Development of an impact-pressure probe for flow vector measurements
by Travis William Chevallier, Jr

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Mechanical Engineering
Montana State University

Abstract:
The development and testing of a miniature probe for determining fluid flow direction and magnitude is considered. The new probe obtains pressure data from a pair of angled tip impact tubes at a point in a flow. This is combined with a static pressure measurement to obtain the flow vector. Basic theory and calibration of the probe is discussed. A numerical example of how the probe is used is included.

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Date 2 Dec 80

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Approved:

Chairperson, Graduate Committee

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MONTANA STATE UNIVERSITY
Bozeman, Montana

December, 1980

ACKNOWLEDGMENTS

The author wishes to thank Dr. A. Demetriades and Dr. T. C. Reihman for their help and guidance in the performance of this study. Sincere thanks are also due to Tim Boucher, Margaret Roukema and Charlene Townes for their help in preparing the final copy of the thesis.

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NOMENCLATURE

Symbol	Description
C_p	Dimensionless pressure coefficient
C_{pa}	Dimensionless pressure coefficient;equals $\frac{Pa-Pb}{q}$
C_{ps}	Dimensionless pressure coefficient;equals $\frac{Ps-Pb}{q}$
D_{pw}	Differential pressure coefficient of a wedge;equals $\frac{Pa-Pb}{Ps-Pb}$
D_{py}	Differential pressure coefficient of a yaw probe;equals $\frac{Pa-Pb}{Ps-Pb}$
D_{py}^{-1}	Inverse of D_{py}
f, g, z	Functions
ID	Inside diameter
M	Mach number
OD	Outside diameter
P	Static pressure at a point
P_a	Pressure seen by a surface A
P_b	Pressure seen by a surface B
P_o	Freestream impact pressure
P_s	Freestream static pressure
q	Dynamic pressure equals $P_o-P_s=\frac{1}{2}\rho U^2$
r	Radial distance from a corner
Re_D	Reynolds number based on outside diameter
T	Absolute temperature

Symbol	Description
t^*	Gas relaxation time
U	Freestream velocity
u	Local velocity
V_r	Radial velocity
V_θ	Tangential velocity
w	Wall thickness
α	Angle of attack
β	Angle between a surface and the flow direction
γ	Ratio of specific heats (1.4 for air)
θ	Angular position from a corner wall
ρ	Density
ϕ_w	Wedge angle of probe tips and infinite wedges
ϕ	Potential function of inviscid flow
ψ	Stream function of inviscid flow

ABSTRACT

The development and testing of a miniature probe for determining fluid flow direction and magnitude is considered. The new probe obtains pressure data from a pair of angled tip impact tubes at a point in a flow. This is combined with a static pressure measurement to obtain the flow vector. Basic theory and calibration of the probe is discussed. A numerical example of how the probe is used is included.

CHAPTER I

INTRODUCTION

Mapping of flow fields over bodies immersed in a moving fluid has received a great deal of attention in recent years. In the realm of flight vehicles, studies of the flow over airfoils, control surfaces, engine inlets, antennaes, and radomes have received intense scrutiny as engineers seek to reduce turbulence, drag, buffeting and increase range and performance.

This effort has taken two thrusts. One is to numerically model inviscid flow fields by solving the equations of continuity, momentum, and energy over very fine grids about areas of interest. This has met with some success but the complexities of the flow make simplification of the equations difficult. The result is that the investigator frequently obtains large systems of nonlinear, coupled equations to solve that require large amounts of computer time.

The inclusion of viscosity effects can make the problem of obtaining analytical solutions to flow fields insurmountable for all but the simplest geometries.

The second major thrust has been experimental. Mapping of flow fields by making measurements of velocities, temperatures and pressures require sensors that are simple, rugged and reliable. The purpose of this investigation was to develop such a device for measuring flow magnitude and direction in air, that had the capability of making a precise measurement in regions of high velocity gradients. Such a device must be suitable for miniaturization to minimize flow disturbances and to prevent spurious readings caused by a large sensing surface in a high gradient.

The sensor studied was a pair of impact tubes fastened side by side whose tips were oriented at different angles to the flow.

Mach numbers in this study ranged over 0.025 - 0.065, flow speeds from 8-25 meters/second and the Reynolds number based on probe diameter had a range of 300 - 3000.

Results obtained were calibration curves of flow angle of attack as a function of pressure readings, and dynamic pressure as a function of pressure coefficients and angle of attack.

