Analysis of Supercooled Large Drop Velocity Measurement in the NASA Icing Research Tunnel

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Outline

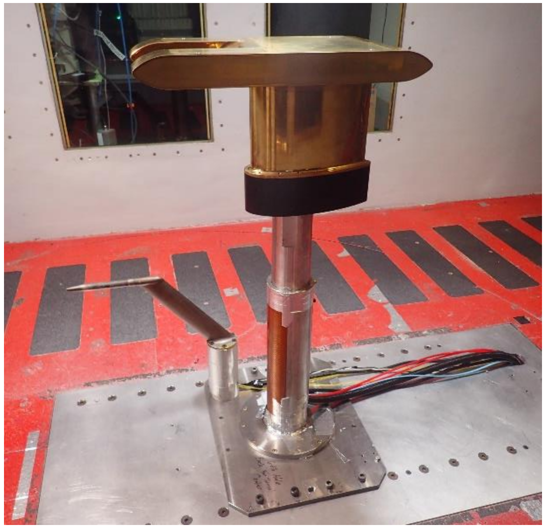
- Introduction
- Experimental Approach
- Key Results
- Conclusions
- Recommendations
- Acknowledgements

Introduction

- The FAA Part 25 Appendix O was issued in 2015 to define a representative icing environment for supercooled large drops (SLD) including
  - freezing drizzle (FZDZ) and freezing rain (FZRA) conditions
- The NASA Icing Research Tunnel (IRT) is a sea level icing test facility that operates* in
  - Appendix C conditions
  - Limited SLD conditions in FZDZ
- The SLD cloud development & calibration in the IRT need to be expanded to consider
  - Velocity deficit (or slip velocity) of large drops

*Timko, Emily. N.; King-Steen, Laura. E.; Van Zante, Judith. F.; Acosta, Waldo. J.: NASA Glenn Icing Research Tunnel: 2019 Cloud Calibration Procedure and Results NASA/TM-20205009045, 2021 https://ntrs.nasa.gov

Artium PI-PTV
Particle Imaging - Particle Tracking Velocimetry



Probe Specifications & Upgrades

- 4.5 microns/pixel; 9 – 1800 um
- 1936 x 1464 pixels (2.8 Mpixels)
- Sample area = 11.7 mm x 9.7 mm
- Frame rate 400 fps
- Illumination LED at ~30 ns
- Double pulse capability, 20-40 us
- Ran with and w/o Velocity mode (double pulse)
- The AIMS software controls the probe and allows for data analysis
- Additional heaters in the leading edge to avoid/reduce icing

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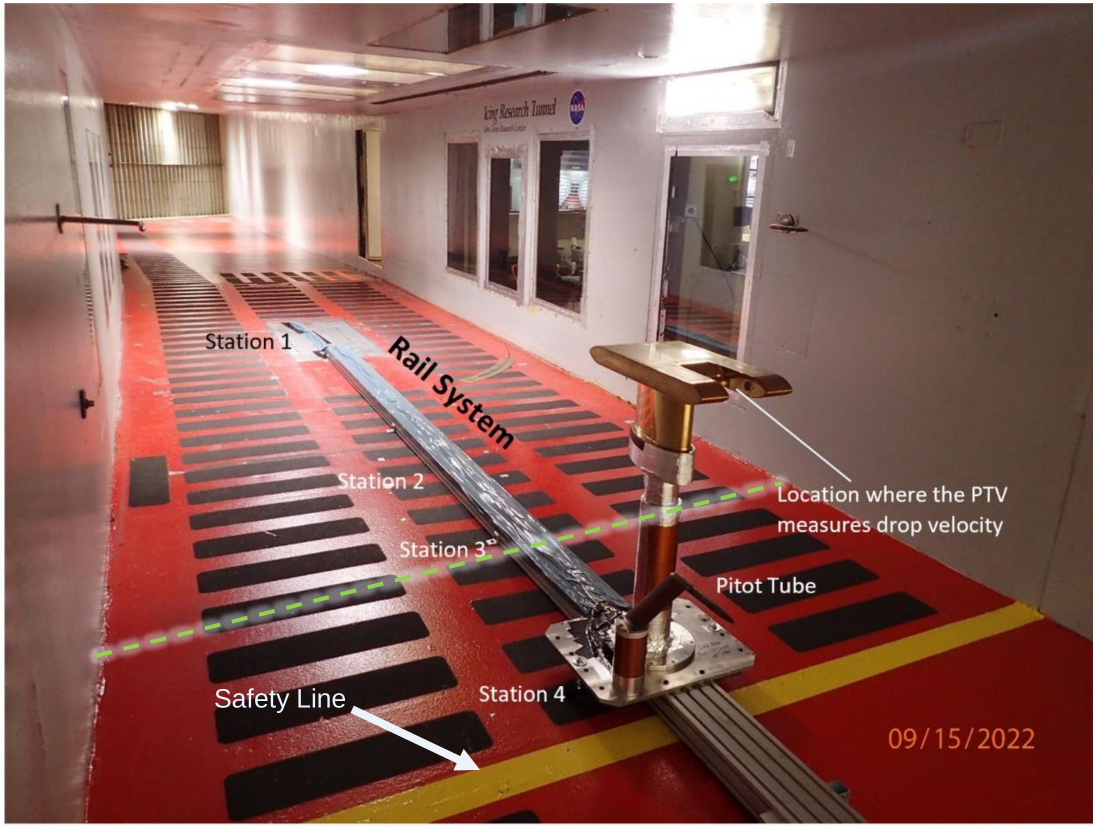
Artium PI-PTV
with mounting stand on rail system



Station 1	Station 2	Station 3*	Station 4
x = 0”	X = 90”	X = 108.5”	X = 180”

***At the end of the tunnel contraction**

Test Description

- NASA Glenn Icing Research Tunnel (IRT)
- A 10-day test entry (Sep12 – 23, 2022)
- Measure spray cloud drop size, velocity, shape and number density distributions at 4 different stations in the IRT
- Test Conditions
  - Tunnel Velocities: 130 kt, 170 kt, 210 kt and 250 kt
  - Tunnel Temperature: at -5 ºC total temperature
  - Cloud Conditions:
    - Mod1 spraybar nozzles
    - P_{air} = 2 psig and ΔP_{water} = 30, 40, 50 & 60 psid (MVD↑ as ΔP_{water}↑)
    - Some SLD Scaling reference sprays

