3. EXPERIMENTAL FACILITIES AND METHODS

3.1 Equipment

3.1.1 Test Cell

The layout of the test cell at the Virginia Tech Airport is shown in Figure 3.1. It is rectangular in shape with a length of 25.0 ft (7.62 m), width of 12.5 ft (3.81 m), and height of 15.0 ft (4.57 m).

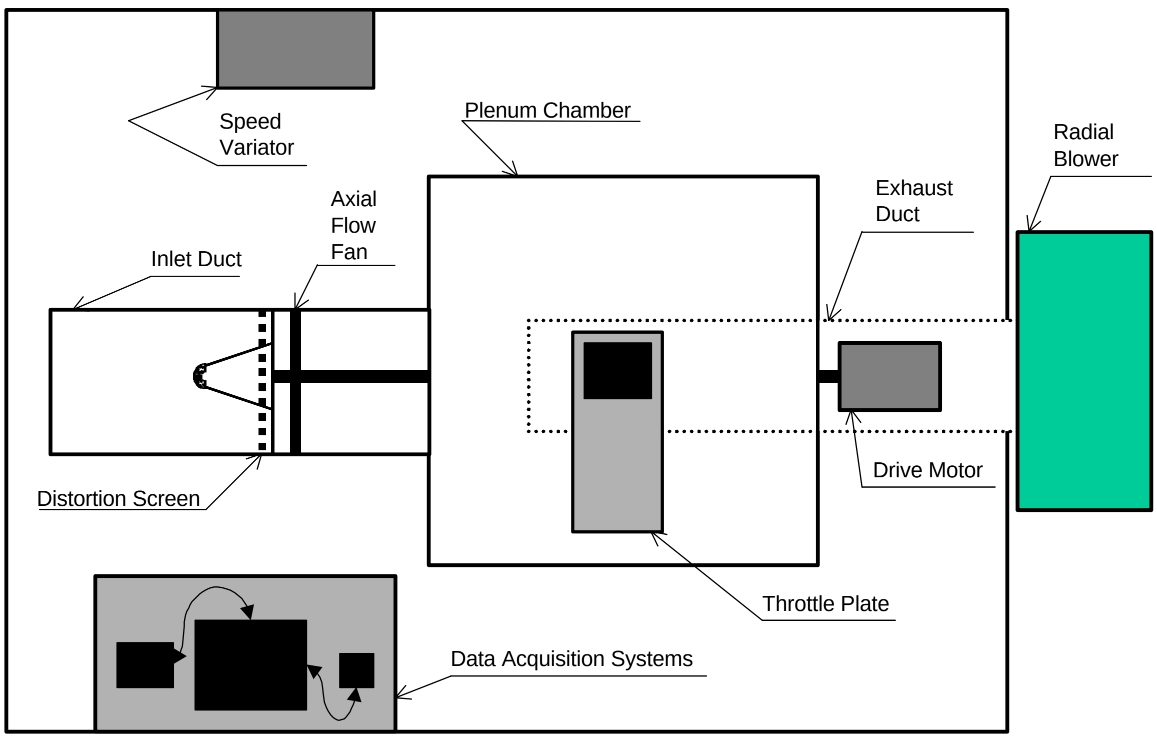


Figure 3.1: Schematic of Test Cell (Top View).

3.1.2 Rotor

The test machine used in this experiment is an open-circuit, subsonic General Electric Company Model 5GDY34A1 axial-flow compressor, the rotor of which is shown in Figure 3.2. The compressor may be operated in either a one-stage or two-stage configuration. However, for the present investigation it was used as an isolated rotor without stators or IGV in order to eliminate the effects of inter-stage flow interactions. It is driven by a 5 Hp General Electric motor with a rotational speed that is continuously variable from 500 to 3000 rpm. The annulus has an inner diameter of 12.375 inches (0.314 m) and an outer diameter of 18.0 inches (0.457 m). The rotor consists of 24 RAF-6 propeller sections whose profile is shown in Figure 3.3. These blades have a span of 2.75 inches (0.070 m) and chord length of 1.67 inches (0.0424 m). A stagger angle of 55° at the mid span and 4° angle of twist result in a tip angle of 57° and a root angle of 53° from the machine axis. The nominal rotor blade casing clearance was 0.05 inches (0.0013 m). This arrangement resulted in a hub to tip ratio of 0.687, a solidity of 0.84 at the mean radius, and an aspect ratio of 1.68, producing a flow area of 0.975 ft^2 (0.091 m^2). An aluminum nosecone positioned at the rotor inlet had a base diameter of 12.375 inches (0.314 m), an axial length of 18.0 inches (0.457 m), and a tip radius of 1.5 inches (0.038 m).

