ILASS 2008
Sep. 8-10, 2008, Como Lake, Italy

Paper ID ILASS08-10-6

# ANALYSIS' OF IWT SPRAY FOR SUPER COOLED DROPLETS GENERATIONS

A. Amoresano *, C. Allouis °, B. Esposito *

* Department of Mechanical Engineering Naples University "Federico II", Via Claudio 21
° CNR-IRC Combustion Research Institute, Naples, Via Claudio 21
*CIRA Italian Aerospace Research Centre, Via Maiorise Capua (CE)1

**ABSTRACT**

The icing, or the formation of ice on the airfoil of an aircraft, is a complex phenomenon which contribute many factor. When an aircraft passes through a cloud of supercooled droplets, the impact destroys the metastabile equilibrium, emphasizing the freezing and the collecting of ice on aircraft components. The ice, collecting in various shape on the airfoils, reduces the aerodynamic efficiency. There are many factor which affect the icing like the liquid water content (LWC), the diameter of the droplets, the temperature of the air and, very important, the operational condition of the aircraft. The icing wind tunnels with suitable aerodynamic flow and icing cloud characteristics are used to support on-ground the aircraft icing certification process. The water droplet spectrum and the liquid water content required for the test conditions are injecting in the tunnel by means of an array of spray nozzles.In this paper air supplied nozzles are characterised by use of PDA system to evaluate (MVD), the droplets spectrum velocity and other parameters to verify the behaviour and envelope of a spray nozzle with the internal mix considered in this study for each value of ΔP ($P_{air}$-$P_{water}$).

## 1 INTRODUCTION

A spray is generally considered as a system of drops immersed[1] in a gas continuous phase. Most practical atomizers generate drops in the size range from a few micrometers up to around 500 µm. Owing to the heterogeneous nature of the atomization process, the threads and the ligaments formed by the various mechanisms of jet and sheet disintegration vary widely in diameter, and the resulting main drops and satellite drops vary in size correspondingly. Practical atomizers[2] do not produce sprays of uniform drop size at any given operating condition; instead, the spray can be regarded as a spectrum of drop sizes distributed about some arbitrarily defined mean value . In addition to mean drop size, another important parameter of importance in the definition of a spray is the distribution of drop sizes it contains. A simple method of illustrating the distribution of drop sizes in a spray is to plot a histogram where each ordinate represents the number of droplets whose dimensions fall between the limits D-ΔD/2 and D+ΔD/2. As the drop size bin width (ΔD) is made smaller, the histogram assumes the form of a frequency distribution curve. Because the graphical representation of droplet size distribution is laborious and not easily related to experimental results, many workers have used to replace it with mathematical expressions and their parameters can be obtained from a limited number of drop size measurements. The most widely used expression for drop size distribution is Rosin - Rammler, it may be expressed in the form

$$1-Q = \exp[-(D/X)^q] \quad (1)$$

Where Q is the fraction of the total volume contained in of diameter drops less than D, and X and q are constants that are determined experimentally; the exponent q provides a measure of the spread of drop size. The higher the value of q, the more uniform the spray. If q is infinite, the drops in the spray are all the same size. For most practical sprays the value of q is between 1.8 and 3.0. In this paper the study of spray that can generate droplets able to reproduce, in freeze environment, cloud conditions and in particular to generate supercooled droplets is carry out.The clouds can have infinite shapes and dimensions. Their classification is based on:
Difference of quota in their vertical development
Ratio between horizontal and vertical dimension For convenience it has been established to vertically subdivide the part of the atmosphere in which clouds they are introduced habitually, in the regions, with reference to the zones moderated of the medium latitudes Region from 5 to 13 km; Region from 2 to 7 km; Region from .5km to 2 km. This

