Snowflake Measurement and Analysis System (SMAS)

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***Abstract*—We present a novel system for measurement and analysis of snow particles in free fall, constituting the Snowflake Measurement and Analysis System (SMAS). The SMAS features seven high-resolution cameras placed in a 3D fashion for 3D visual hull reconstruction of particle shapes and particle fall speed measurements. The SMAS data enable particle scattering computation, studies of snow habits, analysis of microphysical characteristics of particles, and hydrometeor classification.**

I. Introduction

With the advent of optical imaging disdrometers that can measure fall speed along with projected particle views in either one plane (Precipitation Imaging Package – PIP), two planes (2D-Video Disdrometer – 2DVD [1]), or multiple planes (Multi-Angle Snowflake Camera – MASC [1]), there has been great progress in microphysical and geometrical measurements and characterization of ice and snow particles in snowstorms. Such advances enable new discoveries based on the synergy between optical measurements and processing, electromagnetic scattering computations, and radar observations [1].

This summary presents a brand new, in-house designed and developed optical instrument for the measurement and analysis of snowflakes and snowfall, and outlines its capabilities and potential for characterization of physical and scattering properties of ice particles in winter precipitation, independently and in relation to radar observations.

II. Novel Instrument for Measurement and Analysis of Snowflakes and Snowfall

Several teams of engineering (Electrical and Computer Engineering and Mechanical Engineering) graduate and undergraduate students at Colorado State University have designed, developed, and built a novel system for measurement and analysis of snow particles in free fall, constituting the Snowflake Measurement and Analysis System (SMAS), shown in Fig. 1. The shape of the cover for the SMAS was a streamlined design and built by the Mechanical Engineering design team to reduce air motion fluctuations near the sensor area due to uniform horizontal wind (up to 20 m/s), as depicted in Fig. 2. The main advantages of the SMAS over the existing instruments are: seven high-resolution cameras placed in a 3D fashion for 3D visual hull reconstruction and fall speed measurement purposes, capability for full usage, processing, and analysis, including particle fall speed, of images/frames with multiple snowflakes per frame, increased image capture rate, and enhanced reliability and stability of the instrument in operations.

The 3D reconstruction using visual hull needs software calibration of the cameras [2] as well the determination of the sampling volume. Our objective is more accurate characterization of 3D geometrical properties simultaneous with fall velocity and particle size distribution (PSD).

The SMAS is equipped with 7 cameras, 6 flashes, 5 sensor boards, 2 lasers, a printed circuit board (PCB), and a built-in PC computer. The PCB is used to control the flashes, lasers, and cameras with a PIC (peripheral interface controller) microcontroller. When a snowflake falls through the system and the laser plane gets blocked, the PIC triggers the cameras and flashes. A C++ code is running in the PC that organizes and stores the pictures captured by the cameras to a RAID storage. The camera IDs and camera layouts are shown in Fig. 3. Cam_3, cam_4, cam_5, and cam_6 in the top layer aim down at 45°, and cam_0, cam_1, and cam_2 in the bottom layer aim horizontally. Some important parameters of the cameras are 16 (or 25) mm lens, 5 Mega pixel resolution, aperture set to f/16 and depth of field in the range 50-70 mm.

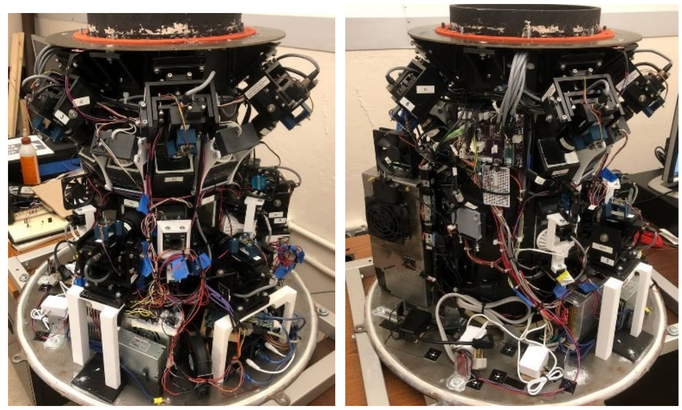

Figure 1. Snowflake Measurement and Analysis System (SMAS).

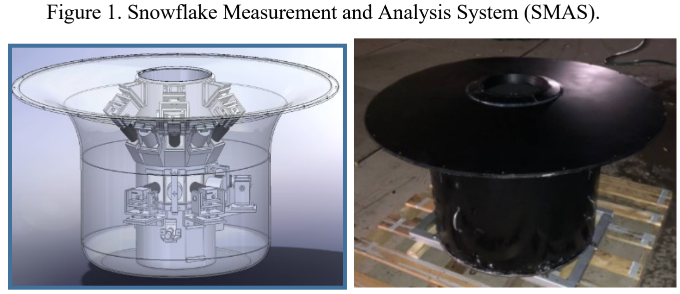

Figure 2. (left panel) CAD model (transparent CAD solid model) of SMAS outer chassis – in Nipher shield shape, which maximally reduces turbulence. (right panel) SMAS prototype outer chassis photograph.

