Machine Learning, Sensing, and Image Processing for Snow Research

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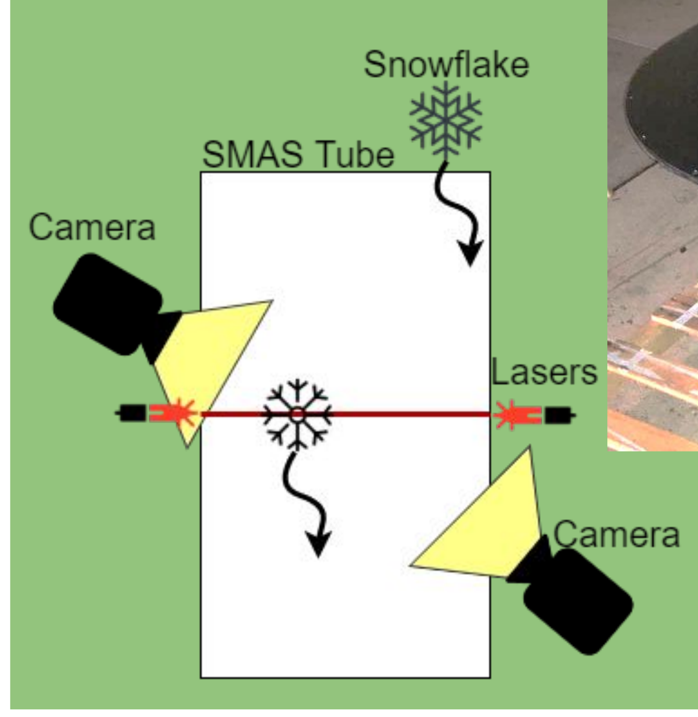
Introduction

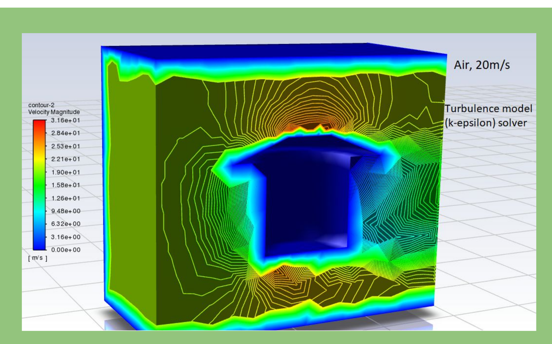
- **Project Goal:**
  - Automatically collect images of snowflakes for research, 3D reconstruction, classification of individual snowflakes
- **The Snowflake Measurement and Analysis System (SMAS) current features:**
  - 7 different angled cameras
  - A Laser triggering system (cross planes)
  - A CAN Bus system
  - IPX5 waterproofing and weatherproofing

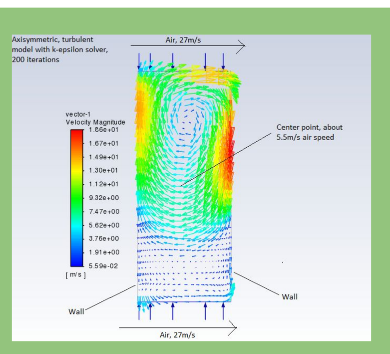


Top: SMAS
Left: Simplified diagram of SMAS operation.

Mechanical Design

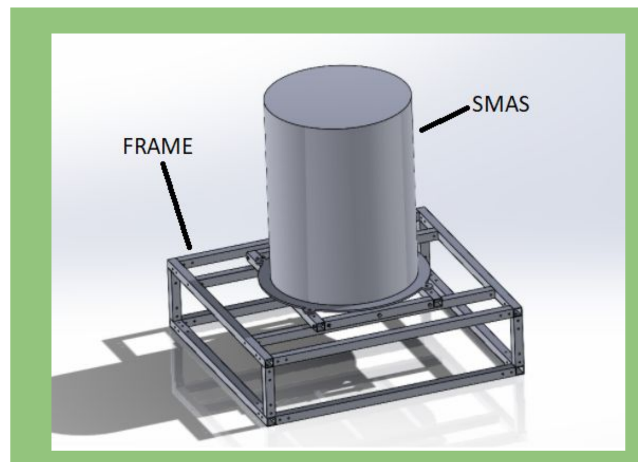
- **Completed Objectives**
  - Device is physically robust
  - Can be transported safely and set up easily
- **Snowflake Fall Speed Measurement**
  - Find actual fall speed based on apparent fall speed
  - Use Computational Fluid Dynamics for analysis of disturbance