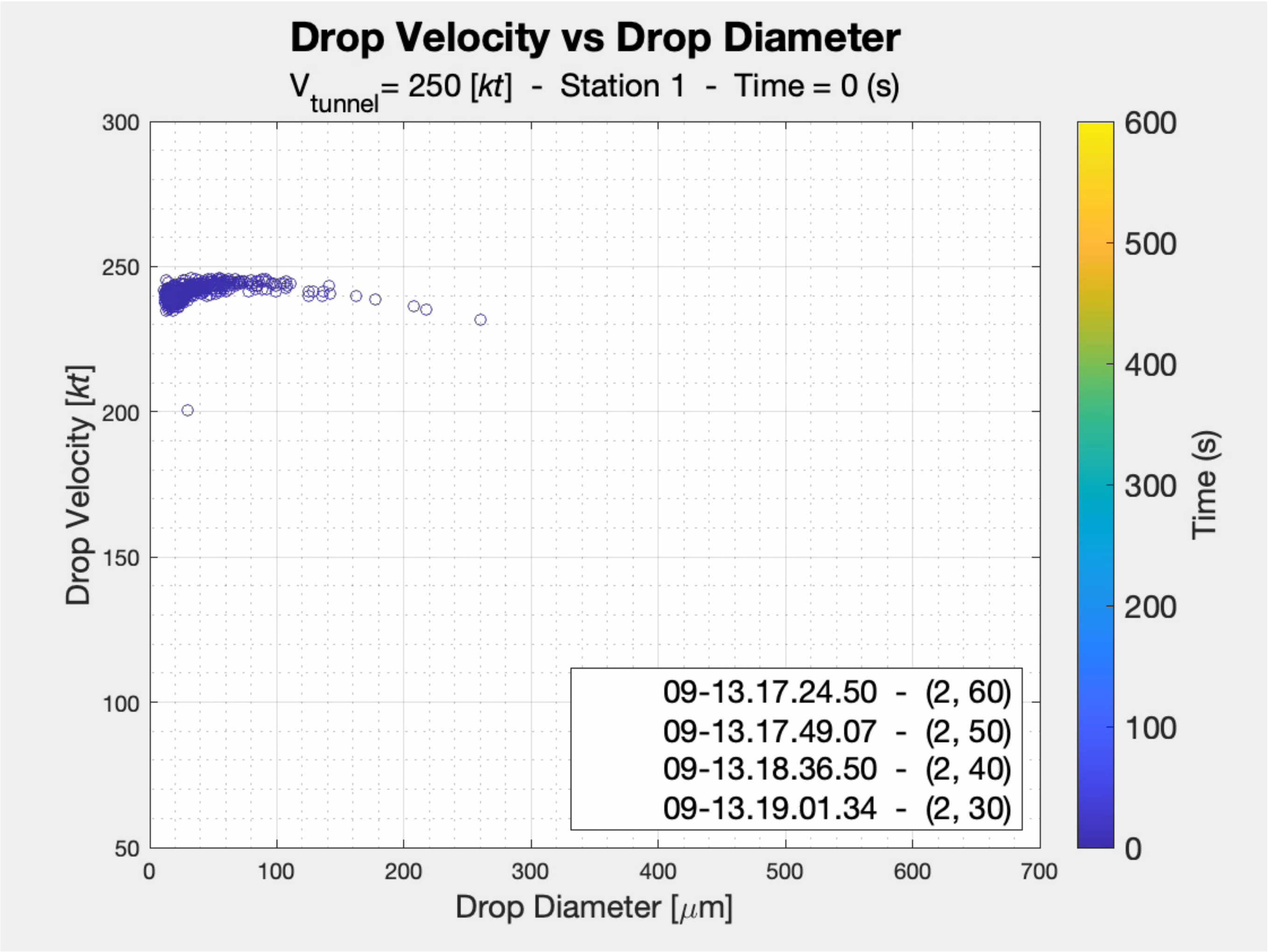
Test Conditions on 9/13/22

Station #	AIMS STAMP	Spray Delay	Spray Time	Total Temp, TTTSC	Velocity	$D_{v0.5}$	$D_{v0.99}$ ★	MVD	LWC	Density of Drops	Pair	DeltaP M
1	hour minute sec	[s]	[min]	[C] ± 1	[kts] ± 1	[um]	[um]	[um]	[g/m3]	#/cc	[psig] ± 0.1	[psid] ± 0.5
PI-PTV Wing-shape							approx	calc'd		approx		
Run #								2019 cal				
1	17 24 50	30	10	-5	250	393	1125	472	1.08	305	2	60
2	174907	30	10	-5	250	379	1075	412	0.97	264	2	50
3	18 36 50	30	10	-5	250	320	1025	347	0.85	236	2	40
4	19 01 34	30	10	-5	250	272	925	277	0.72	180	2	30
5	19 38 13	30	7	-5	250	200	726	200	0.69	250	3	31.5
6	19 56 24	30	7	-5	250	242	780	242	0.79	275	3	38.8
7	20 13 06	30	7	-5	250	200	775	200	0.69	250	3	31.5
8	20 33 35	30	5	-5	250	150	580	150	0.68	275	4	33.6
9	20 48 51	30	5	-5	250	100	575	100	0.54	250	4	23.4
10	21 03 00	30	10	-5	250	393	1125	472	1.08	305	2	60
11	21 23 25	30	10	-5	250	379	1075	412	0.97	264	2	50
12	21 44 22	30	10	-5	210	393	1125	472	1.26	305	2	60

★ These values came from data collected with the OAP-230Y during the 2019 calibration

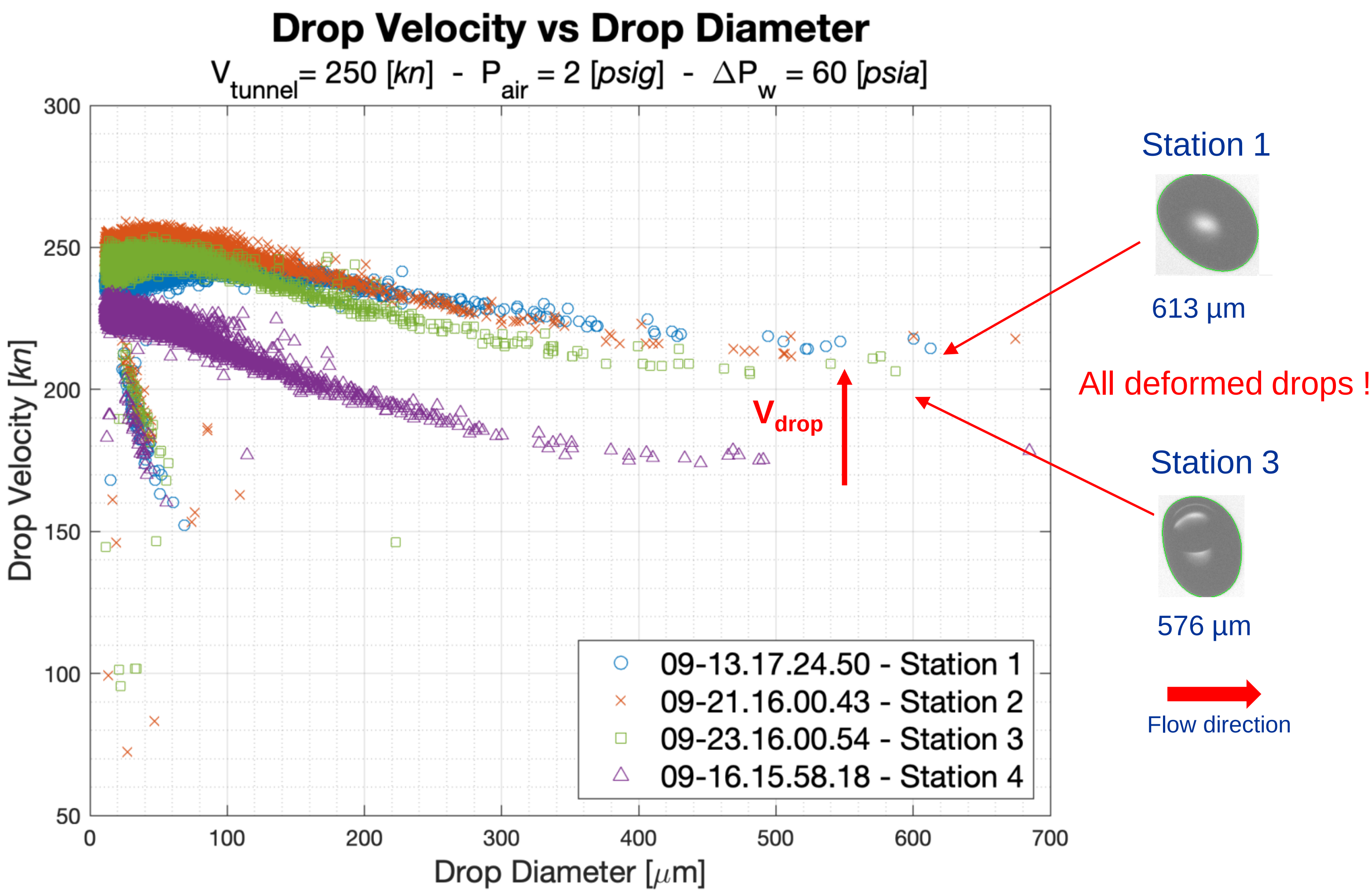
Key Results

AIMS imaging data (a mp4 video)

