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Crossed Hot-Wire Data Acquisition and Reduction System

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SYMBOLS

A(i)	ith (current or updated) average
a(i)	ith sample value
C	temperature-shift correction constant
E_{corr}	corrected bridge output voltage
E_{meas}	measured bridge output voltage
E_o	fictive no-flow bridge voltage
$\bar{E}_{meas}$	average value of the measured bridge voltage
i	sample number
K	constant
Ns	number of samples
n	log slope (about 0.45, typical value)
OHR	overheat ratio (usually about 1.8)
Sa	average of quantity a, defined by equations (15)
S⟨a(i)⟩	sum of a(i) from i = 1 to i = Ns
T	current flow temperature
T_{cal}	calibration flow temperature
U	calibration velocity
U_{eff}	effective cooling velocity
$[U_{eff}]$	the vector of effective cooling velocities
u,v,w	instantaneous velocity components in x,y,z directions
[V]	instantaneous velocity vector
$\|V\|$	magnitude of the velocity vector
x,y,z	Cartesian coordinate directions
α	wire resistivity coefficient (typical value for tungsten = 0.005 per °C)
δ	yaw calibration angle setting
ψ	yaw angle

$[\psi]$ angular sensitivity matrix

Subscripts:

1,2 used to denote a particular quantity referred to wire 1 or wire 2

uv,uw quantity determined in uv or uw measurement plane

Superscripts:

' fluctuating quantity, e.g., $u = \bar{u} + u'$, or used to indicate an intermediate quantity (e.g., eq. (11))

$-$ time average

SUMMARY

The report describes a system for rapid computerized calibration acquisition, and processing of data from a crossed hot-wire anemometer. Advantages of the system are its speed, minimal use of analog electronics, and improved accuracy of the resulting data. Two components of mean velocity and turbulence statistics up to third order are provided by the data reduction. The report presents details of the hardware, calibration procedures, response equations, software, and sample results from measurements in a turbulent plane mixing layer.

1. INTRODUCTION

A system for rapid computerized acquisition and processing of analog signals from a hot-wire anemometer is described. Most of the discussion considers the crossed-wire anemometer; the simpler case of a single wire is briefly addressed. The objective of the work was to develop a system for measuring the statistical properties of the velocity field of a moderately turbulent, two-dimensional, incompressible, isothermal air flow. This report is intended to document the system for reference in several researches in which the system will be applied.

A crossed hot-wire probe operated by constant-temperature bridges (CTA) can provide a signal from which the two instantaneous components of velocity and related statistical properties of a moderately turbulent flow may be derived. Traditionally, analog hardware is used to linearize and process the signals from multichannel CTA systems. More analog hardware is required to process and average the resulting signals to obtain the desired statistics; for example, $\overline{u'^2}$, $\overline{v'^2}$ and $\overline{u'v'}$ for a crossed-wire. The present report describes a more modern approach wherein all nonlinear analog processing hardware is replaced by a computerized system for probe calibration, data acquisition, and reduction. The approach described differs from the old fully analog methods in that it uses fewer, more stable electronic components, and, more importantly, is much faster. Complete calibration and acquisition for a typical 20-point profile required less than 60 min. Corrections (e.g., of ambient temperature drift) are easily implemented in software. Although specific hardware with particular response equations are presented, the approach taken is very general and could be easily adapted to different measurement conditions, other types of anemometers, or three-wire probes.

The experimental procedure and apparatus are discussed in detail in the next section. Hot-wire response equations — which give simple but accurate relations for the cooling law, directional sensitivity, and the effects of ambient temperature drift — and algorithms for computing desired statistical signal properties, such as mean, variance, and higher-order cross-correlations, are presented in the third section. Sample results from an experiment to measure turbulence quantities in a plane mixing layer are provided in the fourth section, and concluding remarks are presented in the final section. Software for both single- and crossed-wire systems written in BASIC to run on the HP 9845B desk-top computer is included in the appendix.

2. EXPERIMENTAL PROCEDURE AND APPARATUS

Experimental Procedure

The hardware configuration of the system is conceptually simple and requires little routine adjustment. Two DISA constant-temperature bridges were employed to drive the crossed-wires. A fixed dc shift and gain were applied to the bridge outputs which were low-pass filtered (to remove high-frequency electrical noise) and then input to a bipolar 12-bit A/D converter. An external clock generated a sample pulse (typical sampling rate was 500 Hz) to the A/D which caused the two inputs to be frozen ("sample-and-hold"). These channels were sequentially converted; the converted values passed through a multiplexer to a high-speed, 16-bit parallel interface to the computer. After filling the computer's data buffer, raw data were written to floppy disk. The raw data were reduced off-line to provide the signal statistics. Before data acquisition began, a complete system calibration check was performed, and relevant quantities were written to the floppy-disk data files. Taking up to 3,000 samples per data point required less than 2 min; the calibration procedure required about 15 min. Thus, a typical 20-point profile required less than a hour for data acquisition (including calibration), using the program shown here (see appendix sec. A.1.2). The current off-line data reduction program (see appendix sec. A.1.3) took about 45 min to reduce these data.

Simple but established models have been implemented to describe the sensitivity of the constant-temperature hot-wire to variations in flow velocity, wire orientation, and ambient temperature drift. The relations selected are applicable to incompressible, isothermal flow of "clean" (filtered) air over a fine wire with "moderate" local turbulence intensity (less than about 30%) and negligible instantaneous local flow reversal frequency. King's law was used to provide a relation between the "effective" cooling velocity and the bridge output. A "cosine law" was used to relate the effective cooling velocity to the magnitude and direction of the velocity vector. The entire calibration was shifted to account for the effects of small ambient temperature changes over the course of a run, based on the overheat ratio and wire resistivity. Once the King's law calibration was implemented and shifted for ambient temperature drift, the effective velocities measured by each wire were used to solve for the instantaneous velocity components in the measurement plane by inverting the angular sensitivity matrix. Then the instantaneous values of the velocity components were used to form the statistical properties of the signal. Computed results included the mean and variance, as well as second- and third-order cross-correlations (i.e., $\overline{u}$, $\overline{v}$, $\overline{u'^2}$, $\overline{v'^2}$, $\overline{u'v'}$, $\overline{u'^2v}$, $\overline{v'^2u'}$ for wires in the u-v plane).

Experimental Apparatus

Figure 1 shows the system hardware schematically and provides a list of component manufacturers and model numbers. In the following discussion of the hardware, the system is divided into four areas: (1) probes used, (2) DISA bridges and signal conditioners, (3) NASA LDV-A/D computer interface, and (4) HP computer interface, desk-top computer, and floppy-disk drive. Little explicit mention will be made of the digital voltmeter or oscilloscope, which are used to monitor the analog signals, or of the pulse generator, which provides a sample trigger to the A/D converter.

<u>Crossed-wire probes</u>- Miniature crossed-wire probes were manufactured in-house at Ames. These probes had two nominally perpendicular wires mounted at angles of about

±45° to the probe stem (see fig. 2). The planes that contain each wire and its two support needles were parallel and separated by about 1 mm. The wires were 5-μm tungsten elements about 1 mm long; they were welded to the supports. The "cold" (room-temperature) resistance of each wire was about 5 ohms, and the operating overheat ratio used was 1.8 (ratio of hot, or operating, resistance to cold, or unheated, wire resistance). The probe tips were mounted in a stem which was in turn held in a rotating collar. A spring-loaded mechanism in the collar could be rotated to yaw the probe in five fixed positions in 5° increments. In this way, yaw calibration of the wire was performed. Often it was convenient to mount the probe so that the axis of rotation of the collar was parallel (rather than perpendicular) to the desired plane of measurement. Then a special procedure was used wherein the yaw calibration was performed in the u-w plane, but the probe was then rotated about the stem axis for measurement in the u-v plane (see Summary: Calibration and Data-Acquisition Procedure in the next section).

Bridges and signal conditioners- Two DISA 55D31 bridges were used to operate the crossed hot-wires at constant temperature. The cable resistance was compensated for using a shorting probe. The probe resistance was measured, and the operating resistance of each probe was set at 1.8 times the cold resistance; this is a nominal value, because the operating resistance was not changed to account for daily changes in ambient temperature. However, the frequency response was checked daily as described below.

The frequency response of each channel was optimized using the internal 1-kHz square-wave generator and varying the bridge gain (as well as the cable compensation adjustments). Typically, the "3-dB-down" point was about 20 kHz on each channel (Freymuth method). A bridge gain of 4 and an HF filter setting of 2 were usual values. The bridge output voltage ranged from about 3 V (no-flow) to about 4.7 V (25 m/sec flow velocity); since the input voltage range of the available A/D converter was -10 to +10 V (with 12-bit resolution), linear signal conditioning elements were used to obtain better resolution of the bridge output voltage.

Commercial signal conditions manufactured by DISA (model 55D26) were used to dc shift, to amplify, and to low-pass filter the bridge outputs before A/D conversion. A dc shift of about 4 V and a gain of 10 were applied to each channel, yielding a voltage covering most of the ±10-V range of the 12-bit A/D converter. Note that the exact values of the gain and offset used were calibrated during setup of the system for each run (see the description of the software below), so that it was not necessary for the actual gain or offset to be determined from the nominal settings. The low-pass filter cutoff was 10 kHz with 18 dB/octave roll-off; the high-pass stage was set to "direct." The filtering was intended to eliminate spurious electrical noise which would contaminate measurements of low turbulence intensity.

NASA LDV-A/D computer interface- Two channels of the A/D conversion stage of the NASA LDV-A/D computer interface (ref. 1) were used to convert the conditioned signals to digital form and multiplex them to the HP computer interface (described below). Figure 1 shows how the NASA LDV-A/D fits into the measurement system, and figure 3 gives the details of the various settings and connections for the interface. A sample pulse was generated by a Tektronix PG 508 pulse generator and applied to the "channel 1 event" and "external reset" inputs. This signal acted as a sampling trigger to initiate a "sample-and-hold" of the two A/D inputs when the interface was enabled by the computer setting "CTL0."

Four 16-bit TTL data words were then multiplexed to the computer. The first word gave the time between samples (a count dependent on the operating mode (see ref. 1 for details)); these data were typically discarded after verifying that the nominal sample rates were actually attained. The second word gave status information; it was also checked then discarded. The third and fourth words were the two channels of anemometry data in directly computer-compatible integer representation. Since the A/D that was used had only 12 bits of resolution, this required that the upper 4 bits be either all 0's or all 1's, depending on whether the converted voltage was positive or negative, respectively. Thus, the converted A/D data could take on integer values of -2,048 to +2,047, inclusive.

An important feature of the NASA LDV-A/D hardware was the fast sample-and-hold hardware. The measurement strategy required that the two channels be sampled simultaneously so that the instantaneous-velocity vector components in the measurement plane could be determined. Since the frequency response of the anemometer was limited to about 20 kHz, it was desirable that the two signals be sampled within, say, 10 μsec or so. The sample-and-hold hardware in the LDV-A/D was capable of locking in the input analog signal within 0.5 μsec of receiving the sample trigger. Then the A/D conversion and multiplexing could take place asynchronously (as long as all four words were passed before the next sample pulse). For each A/D conversion, a minimum of 14 μsec were required.

HP computer and parallel interface- Multiplexed data were passed to the HP computer from the NASA LDV-A/D using the HP 98032A high-speed 16-bit parallel interface. Jumpers labeled "9,B,D" were connected inside the 98032A for proper operation with the LDV-A/D. A select code of 10 (screw setting on the 98032A) was set for use with the software described in the appendix.

A data buffer of 24 kbytes was provided in the memory of the HP 9845B desk-top computer for storage of up to 3,000 samples obtained from one measurement location (four words of 2 bytes each are passed from the LDV-A/D). Since two of the four data words passed for each sample were merely monitored and discarded as described above, 12 kbytes of raw data remained to be stored for each point. An HP 9895A floppy-disk drive was used for archival storage of raw data. The buffered data were written in real time to a sequential-access floppy-disk file. Enough header information was written to each file to identify the run, as well as to reproduce calibration tables and correct for ambient temperature drift. About 1 min per point was required for storing the data on floppy disk.

Fairly rapid and simple data buffering was possible with the HP computer, using convenient high-level commands. Sampling rates as high as 10,000 samples per second were used (indicating interface transfer rates 4 times as high in 16-bit words per second). Direct memory access (DMA) was not used; the processor was simply dedicated to the real-time task.

The system described above was also streamlined for the simplified case of single-channel, hot-wire anemometry. Of course, just half the hardware shown before the A/D in figure 1 was needed. The calibration procedure consisted of simply setting up the signal conditioner and compiling the King's law data. On-line data reduction was implemented, since this could be done rapidly with only one channel. Thus, the look-up table was constructed immediately following the static velocity calibration and implemented after filling each data buffer. Mean and fluctuating values of velocity were stored; raw data were not usually archived.

