Droplet Temperature Measurements for Efficient Combustors and Icing Safety:

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RainbowVision SAS

INTRODUCTION

- Introduction and basic principle of Global Rainbow Technique (GRT)
- Global Rainbow Technique applications to:
  - ✓ Combustion
  - ✓ Icing
- Extension of GRT to measure Super-cooled Large Droplets (SLD) in Icing Wind Tunnel
- Conclusion and Perspectives

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Basic Principle of Global Rainbow Technique (GRT)

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OBJECTIVE !

To increase combustion efficiency &
To improve icing protection system

NEED!

Measurement of droplets temperature

- **Evaporation rate**
- **Icing properties**
- **Need for numerical simulation validation**

Optical Techniques → ***Develop Global Rainbow Technique (GRT)***

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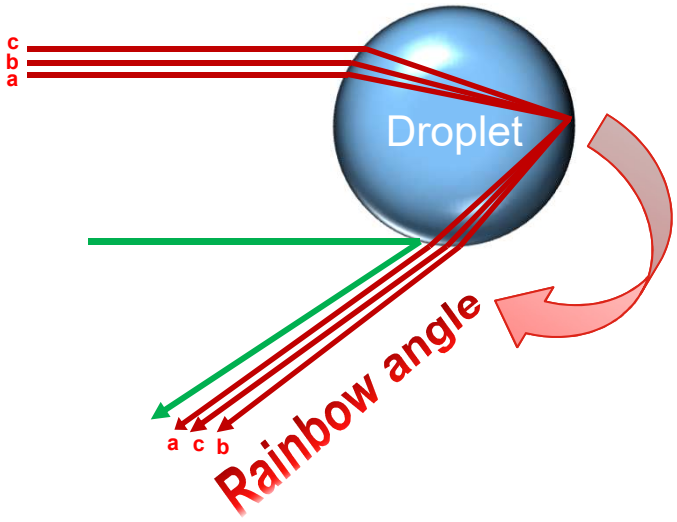
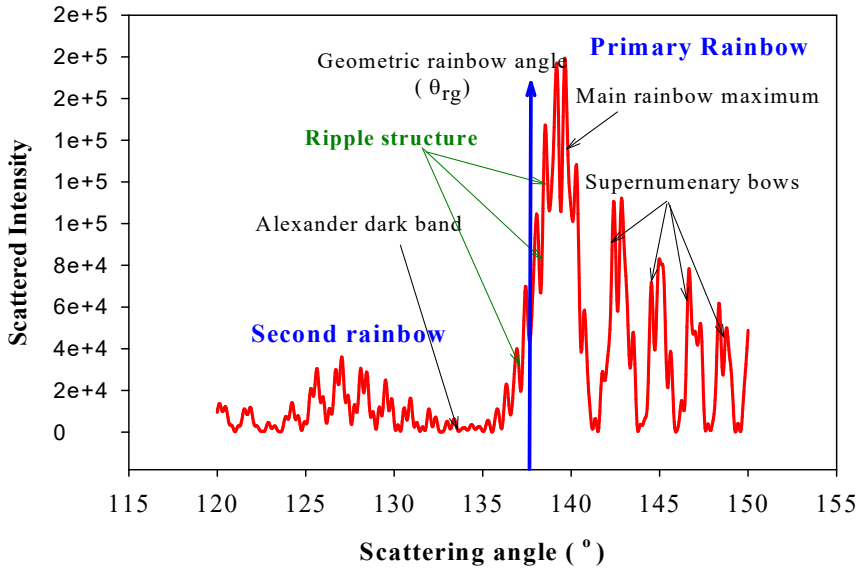
GLOBAL RAINBOW TECHNIQUE



Scattering diagram around the rainbows by Lorenz-Mie Theory

(d = 100 µm, n=1.333)



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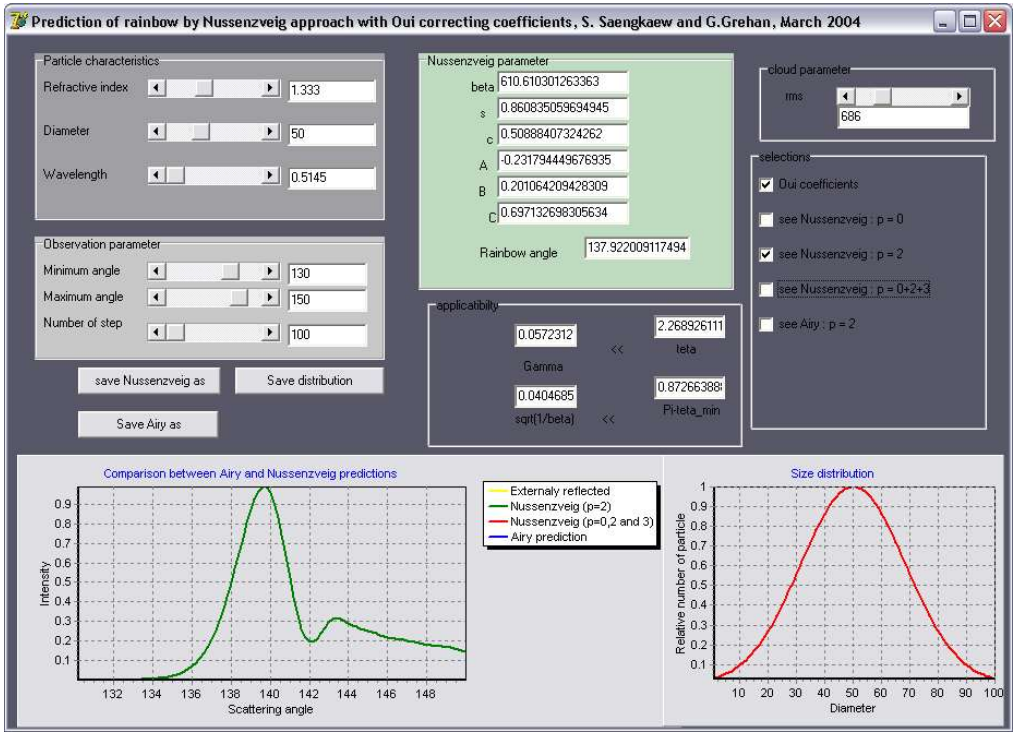
GLOBAL RAINBOW TECHNIQUE