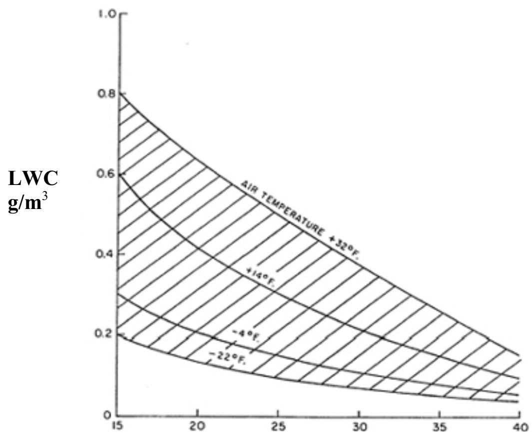


Fig.1 Mass effective droplet diameter horizontal extension 17.4 Nautical Miles

kind of division depends on the latitude like shown in the following table

| | Polar regions | Medium latitude | Tropical regions |
|---|---|---|---|
| High clouds | 3-4 | 5-13 | 6-18 |
| Medium clouds | 2-4 | 2-7 | 2-8 |
| Low clouds | 0-2 | 0-2 | 0-2 |

There are two types of clouds that can make to grow ice on an aircraft: the stratiform clouds and the cumuliform clouds. In stratiform clouds the ice conditions are less strict than those present ones in cumuliform clouds. The content of water varies from 0.1 to 0.8 g/m$^3$ and the diameter of the water droplets form 5 to 50 µm. In cumuliform clouds, the air contains a great amount of water drops. The water concentration varies from 0.1 to 3.0 g/m$^3$and in some occasion it can catch up 3.9 g/m$^3$ for shorter cloud horizontal extent (0.26 Nautical Miles). The exposures of the aircrafts to this type of cloud, can be much dangerous also for short periods

The characterization of clouds comes carried out on the base of the data experiences collected them from the FAA on the base of Medium Volume Diameter (MVD),

Liquid Water Content (LWC), and Cloud extension

From the experimental reliefs done inside the clouds the diameter of the water drops assume values between the 15 and the 50. During the last few years it has been observed that, in particular atmospheric conditions can exist also clouds constituted from having water drops diameters much greater regarding those of the norms of certification FAR25 C appendix, consequently, characterized from values of the MVD more elevates

(2000 µm ). Such conditions are indicated like "Super cooled Large Droplets" SLD.

For the certification of the aircrafts to the flight in ice conditions, the FAA uses two envelopes standards, defined as continuous maximum and intermittent maximum cloud envelopes, that they represent a combination of weather ice conditions that can have effects denied on the flight. The figures 1 and 2 show the distribution of LWC like one function of the diameter of the drops to different temperatures of the air.

## 2 SPECIFIC OBJECTIVES

The challenge to be deal is to create inside a confined space the environment that is in the inner of ~~a~~ an icing cloud. If we look a cloud form the land we note that its development is upwards so the horizontal directions are frequently greater than the size of the entire icing object (Cober *et al.,* 2001; Jeck, 1996), whereas during experimental modeling in a wind tunnel the same factors are of the same order of magnitude. Thus, the question of the uniformity of an artificial icing cloud arises, and is directly related to the problem of the successful generation and measurement of clouds' attributes in the wind tunnel (B, M. Esposito, et al., 2007). The Icing Wind Tunnel considered is the largest and most advanced facility in the world that allows you to perform tests to type aerodynamic than in ice.

The IWT is a wind tunnel closed circuit that allows you to play on the ground, in an environment completely safe, controlled and repeatable, the real flight conditions inside a cloud The IWT [11]considered in this work allows the simulation of all key parameters of flight cloud as:

- the speed equivalent to a Mach between 0.25 and 0.7,
- the share in a range between 0 and 7000 m,
- the temperature between -40 ° C and +35 ° C,

ability to control humidity in a range that depending on conditions can vary between 70% RH and 100% RH.