CHAPTER II

DESCRIPTION OF PREVIOUS WORK

Previous attempts have been made to construct yaw probes based on impact tube bundles whose tips are oriented at different angles to the flow.

Hall [1] constructed three-tube probes of the type shown in Figure 2.1 in 1962, using them for turbulent boundary layer studies. He used 0.020 inch outside diameter tubing and a wedge angle of 60°. One size of probe was used only. Hall operated his probe in the null mode, i.e. the probe was rotated until the pressure sensed by the outer tubes was equal. Using a yaw probe in this manner does not necessitate making calibration curves of flow angle of attack versus pressure readings. It does require, however, that the aerodynamic center of the probe be found.

In 1969, Dudzinski and Krause [2] developec probes based on the same tip geometry as Hall's, but they calibrated their probes so that they could be operated in a non-rotary, fixed position. Fixed-position probes have several advantages over rotating ones. They are less complex to fabricate and use, they require less space, and since they do not have to be rotated to a null position their response is much quicker.

Also developed and calibrated by Dudzinski and Krause were three-dimensional probes consisting of five tubes as in Figure 2.2. Their two-dimensional probes were constructed of 0.064 inch OD tubing and their three-dimensional probes were made of 0.032 inch OD tubing.

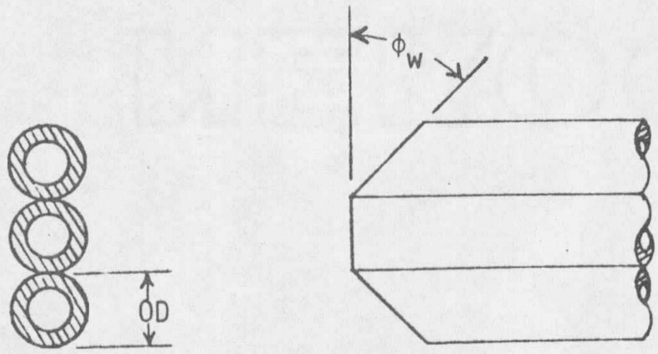

Figure 2.1 Tip geometry of a three-tube yaw probe

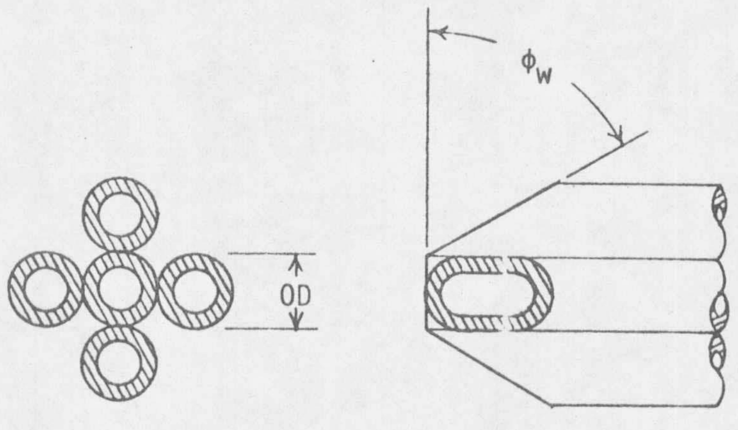

Figure 2.2 Tip geometry of a five-tube, three dimensional yaw probe

In 1975, Spaid, Hurley, and Hellman [3] designed miniature probes as in Figure 2.3 for transonic boundary layer mapping. Their probe is a flattened version of the standard three-tube arrangement, shown in Figure 2.1. The probe was manufactured from 0.010 inch OD tubing that was flattened to a height of 0.006 inch. The finished probe had tip dimensions of 0.040 inch x 0.006 inch. The wedge angle of the beveled faces was 45°.

The Spaid group calibrated their probe so that it could be used in a fixed mode, i.e. once the probe was placed in an area of interest it was moved in a translational manner only.

The probes mentioned before were all of the three-tube type. Two beveled tubes are used to obtain flow direction and an unbeveled center tube is used to obtain impact pressure. From these three measurements the flow speed and direction can be deduced.

Two-tube yaw probes, having no center tube, can be used to determine flow direction, (see Figure 2.4). According to Roberson and Crowe [4], such devices are always used in the null mode. This necessitates mounting the probes so they rotate and as mentioned previously, this has some disadvantages. Also, no flow speed is obtained from the probe.

The development of a fixed yaw probe consisting of two tubes only would provide some advantages to the experimenter. First, since only two tubes are used, the probe would be easier and less expensive to fabricate. Secondly, if the probe tip cross-sectional area must be