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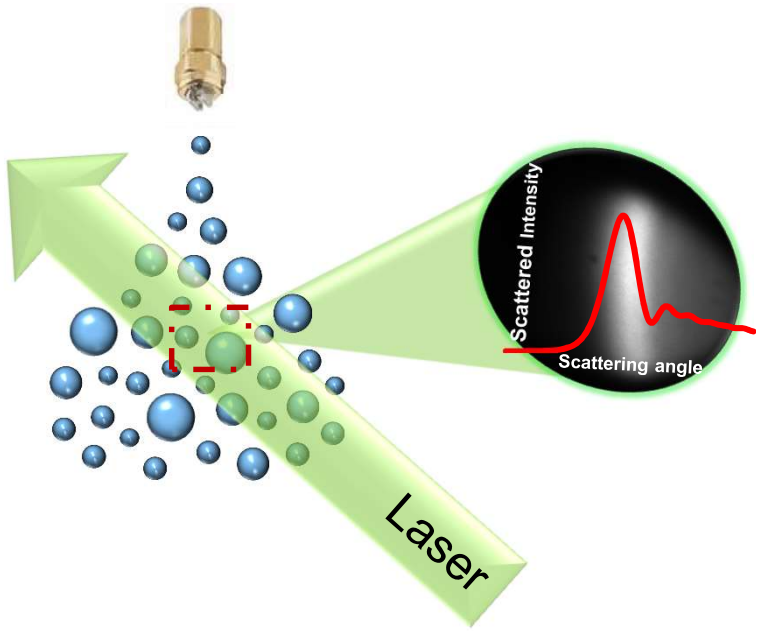
GLOBAL RAINBOW TECHNIQUE



GRT ➔ Average Measurement

1. Average refractive index/ temperature
2. Size distribution

$$\overline{n_{avg}} = \frac{\sum_{i=1}^{n} n_i \times n_{di} \times \left(\frac{d_{di}}{d_{\min}} \right)^{7/3}}{\sum_{i=1}^{n} n_i \times n_{di}}$$

Advantages of GRT

The measurement accuracy are:

- Refractive index: 0.01% in the range of 1.3-1.5
- Size: about 10% in the range of 5-500 µm

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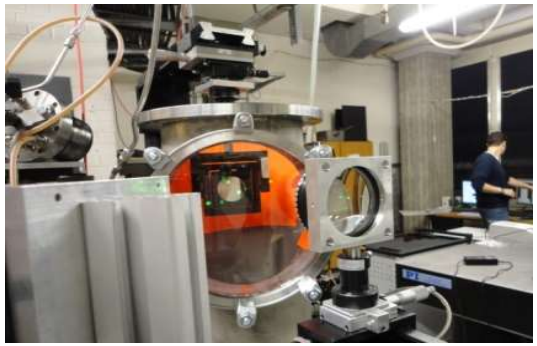
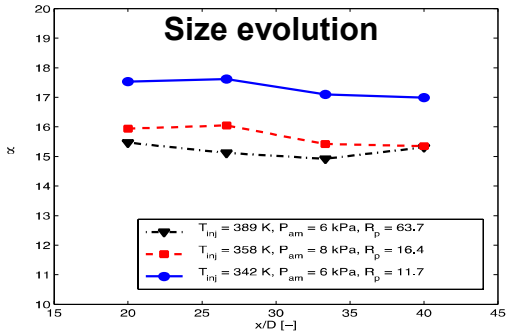
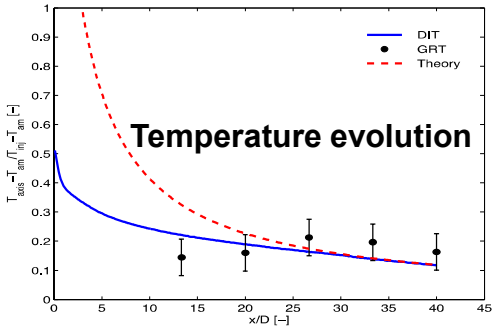
Application in Combustion

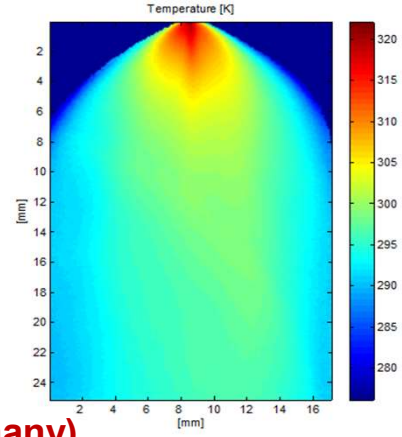
DIFFERENT APPLICATION USING GRT



❖ **Flash evaporation**







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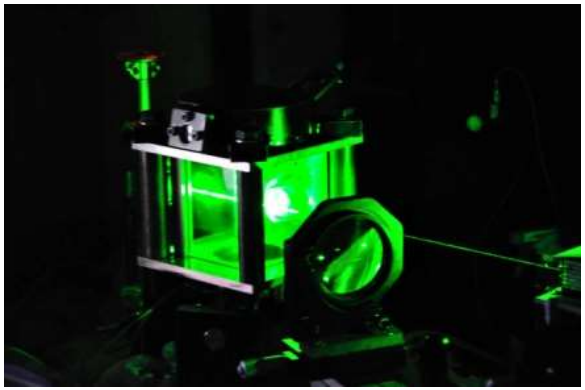
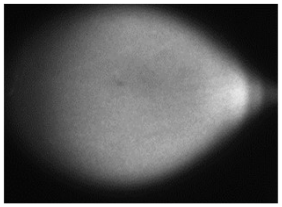
DIFFERENT APPLICATION USING GRT