A DISA 55P11, platinum-plated, tungsten hot-wire was used for the single-wire work. The overheat ratio and bridge setup were exactly as described earlier. The BASIC program to run the single-wire anemometry system is provided in the appendix.

3. CROSSED-HOT-WIRE RESPONSE EQUATIONS

Simple relations that describe the response of a fine, heated wire to variations in flow velocity, orientation, and ambient temperature drift have been incorporated into the off-line data reduction program. Of course, the equations selected have a strong effect on the type of calibration performed and on the accuracy of the results. The response equations are first discussed separately, the calibration procedure is summarized, and the algorithms actually used for implementing the response equations and computing the signal statistics are then given.

Static Velocity Response: King's Law

The effective, instantaneous wire velocity was assumed to be related to the bridge output voltage by the generalized King's law:

$$U_{eff} = K(E_{eff}^2 - E_o^2)^{1/n} \tag{1}$$

This is an approximate relation which has been determined to be fairly accurate in describing the steady-flow heat loss over cylinders in cross-flow; the (constant) value of the log slope n selected (0.45) provides a good fit to experimental data at moderate-to-low Reynolds numbers, based on wire diameter. Our steady-flow calibration data fit King's law with an rms error of 0.5% over the range of 5-25 m/sec. Although simple interpolation or polynomial fit of the calibration may seem equally acceptable, the log-linear King's law fit provides a quick way to evaluate whether the calibration is "typical," and it smooths minor "jitter" in the calibration data. Also, the King's law calibration may be confidently extrapolated slightly outside the range of the actual calibration data.

Yaw Sensitivity: Cosine Law

The "effective cooling velocity" is taken to be that component of the velocity vector perpendicular to the wire. This assumption implies that a wire yawed in a uniform constant-velocity stream will respond to an effective flow velocity that is proportional to the cosine of the yaw angle (see fig. 2 for nomenclature). Neglecting the axial component of velocity (along the wire axis) is strictly an approximation — one that is often made, however, and one that works quite well for moderately turbulent flows.

$$U_{eff} = |V| \cos \psi \tag{2}$$

For two wires at angles ψ_1 and ψ_2 to the reference coordinate direction, the following two equations result, if sensitivity to out-of-plane velocity fluctuations is neglected:

$$\begin{aligned} U_{eff_1} &= u \cos \psi_1 + v \sin \psi_1 = K_1(E_1^2 - E_{01}^2)^{1/n_1} \\ U_{eff_2} &= u \cos \psi_2 + v \sin \psi_2 = K_2(E_2^2 - E_{02}^2)^{1/n_2} \end{aligned} \tag{3}$$

Here u and v are the instantaneous velocity components in the measurement plane. Note that U_{eff} for each wire may be found immediately from the King's law calibration; only the bridge voltage must be known. A matrix form more convenient for discussion or generalization is

$$[U_{eff}] = [\psi][V] \tag{4}$$

The entries for the angular sensitivity matrix are found by a yaw-calibration procedure described below. Then, the inverse of this matrix is computed once and stored. Solution for the instantaneous velocity components is simple:

$$[V] = [\psi]^{-1}[U_{eff}] \tag{5}$$

The explicit solution of equation (3) gives the equations actually used to compute the instantaneous velocity components:

$$\left.\begin{aligned} u &= \frac{(\sin\psi_1)U_{eff_2} - (\sin\psi_2)U_{eff_1}}{(\sin\psi_1)(\cos\psi_2) - (\cos\psi_1)(\sin\psi_2)} \\ v &= \frac{(\cos\psi_2)U_{eff_1} - (\cos\psi_1)U_{eff_2}}{(\sin\psi_1)(\cos\psi_2) - (\cos\psi_1)(\sin\psi_2)} \end{aligned}\right\} \tag{6}$$

Temperature Drift Correction

Temperature drift of a few degrees Fahrenheit is commonly encountered and has some effect on measurement accuracy since the probe is operated at constant temperature. For typical wire-overheat ratios and sensor resistivity properties, the temperature difference between the wire and flow is a few hundred degrees Fahrenheit, so that a few degrees drift will change the perceived heat-transfer coefficient between wire and flow by a percent or so. A small correction to the bridge voltage is applied to account for this variation in ambient temperature:

$$\frac{E_{corr} - E_{meas}}{E_{meas}} = \frac{\alpha}{2(\mathrm{OHR})}(T - T_{cal}) \equiv C \tag{7}$$

where C represents the percent shift required for the instantaneous bridge voltage — fixed by the operating parameters and current-flow temperature. Since fluctuations in the bridge voltage are fairly small, a further simplifying approximation is that the instantaneous bridge voltage can be simply shifted by the fixed percentage of the average output voltage. Then the calibration is easily implemented after the shift is computed and applied to each voltage reading. The equation actually used is then

$$E_{corr} = E_{meas} + C \times \bar{E}_{meas} \tag{8}$$

Note that each voltage reading is corrected for ambient temperature changes. The correction will, therefore, influence both mean and fluctuating time-averaged results, as it should.

Summary: Calibration and Data-Acquisition Procedure

Figure 4 shows a flowchart that represents the verbal description of the calibration and data-acquisition procedure below. The calibration consisted of four steps performed for each channel: (1) in-place calibration of the A/D converter and DISA signal conditioner; (2) static calibration for determining the King's law constants; (3) yaw calibration with wires in the u-w plane; and (4) recalibration to determine the effective angle in the measurement plane (if differenct from the u-w plane). Data acquisition with the calibrated system consisted of acquiring the data from the two channels in a buffer then dumping the buffer with identifying information to a floppy-disk file.

The shorted-input reading of the A/D converter can drift a few bits from the nominal value of 0 and was, therefore, checked for each run. Then a reference dc voltage was measured with the signal conditioners bypassed. An offset value was then fixed on the dc offset stage of the DISA 55D26 conditioner and the offset was deduced by measuring the A/D value for the known reference with added offset. Finally, a gain was applied to the offset reference voltage through the amplifier section of the DISA conditioner. The effective value of the gain factor could be deduced since the input reference voltage and offset were accurately known. From the known calibration constants, the bridge output voltage could be accurately computed from the measured A/D converted value.

Static calibration of the wire velocity response was performed with the wire at fixed orientation in a steady flow of variable velocity. Note, however, that the actual orientation is not yet known, but is to be determined through calibration. If the calibration velocity is taken to be U, then, from equation (2),

$$U_{eff} = U \cos \psi \tag{9}$$

where ψ is the angle between the calibration velocity vector and the wire. We first aligned the probe so that the wires lay in the u-w plane; this wire angle is called ψ_{uw}. With equation (1), this yields

$$U = K'_{uw}(E^2 - E_o^2)^{1/n} \tag{10}$$

where

$$K'_{uw} = K/(\cos \psi_{uw}) \tag{11}$$

Thus, the constants K'_{uw} and E_o^2 were determined from a straightforward, linear, least-square fit of the calibration data with n specified (n is dependent on the calibration range; we used $n = 0.45$ for $5 < U < 25$ m/sec). Next, ψ_{uw} was determined via direct yaw calibration (see below); K was then computed from equation (11).

The wires are now set at various known angles to the calibration flow in order to determine the "effective" wire angle ψ_{uw}. The calibration velocity was held constant in magnitude and direction at a value of about 70% of the maximum calibration velocity. If the yaw angle relative to the effective angle ψ_{uw} is denoted δ, then equation (3) can be used to derive an equation that relates the bridge output for $\delta = 0$ to the output for a particular value of δ; rearranging yields an expression for the effective wire angle ψ_{uw}:

$$\tan \psi_{uw} = \frac{\cos(\delta_1) - \dfrac{U_{eff}(\delta = \delta_1)}{U_{eff}(\delta = 0)}}{\sin(\delta_1)} \tag{12}$$

In practice, we computed ψ_{uw} for four different values of delta of -10°, -5°, 5°, and 10°. These results were averaged to get the value of ψ_{uw}.

Now the system is calibrated for measurement in the u-w plane. When measurements in the u-v plane were desired, one further step was required. The probe stem was first rotated 90° to position the wires in the u-v plane. At this point, the effective wire angle ψ_{uv} is unknown; although ψ_{uv} would be nominally the same as ψ_{uw}, it can be slightly different because of slight pitching of the probe stem. Another static velocity calibration was performed as described above. However, this time n and E_0^2 were fixed when the King's law was fitted to the data; K'_{uv} was found by linear least-square fit, then ψ_{uv} was computed as before:

$$\cos(\psi_{uv}) = K/K'_{uv} \tag{13}$$

Data acquisition now took place. Identifying information regarding, for example, run number and probe position, was entered from the keyboard. The current flow temperature (measured with a thermocouple and digital readout) was also entered from the keyboard. Then the data buffer would be filled. A few samples were used to compute the average bridge voltage for use in computing the temperature shift. The temperature correction shift was written to the floppy-disk data file along with the identifying information, calibration data, and the raw data buffer; 25 kbytes were provided for each data file. Probe calibrations were fairly stable and repeatable for several hours of running, so that 60-100 data points could be reduced using the same calibration constants with the ambient drift correction.

Computation of Signal Statistics

Figure 5 is a flowchart of the data-reduction algorithm for computing signal statistics. Starting with raw data written into floppy-disk files as described above, the data reduction began with construction of a look-up table from which a velocity could be assigned to any raw A/D voltage. This simply required that for every possible A/D reading, the King's law calibration be used to compute a corresponding effective flow velocity, U_{eff}. Then, after adding the temperature correction shift to each reading, the table was entered for every raw data sample. The result for a single reading would be two values of U_{eff} — one from each channel of the crossed wires. Equation (6) was then used to compute the values of the instantaneous velocity components u and v. Once the calibration was implemented and the instantaneous-velocity vector components computed for each raw data point pair, the various signal statistics were computed. It is noteworthy that wherever reference is made to an average value, the average is computed using the "running average" formula:

$$S\langle a(i)\rangle = A(i = Ns) \tag{14}$$

where

$$A(i) = A(i - 1) + [a(i) - A(i - 1)]/i \tag{15}$$

Average values of the various moments were computed as defined below:

$$\left.\begin{aligned}
Su &= S\langle u(i)\rangle/Ns \\
Sv &= S\langle v(i)\rangle/Ns \\
Suu &= S\langle u(i)u(i)\rangle/Ns \\
Suv &= S\langle u(i)v(i)\rangle/Ns \\
Svv &= S\langle v(i)v(i)\rangle/Ns \\
Suuv &= S\langle u(i)u(i)v(i)\rangle/Ns \\
Suvv &= S\langle u(i)v(i)v(i)\rangle/Ns
\end{aligned}\right\} \qquad (16)$$

Using these definitions, the signal statistics were then computed assuming nearly infinite sample size:

$$\left.\begin{aligned}
\bar{u} &= Su \\
\bar{v} &= Sv \\
\overline{u'^2} &= Suu - SuSu \\
\overline{v'^2} &= Svv - SvSv \\
\overline{u'v'} &= Suv - SuSv \\
\overline{u'^2v'} &= Suuv - 2SuSuv - SvSuu + 2SvSuSu \\
\overline{u'v'^2} &= Suvv - 2SvSuv - SuSvv + 2SuSvSv
\end{aligned}\right\} \qquad (17)$$

4. SAMPLE RESULTS FOR A PLANE MIXING LAYER

Selected results of measurements made in the near-field of a plane mixing layer are presented in figure 7. Figure 6 depicts the situation and needed reference quantities. The mixing-layer velocity ratio was about 2:1, with a maximum velocity of 21 m/sec. Results for both tripped and untripped initial boundary layers are presented in figure 7.

The profiles of mean velocity shown in figure 7(a) were fitted to the similarity coordinates for the developed mixing layer as recommended by, for example, Townsend (ref. 2). The fit results in a collapse of the mean profiles to the error function shape at successive streamwise locations, and the growth rate inferred from the resulting thickness parameter can be used to check the measured values of $\overline{u'v'}$ shown in figure 7(d). The actual values and trends of the turbulence quantities, such as those shown in figure 7(b-d), measured using the present system, compare extremely well with theory and data from other experiments. Full details of the measurements in plane mixing layers are given in reference 3.

5. CONCLUDING REMARKS

A system for rapid computerized acquisition and processing of analog signals from a hot-wire anemometer has been developed. Probe calibration is also implemented in the system. Correction for ambient temperature drift is implemented in the software. Complete calibration and acquisition for a typical 20-point profile requires less than 60 min.

Data acquired with this system in a plane mixing layer, including turbulence measurements up to third-order correlations, agree well with theory and existing data.

