Definition of Yaw Meter Sensitivity for the "Null Reading" Technique

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Nomenclature

C_p = pressure coefficient, $p_a - p_b / \frac{1}{2}\rho U^2$
$(C_p)_\psi$ or C_ψ = yaw meter sensitivity coefficient, $p_a - p_b / \frac{1}{2}\rho U^2 \psi$
$C_{\psi 0}$ = yaw meter sensitivity coefficient for "null reading" technique, $(1/\frac{1}{2}\rho U^2)\ (\partial p/\partial\psi)_{\psi=0}$
U = freestream velocity
p = pressure difference between yaw meter tubes, $p_a - p_b$
p_a, p_b = pressure in yaw meter tube
ρ = fluid density
ψ = yaw angle of probe to freestream direction

Introduction

An important parameter in an investigation of flow phenomena in any fluid mechanics problem is the measurement of flow direction. Although many devices such as tufts, streamers, and vanes have been used, their indication of direction is not easily related to a reference axis, their introduction can produce further disturbances into the flow, and their directional accuracy is difficult to define. Pressure probes have therefore also been used as direction indicators and offer advantages over mechanical indicators by avoiding some of the errors caused by inertial and gravitational forces. These pressure probes can also offer a further advantage in that it is possible to define the accuracy with which the flow direction can be measured.

There are two major ways in which the flow direction can be measured using pressure probes, although in either case the probes are similar and usually have an axisymmetric arrangement of sensing holes. In the first method, often named "null reading," the probe is orientated in the flow until the pressure on each hole is equal. The flow direction is then indicated by the geometry of the probe. In the second method the probe is kept stationary and the pressure differences are measured and related to the flow direction from a calibration curve determined in a known uniform flowfield.

The first of these methods is the most commonly used for a number of reasons; for example, it is relatively easy to design probes which will give a high value for pressure difference per unit change in flow direction over a small range of flow angles, and the probes can be used with small range manometers, giving a faster response time. Additionally the interference of a probe aligned with the flow is generally less than with the alternative method.

Yaw Meter Sensitivity

In assessing the different types of probe such as those described by Bryer and Pankhurst,[1] or in evaluating a new design of probe, for a particular flow configuration, it is important to define the sensitivity of the probe to flow direction and hence the accuracy with which the flow direction can be measured. For an incompressible flow situation the sensitivity has been expressed[1] as

$$C_\psi \text{ or } (C_p)_\psi = \frac{(p_a - p_b)}{(\frac{1}{2}\rho U^2 \psi)} \tag{1}$$

where p_a and p_b are the pressure readings on the two arms of the probe, $\frac{1}{2}\rho U^2$ is the dynamic pressure, and ψ is the yaw angle. A typical curve for the nondimensional pressure difference measured by a yaw meter, based on data in Ref. 2, is shown in Fig. 1. It can be seen that the pressure difference varies nonlinearly with yaw angle, except in the proximity of zero yaw angle, with the result that the yaw meter sensitivity, as defined by Eq. (1) is also nonlinear. Furthermore the sensitivity is indeterminate at zero yaw angle since both the yaw angle and the pressure difference are also zero. However, it can be seen in Fig. 1, and has also been found by other investigators[1,3,4] that over a small range of yaw angles about the zero position, generally about ±15 deg, there is a linear relationship between pressure difference and yaw angle. Since it is the sensitivity in the region of zero that is particularly important for the "null reading" technique, it is possible therefore to define an appropriate sensitivity coefficient, which is not indeterminate, as

$$C_{\psi 0} = \frac{1}{\frac{1}{2}\rho U^2}\left(\frac{\partial p}{\partial \psi}\right)_{\psi=0} \tag{2}$$

where $p = p_a - p_b$ and the slope of this curve of pressure difference against yaw angle $(\partial p/\partial\psi)$ is evaluated at $\psi = 0$.

