Crossed Hot-Wire Data Acquisition and Reduction System

R. V. Westphal
R. D. Mehta, Ames Research Center, Moffett Field, California
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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)
\bar{S}_{a}  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
\alpha  wire resistivity coefficient (typical value for tungsten = 0.005 per °C)
\delta  yaw calibration angle setting
\psi  yaw angle
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, $u'^2, v'^2$ and $u'v'$ 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., \(u, v, u'^2, v'^2, u'v', u'^2v, v'^2u'\) 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.

Crossed-wire probes- 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 lowpass 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 "CTLO."

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:

\[ U_{\text{eff}} = K \left( E_{\text{eff}}^2 - E_0^2 \right)^{1/n} \]  

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.

\[ U_{\text{eff}} = |V| \cos \psi \]  

For two wires at angles \( \psi_1 \) and \( \psi_2 \) to the reference coordinate direction, the following two equations result, if sensitivity to out-of-plane velocity fluctuations is neglected:

\[ U_{\text{eff}} = u \cos \psi_1 + v \sin \psi_1 = K_1 (E_{1}^2 - E_{01}^2)^{1/n_1} \]

\[ U_{\text{eff}} = u \cos \psi_2 + v \sin \psi_2 = K_2 (E_{2}^2 - E_{02}^2)^{1/n_2} \]

Here \( u \) and \( v \) are the instantaneous velocity components in the measurement plane. Note that \( U_{\text{eff}} \) 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

\[ [U_{\text{eff}}] = [\psi][V] \]  

(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:

\[ [V] = [\psi]^{-1}[U_{\text{eff}}] \]  

(5)

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

\[
\begin{align*}
\mathbf{u} &= \frac{(\sin \psi_1)U_{\text{eff}2} - (\sin \psi_2)U_{\text{eff}1}}{(\sin \psi_1)(\cos \psi_2) - (\cos \psi_1)(\sin \psi_2)}, \\
\mathbf{v} &= \frac{(\cos \psi_2)U_{\text{eff}1} - (\cos \psi_1)U_{\text{eff}2}}{(\sin \psi_1)(\cos \psi_2) - (\cos \psi_1)(\sin \psi_2)}
\end{align*}
\]  

(6)

\[ \text{Temperature Drift Correction} \]

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:

\[ \frac{E_{\text{corr}} - E_{\text{meas}}}{E_{\text{meas}}} = \frac{\alpha}{2(\text{OH})} (T - T_{\text{cal}}) \equiv C \]  

(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

\[ E_{\text{corr}} = E_{\text{meas}} + C \times E_{\text{meas}} \]  

(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 different 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),

$$U_{\text{eff}} = U \cos \psi$$

where $\psi$ 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 $\psi_{uw}$. With equation (1), this yields

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

where

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

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, $\psi_{uw}$ 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 $\psi_{uw}$. 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 $\psi_{uw}$ is denoted $\delta$, 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 $\delta$; rearranging yields an expression for the effective wire angle $\psi_{uw}$:
In practice, we computed $\psi_{uw}$ for four different values of delta of $-10^\circ$, $-5^\circ$, $5^\circ$, and $10^\circ$. These results were averaged to get the value of $\psi_{uw}$.

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 $90^\circ$ to position the wires in the $u$-$v$ plane. At this point, the effective wire angle $\psi_{uv}$ is unknown; although $\psi_{uv}$ would be nominally the same as $\psi_{uw}$, 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 $\psi_{uv}$ was computed as before:

$$\cos(\psi_{uv}) = K/K'_{uv}$$  \hspace{1cm} (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:

$$S(a(i)) = A(i = Ns)$$  \hspace{1cm} (14)

where

$$A(i) = A(i - 1) + [a(i) - A(i - 1)]/i$$  \hspace{1cm} (15)
Average values of the various moments were computed as defined below:

\[
\begin{align*}
Su &= S(u(i))/Ns \\
Sv &= S(v(i))/Ns \\
Suu &= S(u(i)u(i))/Ns \\
Suv &= S(u(i)v(i))/Ns \\
Svv &= S(v(i)v(i))/Ns \\
Suuv &= S(u(i)u(i)v(i))/Ns \\
Suw &= S(u(i)v(i)v(i))/Ns
\end{align*}
\]

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

\[
\begin{align*}
\bar{u} &= Su \\
\bar{v} &= Sv \\
\overline{u'^2} &= Suu - SuSu \\
\overline{v'^2} &= Svv - SvSv \\
\overline{u'v'} &= Suv - SuSv \\
\overline{u'^2v'} &= Suuv - 2SuSuv - SvSuu + 2SvSuSu \\
\overline{u'v'^2} &= Suw - 2SvSuv - SuSvv + 2SuSvSv
\end{align*}
\]

