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Simulation of Freezing and Frozen Precipitation for the Evaluation of De/anti-icing Systems

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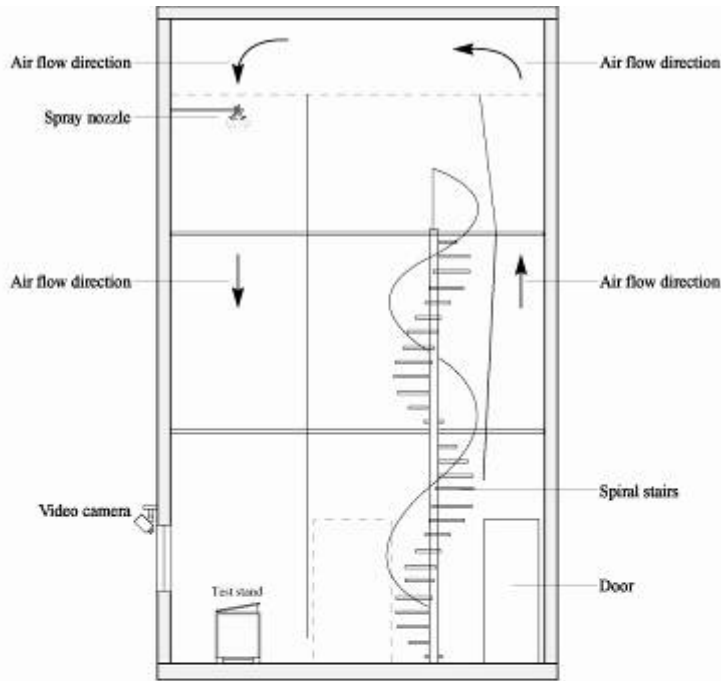
Ice = Transportation Problem



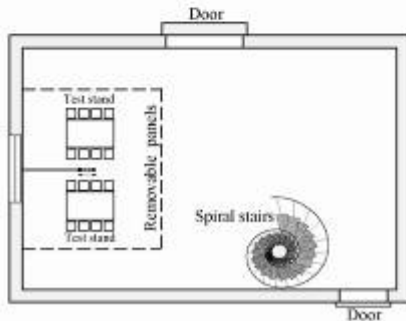
Simulated Precipitation

- Freezing Rain
- Freezing Drizzle
- Freezing Fog
- Frost
- Snow
 - Snow Pellets
- Ice Pellets
- In-cloud Icing

Freezing Rain



Section View



Top View

FZRA occurs when supercooled water droplets freeze on impact with an object \leq freezing droplets > 0.5 mm

Simulation:

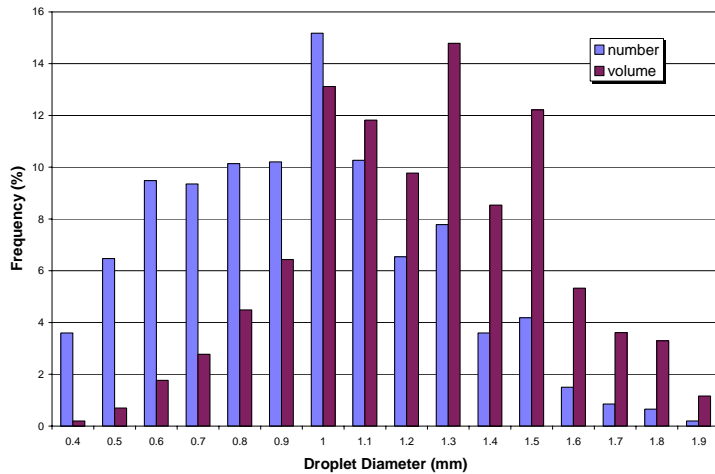
Height: 9 m

Test area: 1 m²

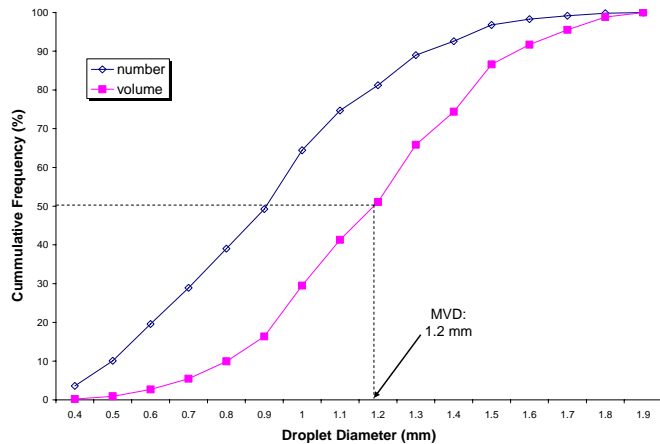
Icing rate control by on/off of spray nozzle 'on' $\approx 2\%$