APPENDIX

SOFTWARE FOR THE HP9845B DESK-TOP COMPUTER

The HP9845B desk-top computer used included an I/O ROM and ran programs written in BASIC. Three programs are included: "UWIRE," a program for single hot-wire data acquisition and real-time data reduction; "XWIRE," for calibration, data acquisition, and storage of data using the crossed hot-wire CTA system; and "UVBAR," used to reduce the data from files written by the data acquisition program "XWIRE."

```
10     REM  PROGRAM UWIRE
20     !  PROGRAM TO ACQUIRE SINGLE-WIRE DATA USING THE LDV-A/D CI
30     OPTION BASE 1
40     DIM Titl$[80],Ystr$ [illegible]   ! information strings for data file
50     INTEGER D1(3000,4)      !data buffer
60     INTEGER S(3000),C(2,3000),T(3000      ! [illegible] words from CI
70     INTEGER Ns
80     INTEGER Zero,Eref,Off,Egain,Eoff,Ezero,E1a  R1av
90     INTEGER Obts,Off1
100    INTEGER E1in(20)
110    INTEGER E0del,Edel(10)
120    INTEGER J,Jntr
130    INTEGER Ical,Ipt,Ncal
140    REAL Rgain,Gain
150    REAL V1(20),Ucal(20)
160    REAL N,K,Esq
170    REAL U1cal,Tcal,Tnow,Ohr,Alpha
180    REAL Vhwb,Uest
190    REAL Ueff(4096)    ! look-up table for Ueff calibration 12-bit A/D
200    REAL Yval(30)
210    SHORT Ueff12(3000) ! data array written to floppy
220    SHORT Ubar(30),Upri(30)
230    PRINT
240    PRINTER IS 0
250    PRINT "** << PROGRAM UWIRE : FULLY-DIGITAL U-WIRE DATA ACQISITION >> **"
260    PRINT
270    PRINT " PROGRAM STRUCTURE :"
280    PRINT " 1. Calibrate the A/D converter of the LDV CI."
290    PRINT " 2. Calibrate the probe vs. velocity."
300    PRINT " 3. Construct look-up table."
310    PRINT " 4. Acquire data and write U to disk file."
320    PRINT " 5. Repeat (4.) for each data point taken."
330    PRINT " 6. Reduce data off-line with another program."
340    PRINT
350    !
360    ! ** Calibrate the A/D channel 1
370    !
380    PRINT
390    PRINT "** CALIBRATION OF THE A/D CONVERTER **"
400    PRINT
410    Ns=10          !10 samples are averaged at each point
420    Ic[illegible]n=1
430    GOSUB Adcal
440    Ezero=Zero
450    Eoff=Off
460    Gain=Rgain
470    !
480    ! ** Calibrate wire vs. velocity
490    !
500    !     1. Compile raw calibration data table
510    PRINT
520    PRINT "** CALIBRATION TO DETERMINE Ebridge vs. Ueff **"
530    PRINT
540    INPUT "Enter calibration flow temperature in deg. F:",Tcal
550    Tcal=.5556*(Tcal-32)
560    INPUT "Enter wire temperature resistivity coefficient :",Alpha
570    INPUT "Enter nominal overheat ratio used (about 1.8) :",Ohr
580    ! NOTE: Wire parameters are needed to do temperature correction
590    PRINT "Kings Law will be used to construct the look-up table -"
```

```
600   PRINT "                   U = K*(E^2-E0^2)**(1/N)"
610   PRINT "The constants K, E0^2, and N may be determined from direct"
620   PRINT "calibration or input directly. Enter C to calibrate, or I"
630   PRINT "to input the constants directly."
640   INPUT "     (enter C or I) :",Cal$
650   IF Cal$="C" THEN GOTO 720
660   IF Cal$="I" THEN GOTO 680
670   GOTO 640
680   INPUT "Enter K : ",K
690   INPUT "    E0^2 : ",Esq
700   INPUT "       N : ",N
710   GOTO 960
720   INPUT "Enter no. points to be taken (<= 20 total) :",Ncal
730   Ns=100          !100 samples are to be taken at each point
740     FOR Ical=1 TO Ncal
750     PRINT "Point no. ";Ical
760     INPUT "Enter calibration velocity :",Ucal(Ical)
770     GOSUB Atod
780       E1in(Ical)=0          !compute average bridge output value
790       FOR Icpt=1 TO Ns
800       E1in(Ical)=E1in(Ical)+(C(1,Icpt)-E1in(Ical))/Icpt
810       NEXT Icpt
820   !     2. Convert to volts
830     V1(Ical)=FNVbrg(E1in(Ical),Ezero,Eoff,Gain)
840     PRINT Ical;Ucal(Ical);V1(Ical)
850     NEXT Ical
860   PRINT "** CALIBRATION DATA ACQUISITION COMPLETE **"
870   PRINT
880   !     3. Perform King's law fit
890   PRINT "Perform King's law fit --"
900   PRINT "Channel 1 :"
910   CALL Hwcal(Ncal,V1(*),Ucal(*),N,K,Esq)
920   PRINT
930   !
940   ! ** Construct look-up table to implement the calibration
950   !
960   PRINT
970   PRINT "** LOOK-UP TABLE CONSTRUCTION AND VERIFICATION **"
980   PRINT
990   ! The matrix Ueff is a look-up table of values of velocity
1000  ! from the King's Law fit versus the input value.
1010    FOR J=1 TO 4096
1020    Vhwb=FNVbrg(J,Ezero,Eoff,Gain)
1030    IF Vhwb^2>Esq THEN GOTO 1060
1040    Ueff(J)=0
1050    GOTO 1070
1060    Ueff(J)=FNKing(Vhwb,K,Esq,N)
1070    NEXT J
1080  IF Cal$="I" THEN GOTO 1240
1090  PRINT "Re-contruction of calibration data :"
1100  PRINT
1110  ! Verify look-up table by re-constructing calibration data
1120  !
1130  PRINT "PT.  Uactual  E1   U1CAL"
1140  PRINT "------------------------------"
1150    FOR Icpt=1 TO Ncal
1160    Jntr=E1in(Icpt)
1170    U1cal=Ueff(Jntr)
1180    PRINT Icpt;Ucal(Icpt);E1in(Icpt);U1cal
```

```
1190    NEXT Icpt
1200  PRINT
1210  !
1220  ! ** Acquire and store data at successive points:
1230  !
1240  Isft1=0
1250  Tnow=Tcal
1260  PRINT "** DATA ACQUISITION **"
1270  PRINT
1280  PRINT "   Enter run parameters: "
1290  PRINT
1300  INPUT " - No. data samples per point (<3000) :",Ns
1310  REDIM Ueff12(Ns)
1320  PRINT "Enter response to determine type of data file to write:"
1330  PRINT "N - no data file written"
1340  PRINT "R - raw data written at each point"
1350  PRINT "S - only summary written at the end of the profile"
1360  INPUT "Enter N, R, or S :",Afil$
1370  IF Afil$="N" THEN GOTO 1400
1380  PRINT "Enter parent filename - for raw data file, the point number"
1390  PRINT "is appended to this name. This will be the name used for a"
1400  PRINT "summary data file."
1410  INPUT "Enter filename :",Name$
1420  INPUT " - Enter Y if temperature correction is desired :",Atem$
1430  Ipt=1
1440  !     1. Move to next location (& enter flow temp if correcting)
1450  PRINT
1460  PRINT "POINT NUMBER : ";Ipt
1470  INPUT "Enter Y location :",Yval(Ipt)
1480  INPUT "Enter flow temperature in deg. F: ",Tnow
1490  Tnow=.5556*(Tnow-32)
1500  !     2. Obtain raw data
1510  GOSUB Atod
1520  !     3. Estimate average bridge output voltage (if temp correcting)
1530  E1av=0
1540    FOR I=1 TO 10
1550    E1av=E1av+(C(1,I)-E1av)/I
1560    NEXT I
1570  Uest=Ueff(E1av)
1580  V1av=FNVbrg(E1av,Ezero,Eoff,Gain)
1590  PRINT "Approx. A/D value = ";E1av;" =>";V1av;" Volts & U = ";Uest
1600  IF Atem$<>"Y" THEN GOTO 1670