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 \(u'v'\) 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."
REM PROGRAM UWIRE
OPTION BASE 1
DIM Tit1$"D801,Ystr$"" ! information strings for data file
INTEGER DI(3000,4) ! data buffer
INTEGER S(3000),C(2,3000),T(3000) ! words from CI
INTEGER Ns
INTEGER Zero,Eref,Off,Eoff,Ezero,E1a, R1a
INTEGER Obbs,Off1
INTEGER Elin(20)
INTEGER E0del,Edel(10)
INTEGER Jntr
INTEGER Ical,Ip,t,Ncal
REAL Rgain,Gain
REAL VI(20),Ucal(20)
REAL H,K,Esq
REAL Ucal,Tcal,Tohr,0hr,Alpha
REAL Vhm,h,Usq
REAL Ueff(4096) ! look-up table for Ueff calibration 12-bit A/D
REAL Yval(30)
SHORT Ueff12(3000) ! data array written to floppy
SHORT Ubar(30),Upr(30)
PRINT
PRINT"** << PROGRAM UWIRE : FULLY-DIGITAL U-WIRE DATA ACQUSITION >> **"
PRINT
PRINT"PROGRAM STRUCTURE :"
PRINT"1. Calibrate the A/D converter of the LDV CI."
PRINT"2. Calibrate the probe vs. velocity."
PRINT"3. Construct look-up table."
PRINT"4. Acquire data and write U to disk file."
PRINT"5. Repeat (4.) for each data point taken."
PRINT"6. Reduce data off-line with another program."
PRINT
! ** Calibrate the A/D channel I
!
PRINT
PRINT"** CALIBRATION OF THE A/D CONVERTER **"
PRINT
I=s=10 !10 samples are averaged at each point
CALL m=1
GOSUB Adcal
Ezero=Zero
Eoff=off
Gain=rgain
!
! ** Calibrate wire vs. velocity
!
! 1. Compile raw calibration data table
PRINT
PRINT"** CALIBRATION TO DETERMINE Ebridge vs. Ueff **"
PRINT
INPUT "Enter calibration flow temperature in deg. F:",Tcal
Tcal=.5556*(Tcal-32)
INPUT "Enter wire temperature resistivity coefficient :",Alpha
INPUT "Enter nominal overhear ratio used (about 1.8) :",0hr
NOTE: Wire parameters are needed to do temperature correction
PRINT "Kings Law will be used to construct the look-up table -"
130 PRINT "U = K*(E^2 - E0^2)**(1/N)"
130 PRINT "The constants K, E0^2, and N may be determined from direct"
130 PRINT "calibration or input directly. Enter C to calibrate, or I"
130 PRINT "to input the constants directly."
130 INPUT "(enter C or I):", Cal$
130 IF Cal$="C" THEN GOTO 720
130 IF Cal$="I" THEN GOTO 680
130 GOTO 640
130 INPUT "Enter K : ", K
130 INPUT "E0^2 : ", E0
130 INPUT "N : ", N
130 GOTO 960
130 INPUT "Enter no. points to be taken (<= 20 total) :", Ncal
130 Ns=100  '100 samples are to be taken at each point
130 FOR Ical=1 TO Ncal
130 PRINT "Point no. ", Ical
130 INPUT "Enter calibration velocity :", Ucal(Ical)
130 GOSUB Atod
130 E1(Ical)=0       'compute average bridge output value
130 FOR Icpt=1 TO Ns
130 E1(Ical)=E1(Ical)+(C(Icpt)-E1(Ical))/Icpt
130 NEXT Icpt
130 ! 2. Convert to volts
130 V1(Ical)=FHVbrg(E1(Ical),Ezero,Eoff,Gain)
130 PRINT Ical;Ucal(Ical);V1(Ical)
130 NEXT Ical
130 PRINT "** CALIBRATION DATA ACQUISITION COMPLETE **"
130 PRINT
130 PRINT "Perform King's law fit -""
130 PRINT "Channel 1 :"
130 CALL Hcal(Ncal,V1(+),Ucal(+),N,K,E0)
130 PRINT
130 ! ** Construct look-up table to implement the calibration
130 !
130 PRINT "** LOOK-UP TABLE CONSTRUCTION AND VERIFICATION **"
130 PRINT
130 ! The matrix Ueff is a look-up table of values of velocity
130 ! from the King's Law fit versus the input value.
130 FOR J=1 TO 4096
130 Vhub=FHVbrg(J,Ezero,Eoff,Gain)
130 IF Vhub^2>E0 THEN GOTO 1060
130 Ueff(J)=0
130 GOTO 1070
130 Ueff(J)=FHKing(Vhub,K,E0,N)
130 NEXT J
130 IF Cal$="I" THEN GOTO 1240
130 PRINT "Re-construction of calibration data :"
130 PRINT
130 ! Verify look-up table by re-constructing calibration data
130 !
130 PRINT "PT. Uactual E1 U1CAL"