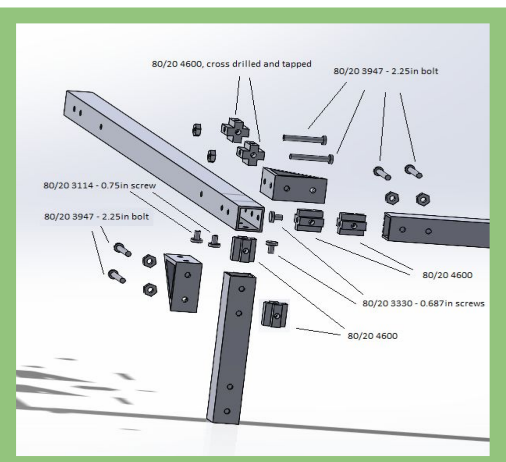




CFD simulations in 3D and 2D to analyze the external and internal wind speeds caused by disturbance in the environment.

- **Pedestal Design and Manufacturing**
  - Maintain upright position of system
  - Allows rain and snow to collect underneath instead of around device



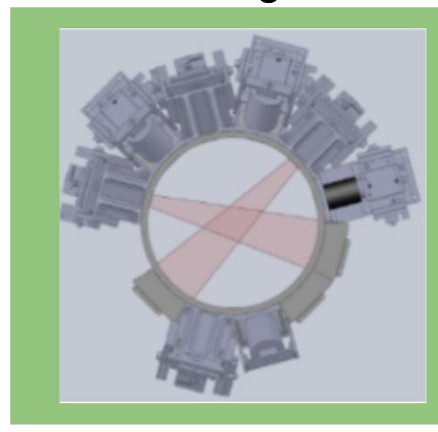


Design of pedestal, solidworks model shown along with all parts used for manufacturing.

- **Testing of Device**
  - Temperature tested at maximum and minimum environment conditions
  - Water tested -> IPX5 standard

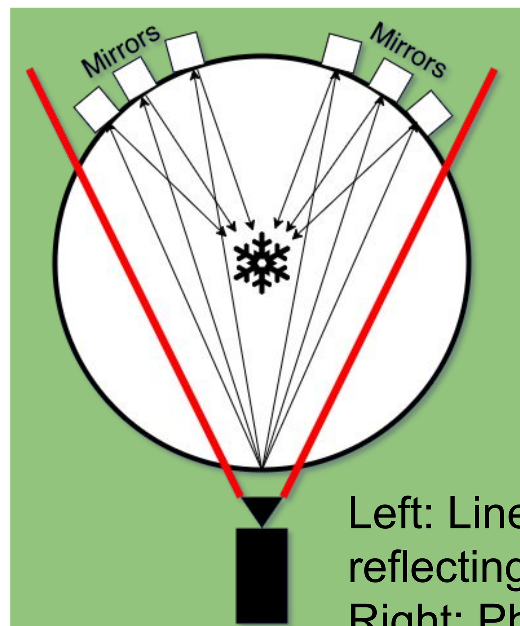
Electrical Design

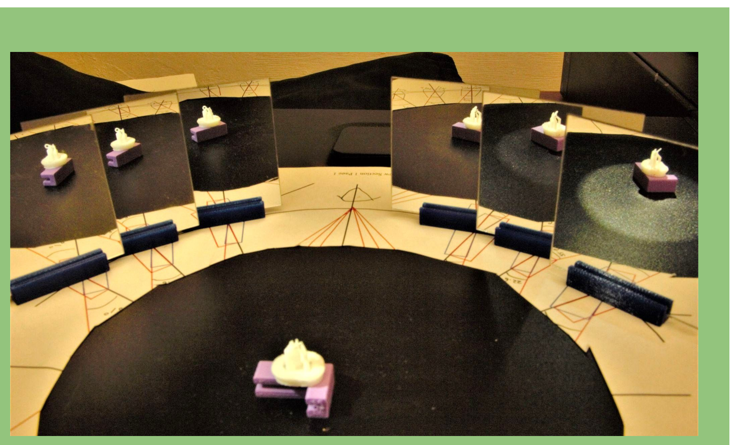
- **Completed Objectives**
  - Snowflakes centered in images
  - Synchronized images
  - Illuminated subjects
  - Image transfer bandwidth maximized
  - Has sensors for local temp, humidity, and particle detection
  - Power usage minimized



Original design using crossplane lasers. Cameras only trigger when snowflakes fall in center of the tube.