1610  R1av=Gain*Eoff+(E1av-Ezero)
1620  !     4. Compute shift to calibration for temperature drift
1630  Isft1=FNShift(Alpha,Ohr,Tcal,Tnow,R1av)
1640  Uest=Ueff(E1av+Isft1)
1650  Vest=FNVbrg(E1av+Isft1,Ezero,Eoff,Gain)
1660  PRINT "Shifted A/D value = ";E1av+Isft1;" =>";Vest;" Volts & U = ";Uest
1670  !     5. Implement look-up table
1680  Ubar(Ipt)=0
1690  Upri(Ipt)=0
1700    FOR J=1 TO Ns
1710    J1lt=C(1,J)+Isft1
1720    Ueff12(J)=Ueff(J1lt)
1730    Ubar(Ipt)=Ubar(Ipt)+(Ueff12(J)-Ubar(Ipt))/J
1740    Upri(Ipt)=Upri(Ipt)+(Ueff12(J)*Ueff12(J)-Upri(Ipt))/J
1750    NEXT J
1760  Upri(Ipt)=Upri(Ipt)-Ubar(Ipt)*Ubar(Ipt)
1770  Upri(Ipt)=SQR(Upri(Ipt))
```

```
1780  PRINT "Y= ";Yval(Ipt);"UBAR = ";Ubar(Ipt);"  UPRIME = ";Upri(Ipt)
1790  PRINT
1800  IF Afil$<>"R" THEN GOTO 1830
1810  !    6. Store data on floppy disk
1820  GOSUB Dfile
1830  PRINT
1840  INPUT "Enter Y to take another data point, else N : ",Ans$
1850  IF Ans$="N" THEN 1900
1860  IF Ans$<>"Y" THEN 1840
1870  Ipt=Ipt+1
1880  GOTO 1450
1890  !
1900  REDIM Ubar(Ipt)
1910  REDIM Upri(Ipt)
1920  REDIM Yval(Ipt)
1930  IF Afil$="S" THEN GOSUB Dfile
1940  PRINT "Enter one of the following to proceed:"
1950  PRINT "M - Take another profile with same calibrations"
1960  PRINT "R - Recalibrate"
1970  PRINT "E - Exit program"
1980  INPUT "Press M, R, or E :",Ans$
1990  IF Ans$="M" THEN GOTO 1200
2000  IF Ans$="R" THEN GOTO 380
2010  IF Ans$="E" THEN GOTO 2030
2020  GOTO 1980
2030  END
2040  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2050  ! ************** END OF MAIN PROGRAM UWIRE **************
2060  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2070 Dfile:      ! write data file to floppy
2080  PRINT
2090  PRINT "** DATA FILE WRITE TO FLOPPY DISK **"
2100  PRINT
2110  PRINT "At this point be sure there is a floppy in drive 0 of"
2120  PRINT "the 9895A with space for a file of 50, 256-byte records."
2130  DISP "**** Press CONT to proceed when ready ****"
2140  PAUSE
2150  DISP "**** File write in progress ****"
2160  File$=Name$
2170  IF Afil$="R" THEN File$=Name$&VAL$(Ipt)
2180  MASS STORAGE IS ":H8,0,0"    ! set floppy drive (9895A drive 0) as default
2190  CREATE File$,50               ! open file with 100 records 256 bytes each
2200  ASSIGN File$ TO #1
2210  PRINT #1;Titl$
2220  IF Afil$="R" THEN PRINT #1;Yval(Ipt)
2230  PRINT #1;K,Esq,N
2240  PRINT #1;Tcal,Tnow,Alpha,Ohr
2250  PRINT #1;Isft1
2260  PRINT #1;Ns
2270  IF Afil$="S" THEN MAT PRINT #1;Yval
2280  IF Afil$="S" THEN MAT PRINT #1;Ubar
2290  IF Afil$="S" THEN MAT PRINT #1;Upri
2300  IF Afil$="R" THEN MAT PRINT #1;Ueff12
2310  ASSIGN * TO #1          ! close data file
2320  DISP "**** File write completed ****"
2330  RETURN
2340  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2350 Adcal:   ! calibrate the A/D converter of the LDV CI
2360            ! enter the routine with Ichan and Ns set
2370  ! !!! This segment is for fixing the shorted-input value
```

```
2380  PRINT
2390  PRINT " *** Calibrate the A/D converter channel ";Ichan;" ***"
2400  DISP "Short input of channel ";Ichan;" then press CONT"
2410  PAUSE
2420    GOSUB Atod
2430  !  Average the 10 readings to get the zero value
2440    Zero=0
2450    FOR I=1 TO Ns
2460    Zero=Zero+C(Ichan,I)
2470    NEXT I
2480  Zero=Zero/Ns
2490  PRINT "Zero-level output is : ";Zero;" of 12 bits"
2500  ! !!! Now read the reference value
2510  PRINT "Now calibrate the GAIN=1 vs. DIRECT before proceeding"
2520  DISP "Connect REF voltage to chan ";Ichan;" then press CONT"
2530  PAUSE
2540    GOSUB Atod
2550    Eref=0
2560    FOR I=1 TO Ns
2570    Eref=Eref+(C(Ichan,I)-Eref)/I
2580    NEXT I
2590  PRINT "Reference voltage applied to channel";Ichan;" is ";Eref
2600 ! !!! Offset calibration
2610  DISP "Apply an OFFSET to channel ";Ichan;" then press CONT"
2620  PAUSE
2630    GOSUB Atod
2640    Off=0
2650    FOR I=1 TO Ns
2660    Off=Off+(C(Ichan,I)-Off)/I
2670    NEXT I
2680  Obts=Off
2690  Off1=Eref-Off
2700  PRINT "Offset value is : ";Off1
2710  ! !!! Set GAIN now
2720  DISP "Set GAIN on channel";Ichan;" then press CONT"
2730  PAUSE
2740    GOSUB Atod
2750    Egain=0
2760    FOR I=1 TO Ns
2770    Egain=Egain+(C(Ichan,I)-Egain)/I
2780    NEXT I
2790  Rgain=(Egain-Zero)/(Obts-Zero)
2800  PRINT "Gain is : ";Rgain
2810  ! !!! Reset OFFSET as desired
2820  DISP "Reset OFFSET on channel";Ichan;" then press CONT"
2830  PAUSE
2840    GOSUB Atod
2850    Off=0
2860    FOR I=1 TO Ns
2870    Off=Off+(C(Ichan,I)-Off)/I
2880    NEXT I
2890  Off=(Egain-Off)/Rgain+Off1
2900  PRINT "Final OFFSET value is : ";Off;" bits"
2910  RETURN
2920 ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2930 Atod:  ! Subroutine for input from the LDV-A/D CI
2940        ! Enter routine with Ns=no. samples
2950  DISP "Press CONT to initiate data acqusition"
2960  PAUSE
```

```
2970  RESET 10
2980  CONTROL MASK 10;1
2990  WRITE IO 10,5;0
3000  WRITE IO 10,5;1   !start handshake by setting CTL0
3010  Nt=4*Ns
3020    FOR I=1 TO 3
3030    Dummy=READBIN(10)
3040    NEXT I
3050    REDIM D1(Ns,4)
3060      ENTER 10 WFHS Nt NOFORMAT;D1(*) !fast data acquisition
3070      FOR I=1 TO Ns
3080      C(1,I)=D1(I,3)+2048
3090      NEXT I
3100  DISP "Data acqusition complete"
3110  RETURN
3120  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3130 SUB Hwcal(INTEGER Np,REAL E(*),REAL U(*),REAL N,REAL K,REAL Esq)
3140  ! Subprogram to compute hot-wire calibration constants for
3150  ! King's law calibration via linear least square fit
3160  OPTION BASE 1
3170  INPUT "Enter exponent N (approx. 0.45) : ",N
3180    L0=0           ! initialize sums for linear least-squares fit
3190    L2=0
3200    S2=0
3210    S4=0
3220    FOR I=1 TO Np
3230    L0=L0+U(I)^N
3240    L2=L2+E(I)^2*U(I)^N
3250    S2=S2+E(I)^2
3260    S4=S4+E(I)^4
3270    NEXT I
3280  D=S2*S2-Np*S4
3290  A=(L0*S2-Np*L2)/D
3300  B=(S2*L2-S4*L0)/D
3310  K=A^(1/N)                   ! scale factor
3320  Esq=-B/A                    ! effective no-flow bridge output squared
3330  PRINT "Scale factor : ";K
3340  PRINT "Ezero squared: ";Esq
3350    Err=0           ! compute RMS % error of the fit
3360    FOR I=1 TO Np
3370    Err=Err+((U(I)-K*(E(I)*E(I)-Esq)^(1/N))/U(I))^2
3380    NEXT I
3390  Err=100*SQR(Err/Np)
3400  PRINT "RMS percent error of the fit : ";Err;" %"
3410  SUBEND
3420  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3430 DEF FNVbrg(INTEGER Ein,INTEGER Zero,INTEGER Off,REAL Gain)