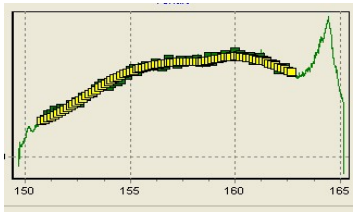


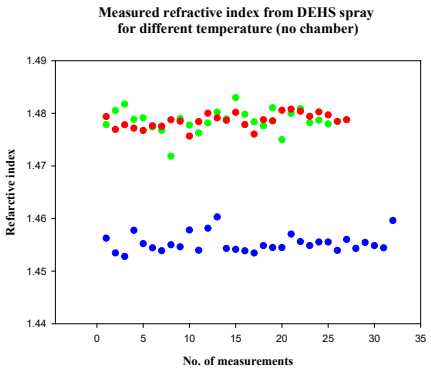
- Flash evaporation
- High pressure car injector

Recorded rainbow image

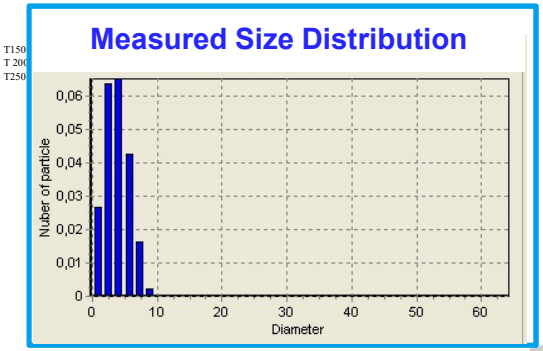


Recorded rainbow signal





Measured refractive index = 1.4487



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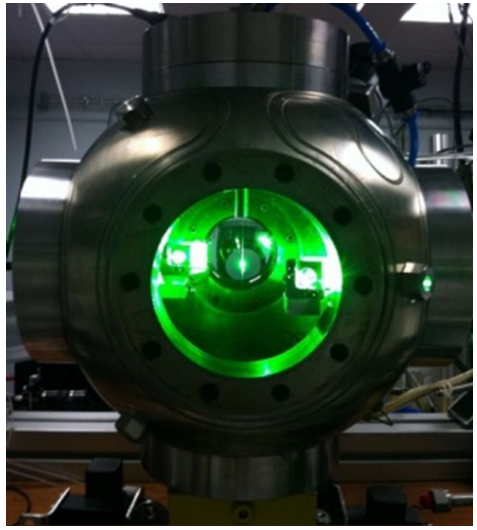
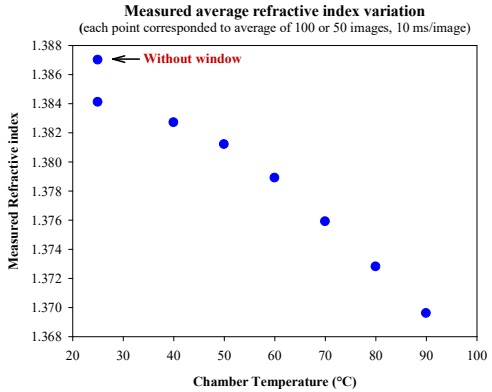
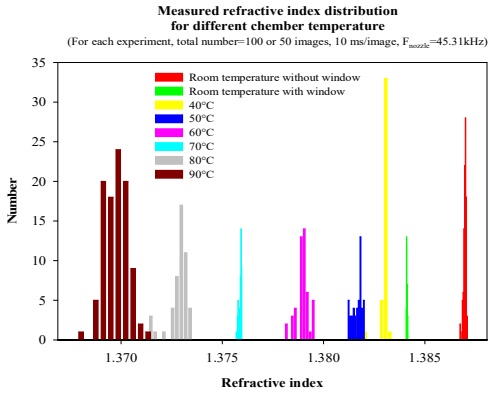
DIFFERENT APPLICATION USING GRT



- Flash evaporation
- High pressure car injector
- Evaporation at high pressure





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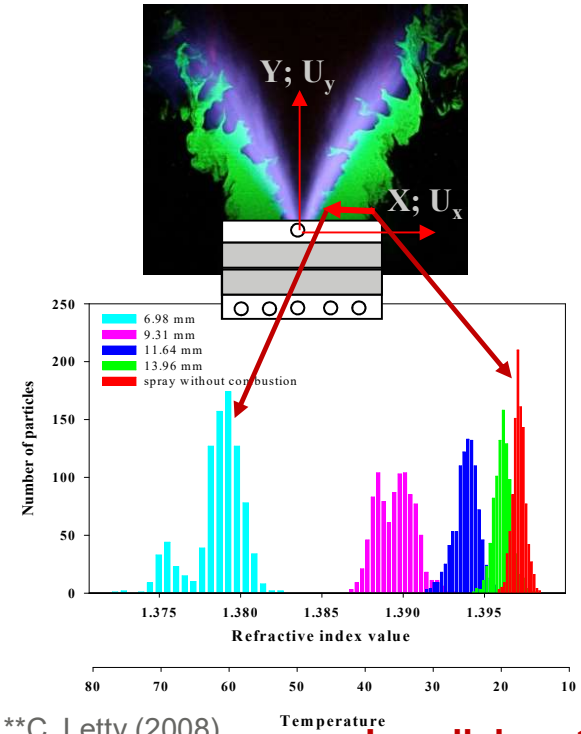
DIFFERENT APPLICATION USING GRT



**C. Letty (2008)

- Flash evaporation
- High pressure car injector
- Evaporation at high pressure
- Spray combustion in realistic flames

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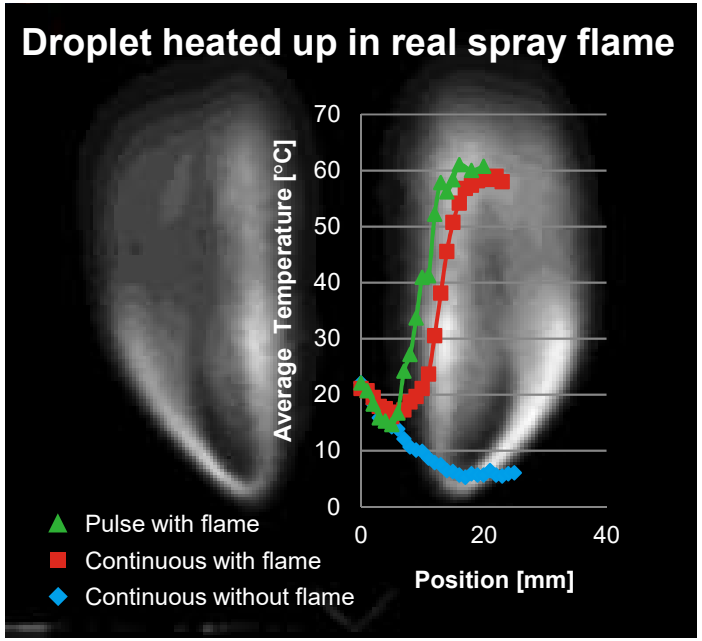
DIFFERENT APPLICATION USING GRT



