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USAGE OF MULTI-HOLE PROBE ON UAV WITH WARHEAD

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Abstract: *This paper is about usage of multi-hole probes (MHPs) on unmanned aerial vehicle (UAV). Multi-hole probes are widely used in turbomachinery to determine angularity of velocity vector in unknown flow fields. New versions of UAV and the specter of their usage nowadays, request new solution in every area of their design. Strictly speaking, MHPs can be used on kamikaze UAV to determine sideslip angle in dive. This study present design of MHP with consideration the usage of UAV. Because this UAV is one-time use the goal is to get solution that is simple and easy to manufacture, but also precise to measure small sideslip angle. Precision of MHP measurements directly effect on epilogue if UAV hit the target or not. Computational Fluid Dynamics (CFD) are used to determine range of pressure difference created by probe head.*

Keywords: *Multi-hole probe, Five-hole probe, side slip angle, UAV, CFD.*

1. INTRODUCTION

Unmanned aerial vehicles (UAV) with warhead have become the most common weapon for neutralization tanks and other large and slow moving vehicles. The goal is to get high success with cheap but reliable drones. That leads us to the fact that we are not able to use high quality and expensive equipment. To enhance the accuracy and performance of these UAV's, it is crucial to accurately measure aerodynamic parameters such as the angle of attack and side slip angle. These metrics are vital for ensuring that the UAV maintains optimal flight dynamics and precise targeting capabilities. A practical solution for this purpose is the five-hole probe, a relatively simple and inexpensive device used in aerodynamics.

The five-hole probe measures pressure differences at multiple points around the probe's surface, allowing for the determination of the direction and magnitude of airflow relative to the UAV [1-2]. By analyzing these pressure readings, the angle of attack and side slip angle can be calculated, providing essential data for flight control and stability. Despite its simplicity, the five-hole probe delivers reliable and accurate information crucial for the UAV's performance, making it an ideal choice for cost-sensitive applications [3].

2. GEOMETRY OF MHP AND PROBE HEAD

There are variety of possible configurations of a probe head. The most commonly employed probe head designs include conical, hemispherical, and pyramidal geometries, each tailored to different measurement needs and flow conditions, as shown on Figure 1 [4]. Each of these types has its advantages and disadvantages.

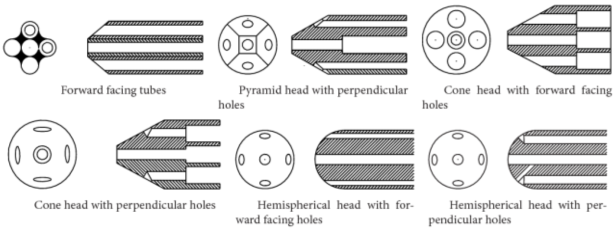

Figure 1. Types of five hole probe tip

For getting more resistible probe we choose pyramidal head with perpendicular holes. Reason for that is intentions to force flow separation along the corners of the head. This is very important since flow separation over holes gives us inaccurate pressure readings, as the separation causes turbulence and uneven pressure distribution.

As illustrated in Figure 2, we have selected a 40-degree apex angle for the probe tip, which represents an optimal compromise between sensitivity and measurement

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accuracy. A sharper probe tip, with a smaller apex angle, generally provides higher sensitivity to changes in the angle of attack and side slip angle, which can be advantageous for detecting fine variations in flight angles. However, such a design is more prone to flow separation at high angles of attack. On the other hand, a blunter probe tip with a larger apex angle results in lower sensitivity. This design tends to produce smaller pressure differences between opposite measurement holes, which can be less responsive to subtle changes in airflow [5]. Despite this, the blunter geometry offers greater stability by maintaining more consistent flow over the probe head at high angles of attack.