Rates: 0.5 and 7.5 mm/h (15%)

Freezing Rain



a) Droplet Size Histogram



b) Droplet Cumulative Size Frequency

MVD: 1.2 mm

Height required to achieve

$V_t = 2.2$ m

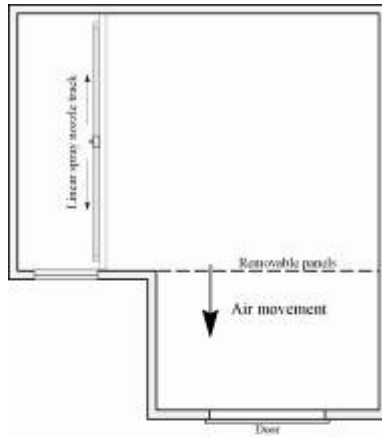
63% of $T = 40$ m

(if MVD 0.5 mm; 63% of $T = 8$ m)

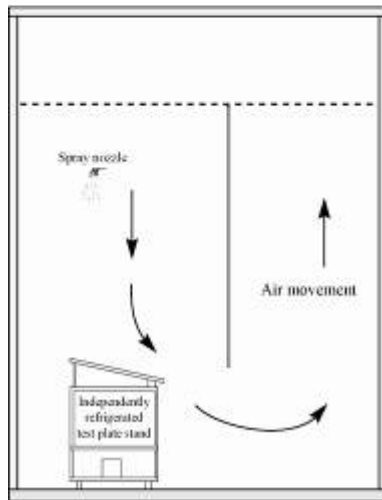
Typical evaluations:

- aircraft de/anti-icing fluids
- ice detectors
- anemometers
- overhead cables
- icephobic materials

Freezing Drizzle



Top View



Section View

FZDZ is a fairly steady, light precipitation.
The drop size: 0.2 to 0.5 mm in diameter.
Drizzle appears to float but falls to the ground

Simulation:

Height: 4 m

Test area: 1 m²

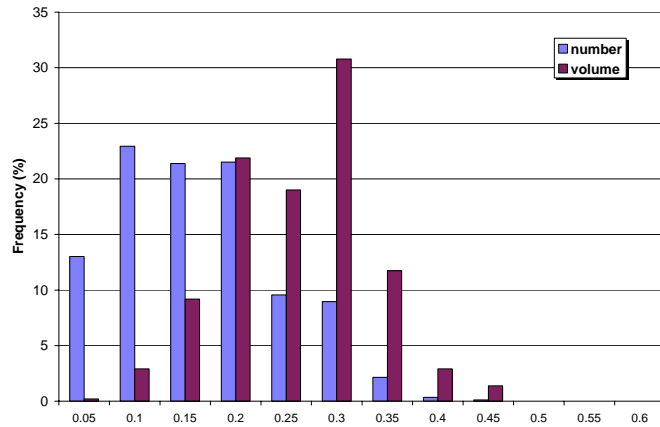
Icing rate control by on/off of spray nozzle

‘on’ \approx 15%

Rates: 0.5 and 7.5 mm/h (15%)

‘L’ shaped room good for icing
and further testing
e.g. runway deicer performance
ice adhesion testing

