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A 3-COMPONENT LASER-DOPPLER VELOCIMETER DATA ACQUISITION AND REDUCTION SYSTEM

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ABSTRACT

This report describes a Laser Doppler Velocimeter capable of measuring all three components of velocity simultaneously in low-speed flows. All the mean velocities, Reynolds stresses, and higher-order products can then be evaluated. The approach followed is to split one of the two colors used in a 2-D system, thus creating a third set of beams which is then focused in the flow from an off-axis direction. The third velocity component is computed from the known geometry of the system. In this report, the laser optical hardware and the data acquisition electronics are described in detail. In addition, full operating procedures and listings of the software (written in BASIC and ASSEMBLY languages) are also included. Some typical measurements obtained with this system in a vortex/mixing layer interaction are presented and compared directly to those obtained with a cross-wire system. A brief discription of the present system together with a review of existing 3-D Laser Doppler Velocimeters is given in Ref. 1.

LIST OF FIGURES

NOMENCLATURE

$a(i)$	ith sample value
d_f	fringe spacing
f	frequency
i	sample number
Ns	number of samples
R	range setting on Macrodyne processor
S<a(i)>	sum of a(i) from i = 1 to i = Ns
Sa	average of quantity a, defined by equations (3)
$\overline{u},\overline{v},\overline{w}$	mean velocity components in x,y,z directions, respectively
u,v,w	instantaneous velocity components in x,y,z directions, respectively
U_o	$U_1 - U_2$, velocity difference between the two streams in the mixing layer
x,y,z	Streamwise, normal, and spanwise coordinate directions, respectively

Subscripts:

bragg	Bragg
mix	mixing
dopp	doppler
res	resultant
1	quantity measured in high-speed side of mixing layer
2	quantity measured in low-speed side of mixing layer

Superscripts:

'	fluctuating quantity, e.g., $u = \overline{u} + u'$
—	time average

1. INTRODUCTION

Our ability to understand and model turbulent flows still relies heavily on the availability of accurate measurements of mean and fluctuating quantities within the flow. Until recently, the hot wire was the only reliable tool available for the measurement of fluctuating velocities. In fact, almost all of our present knowledge about turbulent flows is based on measurements made with hot wires. In relatively simple flows (moderately two-dimensional with small cross-flows), reliable and accurate hot wire measurements are now possible with fully automated data acquisition and reduction systems which minimize errors due to drifts in calibrations. An example of such a system is given in Ref. 2.

However, as we turn our attention towards more complex turbulent flows, a need for more sophisticated measurement techniques has become apparent. These complex flows include those with compressibility effects, strong three-dimensionality (with steep mean gradients), flow reversals, and time-dependent behavior. Since about the mid-sixties, the most popular alternative tool for measuring mean and fluctuating velocities in turbulent flows has been the Laser Doppler Velocimeter (LDV).

The most popular LDV arrangement used for wind tunnel measurements is the dual beam or fringe method. In this method, one of the laser lines is split into two lines of equal intensity which are then focused through a lens so that they cross over at the focal point. The flow is seeded with small particles (typically less than 3-4 μm in diameter) which follow the fluid motion. As these particles pass through interferometric fringes created by the crossed laser beams, light is scattered off them which is received by a photodetector. The frequency of this scattered light, along with a knowledge of the fringe pattern formed by the laser beams, provide the means to calculate the velocity of the particle. The fringe method, especially in the forward scatter, off-axis mode, generally offers the best signal-to-noise ratios and spatial resolution.

Although LDV systems are somewhat complex and tiresome to set up, they have certain advantages over hot wires for turbulence measurements. The fact that Laser Doppler Velocimetry is non-intrusive is especially beneficial in the measurement of unstable flow phenomena which are very sensitive to the presence of measurement probes. In certain situations, LDV systems can also provide greater spatial resolution and better directional descrimination than hot wires. This makes it possible to use LDV systems for the measurement of separated flows. Since an LDV measures the velocity directly, independent of the thermodynamic properties of the flow, it is particularly attractive for velocity measurements in compressible flows. Furthermore, the calibration converting the frequency to velocity is linear and easy to implement in software. This feature also allows for uniform sensitivity in measuring both moderate and high turbulence intensities.

Two-color LDV systems capable of measuring two components of velocity simultaneously are now being widely used. However, the main interest in the present investigation was to study three-dimensional interactions where it is desirable to obtain measurements of all three velocities. Hence, the first objective was to develop a laser velocimeter system capable of measuring all three components of velocity simultaneously so that all six components of Reynolds stress may be computed. Another objective was to compare these LDV measurements directly with those obtained with hot wires in flow fields where both techniqes are expected to perform satisfactorily. The purpose of this is to evaluate the performance of the system quantitatively and objectively.

The approach followed in the present investigation was to convert an existing two-component LDV system into one capable of measuring all three components of velocity simultaneously. The system utilizes two wavelengths (488.0 and 514.5 nm) from a 4-watt Argon-Ion laser. The main four-beam matrix measures u and v directly. The green line in the four-beam matrix is split (in half) using a dichroic filter and directed over the top of the traverse mechanism with mirrors, giving the third beam pair for the measurement of the w-component. This pair of beams (with rotated polarization) measures w sin 45°+ v cos 45°. Scattered light is collected in the off-axis forward scatter mode using two collection lenses.

Signal processing is accomplished with single-particle burst counters, and the validated data are multiplexed through a "home-built" interface to an HP 9845B desk-top computer. Some selected first and second order products are reduced on-line, and the raw data is dumped onto floppy disk. An off-line program reduces the data, giving up to third order quantities and also plots histograms of the raw data for each channel. The software includes the capability to filter out noise by examining the histograms.

The optical and signal processing hardware is described in Section 2. The data acquisition and reduction software is described in Section 3 and detailed operating procedures are given in Section 4. Some problems, inherent to 3-component LDV systems, are presented in Section 5. Sample results from an experiment measuring mean and turbulence quantities in a vortex/mixing layer interaction are compared directly to results obtained using crossed hot-wire anemometry in Section 6, and concluding remarks are presented in the final section. Complete software listings written in BASIC and ASSEMBLY languages to run on the HP 9845B desk-top computer are included in the appendix.

2. OPTICAL SYSTEM AND SIGNAL PROCESSING HARDWARE

The hardware for the 3-component LDV system can be divided into three categories: the optical system, the signal processing instrumentation, and the computer. The LDV optics consist of the optics table, where the laser beam is split into green and blue beam pairs, the transmitting optics, where the beams are directed into the flow field, and the receiving optics, where the scattered light is picked up by photodetectors. The signal processing instrumentation consists of amplifiers, filters, burst counters and a computer interface. The sampling procedures are all computer controlled.

2.1 Optics Table

The optics table consists of the laser and all the optical elements needed to provide the necessary four-beam matrix. Fig. 1 shows a schematic of the arrangement with component numbers as referred to in this section. A 4-watt Argon-Ion laser (Lexel Model 95) is used to produce the main beam. The beam then passes through a collimator (1), which ensures that the beam waist occurs at the focal point of the transmitting lens.

The collimated beam is passed through a color separator box, which consists of a polarization rotator (2), an attenuator (3), and a pair of high dispersion Brewster angle prisms (4) which are used to separate the multi-line beam into two colors, blue (488 nm) and green (514.5 nm). These two beams are then reflected across the box by mirror (5), and out of the box by mirrors (6, 7).

Following the color separation, the green beam's polarity is rotated to horizontal (8), and the beam is split into two beams in the vertical plane (9). Most beam splitters prefer this type of perpendicular polarization for maximum efficiency. Using the beam displacer (10), the blue beam is then moved to the center of the optics, and its polarity is rotated to vertical (11). The blue beams are split in the horizontal plane (12). At this point, the four beams are each displaced 25 mm from the optical axis.

Two Bragg cells (13, 14) are used to shift the frequency of one beam from each pair. The unshifted beam passes through an optical rod so that the path lengths are matched. The frequency is shifted by a fixed amount of 40 Mhz. This shift creates a moving system of fringes at the beam intersection point, allowing for directional discrimination of the velocity. Frequency shifting also helps to reduce the percentage of frequency change in highly turbulent flow, to reduce fringe bias, and to optimize frequency, thus enabling easy removal of the pedestal by high pass filtering.

The four beams are then passed through a beam steering module (15). The module consists of a set of wedge prisms that can be independently rotated about the beam axis to steer the shifted beam in any direction. This allows a more precise alignment of the beams. The beams are finally passed through a beam displacer (16) to reduce the beam spacing to 13 mm and a rotating prism (17) before leaving the optics table. The rotating prism enables the four-beam matrix to be rotated independently so that the beams may be aligned relative to the tunnel axes.

2.2 Transmitting Optics

The transmitting optics (Fig. 2) are mounted on a traversing mechanism with three degrees of freedom. The traverses are driven by individual stepper motors. The four beams from the optics table are directed by a set of five mirrors through a dichroic filter before being focused by a 380 mm (15 inch) focal length lens. This main four-beam matrix measures u and v directly. The dichroic filter, set at an angle of about 30 degrees to the incoming beams, splits the green beams in half, which provides the third beam pair for the third velocity component, w. This third beam pair is directed over the top by mirrors, passed through a polarization rotator (giving it a different polarity than the main-axis green beam pair) and then focused at the focal point of the main beam set. Since this third beam pair intersects the main measuring volume at a 45^0 angle to the main axis, it measures v and w with equal sensitivity, with the measured component being $w_V = (v \cos 45^0 + w \sin 45^0)$. Since v is measured directly, w can be evaluated using the equation:

$$w = \frac{w_V - v \cos 45^\circ}{\sin 45^\circ} \qquad (1)$$

Typical probe volume dimensions for each beam pair in the present configuration are 10 mm in length and 0.2 mm in diameter (Fig. 3). However, the actual "viewed" dimensions are reduced considerably, as discussed below, in Section 2.3.

2.3 Receiving Optics

The detector system (Fig. 4) is in the off-axis forward scatter mode. The receiving optics are mounted on a traversing gear, also run by stepper motors, which moves synchronously with the transmitting optics. Scattered light is collected by two 380 mm (15 inch) focal length lenses. The collimated light is passed through filters to separate the colors and the off-axis line is additionally passed through a polarization filter to avoid collecting light scattered by the main axis green pair. The collected light is then focused by 250 mm (10 inch) focal length lenses onto pin-hole apertures mounted in front of the three photomultipler tubes. The collection angle and diameter can be adjusted to select the effective (viewed) probe length (Fig. 5). In the present set-up, a collection angle of 30 degrees and an aperture diameter of 0.5 mm were used to give an effective length of about 1.5 mm.

2.4 Signal Processing Hardware

The signals from the photomultiplier tubes are amplified and relayed to the signal processors via high-pass filters and mixers (Fig. 6). The amplifiers used are EIN model 403LA with a fixed gain of 37 dB and the filters are Allen Avionics F2440 with a fixed high-pass cutoff of 10 MHz. The filtered signals are mixed electronically with sine waves from three Tektronix SG503 Levelled Sine Wave Generators. The mixer is commercially available from Hewlett-Packard, model 10534A. The mixing procedure is necessary for low-speed flows, where the actual Doppler frequencies are small compared to the Bragg frequency of 40 MHz. So in order to reduce the effective measured frequency and hence improve the counter resolution, the incoming signals are mixed with sine waves of known frequency.

The mixed signal is fed into single particle burst counters (Macrodyne model 2096-2 and 3003) via high-pass/low-pass filters and an amplifier (x10). The counters measure the zero crossings of the Doppler signal, which is related to the Doppler frequency by the range set on the Macrodyne. The range is set manually based on expected flow velocities, since it limits the frequencies that the processor can see for the given 10 bits of resolution.

The processors use two checks to validate a Doppler signal. The first check is the usual 5/8 comparison, where the processor checks the frequency for 5 zero crossings against that for 8 crossings. The second check is the multi-sequence check. Positive and negative thresholds are set on the signal, and a validated output is permitted only if, for all eight fringe crossings, the signal passes through a positive threshold, a zero level, and a negative threshold in the proper sequence. The digital data (consisting of a 10 bit data word with 3 bits giving the range) and a sync pulse (produced every time the front end of a valid burst is detected) are passed to the computer interface.

2.5 Computer Interface

A NASA LDV-A/D computer interface (CI) is used to transfer data from the LDV signal processor to the computer (Fig. 7). The CI can interface either digital or mixed analog and digital data to an HP 9845B desk-top computer. The CI consists of an eight-channel multiplexer, a four-channel A/D converter, and an event synchronizer with time interval counter.

For use with the LDV, the inputs to the CI are all digital. Six of the eight words come from the processor, and two are time and status words from the synchronizer. The inputs are multiplexed to a single digital data channel output.

The CI can accept data from the three processors in either random mode or sync mode. In random mode, the CI will accept data inputs when an event occurs on any of the three channels. A dead time (between 5 and 50 µs) is set in this mode, which controls the minimum time between samples to ensure that a given particle is sampled only once. In sync mode, the CI will accept data inputs when all three processors sample simultaneous events. In this mode, a coincidence time (between 5 and 50 µs) has to be set, which determines the time window within which all three events must occur. A detailed description of the CI can be found in Ref. 5.

2.6 HP 9845B Desk-top Computer

Multiplexed data are 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" are connected inside the 98032A for proper operation with the LDV-A/D. A select code of 10 (screw setting on the 98032A) is set for use with the software described in the appendix. A data buffer of 24 kbytes is provided in the memory of the HP 9845B desk-top computer for storage of up to 2000 samples obtained from one measurement location. Since three of the six data words passed for each sample are merely monitored and discarded as described above, 12 kbytes of raw data remain to be stored for each point. An HP 9895A floppy-disk drive is used for archival storage of raw data. The buffered data are written in real time to a sequential-access floppy-disk file. Enough header information is written to each file to identify the run, and to reproduce calibration tables.

3. DATA ACQUISITION AND REDUCTION SOFTWARE

Data aquisition and reduction on the HP 9845B is done via two programs. The data acquisition program controls the processor sampling. The program accepts heading and initialization parameters provided by the operator, performs a fast I/O handshake to acquire the raw data from the LDV-A/D computer interface, and writes the raw data and initialization parameters onto floppy-disk. In addition, the data acquisition program has a limited capability for on-line data reduction so that key results may be monitored during a run. The off-line data reduction program converts the raw data into instantaneous velocities and computes all the statistical quantities. The off-line program also has options to plot histograms of the raw data, to plot profiles of the reduced data, and to filter out noise.

3.1 Data Acquisition Program

The data acquisition program structure can be divided into four areas: (1) initialization of variables, (2) data acquisition, (3) limited data reduction, and (4) raw data storage (see the block diagram in Fig. 8). During the initialization stage of the program, relevant test parameters are input to be saved along with the data. These parameters include the spatial coordinates, Bragg and mixing frequencies, and angle of the third beam pair. Fringe spacings and probe dimensions are also calculated at this time.

Data is acquired from the LDV computer interface by means of a fast I/O handshake. The operator requests that a certain number of data samples be taken and stored in the data buffer as described in Section 2.6. The 16-bit data words are put into an integer array, three words wide, containing values for the three velocity components. The number acquired from the counter occupies only bits 0-9 of the data word. Bits 10-13 specify the range, and bits 14 and 15 are unused. The data array, along with the initialization parameters given by the operator, are stored in a floppy-disk file. As an option, some of the data can be reduced on-line, before the raw data is written to floppy-disk. This on-line reduction feature uses the same algorithms as the off-line data reduction program, but is faster since it computes fewer quantitites. Data acquisition times depend on many factors other than the software, but on-line data reduction takes about 30 seconds per point on the HP 9845B, and each file write to the floppy-disk requires about 20 seconds, assuming 2000 samples are taken per point.

3.2 Data Reduction Program

A separate off-line program is used to reduce the complete data. The data reduction program has four major sections: (1) data read from floppy-disk, (2) conversion of raw data to instantaneous velocities, (3) calculation of sums of instantaneous velocity components, and (4) calculation of moments from the sums (see the block diagram in Fig. 9). Since the HP 9845B is a relatively slow micro-computer, the bulk of the calculation routines are written in ASSEMBLY language to reduce computation time.

The program reads the initialization parameters and raw data which were written on floppy-disk by the data acquisition program. The raw data is used together with the mixing frequencies, Bragg shift frequency, third beam crossing angle, and fringe spacings to calculate the three velocity components for each sample. The velocities for each sample are calculated in turn, and a running sum is maintained. After the samples have been summed, the average values of the various moments are computed, and the mean velocities and turbulence quantities are calculated from them. Reading from the floppy-disk takes about 20 seconds, while the data reduction including histogram plots requires about 90 seconds per point on the HP 9845B.

The procedure for data reduction is fairly straightforward. The raw data is converted to frequencies using the range set on the processor. The measured frequency is given by the relation

$$f_{res} = 3.2 * 10^4 / 2^R * D \tag{2}$$

where D = raw data.

The velocities are then calculated from the resultant frequencies, by the relation:

$$velocity = d_f * ((f_{bragg} - f_{mix}) - f_{res}) \tag{3}$$

Once the velocities have been evaluated, average values of the various moments are computed as defined below:

$$\begin{aligned}
Su &= S<u(i)> / Ns \\
Sv &= S<v(i)> / Ns \\
Sw &= S<w(i)> / Ns \\
Suu &= S<u(i)u(i)> / Ns \\
Suv &= S<u(i)v(i)> / Ns \\
Suw &= S<u(i)w(i)> / Ns \\
Svv &= S<v(i)v(i)> / Ns \\
Svw &= S<v(i)w(i)> / Ns \\
Sww &= S<w(i)w(i)> / Ns \\
Suuv &= S<u(i)u(i)v(i)> / Ns \\
Suuw &= S<u(i)u(i)w(i)> / Ns \\
Suvv &= S<u(i)v(i)v(i)> / Ns \\
Suww &= S<u(i)w(i)w(i)> / Ns \\
Suvw &= S<u(i)v(i)w(i)> / Ns
\end{aligned} \tag{4}$$

Using these definitions, the signal statistics are then calculated assuming nearly infinite sample size:

$$\begin{aligned}
\overline{u} &= Su \\
\overline{v} &= Sv \\
\overline{w} &= Sw \\
\overline{u'^2} &= Suu - SuSu \\
\overline{v'^2} &= Svv - SvSv
\end{aligned} \tag{5}$$

$$\overline{w'^2} = Sww - SwSw$$

$$\overline{u'v'} = Suv - SuSv$$

$$\overline{u'w'} = Suw - SuSw$$

$$\overline{v'w'} = Svw - SvSw$$

$$\overline{u'^2v'} = Suuv - 2SuSuv - SvSuu + 2SvSuSu$$

$$\overline{u'^2w'} = Suuw - 2SuSuw - SwSuu + 2SwSuSu$$

$$\overline{u'v'^2} = Suvv - 2SvSuv - SuSvv + 2SuSvSv$$

$$\overline{u'w'^2} = Suww - 2SwSuw - SuSww + 2SuSwSw$$

$$\overline{u'v'w'} = Suvw - SuSvw - SvSuw - SwSuv + 2SuSvSw$$

The implementation of the data reduction software is somewhat more complex. In order to achieve reasonable running times, the ASSEMBLY code is optimized for speed rather than clarity of operation. Operations which do not change between samples are performed only once. Thus,

$$\text{velocity} = d_f * ((f_{bragg} - f_{mix}) - f_{res}) * 10^6 \qquad (6)$$

becomes

$$f_{int} = f_{bragg} - f_{mix} \;;\; d_{int} = d_f * 10^6 \qquad (7)$$

hence, $\text{velocity} = d_{int} * (f_{int} - f_{res})$ (8)

Additional calculations are required to obtain the w component velocity. Since the third set of beams measures $w_v = w \sin 45^o + v \cos 45^o$, to find w, we must also perform the calculation:

$$w = (w_v - v \cos 45^o) / \sin 45^o. \qquad (9)$$

The raw data output of the digitizer is in the form of a 10 bit data word, giving a range of possible values (counts) from 0 to 1023. Since 2000 samples are normally taken for each point, a given value may be encountered many times. Accordingly, each time a new value of the raw data is encountered, the corresponding velocity is calculated and stored in a look-up table. The next time that value is encountered by the program, the proper velocity can be easily looked up, eliminating the need for another time-consuming real variable calculation. The exact running procedure of the data reduction program therefore, is as follows:

1. Reads header and all raw data for a particular point from floppy disk.

2. Strips bits 10-13 from three raw data words corresponding to the three different velocity components, and uses them to calculate the three ranges set on the A/D.

3. Calculates various intermediate values which remain the same throughout the point.

4. Reads a data word, strips off bits 0-9, and uses this raw datum as an index to look up its corresponding velocity.

5. If it is a new value, the program calculates the velocity using the raw datum, and stores it in the appropriate place in the look-up table.

6. For the w velocity component, it finds the actual velocity from $w = (w_v - v \cos 45^0) / \sin 45^0$.

7. Performs steps 4, 5, and 6 three times--once for each velocity component of the sample.

8. Updates the running sums of the velocity components and products of the velocity components.

9. Performs steps 4 through 8 for all samples.

10. Uses the sums to obtain the average velocities, Reynolds stresses, and third order products, and then prints these quantities.

11. Plots histograms of the raw data for all three channels.

12. Performs steps 1 through 11 for each profile point.

13. Plots profiles of the reduced data.

14. Tabulates normalized data profiles.

15. Writes a summary file containing the reduced data to disk.

The data reduction program also has a routine to filter noise and spurious data. Each of the 2000 data samples has 3 counts corresponding to the 3 velocities associated with it. The filtering routine causes the data reduction program to ignore samples associated with counts which are excessively far from the mean.

The filtering routine first sorts the data into three frequency tables, one for each channel. In a table, each count, i, has associated with it a number, S_i, which is the number of samples with that particular count.

The filtering routine finds the average count for each channel by going through the frequency tables and using the formula

$$C_j = \sum_{i=1}^{1024} \frac{i \times S_{ij}}{Ns} \tag{10}$$

where j = 1,2,3 = channel number

C_j = average count

Ns = number of samples.

Next, the filtering routine finds the standard deviation by performing the summation

$$\sigma_j^2 = \sum_{i=1}^{1024} \frac{S_{ij}(i - C_j)^2}{Ns} \tag{11}$$

where σ_j = standard deviation.