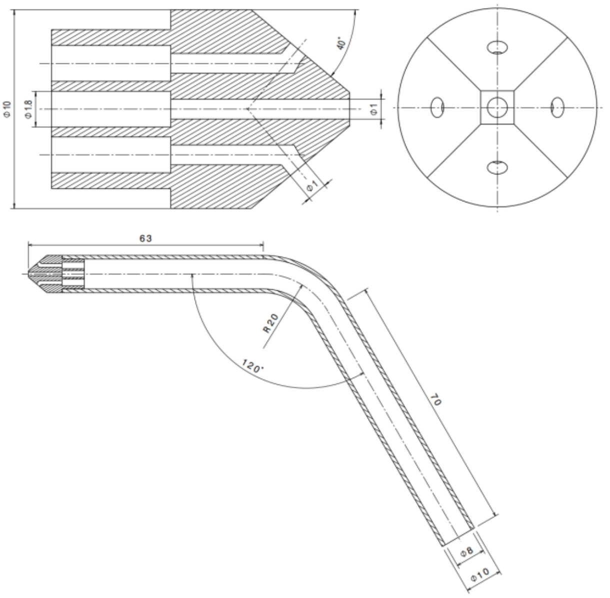

Figure 2. Design of the probe

The outer diameter of the probe is designed to be 10 mm, which accommodates the necessary space for the five hoses that channel pressure to the sensors. Diameters of all five probe holes is 1 mm. To ensure stable and consistent flow through the probe, its length of straight part is set to 63 mm. This length is crucial for maintaining proper flow conditions and minimizing any potential disturbances that could affect the accuracy of the pressure measurements. To ensure accurate and timely pressure measurements, it is crucial to minimize the distance between the probe head and the sensors. A shorter distance allows the sensors to detect pressure changes more quickly, which is essential for capturing real-time data. The challenge lies in optimizing this distance while maintaining proper flow conditions within the probe's tubes. If the distance is too short, there may be issues with turbulence or interference, which can affect measurement accuracy [6]. Conversely, if the distance is too long, there could be delays in signal transmission and reduced responsiveness.

3. NUMERICAL SIMULATION

Numerical simulations are performed to analyze and get near value of the pressure differences generated by the Multi-Hole Probe (MHP). The computational fluid dynamics (CFD) simulations are conducted using ANSYS Fluent software [7]. First step is to check MHP independently, without the UAV. As show at the Figure 3, the simulation focuses on the first segment of the probe, which contains five small tubes internally. The end of these tubes is used to get value of the pressure created by this MHP.

Figure 3. CAD model used for numerical simulation

An unstructured computational surface mesh is designed to accurately capture pressure variations at the probe head. To achieve this, a fine mesh is employed on the probe head surfaces and the internal walls of the tubes, ensuring detailed resolution where pressure changes are most critical. Coarser mesh is used further from the probe head, especially on the outer wall of the probe as it is shown at Figure 4. This mesh consists of 3,8 million cells.

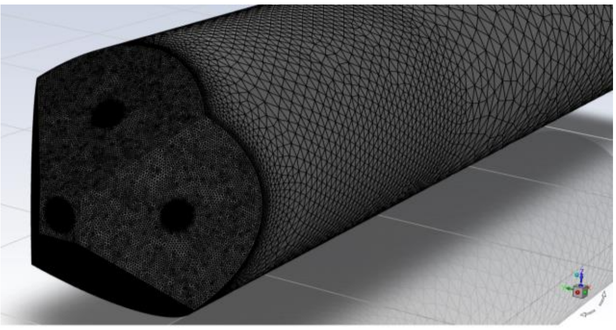

Figure 4. The resolution of a surface mesh on probe

Due to small Reynolds number, the simulation is calculated with laminar viscous model. The velocity inlet boundary conditions have been used for defining the velocity and direction of free stream. The simulation was carried out until the solution met the convergence criteria, ensuring that the numerical results were stable and precise.

4. RESULTS AND DISCUSSION

The simulation examines a range of angles from -15 to +15 degrees and only for both the angle of attack and the side slip angle Due to the symmetrical design of the probe, the choice of which angle is used in the simulation does not affect the results. This range is determined because of limitation in maneuverability of this UAV in real flight.

As expected, when the side slip angle is zero, the difference in pressure is negligible. Figure 5, Figure 6 and Figure 7 shows the pressure differentials on the probe head as a result of varying flow angles. In these figures, it is evident that the face of the probe head oriented directly into the flow experiences a higher local pressure in that specific region. The visual data from these figures demonstrate how the pressure distribution on the probe head is influenced by the angle of the incoming flow [8]. These observations are crucial for understanding the aerodynamic performance of the probe and for calibrating it to accurately measure pressure differences in various flight conditions.