130 PRINT "-----------------------------"
130 FOR Icpt=1 TO Ncal
130 Jntr=E1(Icpt)
130 U1cal=Ueff(Jntr)
130 PRINT Icpt;Ucal(Icpt);E1(Icpt);U1cal
1190 NEXT Icpt
1200 PRINT
1210 !
1220 ! ** Acquire and store data at successive points:
1230 !
1240 Isft1=0
1250 Tnow=Tcal
1260 PRINT "** DATA ACQUISITION **"
1270 PRINT
1280 PRINT " Enter run parameters: "
1290 PRINT
1300 INPUT " - No. data samples per point (<3000) :", Hs
1310 REDIM Ueff12(Hs)
1320 PRINT "Enter response to determine type of data file to write:
1330 PRINT " N - no data file written"
1340 PRINT " R - raw data written at each point"
1350 PRINT " S - only summary written at the end of the profile"
1360 INPUT " Enter N, R, or S :", Arfl$#
1370 IF Arfl$="N" THEN GOTO 1400
1380 PRINT " Enter parent filename - for raw data file, the point number"
1390 PRINT " is appended to this name. This will be the name used for a "
1400 PRINT " summary data file."
1410 INPUT " Enter filename :", Name$#
1420 PRINT " Enter Y if temperature correction is desired :", Atem$#
1430 Ipt=1
1440 ! 1. Move to next location (& enter flow temp if correcting)
1450 PRINT
1460 PRINT " POINT NUMBER : "; Ipt
1470 INPUT " Enter Y location : ", Yval(Ipt)
1480 PRINT " Enter flow temperature in deg. F: "; Tnow
1490 Tnow= .5556*(Tnow-32)
1500 ! 2. Obtain raw data
1510 COSUB Atod
1520 ! 3. Estimate average bridge output voltage (if temp correcting)
1530 Elav=0
1540 FOR I=1 TO 10
1550 Elav=Elav+(C(I,I)-Elav)/I
1560 NEXT I
1570 Uest=Ueff(Elav)
1580 V1av=FNVbrg(Elav,Ezero,Eoff,Gain)
1590 PRINT "Approx. A/D value = "; Elav; " =">"; V1av; " Volts & U = "; Uest
1600 IF Atem$="Y" THEN GOTO 1670
1610 R1av=Gain*Eoff+(Elav-Ezero)
1620 ! 4. Compute shift to calibration for temperature drift
1630 Isft1=FNShiftAlpha(Alpha,Ohr,Tcal,Tnow,R1av)
1640 Uest=Ueff(Elav+Isft1)
1650 Vest=FNVbrg(Elav+Isft1,Ezero,Eoff,Gain)
1660 PRINT "Shifted A/D value = "; Elav+Isft1; " =">"; Vest; " Volts & U = "; Uest
1670 ! 5. Implement look-up table
1680 Ubar(Ipt)=0
1690 Upri(Ipt)=0
1700 FOR J=1 TO Hs
1710 Jlt=10*J+Isft1
1720 Ueff12(J)=Ueff(Jlt)
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)=SQRT(Upri(Ipt))
1780 PRINT "Y= "; Yval(Ipt);
1790 PRINT
1800 IF Afrl$<">"R" THEN GOTO 1830
1810 ! 6. Store data on floppy disk
1820 GOSUB Dfile
1830 PRINT
1840 INPUT "Enter Y to take another data point, else N : ", Ans$
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 Afrl$="S" THEN GOSUB Dfile
1940 PRINT "Enter one of the following to proceed:
1950 PRINT "M - Take another profile with same calibrations"
1960 PRINT "R - Recalibrate"
1970 PRINT "E - Exit program"
1980 INPUT "Press M, R, or E ", Ans$
1990 IF Ans$="M" THEN GOTO 1200
2000 IF Ans$="R" THEN GOTO 380
2010 IF Ans$="E" THEN GOTO 2030
2020 GOTO 1980
2030 END
2040 ! *---------------------------------------------------------------------------
2050 ! ******************************************************** END OF MAIN PROGRAM WRITE ********************************************************
2060 ! *---------------------------------------------------------------------------
2070 Dfile: ! write data file to floppy
2080 PRINT
2090 PRINT "** DATA FILE WRITE TO FLOPPY DISK **"
2100 PRINT
2110 PRINT "At this point be sure there is a floppy in drive 0 of"
2120 PRINT "the 9895A with space for a file of 50, 256-byte records."
2130 DISP "**** File write in progress ****"
2140 PAUSE
2150 DISP "***** File write completed ****"
2160 File$=Name$
