# MEASUREMENT OF AIR STREAM VELOCITY PROFILES, GENERATED BY FIRE PROTECTION UNITS MOBILE FANS

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**Abstract**

*Mobile positive pressure fans are an essential tool used during rescue operations during fires inside buildings. Due to the nature of the use of these devices, it is very important that the parameters that determine their effectiveness are properly selected and verified. One of the most important parameters determining their effectiveness is the volume flow rate of the air stream. In order to reliably evaluate the performance of fans, tests should be conducted on the basis of appropriately selected test methodologies. With regard to flow rate tests, it is important that the tests are conducted under conditions that reflect the actual use of mobile fans (open-flow tests). This paper presents the design, manufacturing, and functionality of an innovative stand for evaluating the velocity profile characteristics (and volume of the flow stream) of an air stream generated by mobile fans. The paper also presents the results of a fan that is commonly used during rescue operations. The results of the tests confirmed that the fan positioning parameters (i.e. the distance in front of the door opening and the inclination angle of the impeller) have a dominant influence on the stream flow rate, pumped into the ventilated cubature. Depending on the setup configuration of the fan unit, the discharge flow rate varied from 12087.6 $m^3$/h to 42269.3 $m^3$/h.*

**Keywords:** *PPV, Positive Pressure Ventilator, PPA, Positive Pressure Attack, rescue equipment, fan velocity profile, fire tests*

## 1. INTRODUCTION

Mobile positive pressure fans used by fire protection units are an important tool used during rescue and firefighting operations. These devices can be used to perform the following activities [1]:

- positive pressure ventilation (PPV) – a technique whereby air is forced through the inlet opening of a structure using a mobile fan positioned in front of the inlet opening;
- negative pressure ventilation – a technique that involves forcing air through the outlet opening of a structure using a mobile fan positioned on the surface of the outlet opening,
- positive pressure attack (PPA) – operation consisting in ventilation of the rooms in a building on fire with simultaneous administration of water currents by the crew starting the rescue operation,
- assisting in the suppression of fires in free-standing structures, e.g. waste containers or motor vehicles,
- delivering a portion of fresh air to hard-to-reach areas where people are trapped.

Due to the nature of the use of this type of equipment (work in a dangerous fire environment to save people and property), it is very important that the parameters determining their performance are properly verified. The most important technical and operational features that determine the efficiency of mobile fans include: aerodynamic efficiency (volumetric flow rate), air jet shape (area of effective jet distribution as a function of distance) and, moreover, noise, operating time, mass and geometric dimensions of the device [4]. Currently, many researchers are conducting numerous research works related to the efficiency of mobile fans. Lougheed [5] tested different distances of fan positioning in front of the door opening (1.2 m; 1.8 m and 2.8 m).

During testing, he showed that the highest airflow rate was obtained when the fan was located at a distance of 1.2 m to the plane of the door. Pandire [6] performed a study related to evaluating the effect of the size of the inlet opening on PPV ventilation efficiency. In the study, he showed that the flow rate could be increased by installing a mobile smoke curtain in the upper area of the door frame. Studies of mobile fans using standardized stands are also present in the literature. In 2022 Kaczmarzyk et al. [7] evaluated the impact of the volumetric airflow measurement test methodology on the mechanical performance of the power unit. The obtained results confirmed that depending on the test method (tests in a pipe according to ISO 5801 [9] or in open flow according to ANSI/AMCA 240 [2]), the fan motor shows a difference in drive power demand of 3.2 to 4.5%. The indicated differences translate into fuel consumption and emissions of harmful exhaust gases generated by the combustion drive units (4 kW). In their publication Fritsche et al. [8] pointed out that the performance values (volumetric airflow) declared by the manufacturers may differ from the actual ones due to the lack of a standardized test methodology for testing mobile fans. In their work, Fritsche et al. presented a test stand and test methodology to measure the flow rate of PPV fans.

This study presents a prepared test stand for evaluating the characteristics of the velocity profile of airflow generated by the mobile fans. The article describes the functionality of the test device and representative results of the tests of velocity profile and volumetric flow rate of air stream, produced by the fan which is a tool commonly used during rescue operations.