Freezing Drizzle

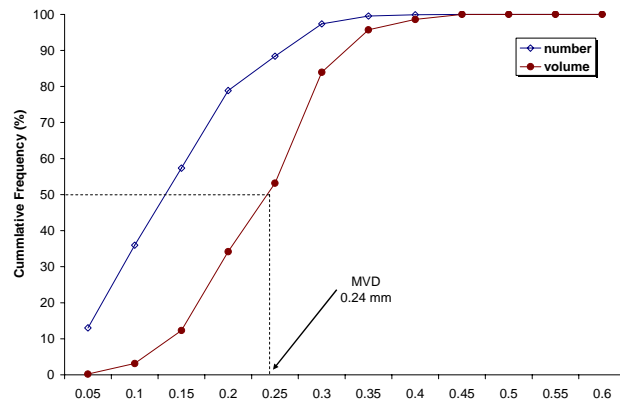


a) Droplet Size Histogram

MVD: 0.24 mm

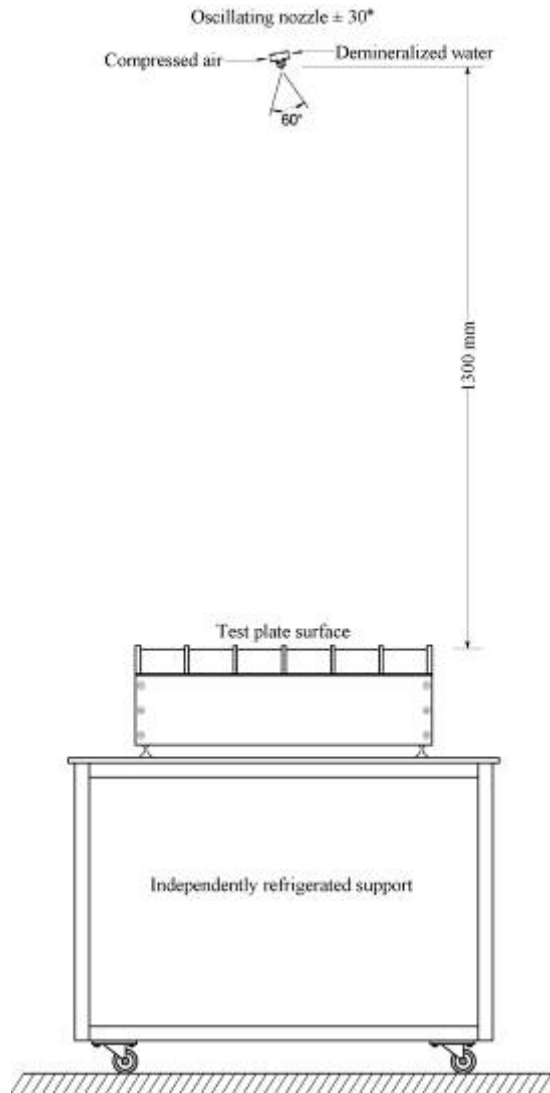
Height required to achieve
 $V_t = 0.1$ m

63% of $T = 0.7$ m



b) Droplet Size Cumulative Frequency

Freezing Fog



FZFG occurs when liquid fog droplets freeze to cold surfaces near the ground, forming white rime ice

Simulation:

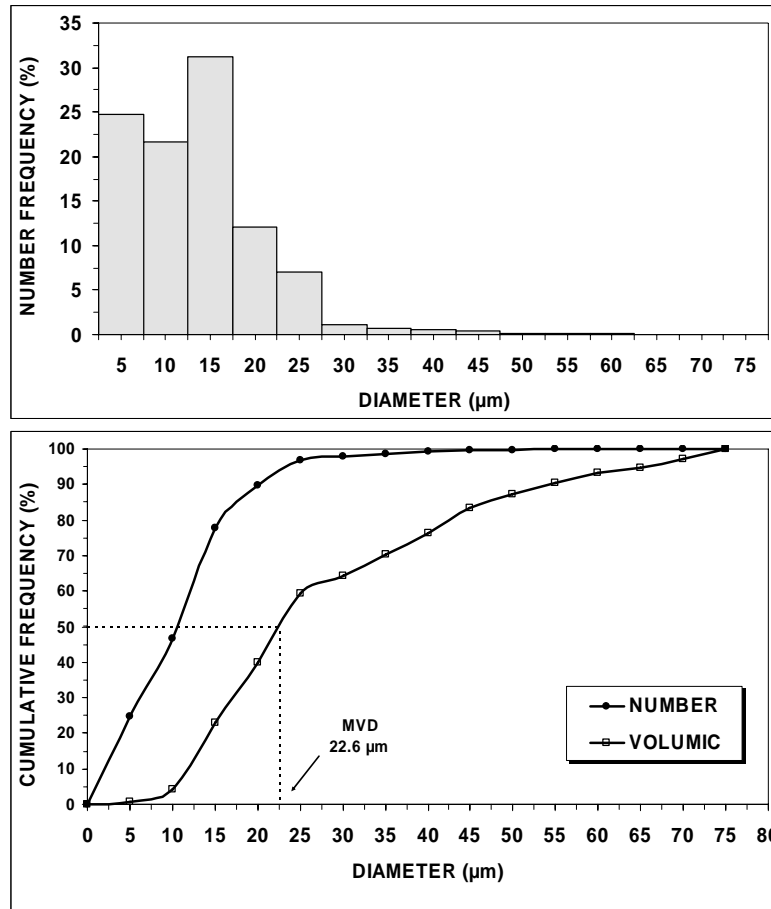
Fine water spray mixed with air to atomize the water

Height: 3 m

Test area: 0.5 m²

Icing rates: 0.2 and 0.5 mm/h (10%)