The system bars spraying of 'IWT is capable of generating droplets of water with diameters (MVD) and density of water in the cloud (LWC) comply with the regulations described by Appendix C of FAR 25/29 to flight conditions in clouds. The system of bars is positioned in the chamber of stagnation 18 meters from the centre of the test chamber. Upstream of SBS, there is a grid honeycomb, capable of breaking down the component of turbulence, directing the flow perpendicular to it. The system is composed of 20 bars having a low profile aerodynamic drag and each of which is removable and adjustable vertically to make uniform the cloud undergoing characterization. Each bar is equipped with 50 nozzles, for a total of 1000 possible points of injection. The nozzles can open and close remotely and the configuration can change instantly so it is possible to achieve considerable uniformity

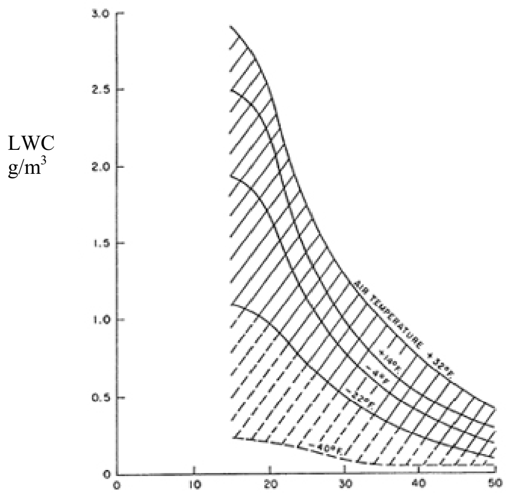
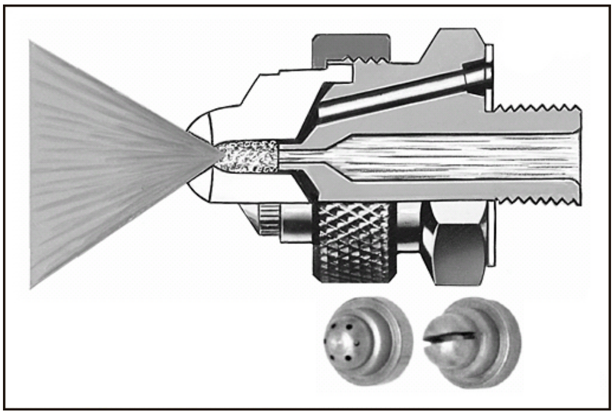



Fig.2 Mass effective droplet diameter horizontal extension 20 miles

in the LWC field of an experimentally modeled icing cloud. In this way the dimensions of zone of uniformity of the icing clouds are close to the conditions of the natural clouds. The LWC prevailing under icing conditions in most of the clouds is in the range of 0.1 ; however, values more than one order of magnitude greater than the average were also reported (AFGL, 1985; Cober *et al.*, 2001; Jeck, 1996; Jeck, 2002; Mazin *et al.*, 2001). A further distinction between both types of icing cloud lies in the significantly different features of the air turbulence involved: the intensity and the spatial scale of turbulence in a wind tunnel is consistently different than that recorded under natural conditions (Gonsalez *et al.*, 2001; List *et al.*, 1987; Oleskiw *et al.*, 2001; Poinsatte, 1990). In the atmospheric boundary layer, the sources of turbulence are buoyancy and wind shear, while in an experimental environment, the free stream turbulence produced by the tunnel configuration may be enhanced by the air jet used for atomizing the water in the nozzles and by the presence of nozzle-bearing spray-bars (Marek and Olsen Jr., 1986).

The DSD of a air assisted atomizer, under specific combinations of parameters, contains a significantly higher concentration of larger droplets (over 40 µm in diameter) whose trajectories are influenced to a considerable extent by gravity. Furthermore, in the modeling of low air speeds below 20 m/s (in our case 3/5 m/s), which is often prevailing during atmospheric icing processes (Jeck, 1996), gravity affects even droplets of medium diameters (around 30-40 µm). In the case of the characterization of our spray with the axis facing down. This gravitational effect creates difficulties in the normal modeling of icing clouds with a DSD containing large droplets in horizontal icing wind tunnels at low air speeds, since it would produce droplet separation according to diameter. The problem is to study the DSD at the end of the spray and analyze the droplet distribution at the end of the jet where the radial velocity close to 0 and the gravitational effect are predominant respect the kinetic energy.
The main objective of this paper is to reveal the effect of ΔP