## 2. TEST STAND

For the purpose of testing the technical and operating features of mobile fans, CNBOP-PIB specialists designed and constructed a test stand for evaluating the characteristics of air stream velocity profile generated by mobile fans. The stand allows to evaluate the velocity of the incoming air stream in three dimensions (length, height, width) as a function of distance, including the distribution of the volume straem in the open flow.

The manufactured test apparatus allows to perform measurements (in arbitrarily defined points) of the value of the velocity of the air stream generated by the mobile fan, which is positioned at a certain distance in front of the measuring plane of the test stand. The effective size of the measurement plane on which measurements can be performed is 2880 x 3070 mm (width × height). An unquestionable advantage of the stand is the fact that it allows taking into account geometrical parameters related to the positioning of the fan, i.e. setting distance or the angle of inclination of the impeller. The designed test stand consists of the following components:

1. The body of the test stand, enabling stable mounting and transport of the probe on the surface of the measurement plane, made of aluminium profiles with dimensions of 40x40 mm and wall thickness of 3 mm. The frame connections were developed using components made by 3D printing (FFF) and aluminum sheet,
2. Transporting device (allowing to move the probe along the measuring plane) made of perforated aluminum sheet of 3 mm thickness. The device is also equipped with rods, on which bearings and wheels are placed in order to enable the element to move along the guide. The indicated component is also equipped with a rotating prism socket that allows the sensor to be positioned at a selected distance and angle to adapt the probing conditions to the tested sample of a mobile fan,
3. A transport device (designed to transport the probe) is driven by two NEMA 23 bipolar stepper motors (supplied with a maximum current of 4.2 A, producing a holding torque of 2.8 Nm). An absolute encoder with a resolution of 2000 pulses per revolution is used to control the position of the transport element, resulting in a positioning accuracy of the measuring probe of 12 μm;
4. A measuring module, fixed to the surface of the transport element, in the form of a TSI thermoresistance anemometer type 8455 (with a measuring range from 0.127 – 50 m/s and an accuracy of about 1% of reading), whose voltage signal (0-10V) is read by an analogue-digital converter. The measured values from the AD converter are read via the I2C network using an

Arduino Nano Every microcontroller, which sends the data wirelessly to the main drive controller using a radio module;

5. Laser pointer for positioning the fan at the desired distance in front of the test stand.

A diagram of the test stand is shown in Fig. 1.

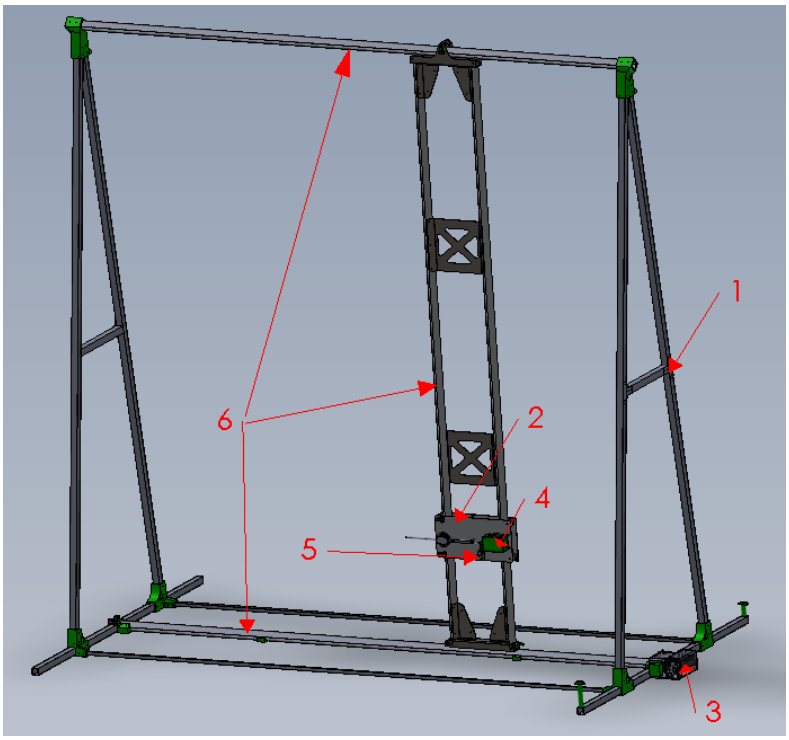



**Fig. 1.** A test stand for evaluating the characteristics of the velocity profile of airflow generated by mobile positive pressure fans. Key: 1 – frame of the test stand; 2 – probe carrier (carriage); 3 – drive (NEMA motors); 4 – radio measuring module; 5 – laser pointer; 6 – transport rails.