An input variable called S_{dev} is read by the filtering routine. All counts further than S_{dev} standard deviations away from the mean will be filtered out. This is done by multiplying S_{dev} by σ_j for each channel, and going through the frequency tables one more time. If the magnitude of $(i - C_j) > S_{dev} * \sigma_j$, then S_{ij} is set equal to zero.

The routine which calculates the statistical quantities takes each sample one at a time. The three counts associated with each sample are found and looked up in the frequency table. If for any count the table entry (S_{ij}) is zero, then the sample is discarded. Thus any sample which is excessively far from the mean in any one of its three counts is not used.

4. OPERATING PROCEDURE

4.1 Alignment Procedure

To achieve the best possible beam crossing and the most effective measuring volume, each module in the optics system must be carefully aligned. Detailed alignment instructions for individual optical components are given in Ref. 3. The overall alignment procedure is described in this report. Component numbers in this section refer to those shown in Fig. 1.

The first step is to check that the laser output beam is parallel to the optics table at the specified height, using the system alignment blocks. The collimator (1) should be positioned so that the laser beam goes through the center of the lens, and focused so that the beam waist occurs at the cross-over point. The aligned beam then passes through the polarization rotator (2) and into the color separator box. The attenuator (3) ensures that the beam has horizontal polarity at this point.

Each component of the color separator must be aligned separately. The dispersion prism (4) should be aligned so that the path length is the same in both prisms and is parallel to the base of each prism. Several beams emerge from the prism, with the two brightest ones being green (514.5 nm) and blue (488 nm). The two beams are reflected out of the box using mirrors. The beams should be centered on mirrors (6) and (7). As the beams come out of the box, alignment blocks are used to check the beam positions. If both beams are off-axis in the same direction, mirror (5) is used to align them. If only one beam is off, the appropriate mirror, (6) or (7), is used for the adjustment. Beam splitter efficiency is maximized when the beam polarization is perpendicular to the plane of the split beams. This is achieved through components (8) and (11). The beam splitters (9) and (12) cannot split the beam intensity exactly in half, so one beam of each pair is always slightly brighter. Since the Bragg cells (13) and (14) normally attenuate the shifted beam, the brightest beam is frequency shifted so that the output beam pairs have nearly equal intensities. Detailed instructions for aligning the Bragg cells are given in Ref. 4. After passing through the Bragg cells, directional wedges are used to project the beams onto a distant surface ($\sim$ 3 m). Any beam misalignments are more easily seen this way, and with the use of a marked mask, the beams can be adjusted to the correct orientation. Mirrors (6, 7) are used to adjust the unshifted beams, and the beam steering modules (15) are used for rotating the shifted beams along two circular arcs.

The next check is to ensure that the beams are parallel to each leg of the traverse mechanism on the transmitting optics table, so that beam alignment is maintained while traversing. The dichroic filter (Fig. 2) is adjusted so that the green beam pairs are split equally. Once the beams pass through the transmitting optics, the four beams must be arranged so that they all cross at the same position. A microscope objective is used to view the beam crossing. If the four beams are not symmetric about the optical axis, mirrors (6) or (7) can be adjusted to correct this. The beam steering modules (15) are used to ensure that the beams cross at the same point along the axis. The third pair of beams are now aligned (by eye) so that they also cross at the same point as the main line beams.

To align the receiving optics, a piece of translucent tape is placed at the beam intersection point to scatter the laser light. By tracking the scattered light, the receiving optics are aligned to give a sharp image at the pin-hole aperature in front of the photomultiplier tubes.

4.2 Signal Processing

The sensitivity of the photomultiplier (PM) tubes used in the receiving optics can be varied by varying the applied voltage. Typically, a voltage of about 1000 volts is applied. This voltage can be increased to make the PM tubes more sensitive, as long as the threshold levels on the processors are increased accordingly, since the amount of noise picked up is also increased.

The measured signal is mixed electronically with the signal from a sine wave generator. The frequency of the sine wave (the mixing frequency) is chosen based on the expected flow velocities. The mixing frequency is chosen such that the difference between it and the Bragg shift is about twice the maximum expected Doppler frequency. This allows enough margin for fluctuations about the expected Doppler frequency and still have a remaining nonzero resultant frequency ($f_{res} = f_{bragg} - f_{mix} - f_{dopp}$). If f_{mix} is too high, a biasing results, similar to the fringe biasing caused by stationary fringes. The number of fringes crossed by a particle per second (as seen by the processor) is proportional to $\Delta t(f_{bragg} - f_{mix})$, where Δt is the time taken by a particle to cross one fringe. Noting that Δt is only determined by the fringe spacing and the flow speed, if f_{mix} is increased, the number of fringes crossed by a particle is effectively reduced. This means that signals from particles which cross the fringes at an angle may not have enough fringe crossings (8) to be validated, and hence a bias towards particles moving perpendicularly to the fringes (higher velocity) results. This gives a higher mean velocity but a lower fluctuation level.

The amplitude of the sine wave must be chosen so that an adequate signal-to-noise ratio is maintained. Typically, a peak-to-peak amplitude of 1 volt is required.

The mixed signal is then fed into single particle burst (Macrodyne) processors. The high pass and low pass filter frequencies are set so that the processor frequency is centered between the two. Usually the high pass filter is set at 0.5 Mhz, which is the lowest non-zero setting, and the low pass filter is set anywhere from 2 to 16 Mhz, depending on the magnitude of the velocity component being measured. The filter bandwidth should be broad enough so that no parts of the fluctuating signal are attenuated.

The gain on the processor is normally set to 10. The output of the processors is displayed on an oscilloscope, and the Doppler signals should read about 1 volt peak-to-peak. The PM tube voltage can be adjusted so that the signal is at the desired level. Signal levels of more than about 1 volt end up being clipped and will therefore not be validated by the processor.

The comparator accuracy for the 5/8 signal validation test can be set between 0 and 10 count variation. The 0 setting is the most accurate, and 11 is off. The processor manufacturer recommends that this level be usually set to 9.

The range on the processor sets the bandwidth of frequencies that the processor can see, according to Table 1. For each range, a particular frequency corresponds to a count, from 0 to 1023. The processor frequency should be matched to a number in the central column in Table 1, and the corresponding range should be set on the Macrodyne processor. An additional check can be made on the range setting by monitoring the analog output from the Macrodyne on a DC voltmeter. The output ranges from 0 to 10 volts, which corresponds to the counts from 0 to 1023. The correct range setting is that which gives about 5 volts on the voltmeter at the operating velocity.

The threshold is then set for the multi-sequence check. The threshold should be set so that the data rate is about half of the data rate at zero threshold. Another check is to block one beam in each color pair. The data rate on the corresponding channel should be zero when one beam is blocked.

To obtain good data rates in air, the flow must be seeded with uniformly sized particles. Smoke, obtained from burning mineral oil or incense, provides particles of approximately 2 μm.

The computer interface should be set up as shown in Fig. 10. First choose the coincidence mode. If shear stresses are to be evaluated, coincidence on all 3 channels must be selected. The coincidence time (5 to 50 μs) sets the window width during which coincidence is defined. This should be set at 5 μs. If only the individual velocities are desired, then the random mode can be selected. The dead time (5 to 50 μs) should then be set so that data from one particle is not recorded twice. A setting of about 25 μs is recommended for low-speed flows.

The number of words that must be multiplexed can be calculated as follows: #words = #inputs + 2. This number should be rounded to the nearest even number. In the present case a setting of six is used. The event mode is set to LDV (digital data only). The LDV-A/D switch enables both digital and analog data to be interfaced simultaneously. The counter clock frequency is set to equal the approximate data rate, and the computer select is set to HP.

5. INHERENT PROBLEMS

Some design problems inherent to 3-component LDV systems are discussed in this section. One main problem with some of the earlier designs which called for splitting a color to create the third beam pair had to do with cross-talk. This is where signals from the two channels bearing the same color could not be adequately separated. In the original design of the present set-up, the polarization of one of the green beam pairs was rotated relative to the other, so that the receiving optics could distinguish between the two signals. However, using a relatively large angle for the off-axis beams (45°) and two separate collection lenses, cross-talk between the two green channels has been almost eliminated, thus making the polarization rotation dispensable.

Some earlier designs of 3-component LDV systems measured the u + w velocity component with the off-axis third beam pair. It is shown in Ref. 1 that measuring the v + w component instead, as done in the present system, reduces the uncertainty in the w component relative to the uncertainty in w from these earlier systems.

Another problem has to do with signal coincidence. Details of the probe volumes for the present system are shown in Fig. 3. It is clearly illustrated how the cross-over region between the three sets of beams forms a very small fraction of the overall probe volume. Thus, with heavy seeding (necessary for three-channel work), the electronics may validate data received from different particles which are not necessarily in the cross-over region but are within the coincidence time window set on the interface. This results in a lack of correlation between the measured velocities, and causes the evaluated shear stresses to be inaccurate. Two schemes have been used in an attempt to minimize this problem. First, the coincidence time was made so short that measurements from different particles may be considered instantaneous. The minimum setting of 5 μs available in the present hardware was used; this is equivalent to about half the flight time of a particle passing through the probe volume. The second procedure involved reducing the effective "viewed" probe length and thereby reducing the probability of this "apparent coincidence" (Fig. 5). A collection angle θ of 30° and an aperture diameter of 0.5 mm were used to give an effective length of about 1.5 mm.

6. SAMPLE RESULTS

As an initial check on the accuracy of the present system, some preliminary measurements have been made in a vortex/mixing layer interaction, previously investigated using the cross-wire technique (Ref. 6). Since the induced cross-flow angles in this interaction are only 5°-10°, cross-wire measurements are expected to be accurate to within about 5%. A schematic of the experimental set-up is shown in Figs. 11a and b. LDV measurements of the secondary flow velocities at one streamwise station (x = 229 mm) are presented and compared to the cross-wire measurements in Figs. 12a and b. LDV and cross-wire measurements of the turbulence quantities at one spanwise position (z = 13 mm) are compared in Fig. 13.

The secondary flow velocities are qualitatively similar, although the LDV measurements indicate a somewhat higher $\overline{w}$. The normal intensity $\overline{w'^2}$ also seems slightly high. The higher $\overline{w}$ measurements are more likely caused by a slight misalignment of the beams relative to the tunnel axis rather than by remnants of the apparent coincidence problem (discussed above in Section 5), since the latter would not affect the $\overline{w}$ measurements. $\overline{v'^2}$ seems to agree very well whereas $\overline{u'^2}$ is a bit low, and since $\overline{u}$ was a bit high, this was probably a result of fringe biasing caused by too high a mixing frequency (as discussed above in Section 4.2). (The mixing frequencies used for these measurements were 37.5 Mhz for the u channel, and 38 MHz for the v and w_V channels.) However, the normal stress measurements agree to within 10%, and the shear stresses are consequently affected. $\overline{u'v'}$ is somewhat low (about 20%) whereas $\overline{u'w'}$ is low by almost a factor of two. The measurement of $\overline{u'w'}$ with the present system seems to be very sensitive. This is due to the fact the w_V * u is of the same order as u * v cos 45°, so any small error in the measurement of these velocities or the off-axis angle can result in large errors in $\overline{u'w'}$. $\overline{v'w'}$ in vortex affected flows is generally of the same order as $\overline{u'w'}$ and this seems to be the case with the present measurements. With a cross-wire, $\overline{v'w'}$ has to be evaluated from measurements made in four different planes about the probe axis, and hence was not measured here. The comparisons clearly demonstrate the potential of the system in measuring detailed mean flow and turbulence quantities in three-dimensional flows. Work is in progress on optimizing the problems discussed above so that the measurement accuracies may be improved.

6. CONCLUDING REMARKS

A 3-component LDV system, capable of measuring all three components of velocity simultaneously has been developed for use in low-speed three-dimensional flows. All the six components of Reynolds shear stress and higher order products of interest can hence be evaluated. The approach followed was to convert an existing 2-component system by splitting one of the colors to produce the third beam pair. The additional optical hardware required for this process is relatively minor.

For the first time, three-component measurements made with an LDV system have been compared directly with those obtained with the cross-wire technique, in a three-dimensional flow field where both techniques are expected to perform satisfactorily. The preliminary measurements are encouraging and work is in progress on improving the system accuracy.

APPENDIX

SOFTWARE FOR THE HP 9845B DESK-TOP COMPUTER

Complete listings of two programs written in BASIC and ASSEMBLY languages are included in this appendix: "LDV" for data acquisition, some on-line data reduction, and storage of data on floppy disks; and "STAT" for complete off-line data reduction from files written to disk.

```
10    REM  PROGRAM LDV
20    ! PROGRAM TO ACQUIRE DATA FROM THREE-COMPONENT LDV SYSTEM
30    ! The program asks for initialization data and calculates the
40    ! calibration constants from them. It reads 3 channels of raw
50    ! LV data from the LDV A/D CI and writes them to a disk file
60    ! together with the calibration constants. The program can reduce
70    ! the data and display real-time histograms of the raw LV data
80    ! if desired.
90    OPTION BASE 1
100   ICOM 16600
110   IDELETE ALL
120   IASSEMBLE Find_vel
130   IASSEMBLE Data_trans
140   IASSEMBLE Draw_hist
150   COM INTEGER Data(3,2000),D1(2000,6),Ns,Nn ! D1 is data buffer
160   COM REAL Df1,Df2,Df3
170   COM REAL Theta,Nub,Numix1,Numix2,Numix3
180   COM REAL Su,Sv,Sw,Suu,Svv,Sww,Suv,Suw,Svw
190   DIM Date$[80],File$[6],Name$[4],Titl$[80]
200   REAL Xpos,Ypos,Zpos
210   INTEGER A,B,Range1,Range2
220   INTEGER Run,Dn,Nss,N
230   REAL Ph1,D,F,Ph2
240   REAL Lam1,Lam2,Lam3,Db,Prwid1,Prlen1
250   REAL Re,Ue
260   REAL Prwid2,Prwid3,Prlen2,Prlen3
270   REAL Nfr1,Nfr2,Nfr3
280   REAL U,V,W
290   Ns=2000
300   DEG
310   PRINT
320   PRINT " ** << PROGRAM LDV :  3-COMPONENT VELOCITY DATA >> ** "
330   PRINT
340   PRINT "PROGRAM STRUCTURE"
350   PRINT " 1.  INITIALIZE VARIABLES AND CALCULATE PARAMETERS"
360   PRINT " 2.  ACQUIRE DATA FROM A/D"
370   PRINT " 3.  WRITE TO FLOPPY DISC"
380   PRINT
390   !
400   ! ** CHECK HISTOGRAMS **
410   !
420   Ans$="N"
430   INPUT "DO YOU WISH TO LOOK AT HISTOGRAMS ? (Y/N, DEFAULT N)",Ans$
440   IF Ans$="Y" THEN GOSUB Hist
450   !
460   ! ** INITIALIZE RUN **
470   !
480   PRINT " ** INITIALIZATION ** "
490   Run=1
500   PRINT " ENTER RUN PARAMETERS:"
510   PRINT
520   INPUT "Enter date and time:",Date$
530   INPUT "Enter 1-Line Name For Profile :",Titl$
540   INPUT "No. of data samples per point (2000 maxm.) :",Ns
550   !
560   ! BEAM SPACING D IS FIXED
570   !
580   D=.013
590   !
600   ! FOCAL LENGTH F IS FIXED
```

```
610   !
620   F=.381
630   !
640   ! WAVELENGTHS OF 3 BEAMS ARE FIXED
650   !
660   Lam1=4.88E-7
670   Lam2=5.145E-7
680   Lam3=5.145E-7
690   !
700   ! REFERENCE VELOCITY SET TO ZERO
710   !
720   Ue=0
730   !
740   ! CALCULATE HALF-ANGLES FROM BEAM SPACINGS AND FOCAL LENGTH
750   !
760   Ph1=ATN(D/2/F)
770   Ph2=Ph1*2
780   !
790   ! CALCULATE FRINGE SPACINGS FROM WAVELENGTHS AND HALF-ANGLES
800   !
810   Df1=Lam1/2/SIN(Ph1)
820   Df2=Lam2/2/SIN(Ph1)
830   Df3=Lam3/2/SIN(Ph1)
840   !
850   ! BEAM DIAMETER Db IS FIXED
860   !
870   Db=1.20E-3
880   !
890   ! CALCULATE PROBE VOLUME WIDTH AND LENGTH
900   !
910   Prwid1=4*Lam1*F/PI/Db/COS(Ph1)
920   Prlen1=4*Lam1*F/PI/Db/SIN(Ph1)
930   Prwid2=4*Lam2*F/PI/Db/COS(Ph1)
940   Prlen2=4*Lam2*F/PI/Db/SIN(Ph1)
950   Prwid3=Prwid2
960   Prlen3=Prlen2
970   Nfr1=Prwid1/Df1
980   Nfr2=Prwid2/Df2
990   Nfr3=Nfr2
1000  !
1010  ! GET MORE RUN PARAMETERS
1020  !
1030  INPUT "Enter Bragg shift frequency (MHz) :",Nub
1040  Kill_w=3
1050  INPUT "Is this a two-channel or three-channel run (2/3, default 3) ?",Kill
_w
1060  IF Kill_w=3 THEN GOTO 1110
1070  INPUT "Enter mixing frequency (MHz, 2 nos.)",Numix1,Numix2
1080  Numix3=0
1090  Theta=0
1100  GOTO 1130
1110  INPUT "Enter mixing frequency (MHz, 3 nos.)",Numix1,Numix2,Numix3
1120  INPUT "Enter 3rd beam angle (degrs) :",Theta
1130  INPUT "Enter tunnel reference voltage (volts)",Vref
1140  PRINTER IS 0
1150  !
1160  ! PRINT HEADER
1170  !
1180  PRINT Titl$
1190  PRINT "TEST DATE AND TIME :",Date$
1200  PRINT "BEAM SPACINGS (m) =",D
```

```
1210  PRINT "TOTAL ANGLE BETWEEN BEAMS (Degrs) =",Ph2
1220  PRINT "FRINGE SPACINGS (m) =",Df1,Df2,Df3
1230  PRINT "PROBE WIDTHS (m) =",Prwid1,Prwid2,Prwid3
1240  PRINT "PROBE LENGTHS (m) =",Prlen1,Prlen2,Prlen3
1250  PRINT "NO. OF FRINGES = ",Nfr1,Nfr2,Nfr3
1260  PRINT "BRAGG SHIFT FREQUENCY (MHz) =",Nub
1270  PRINT "MIXING FREQUENCY (MHz) =",Numix1,Numix2,Numix3
1280  PRINT "THIRD BEAM SET ANGLE (Degrs) =",Theta
1290  PRINT "RUN NUMBER = ",Run
1300  PRINT "TUNNEL REFERENCE VOLTAGE (volts) =",Vref
1310  PRINTER IS 16
1320  Ans$="N"
1330  INPUT "DO YOU WISH TO MAKE ANY CHANGES? (Y/N, DEFAULT N)",Ans$
1340  IF Ans$="Y" THEN GOTO 540
1350  !
1360  !  DATA ACQUISITION
1370  !
1380  PRINT
1390  PRINT " ** DATA ACQUISITION ** "
1400  REDIM Data(3,Ns)
1410  Ans$="N"
1420  INPUT "DO YOU WISH TO CHANGE FILE NAME ? (Y/N, DEFAULT N)",Ans$
1430  IF Ans$="N" THEN GOTO 1490
1440  INPUT "Enter 4-digit filename:",Name$
1450  PRINTER IS 0
1460  PRINT "4-digit filename for profile :",Name$
1470  INPUT "Enter Disk Number :",Dn
1480  PRINT "Disk Number =",Dn
1490  PRINTER IS 16
1500  INPUT "Enter X, Y, AND Z locations:",Xpos,Ypos,Zpos
1510  !
1520  !  TAKE DATA
1530  !
1540  PRINTER IS 0
1550  PRINT
1560  PRINT
1570  PRINT "POINT NUMBER IN PROFILE : ",Run
1580  PRINT "X,Y,Z = ",Xpos,Ypos,Zpos
1590  PRINTER IS 16
1600  GOSUB Atod
1610  !
1620  !             CALCULATE SAMPLE VELOCITIES
1630  !
1640  Ans$="N"
1650  INPUT "DO YOU WISH TO OBTAIN ESTIMATES OF U AND V ? (Y/N, DEFAULT N)",Ans$
1660  IF Ans$="N" THEN GOTO 1720
1670  RAD
1680  ICALL Find_vel
1690  GOTO 2420
1700  !
1710  ! WRITE CALIBRATION CONSTANTS AND DATA TO DISK
1720  !
1730  GOSUB Dfile
1740  Ans$="Y"
1750  INPUT "DO YOU WISH TO TAKE ANOTHER POINT ? (Y/N, DEFAULT Y)",Ans$
1760  IF Ans$="N" THEN GOTO 1820
1770  Run=Run+1
1780  Ans$="N"
1790  INPUT "DO YOU WISH TO CHANGE ANY PARAMETERS ? (Y/N, DEFAULT N)",Ans$
1800  IF Ans$="Y" THEN GOTO 540
```

```
1810  GOTO 1410
1820  END
1830  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1840  ! *********** END OF MAIN PROGRAM LDV *********************
1850  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1860 Atod:        ! Subroutine for input from the LDV-A/D CI
1870              ! Enter routine with Ns = no. samples
1880  DISP "Press CONT to initiate data acquisition"
1890  PAUSE
1900  DISP "Acquiring Data"
1910  RESET 10
1920  CONTROL MASK 10;1
1930  WRITE IO 10,5;0
1940  WRITE IO 10,5;1       ! start handshake by setting CTL0
1950  Nt=6*Ns
1960    FOR I=1 TO 5
1970    Dummy=READBIN(10)
1980    NEXT I
1990    REDIM D1(Ns,6)
2000    !
2010      ENTER 10 WFHS Nt NOFORMAT;D1(*)  !fast data acquisition
2020      WRITE IO 10,5;0
2030      PRINT
2040  DISP "Data acquisition complete"
2050  PRINT
2060  ICALL Data_trans
2070  RETURN
2080  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2090 Dfile:       ! write data file to floppy disc
2100  PRINTER IS 16
2110  PRINT
2120  PRINT "** DATA FILE WRITE TO FLOPPY DISK **"
2130  PRINT
2140  PRINT "At this point be sure there is a floppy in drive 0 of"
2150  PRINT "the 9895A with space for a file of 101, 256-byte records."
2160  PRINT
2170  PRINT
2180  Ans$="Y"
2190  INPUT "DO YOU WISH TO WRITE THESE DATA TO DISK ? (Y/N, DEFAULT Y)",Ans$
2200  IF Ans$="N" THEN GOTO 2380
2210  File$=Name$&VAL$(Run)
2220  DISP "File ";File$;" being written to disk"
2230  MASS STORAGE IS ":H8,0,0"   ! set floppy drive (9895A drive 0) as default
2240  CREATE File$,101            ! open file with 101 records 256 bytes each
2250  ASSIGN File$ TO #1
2260  PRINT #1;Date$
2270  PRINT #1;Titl$
2280  PRINT #1;Name$
2290  PRINT #1;Dn
2300  PRINT #1;Nub,Numix1,Numix2,Numix3,Theta,Run
2310  PRINT #1;Vref,Ue,Df1,Df2,Df3
2320  PRINT #1;Xpos,Ypos,Zpos,Ns
2330  MAT PRINT #1;Data
2340  PRINT "***** File write completed *****"
2350  ASSIGN * TO #1               ! close data file
2360  MASS STORAGE IS ":H8,0,1"   ! reset program disk as mass storage
2370  GOTO 2390
2380  Run=Run-1
2390  RETURN
2400  ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

