Simulation of Fluid Flow and Collection Efficiency for a SEA Inc. Multi-Element Probe and Ice Crystal Detector Using GlennICE

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Overview

Background

- Hot-Wire probes are used to measure water content and detect the phase of water in clouds
- These probes have been widely used in both experimental ground facilities as well as on aircraft
- Correction factors for these probes are needed to account for different types of mass losses and efficiencies
- This paper analyzes two commercial probes using GlennICE and compares results with previously presented LEWICE3D results

Hot-Wire Probe Description

- Hot-Wire Probes operate at a constant temperature above the boiling point of water
- Impinging water removes heat from the wire, requiring additional power to maintain temperature
- Power required can be used to determine amount of impinging water
- The local collection efficiency β is defined as the ratio of the surface flux of impinging water to the free stream mass flux of water
- Total collection efficiency by the equation below

Total Collection Efficiency

$$E_m = \frac{\iint_S \beta dS}{A_{proj}} \tag{1}$$

Multi-Element Probe (Multiwire)

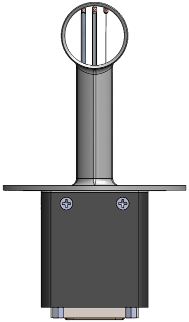


Figure 1: Front View of Multiwire

- The multiwire consists of two off-center convex surface facing flow elements (left and right) and a single concave surface facing flow element
- Ice crystals are thought to bounce off convex surface elements and therefore only measure liquid water
- The concave surface element is thought to capture both ice crystals and liquid water particles

Multi-Element Probe (Multiwire)

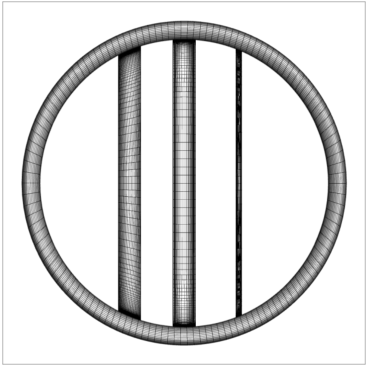


Figure 2: Frontal View of Multiwire Shroud and Elements Mesh Used for Simulations

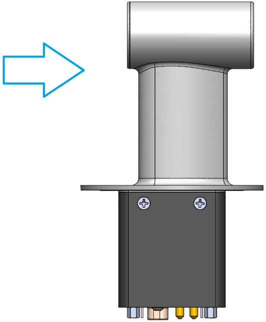


Figure 3: Side View of Multiwire (Flow Direction L-R).

Ice Crystal Detector (ICD)

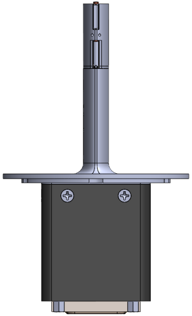


Figure 4: Frontal View of Ice Crystal Detector.

- The ICD was developed from a similar probe known as the Robust Probe which consists of a single TWC element meant to withstand potential ice damage
- The ICD consists of a convex element and a concave element mounted at the leading edge of an airfoil

Ice Crystal Detector (ICD)

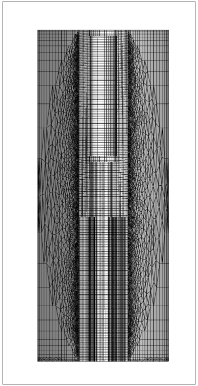


Figure 5: Frontal View of Ice Crystal Detector Geometry Used for Simulations.

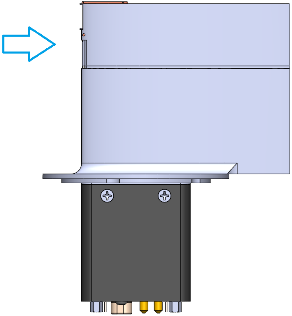


Figure 6: Side view of Ice Crystal Detector (Flow Direction L-R).

Simulation Set-Up

- Flow solutions were calculated using NASA's FUN3D 13.7
  - Probe surfaces set as non-slip
  - Spalart-Allmaras turbulence model was used
  - Time accurate solutions
- Collection efficiency was calculated using NASA's GlennICE 2.1

Multiwire Flow Solution

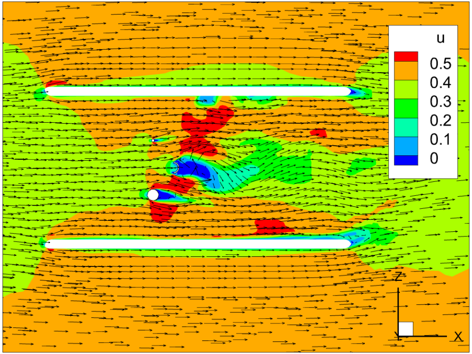


Figure 7: Instantaneous Flow Solution.