The test stand is controlled using a program written in C++ FrameWork Qt 5.4 that communicates with the controller and reads data using a USB interface. The program enables to design any research scenario, allowing to verify the value of jet speed generated by mobile fans for any number of selected measurement points. The test stand was designed and constructed in such a manner as to perform tests of the characteristics of the velocity profile of the air stream also taking into account obstacles present in the nominal conditions of the equipment operation, e.g. window or door openings. Thus, it is possible to estimate the value of air masses transported into the building and those that are lost by the presence of a fixed obstacle.

## 3. MATERIALS AND METHODS

To perform the tests, a test stand was used to evaluate the characteristics of the velocity profile generated by mobile positive pressure fans. In addition, a test configuration was developed, extended with an obstacle imitating a doorway with dimensions of 2.03x0.91 m [2], which in this case constituted the measurement plane of the airflow velocity profile. For the purpose of the test, 50 measurement points were selected, evenly distributed over the entire measurement area of the doorway. The determination of points was performed based on the requirements of ISO 5221 standard [3]. The location of the measurement points is shown in Fig. 2.

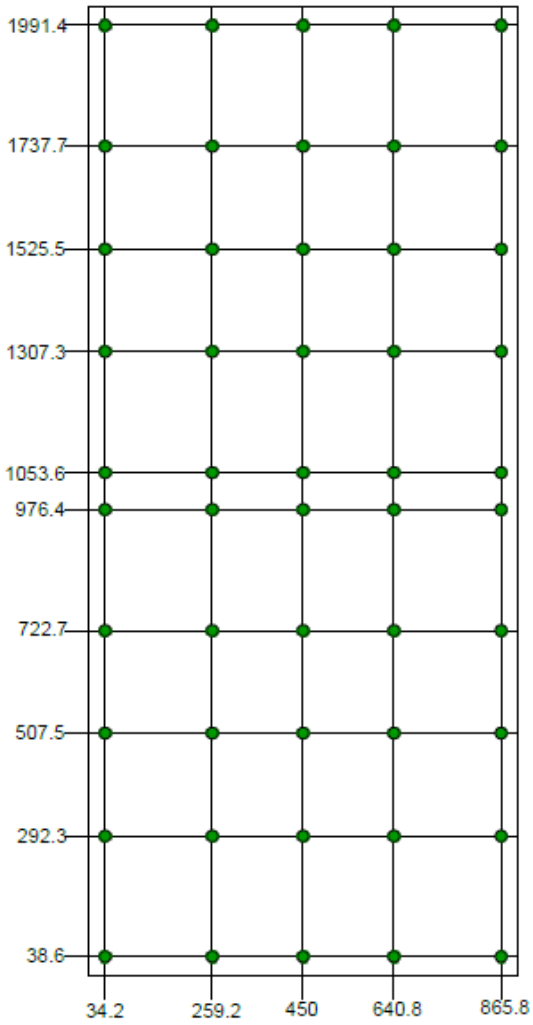



**Fig. 1.** Location of measurement points, determined according to ISO 5221 requirements, on the surface of the measurement plane of the door opening

The test program was planned so that at each point the acquisition frequency was 10 Hz and the measurement duration corresponded to a value of 30 s. During the test, the velocity profile of a mobile fan with the impeller surface facing the measurement plane of the doorway was evaluated for the variable distances of 1, 3, 4, 5, and 7 [m] and impeller angles of 0°, 5°, 11°, and 17°. In the course of the test, from the product of the average value of the airflow velocity generated by the fan and the surface of the door opening, the volumetric flow rate, coming to the surface of the door opening, was estimated.

$$Q\left[\frac{m^3}{h}\right] = Va\left[\frac{m}{s}\right] * 3600\,[s] * S[m^2]$$

Where:

Va – average value of the velocity of the air stream generated by the mobile fan [m/s];

S – measuring surface of the door opening (measuring plane) [$m^2$].

