The experimental investigation of water spray disperse parameters behind the water injecting system at the aircraft engine inlet by applying PSV

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Abstract. To provide an aircraft engine certification tests for water ingestion, it is necessary to control accurately the parameters of the water drops generated by the water injecting device simulating rain at the engine inlet. The paper presents the results of autonomous tests of a single-channel centrifugal nozzle for the water injecting device. The tests purpose is to investigate the disperse parameters of the water spray for the typical operation modes of the nozzle as a part of the water injecting system. Tests were carried out at the experimental setup using the PSV (Particle Shadow Velocimetry) technique at three typical nozzle operation modes. As a result of the tests, the distribution graphs of the $D_{10}$, $D_{32}$ and $D_{50}$ diameters, axial velocity ($U$) and mass flow ($M_{ab}$) of water droplets over the radius of the spray pattern have been obtained. To assess $D_{50}$ mean median diameter of spray droplets the cumulative distribution functions of the droplets mass fraction depending on the size for each of the operation modes of the nozzle have been plotted. On the basis of these functions, the mean median diameters of water spray droplets have been calculated.

1. Introduction
According to the requirements of IAC normative documents [1] it has to be demonstrated that the engine is capable of ingesting simulated rainfall without suffering operating problems. The engine acceptable operation does not allow for flameout, stoppage, prolonged surging or stall. After ingestion the absence of unacceptable mechanical damage, power loss or other adverse effects have to be demonstrated.

To provide an aircraft engine certification tests for water ingestion, it is necessary to control accurately the parameters of the water drops generated by the water injecting device simulating rain at the engine inlet. The autonomous tests of a single-channel centrifugal nozzle for the water injecting device have to be carried out using the PSV technique. The tests purpose is to investigate the disperse parameters of the water spray for the typical operation modes of the nozzle as a part of the water injecting system.
2. Operating principle of the PSV technique
The PSV (Particle Shadow Velocimetry) technique is used to visualize particles (e.g. droplets from a spray or bubbles in liquid). The technique is based on high resolution imaging with pulsed backlight illumination (see figure 1). The measurement volume is defined by the focal plane and the depth of field of the imaging system. This technique is independent of the shape and material (either transparent or opaque) of the particles and allows to investigate sizes down to 7 µm using an appropriate imaging system and light source. A double-pulse laser combined with a double-frame camera allows to investigate size dependent velocities. This technique provides information like size distribution, shape and velocity of particles.

![Figure 1. The PSV hardware setup.](image)

The double-pulse laser is located in front of the camera lens. The light from the laser passes through the diffuser and is directed to the area of interest. After the light has passed through the area, its image enters the microscope, and then the magnified image enters the camera matrix and is transmitted to the computer. Using a specialized software, the measurement of particle sizes and their velocities is performed.

For PSV measurements of the characteristics of the spray pattern formed behind the nozzle the optical scheme adjustment and depth of field calibration for the droplet size range from 20 to 1500 µm was performed. The size of the measuring volume after the adjustment is 6.1×4.6×11 mm.

3. Experiment and results
The autonomous tests of a single-channel centrifugal nozzle for the water injecting device have been carried out using the PSV technique. The scheme of the experimental setup is shown in figure 2.

![Figure 2. The experimental setup.](image)
The measurements have been carried out in cross section along the spray pattern radius, from the axis of the spray jet \((R = 0)\) to the distance \(R = 170 \text{ mm}\) in increments of 10 mm. In each measurement point 300 images have been shot. Measurements of the spray characteristics have been carried out at a distance of 300 mm from the nozzle at three typical nozzle operation modes:

- \(\Delta P_w = 250 \text{ kPa}, G_w = 0.162 \text{ l/s}\);
- \(\Delta P_w = 390 \text{ kPa}, G_w = 0.203 \text{ l/s}\);
- \(\Delta P_w = 700 \text{ kPa}, G_w = 0.263 \text{ l/s}\).

The nozzle flow characteristics \((G_w, \text{l/s})\) were measured using Krohne mass flow meters. The differential pressure of the water supply \((\Delta P_w, \text{kPa})\) was measured by sensors ADZ-SML-25.

The photos of the water torch pattern are shown in figure 3. The shadow images with derived diameters and velocities at the distance \(R = 170 \text{ mm}\) from the spray jet axis are shown in figure 4.

**Figure 3.** The water torch patterns at operation modes: (a) \(\Delta P_w = 250 \text{ kPa}, G_w = 0.162 \text{ l/s}\); (b) \(\Delta P_w = 390 \text{ kPa}, G_w = 0.203 \text{ l/s}\); (c) \(\Delta P_w = 700 \text{ kPa}, G_w = 0.263 \text{ l/s}\).

**Figure 4.** The shadow images with derived diameters and velocities at operation modes: (a) \(\Delta P_w = 250 \text{ kPa}, G_w = 0.162 \text{ l/s}\); (b) \(\Delta P_w = 390 \text{ kPa}, G_w = 0.203 \text{ l/s}\); (c) \(\Delta P_w = 700 \text{ kPa}, G_w = 0.263 \text{ l/s}\).
As a result of the tests, the distribution graphs of the $D_{10}$ (arithmetic average of the particle diameter), $D_{32}$ (Sauter mean diameter) and $D_{50}$ (mean median diameter), axial velocity ($U$) and mass flow ($M_{abs}$) of water droplets over the radius of the spray pattern have been obtained. These graphs are shown in figures 5 and 6 below.
Figure 5. The distribution graphs of the $D_{10}$ (a), $D_{32}$ (b) and $D_{V_{50}}$ (c) diameters of water droplets over the radius of the spray pattern.
Figure 6. The distribution graphs of the axial velocity $U$ (a) and mass flow $M_{\text{abs}}$ (b) of water droplets over the radius of the spray pattern.

The figure 6 (b) shows that major part of the water is distributed in the cross section of the spray torch along the ring at the radii of 100 and 130 mm. The diameter of the spray torch in the measurement plane is 340 mm.

To estimate the mean median $D_{v50}$ diameter of water droplets in the spray torch cumulative functions of the droplet mass fraction distribution were constructed depending on the size for each of the nozzle operation modes (figure 7). On the basis of these functions, the mean median diameters of water droplets in the spray torch are calculated, the calculation results are presented in table 1.

Figure 7. The cumulative functions of the droplet mass fraction distribution.
Table 1. Mean median diameters of water droplets in the spray torch.

| Operation mode number | ∆Pw, kPa | Gw, l/s | Mean median diameter, mkm |
|-----------------------|----------|--------|--------------------------|
| 1                     | 250      | 0.162  | 380                      |
| 2                     | 390      | 0.203  | 360                      |
| 3                     | 700      | 0.263  | 270                      |

The results obtained in the study allow to choose optimal operating mode and the location of the nozzles in the water injecting device to ensure the required distribution and mean median diameter of the droplets in the stream.

References
[1] Aviation regulations 2018 *Airworthiness standards for aircraft engines* part 33 IAC