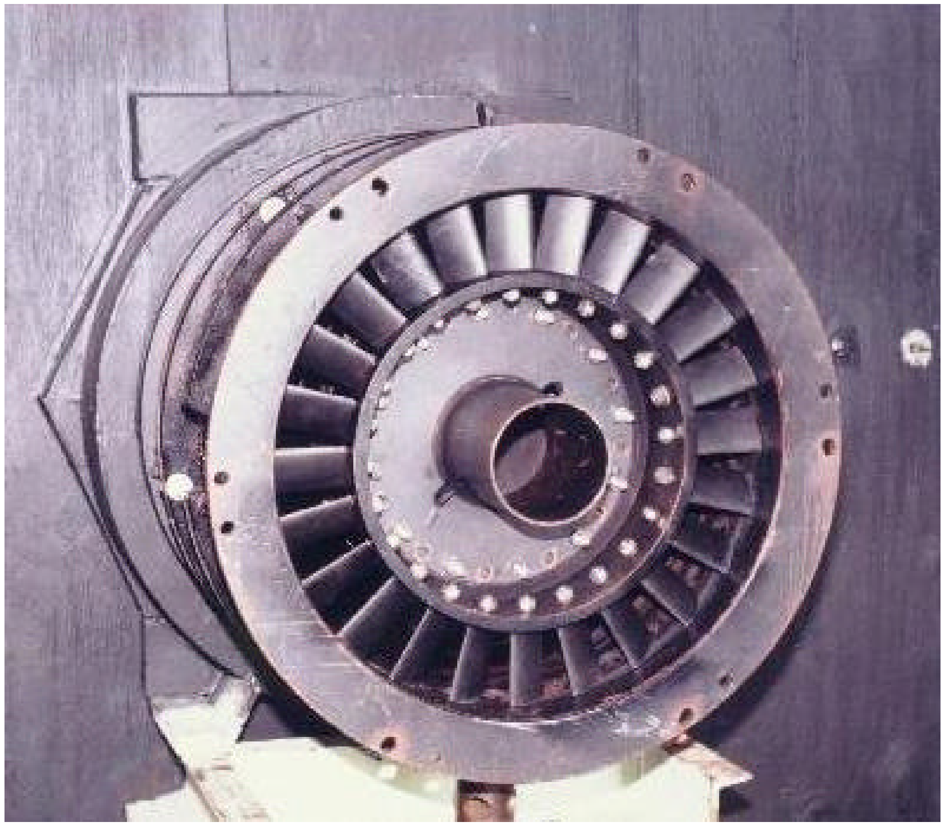


Figure 3.2: Photo of Low-speed Rotor.

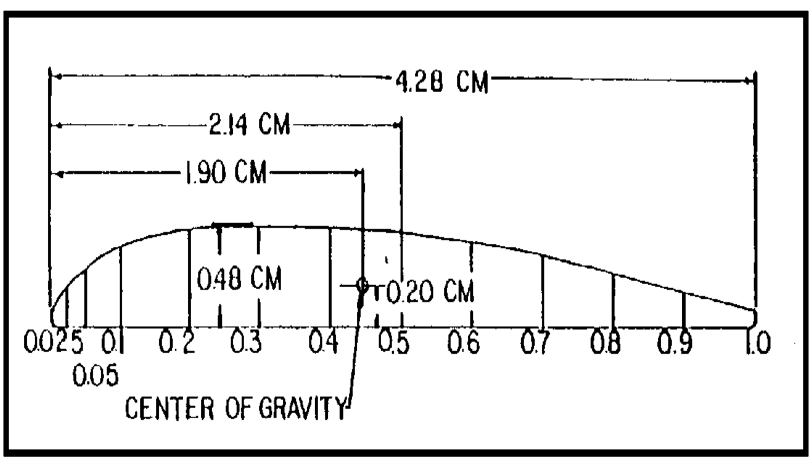


Figure 3.3: Cross Section of RAF-6 Airfoil.