- ❖ Flash evaporation
- ❖ High pressure car injector
- ❖ Evaporation at high pressure
- ❖ Spray combustion in realistic flames

Ref. *Combustion Institue (2016)* : Experimental study of local flame structures and fuel droplet properties of a spray jet flame

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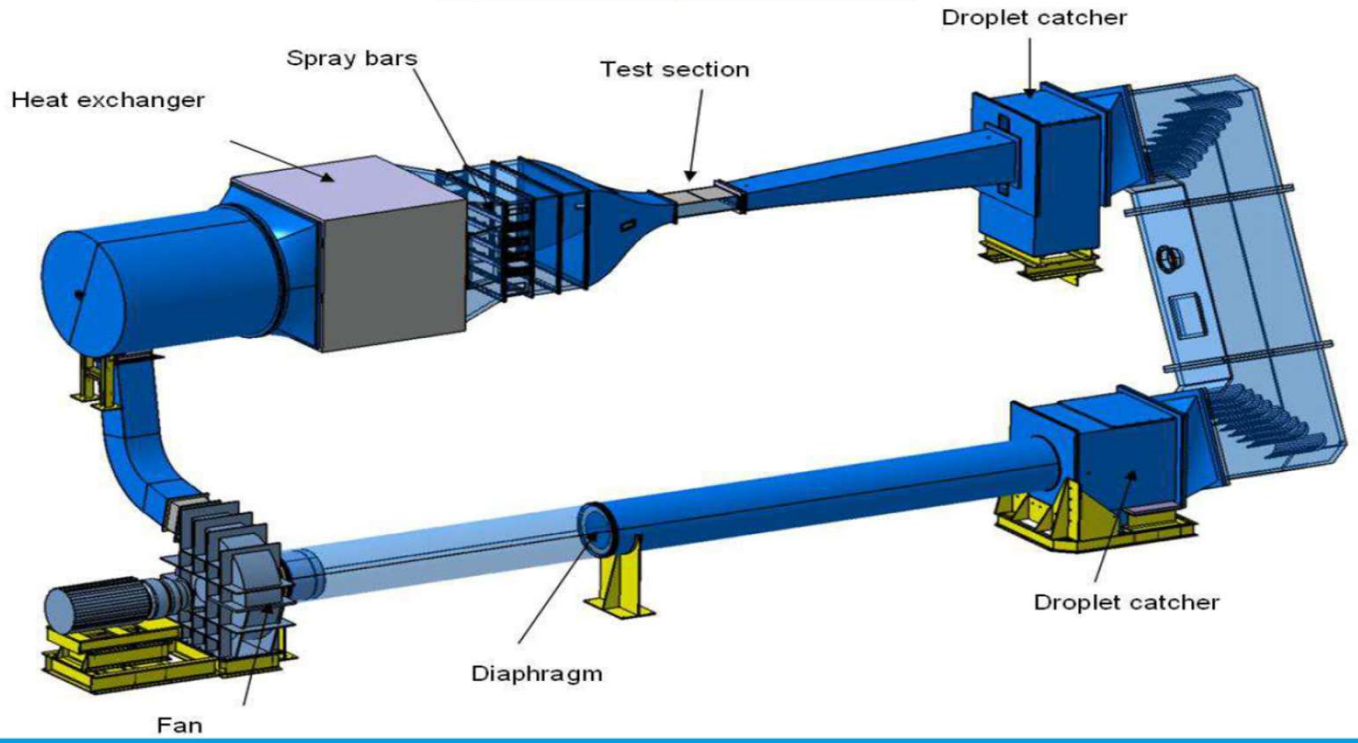
Application in Icing Wind Tunnel

ICING WIND TUNNEL MEASUREMENTS

Figure n°1 : Facility scheme overview



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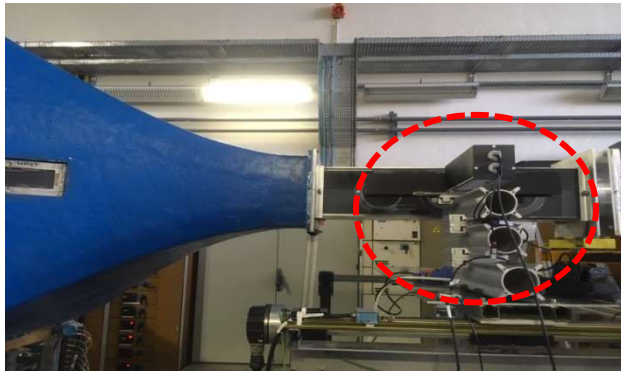
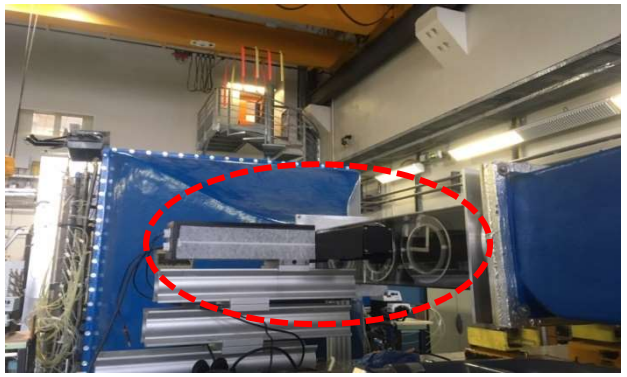
ICING WIND TUNNEL MEASUREMENTS