3440  ! Compute the bridge output voltage based on calibration values
3450  RETURN ((Ein-Zero)/Gain+Off)*20/4096
3460  FNEND
3470 DEF FNYaw(REAL Del,REAL Ebr,REAL A,REAL N,REAL E0brs)
3480  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3490 DEF FNKing(REAL Ebr,REAL K,REAL E0sq,REAL N)
3500  ! Compute velocity based on King's Law calibration constants
3510  RETURN K*(Ebr^2-E0sq)^(1/N)
3520  FNEND
3530  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3540 DEF FNShift(REAL Alpha,REAL Ohr,REAL Tref,REAL T,INTEGER R)
3550  ! Compute temperature drift correction to bridge voltage
```

```
3560  Cpct=Alpha*(T-Tref)/(2*(Ohr-1))  ! % shift in bridge output voltage
3570  RETURN Cpct*R
3580  FNEND
3590  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3600 DEF FNYaw(REAL Del,REAL Ebr,REAL A,REAL N,REAL E0brs)
3610  FNEND
```

```
10    REM  PROGRAM XWIRE2
20    !  PROGRAM TO ACQUIRE X-WIRE DATA USING THE LDV-A/D CI
30    OPTION BASE 1
40    DIM Titl$[80],Ystr$[80]    ! information strings for data file
50    INTEGER D1(3000,4)      !data buffer
60    INTEGER C(2,3000)       ! data words from CI
70    INTEGER Ns,Ichan
80    INTEGER Zero,Eref,Off,Egain,Eoff(2),Ezero(2)
90    INTEGER E1in(20),E2in(20)
100   INTEGER E0del(2),Edel(2,10)
110   INTEGER Jntr,J,Ncal,Ipt,Ical
120   INTEGER R1av,R2av
130   INTEGER Flag
140   REAL Ohr,Alpha,Tcal,Tnow
150   REAL Rgain,Gain(2)
160   REAL V1(20),V2(20),Ucal(20)
170   REAL N(2),Kstr(2),K(2),Esq(2),Ca(2),Ang(2)
180   REAL N2(2),K2str(2),K2(2),E2sq(2),C2a(2)
190   REAL V0del(2),Vdel(2),Del(10),T1a,T2a,U1cal,U2cal.T1al,T2al
200   PRINT
201   PRINTER IS 16
220   PRINT "** << PROGRAM XWIRE2 : FULLY-DIGITAL X-WIRE DATA ACQISITION >> **"
230   PRINT
240   PRINT " PROGRAM STRUCTURE :"
250   PRINT " 1. Calibrate the A/D converter of the LDV CI."
260   PRINT " 2. Calibrate the X probe vs. velocity."
270   PRINT " 3. Yaw calibration of the X probe to determine wire angles."
280   PRINT " 4. Acquire data and write raw data from chs 1 & 2 to disk file."
290   PRINT " 5. Repeat (5.) for each data point taken."
300   PRINT " 6. Reduce data off-line with another program."
310   PRINT
320   !
330   ! ** Calibrate the A/D - both channels
340   !
341   PRINTER IS 0
350   PRINT
360   PRINT "** CALIBRATION OF THE A/D CONVERTER **"
370   PRINT
380   !     1. Channel 1 is done first
390   Ns=10           !10 samples are averaged at each point
400   Ichan=1
410   GOSUB Adcal
420   Ezero(Ichan)=Zero
430   Eoff(Ichan)=Off
440   Gain(Ichan)=Rgain
450   !     2. Channel 2 is calibrated next
460   Ichan=2
470   GOSUB Adcal
480   Ezero(Ichan)=Zero
490   Eoff(Ichan)=Off
500   Gain(Ichan)=Rgain
510   Acal$="N"
520   !
530   ! ** Calibrate both wires at fixed angle vs. velocity
540   !
550   !     1. Compile raw calibration data table
560   PRINT
570   PRINT "** CALIBRATION TO DETERMINE Ebridge vs. Ueff **"
580   PRINT
```

```
590   INPUT "Enter calibration flow temperature in deg. F:" Tcal
600   Tcal=.5556*(Tcal-32)
610   INPUT "Enter wire temperature resistivity coefficient :",Alpha
620   INPUT "Enter nominal overheat ratio used (about 1.8) :",Ohr
630   ! NOTE: Wire parameters are needed to do temperature correction
631   PRINT " ALPHA = ";Alpha;"  OHR = ";Ohr;"  TCAL = ";Tcal;" C"
640   PRINT
650   INPUT "Enter no. points to be taken (<= 20 total) :",Ncal
660   Ns=100         !100 samples are to be taken at each point
670     FOR Ical=1 TO Ncal
680     DISP "Point no. ";Ical
690     INPUT "Enter the calibration velocity : ",Ucal(Ical)
700     GOSUB Atod
710       E1in(Ical)=0          !compute average bridge output value
720       E2in(Ical)=0
730       FOR Icpt=1 TO Ns
740       E1in(Ical)=E1in(Ical)+(C(1,Icpt)-E1in(Ical))/Icpt
750       E2in(Ical)=E2in(Ical)+(C(2,Icpt)-E2in(Ical))/Icpt
760       NEXT Icpt
770   !     2. Convert to volts
780     V1(Ical)=FNVbrg(E1in(Ical),Ezero(1),Eoff(1),Gain(1))
790     V2(Ical)=FNVbrg(E2in(Ical),Ezero(2),Eoff(2),Gain(2))
800     PRINT "Point ";Ical;" U= ";Ucal(Ical);" V1= ";V1(Ical);" V2= ";V2(Ical)
810     NEXT Ical
820   PRINT "** CALIBRATION DATA ACQUISITION COMPLETE **"
830   PRINT
840   !     3. Perform King's law fit
850   PRINT "Perform King's law fit for both channels --"
860   PRINT "The results will be a scale factor K* = K/COS(A) and"
870   PRINT "effective no-flow output E0^2. A is the effective wire"
880   PRINT "angle in the plane of the wire."
890   PRINT
900   PRINT "Channel 1 :"
910   Flag=0
920   IF Acal$="Y" THEN Flag=1      ! E0^2 is fixed for Acal$=1
930   CALL Hwcal(Ncal,V1(*),Ucal(*),N2(1),K2str(1),E2sq(1),Flag)
940   PRINT
950   PRINT "Channel 2 :"
960   CALL Hwcal(Ncal,V2(*),Ucal(*),N2(2),K2str(2),E2sq(2),Flag)
970   !  Kstr is K/COS(A), where A is the effective wire angle
980   !  which is determined in the next program segment
990   !  Note that the effective zero-flow voltage Esq is needed
1000  !  for the yaw calibration.
1010  IF Acal$="Y" THEN GOTO 1890
1020  !
1030  ! ** Yaw calibration to determine effective wire angles
1040  !
1050  PRINT
1060  PRINT "** YAW CALIBRATION - PROBE YAWED IN WIRE PLANE **"
1070  PRINT
1080  RAD
1090  Ns=100    !100 samples are used in yaw calibration
1100  !     1. Fix the velocity and get data at delta=0
1110  PRINT "The nominal yaw angle is Delta - the effective wire"
1120  PRINT "angle in the wire plane is now determined by the"
1130  PRINT "yaw calibration."
1140  PRINT
1150  DISP "Set probe at Delta=0 then press CONT"
1160  PAUSE
```

```
1170  GOSUB Atod
1180    E0del(1)=0
1190    E0del(2)=0
1200    FOR Icpt=1 TO Ns
1210    E0del(1)=E0del(1)+(C(1,Icpt)-E0del(1))/Icpt
1220    E0del(2)=E0del(2)+(C(2,Icpt)-E0del(2))/Icpt
1230    NEXT Icpt
1240  V0del(1)=FNVbrg(E0del(1),Ezero(1),Eoff(1),Gain(1))
1250  V0del(2)=FNVbrg(E0del(2),Ezero(2),Eoff(2),Gain(2))
1260  V0del(1)=V0del(1)^2
1270  V0del(2)=V0del(2)^2
1271  PRINT
1280  PRINT "Zero values : ch.1 : ";V0del(1);"  ch. 2 : ";V0del(2);" volts2"
1290  PRINT
1300  !     2. Yaw the probe through a series of angles
1310  Nyaw=1
1320  PRINT "Now the probe will be yawed through a series of angles"
1330  PRINT "after which the average effective wire angle is computed."
1340  PRINT
1350  PRINT " - Point no. ";Nyaw
1360    INPUT "Enter the wire angle Delta :",Del(Nyaw)
1370    GOSUB Atod
1380    Edel(1,Nyaw)=0
1390    Edel(2,Nyaw)=0