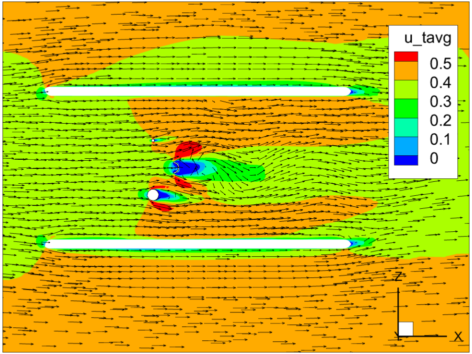


Figure 8: Time Averaged Flow Solution.

Multiwire Collection Efficiency

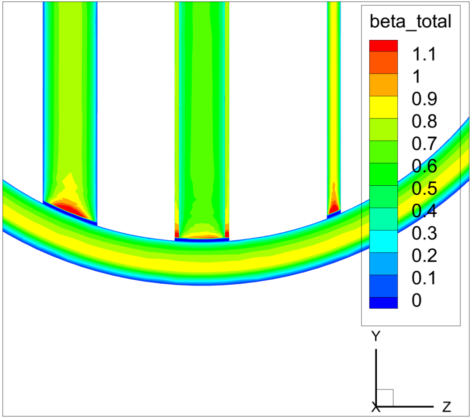


Figure 9: Close-up View of 5μm Case.

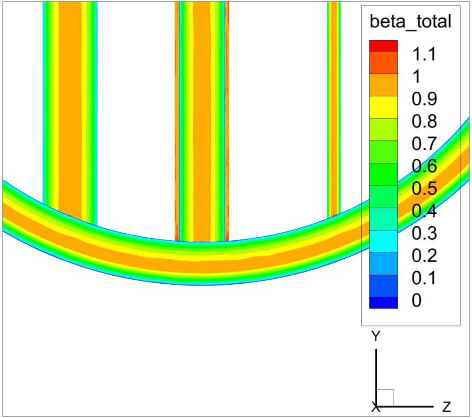


Figure 10: Close-up View of 100μm Case.

Multiwire Collection Efficiency Results

Table 1: Collection Efficiency Results of Multiwire using GlennICE and LEWICE3D from [1]

P0 (psia)	V (m/s)	Particle Size (μm)	GlennICE HP: E_m	LEWICE3D HP: E_m	GlennICE 083: E_m	LEWICE3D 083: E_m	GlennICE 021: E_m	LEWICE3D 021: E_m
6.5	85	5	0.762	0.727	0.724	0.655	0.848	0.829
6.5	85	20	0.949	0.943	0.948	0.936	0.963	0.957
6.5	85	50	0.987	0.986	0.988	0.985	0.990	0.989
6.5	85	100	0.996	0.996	0.997	0.995	0.997	0.996
13.5	85	5	0.686	0.703	0.631	0.627	0.806	0.820
13.5	85	20	0.924	0.935	0.921	0.926	0.944	0.957
13.5	85	50	0.980	0.983	0.981	0.981	0.984	0.988
13.5	85	100	0.993	0.994	0.994	0.993	1.001	0.995
13.5	135	5	0.739	0.757	0.682	0.686	0.833	0.841
13.5	135	20	0.940	0.949	0.937	0.942	0.958	0.963
13.5	135	50	0.983	0.987	0.983	0.985	0.987	0.990
13.5	135	100	0.995	0.995	0.994	0.994	1.013	0.996

ICD Flow Solution

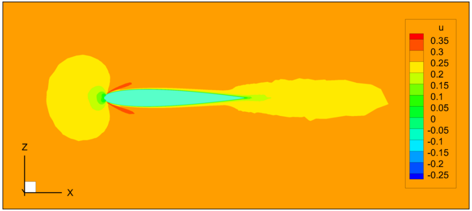


Figure 11: Instantaneous Flow Solution.

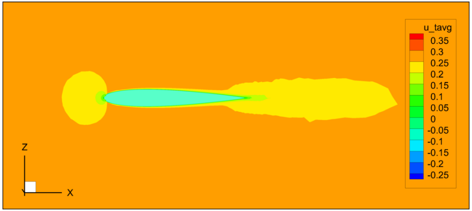


Figure 12: Time-Averaged Flow Solution.

ICD Flow Solution (Side View)

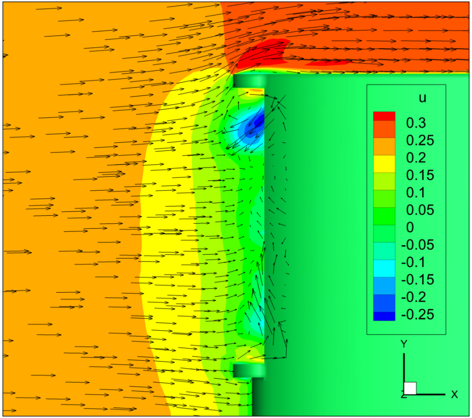


Figure 13: Instantaneous Flow Solution.