Test section area





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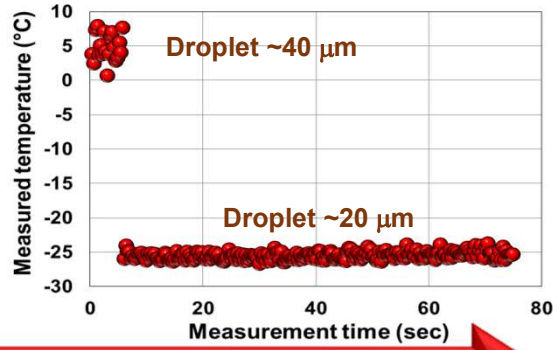
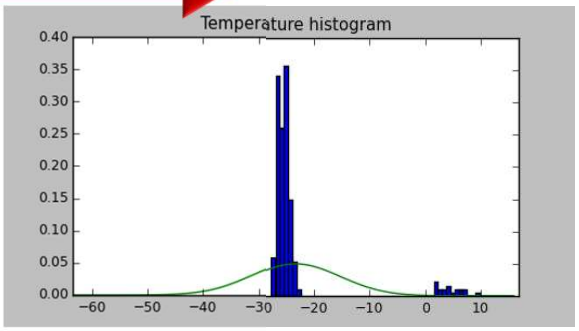
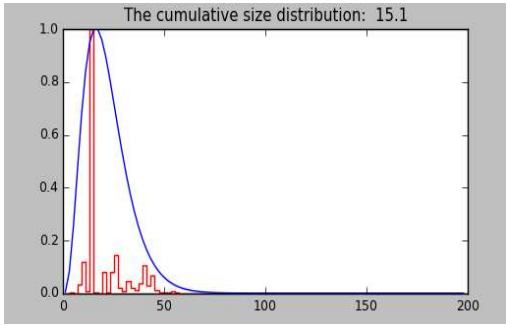
ICING WIND TUNNEL MEASUREMENTS

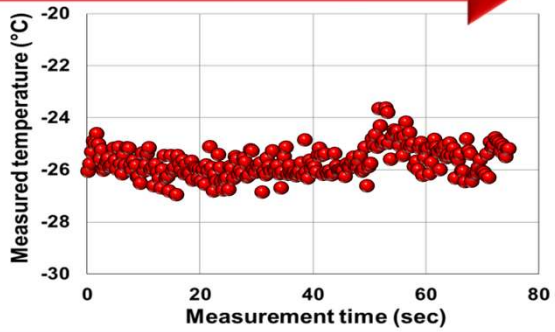
: Decrease droplet size from 40 µm to 20 µm

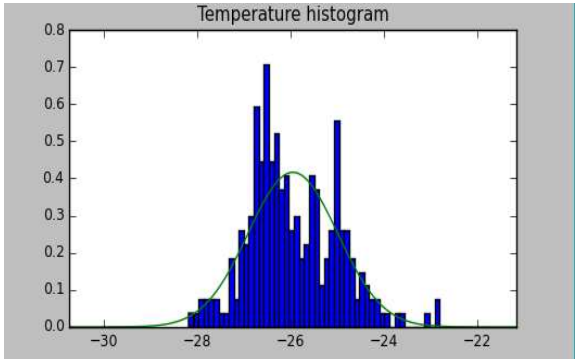


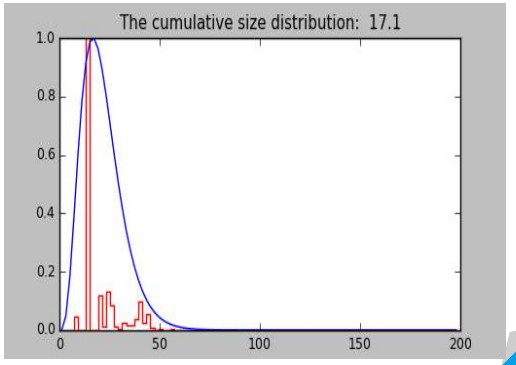




: Change hygrometry







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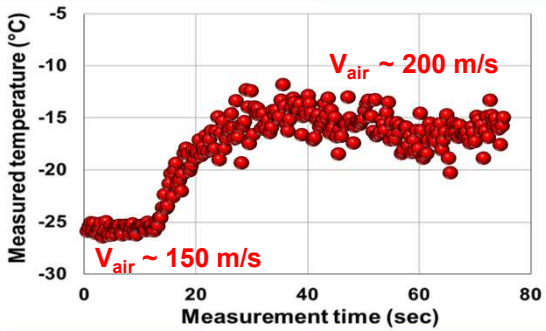
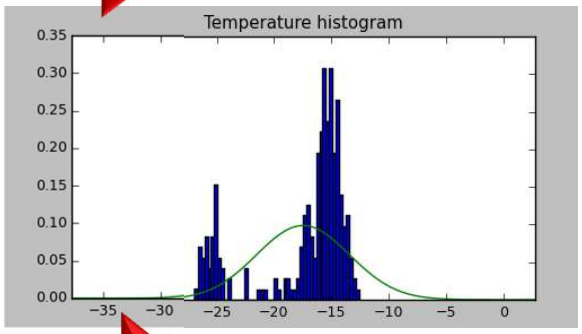
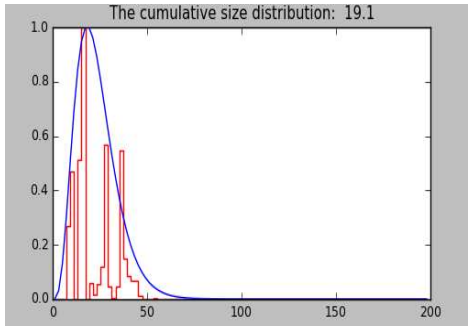
ICING WIND TUNNEL MEASUREMENTS