```
2410 Uguess:        ! Estimate U-component of velocity
2420  DISP "CALCULATING ESTIMATES OF U AND V VELOCITIES"
2430  !
2440  !
2450  IF Kill_w=3 THEN GOTO 2490
2460  DATA 0,0,0
2470  RESTORE 2460
2480  READ Sw,Sww,Suw
2490  Ubar=Su/Ns
2500  Vbar=Sv/Ns
2510  Wbar=Sw/Ns
2520  Upri2=Suu/Ns-Ubar*Ubar
2530  Vpri2=Svv/Ns-Vbar*Vbar
2540  Wpri2=Sww/Ns-Wbar*Wbar
2550  Uvbar=Suv/Ns-Ubar*Vbar
2560  Uwbar=Suw/Ns-Ubar*Wbar
2570  Vwbar=Svw/Ns-Vbar*Wbar
2580  PRINTER IS 0
2590  PRINT "ESTIMATE OF QUANTITIES FROM SAMPLES :",Ns
2600  PRINT "Ubar =",Ubar
2610  PRINT "Vbar =",Vbar
2620  PRINT "Wbar =",Wbar
2630  PRINT "Upri2 =",Upri2
2640  PRINT "Vpri2 =",Vpri2
2650  PRINT "Wpri2 =",Wpri2
2660  PRINT "Uvbar =",Uvbar
2670  PRINT "Uwbar =",Uwbar
2680  PRINT "Vwbar =",Vwbar
2690  GOTO 1700
2700  ISOURCE             NAM Find_vel
2710  ISOURCE !
2720  ISOURCE ! This subroutine converts raw data counts into instantaneous
2730  ISOURCE ! velocities, then sums several different products of the
2740  ISOURCE ! velocity components. All input and output data is passed
2750  ISOURCE ! through the COMMON storage area. The inputs are the raw
2760  ISOURCE ! data array (Arrayd), the Bragg shift frequency (Nub), the
2770  ISOURCE ! mixing frequencies (Numix1, Numix2, Numix3), the fringe
2780  ISOURCE ! spacings (Df1, Df2, Df3), the crossing angle of the third
2790  ISOURCE ! beam (Theta), and the number of samples in a data point (Ns).
2800  ISOURCE ! The outputs are the summations of various products of the
2810  ISOURCE ! velocity components, including U, V, W, U*U, V*V, W*W, U*V,
2820  ISOURCE ! U*W, and V*W.
2830  ISOURCE !
2840  ISOURCE             EXT Get_value    ! Declare subroutines stored
2850  ISOURCE             EXT Get_info     ! outside of the main program.
2860  ISOURCE             EXT Get_element
2870  ISOURCE             EXT Int_to_rel
2880  ISOURCE             EXT Rel_math
2890  ISOURCE             EXT Put_value
2900  ISOURCE !
2910  ISOURCE             COM
2920  ISOURCE Data_par:   INT (*)          ! Declare common variables.
2930  ISOURCE D1_par:     INT (*)
2940  ISOURCE Ns_par:     INT
2950  ISOURCE Nn_par:     INT
2960  ISOURCE Df1_par:    REL
2970  ISOURCE Df2_par:    REL
2980  ISOURCE Df3_par:    REL
2990  ISOURCE Theta_par:  REL
3000  ISOURCE Nub_par:    REL
```

```
3010   ISOURCE Nmix1_par: REL
3020   ISOURCE Nmix2_par: REL
3030   ISOURCE Nmix3_par: REL
3040   ISOURCE Su_par:    REL
3050   ISOURCE Sv_par:    REL
3060   ISOURCE Sw_par:    REL
3070   ISOURCE Suu_par:   REL
3080   ISOURCE Svv_par:   REL
3090   ISOURCE Sww_par:   REL
3100   ISOURCE Suv_par:   REL
3110   ISOURCE Suw_par:   REL
3120   ISOURCE Svw_par:   REL
3130   ISOURCE !
3140   ISOURCE Arrayd:    BSS 39          ! Reserve space for data array
3150   ISOURCE Elementd:  EQU Arrayd+16   ! descriptor.
3160   ISOURCE Array1:    BSS 4096        ! Reserve space for lookup tables used
3170   ISOURCE Array2:    BSS 4096        ! for count to velocity conversion.
3180   ISOURCE Array3:    BSS 4096
3190   ISOURCE Ns:        BSS 1           ! Reserve space for various input
3200   ISOURCE Df1:       BSS 4           ! and output variables.
3210   ISOURCE Df2:       BSS 4
3220   ISOURCE Df3:       BSS 4
3230   ISOURCE Theta:     BSS 4
3240   ISOURCE Nub:       BSS 4
3250   ISOURCE Numix1:    BSS 4
3260   ISOURCE Numix2:    BSS 4
3270   ISOURCE Numix3:    BSS 4
3280   ISOURCE Su:        BSS 4
3290   ISOURCE Sv:        BSS 4
3300   ISOURCE Sw:        BSS 4
3310   ISOURCE Suu:       BSS 4
3320   ISOURCE Svv:       BSS 4
3330   ISOURCE Sww:       BSS 4
3340   ISOURCE Suv:       BSS 4
3350   ISOURCE Suw:       BSS 4
3360   ISOURCE Svw:       BSS 4
3370   ISOURCE Count:     BSS 1   ! Count and I are general purpose index vari-
3380   ISOURCE I:         BSS 1   ! ables. Count is usually 0, 1, or 2, to denote
3390   ISOURCE Check:     BSS 1   ! whether U,V, or W is being calculated.
3400   ISOURCE Int:       BSS 1   ! Int, Address, and Offset are all general
3410   ISOURCE Address:   BSS 1   ! purpose storage areas.
3420   ISOURCE Offset:    BSS 1
3430   ISOURCE R1:        BSS 4   ! R1, R2, and R3 are the count-to-
3440   ISOURCE R2:        BSS 4   ! frequency conversion factors.
3450   ISOURCE R3:        BSS 4
3460   ISOURCE Xvar:      BSS 4   ! Xvar and Yvar are general purpose real
3470   ISOURCE Yvar:      BSS 4   ! number storage areas.
3480   ISOURCE U:         BSS 4   ! reserve space for instantaneous velocity
3490   ISOURCE V:         BSS 4   ! components.
3500   ISOURCE W:         BSS 4
3510   ISOURCE Uu:        BSS 4
3520   ISOURCE Uv:        BSS 4
3530   ISOURCE Cos:       BSS 4   ! Cos and Sin are the cosine and sine of Theta.
3540   ISOURCE Sin:       BSS 4
3550   ISOURCE Rad:       DAT 5.729578E1
3560   ISOURCE Mill:      DAT 1.E6
3570   ISOURCE One:       DAT 1.
3580   ISOURCE Zero:      DAT 0.
3590   ISOURCE !
3600   ISOURCE            SUB
```

```
3610   ISOURCE Find_vel:  LDA =Ns          ! Get number of samples.
3620   ISOURCE            LDB =Ns_par
3630   ISOURCE            JSM Get_value
3640   ISOURCE            LDA =Arrayd      ! Get parameters of data array.
3650   ISOURCE            LDB =Data_par
3660   ISOURCE            JSM Get_info
3670   ISOURCE            LDA =Df1         ! Get input parameters.
3680   ISOURCE            LDB =Df1_par
3690   ISOURCE            JSM Get_value
3700   ISOURCE            LDA =Df2
3710   ISOURCE            LDB =Df2_par
3720   ISOURCE            JSM Get_value
3730   ISOURCE            LDA =Df3
3740   ISOURCE            LDB =Df3_par
3750   ISOURCE            JSM Get_value
3760   ISOURCE            LDA =Theta
3770   ISOURCE            LDB =Theta_par
3780   ISOURCE            JSM Get_value
3790   ISOURCE            LDA =Nub
3800   ISOURCE            LDB =Nub_par
3810   ISOURCE            JSM Get_value
3820   ISOURCE            LDA =Numix1
3830   ISOURCE            LDB =Nmix1_par
3840   ISOURCE            JSM Get_value
3850   ISOURCE            LDA =Numix2
3860   ISOURCE            LDB =Nmix2_par
3870   ISOURCE            JSM Get_value
3880   ISOURCE            LDA =Numix3
3890   ISOURCE            LDB =Nmix3_par
3900   ISOURCE            JSM Get_value
3910   ISOURCE !
3920   ISOURCE ! The loop headed by Get_freq is repeated three times to get
3930   ISOURCE ! the count-to-frequency conversion factors (which depend on
3940   ISOURCE ! the range) for U, V, and W. Whenever a loop is controlled by
3950   ISOURCE ! the variable "Count", the loop contains operations which are
3960   ISOURCE ! the same for U, V, and W.
3970   ISOURCE !
3980   ISOURCE            LDA =0
3990   ISOURCE            STA Count
4000   ISOURCE Get_freq:  LDA Count        ! Get the first word of the column of
4010   ISOURCE            LDB Ns           ! the data array which contains the
4020   ISOURCE            MPY              ! velocity component for which we want
4030   ISOURCE            STA Elementd     ! to get the range.
4040   ISOURCE            LDA =Int
4050   ISOURCE            LDB =Arrayd
4060   ISOURCE            JSM Get_element
4070   ISOURCE            LDA Int          ! Mask and rotate to get the four
4080   ISOURCE            LDB =15360       ! bits containing the range.
4090   ISOURCE            AND B
4100   ISOURCE            SAR 10
4110   ISOURCE            TCA              ! Subtract from 15 to get the
4120   ISOURCE            LDB =15          ! actual range.
4130   ISOURCE            ADA B
4140   ISOURCE            LDB =1
4150   ISOURCE            SZA Loopend
4160   ISOURCE Loop:      SBL 1            ! Use the range to find the power
4170   ISOURCE            DSZ A            ! of two needed for the divisor.
4180   ISOURCE            JMP Loop
4190   ISOURCE Loopend:   STB Int
4200   ISOURCE            LDA =Int         ! Convert the power of two into a
```

```
4210  ISOURCE              STA Oper_1      ! real number.
4220  ISOURCE              LDA =Yvar
4230  ISOURCE              STA Result
4240  ISOURCE              JSM Int_to_rel
4250  ISOURCE              LDA ==3.2E4     ! Divide 3.2E4 by the appropriate
4260  ISOURCE              LDB =Xvar       ! power of two, using BCD math.
4270  ISOURCE              XFR 4
4280  ISOURCE              STB Oper_1
4290  ISOURCE              LDA =Yvar
4300  ISOURCE              STA Oper_2
4310  ISOURCE              LDA Count       ! Decide whether to put the result
4320  ISOURCE              LDB =4          ! in R1, R2, or R3, depending on
4330  ISOURCE              MPY             ! Count.
4340  ISOURCE              ADA =R1
4350  ISOURCE              STA Result
4360  ISOURCE              LDA =2
4370  ISOURCE              LDB =147155B    ! Now, finally, call the utility to
4380  ISOURCE              JSM Rel_math    ! perform the division.
4390  ISOURCE              ISZ Count
4400  ISOURCE              LDA =3          ! Increment and check Count so as
4410  ISOURCE              CPA Count       ! to follow the loop three times.
4420  ISOURCE              JMP *+2
4430  ISOURCE              JMP Get_freq
4440  ISOURCE !
4450  ISOURCE              LDA =Array1     ! Zero out the entire count-to-
4460  ISOURCE              LDB =768        ! velocity conversion table so that
4470  ISOURCE Continue:    CLR 16          ! it must be recalculated for each
4480  ISOURCE              ADA =16         ! point. (This must be done if the
4490  ISOURCE              DSZ B           ! mixing frequencies or ranges are
4500  ISOURCE              JMP Continue    ! changed between counts.)
4510  ISOURCE !
4520  ISOURCE              LDA =Su         ! Set initial values of Su, Sv,
4530  ISOURCE              LDB =9          ! Sw, Suu, etc. to zero.
4540  ISOURCE Clear:       CLR 4
4550  ISOURCE              ADA =4
4560  ISOURCE              DSZ B
4570  ISOURCE              JMP Clear
4580  ISOURCE !
4590  ISOURCE              LDA =Theta      ! Convert Theta from degrees to
4600  ISOURCE              STA Oper_1      ! radians using the Rel_math
4610  ISOURCE              LDA =Rad        ! utility.
4620  ISOURCE              STA Oper_2
4630  ISOURCE              LDA =Xvar
4640  ISOURCE              STA Result
4650  ISOURCE              LDA =2
4660  ISOURCE              LDB =147155B
4670  ISOURCE              JSM Rel_math
4680  ISOURCE !
4690  ISOURCE              LDA =Xvar       ! Find the sine and cosine of
4700  ISOURCE              STA Oper_1      ! Theta,and store them in the
4710  ISOURCE              LDA =Sin        ! locations Sin and Cos, respectively.
4720  ISOURCE              STA Result
4730  ISOURCE              LDA =1
4740  ISOURCE              LDB =34213B
4750  ISOURCE              JSM Rel_math
4760  ISOURCE              LDA =Cos
4770  ISOURCE              STA Result
4780  ISOURCE              LDA =1
4790  ISOURCE              LDB =34224B
4800  ISOURCE              JSM Rel_math
```

```
4810  ISOURCE !
4820  ISOURCE ! The loop defined by Get_int calculates intermediate values
4830  ISOURCE ! used in converting counts to velocities. These values are the
4840  ISOURCE ! same for all samples in a point, so they can be calculated
4850  ISOURCE ! separately. The loop calculates (Nub-NumixN) and (Mill*DfN),
4860  ISOURCE ! where N is 1, 2, and 3.
4870  ISOURCE !
4880  ISOURCE            LDA =3
4890  ISOURCE            STA Count
4900  ISOURCE Get_int:   LDA Count
4910  ISOURCE            ADA =-1
4920  ISOURCE            SAL 2
4930  ISOURCE            STA Offset
4940  ISOURCE            LDA =Nub          ! Find NumixN=Nub-NumixN.
4950  ISOURCE            STA Oper_1
4960  ISOURCE            LDA =Numix1
4970  ISOURCE            ADA Offset
4980  ISOURCE            STA Oper_2
4990  ISOURCE            STA Result
5000  ISOURCE            LDA =2
5010  ISOURCE            LDB =146717B
5020  ISOURCE            JSM Rel_math
5030  ISOURCE            LDA =Df1          ! Find DfN=Mill*DfN.
5040  ISOURCE            ADA Offset
5050  ISOURCE            STA Oper_1
5060  ISOURCE            STA Result
5070  ISOURCE            LDA =Mill
5080  ISOURCE            STA Oper_2
5090  ISOURCE            LDA =2
5100  ISOURCE            LDB =147037B
5110  ISOURCE            JSM Rel_math
5120  ISOURCE            DSZ Count
5130  ISOURCE            JMP Get_int
5140  ISOURCE !
5150  ISOURCE ! The loop Begin is performed three times, once for U, V,
5160  ISOURCE ! and W. Each time through the data array is read, a count (a
5170  ISOURCE ! raw datum) is taken from it, and is converted into a velocity.
5180  ISOURCE ! The velocity is stored in U, V, or W depending on whether
5190  ISOURCE ! this is the first, second, or third iteration of the loop. The
5200  ISOURCE ! first time any particular count is encountered, the velocity
5210  ISOURCE ! corresponding to it is calculated using the intermediate values
5220  ISOURCE ! found in Get_int, and the velocity is stored in a table. If that
5230  ISOURCE ! count is found again in the data array, the corresponding vel-
5240  ISOURCE ! ocity is looked up rather than being calculated again.
5250  ISOURCE !
5260  ISOURCE            LDA =0
5270  ISOURCE            STA Count
5280  ISOURCE            LDA =5
5290  ISOURCE            STA Check
5300  ISOURCE            LDA Ns
5310  ISOURCE            STA I
5320  ISOURCE !
5330  ISOURCE Begin:     LDA Count
5340  ISOURCE            STA B
5350  ISOURCE            SBL 2
5360  ISOURCE            STB Offset
5370  ISOURCE            LDB Ns            ! Figure out which element of the
5380  ISOURCE            MPY               ! data array we want to pick up.
5390  ISOURCE            ADA I
5400  ISOURCE            ADA =-1
```

```
5410   ISOURCE            STA Elementd
5420   ISOURCE            LDA =Int          ! Get a raw datum from the data array.
5430   ISOURCE            LDB =Arrayd
5440   ISOURCE            JSM Get_element
5450   ISOURCE            LDA Int
5460   ISOURCE            LDB =1023         ! Strip off the first six
5470   ISOURCE            AND B             ! bits of the raw data word.
5480   ISOURCE            LDB Count         ! See if Count = Check.
5490   ISOURCE            TCB
5500   ISOURCE            ADB Check
5510   ISOURCE            SZB Straight      ! If true, use the stripped data
5520   ISOURCE            TCA               ! word as an index. If not, use
5530   ISOURCE            ADA =1024         ! 1024 minus the data word.
5540   ISOURCE Straight:  STA Int           ! Store the count we have gotten.
5550   ISOURCE            LDA Count         ! Now, use Count to find out
5560   ISOURCE            LDB =4096         ! which lookup table array
5570   ISOURCE            MPY               ! we want to use, and use the
5580   ISOURCE            LDB Int           ! count we got from the data array
5590   ISOURCE            ADB =-1           ! to find exactly where in the table
5600   ISOURCE            SBL 2             ! we want to go.
5610   ISOURCE            ADA B
5620   ISOURCE            ADA =1
5630   ISOURCE            ADA =Array1
5640   ISOURCE            STA Address
5650   ISOURCE            LDA Address,I     ! If that table entry is zero,
5660   ISOURCE            SZA Calculate     ! calculate a velocity for it.
5670   ISOURCE            JMP Over
5680   ISOURCE Calculate: LDA =Int
5690   ISOURCE            STA Oper_1        ! Convert the count to a real number.
5700   ISOURCE            LDA =Yvar
5710   ISOURCE            STA Result
5720   ISOURCE            JSM Int_to_rel
5730   ISOURCE            STB Oper_2
5740   ISOURCE            LDA =R1           ! Divide the range we found
5750   ISOURCE            ADA Offset        ! earlier by the count to get a
5760   ISOURCE            STA Oper_1        ! frequency.
5770   ISOURCE            LDA =Xvar
5780   ISOURCE            STA Result
5790   ISOURCE            LDA =2
5800   ISOURCE            LDB =147155B
5810   ISOURCE            JSM Rel_math
5820   ISOURCE !
5830   ISOURCE            LDA =Numix1       ! Find (Nub-NumixN)-FrequencyN.
5840   ISOURCE            ADA Offset
5850   ISOURCE            STA Oper_1
5860   ISOURCE            LDA =Xvar
5870   ISOURCE            STA Oper_2
5880   ISOURCE            LDA =Yvar
5890   ISOURCE            STA Result
5900   ISOURCE            LDA =2
5910   ISOURCE            LDB =146717B
5920   ISOURCE            JSM Rel_math
5930   ISOURCE !
5940   ISOURCE            LDB Count         ! If we are calculating U, reverse
5950   ISOURCE            ADB =-1           ! the sign of ((Nub-NumixN)-FrequencyN)
5960   ISOURCE            SBM *+2           ! so as to reverse the sign of U.
5970   ISOURCE            JMP Samesign      ! Leave V and W alone.
5980   ISOURCE            LDA =Zero
5990   ISOURCE            STA Oper_1
6000   ISOURCE            LDA Result
```

```
6010   ISOURCE              STA Oper_2
6020   ISOURCE              LDA =Xvar
6030   ISOURCE              STA Result
6040   ISOURCE              LDA =2
6050   ISOURCE              LDB =146717B
6060   ISOURCE              JSM Rel_math
6070   ISOURCE Samesign:    NOP
6080   ISOURCE !
6090   ISOURCE              LDA Result      ! Find Velocity=((Nub-NumixN)
6100   ISOURCE              STA Oper_1      ! -FrequencyN)*(Mill*DfN)
6110   ISOURCE              LDA =Df1        ! and store in a place in the
6120   ISOURCE              ADA Offset      ! lookup table corresponding to
6130   ISOURCE              STA Oper_2      ! the data count.
6140   ISOURCE              LDA Address
6150   ISOURCE              ADA =-1
6160   ISOURCE              STA Result
6170   ISOURCE              LDA =2
6180   ISOURCE              LDB =147037B
6190   ISOURCE              JSM Rel_math
6200   ISOURCE !
6210   ISOURCE Over:        LDA Address     ! Now transfer the velocity from
6220   ISOURCE              ADA =-1         ! the lookup table to U, V, or W,
6230   ISOURCE              LDB =U          ! as appropriate.
6240   ISOURCE              ADB Offset
6250   ISOURCE              XFR 4
6260   ISOURCE !
6270   ISOURCE              ISZ Count
6280   ISOURCE              LDA =-3         ! Have U,V, and W all
6290   ISOURCE              ADA Count       ! been calculated?
6300   ISOURCE Pause:       NOP
6310   ISOURCE              SZA *+2         ! If not, go back again.
6320   ISOURCE              JMP Begin
6330   ISOURCE              STA Count       ! If so, set Count = 0.
6340   ISOURCE !
6350   ISOURCE ! Now we convert the w we have obtained (which is measured at
6360   ISOURCE ! an angle Theta to the V-axis) to the W we want (which should
6370   ISOURCE ! be measured at an angle of 90 degrees to the V-axis).
6380   ISOURCE ! Thus find W=(Wv-V*Cos(Theta))/Sin(Theta).
6390   ISOURCE !
6400   ISOURCE              LDA =V
6410   ISOURCE              STA Oper_1
6420   ISOURCE              LDA =Cos
6430   ISOURCE              STA Oper_2
6440   ISOURCE              LDA =Xvar
6450   ISOURCE              STA Result
6460   ISOURCE              LDA =2
6470   ISOURCE              LDB =147037B
6480   ISOURCE              JSM Rel_math
6490   ISOURCE              LDA Result
6500   ISOURCE              STA Oper_2
6510   ISOURCE              LDA =W
6520   ISOURCE              STA Oper_1
6530   ISOURCE              LDA =Yvar
6540   ISOURCE              STA Result
6550   ISOURCE              LDA =2
6560   ISOURCE              LDB =146717B
6570   ISOURCE              JSM Rel_math
6580   ISOURCE              LDA Result
6590   ISOURCE              STA Oper_1
6600   ISOURCE              LDA =Sin
```