- **New Camera Configuration**
  - Mirrors to simulate multiple cameras
  - 360º view of snowflake with 2 or 4 cameras
  - Detect motion and fall speed
  - High speed & high resolution cameras
  - Crop out virtual snowflake images





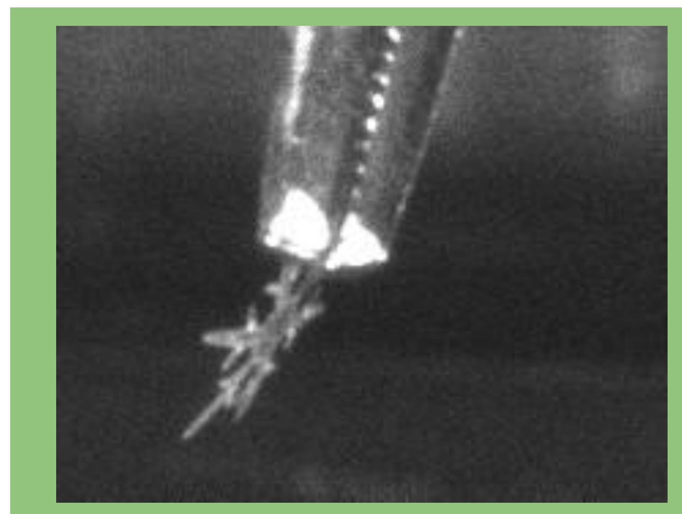
Left: Line-of-sight from camera to snowflake, reflecting off of 6 mirrors.
Right: Physical setup with sample snowflake.

- **Sensors and Remote Sensing**
  - 7 local temperature sensors
  - 4 local humidity sensors
  - CAN Bus for dataflow
  - mmWave radar for snowflake detection and 2D mapping
  - Lidar for atmospheric humidity and temperature sensing

Simplified diagram of mmWave radar operation.

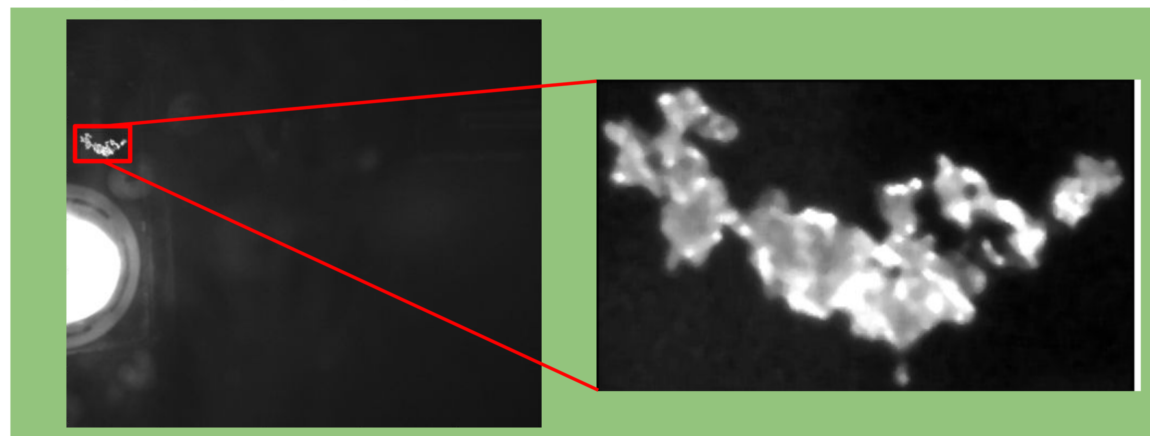
Computer Design

- **Completed Objectives**
  - Computer runs independently for months at a time
  - Progress can be monitored remotely
  - Images can be viewed/uploaded during clear weather
  - Images take up minimal local storage without losing data
  - Additional atmospheric measurements are recorded simultaneously to image saving