A turbofan, having a 7-blade impeller of 605 mm in diameter, driven by a Honda engine of 8.5 hp, was used for this test. The indicated fan is commonly used for rescue operations by fire protection units. Photo 1 shows a mobile fan during testing on a test stand with a present doorway obstacle. The tests were carried out in a 1500 $m^3$ test hall, thanks to which it was possible to ensure stable environmental conditions.



**Photo 1.** Mobile fan during tests on the test stand for the evaluation of the characteristics of the air stream velocity profile generated by a mobile fan (tests including an obstacle in the form of a door opening).

## 4. RESULTS AND DISCUSSION

Measurements of the characteristics of the airflow velocity profile generated by the mobile fan were made for distances of 1, 3, 4, 5, and 7 [m] at varying impeller angle settings of 0°, 5°, 11°, and 17°. During each test, the fan was operated at maximum speed. The obtained results of the volumetric airflow are shown in Table 2 and Fig. 3. At the first positioning distance (1 m), volumetric flow rates ranging from 26105.8 (0° tilt angle) to 33459.3 $m^3/h$ (17°) were obtained. At the next positioning distance (3 m), the mobile fan sample generated a volumetric flow rate that ranged from 31361 $m^3/h$ (at 0° tilt) to 38879.7 $m^3/h$ (17° impeller tilt). At a distance of 4 m from the measurement plane, the fan generated a flow that ranged from 32308.5 $m^3/h$ (0° impeller tilt) to 42269.3 $m^3/h$ (11°). Over a distance of 5 m, volumetric flow rates ranging from 26561.6 $m^3/h$ (17°) to 41168.1 $m^3/h$ (11° tilt) were obtained. At the last positioning distance of the fan unit of 7 m, the measured airflow value was in the range of 12087.6 $m^3/h$ (17° deviation) to 37039.5 $m^3/h$ (5° deviation).

Analysing the obtained results, it should be pointed out that the highest value of the volumetric flow stream (42269.3 $m^3/h$) was obtained for the positioning parameters corresponding to the distance of 4 m and the inclination angle of the impeller of 11°. In this case, the fan impeller axis was oriented at just over half the door height (0.57 m). On the other hand, the smallest value was recorded for the distance of 7 m and 17° – in this configuration, the axis of the fan impeller was directed above the plane of the door opening (1.24 m), so that a significant part of the stream bypassed the measuring surface. The

relationship of the geometric parameters of the pitch angle of the impeller axis (including positioning distance) to the height of the measurement plane (doorway) is shown in Table 2.

Based on the presented results, it is indicated that the positioning parameters (fan positioning distance and impeller angle) have a significant effect on the amount of the airflow that effectively enters the building structure through a doorway. Figure 4 shows a visualization of the velocity stream profiles measured for the fan under conditions where the lowest (7 m and 17°) and highest (4 m and 11°) volumetric flow rate values were obtained, respectively. The highest recorded value of the flow rate (42269.3 $m^3$/h) was possible to obtain by directing the stream in the middle plane of the door. This distance and tilt proved to be the most effective surface for airflow distribution. When analysing the second case, with the smallest value of the recorded flow rate, it should be pointed out that in this case, due to the deviation, the impeller axis was directed to the upper edge of the door frame. This action caused the generated airflow to be pumped into the upper areas, above the door opening. The plane plots presented here further confirm that the positioning parameters have a significant effect on the efficiency of the injected airflow. A visualization of the relationship between the positioning parameters of the fan unit and the door opening is also shown in Fig. 5.

**Table 1.** Relation of the parameters of the inclination angle of the impeller axis to the height of the measuring plane (door opening)

| No. | | Reference of geometrical parameters to the height of the measurement plane (doorway) | | | |
|---|---|---|---|---|---|
| | | Inclination angle of the impeller [°] | | | |
| | | 0 | 5 | 11 | 17 |
| Distance [m] | 1 | 0,18 | 0,22 | 0,28 | 0,34 |
| | 3 | 0,18 | 0,31 | 0,47 | 0,64 |
| | 4 | 0,18 | 0,35 | **0,57** | 0,79 |
| | 5 | 0,18 | 0,40 | 0,66 | 0,94 |
| | 7 | 0,18 | 0,48 | 0,85 | 1,24 |