2170 IF Afrl$="R" THEN File$=Name$&VAL$(Ipt)
2180 M: 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; Tit$
2220 IF Afrl$="R" THEN PRINT #1; Yval(Ipt)
2230 PRINT #1; K,Esq,N
2240 PRINT #1; Tcal,Tnow,Alpha,Ohm
2250 PRINT #1; Isft1
2260 PRINT #1; N$
2270 IF Afrl$="S" THEN MAT PRINT #1; Yval
2280 IF Afrl$="S" THEN MAT PRINT #1; Ubar
2290 IF Afrl$="S" THEN MAT PRINT #1; Upri
2300 IF Afrl$="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 C1
2360 ! enter the routine with Ichan and Ns set
2370 ! ! This segment is for fixing the shorted-input value
2380 PRINT
2381 PRINT "*** Calibrate the A/D converter channel ";Ich;" ***"
2382 DISP "Short input of channel ";Ich;" then press CONT"
2384 PAUSE
2386gosue Atod
2388 ! Average the 10 readings to get the zero value
2389 Zero=0
2390 FOR I=1 TO Ns
2391 Zero=Zero+C(Ichan,I)
2394 NEXT I
2396 Zero=Zero/Ns
2398 PRINT "Zero-level output is ";Zero;" of 12 bits"
2399 PRINT "Now calibrate the GAIN=1 vs. DIRECT before proceeding"
2400 DISP "Connect REF voltage to channel ";Ich;" then press CONT"
2401 PAUSE
2403gosue Atod
2404 Eref=0
2405 FOR I=1 TO Ns
2407 Eref=Eref+(C(Ichan,I)-Eref)/I
2410 NEXT I
2412 PRINT "Reference voltage applied to channel ";Ich;" is ";Eref
2414 PRINT "Offset calibration"
2416 DISP "Apply an OFFSET to channel ";Ich;" then press CONT"
2418 PAUSE
2420gosue Atod
2422 Off=0
2424 FOR I=1 TO Ns
2426 Off=Off+(C(Ichan,I)-Off)/I
2429 NEXT I
2431 Obt=Off
2433 Off=Off=Eref-Off
2435 PRINT "Offset value is ";Off1
2437 PRINT "Set GAIN now"
2439 DISP "Set GAIN on channel ";Ich;" then press CONT"
2441 PAUSE
2443gosue Atod
2445 Egain=0
2447 FOR I=1 TO Ns
2449 Egain=Egain+(C(Ichan,I)-Egain)/I
2452 NEXT I
2454 Rgain=(Egain-Zero)/(Obts-Zero)
2456 PRINT "Gain is ";Rgain
2458 PRINT "Reset OFFSET as desired"
2460 DISP "Reset OFFSET on channel ";Ich;" then press CONT"
2462 PAUSE
2464gosue Atod
2466 Off=0
2468 FOR I=1 TO Ns
2470 Off=Off+(C(Ichan,I)-Off)/I
2473 NEXT I
2475 Off=(Egain-Off)/Rgain+Off1
2477 PRINT "Final OFFSET value is ";Off;" bits"
2479 RETURN
2480gosue Atod: ! Subroutine for input from the LDV-A/D CI
2482 Enter routine with Ns=no. samples
2484 DISP "Press CONT to initiate data acquisition"
2486 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(IO)
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(I,1)=D1(I,3)+2048
3090  NEXT I
3100  DISP "Data acquisition complete"
3110  RETURN
3120  !-----------------------------------------------------------------------
3130  SUB Hnval(INTEGER hp,REAL E(+),REAL U(+),REAL H,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 H (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-Hp*S4
3290  A=(L0+S2-Hp+L2)/D
3300  B=(S2*L2-S4*L0)/D
3310  K=R~(1/N) ! scale factor
3320  Esq=A/B ! 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*SQRT(ERR/Np)
3400  PRINT "RMS percent error of the fit : ";ERR; ".";
3410  SUBEND
3420  !-----------------------------------------------------------------------
3430  DEF FHVbrg(INTEGER Ein,INTEGER Zero,INTEGER Off,REAL Gain)
3440  ! Compute the bridge output voltage based on calibration values
3450  RETURN ((Ein-Zero)/Gain+Off)~2*20/4096
3460  FNEND
3470  DEF FHYaw(REAL Del1,REAL Ebr,REAL A,REAL N,REAL E0bhrs)
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 0hr,REAL Tref,REAL T,INTEGER R)
3550  ! Compute temperature drift correction to bridge voltage
Cpct=Alpha*(T-Tref)/(2*(Ohm-1)) ! % shift in bridge output voltage
RETURN Cpct*R
FNEND