```
6610   ISOURCE            STA Oper_2
6620   ISOURCE            LDA =W
6630   ISOURCE            STA Result
6640   ISOURCE            LDA =2
6650   ISOURCE            LDB =147155B
6660   ISOURCE            JSM Rel_math
6670   ISOURCE !
6680   ISOURCE ! Now take running sums of U, V, W, and several products
6690   ISOURCE ! of these velocities. The sums are taken using the utility
6700   ISOURCE ! "Add". The sums are calculated in an unusual sequence in
6710   ISOURCE ! order to reduce the number of steps needed to calculate
6720   ISOURCE ! them. Program steps which produce sums not considered
6730   ISOURCE ! necessary have been included, but these steps are preceded
6740   ISOURCE ! by the "!" comment marker.
6750   ISOURCE !
6760   ISOURCE            LDA =Su          ! Find Su=Su+U
6770   ISOURCE            LDB =U
6780   ISOURCE            JSM Add
6790   ISOURCE !
6800   ISOURCE            LDA Oper_2       ! Find U*U
6810   ISOURCE            STA Oper_1
6820   ISOURCE            LDA =Uu
6830   ISOURCE            STA Result
6840   ISOURCE            LDA =2
6850   ISOURCE            LDB =147037B
6860   ISOURCE            JSM Rel_math
6870   ISOURCE !
6880   ISOURCE            LDA =Suu         ! Find Su=Su+(U*U)
6890   ISOURCE            LDB Result
6900   ISOURCE            JSM Add
6910   ISOURCE !
6920   ISOURCE            LDA =Sv          ! Find Sv=Sv+V
6930   ISOURCE            LDB =V
6940   ISOURCE            JSM Add
6950   ISOURCE !
6960   ISOURCE            LDA =U           ! Find U*V
6970   ISOURCE            STA Oper_1
6980   ISOURCE            LDA =Uv
6990   ISOURCE            STA Result
7000   ISOURCE            LDA =2
7010   ISOURCE            LDB =147037B
7020   ISOURCE            JSM Rel_math
7030   ISOURCE !
7040   ISOURCE            LDA =Suv         ! Find Suv=Suv+(U*V)
7050   ISOURCE            LDB Result
7060   ISOURCE            JSM Add
7070   ISOURCE !
7080   ISOURCE            LDA =V           ! Find V*V
7090   ISOURCE            STA Oper_1
7100   ISOURCE            STA Oper_2
7110   ISOURCE            LDA =Xvar
7120   ISOURCE            STA Result
7130   ISOURCE            LDA =2
7140   ISOURCE            LDB =147037B
7150   ISOURCE            JSM Rel_math
7160   ISOURCE !
7170   ISOURCE            LDA =Svv         ! Find Svv=Svv+(V*V)
7180   ISOURCE            LDB Result
7190   ISOURCE            JSM Add
7200   ISOURCE !
```

```
7210  ISOURCE             LDA =Sw           ! Find Sw=Sw+W
7220  ISOURCE             LDB =W
7230  ISOURCE             JSM Add
7240  ISOURCE !
7250  ISOURCE             LDA =U            ! Find U*W
7260  ISOURCE             STA Oper_1
7270  ISOURCE             LDA =Xvar
7280  ISOURCE             STA Result
7290  ISOURCE             LDA =2
7300  ISOURCE             LDB =147037B
7310  ISOURCE             JSM Rel_math
7320  ISOURCE !
7330  ISOURCE             LDA =Suw          ! Find Suw=Suw+(U*W)
7340  ISOURCE             LDB Result
7350  ISOURCE             JSM Add
7360  ISOURCE !
7370  ISOURCE             LDA =W            ! Find V*W
7380  ISOURCE             STA Oper_1
7390  ISOURCE             LDA =V
7400  ISOURCE             STA Oper_2
7410  ISOURCE             LDA =Xvar
7420  ISOURCE             STA Result
7430  ISOURCE             LDA =2
7440  ISOURCE             LDB =147037B
7450  ISOURCE             JSM Rel_math
7460  ISOURCE !
7470  ISOURCE             LDA =Svw          ! Find Svw=Svw+(V*W)
7480  ISOURCE             LDB Result
7490  ISOURCE             JSM Add
7500  ISOURCE !
7510  ISOURCE             LDA =W            ! Find W*W
7520  ISOURCE             STA Oper_1
7530  ISOURCE             STA Oper_2
7540  ISOURCE             LDA =Xvar
7550  ISOURCE             STA Result
7560  ISOURCE             LDA =2
7570  ISOURCE             LDB =147037B
7580  ISOURCE             JSM Rel_math
7590  ISOURCE !
7600  ISOURCE             LDA =Sww          ! Find Sww=Sww+(W*W)
7610  ISOURCE             LDB Result
7620  ISOURCE             JSM Add
7630  ISOURCE !
7640  ISOURCE             DSZ I             ! Continue to calculate running
7650  ISOURCE             JMP Begin         ! sums until out of samples.
7660  ISOURCE !
7670  ISOURCE ! Place the finished sums in the COMMON region so that
7680  ISOURCE ! the BASIC program has access to them, and then return to
7690  ISOURCE ! the BASIC program.
7700  ISOURCE !
7710  ISOURCE             LDA =Su
7720  ISOURCE             LDB =Su_par
7730  ISOURCE             JSM Put_value
7740  ISOURCE             LDA =Sv
7750  ISOURCE             LDB =Sv_par
7760  ISOURCE             JSM Put_value
7770  ISOURCE             LDA =Sw
7780  ISOURCE             LDB =Sw_par
7790  ISOURCE             JSM Put_value
7800  ISOURCE             LDA =Suu
```

```
7810   ISOURCE              LDB =Suu_par
7820   ISOURCE              JSM Put_value
7830   ISOURCE              LDA =Svv
7840   ISOURCE              LDB =Svv_par
7850   ISOURCE              JSM Put_value
7860   ISOURCE              LDA =Sww
7870   ISOURCE              LDB =Sww_par
7880   ISOURCE              JSM Put_value
7890   ISOURCE              LDA =Suv
7900   ISOURCE              LDB =Suv_par
7910   ISOURCE              JSM Put_value
7920   ISOURCE              LDA =Suw
7930   ISOURCE              LDB =Suw_par
7940   ISOURCE              JSM Put_value
7950   ISOURCE              LDA =Svw
7960   ISOURCE              LDB =Svw_par
7970   ISOURCE              JSM Put_value
7980   ISOURCE              RET 1
7990   ISOURCE !
8000   ISOURCE ! The utility "Add" is used to add up the running sums.
8010   ISOURCE !
8020   ISOURCE Add:         ISZ Utlcount
8030   ISOURCE              STA Oper_1
8040   ISOURCE              STB Oper_2
8050   ISOURCE              STA Result
8060   ISOURCE              LDA =2
8070   ISOURCE              LDB =146721B
8080   ISOURCE              JSM Rel_math
8090   ISOURCE              DSZ Utlcount
8100   ISOURCE              RET 1
8110   ISOURCE              JSM Utlend
8120   ISOURCE !
8130   ISOURCE              LIT 200
8140   ISOURCE              END Find_vel
8150   ISOURCE !
8160   ISOURCE              NAM Data_trans
8170   ISOURCE !
8180   ISOURCE ! Subroutine to transfer raw data from input array
8190   ISOURCE ! to storage array.
8200   ISOURCE !
8210   ISOURCE              EXT Get_info      ! Declare subroutines stored
8220   ISOURCE              EXT Get_value     ! outside of the main program.
8230   ISOURCE              EXT Get_element
8240   ISOURCE              EXT Put_element
8250   ISOURCE !
8260   ISOURCE              COM
8270   ISOURCE Data_par:    INT (*)           ! Declare common variables.
8280   ISOURCE D1_par:      INT (*)
8290   ISOURCE Ns_par:      INT
8300   ISOURCE !
8310   ISOURCE Arrayd:      BSS 39
8320   ISOURCE Elementd:    EQU Arrayd+16
8330   ISOURCE Array1:      BSS 39
8340   ISOURCE Element1:    EQU Array1+16
8350   ISOURCE Ns:          BSS 1
8360   ISOURCE Count1:      BSS 1
8370   ISOURCE Count2:      BSS 1
8380   ISOURCE I:           BSS 1
8390   ISOURCE Int:         BSS 1
8400   ISOURCE !
```

```
8410  ISOURCE             SUB
8420  ISOURCE Data_trans: LDA =Arrayd     ! Get parameters of data storage array.
8430  ISOURCE             LDB =Data_par
8440  ISOURCE             JSM Get_info
8450  ISOURCE             LDA =Array1     ! Get parameters of data input array.
8460  ISOURCE             LDB =D1_par
8470  ISOURCE             JSM Get_info
8480  ISOURCE             LDA =Ns         ! Get number of samples.
8490  ISOURCE             LDB =Ns_par
8500  ISOURCE             JSM Get_value
8510  ISOURCE !
8520  ISOURCE             LDA =0
8530  ISOURCE             STA I
8540  ISOURCE Start1:     LDA =0
8550  ISOURCE             STA Count1
8560  ISOURCE             LDA =2
8570  ISOURCE             STA Count2
8580  ISOURCE !
8590  ISOURCE Start2:     LDA I
8600  ISOURCE             LDB =6
8610  ISOURCE             MPY
8620  ISOURCE             ADA Count2
8630  ISOURCE             STA Element1
8640  ISOURCE             LDA =Int
8650  ISOURCE             LDB =Array1
8660  ISOURCE             JSM Get_element
8670  ISOURCE !
8680  ISOURCE             LDA Count1
8690  ISOURCE             LDB Ns
8700  ISOURCE             MPY
8710  ISOURCE             ADA I
8720  ISOURCE             STA Elementd
8730  ISOURCE             LDA =Int
8740  ISOURCE             LDB =Arrayd
8750  ISOURCE             JSM Put_element
8760  ISOURCE             ISZ Count1
8770  ISOURCE             ISZ Count2
8780  ISOURCE             LDA =-3
8790  ISOURCE             ADA Count1
8800  ISOURCE             SZA *+2
8810  ISOURCE             JMP Start2
8820  ISOURCE !
8830  ISOURCE             ISZ I
8840  ISOURCE             LDA I
8850  ISOURCE             TCA
8860  ISOURCE             ADA Ns
8870  ISOURCE             SZA *+2
8880  ISOURCE             JMP Start1
8890  ISOURCE             RET 1
8900  ISOURCE             END Data_trans
8910  !
8920  ! ***********************************************************************
8930  ! **                HISTOGRAM SUBPROGRAM                               **
8940  ! ***********************************************************************
8950  !
8960 Hist:       ! Subroutine to produce online
8970             ! histograms of raw LDV data.
8980  ON KEY #0 GOTO 9270
8990  Nn=0
9000  Ns_temp=Ns
```

```
9010  !
9020  INPUT "No. of data samples per point (2000 maxm.) :",Ns
9030  !
9040  REDIM Data(3,Ns)
9050  REDIM D1(Ns,6)
9060  DISP "Press CONT to initiate data acquisition, press K0 to return to main
program."
9070  PAUSE
9080  GCLEAR
9090  GRAPHICS
9100  !
9110  RESET 10
9120  CONTROL MASK 10;1
9130  WRITE IO 10,5;0
9140  WRITE IO 10,5;1        ! start handshake by setting CTL0
9150  Nt=6*Ns
9160    FOR I=1 TO 5
9170    Dummy=READBIN(10)
9180    NEXT I
9190    !
9200      ENTER 10 WFHS Nt NOFORMAT;D1(*)  !fast data acquisition
9210      WRITE IO 10,5;0
9220  ICALL Data_trans
9230  ICALL Draw_hist
9240  IF Ns=2000 THEN GOTO 9270
9250  Nn=1
9260  GOTO 9110
9270  IF Ns=2000 THEN DUMP GRAPHICS
9280  WRITE IO 10,5;0
9290  Ns=Ns_temp
9300  REDIM Data(3,Ns)
9310  REDIM D1(Ns,6)
9320  EXIT GRAPHICS
9330  RETURN
9340  !
9350  ISOURCE             NAM Draw_hist
9360  ISOURCE !
9370  ISOURCE ! The subroutine works by first going to the samples-per-count
9380  ISOURCE ! tables and using them to draw the old histograms in black
9390  ISOURCE ! (Bit=0) to erase them. Then it calculates new samples-per-
9400  ISOURCE ! count tables from the data acquired from the LDV, and uses
9410  ISOURCE ! the new tables to draw histograms in white (Bit=1). Then the
9420  ISOURCE ! subroutine returns to the main program. The very first time
9430  ISOURCE ! (determined by Ntimes(=Nn)) the subroutine is called it doesn't
9440  ISOURCE ! erase the old histograms because there aren't any.
9450  ISOURCE !
9460  ISOURCE             EXT Get_value    ! Declare subroutines stored
9470  ISOURCE             EXT Get_info     ! outside of the main program.
9480  ISOURCE             EXT Get_element
9490  ISOURCE !
9500  ISOURCE             COM
9510  ISOURCE Data_par:   INT (*)          ! Declare common variables.
9520  ISOURCE D1_par:     INT (*)
9530  ISOURCE Ns_par:     INT
9540  ISOURCE Ntime_par:  INT
9550  ISOURCE !
9560  ISOURCE Arrayd:     BSS 39           ! Reserve space for data array
9570  ISOURCE Elementd:   EQU Arrayd+16    ! descriptor.
9580  ISOURCE Array1:     BSS 1024         ! Reserve space for tables which hold
9590  ISOURCE Array2:     BSS 1024         ! the number of samples per count.
9600  ISOURCE Array3:     BSS 1024
```

```
9610  ISOURCE Ns:          BSS 1
9620  ISOURCE Count:       BSS 1    ! Count and I are general purpose index vari-
9630  ISOURCE I:           BSS 1    ! ables. Count is usually 0, 1, or 2, to denote
9640  ISOURCE Check:       BSS 1    ! whether U,V, or W is being calculated.
9650  ISOURCE Int:         BSS 1    ! Int, Address, and Offset are all general
9660  ISOURCE Address:     BSS 1    ! purpose storage areas.
9670  ISOURCE X_coord:     BSS 1
9680  ISOURCE Y_coord:     BSS 1
9690  ISOURCE Bit:         BSS 1
9700  ISOURCE Ntimes:      BSS 1
9710  ISOURCE !
9720  ISOURCE              LIT 30
9730  ISOURCE !
9740  ISOURCE              SUB
9750  ISOURCE Draw_hist:   LDA =Ns          ! Get number of samples.
9760  ISOURCE              LDB =Ns_par
9770  ISOURCE              JSM Get_value
9780  ISOURCE              LDA =Arrayd      ! Get parameters of data array.
9790  ISOURCE              LDB =Data_par
9800  ISOURCE              JSM Get_info
9810  ISOURCE              LDA =Ntimes      ! Get Ntimes, which tells if this is
9820  ISOURCE              LDB =Ntime_par   ! the first time Draw_hist is being
9830  ISOURCE              JSM Get_value    ! called.
9840  ISOURCE !
9850  ISOURCE              LDA =0           ! If this is the first time Draw_hist
9860  ISOURCE              STA Bit          ! is being called, then jump to the
9870  ISOURCE              LDA Ntimes       ! data acquisition section. If not then
9880  ISOURCE              RZA *+2          ! write over the old histogram with
9890  ISOURCE              JMP Acquire      ! black to erase it
9900  ISOURCE !
9910  ISOURCE Do_graph:    LDA =0           ! Produce histograms for all three
9920  ISOURCE              STA Count        ! channels.
9930  ISOURCE Make_hist:   LDA Count        ! Go to the end of the appropriate
9940  ISOURCE              ADA =1           ! samples-per-count table.
9950  ISOURCE              LDB =1024
9960  ISOURCE              STB I
9970  ISOURCE              MPY
9980  ISOURCE              ADA =Array1
9990  ISOURCE              ADA =-1
10000 ISOURCE              STA Address
10010 ISOURCE Make_rod:    LDB Address,I    ! Add together each adjacent pair of
10020 ISOURCE              DSZ Address      ! entries in the table.
10030 ISOURCE              ADB Address,I
10040 ISOURCE              DSZ Address
10050 ISOURCE              DSZ I
10060 ISOURCE              RZB *+2          ! If the result is zero, go to the next
10070 ISOURCE              JMP Skip_bits    ! pair of entries. If not, make sure
10080 ISOURCE              STB Int          ! the sum is <150 and then draw a
10090 ISOURCE              ADB =-150        ! column with height equal to the sum.
10100 ISOURCE              SBM *+3
10110 ISOURCE              LDB =150
10120 ISOURCE              STB Int
10130 ISOURCE !
10140 ISOURCE              LDA I            ! Calculate the X-coordinate of the
10150 ISOURCE              SAR 1            ! column.
10160 ISOURCE              ADA =20
10170 ISOURCE              STA X_coord
10180 ISOURCE !
10190 ISOURCE Make_bit:    LDA =150         ! Calculate the Y-coordinate of the
10200 ISOURCE              LDB Count        ! top of the column.
```

```
10210 ISOURCE               ADB =1
10220 ISOURCE               MPY
10230 ISOURCE               LDB Int
10240 ISOURCE               TCB
10250 ISOURCE               ADA B
10260 ISOURCE               STA Y_coord
10270 ISOURCE !
10280 ISOURCE               LDA =13          ! Prepare the graphics screen for
10290 ISOURCE               STA Pa           ! input.
10300 ISOURCE               LDA =51B
10310 ISOURCE               SFC *
10320 ISOURCE               STA R5
10330 ISOURCE               LDA Y_coord      ! Calculate word location.
10340 ISOURCE               LDB =36
10350 ISOURCE               MPY
10360 ISOURCE               LDB X_coord
10370 ISOURCE               SBR 4
10380 ISOURCE               ADA B
10390 ISOURCE               CMA
10400 ISOURCE               SFC *
10410 ISOURCE               STA R4           ! Input word location.
10420 ISOURCE               STA R7
10430 ISOURCE !
10440 ISOURCE               LDA X_coord      ! Calculate bit location.
10450 ISOURCE               AND =17B
10460 ISOURCE               LDB Bit
10470 ISOURCE               SBL 15
10480 ISOURCE               IOR B
10490 ISOURCE               SFC *
10500 ISOURCE               STA R4           ! Input bit location.
10510 ISOURCE               STA R7
10520 ISOURCE               DSZ Int
10530 ISOURCE               JMP Make_bit
10540 ISOURCE !
10550 ISOURCE Skip_bits:    DSZ I
10560 ISOURCE               JMP Make_rod
10570 ISOURCE !
10580 ISOURCE               ISZ Count        ! Make histograms for all three
10590 ISOURCE               LDA =-3          ! channels.
10600 ISOURCE               ADA Count
10610 ISOURCE               SZA *+2
10620 ISOURCE               JMP Make_hist
10630 ISOURCE !
10640 ISOURCE Acquire:      LDA Bit          ! If Bit=1 then the new histograms
10650 ISOURCE               SZA *+2          ! have been drawn. Go back to the
10660 ISOURCE               JMP Stop         ! main program. If not, continue.
10670 ISOURCE !
10680 ISOURCE               LDA =Array1      ! Zero out the tables which hold the
10690 ISOURCE               LDB =192         ! number of samples per count.
10700 ISOURCE Clear:        CLR 16
10710 ISOURCE               ADA =16
10720 ISOURCE               DSZ B
10730 ISOURCE               JMP Clear
10740 ISOURCE !
10750 ISOURCE               LDA =0           ! Prepare to write new samples-per-
10760 ISOURCE               STA Count        ! count tables.
10770 ISOURCE               LDA =5
10780 ISOURCE               STA Check
10790 ISOURCE               LDA Ns
10800 ISOURCE               STA I
```

```
10810 ISOURCE !
10820 ISOURCE Begin:     LDA Count
10830 ISOURCE            LDB Ns          ! Figure out which element of the
10840 ISOURCE            MPY             ! data array we want to pick up.
10850 ISOURCE            ADA I
10860 ISOURCE            ADA =-1
10870 ISOURCE            STA Elementd
10880 ISOURCE            LDA =Int        ! Get a raw datum from the data array.
10890 ISOURCE            LDB =Arrayd
10900 ISOURCE            JSM Get_element
10910 ISOURCE            LDA Int
10920 ISOURCE            LDB =1023       ! Strip off the first six
10930 ISOURCE            AND B           ! bits of the raw data word.
10940 ISOURCE            LDB Count       ! See if Count = Check.
10950 ISOURCE            TCB
10960 ISOURCE            ADB Check
10970 ISOURCE            SZB Straight    ! If true, use the modified data
10980 ISOURCE            TCA             ! word as an index. If not, use
10990 ISOURCE            ADA =1024       ! 1024 minus the data word.
11000 ISOURCE Straight:  STA Int         ! Store the count we have gotten.
11010 ISOURCE            LDA =1024       ! Increment the appropriate place
11020 ISOURCE            LDB Count       ! in the samples-per-count table
11030 ISOURCE            MPY             ! by one.
11040 ISOURCE            ADA =Array1
11050 ISOURCE            ADA Int
11060 ISOURCE            ISZ A,I
11070 ISOURCE !
11080 ISOURCE            ISZ Count
11090 ISOURCE            LDA =-3         ! Have U,V, and W all been done?
11100 ISOURCE            ADA Count
11110 ISOURCE            SZA *+2         ! If not, go back again.
11120 ISOURCE            JMP Begin
11130 ISOURCE            STA Count       ! If so, set Count=0.
11140 ISOURCE !
11150 ISOURCE            DSZ I           ! Continue to fill samples-per-count
11160 ISOURCE            JMP Begin       ! tables until out of samples.
11170 ISOURCE !
11180 ISOURCE            ISZ Bit         ! Now set Bit=1 and go back and draw
11190 ISOURCE            JMP Do_graph    ! the new histograms in white.
11200 ISOURCE Stop:      RET 1
11210 ISOURCE !
11220 ISOURCE            END Draw_hist
```