Freezing Fog



MVD: 22 μm

Typically used for
WSET for
De/anti-icing fluids
according to
SAE AS5901



Frost



Forms by direct deposition of water vapor to solid ice

Simulation:

Humidity provided by warm water bath evaporating in cold chamber

Test Support Temperature $\leq 3^{\circ}\text{C}$ Air Temperature

Rh $> 80\%$

Rates between 0.005 and 0.03 mm/h (20%)

Snow - Making



SN forms in clouds below freezing by deposition of water vapor onto ice nuclei which combine to form snowflakes

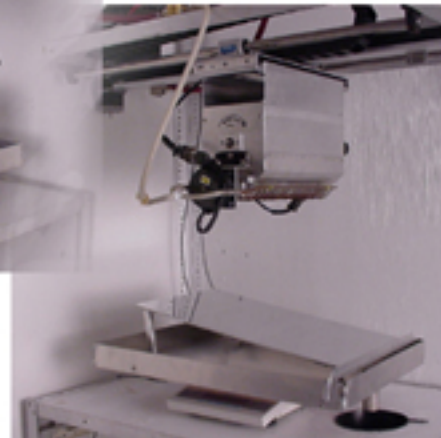
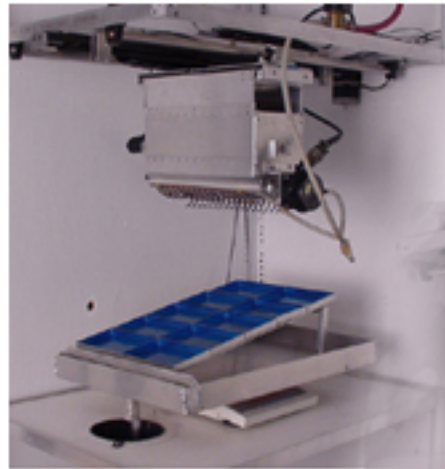
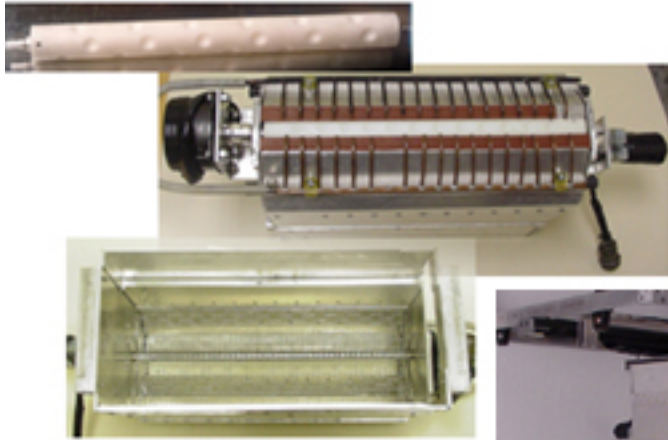
Simulation:

Made with fine water spray at temperatures $< -20^{\circ}\text{C}$

Ice particles similar to light rime

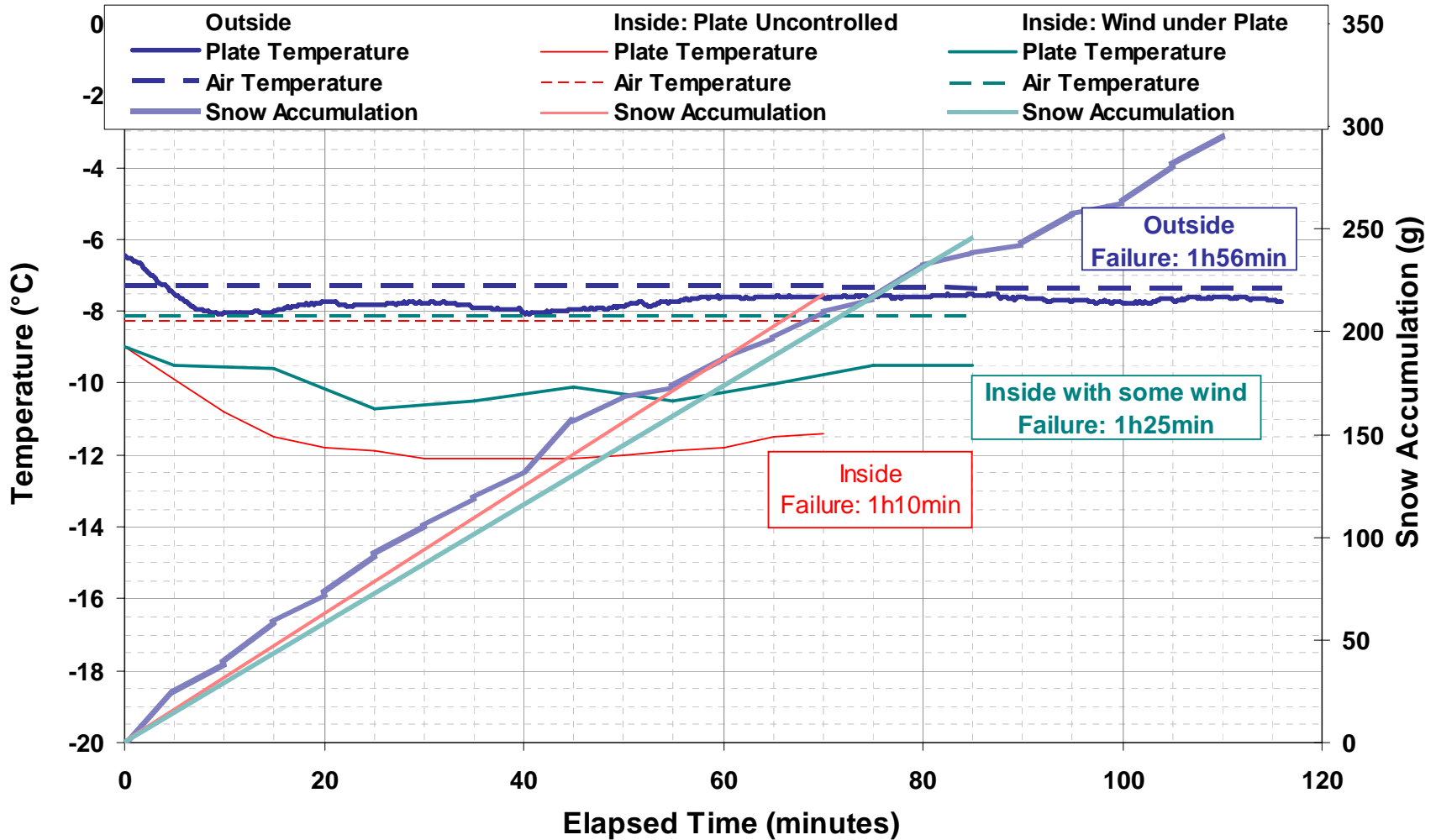
Density $\approx 0.1\text{g/cm}^3$

Snow – Even Distribution



Snow rates:
5 mm/h to 25 mm/h (10%)