3.1.3 Inlet Duct

A circular inlet duct of 4.0 ft (1.219 m) axial length precedes the rotor inlet. The duct is steel and has an inner diameter of 18.0 inches (0.457 m). A short radius aluminum bellmouth is attached to the front of the inlet duct. The bellmouth, inlet duct, and plenum chamber combination is shown in Figure 3.4.

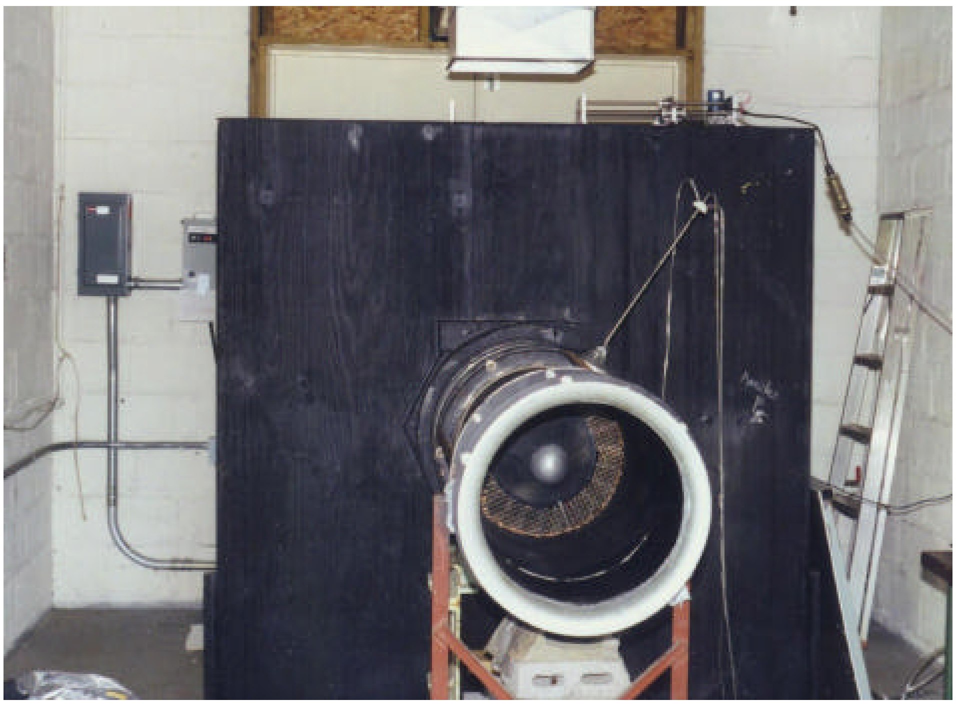


Figure 3.4: Photo of Bellmouth, Inlet Duct, and Plenum Chamber.

3.1.4 Plenum Chamber

The test machine pumps into a cubic plenum chamber of 6.0 ft x 6.0 ft x 4.0 ft (1.83 m x 1.83 m x 1.22 m) dimensions with a resultant volume of 144.0 ft^3 (4.08 m^3). A mechanical throttle valve is positioned at the top of the plenum chamber and is driven by an electric traverse mechanism, allowing throttling of the rotor by decreasing the plenum flow discharge area. The top of the plenum chamber and the throttle valve are shown in Figure 3.5. Due to difficulty in stabilizing the performance of an isolated rotor, the throttle plate was controlled using a feedback control loop which reduced the plenum total pressure and inlet five-hole probe port measurement unsteadiness to ± 5% for normal unstalled operation.