```
10    REM PROGRAM STAT
20    !  PROGRAM TO REDUCE RAW DATA FROM THREE-COMPONENT LDV SYSTEM
30    !  Input is 3 channels of raw LV data and calibration constants
40    !  Output is the three components of mean velocity, all the
50    !  components of Reynolds stress and some selected third-order
60    !  products. Can filter out counts which are excessively far
70    !  from the mean. Can display histograms of raw and
80    !  filtered data for all 3 channels. Plots data at end and displays
90    !  reduced data for entire run. Can write a summary file containing
100   !  all reduced data and calibration constants.
110   OPTION BASE 1
120   ICOM 18000
130   IDELETE ALL
140   IASSEMBLE Find_vel
150   COM INTEGER Data(3,2000),Ns,Ngs,Countbin(3,1024)
160   COM INTEGER Range1,Range2,Range3
170   COM REAL Sdev,Df1,Df2,Df3
180   COM REAL Theta,Nub,Numix1,Numix2,Numix3
190   COM REAL Su,Sv,Sw,Suu,Svv,Sww,Suv,Suw,Svw
200   COM REAL Suuv,Suvv,Suuw,Suww,Suvw
210   !
220   DIM L1(3),R1(3),L11(3),U11(3),Scale(3)
230   DIM Date$[80],File$[6],Name$[4],Titl$[80]
240   !
250   REAL Xpos,Ypos,Zpos
260   REAL Point(20,15)
270   REAL Re,Ue
280   !
290   INTEGER Filno,A,Run
300   !
310   DATA 0,0,0,0
320   READ Max_v,Min_v,Filter,Sdev
330   DATA 75.64,45.64,15.64,99.,69.,39.
340   MAT READ L11,U11
350   DATA 5,46,87,41,82,123
360   MAT READ L1,R1
370   DATA -.8,2.4,0.,.035,-.0025,.01
380   READ Llim(1),Ulim(1),Llim(2),Ulim(2),Llim(3),Ulim(3)
390   DATA .4, .005,.0025
400   MAT READ Scale
410   !
420   PRINT
430   PRINT " ** << PROGRAM STAT : 3-COMPONENT VELOCITY DATA >> ** "
440   PRINT
450   PRINT "PROGRAM STRUCTURE"
460   PRINT "1.  Read raw data from floppy disc"
470   PRINT "2.  Convert to velocity"
480   PRINT "3.  Calculate statistics"
490   PRINT "4.  Print results"
500   PRINT "5.  Write to disc file"
510   PRINT
520   !
530   !  ** Read raw data from floppy disc **
540   !
550   INPUT "Enter parent filename (or E to exit program) :",Name$
560     IF Name$="E" THEN GOTO 1780
570   INPUT "Enter no. of first and last data files ",File1,Nf
580   Kill_w=3
590   INPUT "Is this a two-channel or three-channel run (2/3, Default 3) ?",Kill
_w
600   Hist$="Y"
```

```
610   INPUT "Do you wish to see histograms of the data points (Y/N, Default Y) ?
",Hist$
620   Filter$="N"
630   INPUT "Do you wish to filter the output (Y/N, Default N) ?",Filter$
640     IF Filter$="N" THEN GOTO 660
650         INPUT "Enter standard deviation to throw out",Sdev
660   DISP "READING RAW DATA FROM DISK"
670   MASS STORAGE IS ":H8,0,0"
680   PRINTER IS 0
690   Filno=File1
700   IF Filno>Nf THEN GOTO 1740
710   File$=Name$&VAL$(Filno)
720   ASSIGN File$ TO #1
730   !
740   READ #1;Date$
750   READ #1;Titl$
760   READ #1;Name$
770   READ #1;Dn
780   READ #1;Nub,Numix1,Numix2,Numix3,Theta,Run
790   READ #1;Vref,Ue,Df1,Df2,Df3
800   READ #1;Xpos,Ypos,Zpos,Ns
810   MAT READ #1;Data
820   !
830   PRINT Titl$
840   PRINT "DATE AND TIME OF TEST :",Date$
850   PRINT "FILE NAME ON DISK :",Name$
860   PRINT "DISK NUMBER :",Dn
870   PRINT "RUN NO. (POINT NO. IN PROFILE) :",Run
880   PRINT "X,Y,Z = ",Xpos,Ypos,Zpos
890   !
900   ! CALCULATE VELOCITIES
910   DISP "CALCULATING VELOCITIES AND TAKING RUNNING SUMS"
920   !
930   ICALL Find_vel
940   !
950   ! CALCULATE STATISTICS
960   DISP "CALCULATING STATISTICS"
970   !
980   IF Kill_w=3 THEN GOTO 1030
990   DATA 0,0,0,0,0,0,0
1000  RESTORE 990
1010  READ Sw,Sww,Suw,Svw,Suuw,Suww,Suvw
1020  !
1030  Ubar=Su/Ngs
1040  Vbar=Sv/Ngs
1050  Wbar=Sw/Ngs
1060  Upri2=Suu/Ngs-Ubar*Ubar
1070  Vpri2=Svv/Ngs-Vbar*Vbar
1080  Wpri2=Sww/Ngs-Wbar*Wbar
1090  Uvbar=Suv/Ngs-Ubar*Vbar
1100  Uwbar=Suw/Ngs-Ubar*Wbar
1110  Vwbar=Svw/Ngs-Vbar*Wbar
1120  Uuvbar=Suuv/Ngs-2*Ubar*Suv/Ngs-Vbar*Suu/Ngs+2*Vbar*Ubar*Ubar
1130  Uvvbar=Suvv/Ngs-2*Vbar*Suv/Ngs-Ubar*Svv/Ngs+2*Ubar*Vbar*Vbar
1140  Uuwbar=Suuw/Ngs-2*Ubar*Suw/Ngs-Wbar*Suu/Ngs+2*Wbar*Ubar*Ubar
1150  Uwwbar=Suww/Ngs-2*Wbar*Suw/Ngs-Ubar*Sww/Ngs+2*Ubar*Wbar*Wbar
1160  Uvwbar=Suvw/Ngs-Wbar*Suv/Ngs-Ubar*Svw/Ngs-Vbar*Suw/Ngs+2*Ubar*Vbar*Wbar
1170  !
1180  ! STORE RESULTS IN ARRAY FOR PLOTTING
1190  !
1200  F1=Filno-File1+1
```

```
1210  Point(F1,1)=Ypos
1220  Point(F1,2)=Ubar
1230  Point(F1,3)=Vbar
1240  Point(F1,4)=Wbar
1250  Point(F1,5)=Upri2
1260  Point(F1,6)=Vpri2
1270  Point(F1,7)=Wpri2
1280  Point(F1,8)=Uvbar
1290  Point(F1,9)=Uwbar
1300  Point(F1,10)=Vwbar
1310  Point(F1,11)=Uuvbar
1320  Point(F1,12)=Uvvbar
1330  Point(F1,13)=Uuwbar
1340  Point(F1,14)=Uwwbar
1350  Point(F1,15)=Uvwbar
1360  IF Ypos<Max_y THEN GOTO 1390
1370  Max_y=Ypos
1380  Min_u=Ubar
1390  IF Ypos>Min_y THEN GOTO 1450
1400  Min_y=Ypos
1410  Max_u=Ubar
1420  !
1430  ! PRINT RESULTS
1440  !
1450  PRINT
1460  PRINT "Bragg shift frequency = ",Nub
1470  PRINT "Mixing frequencies=",Numix1,Numix2,Numix3
1480  PRINT "Third beam angle = ",Theta
1490  PRINT "Run number = ",Run
1500  PRINT "Tunnel reference voltage (volts) = ",Vref
1510  PRINT "Fringe spacings = ",Df1,Df2,Df3
1520  PRINT "No. of samples = ",Ns
1530  PRINT "Ranges = ",Range1,Range2,Range3
1540  PRINT "Filter [no. of std. deviations] = ",Sdev
1550  PRINT "Adjusted no. of samples =",Ngs
1560  PRINT "Ubar = ",PROUND(Ubar,-4)
1570  PRINT "Vbar = ",PROUND(Vbar,-4)
1580  PRINT "Wbar = ",PROUND(Wbar,-4)
1590  PRINT "Upri2 = ",PROUND(Upri2,-4)
1600  PRINT "Vpri2 = ",PROUND(Vpri2,-4)
1610  PRINT "Wpri2 = ",PROUND(Wpri2,-4)
1620  PRINT "UVbar = ",PROUND(Uvbar,-4)
1630  PRINT "UWbar = ",PROUND(Uwbar,-4)
1640  PRINT "VWbar = ",PROUND(Vwbar,-4)
1650  PRINT "UUVbar = ",PROUND(Uuvbar,-5)
1660  PRINT "UVVbar = ",PROUND(Uvvbar,-5)
1670  PRINT "UUWbar = ",PROUND(Uuwbar,-5)
1680  PRINT "UWWbar = ",PROUND(Uwwbar,-5)
1690  PRINT "UVWbar = ",PROUND(Uvwbar,-5)
1700  PRINT
1710  IF Hist$="Y" THEN GOSUB Histogram
1720  Filno=Filno+1
1730  GOTO 700
1740  Ue=Max_u-Min_u
1750  Plotr$="Y"
1760  INPUT " Do you wish to see the turbulence quantities (Y/N, Default Y) ?",P
lotr$
1770  IF Plotr$="Y" THEN GOSUB Plot
1780  MASS STORAGE IS ":H8,0,1"
1790  PRINTER IS 16
1800  END
```

```
1810  !
1820  ! *********************PLOT DATA******************************************
1830  !
1840 Plot:  PRINTER IS 16
1850  PRINT "Estimate of normalizing velocity is :";Ue
1860  INPUT "Enter correct normalizing velocity if different.",Ue
1870  Graph$="Y"
1880  INPUT "Do you wish to graph the turbulence quantities (Y/N, Default Y) ?",Graph$
1890  PRINTER IS 0
1900  PRINT "Normalizing velocity is :";Ue
1910  !
1920  FOR I=1 TO 4
1930  DATA 1,2,2,3
1940  READ Exp
1950  Kn=3
1960  IF I=4 THEN Kn=5
1970  FOR J=1 TO Nf-Nfile+1
1980  FOR K=1 TO Kn
1990  Index=(I-1)*3+K+1
2000  Point(J,Index)=Point(J,Index)/Ue^Exp
2010  IF Index>10 THEN Point(J,Index)=Point(J,Index)*1000
2020  NEXT K
2030  NEXT J
2040  NEXT I
2050  IF Graph$="N" THEN GOTO 2860
2060  !
2070  PLOTTER IS 13,"GRAPHICS"
2080  GRAPHICS
2090  DEG
2100  !
2110  Ymax=Point(1,1)
2120  Ymin=Ymax
2130  FOR J=1 TO Nf-File1+1
2140  IF Point(J,1)>Ymax THEN Ymax=Point(J,1)
2150  IF Point(J,1)<Ymin THEN Ymin=Point(J,1)
2160  NEXT J
2170  !
2180  FOR I=1 TO 3
2190  LIMIT 0,184.47,0,149.8
2200  LOCATE L1(I),R1(I),39,99
2210  CLIP L1(I),R1(I),39,99
2220  !
2230  Xmax=Point(1,(I-1)*3+2)
2240  Xmin=Xmax
2250  FOR J=1 TO Nf-File1+1
2260  FOR K=1 TO 3
2270  IF Point(J,(I-1)*3+K+1)>Xmax THEN Xmax=Point(J,(I-1)*3+K+1)
2280  IF Point(J,(I-1)*3+K+1)<Xmin THEN Xmin=Point(J,(I-1)*3+K+1)
2290  NEXT K
2300  NEXT J
2310  !
2320  SCALE Llim(I),Ulim(I),Ymin,Ymax
2330  FRAME
2340  AXES Scale(I),.1,0,0
2350  UNCLIP
2360  !
2370  LORG 8
2380  CSIZE 2.5
2390  Ypos=Ymin
2400  MOVE Llim(I)+Scale(I)/5,Ypos
```

```
2410  DRAW Llim(I),Ypos
2420  SETGU
2430  RPLOT 2,0,-2
2440  SETUU
2450  LABEL DROUND(Ypos,2)
2460  Ypos=Ypos+.1
2470  IF Ypos<=Ymax THEN GOTO 2400
2480  !
2490  LORG 6
2500  Xpos=Llim(I)
2510  MOVE Xpos,Ymin-.04
2520  LABEL DROUND(Xpos,2)
2530  MOVE Xpos,Ymin
2540  DRAW Xpos,Ymin+.05
2550  Xpos=Xpos+Scale(I)
2560  IF Xpos<Ulim(I) THEN GOTO 2510
2570  !
2580  FOR J=1 TO Nf-File1+1
2590  Ypos=Point(J,1)
2600  FOR K=1 TO 3
2610  MOVE Point(J,(I-1)*3+K+1),Ypos
2620  SETGU
2630  ON K GOTO 2640,2700,2760
2640  FOR Arc=0 TO 360 STEP 20
2650  PDIR Arc
2660  RPLOT .5,0
2670  NEXT Arc
2680  PDIR 0
2690  GOTO 2810
2700  RPLOT .5,.5,-2
2710  RPLOT .5,-.5,-1
2720  RPLOT -.5,-.5,-1
2730  RPLOT -.5,.5,-1
2740  RPLOT .5,.5,-1
2750  GOTO 2810
2760  RPLOT 0,.5,-2
2770  RPLOT 0,-.5,-1
2780  RPLOT .5,0,-2
2790  RPLOT -.5,0,-1
2800  GOTO 2810
2810  SETUU
2820  NEXT K
2830  NEXT J
2840  NEXT I
2850  DUMP GRAPHICS
2860  IMAGE 2X"Y"10X,"u2/Uo2",3X,"v2/Uo2",3X,"w2/Uo2",5X,"uv/Uo2",3X,"uw/Uo2",3X
,"vw/Uo2",/
2870  PRINT USING 2860
2880  FOR I=1 TO Nf-File1+1
2890  IMAGE MDD.DD,6X,MD.DDDD,2X,MD.DDDD,2X,MD.DDDD,4X,MD.DDDD,2X,MD.DDDD,2X,MD.
DDDD
2900  PRINT USING 2890;Point(I,1),Point(I,5),Point(I,6),Point(I,7),Point(I,8),Po
int(I,9),Point(I,10)
2910  NEXT I
2920  IMAGE 2/,3X,"Y", 9X,"uuv/Uo3",3X,"uvv/Uo3",5X,"uuw/Uo3",3X,"uww/Uo3",5X,"u
vw/Uo3",/
2930  PRINT USING 2920
2940  FOR I=1 TO Nf-File+1
2950  IMAGE MDD.DD,6X,MD.5D,2X,MD.5D,4X,MD.5D,2X,MD.5D,4X,MD.5D
2960  PRINT USING 2950;Point(I,1),Point(I,11),Point(I,12),Point(I,13),Point(I,14
),Point(I,15)
```

```
2970  NEXT I
2980  !
2990  ! WRITE SUMMARY DATA FILE
3000  !
3010  Sum$="N"
3020  INPUT "Do you wish to write a Summary Data File (Y/N Default N) ?",Sum$
3030  IF Sum$="N" THEN GOTO 3210
3040  File$=Name$
3050  DISP "File ";File$;" being written to disk"
3060  MASS STORAGE IS ":H8,0,0"
3070  CREATE File$,40
3080  ASSIGN File$ TO #1
3090  PRINT #1;Date$
3100  PRINT #1;Titl$
3110  PRINT #1;Name$
3120  PRINT #1;Dn
3130  PRINT #1;Nub,Numix1,Numix2,Numix3,Theta,Run
3140  PRINT #1;Vref,Ue,Df1,Df2,Df3
3150  PRINT #1;Ns,File1,Nf
3160  FOR I=1 TO Nf-Nfile+1
3170  FOR J=1 TO 15
3180  PRINT #1;Point(I,J)
3190  NEXT J
3200  NEXT I
3210  RETURN
3220  !
3230  ! *********************DRAW HISTOGRAMS************************************
3240  !
3250 Histogram:  PLOTTER IS 13,"GRAPHICS"
3260  GRAPHICS
3270  K=1
3280  FOR I=1 TO 3
3290  Cmax=0
3300  FOR J=1 TO 1023 STEP 2
3310  Countbin(I,J)=Countbin(I,J)+Countbin(I,J+1)
3320  IF Countbin(I,J)>Cmax THEN Cmax=Countbin(I,J)
3330  NEXT J
3340  IF (Cmax=0) OR (Cmax=2000) THEN GOTO 3660
3350  LIMIT 0,184.47,0,149.8
3360  LOCATE 7.05,119.63,L11(K),U11(K)
3370  CLIP 7.05,119.63,L11(K),U11(K)
3380  K=K+1
3390  SCALE 1,1024,0,Cmax
3400  FRAME
3410  UNCLIP
3420  LINE TYPE 1
3430  CSIZE 2.8
3440  LORG 8
3450  FOR Y=1 TO 4
3460  Ypos=Y*Cmax/4
3470  PLOT 10,Ypos,-2
3480  PLOT -9,Ypos,-1
3490  MOVE 3,Ypos
3500  LABEL PROUND(Ypos,0)
3510  NEXT Y
3520  LORG 6
3530  Ypos=Cmax/20
3540  FOR X=1 TO 8
3550  Xpos=X*128
3560  PLOT Xpos,Ypos,-2
```

```
3570  PLOT Xpos,-Ypos,-1
3580  MOVE Xpos,-Ypos*1.3
3590  LABEL Xpos
3600  NEXT X
3610  FOR J=1 TO 1023 STEP 2
3620  IF Countbin(I,J)=0 THEN GOTO 3650
3630  MOVE J,0
3640  DRAW J,Countbin(I,J)
3650  NEXT J
3660  NEXT I
3670  MOVE 512,-Ypos*5
3680  LORG 6
3690  LABEL "PLOT OF COUNT VS NUMBER OF SAMPLES PER COUNT"
3700  DUMP GRAPHICS -Ypos*10
3710  RETURN
3720  !
3730  !
3740  ISOURCE                NAM Find_vel
3750  ISOURCE !
3760  ISOURCE ! This subroutine converts raw data counts to instantaneous
3770  ISOURCE ! velocities, then sums several different products of the
3780  ISOURCE ! velocity components. All input and output data is passed
3790  ISOURCE ! through the COMMON stoarage area. The inputs are the raw
3800  ISOURCE ! data array (Arrayd), the Bragg shift frequency (Nub), the
3810  ISOURCE ! mixing frequencies (Numix1, Numix2, Numix3), the fringe
3820  ISOURCE ! spacings (Df1, Df2, Df3), the crossing angle of the third
3830  ISOURCE ! beam (Theta), and the number of samples in a data point (Ns).
3840  ISOURCE ! The outputs are the summations of various products of the
3850  ISOURCE ! velocity components, including U, V, W, U*U, V*V, W*W,
3860  ISOURCE ! U*V, U*W, V*W, U*U*V, U*V*V, U*U*W, U*W*W, and U*V*W.
3870  ISOURCE !
3880  ISOURCE                EXT Get_value    ! Declare subroutines stored
3890  ISOURCE                EXT Get_info     ! outside of the main program.
3900  ISOURCE                EXT Get_element
3910  ISOURCE                EXT Put_element
3920  ISOURCE                EXT Int_to_rel
3930  ISOURCE                EXT Rel_to_int
3940  ISOURCE                EXT Rel_math
3950  ISOURCE                EXT Put_value
3960  ISOURCE !
3970  ISOURCE                COM
3980  ISOURCE Data_par:      INT (*)          ! Declare common variables.
3990  ISOURCE Ns_par:        INT
4000  ISOURCE Ngs_par:       INT
4010  ISOURCE Cbin_par:      INT (*)
4020  ISOURCE Ran1_par:      INT
4030  ISOURCE Ran2_par:      INT
4040  ISOURCE Ran3_par:      INT
4050  ISOURCE Sdev_par:      REL
4060  ISOURCE Df1_par:       REL
4070  ISOURCE Df2_par:       REL
4080  ISOURCE Df3_par:       REL
4090  ISOURCE Theta_par:     REL
4100  ISOURCE Nub_par:       REL
4110  ISOURCE Nmix1_par:     REL
4120  ISOURCE Nmix2_par:     REL
4130  ISOURCE Nmix3_par:     REL
4140  ISOURCE Su_par:        REL
4150  ISOURCE Sv_par:        REL
4160  ISOURCE Sw_par:        REL
```