($P_{air}$-$P_{water}$) on the DSD of a air assisted spray .
The aim of the characterization is to verify if the spray analyzed inserted in the matrix of the spray bar can simulate cloud in the test section of the tunnel. It is important to remember that simulation of a cloud is determined by the following groups of parameters: (Kollar et al.) thermodynamic and dynamic parameters maintained inside

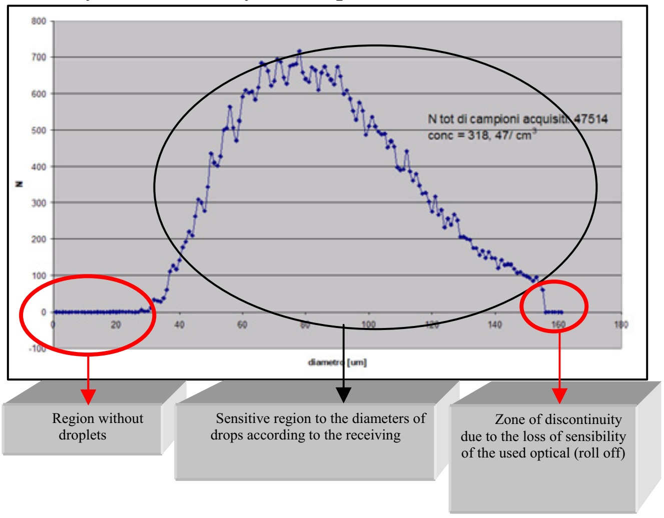



Fig. 4 Diameter distributions

the tunnel, including air speed, air temperature, relative humidity of air, DSD, and level of turbulence in the air flow; characteristics of the tunnel configuration and spray-bar construction specifics, which involve distance from the spray-bar to the location of the icing body, average number of nozzles on one spray bar, number of spray-bars, lateral and vertical spacing of nozzles, contraction ratios in the horizontal and vertical planes, uniformity of air flow over the spray bar in the horizontal and vertical planes, and flow angularity; (3) properties of the nozzles used for the modeling, such as nozzle type and geometry; and, (4) which are the water flow rate, the pressure in the air line[3], and the pressure in the water line, or the differential pressure, i.e. the difference between the pressures in the water and air lines.
This paper gives a first answer to points 3 and 4

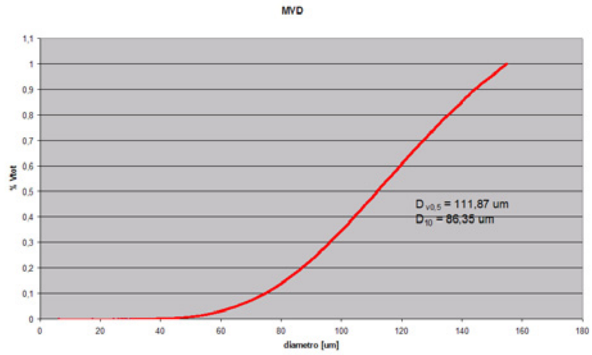



Fig 7

## 3 EXPERIMENTAL SETUP

The system of characterization of the spray is an Anemometer Phase Doppler Dantec constituted from an elettro-acoustic cell laser Ionian of Argon of power in equal

