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

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## INTRODUCTION

Detailed studies and researches about hail characterization 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 Physic 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.

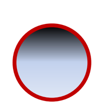
The artificial probes can be dropped by a plane, or potentially by a UAV (Unmanned Aircraft Vehicle) if permitted by specific legislation, which fly above and through the clouds where the hail formation occurs. Each probe is equipped with different sensors and during their falling to the ground, they 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*:

$$V_{hail} = V_{probe}$$



The general expression of *terminal velocity* is:

$$V_l = \sqrt[2]{\frac{2mg}{\rho S C_d}}$$

- *m is the mass of the object;*
- *g is the acceleration due to the gravity;*
- *ρ is the density of the fluid through which the object is falling;*
- *S is the projected contact surface of the object;*
- *$C_d$ is the drag coefficient.*

Therefore:

$$\sqrt[2]{\frac{2m_{hail}\, g}{\rho_{air} S_{hail} \Delta_{hail}}} = \sqrt[2]{\frac{2m_{probe}\, g}{\rho_{air} S_{probe} \Delta_{probe}}}$$

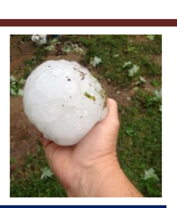
- *$\Delta_{hail}$ and $\Delta_{probe}$ contain all the effects that may affect the fall of the object;*
- *Spherical hailstones and probe are considered;*
- *The mass of both probe and hailstones are evaluated by knowing their densities;*
- *$\rho_{probe}$ is an equivalent density considering together both all the electronic equipment and the container.*

After some simplifications in the formulas, the probe must satisfy the following equation which are the basic point for their design.
($R_{probe}$ and $R_{hail}$ are the radius of the probe and hailstone)

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

$$\frac{R_{hail}\, \rho_{hail}}{\Delta_{hail}} = \frac{R_{probe}\, \rho_{probe_{eq}}}{\Delta_{probe}}$$

## HAIL CHARACTERISTICS



| Altitude [m] | Hailstone characteristics (density ρ=0.87 g/cm³) Diameter [mm] | Surface [m²] | Volume [m³] | Mass [g] | Theoretical Terminal Velocity [m/s] | Theoretical Terminal Velocity [km/h] |
|---|---|---|---|---|---|---|
| 10000 | 5 | 2.6e-5 | 6.5e-8 | 0.06 | 16 | ~58 |
| Ground | | | | | 9.3 | ~33 |
| 10000 | 10 | 1e-4 | 5e-6 | 0.4 | 21 | ~76 |
| Ground | | | | | 12.3 | ~45 |
| 10000 | 15 | 0.02 | 1.77e-3 | 1540 | 92 | ~330 |
| Ground | | | | | 54 | ~190 |