Snow – Temperature



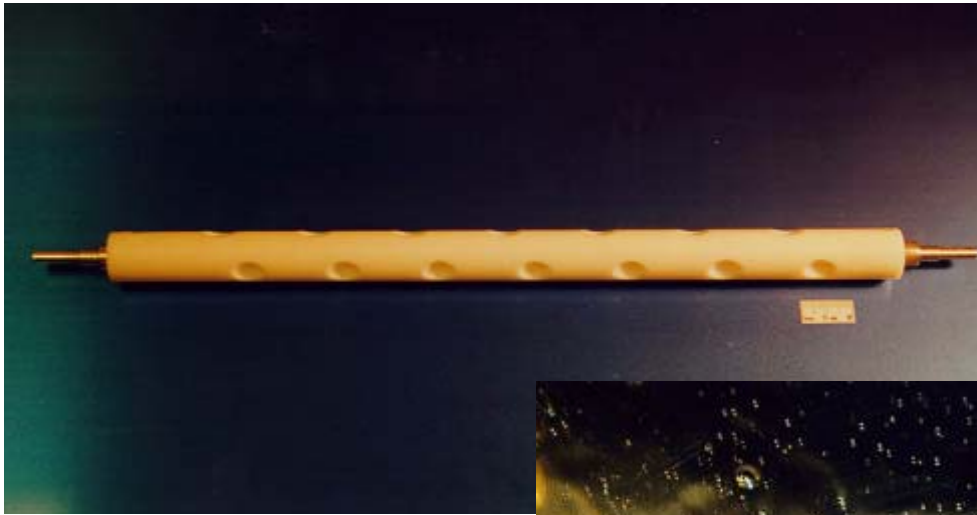
Snow Pellets

GA is a soft hail or graupel
White, opaque, 2-5 mm

formed when a falling ice crystal
accretes supercooled droplets



Snow Pellets



Simulated in lab with cylinder with larger cavities
in snow dispensing machine

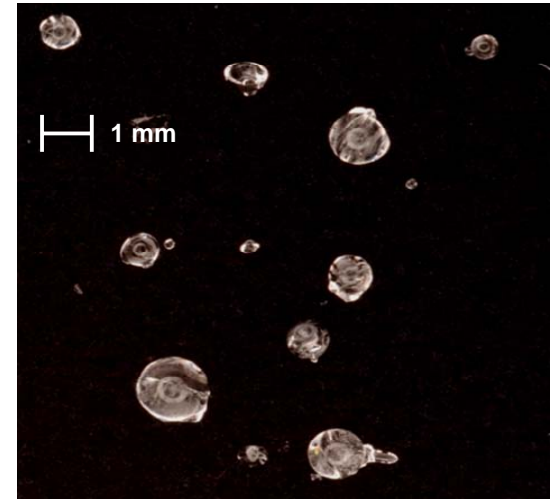
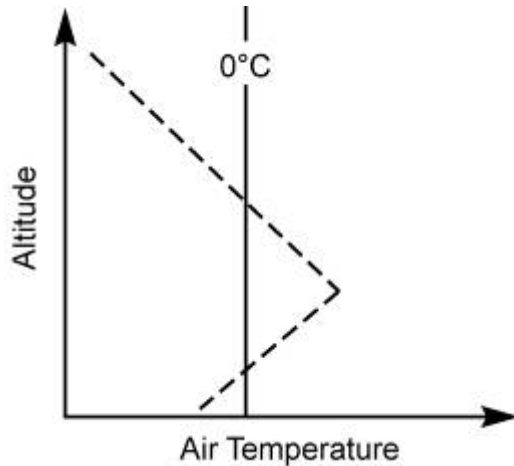
Ice Pellets