**Table 2.** Volume flow generated by the mobile fans

| No. | | Volume flow rate [$m^3$/h] | | | |
|---|---|---|---|---|---|
| | | Inclination angle of the impeller [°] | | | |
| | | 0 | 5 | 11 | 17 |
| Distance [m] | 1 | 26105,8 | 28543,6 | 29293,7 | 33459,3 |
| | 3 | 31361,4 | 36126,9 | 38694,9 | 38879,7 |
| | 4 | 32308,5 | 37928,2 | **42269,3** | 36996,9 |
| | 5 | 33123,3 | 37687,8 | 41168,1 | 26561,6 |
| | 7 | 31807,3 | 37039,5 | 31175,0 | 12087,6 |

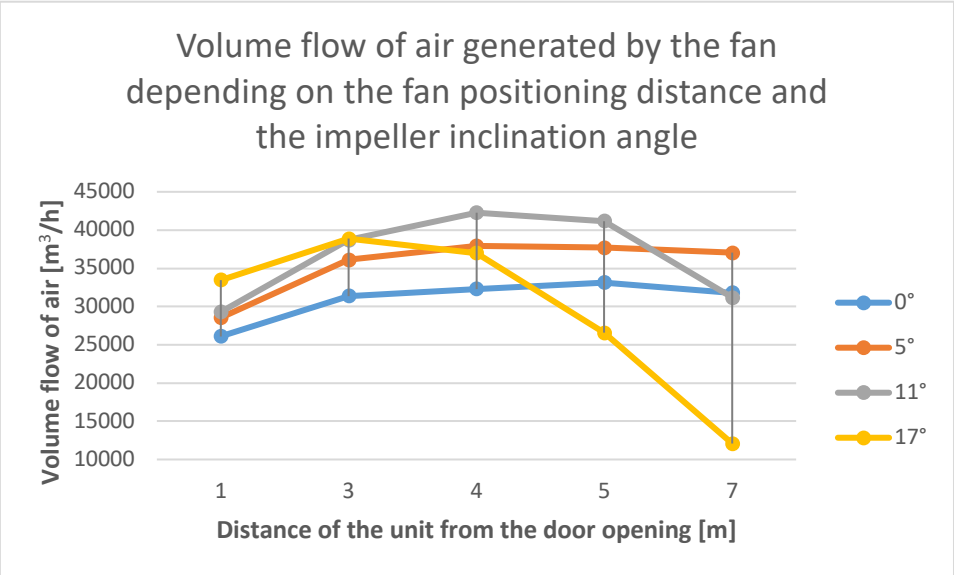



**Fig. 2.** Efficiency of pumping an air stream onto the door opening surface depending on geometrical parameters of the positioning of the fan unit i.e. the distance from the door opening (measurement plane) and the inclination angle of the impeller