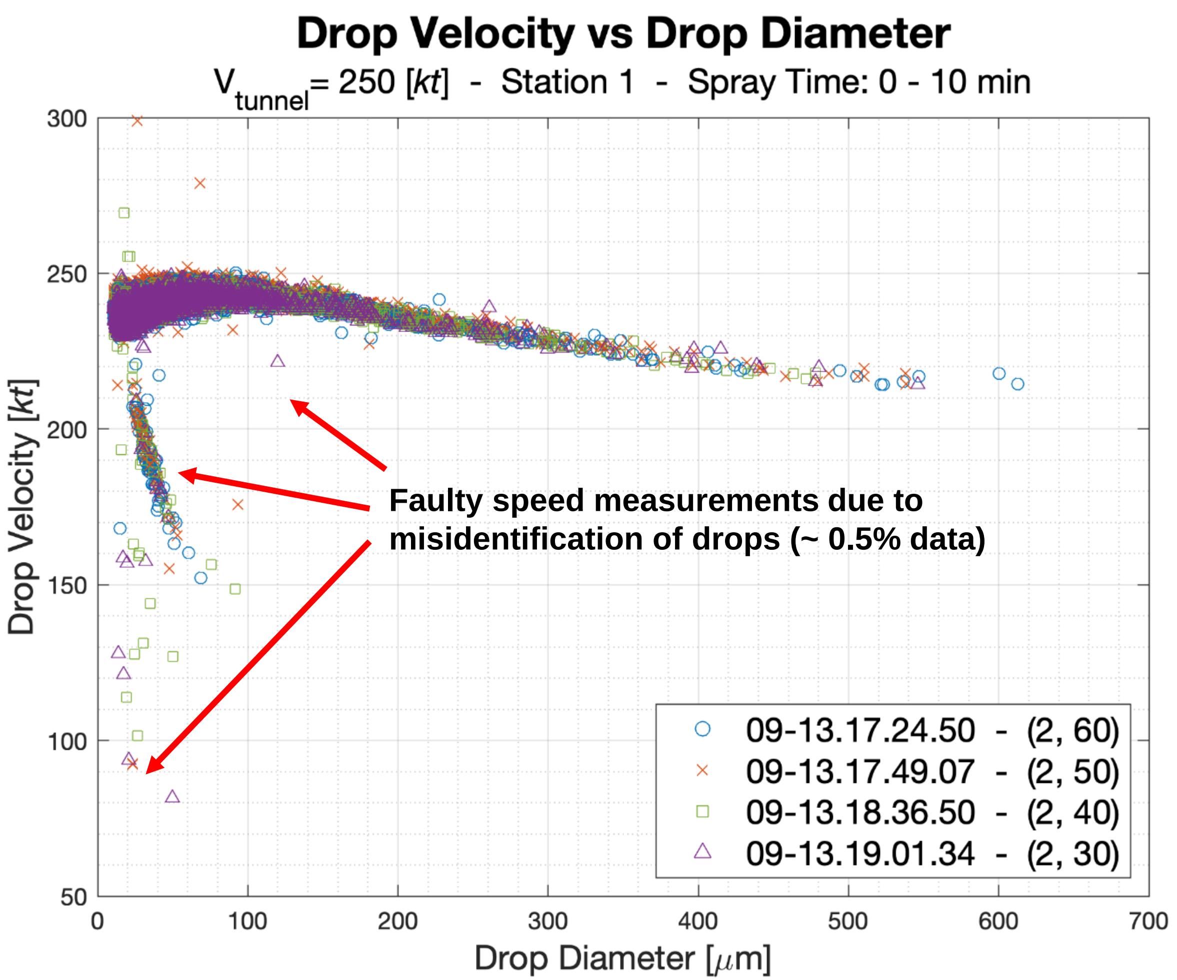


Key Results

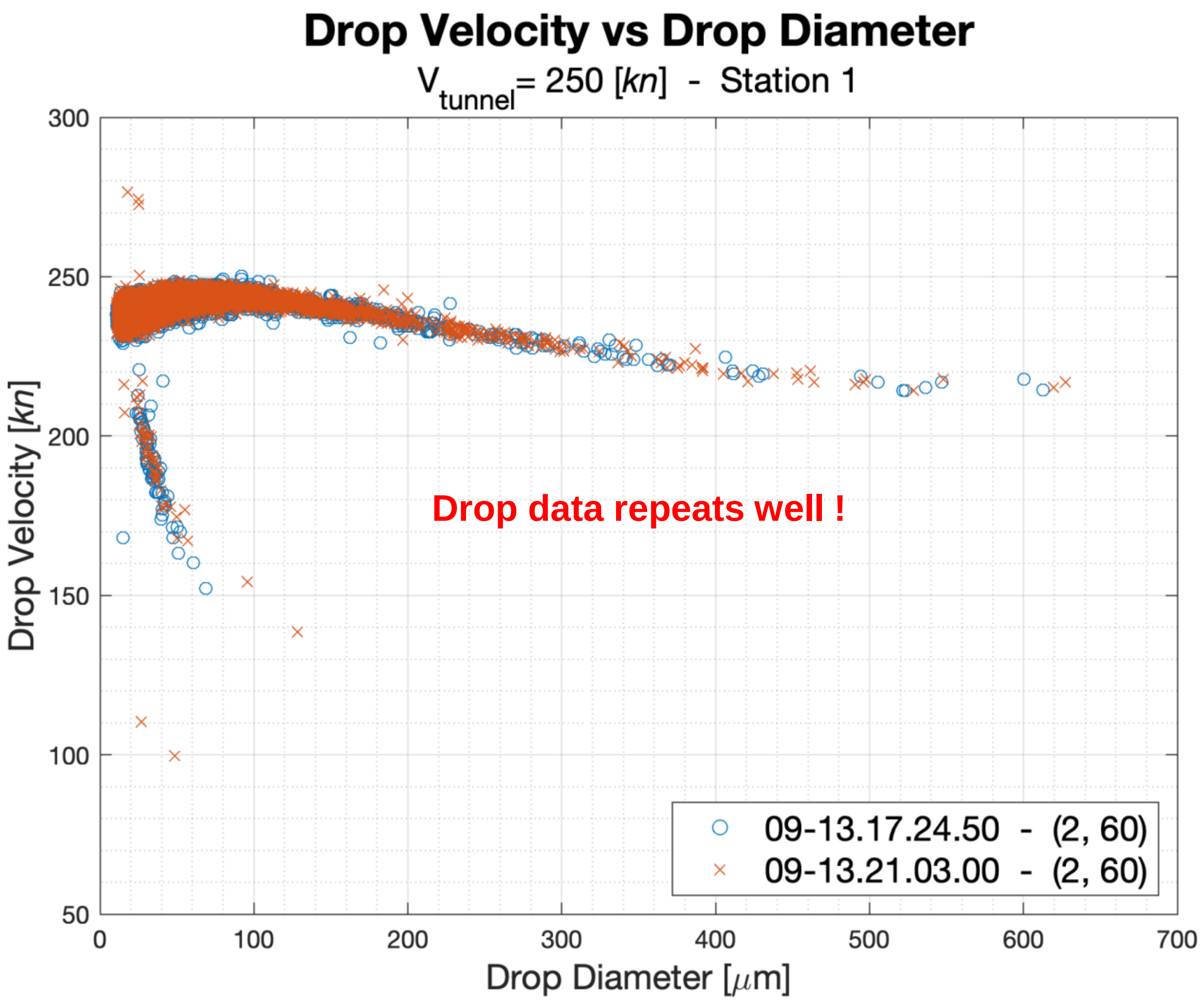
AIMS imaging data



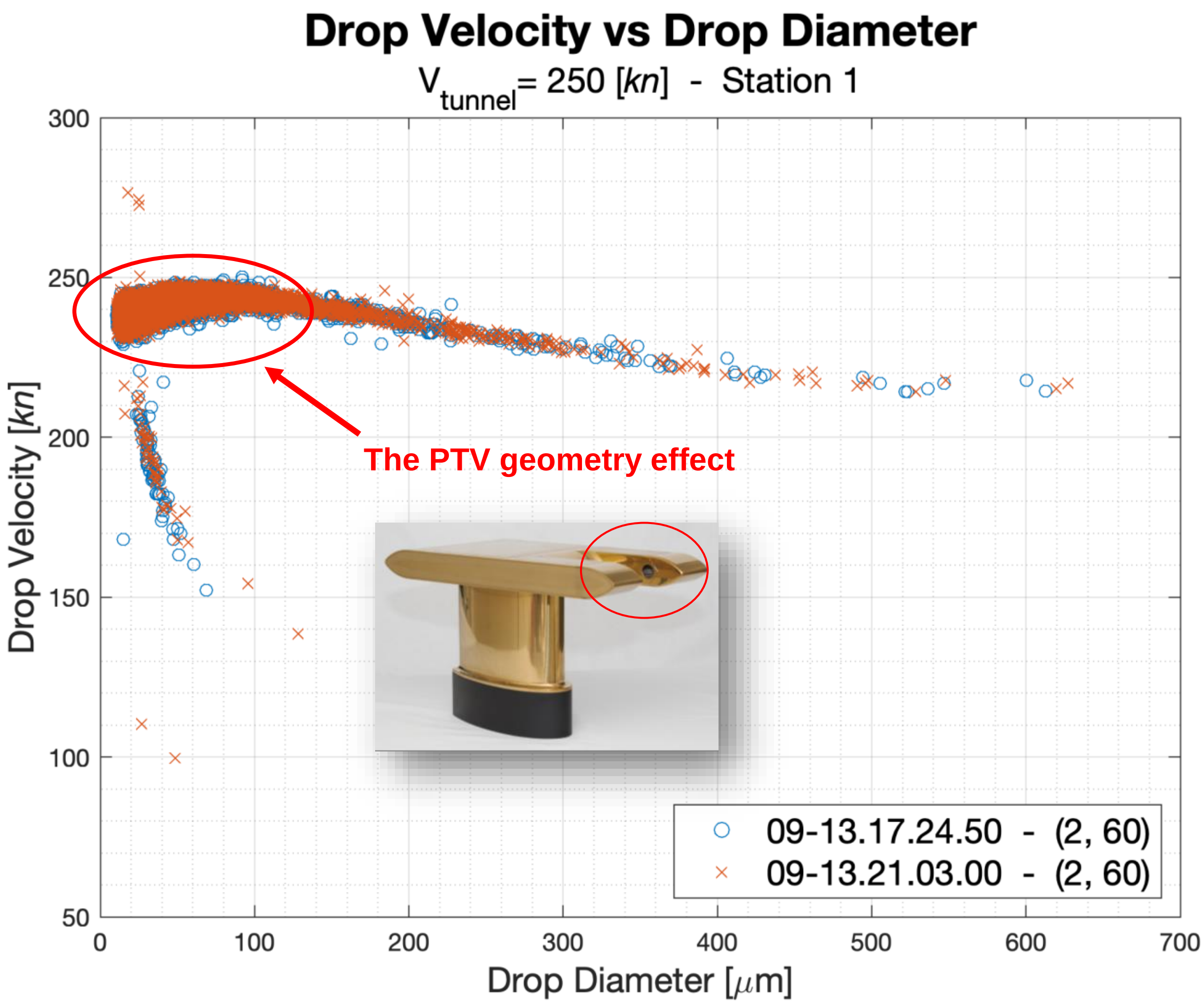
Key Results
AIMS imaging data



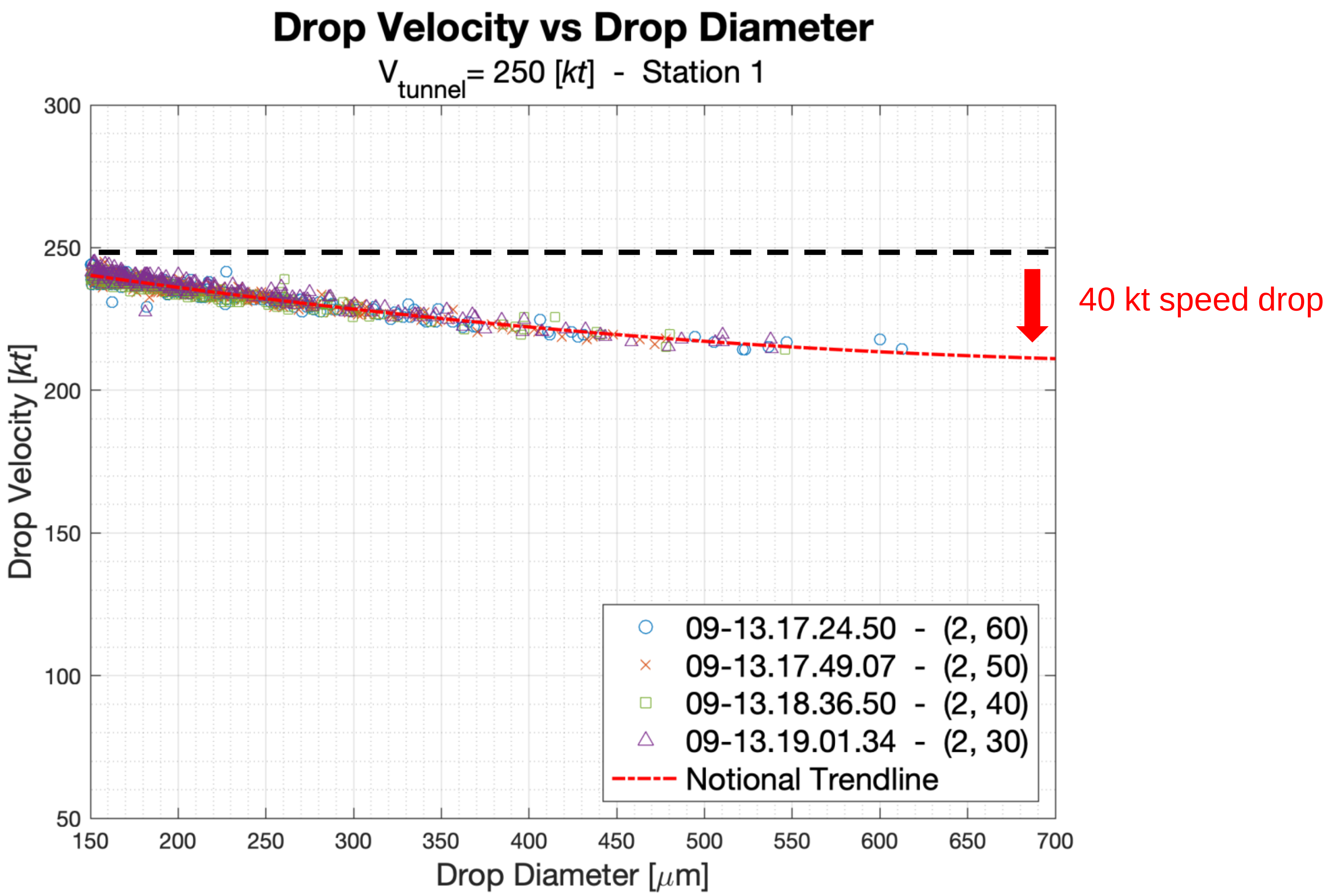
Key Results
AIMS imaging data