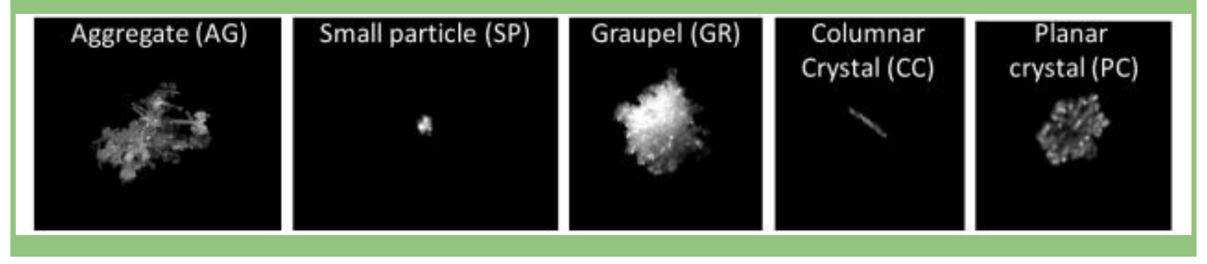


Images of 3D printed snowflakes being held in place by a pair of tweezers that were used to calibrate the shutter speed and the gain of the cameras.

- **Remaining Machine Learning / Image Processing Objectives**
  - Replicate classification accuracy from previous research papers
  - Include capability to add new snowflake classes and/or subclasses
  - Create framework for adding new images to be labelled/trained on

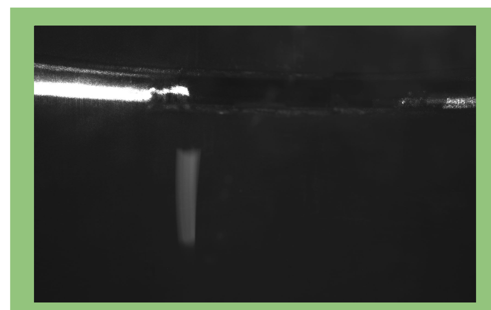


An example of a snowflake being cropped out of a full sized image. This cropped snowflake image would then be classified into one of the classes below.



Computer Design Continued

- **Fall Speed Software**
  - Original approach compares streak length with flake size
    - Works for single snowflakes but not multiple in one image
  - New approach uses computer vision to detect all flakes and streaks
    - Finding the direction of the streak gives as an idea of where the flake should be
    - Matching flakes with streaks allows us to use our original approach iteratively



Original streak

Processed streak

Specific fall speed test

Streaks with bounding boxes drawn around them after processing the image and applying the object detection model. Percentages correspond to confidence.

Flake Number	Time Stamp	Temperature	Humidity
	Dust Level	Fall Speed	Class

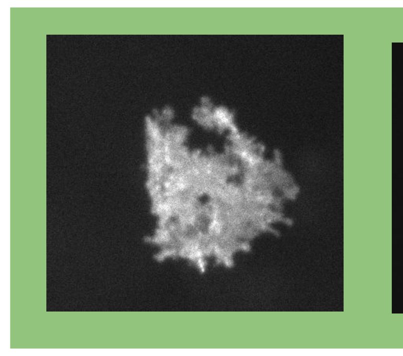
An example of what the output from the device will look like. All this data will be used for weather research.

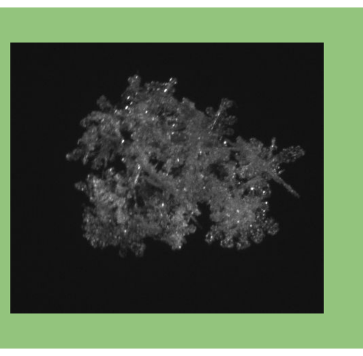
Future Work

- **Improvements on Current Design:**
  - Finish structural design of new SMAS
  - Implement new camera configuration
  - Finish development of snowflake classification with machine learning
- **Research for Future Designs:**
  - Develop better Remote Sensing techniques
  - Optimize interaction between software and hardware for better frame rate and resolution

Results

- Successfully shipped SMAS to a NASA facility in Wallops Island, Virginia for real-time snow data collection
- More research and testing underway to improve various aspects of new SMAS iteration





Example snowflake images taken by the SMAS at the NASA facility.