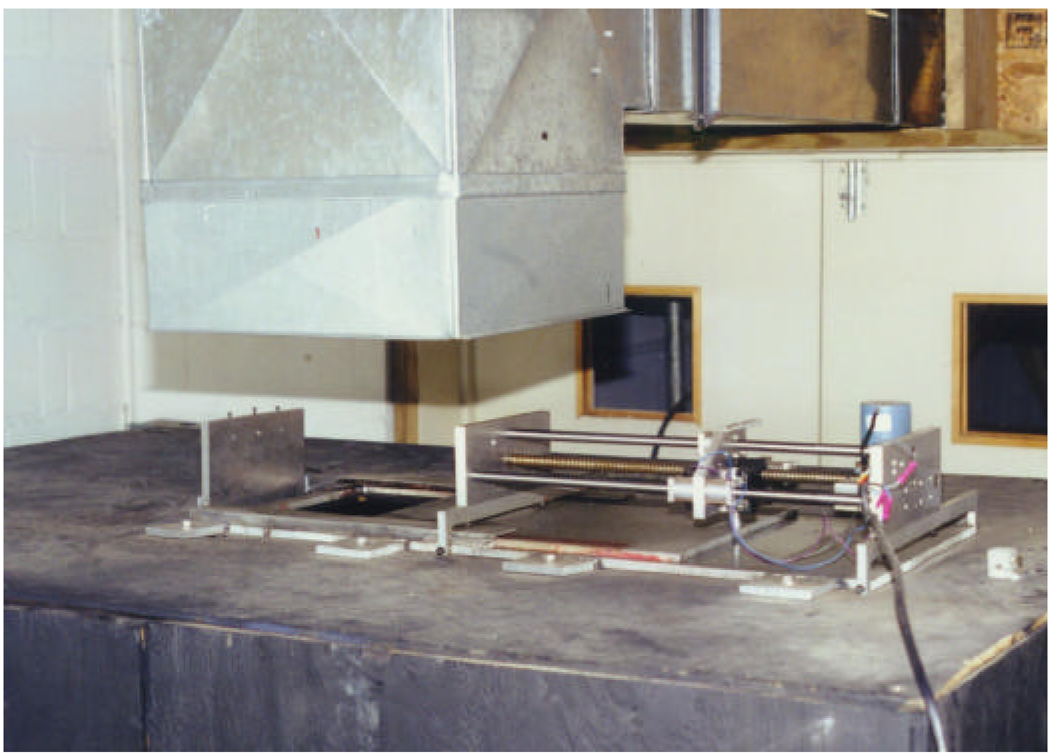


Figure 3.5: Photo of Plenum Chamber and Throttle Valve.

3.1.5 Circumferential Pressure Distortions

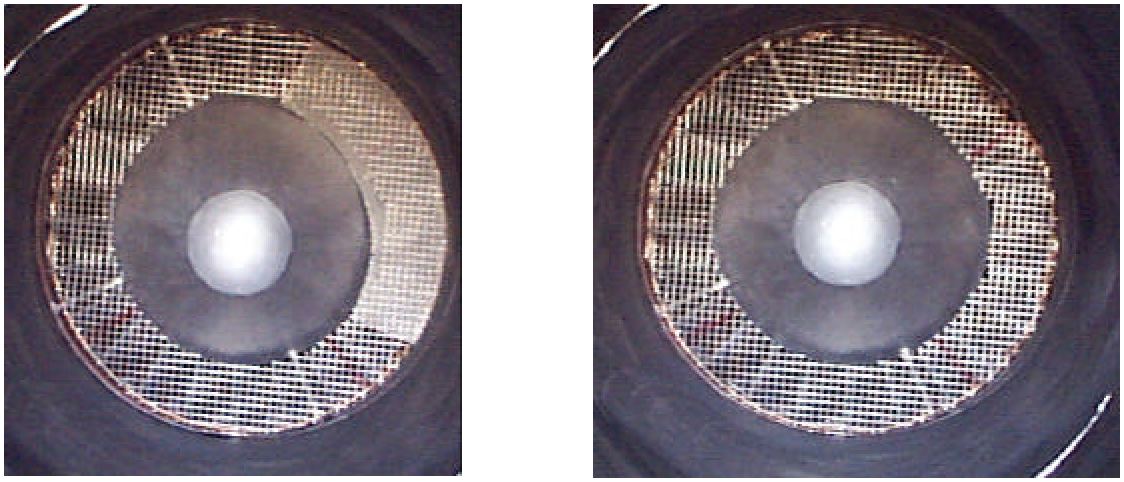
Inlet circumferential total pressure distortions were generated by three 110° circumferential extent screens mounted on a rotatable support mesh assembly located approximately 0.8 chords or 1.375 inches (3.493 cm) upstream of the rotor. The support mesh covered the entire 360° circumference of the inlet and consisted of stainless steel welded wire cloth with a 3 x 3 mesh of 0.047 inch (1.2 mm) wire diameter. The N x N notation below refers to the number of wires per square inch of the grid, while d refers to the wire diameter in inches. Three different 110° circumferential distortion screen combinations were employed and are presented in order of increasing total pressure loss:

1.) A 5 x 5 d = 0.041 coupled with a 3 x 3 d = 0.047.

2.) A 4 x 4 d = 0.047 coupled with a 14 x 14 d = 0.020.

3.) A 10 x 10 d = 0.025 coupled with an 8 x 8 d = 0.025 and a 12 x 12 d = 0.023.

The three screen combinations described above will herein be referred to as Level 1, Level 2, and Level 3, respectively. Rotation of the support mesh and distortion screens was equivalent to rotating the instrumentation in the stationary (absolute) frame of reference. Photos of the inlet duct and support mesh with and without a 110° distortion screen installed are shown in Figures 3.6 (a) and 3.6 (b), respectively.



(a) (b)

Figure 3.6: Photo of Support Mesh With and Without 110° Distortion Screen.

3.1.6 Instrumentation

The mass flow rate was measured using two United Sensor USC-N-210-A Pitot probe rakes for boundary layer regions and a Pitot-static probe measuring the inviscid core flow. The mass flow probes were located in the inlet two machine diameters or 36.0 inches (0.914 m) upstream of the rotor as shown in Figures 3.7 and 3.8. This distance was considered adequate in order to minimize upstream communication from the downstream rotor and screen combinations in the subsonic axial flow. An area-average technique was employed to obtain the mass rate of flow, and is described as follows.

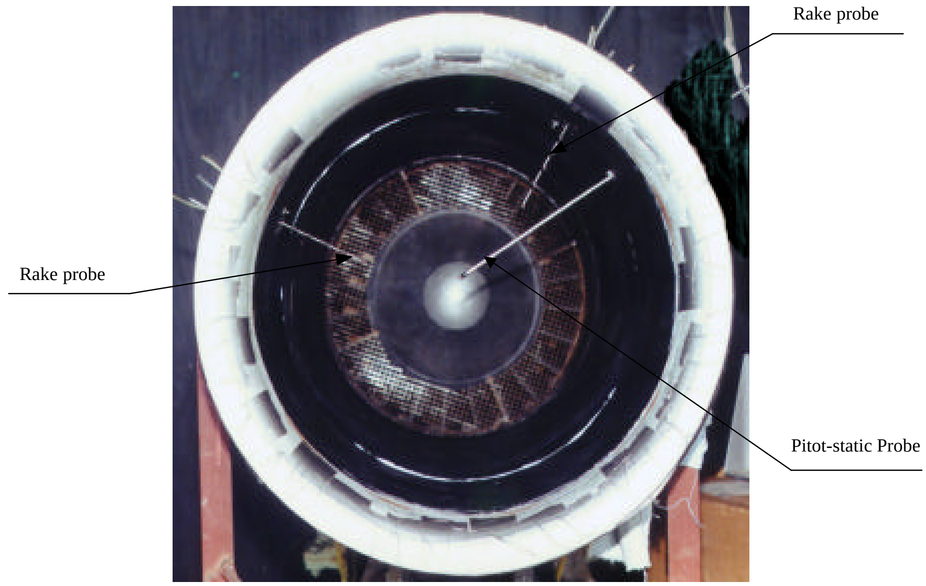


Figure 3.7: Frontal View of Probes for Mass Flow Measurement.