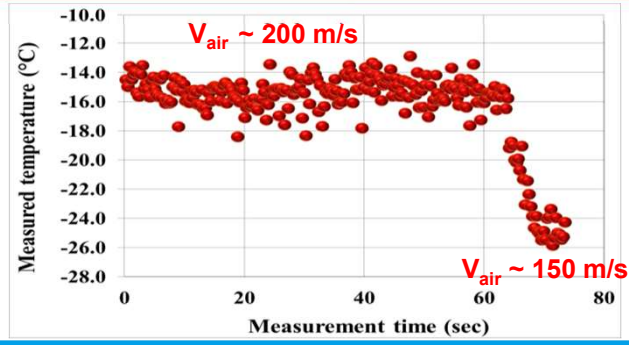
: Increase air velocity from 150 to 200 m/s

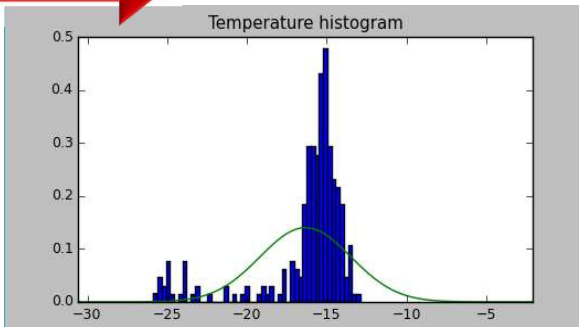


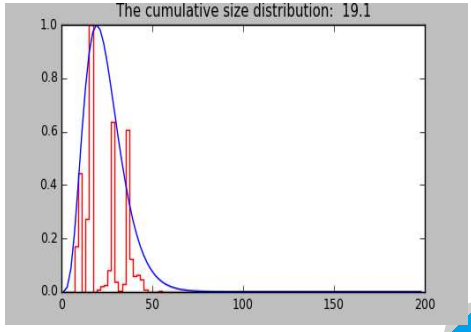




: Decrease air velocity from 200 to 150 m/s







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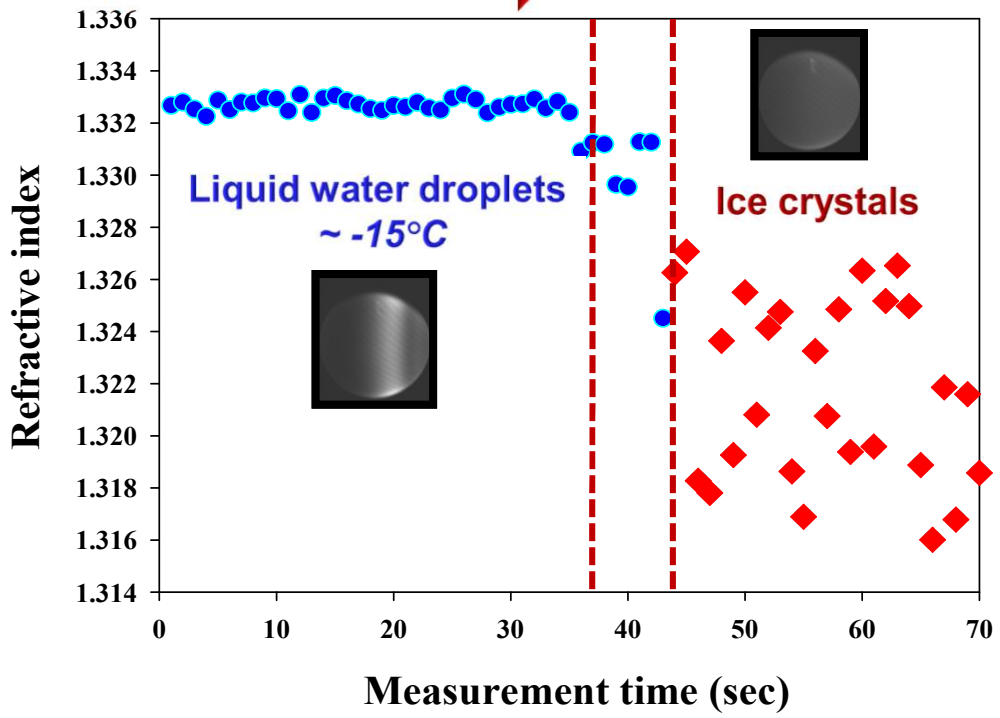
ICING WIND TUNNEL MEASUREMENTS

: Changement de phase



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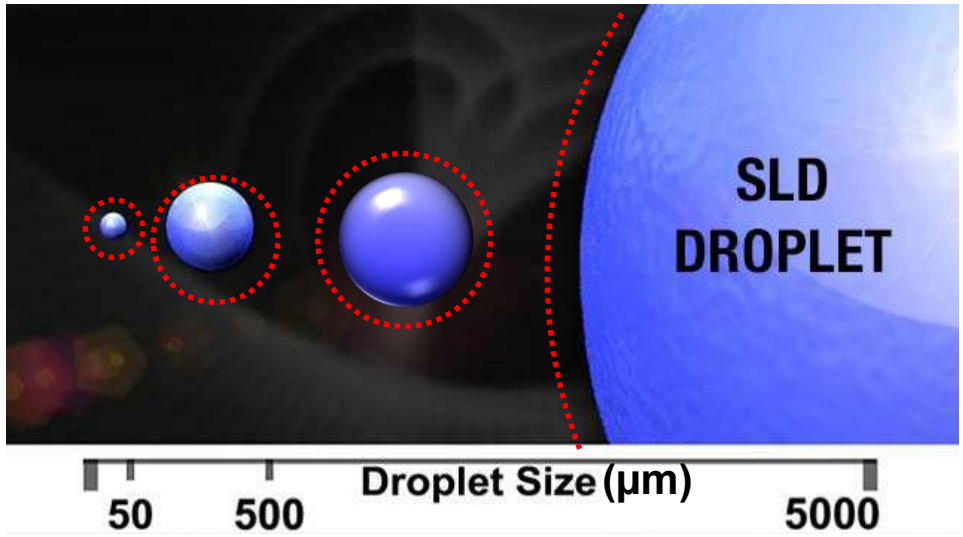
Extension of GRT to measure Super-cooled Large Droplet (SLD)

SUPER-COOLED LARGE DROPLET (SLD)

Different sizes of droplets are naturally mixed in atmosphere.