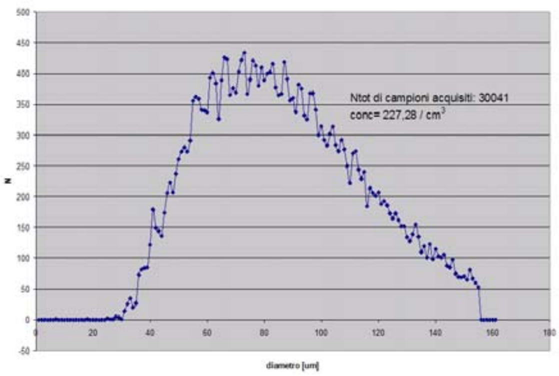
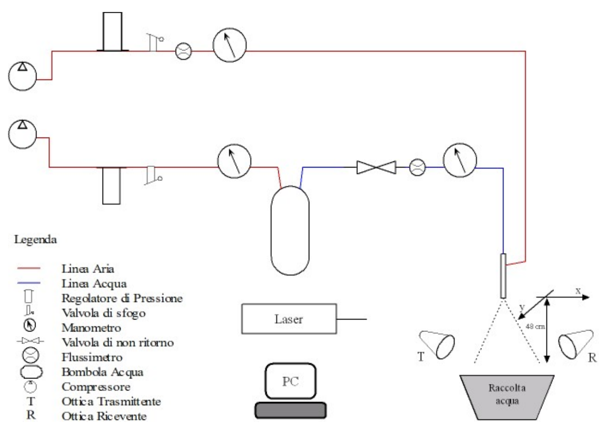



Fig. 6 Diameter distribution for the difference $P_{air}$-$P_{water}$ reported in grid

multiline to 2W and one of Bragg used for one “shift” in 40 equal frequency to MHz. The dimensions of the drops have been determined using mark them deriving from the modality of scattering of refraction[3][4][5][6][7][8][9] of the first order. The light has been polarized in direction parallel to the spread plan and, in order to reduce the reflection effects, it has been adopted an angle of spread of 70°. It marks them Doppler in escape from the receiving probe are transmitted by



means of fiber optics to the unit of acquisition (Dantec Fiber PDA 58N70 Detector Unit)

The nozzle under investigation is a Internal Mixing Two-Fluid Atomizer, assisted to air (fig 3) and fed from water. The air enters with an angle of 30°, filling up the external part of the culvert of feeding of the water and, by means the holes on the lateral surface of the nozzle, pressurizes it is constituted from two lines of feeding, that one of the air and that one of the water (sees outline). From two compressors leave two separated compressed air lines, to avoid strong pressures losses and instability behaviour, One line supply directly the nozzle. On this first line of compressed air, between the compressor and the nozzle, a vent valve and a gauge a pressure regulator (sensibility 0.1 bars) are situated. The second compressed air line serves in order to pressurize the water of feeding of the nozzle; it finishes in a tank in which the demineralised water is contained. This type of setup comes adopted in how much is easier regular the pressure of compressible means that then in its turn act as from piston for the putting in pressure of the water. Between

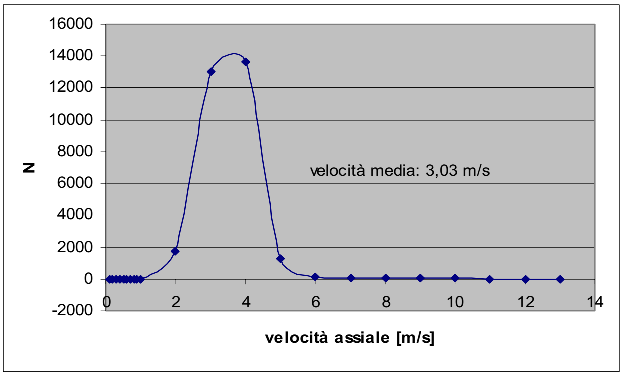



Fig 8 Axial velocity

the compressor and the bottle 0.1 bars are situated a pressure regulator (sensibility), one vent valve and one gauge (sensibility 0.1 bars) for the reading of the pressure of the air. From the bottle the line of the pressurized water to supply the nozzle.

| | $p_{aria}$ *[bar]* | $p_{acqua}$ *[bar]* | $D_{10}$ *[μm]* | $D_{v0,5}$ *[μm]* | ***Medium axial velocity [m/s]*** | ***Medium redial velocity[m/s]*** |
|---|---|---|---|---|---|---|
| **Δp = -0,1 bar** | 0,2 | 0,3 | 86,35 | 111,87 | 3,03 | -0,08 |
| | 0,3 | 0,4 | 72,47 | 102,87 | 3,1 | -0,03 |
| | 0,4 | 0,5 | 82,9 | 104,47 | 4,44 | -0,11 |
| | 0,5 | 0,6 | 55,95 | 82,23 | 5,069 | -0,14 |

## 4 RESULTS AND DISCUSSION

The carried out measures aim to emphasize the different distributions of axial and radial speed, let alone of dimensions of the drops to varying of the air and water pressures in the nozzle. The tests come carried out standardizing the measures to the difference of pressure ($\Delta p = p_{air} - p_{water}$).