Key Results
AIMS imaging data

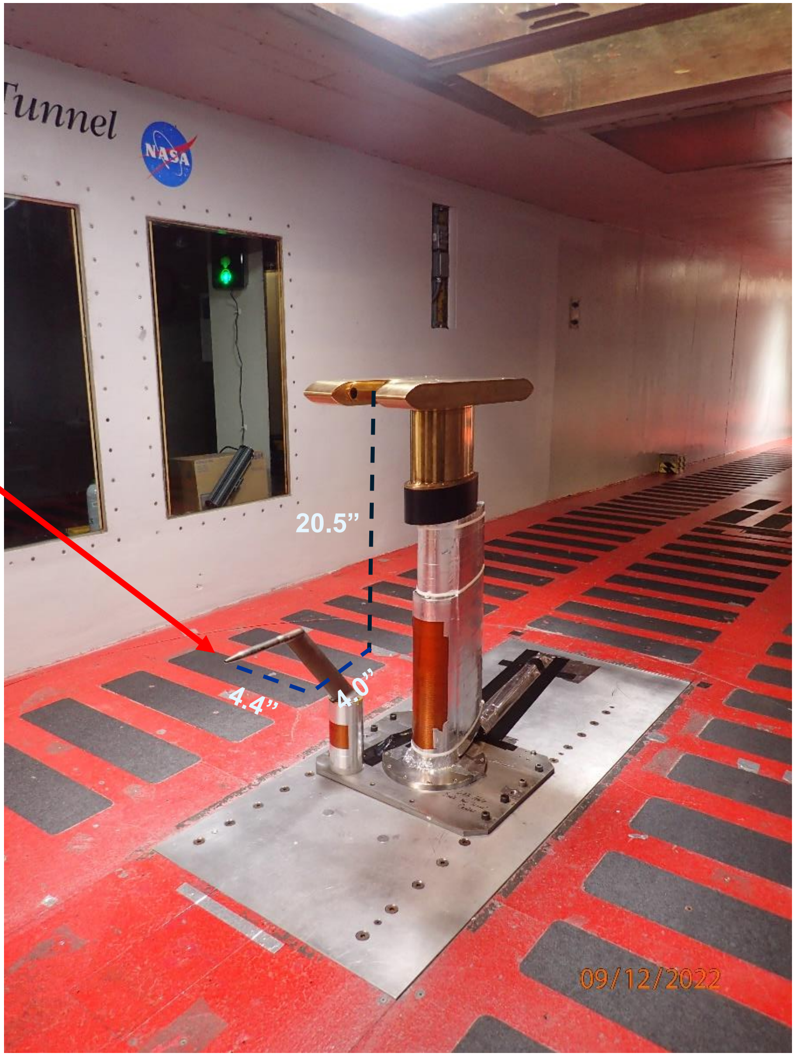


Key Results
AIMS imaging data



Pitot Probe Position
(measure the local air velocity)

The local air velocity measured by the Pitot is affected by the PTV stand