1400    FOR Icpt=1 TO Ns
1410    Edel(1,Nyaw)=Edel(1,Nyaw)+(C(1,Icpt)-Edel(1,Nyaw))/Icpt
1420    Edel(2,Nyaw)=Edel(2,Nyaw)+(C(2,Icpt)-Edel(2,Nyaw))/Icpt
1430    NEXT Icpt
1440  INPUT "Reply Y to do another point, else N ? ",A$
1450  IF A$="N" THEN GOTO 1490
1460  Nyaw=Nyaw+1
1470  GOTO 1350
1480  !     3. Compute tangent of average effective wire angle
1490  PRINT
1500  PRINT "YAW CALIBRATION DATA SUMMARY"
1510  PRINT "PT.  YAW ANGLE     TAN(A1)     TAN(A2)"
1520  PRINT "-------------------------------------"
1530    T1a=0
1540    T2a=0
1550    FOR Icpt=1 TO Nyaw
1560    Vdel(1)=FNVbrg(Edel(1,Icpt),Ezero(1),Eoff(1),Gain(1))
1570    Vdel(2)=FNVbrg(Edel(2,Icpt),Ezero(2),Eoff(2),Gain(2))
1580  ! NOTE: The effective wire angle is computed at each point-
1590    T1al=FNYaw(Del(Icpt),Vdel(1),E2sq(1),N2(1),V0del(1))
1600    T1a=T1a+(T1al-T1a)/Icpt
1610    T2al=FNYaw(Del(Icpt),Vdel(2),E2sq(2),N2(2),V0del(2))
1620    T2a=T2a+(T2al-T2a)/Icpt
1630    PRINT Icpt;"  ";Del(Icpt);"  ";T1al;"  ";T2al
1640    NEXT Icpt
1650    PRINT
1660    PRINT "Averaged values:  Tan psi1 = ";T1a;"  Tan psi2 = ";T2a
1670    PRINT
1680    INPUT "Reply C to change these, else N : ",Ans$
1690    IF Ans$<>"C" THEN GOTO 1720
1700    INPUT "Enter Tan psi1, Tan psi2 :",T1a,T2a
1710    PRINT
1720    C2a(1)=1/SQR(1+ABS(T1a)^2)        !remove effective wire angle
1730    K2(1)=K2str(1)*C2a(1)            !from calibration constants
1740    C2a(2)=1/SQR(1+ABS(T2a)^2)        !for constructing look-up table
```

```
1750    K2(2)=K2str(2)*C2a(2)
1760    PRINT
1790    INPUT "Y to perform orth. cal. in plane of measurement (reply Y or N) :"
,Acal$
1800    FOR I=1 TO 2
1810    K(I)=K2(I)
1820    N(I)=N2(I)
1830    Esq(I)=E2sq(I)
1840    Ca(I)=C2a(I)
1850    NEXT I
1860    IF Acal$="Y" THEN GOTO 640
1870    GOTO 1991
1880  ! 4. Effective wire angle in orthogonal plane is computed
1890    Ca(1)=K(1)/K2str(1)
1900    Ca(2)=K(2)/K2str(2)
1910    PRINT
1920    PRINT "Calibration constants used in look-up table construction:"
1930    PRINT " K1 = ";K(1);" K2 = ";K(2)
1940    PRINT " A1 = ";Esq(1);" A2 = ";Esq(2)
1950    PRINT " N1 = ";N(1);" N2 = ";N(2)
1960    PRINT " COS 1 = ";Ca(1);"  COS 2 = ";Ca(2)
1970    Ang(1)=180*ACS(Ca(1))/PI
1980    Ang(2)=180*ACS(Ca(2))/PI
1990    PRINT " WIRE ANGLES : 1 = ";Ang(1);" 2 = ";Ang(2)
1991    PRINTER IS 16
1992    PRINT "** CRT is now the default printer **"
2000  !
2010  ! ** Acquire and store data at successive points:
2020  !
2030  Isft1=0
2040  Isft2=0
2050  Tnow=Tcal
2060  PRINT "** DATA ACQUISITION **"
2070  PRINT
2080  PRINT "   Enter run parameters: "
2090  PRINT
2100  PRINT " - Enter file name for output data files - not to exceed"
2110  PRINT "   4 characters - e.g. DATA. "
2120  INPUT "   Enter file name : ",Name$
2130  INPUT " - Enter a 1-line file title for the profile :",Titl$
2140  INPUT " - No. data samples per point (<3000) :",Ns
2150  INPUT " - Enter Y if temperature correction is desired :",Atem$
2160  Ipt=1
2170  !    1. Move to next location (& enter flow temp if correcting)
2180  PRINT
2190  PRINT "POINT NUMBER : ";Ipt
2200  INPUT "Enter flow temperature in deg. F: ",Tnow
2210  Tnow=.5556*(Tnow-32)
2220  INPUT "Enter one-line string to identify the current point :",Ystr$
2230  !    2. Obtain raw data
2240  GOSUB Atod
2250  !    3. Estimate average bridge output voltage (if temp correcting)
2260  IF Atem$<>"Y" THEN GOTO 2390
2270  E1av=0
2280  E2av=0
2290    FOR I=1 TO 10
2300    E1av=E1av+(C(1,I)-E1av)/I
2310    E2av=E2av+(C(2,I)-E2av)/I
2320    NEXT I
```

```
2330  R1av=Gain(1)*Eoff(1)+(E1av-Ezero(1))
2340  R2av=Gain(2)*Eoff(2)+(E2av-Ezero(2))
2350  !     4. Compute shift to calibration for temperature drift
2360  Isft1=FNShift(Alpha,Ohr,Tcal,Tnow,R1av)
2370  Isft2=FNShift(Alpha,Ohr,Tcal,Tnow,R2av)
2380  !     5. Store data on floppy disk
2390  GOSUB Dfile
2400  PRINT
2410  PRINT "Enter one of the following to proceed : "
2420  PRINT "E - exit the program"
2430  PRINT "P - another data point, same profile name"
2440  PRINT "N - new profile, same calibration"
2450  PRINT "C - new profile, repeat calibration procedure"
2460  INPUT "Enter E, P, N, or C : ",Ans$
2470  IF Ans$="E" THEN GOTO 2550
2480  IF Ans$="P" THEN GOTO 2520
2490  IF Ans$="N" THEN GOTO 2030
2500  IF Ans$="C" THEN GOTO 350
2510  GOTO 2460
2520  Ipt=Ipt+1
2530  GOTO 2180
2540  !
2550  END
2560  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2570  ! ************** END OF MAIN PROGRAM XWIRE ***************
2580  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2590 Dfile:    ! write raw X-wire data to a floppy file for later
2600           ! reduction (each raw A/D pair is stored)
2610  PRINT
2620  PRINT "** WRITE RAW DATA FILE **"
2630  PRINT
2640  PRINT "At this point be sure there is a floppy in drive 0 of"
2650  PRINT "the 9895A with space for a file of 100 records of 256"
2660  PRINT "bytes each. Press CONT when ready to proceed :"
2680  File$=Name$&VAL$(Ipt)
2690  PRINT "File ";File$;" being written "
2700  MASS STORAGE IS ":H8,0,0"    ! 9895A floppy drive set as default
2710  CREATE File$,100             ! file is 100 records of 256 bytes
2720  ASSIGN File$ TO #1
2730  PRINT #1;Titl$
2740  PRINT #1;Ystr$
2750  PRINT #1;Tcal,Tnow,Alpha,Ohr
2760  PRINT #1;Eoff(1),Ezero(1),Gain(1)   ! A/D cal constants
2770  PRINT #1;Eoff(2),Ezero(2),Gain(2)
2780  PRINT #1;K(1),Esq(1),N(1),Ca(1)   ! cal constants for hot-wire
2790  PRINT #1;K(2),Esq(2),N(2),Ca(2)
2800  PRINT #1;Isft1,Isft2
2810  PRINT #1;Ns
2820  MAT PRINT #1;C               ! Raw data for both wires
2830  ASSIGN * TO #1
2840  MASS STORAGE IS ":T15"       ! reset tape drive as mass storage
2850  PRINT "** FILE WRITE COMPLETE **"
2860  RETURN
2870  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2880 Adcal:    ! calibrate the A/D converter of the LDV CI
2890           ! enter the routine with Ichan and Ns set
2900  ! !!! This segment is for fixing the shorted-input value
2910  PRINT
2920  PRINT " *** Calibrate the A/D converter channel ";Ichan;" ***"
```

```
2930  DISP "Short input of channel ";Ichan;" then press CONT"
2940  PAUSE
2950    GOSUB Atod
2960  !  Average the 10 readings to get the zero value
2970    Zero=0
2980    FOR I=1 TO Ns
2990    Zero=Zero+(C(Ichan,I)-Zero)/I
3000    NEXT I
3010  PRINT "Zero-level output is : ";Zero;" of 12 bits"
3020  ! !!! Now read the reference value