PL are transparent

< 5 mm diameter

Bounce

Form by falling through
temperature inversion

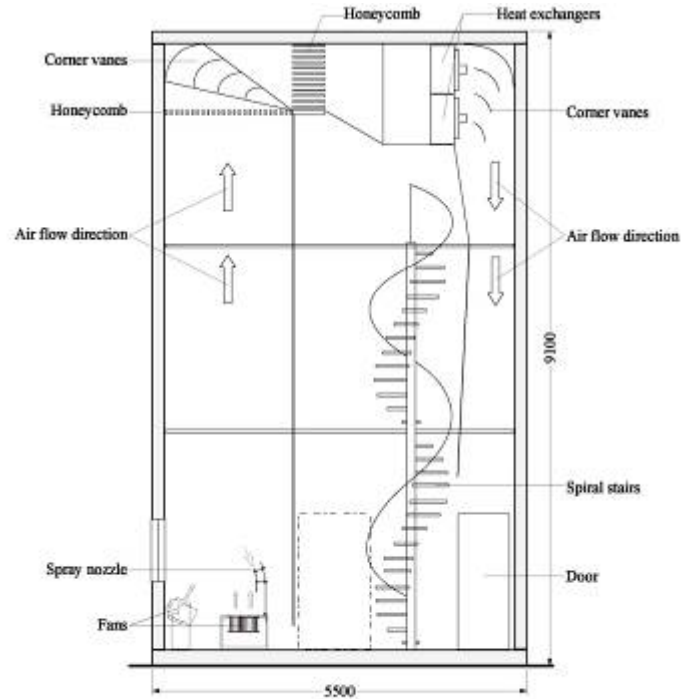


Natural ice pellets

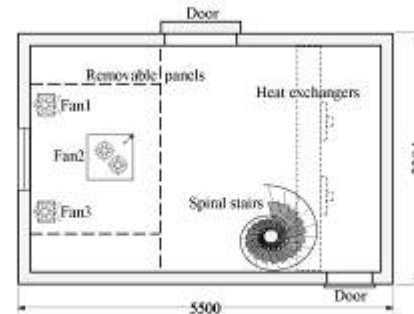


Artificial ice pellets
produced in laboratory

Ice Pellets

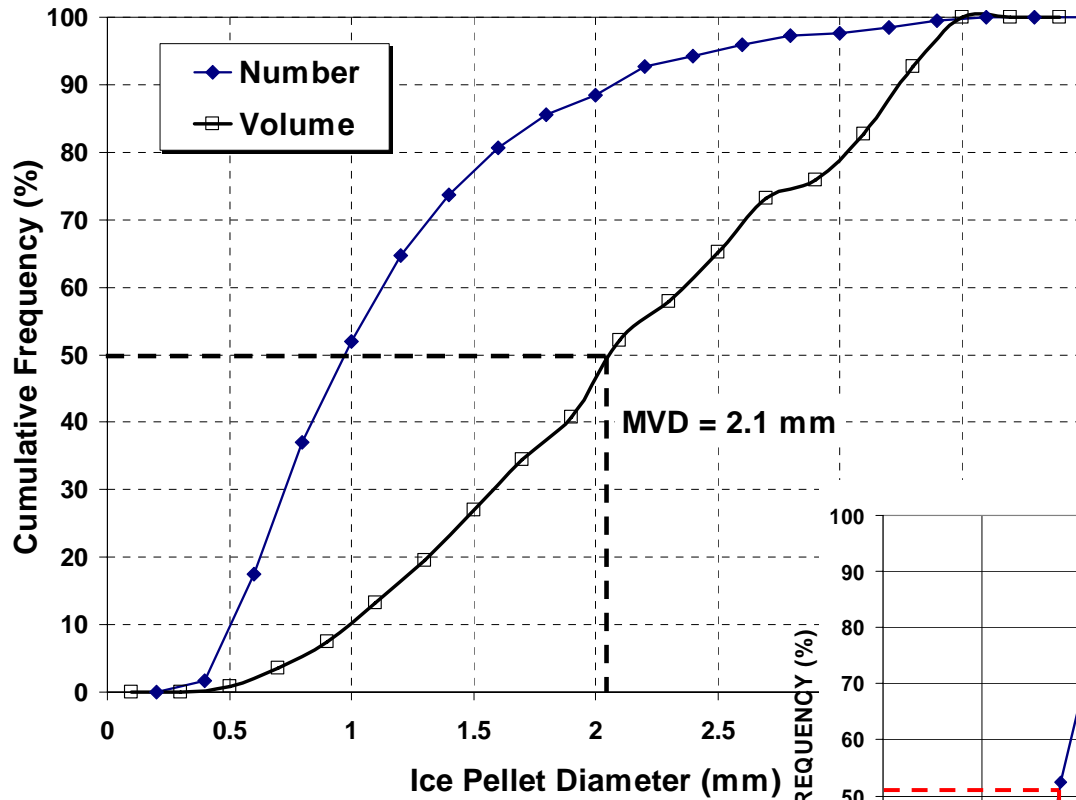


9m Chamber Section View



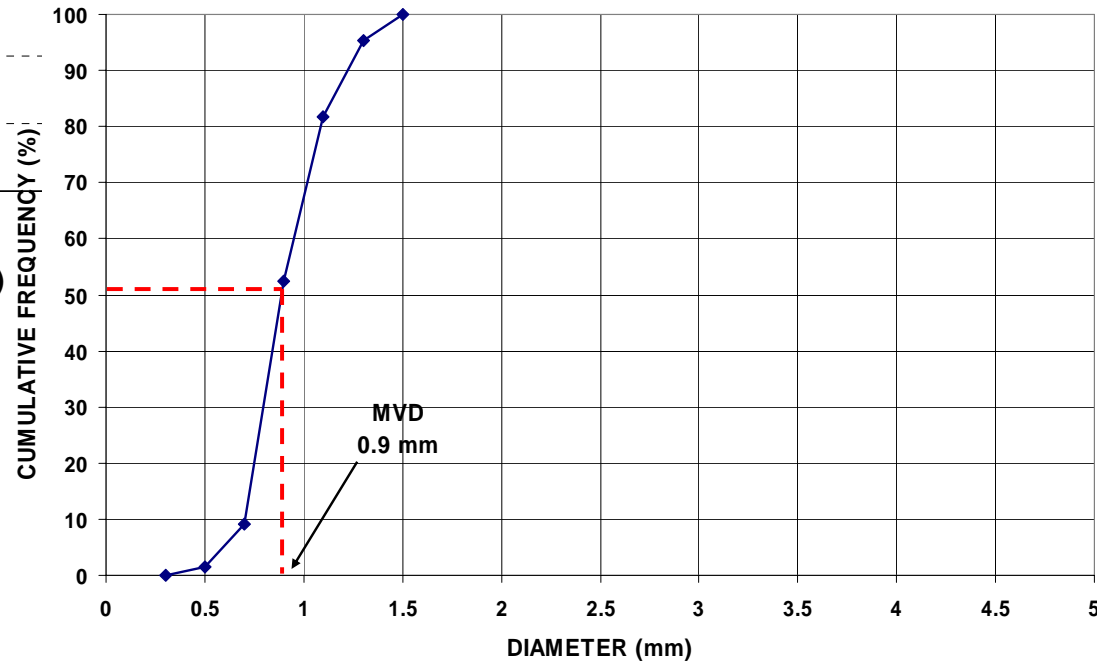
9m Chamber: Top View
Dimensions in mm

Ice Pellets



Laboratory-made
Ice Pellets

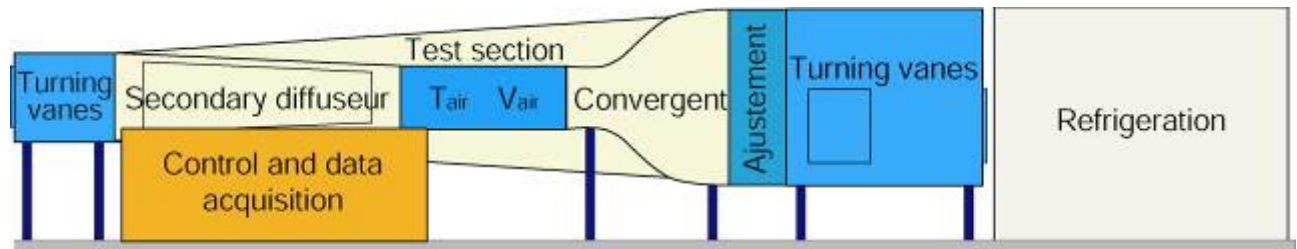
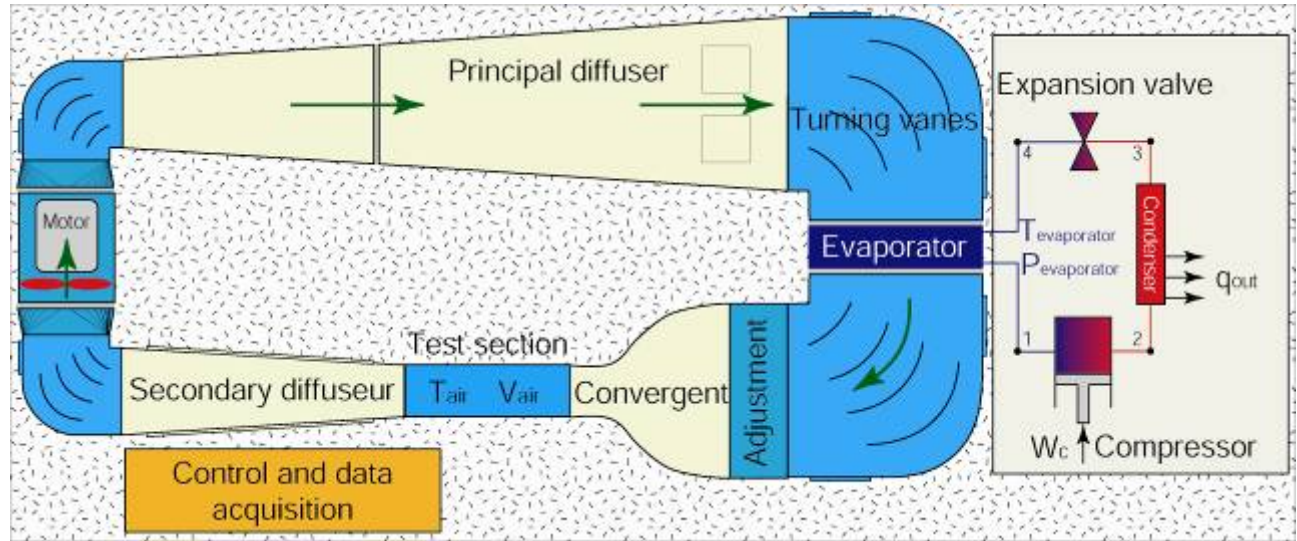
From a Natural Event



In-cloud Icing

Low Speed
Atmospheric
Closed loop
Refrigerated
Icing
Wind Tunnel

Temperatures:
0 to -30°C
(-50°C with N_2)



In-cloud Icing



Air Speed:

Up to 35 m/s icing
(85 m/s without)

Test section:

0.5 m x 0.6 m, and 1.5 m long

LWC:

0.1 to 4.0 g/m³

water droplet MVD:

20 to 200 μm

Uniform cloud:

0.3 x 0.2 m

Summary

Freezing Rain:

- supercooled water droplets > 0.5 mm
- height of chamber sufficient to supercool the drops

Freezing Drizzle:

- supercooled water droplets < 0.5 mm

Freezing Fog:

- fine supercooled water droplets with MVD ~ 25 μm

Frost:

- humid environment
- test substrate temperature below ambient

Summary

Snow:

made from soft rime, or frost formed with fine water spray at very cold temperatures

Snow Pellets:

distribute the snow in discreet clusters

Ice Pellets:

frozen water droplets in the 1 mm MVD range

In-Cloud icing:

refrigerated icing wind tunnel

LWC: 0.1 to 4.0 g/m³

MVD: 20 to 50 μm