The air velocity measurement further deteriorated as icing spray turned on

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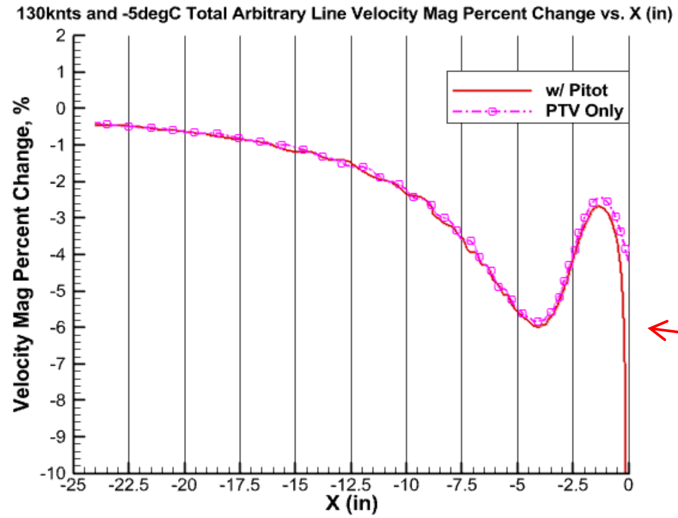
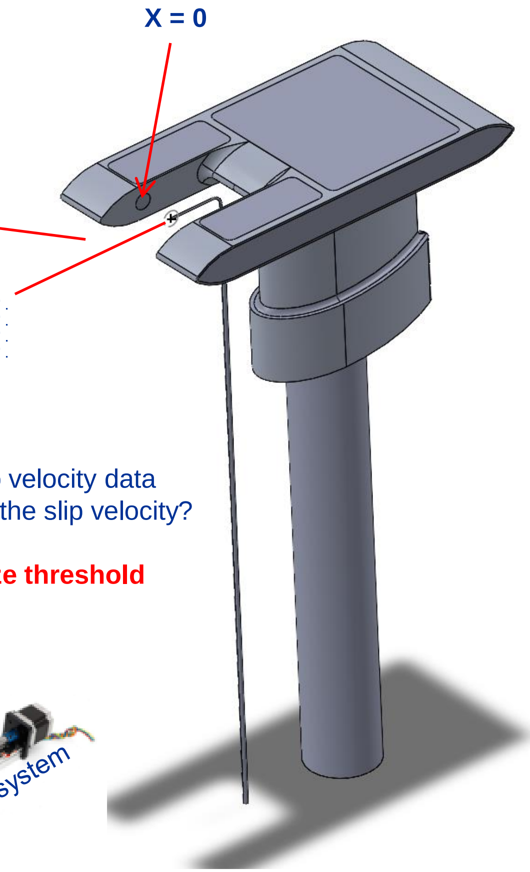
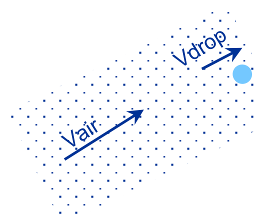
PTV Geometry Effect on Air Velocity