3030  DISP "Connect ref voltage to chan ";Ichan;" then press CONT"
3040  PAUSE
3050    GOSUB Atod
3060    Eref=0
3070    FOR I=1 TO Ns
3080    Eref=Eref+(C(Ichan,I)-Eref)/I
3090    NEXT I
3100  PRINT "Reference voltage applied to channel";Ichan;" is ";Eref
3110  ! !!! An offset is applied and calibrated for channel Ichan
3120  DISP "Apply an offset to channel ";Ichan;" then press CONT"
3130  PAUSE
3140    GOSUB Atod
3150    Off=0
3160    FOR I=1 TO Ns
3170    Off=Off+(C(Ichan,I)-Off)/I
3180    NEXT I
3190  Off1=Eref-Off
3200  PRINT "Offset value is : ";Off1
3210  ! !!! A gain is calibrated - nominal values are set externally
3220  DISP "Set GAIN on channel ";Ichan;" then press CONT"
3230  PAUSE
3240    GOSUB Atod
3250    Egain=0
3260    FOR I=1 TO Ns
3270    Egain=Egain+(C(Ichan,I)-Egain)/I
3280    NEXT I
3290  Rgain=(Egain-Zero)/(Eref-Zero-Off1)
3300  PRINT "Gain of channel ";Ichan;" is ";Rgain
3310  ! !!! Reset the OFFSET value
3320  DISP "Reset the OFFSET on channel ";Ichan;" then press CONT"
3330  PAUSE
3340    GOSUB Atod
3350    Off=0
3360    FOR I=1 TO Ns
3370    Off=Off+(C(Ichan,I)-Off)/I
3380    NEXT I
3390  Off=(Egain-Off)/Rgain+Off1
3400  PRINT "Final OFFSET is :";Off;" bits"
3410  RETURN
3420 ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3430 Atod:  ! Subroutine for input from the LDV-A/D CI
3440        ! Enter routine with Ns=no. samples
3450  DISP "Press CONT to initiate data acqusition"
3460  PAUSE
3470  RESET 10
3480  CONTROL MASK 10;1
3490  WRITE IO 10,5;0
3500  WRITE IO 10,5;1    !start handshake by setting CTL0
3510  Nt=4*Ns
```

```
3520     FOR I=1 TO 3
3530     Dummy=READBIN(10)
3540     NEXT I
3550   REDIM D1(Ns,4)
3560   !
3570     ENTER 10 WFHS Nt NOFORMAT;D1(*) !fast data acquisition
3580   DISP "Data acqusition complete"
3590     FOR I=1 TO Ns      !transfer the data to integer arrays
3600     C(1,I)=D1(I,3)+2048     !two data words (LDV is sending 4 words total
3610     C(2,I)=D1(I,4)+2048     !second data word
3620     NEXT I
3630   RETURN
3640   ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3650  SUB Hwcal(INTEGER Np,REAL E(*),REAL U(*),REAL N,REAL K,REAL Esq,INTEGER F1)
3660   ! Subprogram to compute hot-wire calibration constants for
3670   ! King's law calibration via linear least square fit
3680   OPTION BASE 1
3690   INPUT "Enter exponent N (approx. 0.45) : ",N
3700   IF F1=1 THEN GOTO 3870
3710     L0=0            ! initialize sums for linear least-squares fit
3720     L2=0
3730     S2=0
3740     S4=0
3750     FOR I=1 TO Np
3760     L0=L0+U(I)^N
3770     L2=L2+E(I)^2*U(I)^N
3780     S2=S2+E(I)^2
3790     S4=S4+E(I)^4
3800     NEXT I
3810   D=S2*S2-Np*S4
3820   A=(L0*S2-Np*L2)/D
3830   B=(S2*L2-S4*L0)/D
3840   K=A^(1/N)                    ! scale factor
3850   Esq=-B/A                     ! effective no-flow bridge output squared
3860   GOTO 3940
3870     L0=0
3880     L1=0
3890     FOR I=1 TO Np
3900     L0=L0+U(I)*(E(I)^2-Esq)^(1/N)
3910     L1=L1+(E(I)^2-Esq)^(2/N)
3920     NEXT I
3930   K=L0/L1
3940   PRINT "Scale factor K* : ";K
3950   PRINT "Ezero squared E0^2 : ";Esq
3960     Err=0            ! compute RMS % error of the fit
3970     FOR I=1 TO Np
3980     Err=Err+((U(I)-K*(E(I)*E(I)-Esq)^(1/N))/U(I))^2
3990     NEXT I
4000   Err=100*SQR(Err/Np)
4010   PRINT "RMS percent error of the fit : ";Err;" %"
4020   SUBEND
4030   ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
4040  DEF FNVbrg(INTEGER Ein,INTEGER Zero,INTEGER Off,REAL Gain)
4050   ! Compute the bridge output voltage based on calibration values
4060   RETURN ((Ein-Zero)/Gain+Off)*20/4096
4070   FNEND
4080   ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
4090  DEF FNYaw(REAL Del,REAL Ebr,REAL A,REAL N,REAL E0brs)
4100   ! Compute the effective wire angle given the nominal angle (Del) and
```

```
4110  ! appropriate constants from calibration vs. velocity
4120  Ang=Del*PI/180
4130  RETURN (COS(Ang)-((Ebr^2-A)/(E0brs-A))^(1/N))/SIN(Ang)
4140  FNEND
4150  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
4160 DEF FNKing(REAL Ebr,REAL K,REAL E0sq,REAL N)
4170  ! Compute velocity based on King's Law calibration constants
4180  RETURN K*(Ebr^2-E0sq)^(1/N)
4190  FNEND
4200  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
4210 DEF FNShift(REAL Alpha,REAL Ohr,REAL Tref,REAL T,INTEGER R)
4220  ! Compute temperature drift correction to bridge voltage
4230  Cpct=Alpha*(T-Tref)/(2*(Ohr-1))  ! % shift in bridge output voltage
4240  RETURN Cpct*R
4250  FNEND
```

```
10      REM PROGRAM UVBAR2
20      !  PROGRAM TO REDUCE X-WIRE DATA ACQUIRED WITH PROGRAM XWIRE2
30      ! Input is 2 channels of raw data and calibration constants
40      ! Output is the two components of mean velocity in the wire
50      ! plane as well as the in-plane turbulence stresses and third
60      ! order products.
70      OPTION BASE 1
80      DIM Titl$[80],Ystr$[80]
90      INTEGER Ns,Nf,Filno
100     INTEGER Eoff(2),Ezero(2)
110     INTEGER Isft1,Isft2
120     INTEGER C(2,3000)
130     INTEGER I,J,Jntr
140     REAL Vhwb
150     REAL Gain(2)
160     REAL Tcal,Tnow,Alpha,Ohr
170     REAL K(2),Esq(2),N(2),Ca(2)
180     REAL C1a,C2a
190     REAL Ueff(2,5000)
200     SHORT Ueff12(3000,2)
210     PRINT
220     PRINT " ** PROGRAM UVBAR2 - REDUCES RAW X-WIRE DATA **"
230     PRINT
240     PRINT "Program outline:"
250     PRINT "1. Read calibration and raw data from specified file."
260     PRINT "2. Construct look-up table and implement calibration."
270     PRINT "3. Compute running sums for statistics up to third order."
280     PRINT "4. Print results."
290     PRINT "NOTE: Channel 1 is assumed to be U+V wire for sign convention."
300     PRINTER IS 0
310     MASS STORAGE IS ":H8,0,0"
320     Filno=0
330     INPUT "Enter parent filename (or E to exit program) :",Name$
340     File$=Name$
350     IF File$="E" THEN GOTO 1310
360     INPUT "Enter no. of data files with parent prefix (0 if parent only)",Nf
370     IF Nf=0 THEN GOTO 410
380     Filno=Filno+1
390     IF Filno>Nf THEN GOTO 1290
400     File$=Name$&VAL$(Filno)
410     ASSIGN File$ TO #1
420     READ #1;Titl$
430     PRINT Titl$
440     READ #1;Ystr$
450     PRINT Ystr$
460     READ #1;Tcal,Tnow,Alpha,Ohr
470     READ #1;Eoff(1),Ezero(1),Gain(1)
480     READ #1;Eoff(2),Ezero(2),Gain(2)
490     READ #1;K(1),Esq(1),N(1),Ca(1)
500     READ #1;K(2),Esq(2),N(2),Ca(2)