To characterize the behaviour of the nozzle it has been supplied with different Δp ($p_{air} < p_{water}$). The pressure of the air has been made vary from 0,2 to 0,5 bars and that one of the water from 0,3 to 0,8 bars, in such way to have Δp that varies from a minimum of -0,5 bar to a maximum of -0,1 bar. For each value of couple of pressures air-water the characterizing data, distribution of the diameters, distribution of axial speed, distribution of radial speed and the medium volumetric diameter (MVD) are carried out.

The regions highlighted in the diagram of fig. 4 are found again on the diagram in fig 5 that describes to the composition of the volume total of the champion of drops analyzed. From this diagram the value of the volumetric medium diameter is gained. It is equal to the diameter correspondent to 50% of the volume total. Of particular relief it is the discontinuity or zone roll-off of diameters due to the loss of sensibility of the instrument for advanced diameters to 160 μm. Such discontinuity is found from the completion of the diagram in the region does not dictate roll-off. In this region the diagram would have to be completed, in the event in which the entire field of diameters he was appreciable, with a horizontal asymptote to the value of the equal formers to 1. The grid of measurement for a specific set-up has been reported in the following table.

For this specific setup fig.6 shows the diameter distribution and fig. 7 the MVD value.

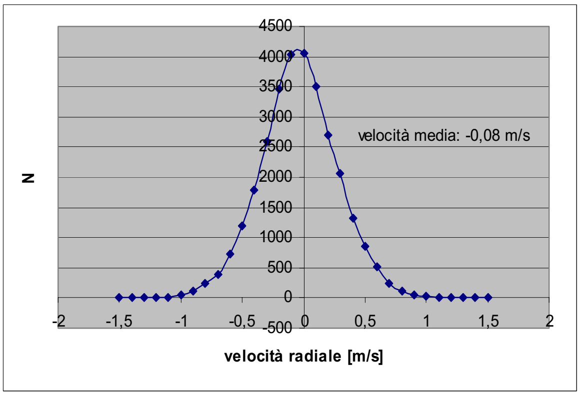



Fig 9 Radial velocity

The speed profiles, but in general terms all the measures have been carried out to approximately 480 millimeter of distance from the nozzle zone in which the greater drops are recovered that have greater probabilities of coalescence in the operation of spray in array configuration.

## 5 CONCLUSIONS

The great difficulty is understood to reproduce in confined atmosphere that that happens naturally in immeasurable spaces.

The analysis of the spray object of the tests begins from the dynamic behaviour and the determination[14] of the distribution of drops comprised in an interval between 1 and 150 μm The distributions of the diameters

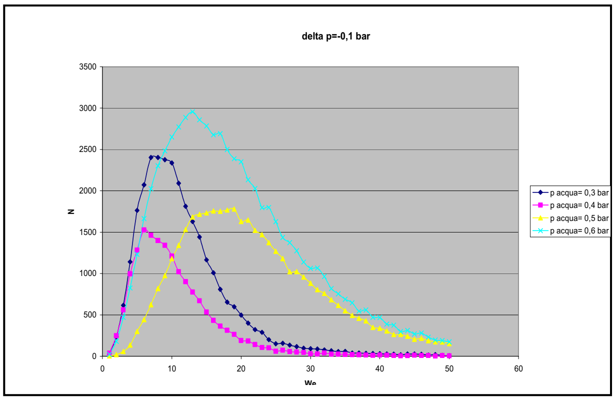



Fig.10 Weber number of the droplets for Δp =0,1 bar evaluated for each value of $p_{water}$