Pitot @Stations 1-3, V_{tunnel} = 130, 170, 210, 250 kt



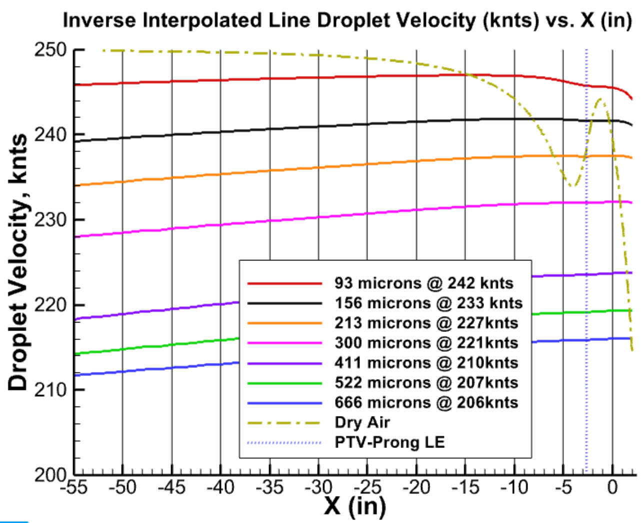
Validate CFD

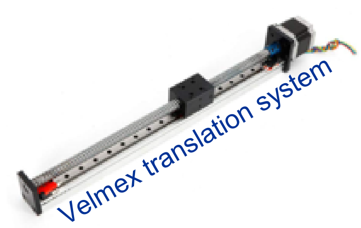




Can we still use larger drop velocity data from PTV for calculation of the slip velocity?

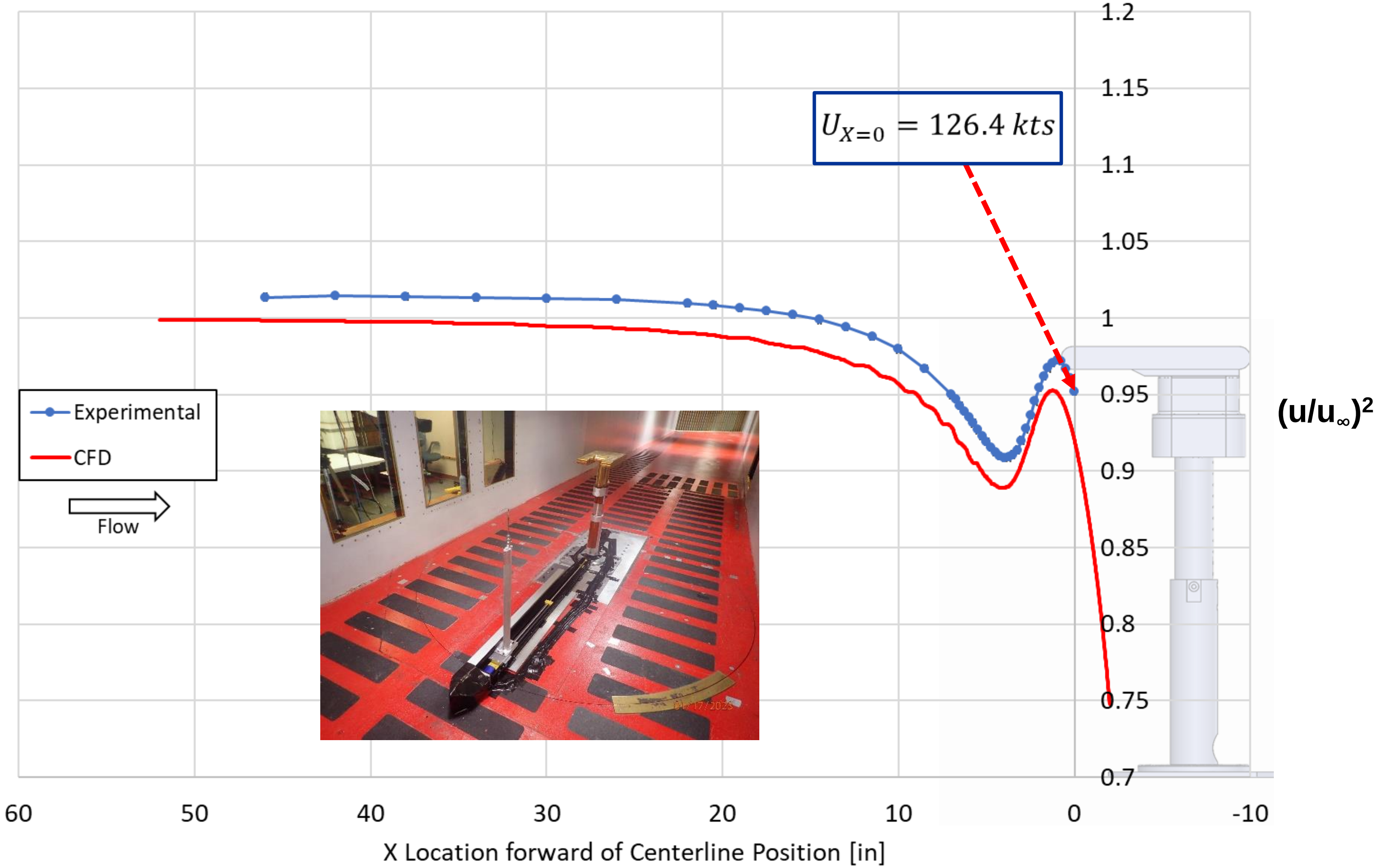
→ **Identify large drop size threshold**