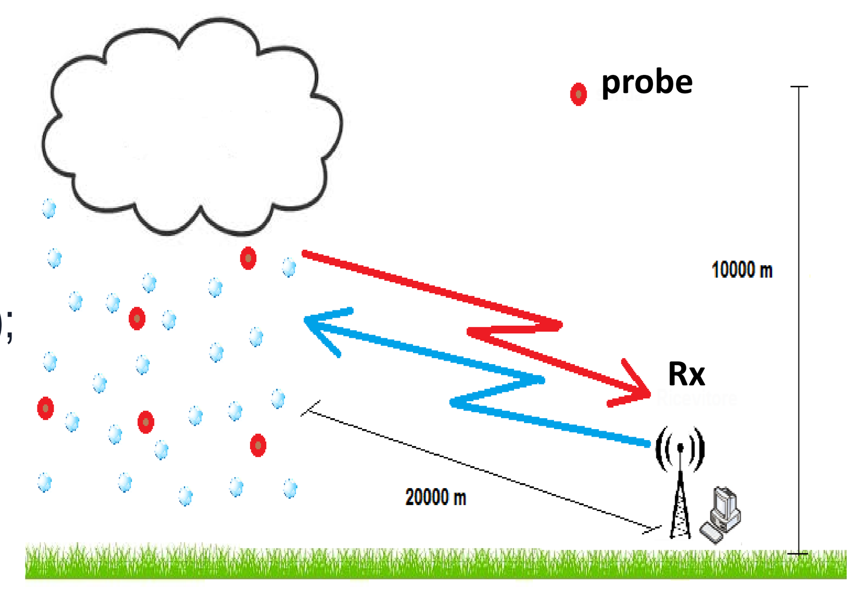
## PROBE REQUIREMENTS

### CONCEPT

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

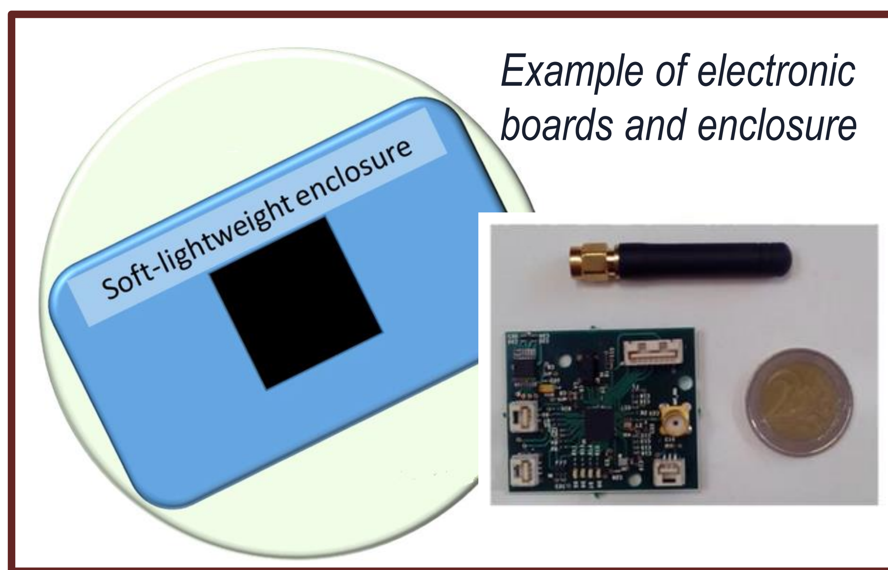
### PROBE DESIGN REQUIREMENTS

- Small size;
- 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.

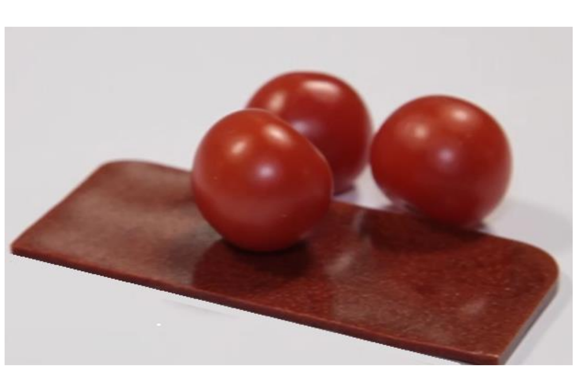



## PROBE FUNCTIONAL SPECIFICATIONS

| | |
|---|---|
| Ray of the probes (spherical) | 35 mm |
| Weight | 10-15 g |
| Outer shell | Laminate resin or HDPE (High Density Polyethylene Molecular) |
| Terminal velocity on the ground | 36-45 km/h |
| Time to fall on the ground from 10000 m | 13-20 minutes |
| Sensors Voltage | 3 V |
| Probe mean power consumption | 100 mA |
| Sensors | Triaxial accelerometer, temperature, pressure, humidity |
| Sampling period of the sensors. | |
| - Temperature: | 2 s (1) |
| - Pressure: | 2 s |
| - Humidity | 2 s |
| - Triaxial accelerometer | 0.1 s (2)<br>(1) it is roughly possible to estimate a variation of 1 °C every 100 m of variation in altitude in free air, it is necessary that the temperature sensor has a sampling period of at least of 10 s. A more redefined sample can be achieved with 2 s.<br>(2) Due to the gravity acceleration, the terminal speed $V_{hail}$= 45 km/h is reached in a time equal to $T_{Vhail}$=1.22 s. Therefore, in order to detect the changes in acceleration with good accuracy, the accelerometer needs a sampling period of 0.1 s. |
| Transmission frequency | 350 MHz – 433 MHz (according also to RFID and DASH7 system local or international normative) |
| Probe RF transceiver | |
| Transmitted power | - 30 dBm |
| Sensitivity | - 70 dBm |
| Ground receiver RF transceiver (3) | |
| Transmitted power | 30 dBm |
| Sensitivity | -130 dBm<br>(3) Not necessary for probe realization but it is needed to evaluate the power link budget and to design the probe transceiver |
| Modulation scheme | GFSK (with CRC for error protection) |
| Transmission speed | 4800 baud |
| Inquiring technique | Polling |




*Example of electronic boards and enclosure*



*Example of bio-rubber. A biodegradable material developed by IIT (Istituto Italiano di Tecnologia). It can be used for the outer shell.*

## 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

- S. Bertoldo et. al., *Hail sensing probes: feasibility analysis for probes to monitor and study hail*, Advances in Remote Sensing, Vol. 5, No. 1, 2016, pp. 43-50
- S. Bertoldo et. al. *Disposable falling sensors to monitor atmospheric parameters*,, Proceedings SPIE 10001, Remote Sensing of Clouds and the Atmosphere XXI, 1000104, SPIE Remote Sensing 2016, Edinburgh (SCO), 26-29/09/2016.