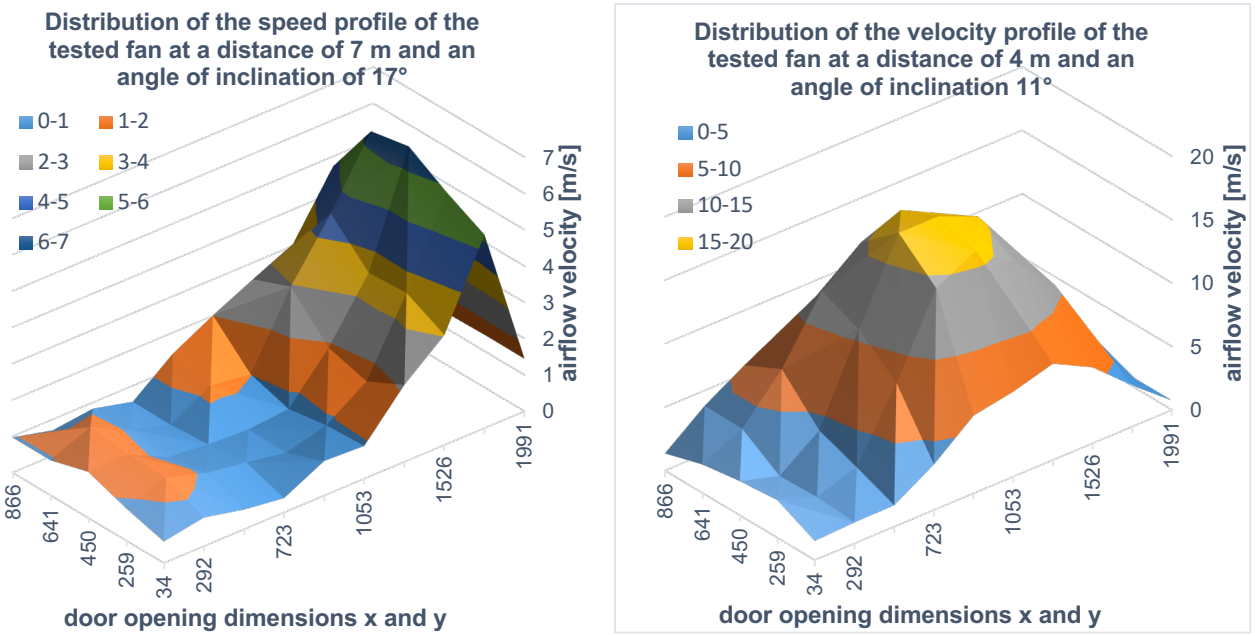



**Fig. 3.** Distribution of air flow velocity profile at the door opening taking into account the positioning distance of the mobile fan 7 m distance and 17° (left) and 4 m and 11° (right).

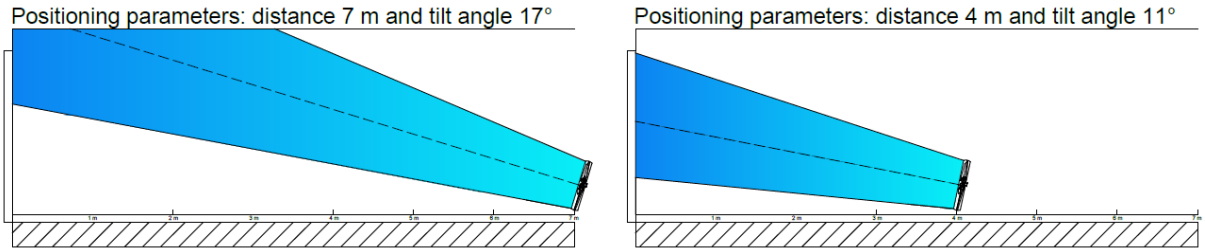



**Fig. 4.** Visualization of the air stream direction, for the fan positioning conditions of 7 m and 17 degrees (where the flow achieved was: 12087,6 $m^3$/h) and 4 m and 11 degrees (where the flow achieved was: 42269,3)

## 5. CONCLUSIONS

The volumetric flow generated by mobile fans is one of the most important parameters for the evaluation of these devices. This paper presents the construction of a test stand for evaluating the characteristics of velocity profiles of the generated air stream (in open flow) by mobile fans and the results of testing the volume flow rate of air that was forced through the measuring surface in the form of a door opening for an example mobile fan. During the study, the test stand was validated and confirmed to be working properly. In the course of the tests, the volume flow rate of the air stream generated by the fan, which was forced into the measurement plane (door opening) was evaluated for the distance of 1, 3, 4, 5 and 7 m at variable settings of the inclination angle of the impeller i.e. 0°, 5°, 11° and 17°. Considering the obtained results, it should be pointed out that the highest value of the flow rate (42269.3 $m^3$/h) was obtained for positioning parameters corresponding to a distance of 4 m and the inclination angle of the impeller of 11°. In contrast, the lowest value was recorded for a distance of 7 m and 17°. In the indicated configuration, the axis of the airflow was directed over the upper edge of the measurement plane, which is a critical parameter for the positioning of the fan. On the basis of the presented results, it is indicated that the positioning parameters (fan positioning distance and impeller angle) have a significant influence on the volumetric flow rate, which effectively reaches the interior of the building through the door opening. Referring to the conditions and assumptions of the conducted research, it should be noted that the obtained results were characterized by repeatability and can be used as the basis to assess the size of the air stream flow of mobile fans in the conditions of real application (open flow). It should be pointed out, however, that the developed test method does not allow the assessment of the size of the air flow, taking into account the pressure, which may be present inside the ventilated volume of a building as a result of, for example, open windows and the wind flowing onto their surface. The authors of the study are currently carrying out further tests to assess the profile and volume of the air stream flow for different fans, i.e. conventional and “turbo” type units with different power sources (combustion engine and electric).

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