DEF FNYaw(REAL De1,REAL Eb1,REAL A,REAL N,REAL Eb1r)
FNEND
REM PROGRAM XWIRE2
! PROGRAM TO ACQUIRE X-WIRE DATA USING THE LDV-A/D CI
OPTION BASE 1
DIM Title$[80],Vstr$[80]  ! information strings for data file
INTEGER D1(3000,4)        !data buffer
INTEGER C(2,3000)         ! data words from CI
INTEGER Ns,Ichan
INTEGER Zero,Eref,Off,EGain,Eoff(2),Ezero(2)
INTEGER E1in(20),E2in(20)
INTEGER E0del(2),Edel(2,10)
INTEGER Jntr,J,Ncal,Ipt,Ical
INTEGER R1av,R2av
INTEGER Flag
REAL Ohvr,Alpha,Tcal,Tnow
REAL Rgain,Gain(2)
REAL V1(20),V2(20),Ucal(20)
REAL N(2),Kstr(2),K2str(2),Esq(2),Ca(2),Ang(2)
REAL N2(2),K2str(2),K2(2),E2sq(2),C2a(2)
REAL Vdel(2),V2del(2),Del(10),T1a,T2a,U1cal,U2cal,T1al,T2al
PRINT
201 PRINT "PRINTER IS 16"
220 PRINT "** << PROGRAM XWIRE2 : FULLY-DIGITAL X-WIRE DATA ACQUISITION >> **"
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 PRINT "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=#"H"
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
INPUT "Enter calibration flow temperature in deg. F:" Tcal
Tcal=.5566*(Tcal-32)
INPUT "Enter wire temperature resistivity coefficient :",Alpha
INPUT "Enter nominal overheat ratio used (about 1.8) :",Ohr
! NOTE: Wire parameters are needed to do temperature correction
PRINT " ALPHA = ";Alpha;" OHR = ";Ohr;" TCAL = ";Tcal;" C"
PRINT
INPUT "Enter no. points to be taken (<= 20 total) :",Ncal
Ns=100
! 100 samples are to be taken at each point
FOR Ical=1 TO Ncal
   DISP "Point no. ";Ical
   INPUT "Enter the calibration velocity : ",Ucal(Ical)
   GOSUB Atod
   E1in(Ical)=0 ! compute average bridge output value
   E2in(Ical)=0
   FOR Icpt=1 TO Ns
      E1in(Ical)=E1in(Ical)+(C1(Icpt)-E1in(Ical))/Icpt
      E2in(Ical)=E2in(Ical)+(C2(Icpt)-E2in(Ical))/Icpt
   NEXT Icpt
! 2. Convert to volts
   V1(Ical)=FNVbrg(E1in(Ical),Ezero(1),Eoff(1),Gain(1))
   V2(Ical)=FNVbrg(E2in(Ical),Ezero(2),Eoff(2),Gain(2))
   PRINT "Point ";Ical;" U = ";Ucal(Ical);" V1 = ";V1(Ical);" V2 = ";V2(Ical)
NEXT Ical
PRINT "** CALIBRATION DATA ACQUISITION COMPLETE **"
PRINT
! 3. Perform King's law fit
PRINT "Perform King's law fit for both channels --"
PRINT " The results will be a scale factor K* = K/\cos(A) and"
PRINT " effective no-flow output E0^2. A is the effective wire"
PRINT " angle in the plane of the wire."
PRINT
PRINT "Channel 1 :"
Flag=0
IF Acal#="Y" THEN Flag=1 ! E0^2 is fixed for Hcal#1
CALL Hocal(Hcal#,V1(*),Ucal(*),N2(1),K2str(1),E2sq(1),Flag)
PRINT
PRINT "Channel 2 :"
CALL Hocal(Hcal#,V2(*),Ucal(*),N2(2),K2str(2),E2sq(2),Flag)
! Kstr is K/\cos(A), where A is the effective wire angle
! which is determined in the next program segment
! Note that the effective zero-flow output E0^2 is needed
! for the yaw calibration.
IF Acal#="Y" THEN GOTO 1890
IF Acal#="Y" THEN GOTO 1890
! Yaw calibration to determine effective wire angles
PRINT
PRINT "** YAW CALIBRATION - PROBE YAWED IN WIRE PLANE **"
PRINT
RAD
Ns=100 ! 100 samples are used in yaw calibration
! 1. Fix the velocity and get data at Delta=0
PRINT "The nominal yaw angle is Delta - the effective wire"
PRINT " angle in the wire plane is now determined by the"
PRINT " yaw calibration."
PRINT
DISP "Set probe at Delta=0 then press CONT"
PAUSE
1170 GOSUB Atod
1180 E0del(1)=0
1190 E0del(2)=0
1200 FOR Icpt=1 TO Nh
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);" volts"
1290 PRINT
1300 ! 2. Yaw the probe through a series of angles
1310 Nyaw=1
1320 PRINT "How 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 Nh
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$="N" THEN GOTO 1490
1460 Nyaw=Nyaw+1
1470 GOTO 1350
1480 ! 3. Compute tangent of average effective wire angle
1490 PRINT
1500 PRINT "YAW CALIBRATION DATA SUMMARY"
1510 PRINT "PT. YAW ANGLE TAN(A1) TAN(A2)"
1520 PRINT "-----------------------------"
1530 T1a=0
1540 T2a=0
1550 FOR Icpt=1 TO Nh
1560 Vdel(1)=FNVbrg(Edel(1,Icpt),Ezero(1),Eoff(1),Gain(1))
1570 Vdel(2)=FNVbrg(Edel(2,Icpt),Ezero(2),Eoff(2),Gain(2))
1580 ! NOTE: The effective wire angle is computed at each point-
1590 T1a=NFYaw(Del(Icpt),Vdel(1),E2sq(1),N2(1),V0del(1))
1600 T1a=T1a+(T1a-T1a)/Icpt
1610 T2a=NFYaw(Del(Icpt),Vdel(2),E2sq(2),N2(2),V0del(2))
1620 T2a=T2a+(T2a-T2a)/Icpt
1630 PRINT Icpt;
1640 PRINT " ";Del(Icpt);" ";T1a;",";T2a
1650 NEXT Icpt
1660 PRINT
1670 PRINT "Averaged values: Tan ps1 = ";T1a;" Tan ps2 = ";T2a
1680 PRINT
1690 INPUT "Reply C to change these, else N : ",Ans$
1700 IF Ans$="C" THEN GOTO 1720
1710 INPUT "Enter Tan ps1, Tan ps2 :",T1a,T2a
1720 PRINT
1730 C2a(1)=1/SQR(1+ABS(T1a)^2)
1740 C2a(2)=1/SQR(1+ABS(T2a)^2)
1750 K2(1)=K2str(T1a)*C2a(1)
1760 K2(2)=K2str(T2a)*C2a(2)
K2(2)=K2str(2)*C2a(2)
PRINT
INPUT "Y to perform orth. cal. in plane of measurement (reply Y or N) :"