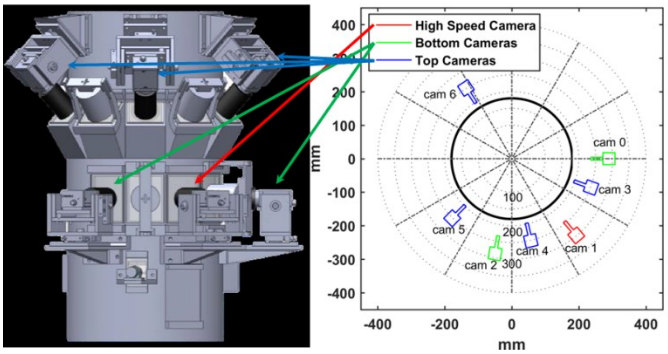

Figure 3. CAD inner model of the SMAS (left panel) and the simplified top view to show the location of the 7 cameras (right panel).

III. EXAMPLES OF SMAS DATA, ANALYSES, AND RESULTS

Figure 4 shows photographs of three snowflakes captured by the SMAS. These images are used for particle classification [3], to perform the 3D reconstruction with the visual hull method [2], to be used in turn, for example, for particle scattering computations [4], and for many other applications.

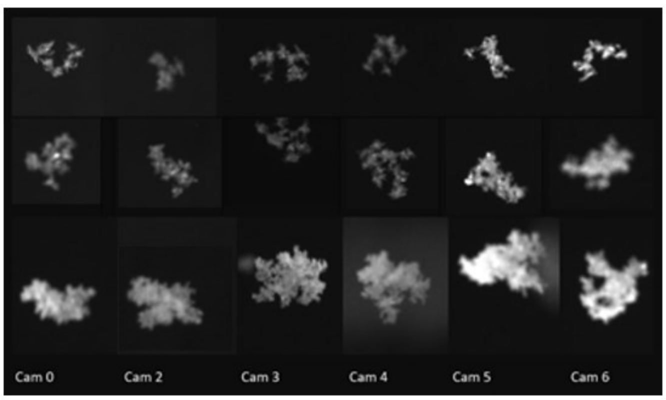

Figure 4. Photographs of three snowflakes captured by the SMAS (each row is for different snowflake example). Within each row the six camera views are shown, at each of the six spatial angles described in Fig. 3. These images are used to perform the 3D reconstruction with the visual hull method.

We have developed a multi-strobe technique for determining the particle fall speed. The PIC controls a dedicated flashlight to flicker or strobe at high frequency, around 490 Hz. During the high-frequency strobing, the shutter speed of the camera is set to a slower speed (i.e., long exposure), for example, half a second. The strobe frequency can be adjusted from 1–495.5 Hz. One of the main motivations behind the SMAS concept in general and the multi-strobe method in particular is to accurately, reliably, and robustly measure the fall speed of multiple snowflakes at once. Three laboratory objects were dropped at once, as shown in Fig. 5.

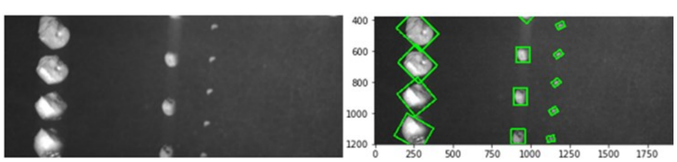

Figure 5. Example of multi-strobe measurement of fall speeds of three different lab objects at once (this is a unique capability of SMAS relative to MASC).

The code properly matched the three objects and returned three fall speeds, given in Table I, where we observe good agreement with the fall speeds of the same objects when measured by the MASC one object at a time.

TABLE I. MEASURED FALL SPEED (M/S) OF 3 LAB OBJECTS BY THE SMAS AT ONCE AND BY THE MASC ONE BY ONE.

Object	SMAS	MASC
1	1.1226	1.11
2	1.6235	1.63
3	1.3360	1.36

The SMAS is also capable of calculating the PSD, e.g., the particle cross section area and diameter, respectively, in real time. Figure 6 shows the PSD obtained by the SMAS deployed for integrated field measurements at the NASA Precipitation Research Facility at Wallops Island, Virginia, during an hour of the snowstorm on January 22, 2022. As can be seen, most of the snowflake particle diameters are in the 0.1–0.5 mm range, indicating that the majority of the hydrometeors during that particular hour were small, which is also confirmed by the visual inspection of the SMAS image samples.

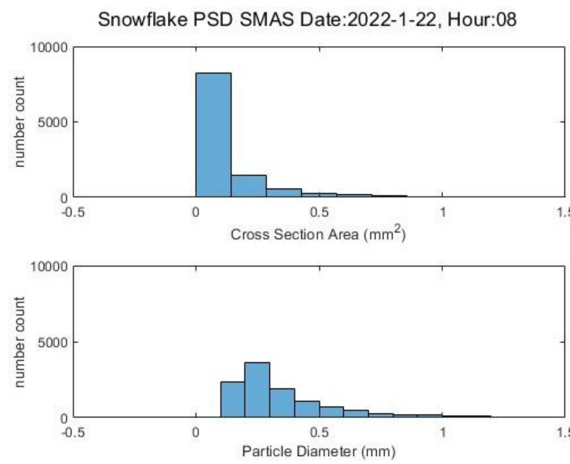

Figure 6. SMAS particle size distribution (PSD) measurements and calculations from UTC 0800 to 0900 on Jan 22, 2022 at the Wallops Island.

ACKNOWLEDGMENT

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