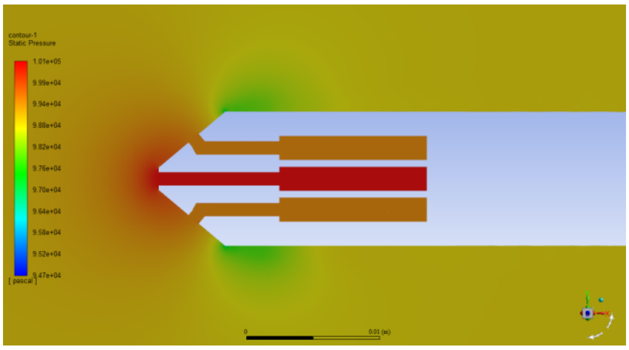

Figure 5. Pressure distribution at side slip angle β = 0°

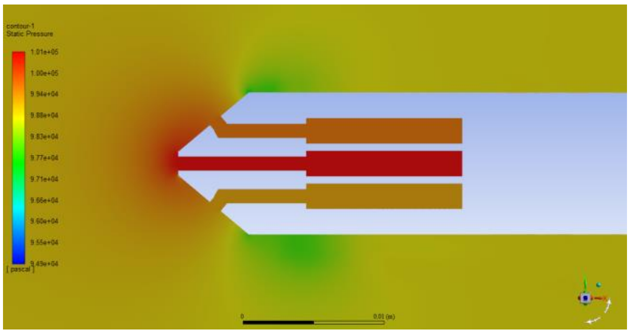

Figure 6. Pressure distribution at side slip angle β = 5°

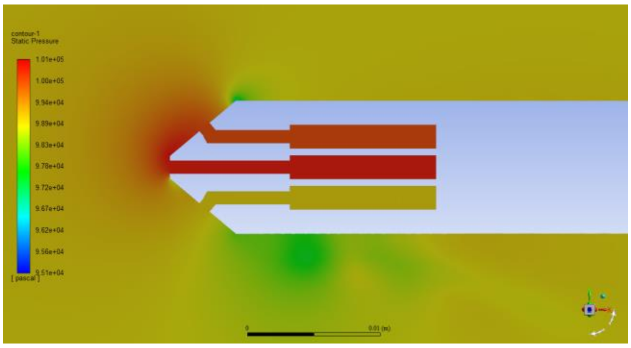

Figure 7. Pressure distribution at side slip angle β = 15°

Table 1 presents the pressure difference values obtained from the simulations, specifically for a velocity of 184 km/h at an altitude of 200 meters. These specific conditions are representative of the real flight scenario of the UAV. Figure 8 illustrates how, at the same altitude but with varying velocities, the pressure differences observed on the probe head change [9-10]. The data clearly show that as the velocity of the free stream increases, the pressure difference also increases. This correlation occurs because dynamic pressure, which is a function of the flow velocity, rises with higher speeds.

Table 1. Pressure difference values at V=184 km/h

Side slip angle β (°)	Pressure difference (Pa)
-15	-978.106
-10	-668.898
-5	-335.853
-2	-133.78
0	0.836
2	136.071
5	342.911
10	687.98
15	990.56

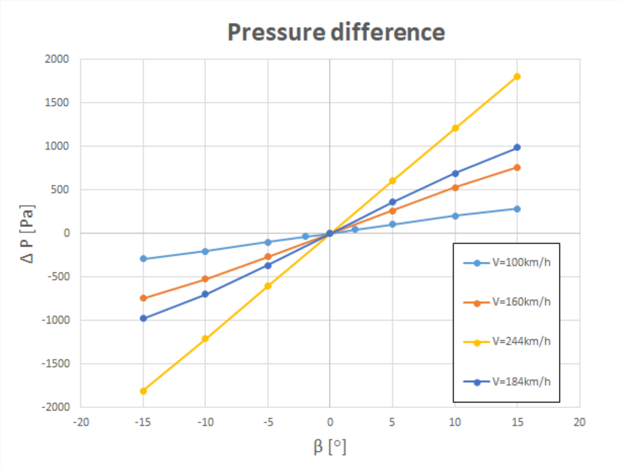

Figure 8. Pressure difference due to changes in velocity

5. CONCLUSION

Having gained an understanding of the pressure differences generated by the Multi-Hole Probe (MHP), we can effectively determine the side slip angle. Each specific angle of the probe corresponds to a distinct pressure difference measured by the probe head. However, it is important to consider that these pressure differences vary with different velocities. To solve this, the obtained results should be normalized with dynamic pressure. Selecting an appropriate pressure difference sensor is crucial. The sensor must be capable of covering the entire range of pressure values measured during flight. It should also have acceptable sensitivity to detect small pressure changes, enabling precise measurement of minor angles of the UAV.

One of the next steps involves conducting wind tunnel testing experiments to validate the results obtained from numerical simulations. These experiments are crucial for confirming the accuracy and reliability of the simulation data under controlled conditions. Additionally, it is essential to analyze the positioning of the probe on the UAV to understand how its placement affects the measurement outcomes. Evaluating the influence of the UAV itself on the obtained results during flight is also necessary. This involves analyzing how the body of UAV interact with the probe and potentially impact the pressure measurements. By combining wind tunnel tests with in-flight analysis, we can ensure that the probe's performance and the data it provides are accurate and reliable under real-world conditions.

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