```
4170  ISOURCE Suu_par:    REL
4180  ISOURCE Svv_par:    REL
4190  ISOURCE Sww_par:    REL
4200  ISOURCE Suv_par:    REL
4210  ISOURCE Suw_par:    REL
4220  ISOURCE Svw_par:    REL
4230  ISOURCE Suuv_par:   REL
4240  ISOURCE Suvv_par:   REL
4250  ISOURCE Suuw_par:   REL
4260  ISOURCE Suww_par:   REL
4270  ISOURCE Suvw_par:   REL
4280  ISOURCE !
4290  ISOURCE Arrayd:     BSS 39          ! Reserve space for data array
4300  ISOURCE Elementd:   EQU Arrayd+16   ! descriptor.
4310  ISOURCE Array1:     BSS 4096        ! Reserve space for lookup tables
4320  ISOURCE Array2:     BSS 4096        ! for count to velocity coversion.
4330  ISOURCE Array3:     BSS 4096
4340  ISOURCE Bin_u:      BSS 1024        ! Reserve space for table of counts
4350  ISOURCE Bin_v:      BSS 1024        ! used to generate histograms.
4360  ISOURCE Bin_w:      BSS 1024
4370  ISOURCE Range1:     BSS 1           ! Reserve space for various input
4380  ISOURCE Range2:     BSS 1           ! and output variables.
4390  ISOURCE Range3:     BSS 1
4400  ISOURCE Ns:         BSS 1
4410  ISOURCE Df1:        BSS 4
4420  ISOURCE Df2:        BSS 4
4430  ISOURCE Df3:        BSS 4
4440  ISOURCE Theta:      BSS 4
4450  ISOURCE Nub:        BSS 4
4460  ISOURCE Numix1:     BSS 4
4470  ISOURCE Numix2:     BSS 4
4480  ISOURCE Numix3:     BSS 4
4490  ISOURCE Su:         BSS 4
4500  ISOURCE Sv:         BSS 4
4510  ISOURCE Sw:         BSS 4
4520  ISOURCE Suu:        BSS 4
4530  ISOURCE Svv:        BSS 4
4540  ISOURCE Sww:        BSS 4
4550  ISOURCE Suv:        BSS 4
4560  ISOURCE Suw:        BSS 4
4570  ISOURCE Svw:        BSS 4
4580  ISOURCE Suuv:       BSS 4
4590  ISOURCE Suvv:       BSS 4
4600  ISOURCE Suuw:       BSS 4
4610  ISOURCE Suww:       BSS 4
4620  ISOURCE Suvw:       BSS 4
4630  ISOURCE Count:      BSS 1   ! Count and I are general purpose index vari-
4640  ISOURCE I:          BSS 1   ! ables. Count is usually 0, 1, or 2 to denote
4650  ISOURCE Check:      BSS 1   ! whether U, V, or W is being calculated.
4660  ISOURCE Int:        BSS 1   ! Int, Address, and Offset are all general
4670  ISOURCE Int2:       BSS 1   ! purpose storage areas.
4680  ISOURCE Address:    BSS 1
4690  ISOURCE Offset:     BSS 1
4700  ISOURCE R1:         BSS 4   ! R1, R2, and R3 are the count-to-
4710  ISOURCE R2:         BSS 4   ! frequency conversion factors.
4720  ISOURCE R3:         BSS 4
4730  ISOURCE Xvar:       BSS 4   ! Xvar and Yvar are general purpose real
4740  ISOURCE Yvar:       BSS 4   ! number storage areas.
4750  ISOURCE U:          BSS 4   ! U, V, and W are the instantaneous velocity
4760  ISOURCE V:          BSS 4   ! components.
```

```
4770  ISOURCE W:          BSS 4
4780  ISOURCE Uu:         BSS 4
4790  ISOURCE Uv:         BSS 4
4800  ISOURCE Cos:        BSS 4    ! Cos and Sin are the cos and sin of Theta.
4810  ISOURCE Sin:        BSS 4
4820  ISOURCE Max_u:      BSS 1
4830  ISOURCE Max_v:      BSS 1
4840  ISOURCE Max_w:      BSS 1
4850  ISOURCE Avg_u:      BSS 4
4860  ISOURCE Avg_v:      BSS 4
4870  ISOURCE Avg_w:      BSS 4
4880  ISOURCE Dev_u:      BSS 4
4890  ISOURCE Dev_v:      BSS 4
4900  ISOURCE Dev_w:      BSS 4
4910  ISOURCE Ngs:        BSS 1
4920  ISOURCE Sdev:       BSS 4
4930  ISOURCE Rad:        DAT 5.729578E1
4940  ISOURCE Mill:       DAT 1.E6
4950  ISOURCE One:        DAT 1.
4960  ISOURCE Zero:       DAT 0.
4970  ISOURCE             LIT 80
4980  ISOURCE !
4990  ISOURCE             SUB
5000  ISOURCE Find_vel:   LDA =Ns          ! Get number of samples.
5010  ISOURCE             LDB =Ns_par
5020  ISOURCE             JSM Get_value
5030  ISOURCE             LDA =Arrayd      ! Get parameters of data array.
5040  ISOURCE             LDB =Data_par
5050  ISOURCE             JSM Get_info
5060  ISOURCE             LDA =Sdev        ! Get input parameters.
5070  ISOURCE             LDB =Sdev_par
5080  ISOURCE             JSM Get_value
5090  ISOURCE             LDA =Df1
5100  ISOURCE             LDB =Df1_par
5110  ISOURCE             JSM Get_value
5120  ISOURCE             LDA =Df2
5130  ISOURCE             LDB =Df2_par
5140  ISOURCE             JSM Get_value
5150  ISOURCE             LDA =Df3
5160  ISOURCE             LDB =Df3_par
5170  ISOURCE             JSM Get_value
5180  ISOURCE             LDA =Theta
5190  ISOURCE             LDB =Theta_par
5200  ISOURCE             JSM Get_value
5210  ISOURCE             LDA =Nub
5220  ISOURCE             LDB =Nub_par
5230  ISOURCE             JSM Get_value
5240  ISOURCE             LDA =Numix1
5250  ISOURCE             LDB =Nmix1_par
5260  ISOURCE             JSM Get_value
5270  ISOURCE             LDA =Numix2
5280  ISOURCE             LDB =Nmix2_par
5290  ISOURCE             JSM Get_value
5300  ISOURCE             LDA =Numix3
5310  ISOURCE             LDB =Nmix3_par
5320  ISOURCE             JSM Get_value
5330  ISOURCE !
5340  ISOURCE ! The loop headed by Get_freq is repeated three times to get
5350  ISOURCE ! the count-to-frequency conversion factors (which depend on
5360  ISOURCE ! the range) for U,V, and W. Whenever a loop is controlled by
```

```
5370  ISOURCE ! the variable "Count", the loop contains operations which are
5380  ISOURCE ! the same for U,V, and W.
5390  ISOURCE !
5400  ISOURCE !
5410  ISOURCE                LDA =0
5420  ISOURCE                STA Count
5430  ISOURCE Get_freq:      LDA Count          ! Get the first word of the column of
5440  ISOURCE                LDB Ns             ! the data array which contains the
5450  ISOURCE                MPY                ! velocity component for which we want
5460  ISOURCE                STA Elementd       ! to get the range.
5470  ISOURCE                LDA =Int
5480  ISOURCE                LDB =Arrayd
5490  ISOURCE                JSM Get_element
5500  ISOURCE                LDA Int            ! Mask and rotate to get the four
5510  ISOURCE                LDB =15360         ! bits containing the range.
5520  ISOURCE                AND B
5530  ISOURCE                SAR 10
5540  ISOURCE                TCA                ! Subtract from 15 to get the
5550  ISOURCE                LDB =15            ! actual range.
5560  ISOURCE                ADA B
5570  ISOURCE                LDB =Range1        ! Store the actual range in RangeN
5580  ISOURCE                ADB Count          ! so that we can transfer it to the
5590  ISOURCE                STA B,I            ! main program
5600  ISOURCE                LDB =1
5610  ISOURCE                SZA Loopend
5620  ISOURCE Loop:          SBL 1              ! Use the range to find the power
5630  ISOURCE                DSZ A              ! of two needed for the divisor.
5640  ISOURCE                JMP Loop
5650  ISOURCE Loopend:       STB Int
5660  ISOURCE                LDA =Int           ! Convert the power of two into a
5670  ISOURCE                STA Oper_1         ! real number.
5680  ISOURCE                LDA =Yvar
5690  ISOURCE                STA Result
5700  ISOURCE                JSM Int_to_rel
5710  ISOURCE                LDA ==3.2E4        ! Divide 3.2E4 by the appropriate
5720  ISOURCE                LDB =Xvar          ! power of two, using BCD math.
5730  ISOURCE                XFR 4
5740  ISOURCE                STB Oper_1
5750  ISOURCE                LDA =Yvar
5760  ISOURCE                STA Oper_2
5770  ISOURCE                LDA Count          ! Decide whether to put the result
5780  ISOURCE                SAL 2              ! in R1, R2, or R3, depending on Count.
5790  ISOURCE                ADA =R1
5800  ISOURCE                STA Result
5810  ISOURCE                LDA =2
5820  ISOURCE                LDB =147155B       ! Now, finally, call the utility to
5830  ISOURCE                JSM Rel_math       ! perform the division.
5840  ISOURCE                ISZ Count
5850  ISOURCE                LDA =3             ! Increment and check Count so as
5860  ISOURCE                CPA Count          ! to follow the loop three times.
5870  ISOURCE                JMP *+2
5880  ISOURCE                JMP Get_freq
5890  ISOURCE !
5900  ISOURCE                LDA =Array1        ! Zero out the entire count-to-
5910  ISOURCE                LDB =768           ! velocity conversion table so that
5920  ISOURCE Continue:      CLR 16             ! it must be recalculated for each
5930  ISOURCE                ADA =16            ! point. (This must be done if the
5940  ISOURCE                DSZ B              ! mixing frequency or ranges are
5950  ISOURCE                JMP Continue       ! changed between counts.)
5960  ISOURCE !
```

```
5970  ISOURCE          LDA =Su        ! Set initial values of Su, Sv,
5980  ISOURCE          LDB =15        ! Sw, Suu, etc. to zero.
5990  ISOURCE Clear:   CLR 4
6000  ISOURCE          ADA =4
6010  ISOURCE          DSZ B
6020  ISOURCE          JMP Clear
6030  ISOURCE !
6040  ISOURCE          LDA =Bin_u     ! Clear the areas of memory which
6050  ISOURCE          LDB =192       ! will be used to hold the number of
6060  ISOURCE Clear2:  CLR 16         ! samples per count for the histograms.
6070  ISOURCE          ADA =16
6080  ISOURCE          DSZ B
6090  ISOURCE          JMP Clear2
6100  ISOURCE !
6110  ISOURCE          LDA =Theta     ! Convert Theta from degrees to
6120  ISOURCE          STA Oper_1     ! radians using the Rel_math
6130  ISOURCE          LDA =Rad       ! utility.
6140  ISOURCE          STA Oper_2
6150  ISOURCE          LDA =Xvar
6160  ISOURCE          STA Result
6170  ISOURCE          LDA =2
6180  ISOURCE          LDB =147155B
6190  ISOURCE          JSM Rel_math
6200  ISOURCE !
6210  ISOURCE          LDA =Xvar      ! Find the sine and cosine of
6220  ISOURCE          STA Oper_1     ! Theta, and store them in the
6230  ISOURCE          LDA =Sin       ! locations Sin and Cos, respectively.
6240  ISOURCE          STA Result
6250  ISOURCE          LDA =1
6260  ISOURCE          LDB =34213B
6270  ISOURCE          JSM Rel_math
6280  ISOURCE          LDA =Cos
6290  ISOURCE          STA Result
6300  ISOURCE          LDA =1
6310  ISOURCE          LDB =34224B
6320  ISOURCE          JSM Rel_math
6330  ISOURCE !
6340  ISOURCE ! The loop defined by Get_int calculates intermediate values
6350  ISOURCE ! used in converting counts to velocities. These values are the
6360  ISOURCE ! same for all samples in a point, so they can be calculated
6370  ISOURCE ! separately. The loop calculates (Nub-NumixN) and (Mill*DfN),
6380  ISOURCE ! where N is 1,2, and 3.
6390  ISOURCE          LDA =3
6400  ISOURCE          STA Count
6410  ISOURCE Get_int: LDA Count
6420  ISOURCE          ADA =-1
6430  ISOURCE          SAL 2
6440  ISOURCE          STA Offset
6450  ISOURCE          LDA =Nub       ! Find NumixN=Nub-NumixN.
6460  ISOURCE          STA Oper_1
6470  ISOURCE          LDA =Numix1
6480  ISOURCE          ADA Offset
6490  ISOURCE          STA Oper_2
6500  ISOURCE          STA Result
6510  ISOURCE          LDA =2
6520  ISOURCE          LDB =146717B
6530  ISOURCE          JSM Rel_math
6540  ISOURCE          LDA =Df1       ! Find DfN=Mill*DfN.
6550  ISOURCE          ADA Offset
6560  ISOURCE          STA Oper_1
```

```
6570  ISOURCE           STA Result
6580  ISOURCE           LDA =Mill
6590  ISOURCE           STA Oper_2
6600  ISOURCE           LDA =2
6610  ISOURCE           LDB =147037B
6620  ISOURCE           JSM Rel_math
6630  ISOURCE           DSZ Count
6640  ISOURCE           JMP Get_int
6650  ISOURCE !
6660  ISOURCE ! This section filters the data to remove counts which are
6670  ISOURCE ! excessively far from the mean. First the section creates
6680  ISOURCE ! a list of the number of times each particular count appears
6690  ISOURCE ! The list consists of 3 1024 word arrays (called Bin_u, Bin_v,
6700  ISOURCE ! and Bin_w) where the address of each word corresponds to the
6710  ISOURCE ! count, and the value of the word indicates the number of times
6720  ISOURCE ! that particular count has appeared.
6730  ISOURCE !
6740  ISOURCE           LDA =0
6750  ISOURCE           STA Count
6760  ISOURCE           LDA =5          ! Set Check to determine whether the
6770  ISOURCE           STA Check       ! count or 1024 minus the count is to
6780  ISOURCE           LDA Ns          ! be used.
6790  ISOURCE           STA I
6800  ISOURCE !
6810  ISOURCE Fill_bin: LDA Count
6820  ISOURCE           LDB Ns          ! Figure out which element of the
6830  ISOURCE           MPY             ! data array we want to pick up.
6840  ISOURCE           ADA I
6850  ISOURCE           ADA =-1
6860  ISOURCE           STA Elementd
6870  ISOURCE           LDA =Int        ! Get a raw datum from the data array.
6880  ISOURCE           LDB =Arrayd
6890  ISOURCE           JSM Get_element
6900  ISOURCE           LDA Int
6910  ISOURCE           LDB =1023       ! Strip off the first six
6920  ISOURCE           AND B           ! bits of the raw data word.
6930  ISOURCE           LDB Count       ! See if Count = Check.
6940  ISOURCE           TCB
6950  ISOURCE           ADB Check
6960  ISOURCE           SZB Skip        ! If true, use the modified data
6970  ISOURCE           TCA             ! word as an index. If not, use
6980  ISOURCE           ADA =1024       ! 1024 minus the data word.
6990  ISOURCE Skip:     STA Int         ! Store the count we have gotten.
7000  ISOURCE           LDA Count
7010  ISOURCE           LDB =1024
7020  ISOURCE           MPY
7030  ISOURCE           ADA Int         ! Go to the address in the array
7040  ISOURCE           ADA =-1         ! corresponding to the value of
7050  ISOURCE           ADA =Bin_u      ! the count.
7060  ISOURCE           ISZ A,I         ! Increment the word by one,
7070  ISOURCE           ISZ Count       ! indicating that one more count
7080  ISOURCE           LDA =-3         ! with that value has been read.
7090  ISOURCE           ADA Count
7100  ISOURCE           SZA *+2
7110  ISOURCE           JMP Fill_bin
7120  ISOURCE           STA Count
7130  ISOURCE           DSZ I
7140  ISOURCE           JMP Fill_bin
7150  ISOURCE !
7160  ISOURCE ! When Sdev>0, use this section to filter the data.
```

```
7170  ISOURCE ! The mean and standard deviation of the data are calculated.
7180  ISOURCE ! The program then throws out all the data which are farther than
7190  ISOURCE ! Sdev standard deviations from the mean.
7200  ISOURCE !
7210  ISOURCE Check_dev: LDB =Sdev
7220  ISOURCE            ADB =1
7230  ISOURCE            LDA B,I          ! If Sdev > 0, use this section to
7240  ISOURCE            RZA *+2          ! filter the data. If not, continue
7250  ISOURCE            JMP Set_begin    ! with the program.
7260  ISOURCE !
7270  ISOURCE            LDA =0           ! Get the average of each set of
7280  ISOURCE            STA Count        ! counts using the information in
7290  ISOURCE Get_avg:   LDA =Zero        ! the Bin_u arrays.
7300  ISOURCE            LDB Count        ! First, set the average=0.
7310  ISOURCE            SBL 2
7320  ISOURCE            ADB =Avg_u
7330  ISOURCE            XFR 4
7340  ISOURCE            LDA Count
7350  ISOURCE            ADA =1
7360  ISOURCE            LDB =1024
7370  ISOURCE            MPY
7380  ISOURCE            ADA =Bin_u
7390  ISOURCE            STA Address
7400  ISOURCE            LDA =1023
7410  ISOURCE            STA I
7420  ISOURCE Sum_count: LDA =I           ! Get  a count and convert it to
7430  ISOURCE            STA Oper_1       ! a real number.
7440  ISOURCE            LDA =Xvar
7450  ISOURCE            STA Result
7460  ISOURCE            JSM Int_to_rel
7470  ISOURCE !
7480  ISOURCE            LDA Address      ! Use the Bin_u arrays to find out how
7490  ISOURCE            STA Oper_1       ! many samples there are with that
7500  ISOURCE            LDA =Yvar        ! count and convert that number to a
7510  ISOURCE            STA Result       ! real number.
7520  ISOURCE            JSM Int_to_rel
7530  ISOURCE !
7540  ISOURCE            LDA =Xvar        ! Multiply the count by
7550  ISOURCE            STA Oper_1       ! the number of times it appears in
7560  ISOURCE            LDA =Yvar        ! the data.
7570  ISOURCE            STA Oper_2
7580  ISOURCE            STA Result
7590  ISOURCE            LDA =2
7600  ISOURCE            LDB =147037B
7610  ISOURCE            JSM Rel_math
7620  ISOURCE !
7630  ISOURCE            LDB Count        ! Keep a running sum of the product of
7640  ISOURCE            SBL 2            ! the count times the number of times
7650  ISOURCE            ADB =Avg_u       ! that it appears. Store this sum in
7660  ISOURCE            STB Oper_1       ! the place   we will eventually use to
7670  ISOURCE            STB Result       ! store the average.
7680  ISOURCE            LDA =Yvar
7690  ISOURCE            STA Oper_2
7700  ISOURCE            LDA =2
7710  ISOURCE            LDB =146721B
7720  ISOURCE            JSM Rel_math
7730  ISOURCE !
7740  ISOURCE            DSZ Address
7750  ISOURCE            DSZ I
7760  ISOURCE            JMP Sum_count
```

```
7770  ISOURCE !
7780  ISOURCE           LDA =Ns          ! Convert the number of samples to
7790  ISOURCE           STA Oper_1       ! a real number.
7800  ISOURCE           LDA =Xvar
7810  ISOURCE           STA Result
7820  ISOURCE           JSM Int_to_rel
7830  ISOURCE !
7840  ISOURCE           LDB Count        ! Divide the sum stored in Avg_u by
7850  ISOURCE           SBL 2            ! the number of samples to get the
7860  ISOURCE           ADB =Avg_u       ! average value of the counts.
7870  ISOURCE           STB Oper_1
7880  ISOURCE           STB Result
7890  ISOURCE           LDB =Xvar
7900  ISOURCE           STB Oper_2
7910  ISOURCE           LDA =2
7920  ISOURCE           LDB =147155B
7930  ISOURCE           JSM Rel_math
7940  ISOURCE !
7950  ISOURCE           LDA Count
7960  ISOURCE           ADA =1
7970  ISOURCE           STA Count
7980  ISOURCE           ADA =-3
7990  ISOURCE           SZA *+2
8000  ISOURCE           JMP Get_avg
8010  ISOURCE !
8020  ISOURCE           LDA =0           ! Get the standard deviation of each
8030  ISOURCE           STA Count        ! set of counts using the average and
8040  ISOURCE Get_sdev: LDA =Zero        ! the information in the Bin_u arrays.
8050  ISOURCE           LDB Count        ! First, set the standard deviation =0.
8060  ISOURCE           SBL 2
8070  ISOURCE           STB Offset
8080  ISOURCE           ADB =Dev_u
8090  ISOURCE           XFR 4
8100  ISOURCE           LDA Offset
8110  ISOURCE           ADA =Avg_u
8120  ISOURCE           STA Int
8130  ISOURCE           LDA Count
8140  ISOURCE           ADA =1
8150  ISOURCE           LDB =1024
8160  ISOURCE           MPY
8170  ISOURCE           ADA =Bin_u
8180  ISOURCE           STA Address
8190  ISOURCE           LDA =1023
8200  ISOURCE           STA I
8210  ISOURCE !
8220  ISOURCE Dev_count: LDA =I          ! Get a count and convert it to a
8230  ISOURCE           STA Oper_1       ! real number.
8240  ISOURCE           LDA =Xvar
8250  ISOURCE           STA Result
8260  ISOURCE           JSM Int_to_rel
8270  ISOURCE !
8280  ISOURCE           LDA =Xvar        ! Subtract the average count from the
8290  ISOURCE           STA Oper_1       ! count we just got.
8300  ISOURCE           LDA Int
8310  ISOURCE           STA Oper_2
8320  ISOURCE           LDA =Yvar
8330  ISOURCE           STA Result
8340  ISOURCE           LDA =2
8350  ISOURCE           LDB =146717B
8360  ISOURCE           JSM Rel_math
```

```
8370  ISOURCE !
8380  ISOURCE             LDA =Yvar         ! Square the difference between the
8390  ISOURCE             STA Oper_1        ! average and the count we got to
8400  ISOURCE             STA Oper_2        ! get the deviation from the mean.
8410  ISOURCE             LDA =Xvar
8420  ISOURCE             STA Result
8430  ISOURCE             LDA =2
8440  ISOURCE             LDB =147037B
8450  ISOURCE             JSM Rel_math
8460  ISOURCE !
8470  ISOURCE             LDA Address       ! Use the Bin_u arrays to find out
8480  ISOURCE             STA Oper_1        ! how many counts there are with the
8490  ISOURCE             LDA =Yvar         ! value we have chosen, and convert
8500  ISOURCE             STA Result        ! that number to a real number.
8510  ISOURCE             JSM Int_to_rel
8520  ISOURCE !
8530  ISOURCE             LDA =Xvar         ! Multiply the number of counts by
8540  ISOURCE             STA Oper_1        ! the deviation from the mean.
8550  ISOURCE             LDA =Yvar
8560  ISOURCE             STA Oper_2
8570  ISOURCE             STA Result
8580  ISOURCE             LDA =2
8590  ISOURCE             LDB =147037B
8600  ISOURCE             JSM Rel_math
8610  ISOURCE !
8620  ISOURCE             LDA =Yvar         ! Add the product to Dev_u, which
8630  ISOURCE             STA Oper_1        ! currently contains a running sum of
8640  ISOURCE             LDA =Dev_u        ! the number of counts times the
8650  ISOURCE             ADA Offset        ! deviation from the mean of each
8660  ISOURCE             STA Oper_2        ! count.
8670  ISOURCE             STA Result
8680  ISOURCE             LDA =2
8690  ISOURCE             LDB =146721B
8700  ISOURCE             JSM Rel_math
8710  ISOURCE !
8720  ISOURCE             DSZ Address
8730  ISOURCE             DSZ I
8740  ISOURCE             JMP Dev_count
8750  ISOURCE !
8760  ISOURCE             LDA =Ns           ! Convert the number of samples to
8770  ISOURCE             STA Oper_1        ! a real number.
8780  ISOURCE             LDA =Xvar
8790  ISOURCE             STA Result
8800  ISOURCE             JSM Int_to_rel
8810  ISOURCE !
8820  ISOURCE             LDB Offset        ! Divide the sum stored in Dev_u by
8830  ISOURCE             ADB =Dev_u        ! the number of samples to get the
8840  ISOURCE             STB Oper_1        ! variance of the counts.
8850  ISOURCE             STB Result
8860  ISOURCE             LDB =Xvar
8870  ISOURCE             STB Oper_2
8880  ISOURCE             LDA =2
8890  ISOURCE             LDB =147155B
8900  ISOURCE             JSM Rel_math
8910  ISOURCE !
8920  ISOURCE             LDA =Dev_u        ! Take the square root of the
8930  ISOURCE             ADA Offset        ! variance to get the standard
8940  ISOURCE             STA Oper_1        ! deviation.
8950  ISOURCE             STA Result
8960  ISOURCE             LDA =1
```