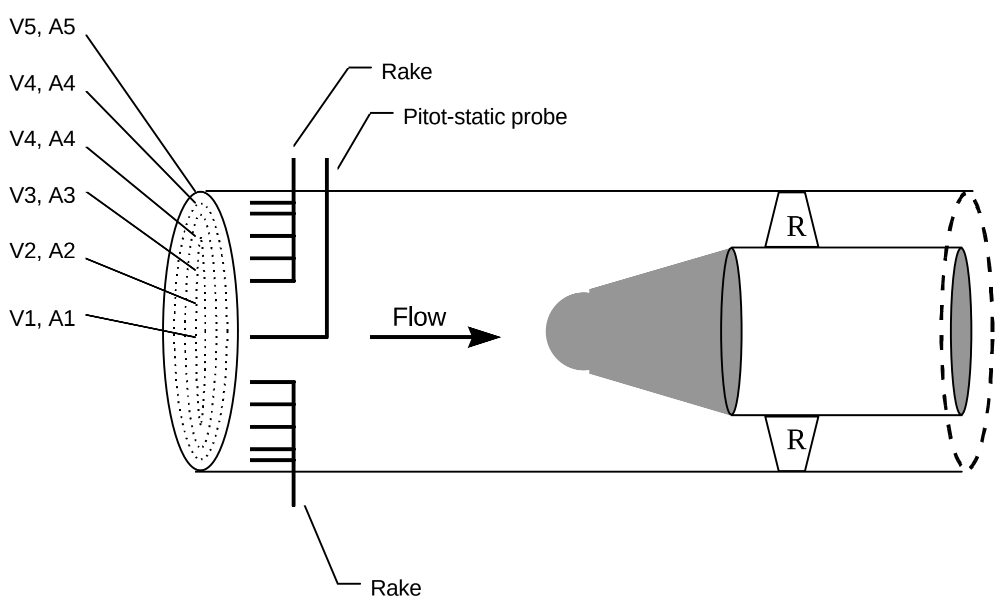


Figure 3.8: Diagram of Area-Average Mass Flow Measurement Scheme.

The inlet static pressure P_s was obtained using the static component of the Pitot-static probe and axial velocities were obtained using the reduced Bernoulli equation with the inlet total pressure P_t

$$V = \sqrt{2(P_t - P_s)/\rho} \qquad \textbf{(3.1)}$$

This procedure assumes a negligible static pressure gradient in the boundary layer of the inlet measurement plane. With the inlet area discretized into concentric circles of area A_i with respect to the Pitot probe positions, the integral from the machine axis to the duct outer edge

$$V_{Ave} = \frac{1}{A} \int V(r)\,dA \qquad \textbf{(3.2)}$$

was approximated as

$$V_{Ave} = \frac{\sum V_i A_i}{\sum A_i} \qquad \textbf{(3.3)}$$

and the resulting average axial velocity at the duct inlet was used to obtain the mass rate of flow through the fan using conservation of mass principles.

In order to measure the three-dimensional velocity triangle at the inlet of the rotor, a United Sensor DC 125 five-hole prism pressure probe was placed 0.25 chords or 0.4175 inches (0.0106 m) upstream of the rotor leading edge in the stationary frame of reference, where inlet flow angles were assumed steady. A schematic of this probe is shown in Figure 3.9. The probe was used in a non-nulling mode throughout the investigation in that it had a fixed orientation with respect to the machine axis. This probe had five measuring ports, one for total pressure measurement and four for pitch and yaw flow angle measurements, which correspond to stationary frame radial and circumferential flow angles in a turbomachine.

