Progress on the realization of innovative low cost disposable hail sensing probes

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INTRODUCTION

Detailed studies and research about hail characteristics are considered to play a key role both in weather prediction and potentially also in damage assessment after a strong hail event occurred. Most monitoring instruments perform indirect monitoring operations, sensing the parameters from a remote position and not being directly inside a hailstorm.

Since 2015 the CINFAI (Italian National Consortium for the Physics of Atmospheres and Hydrospheres) with its local operative research unit at the DET (Department of Electronic and Telecommunications) of Politecnico di Torino, Italy, realized a first preliminary study concerning the realization of artificial disposable sensing probes to study and monitor hail (conducted within a project called HaSP, founded by Regione Piemonte, Italy). The study was continued in cooperation with EST (Envisens Technologies s.r.l.), a small Italian engineering company, in order to realize the first small prototype.

Introducing the appropriate modifications, a similar version of the probe can be also suitable for monitoring atmospheric parameters.

This poster presents the progress on the realization of low cost disposable hail sensing probes for remote sensing and the study of the properties of hail.

The probes are designed as artificial hailstones in order to study both the physical properties of the portion of atmosphere where the formation of hail occurs and the modification of atmospheric conditions while the hailstones are falling to the ground. For this reason, the probes and the hailstones should have the most similar as possible fluid-dynamic properties.

The artificial probes can be dropped by a plane, or potentially by a UAV (Unmanned Aerial Vehicle) if permitted by specific legislation, which fly above and through the clouds where the formation of hail occurs. Each probe is equipped with different sensors and during their falling to the ground, they directly measure different physical parameters (e.g. humidity, temperature, pressure, acceleration...).

All data are sent to a receiver located on the ground exploiting a specific communication link realized at a frequency not affected by the presence of hail and water in the atmosphere.

The hail sensing probes can be used for efficient monitoring operations and studies of hail formation dynamics and conditions, thus increasing the set of instruments used for monitoring, remotely sensing and study the physical properties of hail, and possibly also to improve the hail forecasting models.

THEORETICAL FEASIBILITY PRINCIPLE

In order to have hailstones and artificial probes designed with the same fluid-dynamics properties, it is fundamental that they have the same terminal velocity:

\[ V_{\text{hail}} = V_{\text{probe}} \]

The general expression of terminal velocity is:

\[ V_{t} = \frac{2mg}{\rho V A g} \]

- \( m \) is the mass of the object;
- \( g \) is the acceleration due to the gravity;
- \( \rho \) is the density of the fluid through which the object is falling;
- \( V \) is the velocity of the fluid;
- \( A \) is the projected contact surface of the object;
- \( C_{d} \) is the drag coefficient.

Therefore:

\[ \frac{2m_{\text{hail}}}{\rho \pi V A_{\text{hail}}} = \frac{2m_{\text{probe}}}{\rho \pi V A_{\text{probe}}} \]

After some simplifications in the formulas, the probe must satisfy the following equation which are the basic point for their design.

\[ R_{\text{probe}} = R_{\text{hail}} \]

Carefully design probes by properly modifying these 3 quantities in order to keep the probes with similar fluid dynamic behaviour to hailstones.

PROBE REQUIREMENTS

CONCEPT

- Falling probes with the same fluid-dynamic behavior of hailstones;
- Disposible probes dropped by a plane or a UAV (Unmanned Aerial Vehicle) flying above or inside the clouds.

PROBE DESIGN REQUIREMENTS

- Light weight;
- Low power consumption;
- Work in harsh environment;
- Sensors to measure environmental parameters (humidity, temperature and pressure variations);

While they are falling to the ground, they acquire data and send them to the receiver;

- The receiver on the ground stores information for post processing operations and analysis.

PROBE FUNCTIONAL SPECIFICATIONS

- Ray of the probes (spherical): 35 mm
- Weight: 10-15 g
- Outer shell: Luminous resin or HDPE (High Density Polyethylene Molecular)
- Terminal velocity on the ground: 36-45 m/s
- Time to fall on the ground from 1000 m: 13-20 minutes
- Sensor Voltage: 3 V
- Probe mass power consumption: 100 mA
- Sensors: Tridimensional accelerometer, temperature, pressure, humidity
- Sampling period of the sensors:
  - Temperature: 2 s
  - Pressure: 2 s
  - Humidity: 2 s
  - Tridimensional accelerometer: 0.1 s
- It is simply possible to estimate a variation of 1 °C every 100 m of variation in altitude due to free fall; it is necessary that the temperature sensor has a sampling period of at least 0.1 s. A more detailed model can be estimated with 0.05 s
- Due to the gravity acceleration, the terminal speed \( V_{t} \) of 45 m/s is reached in a time equal to \( t_{\text{hail}} \) of 0.6 s. Therefore, in order to avoid the changes in acceleration going from ground to receiver, the accelerometer needs a sampling period of 0.1 s

Transmission frequency:
- 350 MHz – 613 MHz
- (according also to RFD and DASHT system local or international normative)

Probe IS transceiver:
- Transmitted power:
  - Sensitivity:
    - Up: 30 dBm
    - Down: 70 dBm
- Ground receiver IS transceiver:
  - Transmitted power:
    - Sensitivity:
      - Up: 30 dBm
      - Down: 110 dBm
- It is necessary for the probe modulation to be used to ensure the power link between and to design the probe-antenna

Modulation scheme:
- GFSK (with CRC for error protection)

Transmission speed:
- 4800 bps

Sensing technique:
- Polling

HAIL CHARACTERISTICS

<table>
<thead>
<tr>
<th>Altitude (m)</th>
<th>Diameter (mm)</th>
<th>Surface (m²)</th>
<th>Volume (m³)</th>
<th>Mass (g)</th>
<th>Terminal Velocity (m/s)</th>
<th>Theoretical Terminal Velocity (km/h)</th>
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<td>-330</td>
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</table>

FUTURE WORKS AND OPEN PROBLEMS

- Feasibility analysis for the modification of probe surface by introducing some protrusion, in order to increase the contact surface with the air or change the probes' shape.
- Software simulations of the probes behavior.
- Detailed studies of how the probes can be deployed, considering the ability to know a priori and forecast where such a hailstorm is going to occur, how much advanced notice would be needed to deploy them (e.g. to take off in time the UAV or the small plane), safety aspects.
- To increase the biodegradability of the probes.
- To evaluate the use of graphene and other biodegradable materials in some parts of the probes.

REFERENCES