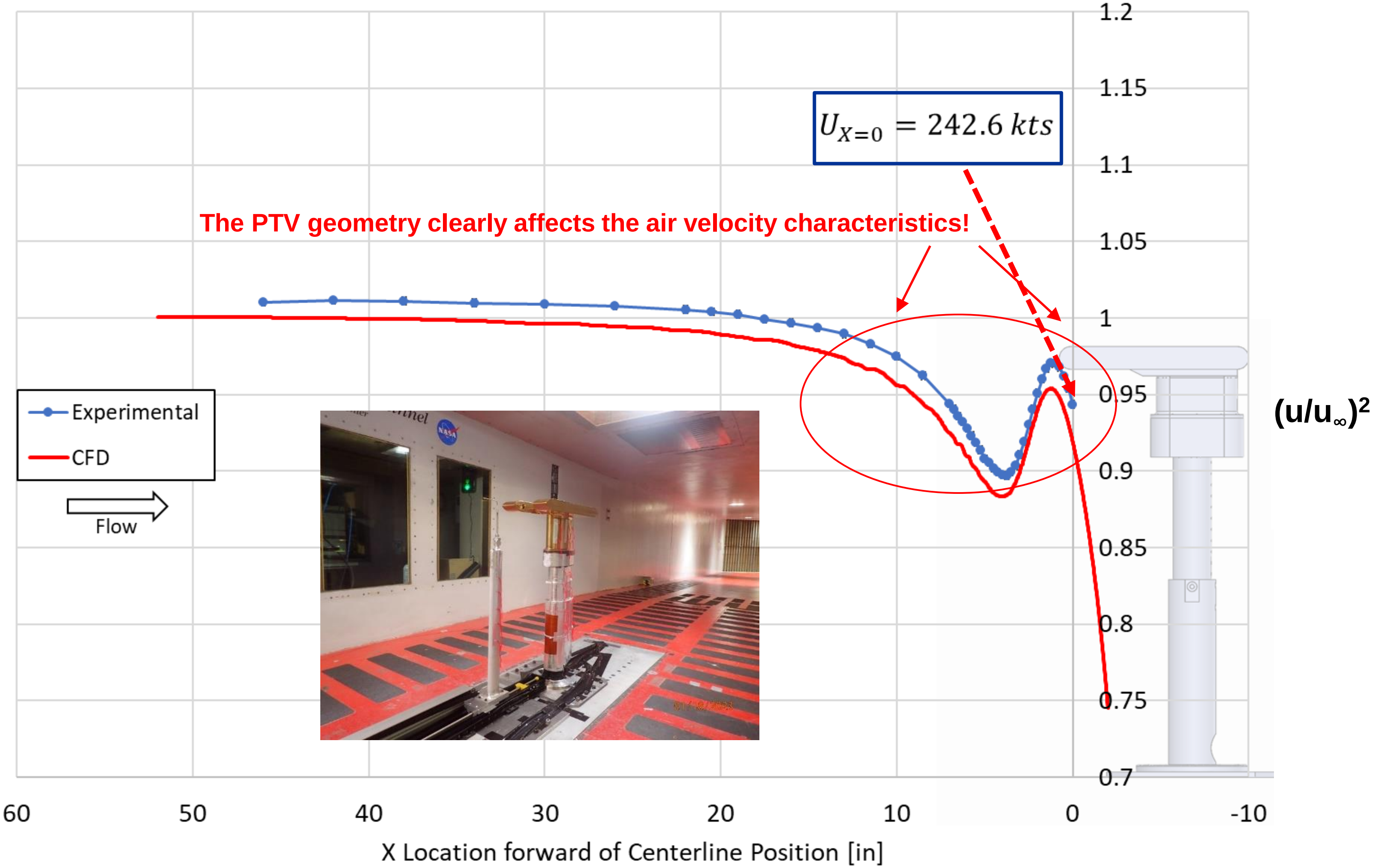
Key Results

PTV geometry effect on air velocity, V_{tunnel}=130 kt



Key Results

PTV geometry effect on air velocity, V_{tunnel}=250 kt



Key Results
PTV stand influences the Pitot probe measurement

Pitot probe w stand

Pitot probe wo stand

V_{tunnel}		Station 1	Station 2	Station 3*
250 kt		x = 0”	X = 90”	X = 108.5”
	V_{air}, Pitot probe w stand	243.4 kt	240.6 kt	238.8 kt
	V_{air}, Pitot probe wo stand	250 kt	250 kt	248.5 kt

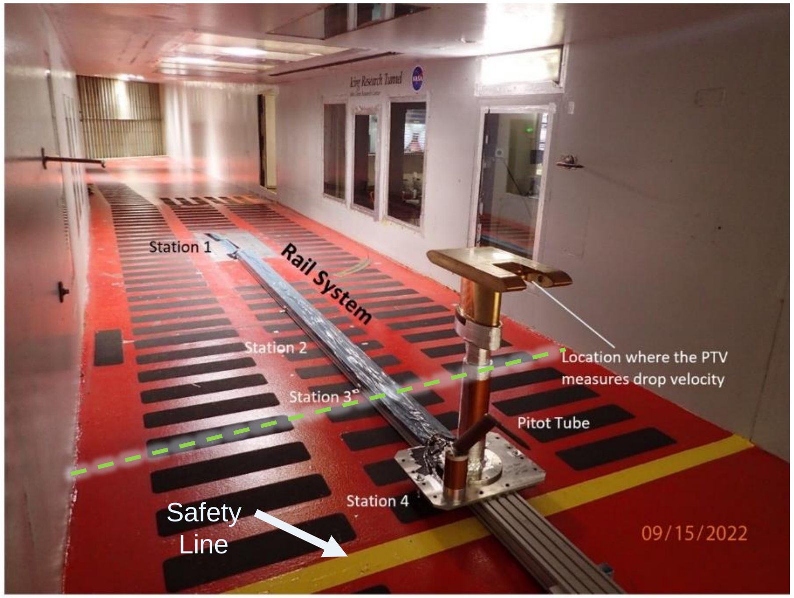
***At the end of the tunnel contraction**

Key Results
Large drop size threshold for PTV

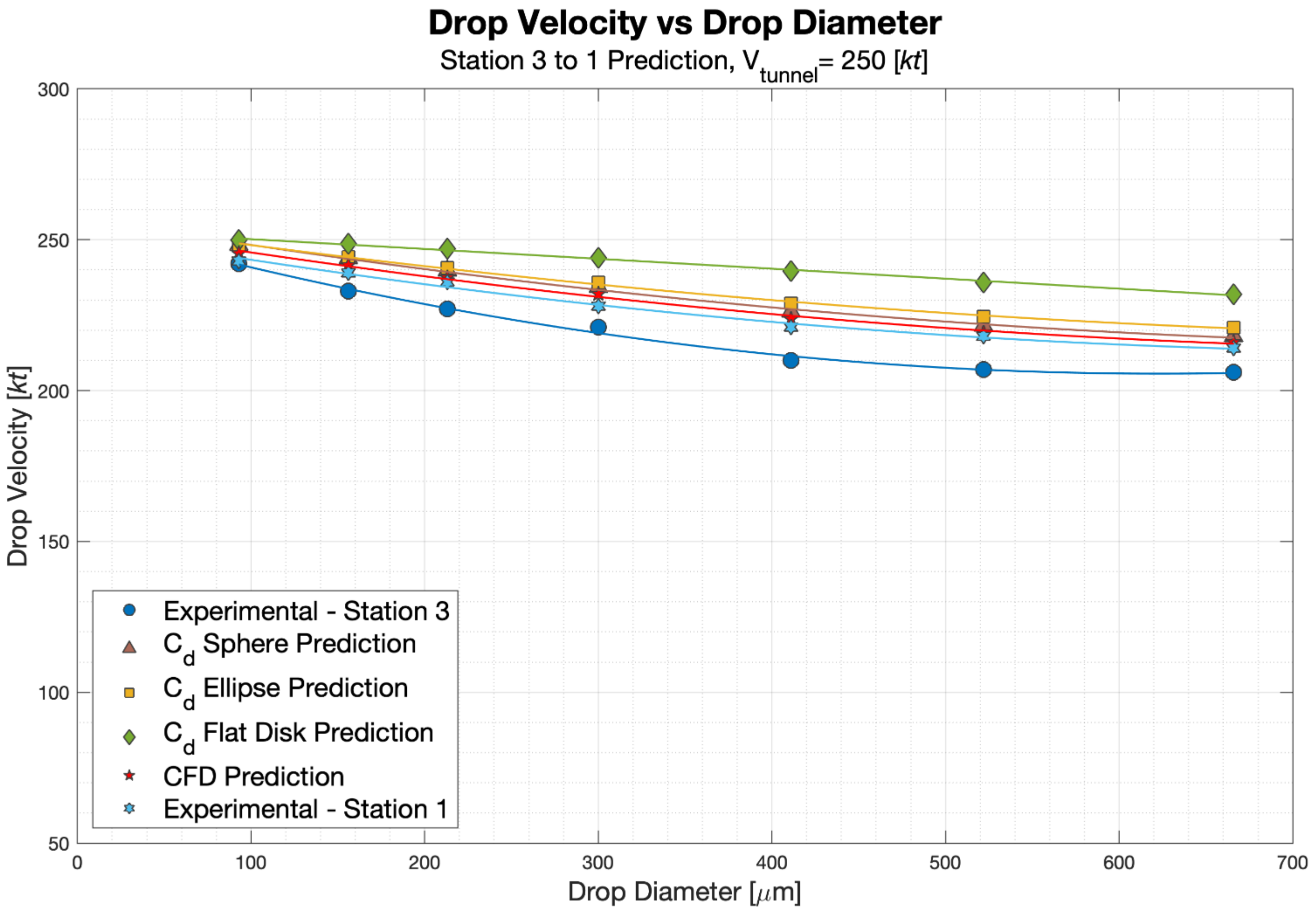
ANSYS DROP3D : The following are the run conditions with drop velocity inputs extracted from PTV measurements at Station 3 (x=108.5"). Run a L-D 7-bin spray of 300µm MVD at 248.5 kt moving toward the PTV stand at station 1 (x=0) position.