In many cases the pressure difference data is expressed in the form of a pressure coefficient where

$$C_p = \frac{(p_a - p_b)}{(\frac{1}{2}\rho U^2)} \tag{3}$$

so that the yaw meter sensitivity can be expressed as

$$C_{\psi 0} = (\partial C_p/\partial\psi)_{\psi=0} \tag{4}$$

It should perhaps also be noted that the definition of yaw meter sensitivity given in Eq. (1) is appropriate only to a linear

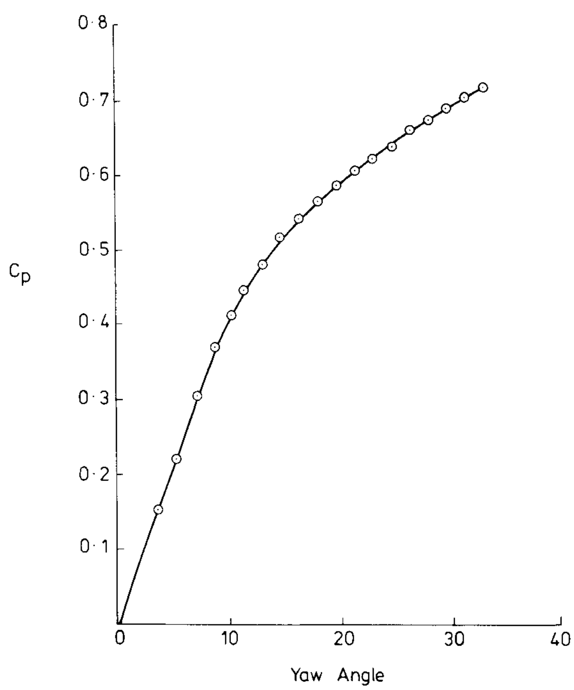

Fig. 1 The variation of yaw meter sensitivity with yaw angle.

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response curve since with a nonlinear curve the value given will be neither an average nor the value at a particular yaw angle. It would therefore be advantageous to redefine the yaw meter sensitivity C_ψ which would be appropriate when the yaw meter is kept stationary and the flow angle is evaluated by using a calibration curve. In this case it would be useful to know the average sensitivity over the range of yaw angles being considered, viz.

$$C_\psi = \int_{\psi_1}^{\psi_2} \frac{C_p d\psi}{(\psi_2 - \psi_1)} \tag{5}$$

It can be seen that, in the case where the yaw meter response is linear and the lower limit of yaw (ψ_1) is zero, the expression given in Eq. (5) reduces to that of Eq. (4) as should be expected.

Conclusions

A definition of yaw meter sensitivity has been given which is appropriate to the commonly used "null reading" technique [Eq. (4)], and it is proposed that the symbol C_{ψ_0} should be adopted for this definition.

In addition, a more precise definition of the yaw meter sensitivity C_ψ has been formulated for general comparison between different types of yaw meter where the instrument is held stationary and the flow angle is determined from a calibration curve.

References

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[3] Bryer, D. W., Walshe, D. E., and Garner, H. C., "Pressure Probes Selected for Three-Dimensional Flow Measurement," Aeronautical Research Council, London, England, R&M 3037, 1958.

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Effect of Hydrostatic Pressure on Underwater Towed Body Cable Configurations

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IN Ref. 1, Goodman and Breslin show that the effect of hydrostatic pressure on the static equilibrium equations of a cable in a stream can be completely accounted for by replacing the tension T in the classical equations by the effective tension Te, where

$$Te = T + \frac{\rho g A_0 z}{(1+\epsilon)} \tag{1}$$

and by multiplying the stream-induced normal and tangential drag forces by the factor $(1 + \frac{1}{2}\epsilon)$.

Here ρ is the mass density of the fluid, g is the acceleration due to gravity, A_0 is the cross-sectional area of the unstretched cable, z is the depth of the cable element below the free surface, ϵ is the extension per unit length of the cable (strain) defined by

$$\epsilon = \frac{1}{E}\left[\frac{T(1+\epsilon)}{A_0} + \rho g z\right] \tag{2}$$

and E is Young's modulus.

Generally, the tension and cable angle φ are known at one end of the cable, and, since the dependent variables of the

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Announcement: 1979 Author and Subject Index

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