FOR I=1 TO 2
K(I)=K2(I)
N(I)=N2(I)
Esq(I)=E2sq(I)
Ca(I)=C2a(I)
NEXT I
IF Acal#="Y" THEN GOTO 640
GOTO 1991
! 4. Effective wire angle in orthogonal plane is computed
Ca(1)=K(1)/K2str(1)
Ca(2)=K(2)/K2str(2)
PRINT
PRINT "Calibration constants used in look-up table construction:");K1 = ";K2 = ";K(2)
PRINT " R1 = ";Esq(1);" R2 = ";Esq(2)
PRINT " N1 = ";N(1);" N2 = ";N(2)
PRINT " COS 1 = ";Ca(1);" COS 2 = ";Ca(2)
Ang(1)=180+ACS(Ca(1))/PI
Ang(2)=180+ACS(Ca(2))/PI
PRINT " WIRE ANGLES : 1 = ";Ang(1);" 2 = ";Ang(2)
PRINTER IS 16
PRINT "** CRT is now the default printer **"
! ** Acquire and store data at successive points:
!
Isft1=0
Isft2=0
Tnow=TCal
PRINT "** DATA ACQUISITION **"
PRINT " Enter run parameters: ";
PRINT " Enter file name for output data files - not to exceed 4 characters - e.g. DATA. ";
INPUT " Enter file name : "Name$
INPUT " Enter a 1-line file title for the profile : ";Titl$
INPUT " Enter no. data samples per point (<3000) : ";Ns
INPUT " Enter Y if temperature correction is desired : ";Atem$
Ipt=1
! 1. Move to next location (& enter flow temp if correcting)
PRINT
PRINT "POINT NUMBER : ";Ipt
INPUT " Enter flow temperature in deg. F: ";Tnow
Tnow=.5556*(Tnow-32)
INPUT " Enter one-line string to identify the current point : ";Ystr$
! 2. Obtain raw data
GOSUB Atod
! 3. Estimate average bridge output voltage (if temp correcting)
IF Atem$="Y" THEN GOTO 2390
E1av=0
E2av=0
FOR I=1 TO 10
E1av=E1av+(C(1,I)-E1av)/I
E2av=E2av+(C(2,I)-E2av)/I
NEXT I
2330 R1av=Gain(1)*Eoff(1)+(E1av-Ezero(1))
2340 R2av=Gain(2)*Eoff(2)+(E2av-Ezero(2))
2350 ! 4. Compute shift to calibration for temperature drift
2360 Isft1=FNShift(Alpha,0hr,Tcal,Tnou,R1av)
2370 Isft2=FNShift(Alpha,0hr,Tcal,Tnou,R2av)
2380 ! 5. Store data on floppy disk
2390 GOSUB Dfile
2400 PRINT
2410 PRINT "Enter one of the following to proceed:":"
2420 PRINT "E - exit the program"
2430 PRINT "P - another data point, same profile name"
2440 PRINT "N - new profile, same calibration"
2450 PRINT "C - new profile, repeat calibration procedure"
2460 INPUT "Enter E, P, N, or C: ", Ans$
2470 IF Ans$="E" THEN GOTO 2550
2480 IF Ans$="P" THEN GOTO 2520
2490 IF Ans$="N" THEN GOTO 2530
2500 IF Ans$="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:"
2670 File$=Name$"VALC$(Ipt)
2680 PRINT "File ":File$, "being written"
2690 PRINT "MASS STORAGE IS ":H8,0,0"!9895A floppy drive set as default
2700 CREATE File$, 100
2710 ! file is 100 records of 256 bytes
2720 ASSIGN File$ TO #1
2730 PRINT #1;Titl$
2740 PRINT #1;Ystr$
2750 PRINT #1;Tcal,Tnou,Alpha,0hr
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;Hs
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 Hs set
2900 ! !!! This segment is for fixing the shorted-input value
2910 PRINT
2920 PRINT "+" *** Calibrate the A/D converter channel ";Ichan;" ***
DISP "Short input of channel ";Ichan;" then press CONT."
PAUSE
GOSUB Atod
! Average the 10 readings to get the zero value
Zero=0
FOR I=1 TO Ns
Zero=Zero+(C(Ichan,I)-Zero)/I
NEXT I
PRINT "Zero-level output is ";Zero;" of 12 bits"
!!! Now read the reference value
DISP "Connect ref voltage to chan ";Ichan;" then press CONT"
PAUSE
GOSUB Atod
Eref=0
FOR I=1 TO Ns
Eref=Eref+(C(Ichan,I)-Eref)/I
NEXT I
PRINT "Reference voltage applied to channel ";Ichan;" is ";Eref"
!!! An offset is applied and calibrated for channel Ichan
DISP "Apply an offset to channel ";Ichan;" then press CONT"
PAUSE
GOSUB Atod
Off=0
FOR I=1 TO Ns
Off=Off+(C(Ichan,I)-Off)/I
NEXT I
Off1=Eref-Off
PRINT "Offset value is ";Off1
!!! A gain is calibrated - nominal values are set externally
DISP "Set GAIN on channel ";Ichan;" then press CONT"
PAUSE
GOSUB Atod
Egain=0
FOR I=1 TO Ns
Egain=Egain+(C(Ichan,I)-Egain)/I
NEXT I
Rgain=(Egain-Zero)/(Eref-Zero-Off1)
PRINT "Gain of channel ";Ichan;" is ";Rgain
!!! Reset the OFFSET value
DISP "Reset the OFFSET on channel ";Ichan;" then press CONT"
PAUSE
GOSUB Atod
Off=0
FOR I=1 TO Ns
Off=Off+(C(Ichan,I)-Off)/I
NEXT I
Off=(Egain-Off)/Rgain+Off1
PRINT "Final OFFSET is ";Off;" bits"
RETURN
Atod: ! Subroutine for input from the LDV-A/D CI
!!! Enter routine with Ns=nc. samples
DISP "Press CONT to initiate data acquisition"
PAUSE
RESET 10
CONTROL MASK 10:1
WRITE IO 10,5:0
WRITE IO 10,5:1  ! start handshake by setting CTL0
Ht=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 Next NOFORMAT;D1(*) !fast data acquisition
3580 DISP "Data acquisition complete"
3590 FOR I=1 TO Ns !transfer the data to integer arrays
3600 C(1,I)=D1(I,3)+2048 !two data words (LIV is sending 4 words total
3610 C(2,I)=D1(I,4)+2048 !second data word
3620 NEXT I
3630 RETURN