```
8970   ISOURCE              LDB =31450B
8980   ISOURCE              JSM Rel_math
8990   ISOURCE !
9000   ISOURCE              LDA Count
9010   ISOURCE              ADA =1
9020   ISOURCE              STA Count
9030   ISOURCE              ADA =-3
9040   ISOURCE              SZA *+2
9050   ISOURCE              JMP Get_sdev
9060   ISOURCE !
9070   ISOURCE              LDA =0            ! Now use the standard deviation to
9080   ISOURCE              STA Count         ! filter out all the counts whose
9090   ISOURCE Dev_filtr:   LDA Count         ! value is more than Sdev standard
9100   ISOURCE              ADA =1            ! deviations away from the mean.
9110   ISOURCE              LDB =1024
9120   ISOURCE              MPY
9130   ISOURCE              ADA =Bin_u
9140   ISOURCE              STA Address
9150   ISOURCE              LDA =1023
9160   ISOURCE              STA I
9170   ISOURCE !
9180   ISOURCE              LDA Count
9190   ISOURCE              SAL 2
9200   ISOURCE              ADA =Dev_u
9210   ISOURCE              STA Oper_1
9220   ISOURCE              LDA =Sdev
9230   ISOURCE              STA Oper_2
9240   ISOURCE              LDA =Xvar
9250   ISOURCE              STA Result
9260   ISOURCE              LDA =2
9270   ISOURCE              LDB =147037B
9280   ISOURCE              JSM Rel_math
9290   ISOURCE !
9300   ISOURCE              LDA =Xvar
9310   ISOURCE              STA Oper_1
9320   ISOURCE              LDA =Int
9330   ISOURCE              STA Result
9340   ISOURCE              JSM Rel_to_int
9350   ISOURCE !
9360   ISOURCE              LDA Count
9370   ISOURCE              SAL 2
9380   ISOURCE              ADA =Avg_u
9390   ISOURCE              STA Oper_1
9400   ISOURCE              LDA =Offset
9410   ISOURCE              STA Result
9420   ISOURCE              JSM Rel_to_int
9430   ISOURCE !
9440   ISOURCE              LDB Offset
9450   ISOURCE              TCB
9460   ISOURCE Filtr_dev:   LDA I
9470   ISOURCE              ADA B
9480   ISOURCE              SAM *+2
9490   ISOURCE              TCA
9500   ISOURCE              ADA Int
9510   ISOURCE              SAP *+3
9520   ISOURCE              LDA Address
9530   ISOURCE              CLR 1
9540   ISOURCE              DSZ Address
9550   ISOURCE              DSZ I
9560   ISOURCE              JMP Filtr_dev
```

```
9570  ISOURCE !
9580  ISOURCE              ISZ Count        ! Go through this whole process
9590  ISOURCE              LDA =-3          ! of checking the deviation and
9600  ISOURCE              ADA Count        ! filtering the data three times,
9610  ISOURCE              SZA *+2          ! once for each channel.
9620  ISOURCE              JMP Dev_filtr.
9630  ISOURCE !
9640  ISOURCE ! The loop Begin is performed three times, once for U, V,
9650  ISOURCE ! and W. Each time through the data array is read, a count (a raw
9660  ISOURCE ! datum) is taken from it and converted into a velocity. The vel-
9670  ISOURCE ! ocity is stored in U, V, or W depending on whether this is the
9680  ISOURCE ! first, second, or third iteration of the loop. The first time a
9690  ISOURCE ! particular count is encountered, the velocity corresponding to
9700  ISOURCE ! it is calculated using the intermediate values found in Get_int,
9710  ISOURCE ! and the velocity is stored in a table. If that count is found
9720  ISOURCE ! again in the data array, the corresponding velocity is looked
9730  ISOURCE ! up rather than being calculated again.
9740  ISOURCE !
9750  ISOURCE Set_begin: LDA =0
9760  ISOURCE              STA Count
9770  ISOURCE              LDA Ns
9780  ISOURCE              STA I
9790  ISOURCE              STA Ngs
9800  ISOURCE !
9810  ISOURCE Begin:       LDA Count
9820  ISOURCE              STA B
9830  ISOURCE              SBL 2
9840  ISOURCE              STB Offset
9850  ISOURCE              LDB Ns           ! Figure out which element of the
9860  ISOURCE              MPY              ! data array we want to pick up.
9870  ISOURCE              ADA I
9880  ISOURCE              ADA =-1
9890  ISOURCE              STA Elementd
9900  ISOURCE              LDA =Int         ! Get a raw datum from the data array.
9910  ISOURCE              LDB =Arrayd
9920  ISOURCE              JSM Get_element
9930  ISOURCE              LDA Int
9940  ISOURCE              LDB =1023        ! Strip off the first six
9950  ISOURCE              AND B            ! bits of the raw data word.
9960  ISOURCE              LDB Count        ! See if Count = Check.
9970  ISOURCE              TCB
9980  ISOURCE              ADB Check
9990  ISOURCE              SZB Straight     ! If true, use the modified data
10000 ISOURCE              TCA              ! word as an index. If not, use
10010 ISOURCE              ADA =1024        ! 1024 minus the data word.
10020 ISOURCE Straight:    STA Int          ! Store the count we have gotten.
10030 ISOURCE !
10040 ISOURCE              LDA Count        ! Now look in the appropriate part
10050 ISOURCE              LDB =1024        ! of the arrays created by the filter
10060 ISOURCE              MPY              ! section.
10070 ISOURCE              ADA Int
10080 ISOURCE              ADA =-1
10090 ISOURCE              ADA =Bin_u
10100 ISOURCE              LDB A,I
10110 ISOURCE              RZB Goodcount    ! If the word corresponding to the
10120 ISOURCE              STB Count        ! count is zero, the count was
10130 ISOURCE              DSZ Ngs          ! filtered out and should be ignored.
10140 ISOURCE              DSZ I            ! Ignore these three counts, go back
10150 ISOURCE              JMP Begin        ! and do the next three.
10160 ISOURCE !
```

```
10170 ISOURCE Goodcount: LDA Count         ! Now, use Count to find out
10180 ISOURCE            LDB =4096         ! which lookup table array
10190 ISOURCE            MPY               ! we want to use, and use the
10200 ISOURCE            LDB Int           ! count we got from the data array
10210 ISOURCE            ADB =-1           ! to find exactly where in the
10220 ISOURCE            SBL 2             ! table we want to go.
10230 ISOURCE            ADA B
10240 ISOURCE            ADA =1
10250 ISOURCE            ADA =Array1
10260 ISOURCE            STA Address
10270 ISOURCE            LDB =Int2
10280 ISOURCE            XFR 1
10290 ISOURCE            LDA Int2          ! If that table entry is zero,
10300 ISOURCE            SZA Calculate     ! calculate a velocity for it.
10310 ISOURCE            JMP Over
10320 ISOURCE Calculate: LDA =Int
10330 ISOURCE            STA Oper_1        ! Convert the count into
10340 ISOURCE            LDA =Yvar         ! a real number.
10350 ISOURCE            STA Result
10360 ISOURCE            JSM Int_to_rel
10370 ISOURCE            STB Oper_2
10380 ISOURCE            LDA =R1           ! Divide the range we found
10390 ISOURCE            ADA Offset        ! earlier by the count to get a
10400 ISOURCE            STA Oper_1        ! frequency.
10410 ISOURCE            LDA =Xvar
10420 ISOURCE            STA Result
10430 ISOURCE            LDA =2
10440 ISOURCE            LDB =147155B
10450 ISOURCE            JSM Rel_math
10460 ISOURCE !
10470 ISOURCE            LDA =Numix1       ! Find (Nub-NumixN)-FrequencyN.
10480 ISOURCE            ADA Offset
10490 ISOURCE            STA Oper_1
10500 ISOURCE            LDA =Xvar
10510 ISOURCE            STA Oper_2
10520 ISOURCE            LDA =Yvar
10530 ISOURCE            STA Result
10540 ISOURCE            LDA =2
10550 ISOURCE            LDB =146717B
10560 ISOURCE            JSM Rel_math
10570 ISOURCE !
10580 ISOURCE            LDB Count         ! If we are calculating U, reverse
10590 ISOURCE            ADB =-1           ! the sign of ((Nub-NumixN)-FrequencyN)
10600 ISOURCE            SBM *+2           ! so as to reverse the sign of U.
10610 ISOURCE            JMP Samesign      ! Leave V and Wv alone.
10620 ISOURCE            LDA =Zero
10630 ISOURCE            STA Oper_1
10640 ISOURCE            LDA Result
10650 ISOURCE            STA Oper_2
10660 ISOURCE            LDA =Xvar
10670 ISOURCE            STA Result
10680 ISOURCE            LDA =2
10690 ISOURCE            LDB =146717B
10700 ISOURCE            JSM Rel_math
10710 ISOURCE Samesign:  NOP
10720 ISOURCE !
10730 ISOURCE            LDA Result        ! Find Velocity=((Nub-NumixN)
10740 ISOURCE            STA Oper_1        ! -FrequencyN)*(Mill*DfN)
10750 ISOURCE            LDA =Df1          ! and store in a place in the
10760 ISOURCE            ADA Offset        ! lookup table corresponding to
```

```
10770 ISOURCE              STA Oper_2       ! the data count.
10780 ISOURCE              LDA Address
10790 ISOURCE              ADA =-1
10800 ISOURCE              STA Result
10810 ISOURCE              LDA =2
10820 ISOURCE              LDB =147037B
10830 ISOURCE              JSM Rel_math
10840 ISOURCE !
10850 ISOURCE Over:        LDA Address      ! Transfer the velocity from
10860 ISOURCE              ADA =-1          ! the lookup table to U, V, or W,
10870 ISOURCE              LDB =U           ! as appropriate.
10880 ISOURCE              ADB Offset
10890 ISOURCE              XFR 4
10900 ISOURCE !
10910 ISOURCE              ISZ Count
10920 ISOURCE              LDA =-3          ! Have U, V, and W all
10930 ISOURCE              ADA Count        ! been calculated?
10940 ISOURCE              SZA *+2          ! If not, go back again.
10950 ISOURCE              JMP Begin
10960 ISOURCE              STA Count        ! If so, set Count = 0.
10970 ISOURCE !
10980 ISOURCE ! Now we convert the W we have obtained (which is measured at an
10990 ISOURCE ! angle Theta to the V-axis) to the W we want (which should
11000 ISOURCE ! be measured at an angle of 90 degrees to the V-axis).
11010 ISOURCE ! Thus find W=(Wv-V*Cos(Theta))/Sin(Theta).
11020 ISOURCE !
11030 ISOURCE              LDA =V
11040 ISOURCE              STA Oper_1
11050 ISOURCE              LDA =Cos
11060 ISOURCE              STA Oper_2
11070 ISOURCE              LDA =Xvar
11080 ISOURCE              STA Result
11090 ISOURCE              LDA =2
11100 ISOURCE              LDB =147037B
11110 ISOURCE              JSM Rel_math
11120 ISOURCE              LDA Result
11130 ISOURCE              STA Oper_2
11140 ISOURCE              LDA =W
11150 ISOURCE              STA Oper_1
11160 ISOURCE              LDA =Yvar
11170 ISOURCE              STA Result
11180 ISOURCE              LDA =2
11190 ISOURCE              LDB =146717B
11200 ISOURCE              JSM Rel_math
11210 ISOURCE              LDA Result
11220 ISOURCE              STA Oper_1
11230 ISOURCE              LDA =Sin
11240 ISOURCE              STA Oper_2
11250 ISOURCE              LDA =W
11260 ISOURCE              STA Result
11270 ISOURCE              LDA =2
11280 ISOURCE              LDB =147155B
11290 ISOURCE              JSM Rel_math
11300 ISOURCE !
11310 ISOURCE ! Now take running sums of U, V, W, and several products
11320 ISOURCE ! of these velocities. The sums are taken using the utility
11330 ISOURCE ! "Add". The sums are calculated in an unusual sequence in
11340 ISOURCE ! order to reduce the number of program steps needed to cal-
11350 ISOURCE ! culate them.
11360 ISOURCE !
```

```
11370 ISOURCE          LDA =Su         ! Find Su=Su+U
11380 ISOURCE          LDB =U
11390 ISOURCE          JSM Add
11400 ISOURCE !
11410 ISOURCE          LDA Oper_2      ! Find U*U
11420 ISOURCE          STA Oper_1
11430 ISOURCE          LDA =Uu
11440 ISOURCE          STA Result
11450 ISOURCE          LDA =2
11460 ISOURCE          LDB =147037B
11470 ISOURCE          JSM Rel_math
11480 ISOURCE !
11490 ISOURCE          LDA =Suu        ! Find Suu=Suu+(U*U)
11500 ISOURCE          LDB Result
11510 ISOURCE          JSM Add
11520 ISOURCE !
11530 ISOURCE          LDA =V          ! Find U*U*V
11540 ISOURCE          STA Oper_1
11550 ISOURCE          LDA =Xvar
11560 ISOURCE          STA Result
11570 ISOURCE          LDA =2
11580 ISOURCE          LDB =147037B
11590 ISOURCE          JSM Rel_math
11600 ISOURCE !
11610 ISOURCE          LDA =Suuv       ! Find Suuv=Suuv+(U*U*V)
11620 ISOURCE          LDB Result
11630 ISOURCE          JSM Add
11640 ISOURCE !
11650 ISOURCE          LDA =Uu         ! Find U*U*W
11660 ISOURCE          STA Oper_1
11670 ISOURCE          LDA =W
11680 ISOURCE          STA Oper_2
11690 ISOURCE          LDA =Xvar
11700 ISOURCE          STA Result
11710 ISOURCE          LDA =2
11720 ISOURCE          LDB =147037B
11730 ISOURCE          JSM Rel_math
11740 ISOURCE !
11750 ISOURCE          LDA =Suuw       ! Find Suuw=Suuw+(U*U*W)
11760 ISOURCE          LDB Result
11770 ISOURCE          JSM Add
11780 ISOURCE !
11790 ISOURCE          LDA =Sv         ! Find Sv=Sv+V
11800 ISOURCE          LDB =V
11810 ISOURCE          JSM Add
11820 ISOURCE !
11830 ISOURCE          LDA =U          ! Find U*V
11840 ISOURCE          STA Oper_1
11850 ISOURCE          LDA =Uv
11860 ISOURCE          STA Result
11870 ISOURCE          LDA =2
11880 ISOURCE          LDB =147037B
11890 ISOURCE          JSM Rel_math
11900 ISOURCE !
11910 ISOURCE          LDA =Suv        ! Find Suv=Suv+(U*V)
11920 ISOURCE          LDB Result
11930 ISOURCE          JSM Add
11940 ISOURCE !
11950 ISOURCE          LDA =V          ! Find U*V*V
11960 ISOURCE          STA Oper_1
```

```
11970 ISOURCE            LDA =Xvar
11980 ISOURCE            STA Result
11990 ISOURCE            LDA =2
12000 ISOURCE            LDB =147037B
12010 ISOURCE            JSM Rel_math
12020 ISOURCE !
12030 ISOURCE            LDA =Suvv       ! Find Suvv=Suvv+(U*V*V)
12040 ISOURCE            LDB Result
12050 ISOURCE            JSM Add
12060 ISOURCE !
12070 ISOURCE            LDA =Uv         ! Find U*V*W
12080 ISOURCE            STA Oper_1
12090 ISOURCE            LDA =W
12100 ISOURCE            STA Oper_2
12110 ISOURCE            LDA =Xvar
12120 ISOURCE            STA Result
12130 ISOURCE            LDA =2
12140 ISOURCE            LDB =147037B
12150 ISOURCE            JSM Rel_math
12160 ISOURCE !
12170 ISOURCE            LDA =Suvw       ! Find Suvw=Suvw+(U*V*W)
12180 ISOURCE            LDB Result
12190 ISOURCE            JSM Add
12200 ISOURCE !
12210 ISOURCE            LDA =V          ! Find V*V
12220 ISOURCE            STA Oper_1
12230 ISOURCE            STA Oper_2
12240 ISOURCE            LDA =Xvar
12250 ISOURCE            STA Result
12260 ISOURCE            LDA =2
12270 ISOURCE            LDB =147037B
12280 ISOURCE            JSM Rel_math
12290 ISOURCE !
12300 ISOURCE            LDA =Svv        ! Find Svv=Svv+(V*V)
12310 ISOURCE            LDB Result
12320 ISOURCE            JSM Add
12330 ISOURCE !
12340 ISOURCE            LDA =Sw         ! Find Sw=Sw+W
12350 ISOURCE            LDB =W
12360 ISOURCE            JSM Add
12370 ISOURCE !
12380 ISOURCE            LDA =U          ! Find U*W
12390 ISOURCE            STA Oper_1
12400 ISOURCE            LDA =Xvar
12410 ISOURCE            STA Result
12420 ISOURCE            LDA =2
12430 ISOURCE            LDB =147037B
12440 ISOURCE            JSM Rel_math
12450 ISOURCE !
12460 ISOURCE            LDA =Suw        ! Find Suw=Suw+(U*W)
12470 ISOURCE            LDB Result
12480 ISOURCE            JSM Add
12490 ISOURCE !
12500 ISOURCE            LDA =W          ! Find V*W
12510 ISOURCE            STA Oper_1
12520 ISOURCE            LDA =V
12530 ISOURCE            STA Oper_2
12540 ISOURCE            LDA =Xvar
12550 ISOURCE            STA Result
12560 ISOURCE            LDA =2
```

```
12570 ISOURCE            LDB =147037B
12580 ISOURCE            JSM Rel_math
12590 ISOURCE !
12600 ISOURCE            LDA =Svw         ! Find Svw=Svw+(V*W)
12610 ISOURCE            LDB Result
12620 ISOURCE            JSM Add
12630 ISOURCE !
12640 ISOURCE            LDA =W           ! Find W*W
12650 ISOURCE            STA Oper_1
12660 ISOURCE            STA Oper_2
12670 ISOURCE            LDA =Xvar
12680 ISOURCE            STA Result
12690 ISOURCE            LDA =2
12700 ISOURCE            LDB =147037B
12710 ISOURCE            JSM Rel_math
12720 ISOURCE !
12730 ISOURCE            LDA =Sww         ! Find Sww=Sww+(W*W)
12740 ISOURCE            LDB Result
12750 ISOURCE            JSM Add
12760 ISOURCE !
12770 ISOURCE            LDA =U           ! Find U*W*W
12780 ISOURCE            STA Oper_1
12790 ISOURCE            LDA =Uu
12800 ISOURCE            STA Result
12810 ISOURCE            LDA =2
12820 ISOURCE            LDB =147037B
12830 ISOURCE            JSM Rel_math
12840 ISOURCE !
12850 ISOURCE            LDA =Suww        ! Find Suww=Suww+(U*W*W)
12860 ISOURCE            LDB Result
12870 ISOURCE            JSM Add
12880 ISOURCE !
12890 ISOURCE            DSZ I            ! Continue to calculate running
12900 ISOURCE            JMP Begin        ! sums until out of samples.
12910 ISOURCE !
12920 ISOURCE ! Now place the finished summs in the COMMON region so that
12930 ISOURCE ! the BASIC program has access to them, and then return to
12940 ISOURCE ! the BASIC program.
12950 ISOURCE Replace:   LDA =Range1
12960 ISOURCE            LDB =Ran1_par
12970 ISOURCE            JSM Put_value
12980 ISOURCE            LDA =Range2
12990 ISOURCE            LDB =Ran2_par
13000 ISOURCE            JSM Put_value
13010 ISOURCE            LDA =Range3
13020 ISOURCE            LDB =Ran3_par
13030 ISOURCE            JSM Put_value
13040 ISOURCE            LDA =Su
13050 ISOURCE            LDB =Su_par
13060 ISOURCE            JSM Put_value
13070 ISOURCE            LDA =Sv
13080 ISOURCE            LDB =Sv_par
13090 ISOURCE            JSM Put_value
13100 ISOURCE            LDA =Sw
13110 ISOURCE            LDB =Sw_par
13120 ISOURCE            JSM Put_value
13130 ISOURCE            LDA =Suu
13140 ISOURCE            LDB =Suu_par
13150 ISOURCE            JSM Put_value
13160 ISOURCE            LDA =Svv
```

