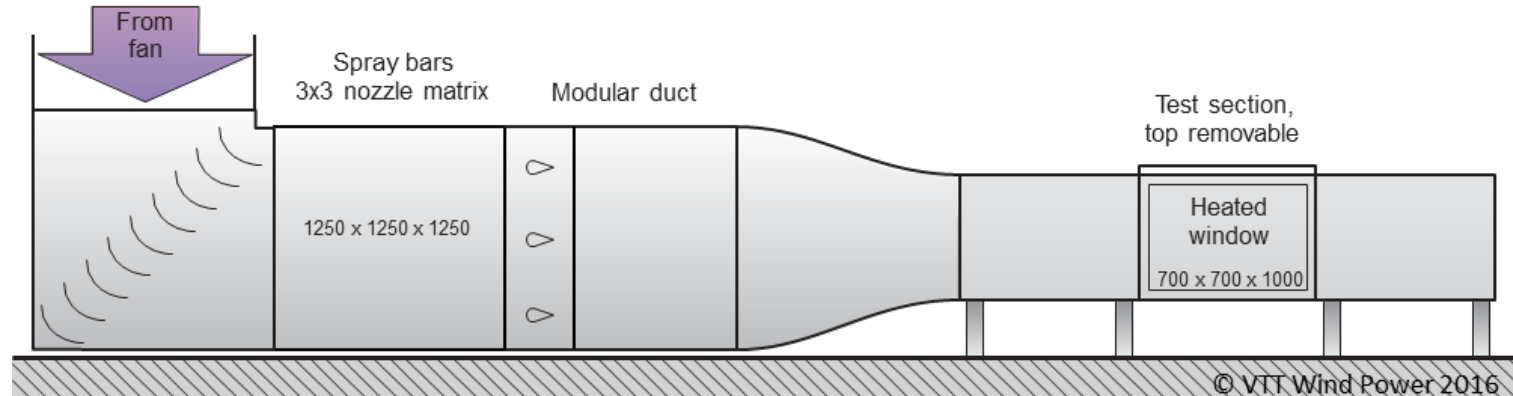
- Purpose of Validation Campaign p. 3
- VTT Icing Wind Tunnel (IWT) Validation Conditions p. 4
- Cloud Droplet Measurement Probes p. 5
- Methods in the Validation Measurements p. 6
- Results of Validation Measurements p. 7 - 8
- Updated VTT IWT operating parameters p. 9
- Summary p. 10
- References p. 11

- Need for improving the knowledge of operating conditions in the icing wind tunnel (IWT) test section:
  - Median Volume Diameter – MVD [ $\mu\text{m}$ ] and Droplet Size Distribution – DSD [ $\mu\text{m}$ ]
  - Liquid Water Content – LWC [ $\text{g}/\text{m}^3$ ]
- 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  $-5^{\circ}\text{C}$
- 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

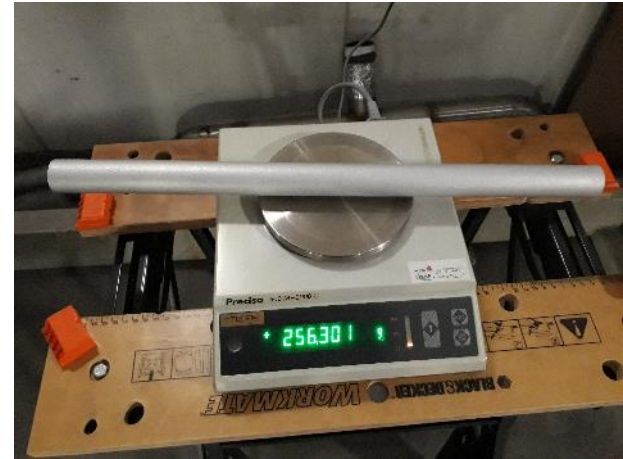
**Calibrated parameter:**

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

**IWT test section:**

- Droplet size, MVD [ $\mu\text{m}$ ]
- Validated with FMI CDP, ICEMET & DTU CDP measurements