3640 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3650 SUB Hucal(INTEGER Hp,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 3670
3710 L0=0 !initialize sums for linear least-squares fit
3720 L2=0
3730 S2=0
3740 S4=0
3750 FOR I=1 TO Hp
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+S-Np*S4
3820 A=(L0+S-Np)L2/D
3830 B=(S2+S-Np)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 Hp
3900 L0=L0+U(I)^N|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 Hp
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 FEND
4080 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
4090 DEF FNYaw(REAL De1,REAL Ebr,REAL A,REAL N,REAL E0brs)
4100 !Compute the effective wire angle given the nominal angle (De1) 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 H)
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 0hr,REAL Tref,REAL T,INTEGER R)
4220 ! Compute temperature drift correction to bridge voltage
4230 Cpct=Alpha*(T-Tref)/(2*(0hr-1)) ! % shift in bridge output voltage
4240 RETURN Cpct*R
4250 FNEND
REM PROGRAM UVBAR2
10 ! PROGRAM TO REDUCE X-WIRE DATA ACQUIRED WITH PROGRAM XWIRE2
20 ! Input is 2 channels of raw data and calibration constants
30 ! Output is the two components of mean velocity in the wire
40 ! plane as well as the in-plane turbulence stresses and third
50 ! order products.
60 OPTION BASE 1
70 DIM Titl#(80),Ystr#$(80)
80 INTEGER Na,Nf,Filno
90 INTEGER Eoff(2),Ezero(2)
100 INTEGER Isft1,Isft2
110 INTEGER C(2,3000)
120 INTEGER I,J,Jntr
130 REAL Vhmb
140 REAL Gain(2)
150 REAL Tcal,Tnow,Alpha,Ohr
160 REAL K(2),Esq(2),N(2),Ca(2)
170 REAL C1a,C2a
180 REAL Ueff(2,5000)
190 SHORT Ueff12(3000,2)
200 PRINT
210 PRINT " ** PROGRAM UVBAR2 - REDUCES RAW X-WIRE DATA **"
220 PRINT
230 PRINT "Program outline:"
240 PRINT "1. Read calibration and raw data from specified file."
250 PRINT "2. Construct look-up table and implement calibration."
260 PRINT "3. Compute running sums for statistics up to third order."
270 PRINT "4. Print results."
280 PRINT "Note: Channel 1 is assumed to be U+V wire for sign convention."
290 PRINTER IS 0
300 MASS STORAGE IS ":HS,0,0"
310 Filno=0
320 INPUT "Enter parent filename (or E to exit program) ":" ,Name$
330 File#=Name$
340 IF File$="E" THEN GOTO 1310
350 INPUT "Enter no. of data files with parent prefix (0 if parent only) " ,Nf
360 IF Nf=0 THEN GOTO 410
370 Filno=Filno+1
380 IF Filno>Nf THEN GOTO 1290
390 File#=Name$&VAL$(Filno)
400 ASSIGN File# TO #1
410 READ #1;Titl$
420 PRINT Titl$
430 READ #1;Ystr$
440 PRINT Ystr$
450 READ #1;Tcal,Tnow,Alpha,Ohr
460 READ #1;Eoff(1),Ezero(1),Gain(1)
470 READ #1;Eoff(2),Ezero(2),Gain(2)
480 READ #1;K(1),Esq(1),N(1),Ca(1)
490 READ #1;K(2),Esq(2),N(2),Ca(2)
500 READ #1;Isft1,Isft2
510 READ #1;Na
520 MAT READ #1;C
530 ! now reduce the data - three steps:
540 ! 1. Construct & implement look-up table
550 ! 2. Convert Ueff1,2 to U and V
560 ! 3. Update running sums
570 IF Filno>1 THEN GOTO 721
580 !
1. Construct & implement look-up table