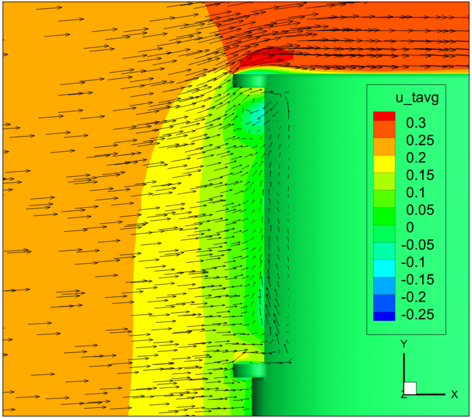
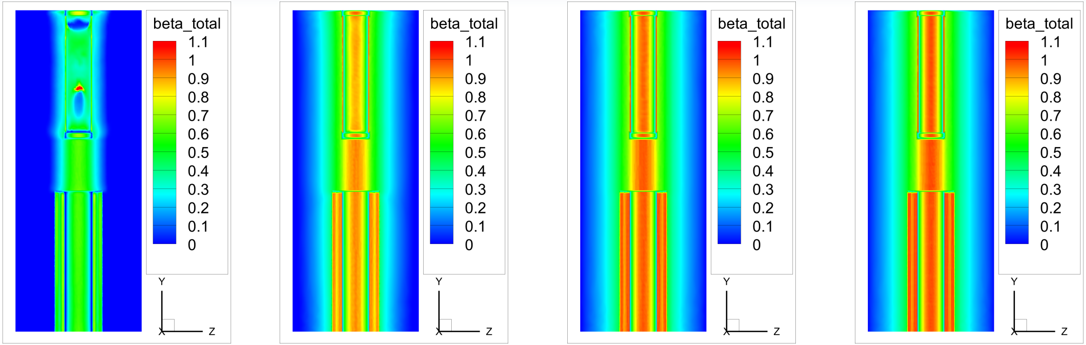


Figure 14: Time-Averaged Flow Solution.

ICD Collection Efficiency



(a) 5 μm Particle Size (b) 20 μm Particle Size (c) 50 μm Particle Size (d) 100 μm Particle Size

Figure 15: Ice Crystal Detector Collection Efficiency Results using GlennICE at V = 85 m/s, P = 13.5 psi

Q-Criterion

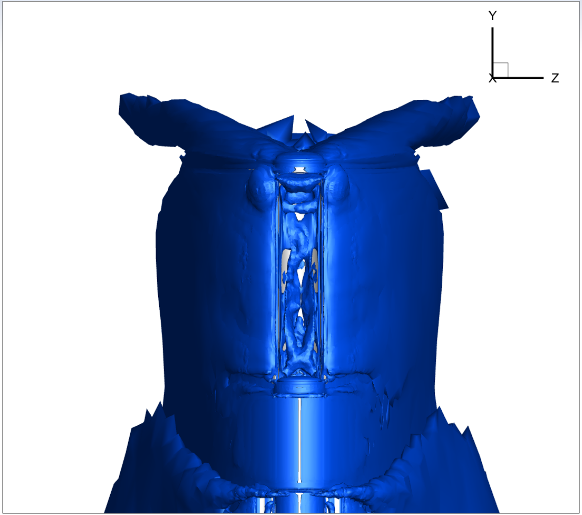


Figure 16: ICD Iso-Surface of Q-Criterion = 0

ICD Collection Efficiency Results

Table 2: Collection Efficiency Results of Ice Crystal Detector using GlennICE

P0 (psia)	V (m/s)	T (C)	Re delta	Particle Size (μm)	GlennICE HP: E_m	GlennICE 083: E_m
6.5	85	−5	14.03	5	0.680	0.608
6.5	85	−5	56.12	20	0.948	0.932
6.5	85	−5	140.3	50	0.986	0.982
6.5	85	−5	280.61	100	0.994	0.993
13.5	85	−5	29.14	5	0.552	0.491
13.5	85	−5	116.56	20	0.925	0.903
13.5	85	−5	291.4	50	0.981	0.975
13.5	85	−5	582.8	100	0.993	0.991
13.5	135	−5	43.92	5	0.630	0.592
13.5	135	−5	175.69	20	0.942	0.930
13.5	135	−5	439.24	50	0.984	0.981
13.5	135	−5	878.47	100	0.993	0.993

Conclusions

- Numerical simulations between GlennICE and LEWICE3D correlate well for larger particle sizes
  - At smaller particle sizes, results diverge slightly
- Hot-wire probes compare well with each other except at small particle sizes where the ICD has a noticeably lower collection efficiency
- Additional investigation of the recirculation effect within the concave element is required to understand effect

Acknowledgments

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Selected References

Please see accompanying paper for full reference list.

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