- **Freezing drizzle**
  MVD< 40 μm or MVD>40
  100 μm <Dmax<500 μm
- **Freezing rain**
  MVD< 40 μm or MVD>40
  500 μm <Dmax<2000 μm

Are we able to measure different sizes of droplets by using GRT?

Ref. https://aircrafticing.grc.nasa.gov/2_2_2_1.html

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NUMERICAL VALIDATION: EXAMPLE

Define parameters

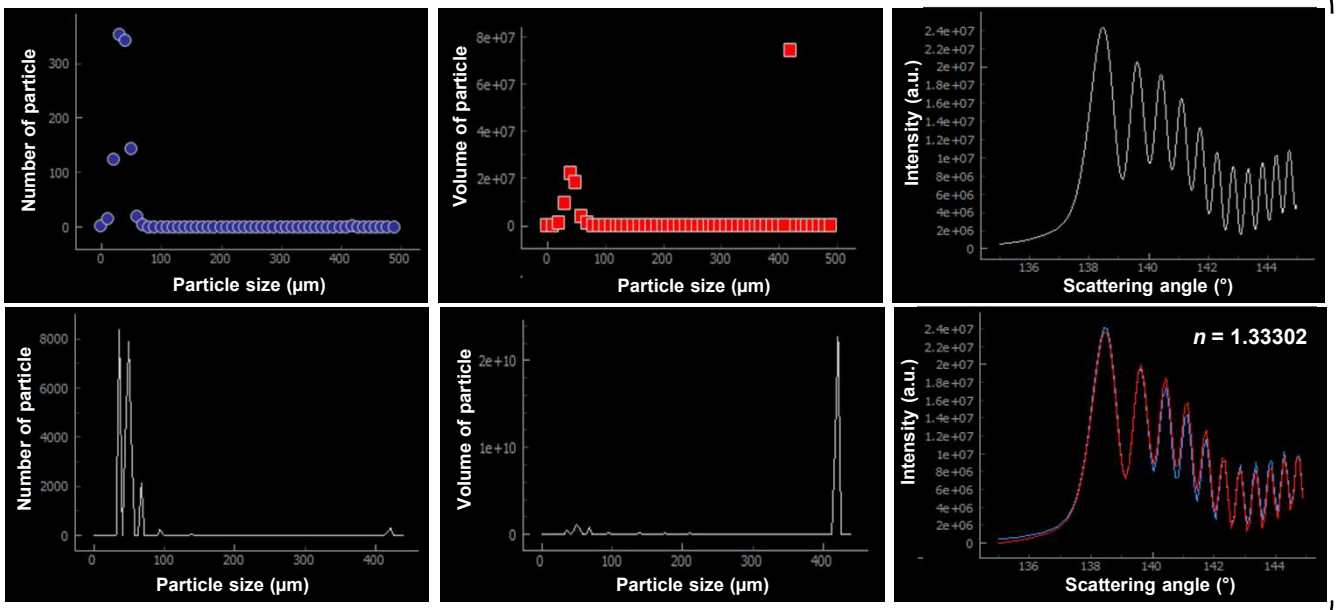
n = 1.333

d_S = 40±10 µm

d_B = 400±20 µm

N_S:N_B = 1000:1

Direct Computation



Extracted Results

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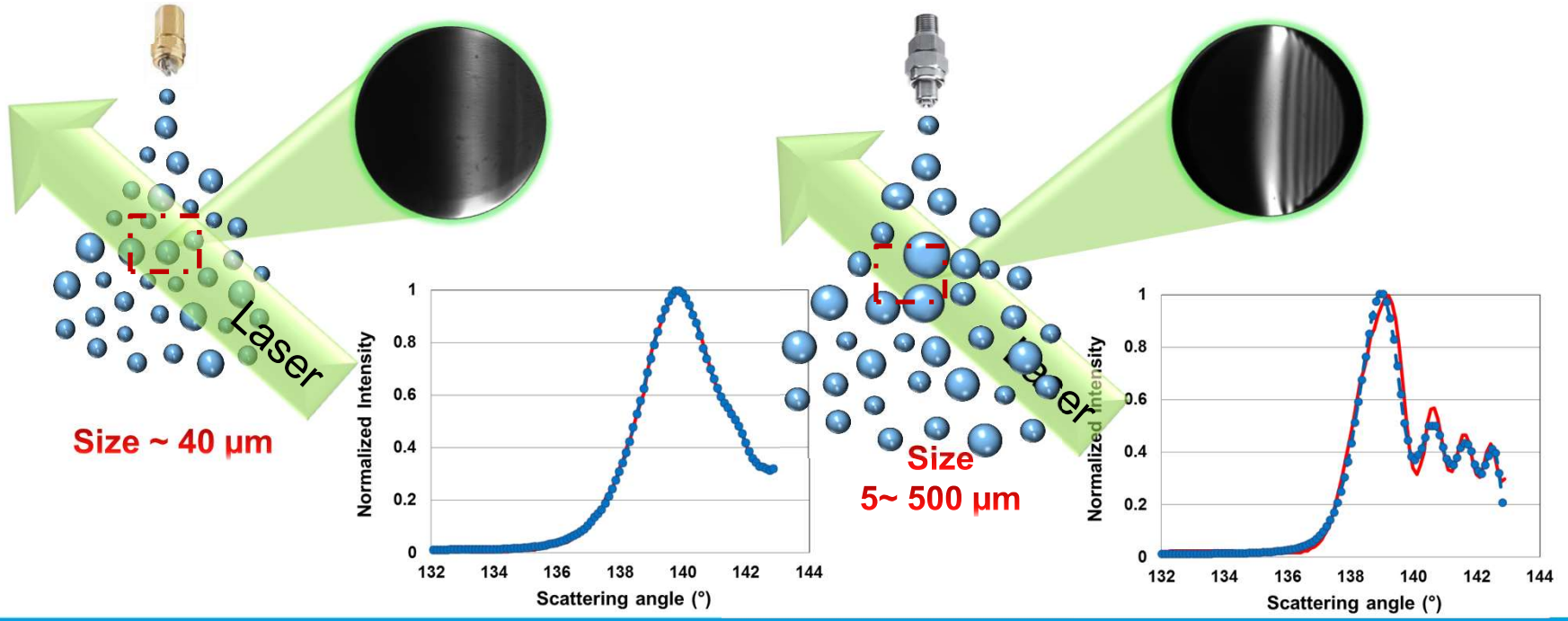
EXPERIMENTAL VALIDATION : PRELIMINARY TEST