FOR J=1 TO 5000
  FOR I=1 TO 2
    Yhwb=FNVbreg(J,Ezero(I),Eoff(I),Gain(I))
    IF Yhwb>2Esq(I) THEN GOTO 680
    Ueff(I,J)=0
  GOTO 680
  Ueff(I,J)=FNKng(Yhwb,K(I),Esq(I),N(I))
  NEXT I
NEXT J

DISP "LOOK-UP TABLE CONSTRUCTION COMPLETED"

! Implement look-up
Nout1=0
Nout2=0

FOR J=1 TO Ns
  Jntc=C(1,J)+Ishift1
  IF C(1,J)<4095 THEN GOTO 750
  Nout1=Nout1+1
  Ueff12(J,1)=Ueff(1,Jntc)
  Jntc=C(2,J)+Ishift2
  IF C(2,J)<4095 THEN GOTO 770
  Nout2=Nout2+1
  Ueff12(J,2)=Ueff(2,Jntc)
  NEXT J

DISP "CALIBRATION IMPLEMENTATION COMPLETED"

! 2. Convert Ueff 1,2 to U and V

Sin1=SOR1-Ca(1)^2
Sin2=SOR1-Ca(2)^2
D=Ca(1)*Sin2+Ca(2)*Sin1
A1=Sin2/D  channel 1 is U+V wire
A2=Sin1/D
A3=Ca(2)/D  channel 2 is U-V wire
A4=-Ca(1)/D
Su1=0
Su1=0
Su2=0
Su2=0
Su3=0
Su3=0
Su2u=0
Su2u=0

FOR Ipt=1 TO Ns
  U=A1+Ueff12(Ipt,1)+A2+Ueff12(Ipt,2)
  V=A3+Ueff12(Ipt,1)+A4+Ueff12(Ipt,2)
  NEXT Ipt

! 3. Running sums for statistics

Su1=Su1+(U-Su1)/Ipt
Su2=Su2+(U2-Su2)/Ipt
Su1=Su1+(V-Su1)/Ipt
Su2=Su2+(V2-Su2)/Ipt
Su3=Su3+(U+V-Su3)/Ipt
Su2u=Su2u+(U+V-Su2u)/Ipt
Su2u=Su2u+(U+V-Su2u)/Ipt

NEXT Ipt

Ubar=Su1
Vbar=Su1
Upri2=Su2-Su1*Su1
Vpri2=Su2-Su1*Su1
Uvbar=Suv-Su1*Su1
U2vbar=Su2u-2*Ubar+Suu-Vbar*Su2+2*Ubar+Ubar*Vbar
V2ubar=Su2u-2*Vbar+Suu-Ubar*Su2+2*Vbar+Vbar*Ubar
PRINT
PRINT "REDUCED DATA: Channel 1 taken as U+V"

PRINT 
PRINT "Out-of-range data: chn 1 " ;Nout1; " chn 2 " ;Nout2
PRINT "Total sample size: " ;Ns
PRINT "UBAR = " ;Ubar; " VBAR = " ;Vbar; " UNITS: L/T"
PRINT "UPRI2 = " ;Upri2; " VPRI2 = " ;Vpri2; " UNITS: (L/T)^2"
PRINT "U2VBAR = " ;U2vbar; " V2UBAR = " ;V2ubar; " UNITS: (L/T)^3"
PRINT
GOTO 380
INPUT "Reply Y to reduce another profile, else N:" ;Ans#
IF Ans#="Y" THEN 310
MASS STORAGE IS "T15"
PRINT IS 16
END
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!! END PROGRAM UVBAR2 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
DEF FKING(REAL Ebr,REAL K,REAL E0sq,REAL N)
! computes velocity based on King's Law calibration
RETURN K*(Ebr^2-E0sq)^(1/N)
FNEND

DEF FNVbrg(INTEGER Ein,INTEGER Zero,INTEGER Off,REAL Gain)
RETURN ((Ein-Zero)/Gain+Off)*20/4096
FNEND

!!!
REFERENCES


## X-WIRE EQUIPMENT LIST

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

**Figure 1.- Crossed-wire system hardware schematic.**
Figure 2.- NASA crossed-wire probe and holder.
Figure 3.- NASA LDV-A/D computer interface connections.
ENTER REFERENCE QUANTITIES
OHR, \( \alpha, T_{\text{cal}} \)

HARDWARE CALIBRATION
A/D ZERO \( Z_j \)
GAIN \( G_j \)
OFFSET \( O_j \)

STATIC VELOCITY CALIBRATION
FIT KING'S LAW
\( K_j, E_0, Z_j, N_j \)

YAW CALIBRATION IN U-W PLANE
\( \psi_{uw, j} \)

YES

ROTATE PROBE TO U-V PLANE?

STATIC VELOCITY CALIBRATION
\( \psi_{uv, j} \)

\( \psi_j = \psi_{uv, j} \)

NO

\( \psi_j = \psi_{uw, j} \)

DATA ACQUISITION
- ENTER LOCATION \( Y_{\text{STR}} \) AND \( T_{\text{NOW}} \)
- ACQUIRE DATA \( A(i, j), i = 1, N_s \)
- COMPUTE TEMPERATURE CORRECTION SHIFT \( S_j \)

DATA FILE WRITE
- OPEN FLOPPY DISK FILE
- WRITE CALIBRATION
\( K_j, E_0, Z_j, N_j, \psi_j \)
- TEMP SHIFT \( S_j \) AND \( Y_{\text{STR}} \)
- RAW DATA \( A(i, j) \)

ANOTHER POINT?

YES

STOP

Figure 4.— Calibration and data-acquisition procedure.

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NOTES:
1) $j$ DENOTES CHANNEL NUMBER
2) SIGN CONVENTION: "$u+v$" IS CHANNEL 1
3) $u$ AND $v$ ARE THE IN-PLANE COMPONENTS OF VELOCITY

Figure 5. - Data-reduction algorithm.
Figure 6.- Schematic of plane mixing layer experimental setup.
Figure 7. Plane mixing layer: sample results.
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.