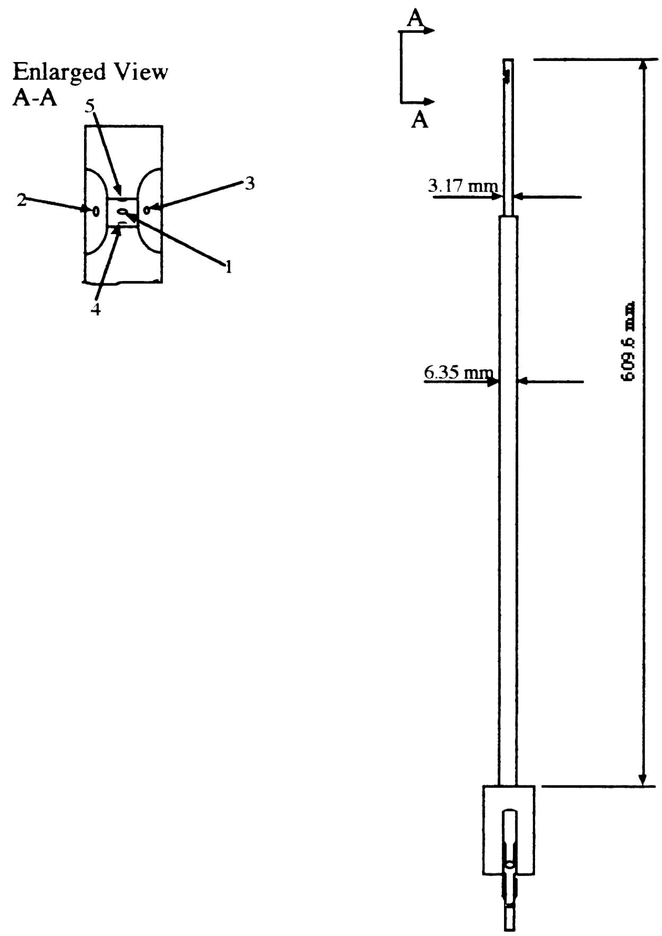


Figure 3.9: Schematic of Five-Hole Pneumatic Pressure Probe.

The procedure of Treaster and Yocum (36) was used to process the five-hole probe data using the dimensionless pressure coefficients in Equations **(3.4)** as related to the indices shown in Figure 3.10. Total pressure p_1 is measured at the central probe hole, while p_2 and p_3 are measured in the yaw plane and p_4 and p_5 are measured in the pitch plane.

$$Cp_{pitch} = \frac{p_4 - p_5}{p_1 - \overline{p}}$$

$$Cp_{yaw} = \frac{p_2 - p_3}{p_1 - \overline{p}} \tag{3.4}$$

$$Cp_{total} = \frac{p_1 - p_{total}}{p_1 - \overline{p}}$$

$$Cp_{static} = \frac{\overline{p} - p_{static}}{p_1 - \overline{p}}$$

$$\overline{p} = \frac{p_2 + p_3 + p_4 + p_5}{4}$$

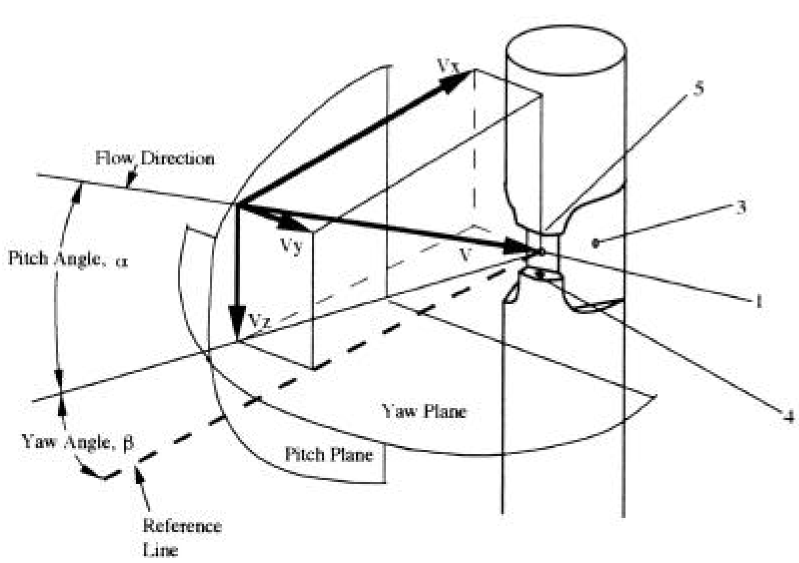


Figure 3.10: Schematic of Five-Hole Pressure Probe Tip and Flow Angles.