of particles are introduced rather wide, sign than one chaotic modality of breach of the imputable liquid jet to the same nature of the nozzle atomizer. Observing the diagrams one looks at that the distributions of the radial speed are centred on values that are close to the zero; that means that, as it attended to us, the motion of particles is developed in axial direction. And' possible to observe, moreover, then, in absolute value, the radial average speeds grow (and therefore are far from value zero) to growing of the pressure of the water; such phenomenon can be explained admitting an increment of the chaotic character of the motion of the drops to growing, exactly, of the pressure of the water. Also for that it concerns the axial average speeds, an increment of the same ones to growing of the pressure of the water is observed. Having information on the diameters and the particle speeds, it is possible to recover informations calculating for each one the Weber number. Of continuation such diagrams to the

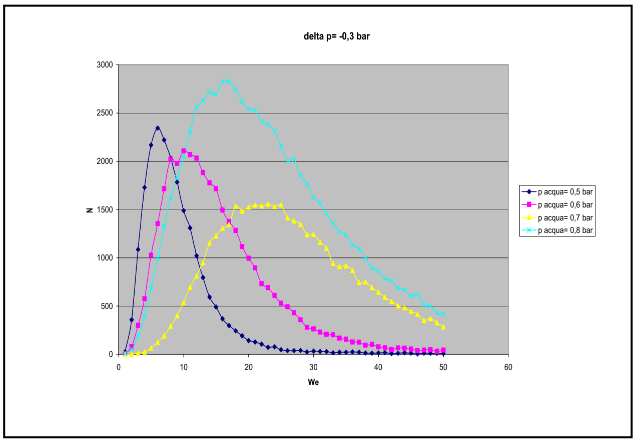



Fig.11 Weber number of the droplets for $\Delta p$ =0,3 bar evaluated for each value of $p_{water}$

hardly specified range are brought back limitedly, subdivided in four groups, many how many are the pressure delta analyze to you. From they one difference of width of the distribution: to growing of the pressure of the water, independently from the $\Delta p$, the distribution of the numbers of Weber, in fact, it is introduced wider. Observing the relative diagrams in Fig 10 and 11 one looks at that the greater part of particles has a number of Weber comprised between 0 and 50.

From the diagrams of the distributions of the diameters

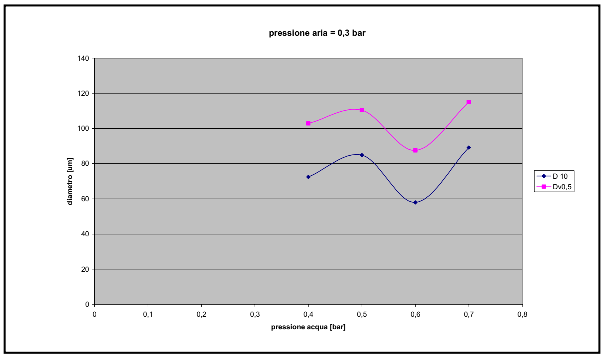



Fig.12 Course of distribution D10 and Dv0.5 varying water pressure for $p_{air}$ constant =0,3 bar

and the speeds, and of the numbers of Weber, it is understood that the parameter that characterizes the fluid dynamic of the jet is not the single $\Delta p$, but the value of the single pressures of the feeding fluid (air and water). In the light of such observation, filler to the successive page a table that reassumes the made measures and the main ones is turned out obtained not already to you organizing them based on the differences of set up pressure air-water, but to varying of the pressure of one of the fluid (in the specific water), having set up the pressure of the other fluid (air).

The figure 12 put in evidence that the diameters distribution of droplets is not linear varying the water pressure for $p_{air}$ constant. To better understand the behaviour of the diameters distribution inside a air assisted spray in order to simulate cloud conditions it will be necessary to extend the measures to the diameters until 1 mm form varying the PDA optical and for much value of $\Delta p$.

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