Test Configuration	Velocity knts	Velocity m/s	P_{static} Pa	T_{static} ^{o}K	T_{total} ^{o}K	T_{total} ^{o}C	AOA degrees
PTV Only	248.5	127.8	94214	259.9	268.2	-5	0

D (µm)	93	156	213	300	411	522	666
V_d $(kt)_3$	242	233	227	221	210	207	206

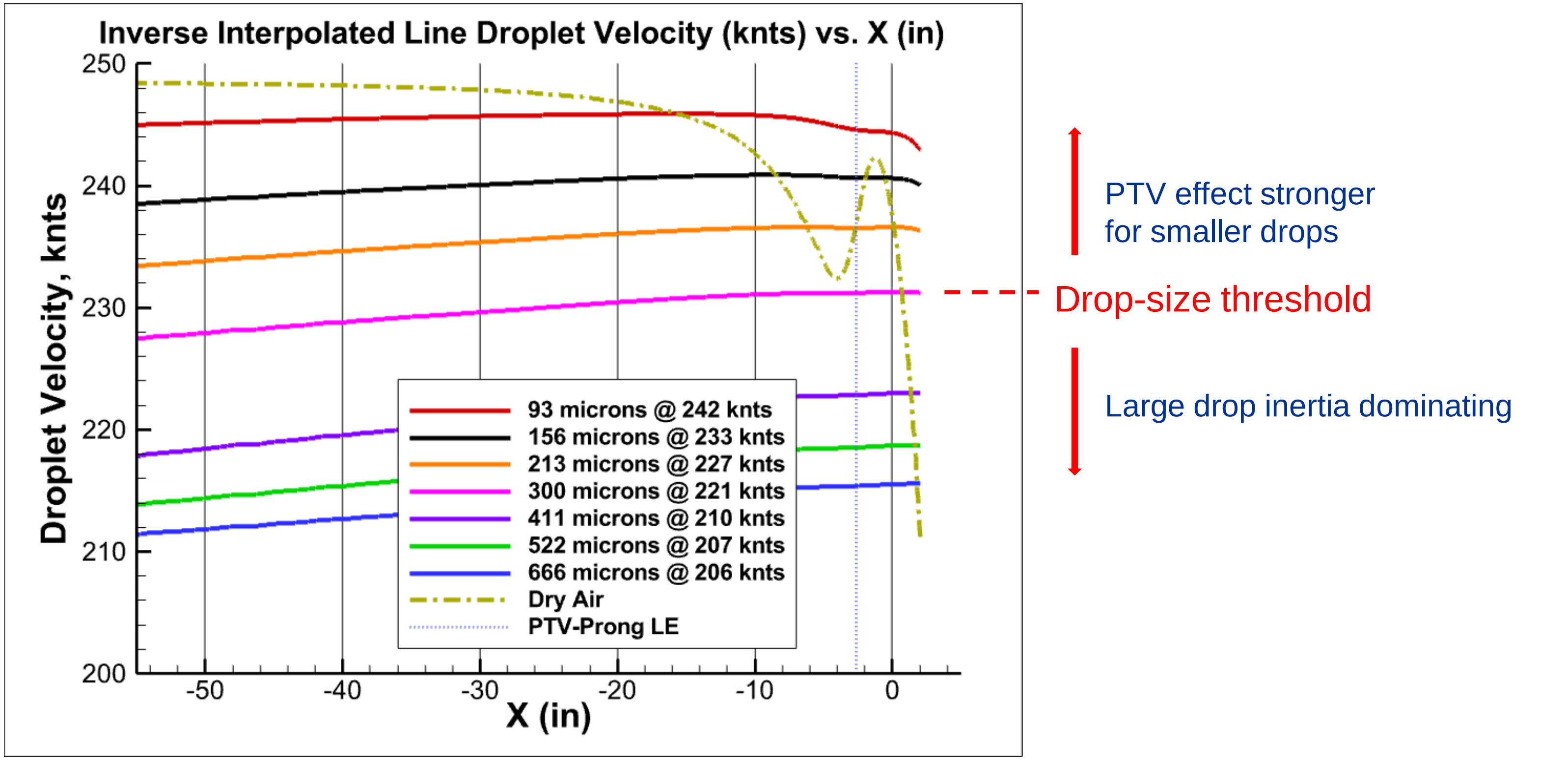


Key Results
Large drop size threshold for PTV



Key Results
Large drop size threshold for PTV

D (μm)	93	156	213	300	411	522	666	
V_d (kt)$_3$	242	233	227	221	210	207	206	
V_d (kt)$_1$	243	239	236	228	221	218	214	PTV
V_d (kt)$_1$	246	242	238	232	224	219	216	DROP3D (spherical drops)



Conclusions

- A 10-day test entry in the IRT was performed in September 12-23, 2022, to evaluate the planned operation of the PTV probe to obtain the supercooled larger drop velocity characteristics
  1. The probe did obtain valid drop size, drop shape and drop velocity data from the SLD icing spray conditions tested in the IRT with measured drop sizes up to 700 µm
  2. The drop velocity distribution at a given air speed in the IRT test section is not affected by different spray bar pressure settings. So, it is desirable to have more shorter spray repeats than fewer longer sprays
  3. The larger drops (e.g., D > 500 µm) generated in the IRT clearly experience significant velocity deficit in comparison with the tunnel airspeed. For an airspeed of 250 kt in the IRT, the velocity of the largest drop measured at the Station 1 was about 40 knots slower
  4. The probe also produces a small fraction of faulty velocity measurements for smaller size drops, and these could be easily filtered out
  5. The PTV probe head influences the smaller drop velocity measurements, but larger drops (D ≥ 300 µm) won't be affected due to large inertia

Recommendations

- Additional test is required to develop the procedure for traversing the PTV probe in the IRT test section to fully characterize the large drop size velocity distribution.
- Attention should also be given to understand what the large drop velocity deficit may do to SLD ice shapes via numerical ice accretion simulation studies
- The SLD cloud development & calibration in the IRT needs to be expanded also to consider
  - supercooling deficit of large drops
- New methodology to obtain the supercooling deficit of SLD clouds generated in the IRT test section is needed

Acknowledgements

- NASA Aeronautics Evaluation and Test Capabilities Project
- The entire IRT staff for their excellent support
- Special thanks to Julien Manin from Artium Technologies, Inc for his technical support

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