Using the same measured device and processing method



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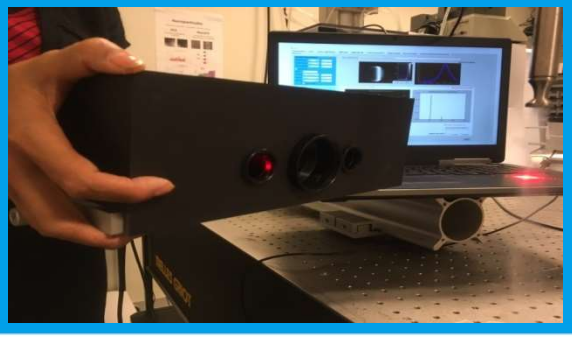
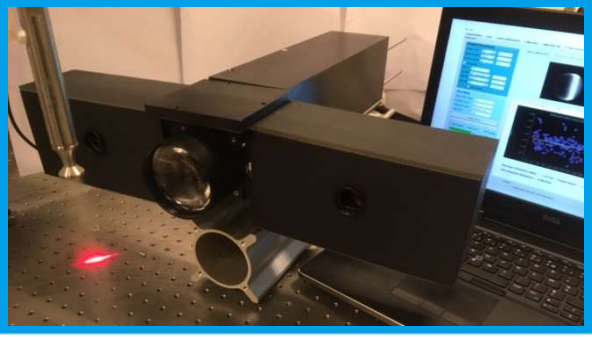
CONCLUSIONS

Temperature of super-cooled droplets has been measured in a real Icing Wind Tunnel under different parameters (Air temperature, Air velocity, droplet size, hygrometry,…)

Next Step:

- Reduce the liquid water content
- Extend to Super-cooled Large Droplet (SLD)





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ACKNOWLEDGEMENTS

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DGA-EP

&

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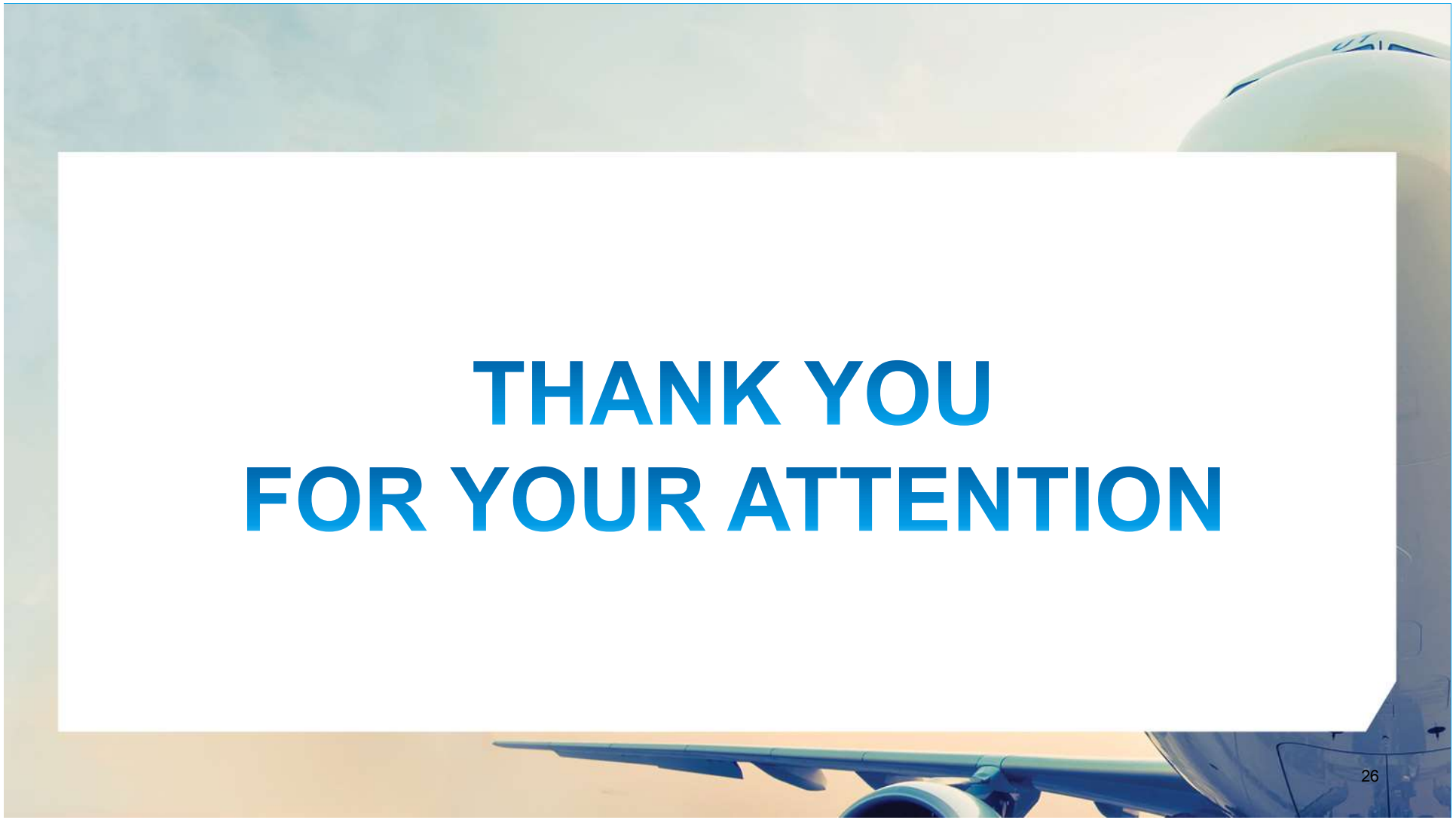
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FOR YOUR ATTENTION