510     READ #1;Isft1,Isft2
520     READ #1;Ns
530     MAT READ #1;C
540     ! now reduce the data - three steps:
550     ! 1. Construct & implement look-up table
560     ! 2. Convert Ueff1,2 to U and V
570     ! 3. Update running sums
580     IF Filno>1 THEN GOTO 721
590     !
```

```
600   ! 1. Construct & implement look-up table
610   !
620     FOR J=1 TO 5000
630       FOR I=1 TO 2
640       Vhwb=FNVbrg(J,Ezero(I),Eoff(I),Gain(I))
650       IF Vhwb^2>Esq(I) THEN GOTO 680
660       Ueff(I,J)=0
670       GOTO 690
680       Ueff(I,J)=FNKing(Vhwb,K(I),Esq(I),N(I))
690       NEXT I
700     NEXT J
710     DISP "LOOK-UP TABLE CONSTRUCTION COMPLETED"
720   ! Implement look-up
721   Nout1=0
722   Nout2=0
730     FOR J=1 TO Ns
740     Jntr=C(1,J)+Isft1
741     IF C(1,J)<4095 THEN GOTO 750
743     Nout1=Nout1+1
750     Ueff12(J,1)=Ueff(1,Jntr)
760     Jntr=C(2,J)+Isft2
761     IF C(2,J)<4095 THEN GOTO 770
763     Nout2=Nout2+1
770     Ueff12(J,2)=Ueff(2,Jntr)
780     NEXT J
790     DISP "CALIBRATION IMPLEMENTATION COMPLETED"
800   !
810   ! 2. Convert Ueff 1,2 to U and V
820   !
830   Sin1=SQR(1-Ca(1)^2)
840   Sin2=SQR(1-Ca(2)^2)
850   D=Ca(1)*Sin2+Ca(2)*Sin1
860   A1=Sin2/D       !channel 1 is U+V wire
870   A2=Sin1/D
880   A3=Ca(2)/D      !channel 2 is U-V wire
890   A4=-Ca(1)/D
900   Su1=0
910   Sv1=0
920   Su2=0
930   Sv2=0
940   Suv=0
950   Su2v=0
960   Sv2u=0
970     FOR Ipt=1 TO Ns
980     U=A1*Ueff12(Ipt,1)+A2*Ueff12(Ipt,2)
990     V=A3*Ueff12(Ipt,1)+A4*Ueff12(Ipt,2)
1000  !
1010  ! 3. Running sums for statistics
1020  !
1030    Su1=Su1+(U-Su1)/Ipt
1040    Su2=Su2+(U^2-Su2)/Ipt
1050    Sv1=Sv1+(V-Sv1)/Ipt
1060    Sv2=Sv2+(V^2-Sv2)/Ipt
1070    Suv=Suv+(U*V-Suv)/Ipt
1080    Su2v=Su2v+(U*U*V-Su2v)/Ipt
1090    Sv2u=Sv2u+(U*V*V-Sv2u)/Ipt
1100    NEXT Ipt
1110  Ubar=Su1
1120  Vbar=Sv1
```

```
1130  Upri2=Su2-Su1*Su1
1140  Vpri2=Sv2-Sv1*Sv1
1150  Uvbar=Suv-Su1*Sv1
1160  U2vbar=Su2v-2*Ubar*Suv-Vbar*Su2+2*Ubar*Ubar*Vbar
1170  V2ubar=Sv2u-2*Vbar*Suv-Ubar*Sv2+2*Vbar*Vbar*Ubar
1180  PRINT
1190  PRINT "REDUCED DATA : Channel 1 taken as U+V "
1191  PRINT
1192  PRINT "Out-of-range data: chn 1 ";Nout1;"  chn 2 ";Nout2
1193  PRINT "Total sample size: ";Ns
1200  PRINT "UBAR   = ";Ubar;"   VBAR   = ";Vbar;" UNITS: L/T"
1220  PRINT "UPRI2  = ";Upri2;"  VPRI2  = ";Vpri2;" UNITS: (L/T)^2"
1240  PRINT "UVBAR  = ";Uvbar;"  UNITS: (L/T)^2"
1260  PRINT "U2VBAR = ";U2vbar;" V2UBAR = ";V2ubar;" UNITS: (L/T)^3"
1270  PRINT
1280  GOTO 380
1290  INPUT "Reply Y to reduce another profile, else N :",Ans$
1300  IF Ans$="Y" THEN 310
1310  MASS STORAGE IS ":T15"
1320  PRINTER IS 16
1330  END
1340  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1350  ! !!!!!!!!!!! END PROGRAM UVBAR2 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1360  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1370 DEF FNKing(REAL Ebr,REAL K,REAL E0sq,REAL N)
1380  ! compute velocity based on King's Law calibraiton
1390  RETURN K*(Ebr^2-E0sq)^(1/N)
1400  FNEND
1410  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1420 DEF FNVbrg(INTEGER Ein,INTEGER Zero,INTEGER Off,REAL Gain)
1430  RETURN ((Ein-Zero)/Gain+Off)*20/4096
1440  FNEND
1450  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

REFERENCES

1. Operator's Manual for NASA 3-D LDV Computer Interface.

2. Townsend, A. A.: The Structure of Turbulent Shear Flow. Second ed., Cambridge University Press, 1976.

3. Mehta, R. D.; and Westphal, R. V.: Near-Field Turbulence Properties of Single and Two-Stream Plane Mixing Layers. AIAA Paper 84-0426, to be presented at the AIAA 22nd Aerospace Sciences Meeting, Reno, Nev., Jan. 9-12, 1984.

X-WIRE EQUIPMENT LIST

ITEM NO.	MFG & MODEL	DESCRIPTION
1	NASA DESIGN (DISA 55P11)	MINIATURE X-WIRE WITH 5μm TUNGSTEN WIRES SINGLE MINIATURE HOT-WIRE WITH 5μm Pt-W SENSOR
2	DISA 55M10	CONSTANT-TEMPERATURE BRIDGE
3	DISA 55D31	DIGITAL VOLTMETER (AVERAGING)
4	DISA 55D26	SIGNAL CONDITIONER
5	TEKTRONIX SC503	10 MHz STORAGE OSCILLOSCOPE (2 CHANNEL)
6	TEKTRONIX PG508	50 MHz PULSE GENERATOR
7	NASA DESIGN	LDV/A-D MUX AND 4-CHANNEL A-D WITH FAST SAMPLE-AND-HOLD
8	HP98032A	HIGH-SPEED 16-BIT PARALLEL INTERFACE
9	HP9845B	DESKTOP COMPUTER WITH I/O ROM INSTALLED
10	HP9895A	FLOPPY DISK DRIVE

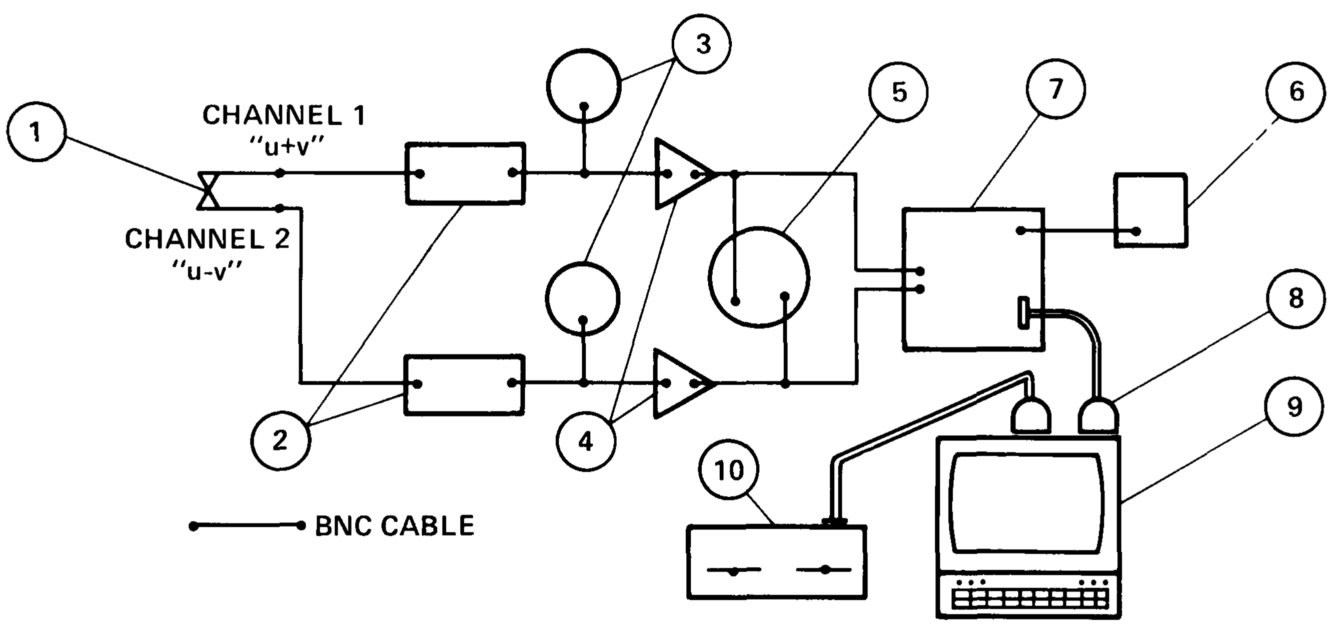


Figure 1.- Crossed-wire system hardware schematic.

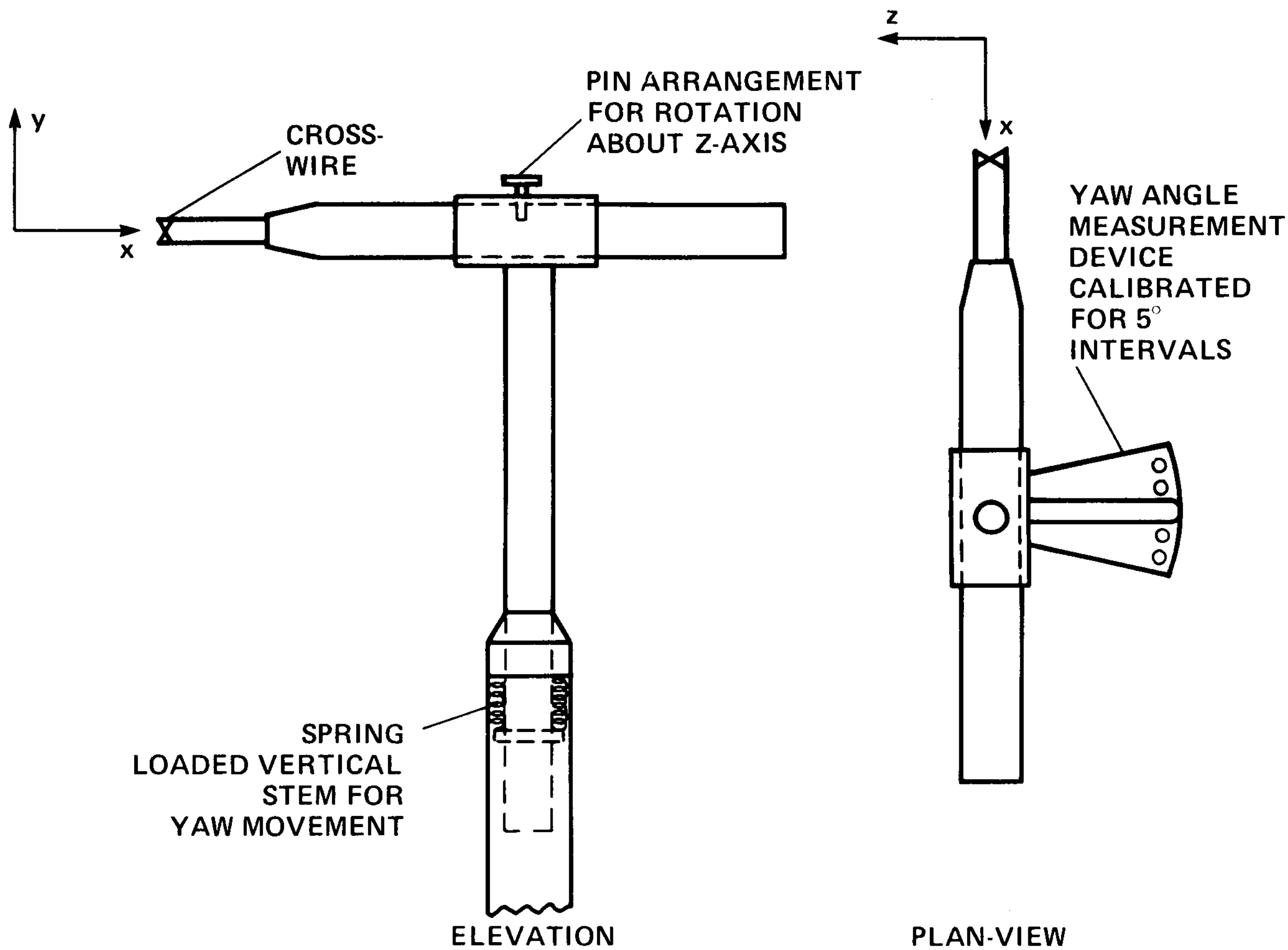
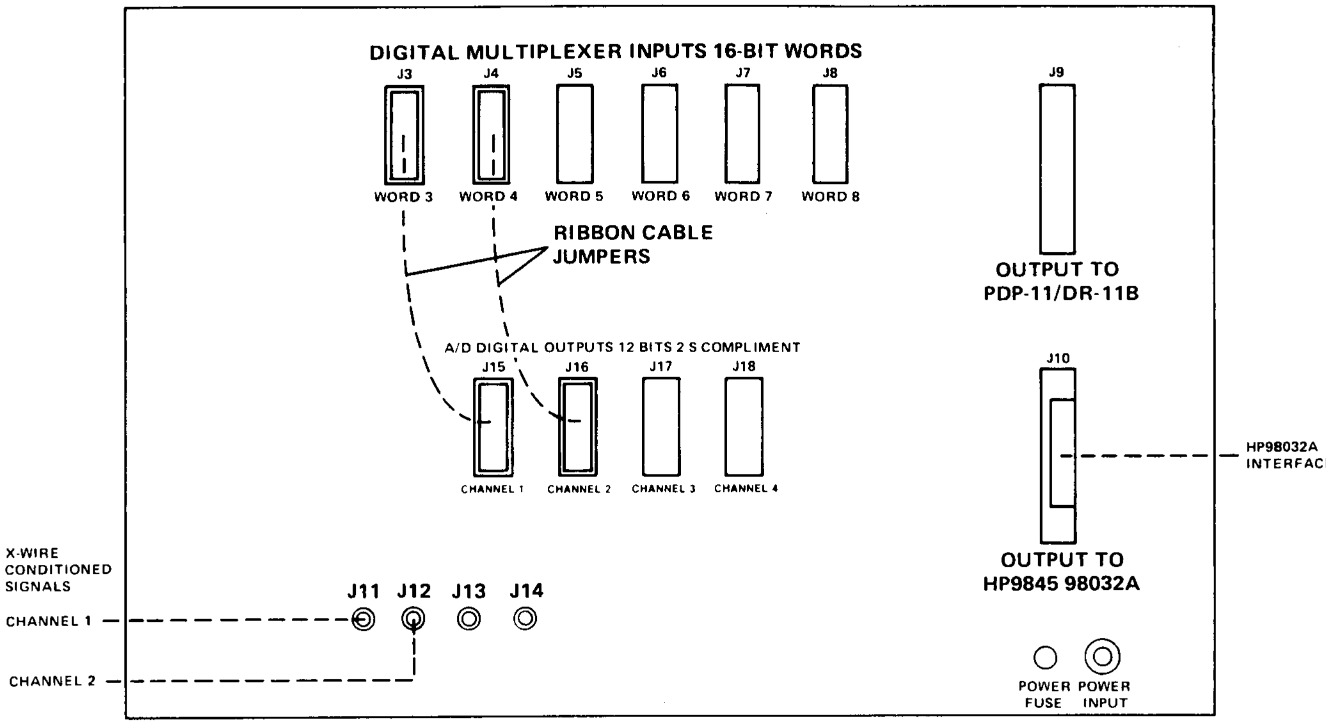


Figure 2.- NASA crossed-wire probe and holder.



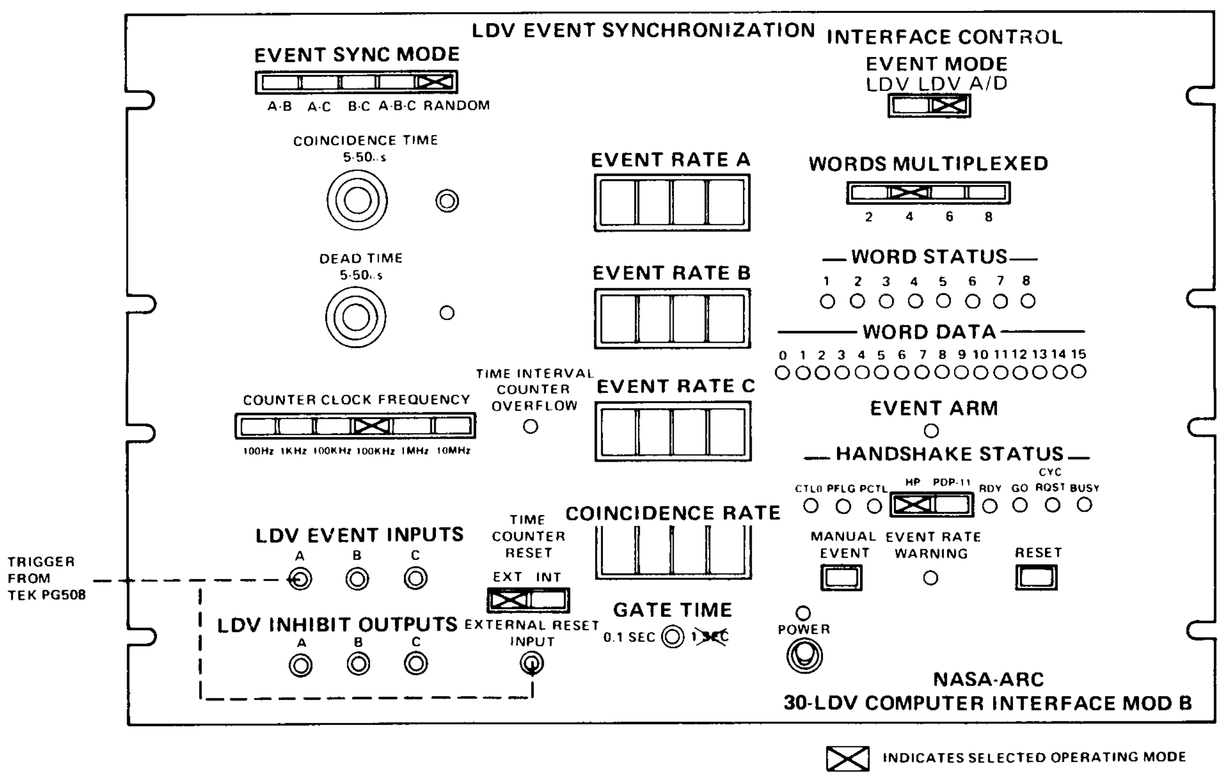


Figure 3.- NASA LDV-A/D computer interface connections.

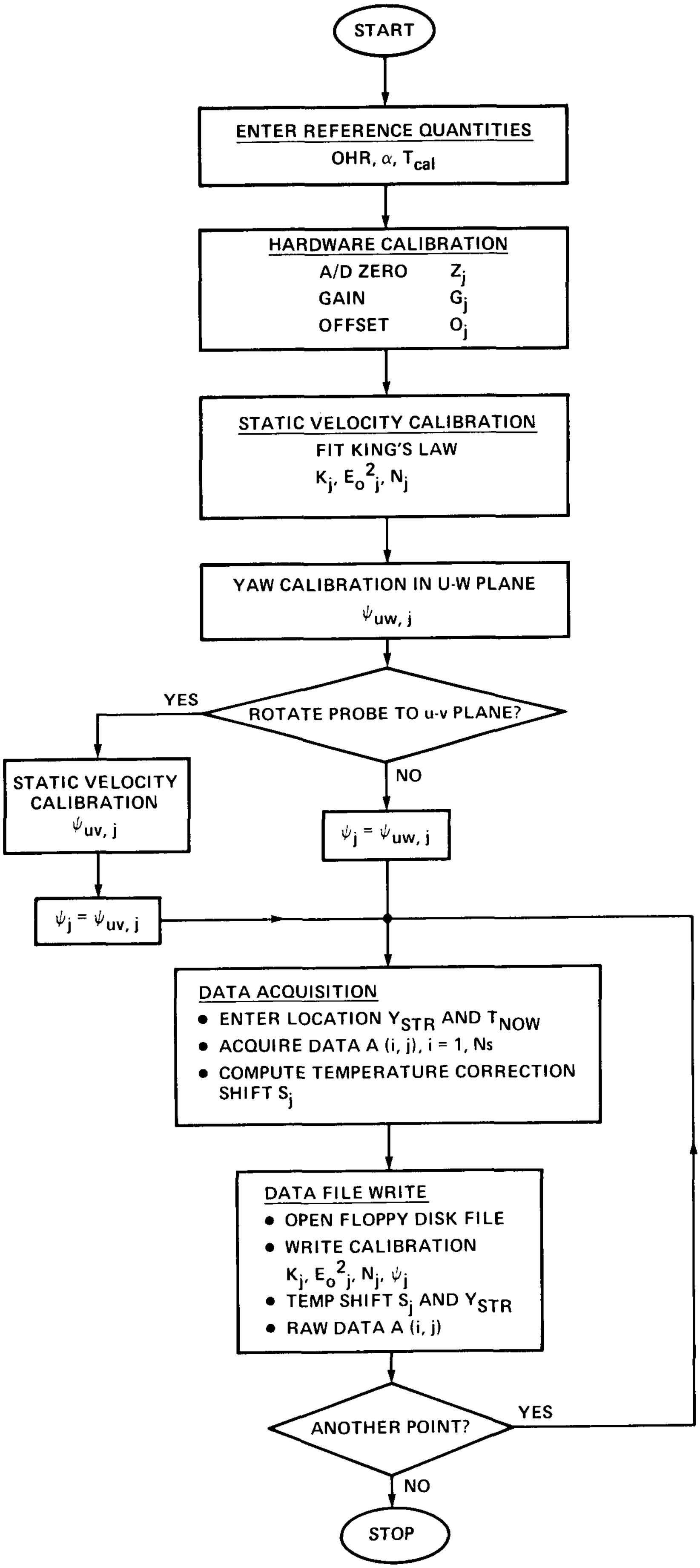


Figure 4.- Calibration and data-acquisition procedure.

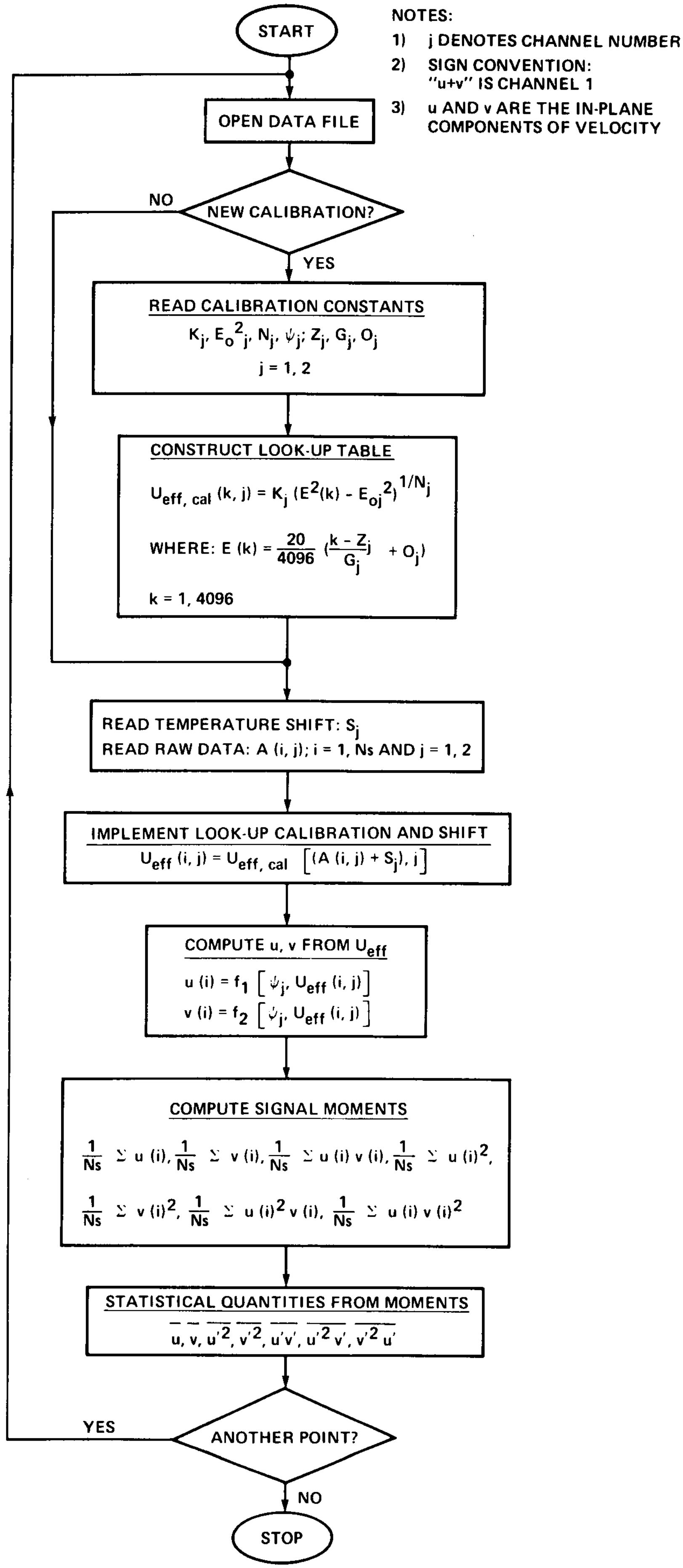


Figure 5.- Data-reduction algorithm.

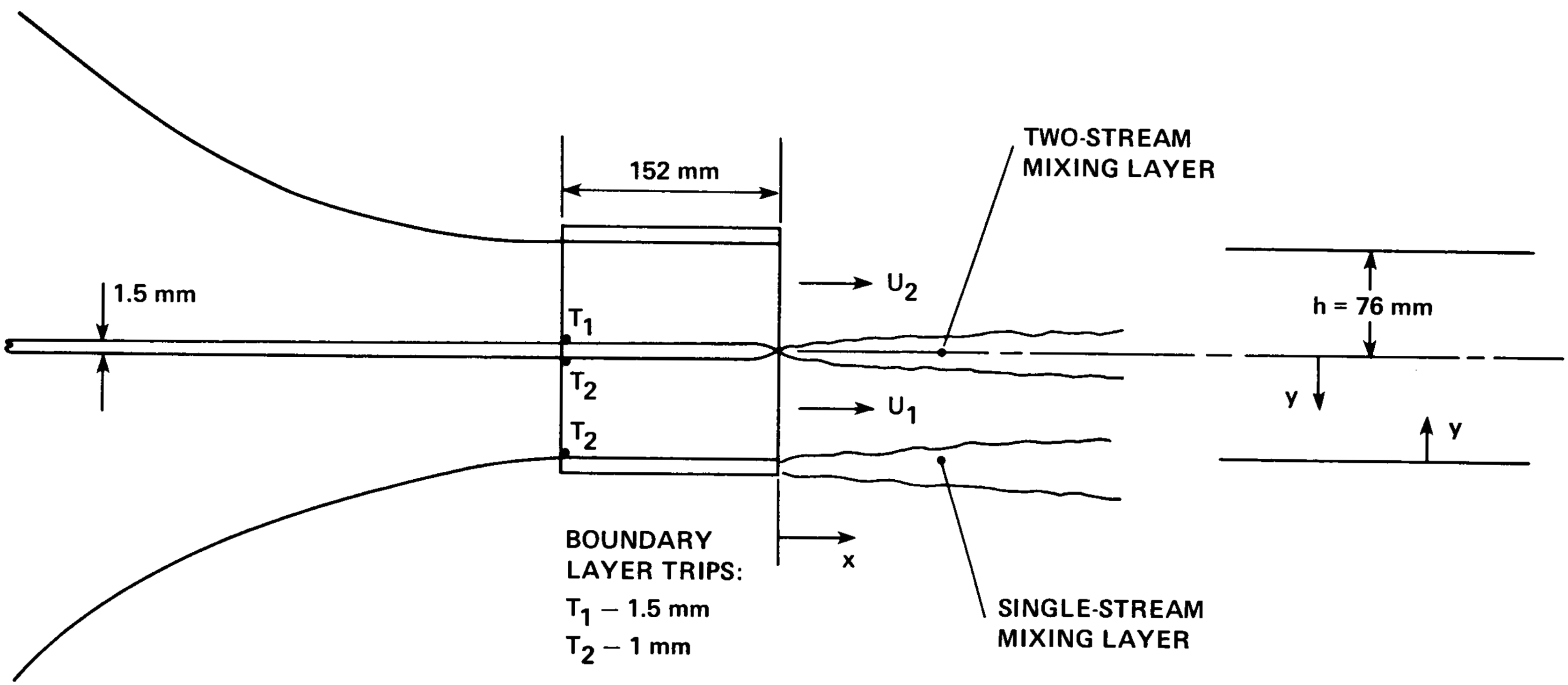


Figure 6.- Schematic of plane mixing layer experimental setup.

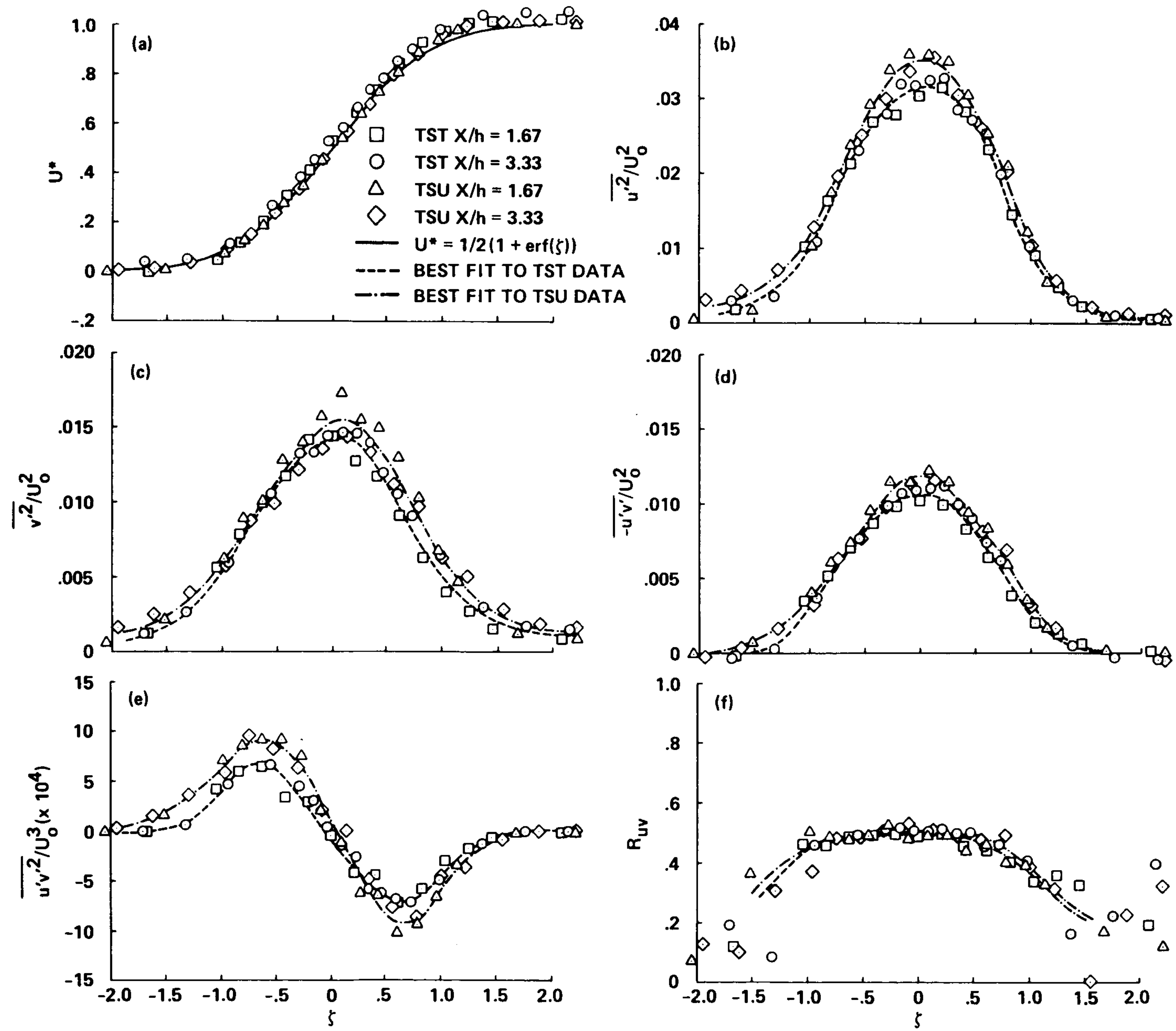


Figure 7.- Plane mixing layer: sample results.

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4. Title and Subtitle CROSSED HOT-WIRE DATA ACQUISITION AND REDUCTION SYSTEM		5. Report Date January 1984
		6. Performing Organization Code ATP
7. Author(s) R.V. Westphal and R.D. Mehta		8. Performing Organization Report No. A-9579
9. Performing Organization Name and Address NASA Ames Research Center Moffett Field, California 94035		10. Work Unit No. T 4033Y
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		13. Type of Report and Period Covered Technical Memorandum
		14. Sponsoring Agency Code 505-21-11

15. Supplementary Notes

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16. Abstract

The report describes a system for rapid computerized calibration acquisition, and processing of data from a crossed hot-wire anemometer. Advantages of the system are its speed, minimal use of analog electronics, and improved accuracy of the resulting data. Two components of mean velocity and turbulence statistics up to third order are provided by the data reduction. The report presents details of the hardware, calibration procedures, response equations, software, and sample results from measurements in a turbulent plane mixing layer.

17. Key Words (Suggested by Author(s)) Hot-wire, Two-component anemometer, Cross-wire, Automated data acquisition, Turbulence measurement	18. Distribution Statement Unlimited. Subject category: 35

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