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



## Differences between cases ?

### Case 1. vs. Case 3.

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

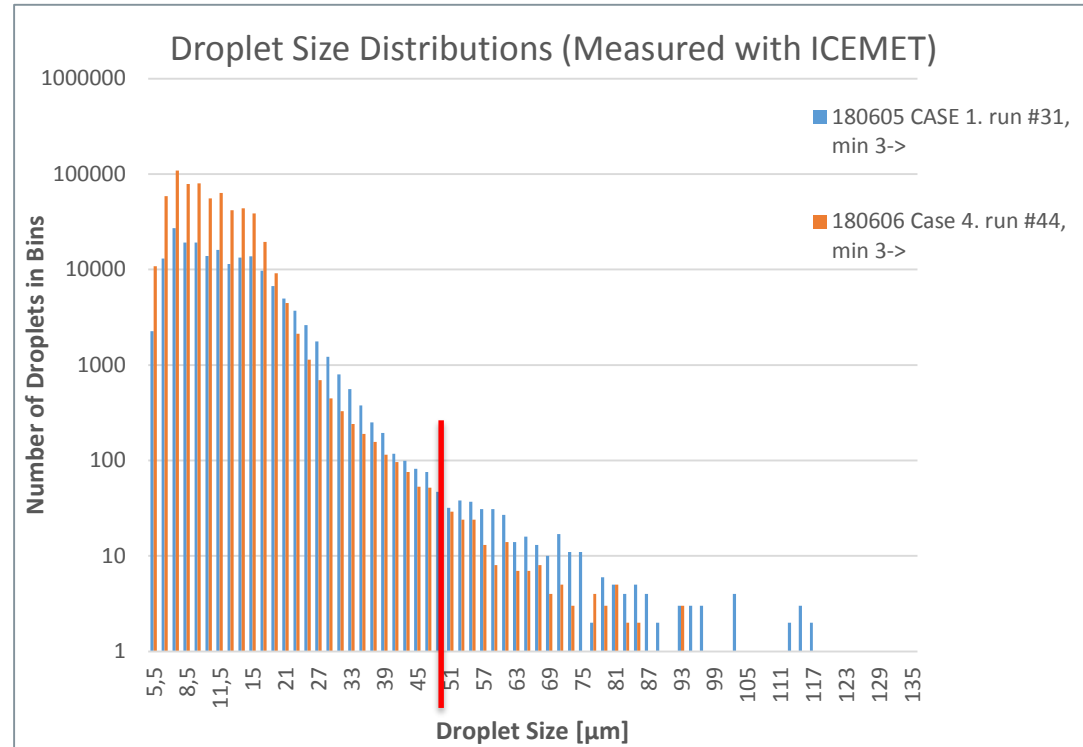
	Case 1.	Case 2.	Case 3.	Case 4.	Case 5.
<b>VTT IWT</b>					
LWC <sub>Theoretical</sub> [g/m <sup>3</sup> ]	0,25	0,44	0,44	0,25	0,44
<b>ICEMET</b>					
MVD [μm]	25,5±0,7	24,3±0,4	25,7±0,5	16,1±0,3	16,6±0,2
LWC [g/m <sup>3</sup> ]	0,27±0,03	0,42±0,03	0,48±0,02	0,22±0,03	0,46±0,05
<b>CDP FMI</b>					
MVD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

## Comparison of MVD [μm] & LWC [g/m<sup>3</sup>] 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<sub>Theoretical</sub> 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)  $\mu\text{m}$
  - ICEMET (5...200)  $\mu\text{m}$
- **Observed during the tests:**
  - ICEMET detected droplets with MVD [ $\mu\text{m}$ ] value higher than 50  $\mu\text{m}$ !
  - 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)





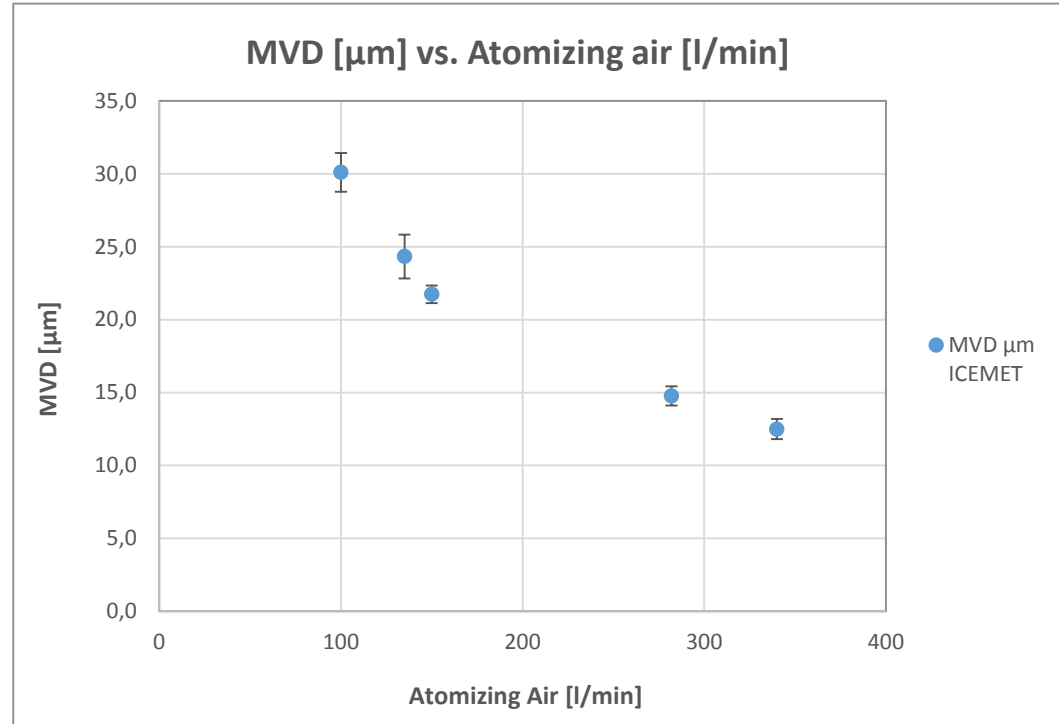
# Updated VTT IWT operating parameters

## Validated Conditions: $T=-5^{\circ}\text{C}$ & $WS=10\text{ m/s}$

- MVD level 1.  $\sim 25\ \mu\text{m}$ 
  - LWC  $0,2 \dots 0,3\ \text{g/m}^3$  Typical Icing
  - LWC  $0,5\ \text{g/m}^3$  Severe Icing
- MVD level 1.  $\sim 16\ \mu\text{m}$ 
  - LWC  $\sim 0,2\ \text{g/m}^3$  Typical Icing
  - LWC  $\sim 0,5\ \text{g/m}^3$  Severe Icing

## Operating regime:

- Wind speed upto  $20\ \text{m/s}$ 
  - Can be operated hours
- Wind speed ( $20 - 50$ )  $\text{m/s}$ 
  - Can be operated shorter periods and has to be assessed case by case
- Temp. range:  $+25^{\circ}\text{C} \dots -25^{\circ}\text{C}$



- 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  $\mu\text{m}$ !
- The calculated  $\text{LWC}_{\text{Theoretical}}$  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!