```
13170 ISOURCE              LDB =Svv_par
13180 ISOURCE              JSM Put_value
13190 ISOURCE              LDA =Sww
13200 ISOURCE              LDB =Sww_par
13210 ISOURCE              JSM Put_value
13220 ISOURCE              LDA =Suv
13230 ISOURCE              LDB =Suv_par
13240 ISOURCE              JSM Put_value
13250 ISOURCE              LDA =Suw
13260 ISOURCE              LDB =Suw_par
13270 ISOURCE              JSM Put_value
13280 ISOURCE              LDA =Svw
13290 ISOURCE              LDB =Svw_par
13300 ISOURCE              JSM Put_value
13310 ISOURCE              LDA =Suuv
13320 ISOURCE              LDB =Suuv_par
13330 ISOURCE              JSM Put_value
13340 ISOURCE              LDA =Suvv
13350 ISOURCE              LDB =Suvv_par
13360 ISOURCE              JSM Put_value
13370 ISOURCE              LDA =Suuw
13380 ISOURCE              LDB =Suuw_par
13390 ISOURCE              JSM Put_value
13400 ISOURCE              LDA =Suww
13410 ISOURCE              LDB =Suww_par
13420 ISOURCE              JSM Put_value
13430 ISOURCE              LDA =Suvw
13440 ISOURCE              LDB =Suvw_par
13450 ISOURCE              JSM Put_value
13460 ISOURCE              LDA =Ngs
13470 ISOURCE              LDB =Ngs_par
13480 ISOURCE              JSM Put_value
13490 ISOURCE !
13500 ISOURCE              LDA =Bin_u       ! Transfer the contents of Bin_n
13510 ISOURCE              LDB =192         ! to the common area without using
13520 ISOURCE              STB I            ! the slow HP-supplied external
13530 ISOURCE              LDB =16          ! subroutines.
13540 ISOURCE              STB Count
13550 ISOURCE              LDB Cbin_par
13560 ISOURCE Transfer:    XFR 16
13570 ISOURCE              ADA Count
13580 ISOURCE              ADB Count
13590 ISOURCE              DSZ I
13600 ISOURCE              JMP Transfer
13610 ISOURCE              RET 1
13620 ISOURCE !
13630 ISOURCE              LIT 200
13640 ISOURCE !
13650 ISOURCE ! The utility "Add" is used to add up the running sums.
13660 ISOURCE !
13670 ISOURCE Add:         ISZ Utlcount
13680 ISOURCE              STA Oper_1
13690 ISOURCE              STB Oper_2
13700 ISOURCE              STA Result
13710 ISOURCE              LDA =2
13720 ISOURCE              LDB =146721B
13730 ISOURCE              JSM Rel_math
13740 ISOURCE              DSZ Utlcount
13750 ISOURCE              RET 1
13760 ISOURCE              JSM Utlend
```

```
13770 ISOURCE !
13780 ISOURCE              END Find_vel
```

ACKNOWLEDGEMENTS

We are grateful to Dr. Oktay Ozcan for help in the initial design of the system and to Dr. Dennis Johnson for many helpful comments. This work was supported by the Fluid Dynamics Research Branch, NASA Ames Research Center under Grant NCC-2-294.

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5. OPERATOR'S MANUAL FOR NASA 3D-LDV COMPUTER INTERFACE, NASA Ames Research Center, Writing Assoc., Sunnyvale, CA, July 1, 1982.

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TABLE 1

MACRODYNE RANGE SETTINGS

MANTISA	1	500	1024
RANGE			
0	32 GHz	64 MHz	31.28 MHz
1	16 "	32 "	15.64 "
2	8 "	16 "	7.20 "
3	4 "	8 "	3.91 "
4	2 "	4 "	1.95 "
5	1 "	2 "	977 kHz
6	500 MHz	1 "	488 "
7	250 "	500 kHz	244 "
8	125 "	250 "	122 "
9	62.5 "	125 "	61 "
10	31.25 "	62.5 "	30 "
11	15.62 "	31.25 "	15 "
12	7.81 "	15.62 "	7.6 "
13	3.90 "	7.81 "	3.8 "
14	1.95 "	3.90 "	1.9 "

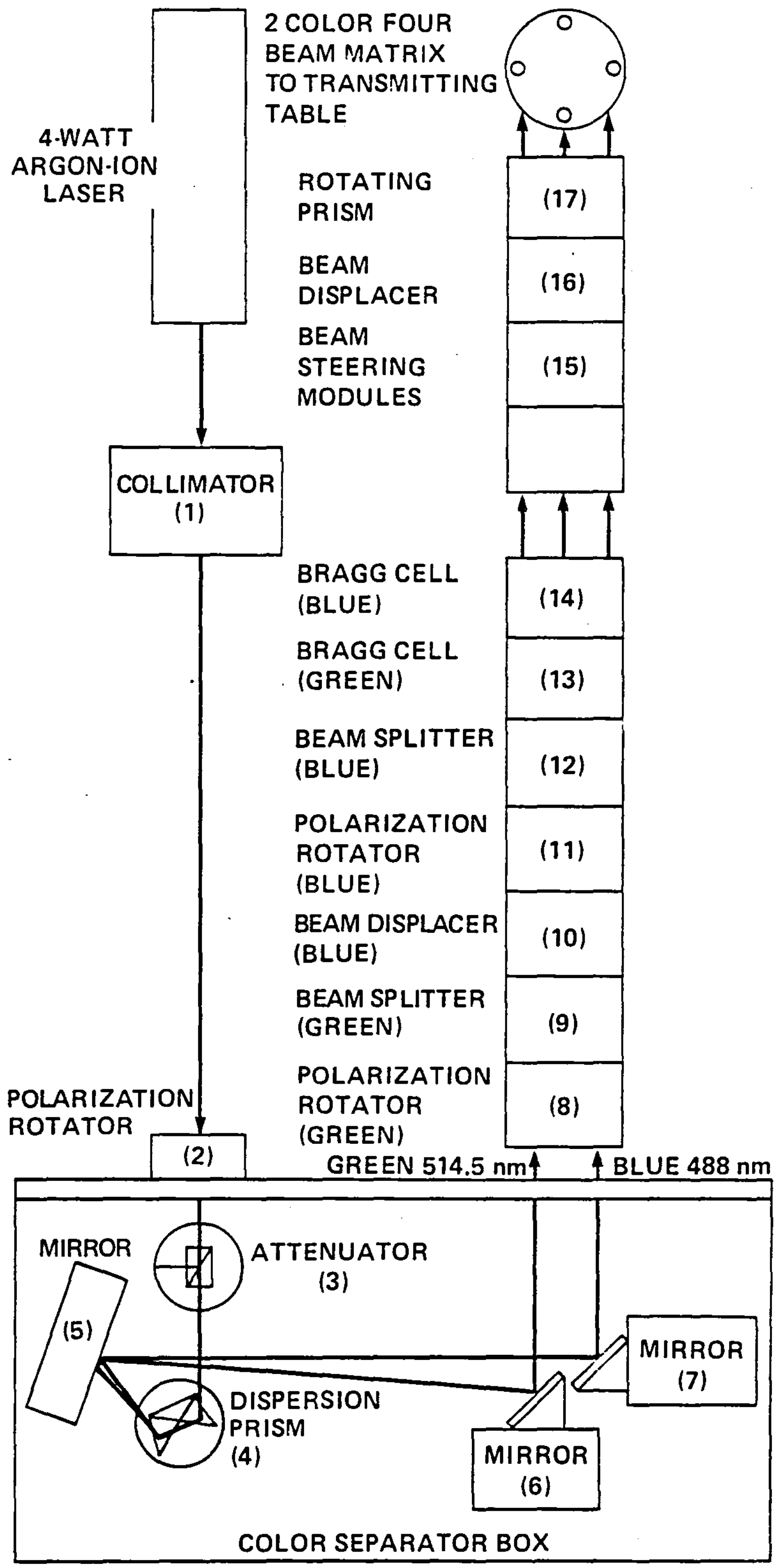


Fig. 1 Schematic of the optics table layout.

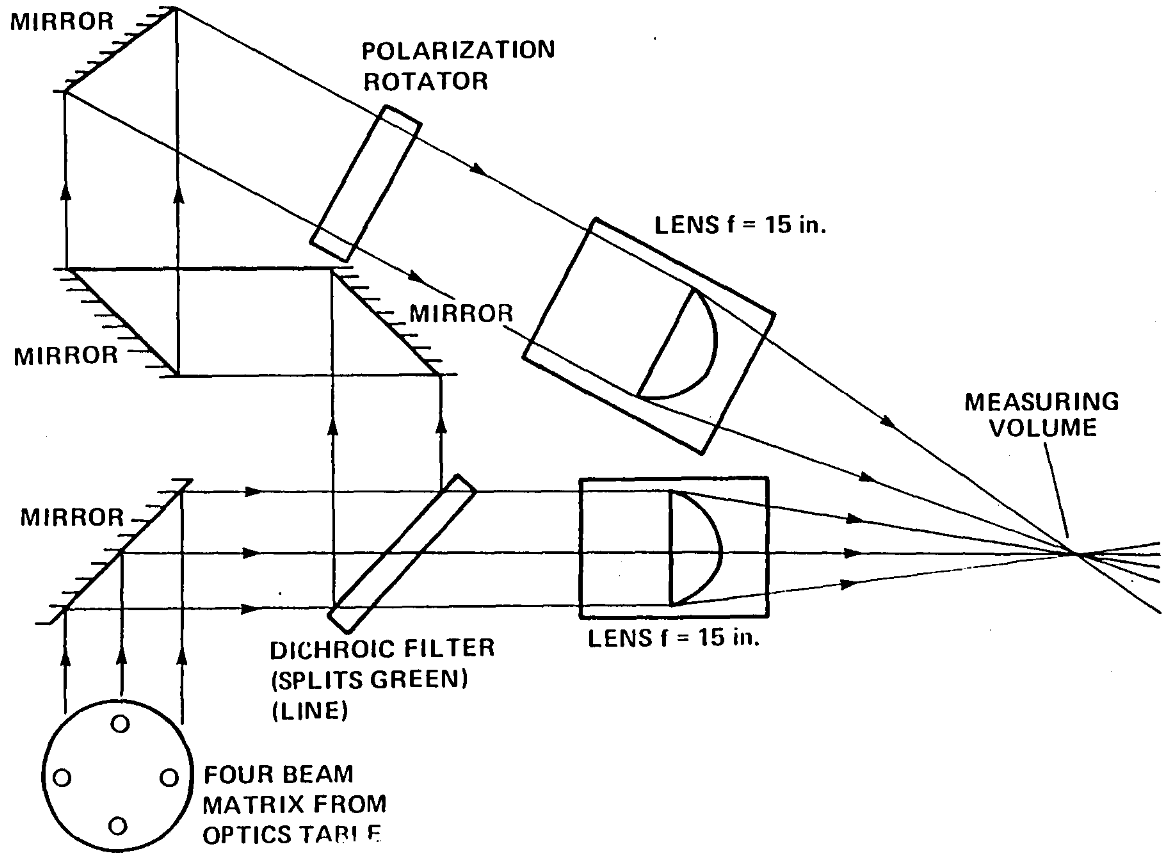


Fig. 2 Schematic of the transmitting optics.

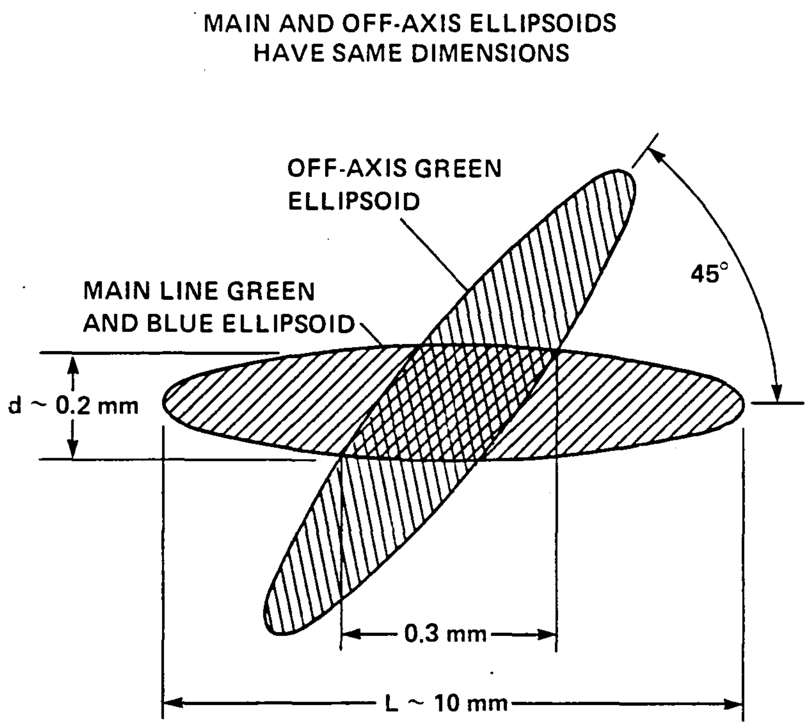


Fig. 3 Details of the probe volumes in the 3-D system.

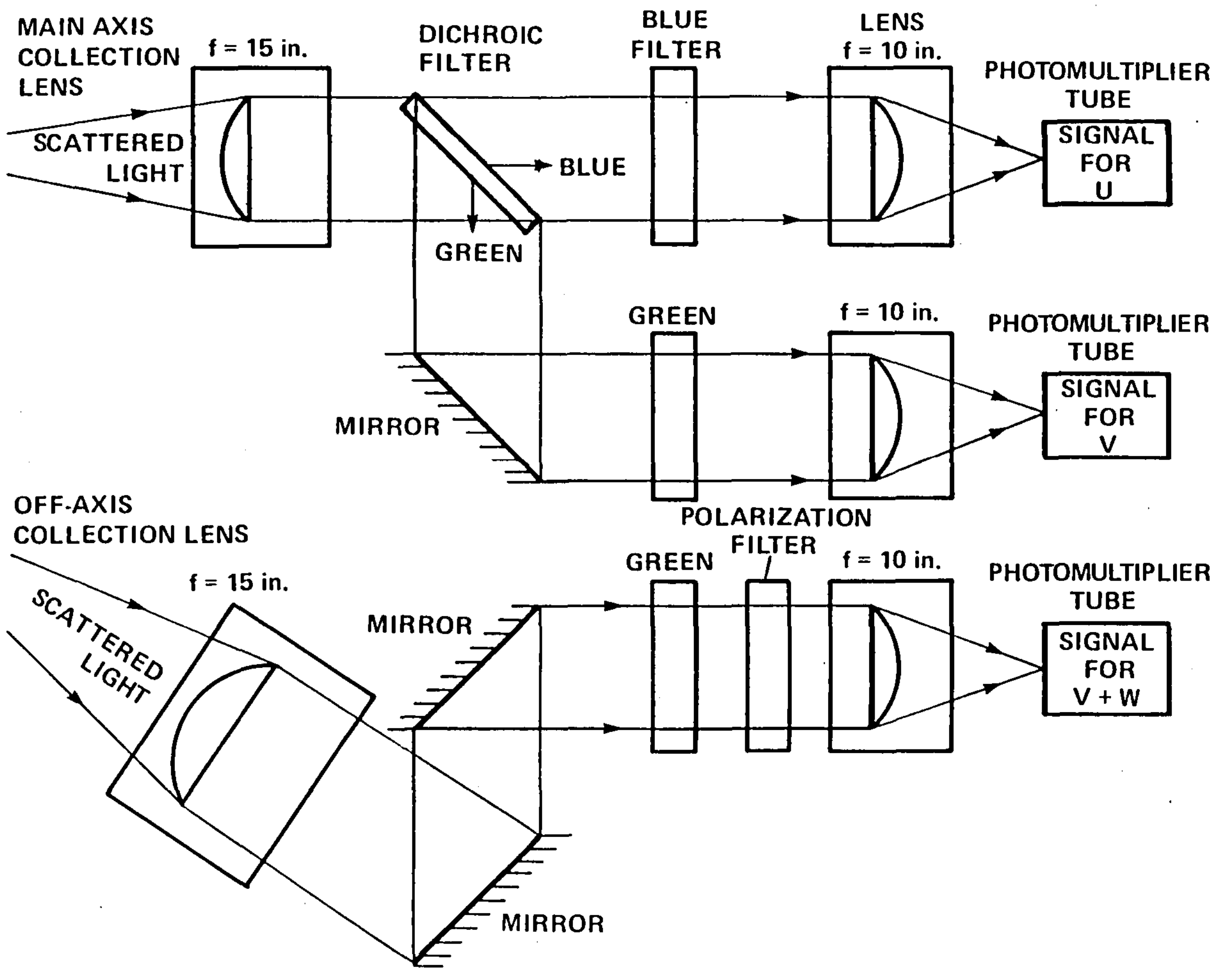


Fig. 4 Schematic of the receiving optics.

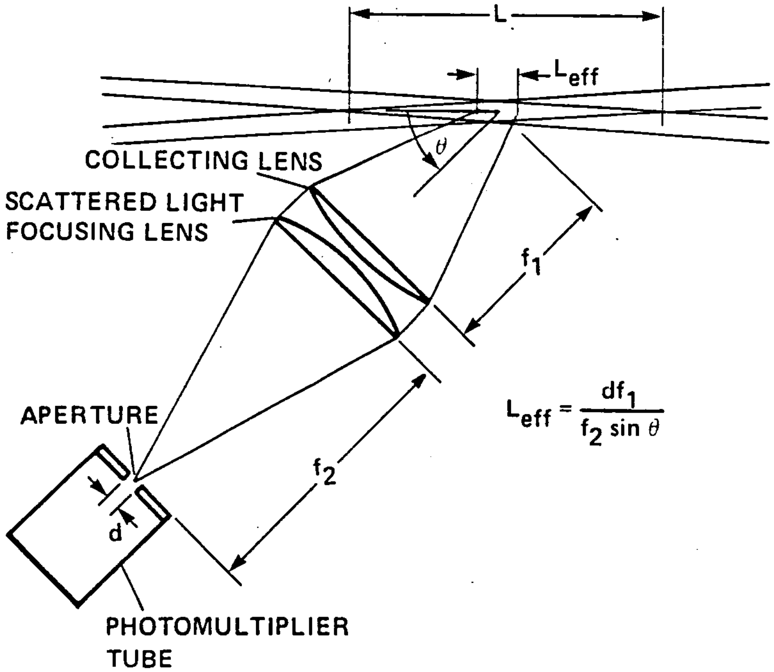


Fig. 5 Evaluation of the effective probe length.

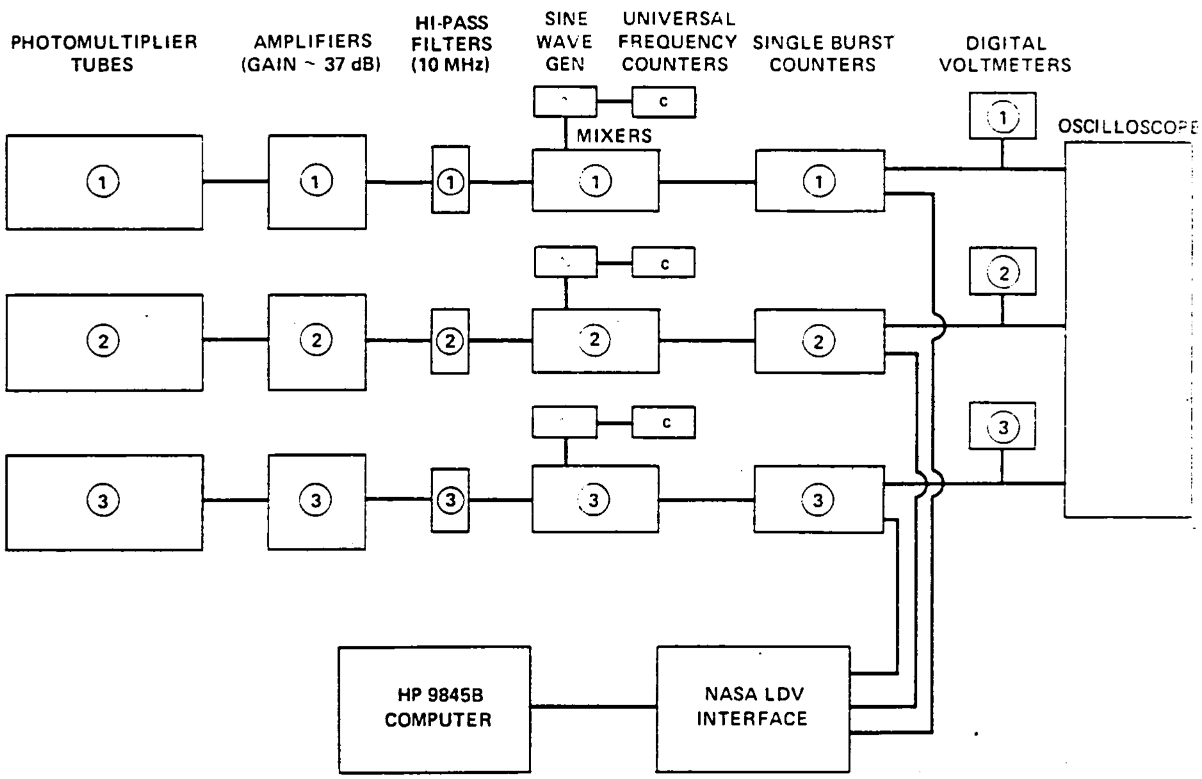


Fig. 6 Schematic of the signal processing electronics.

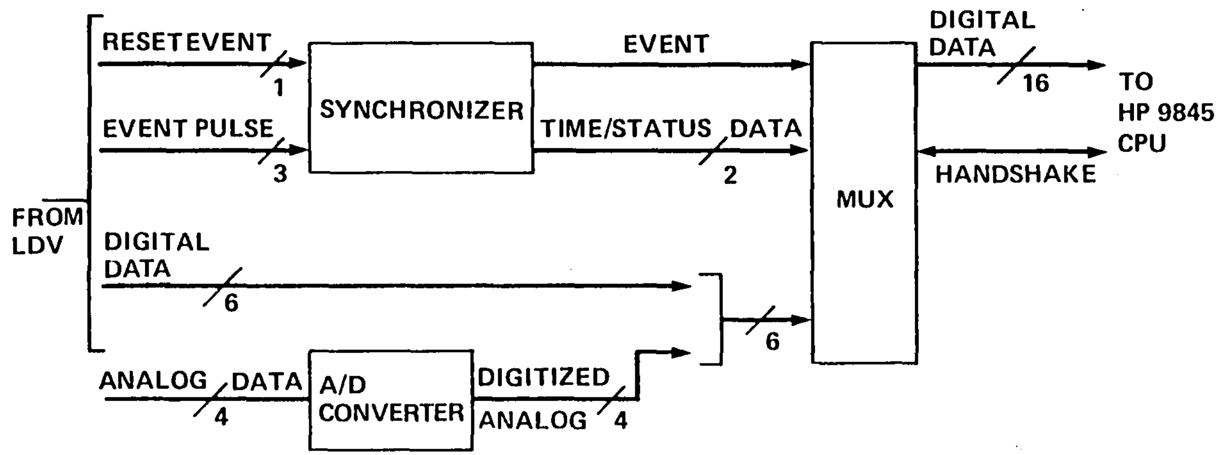


Fig. 7 Computer interface simplified block diagram.

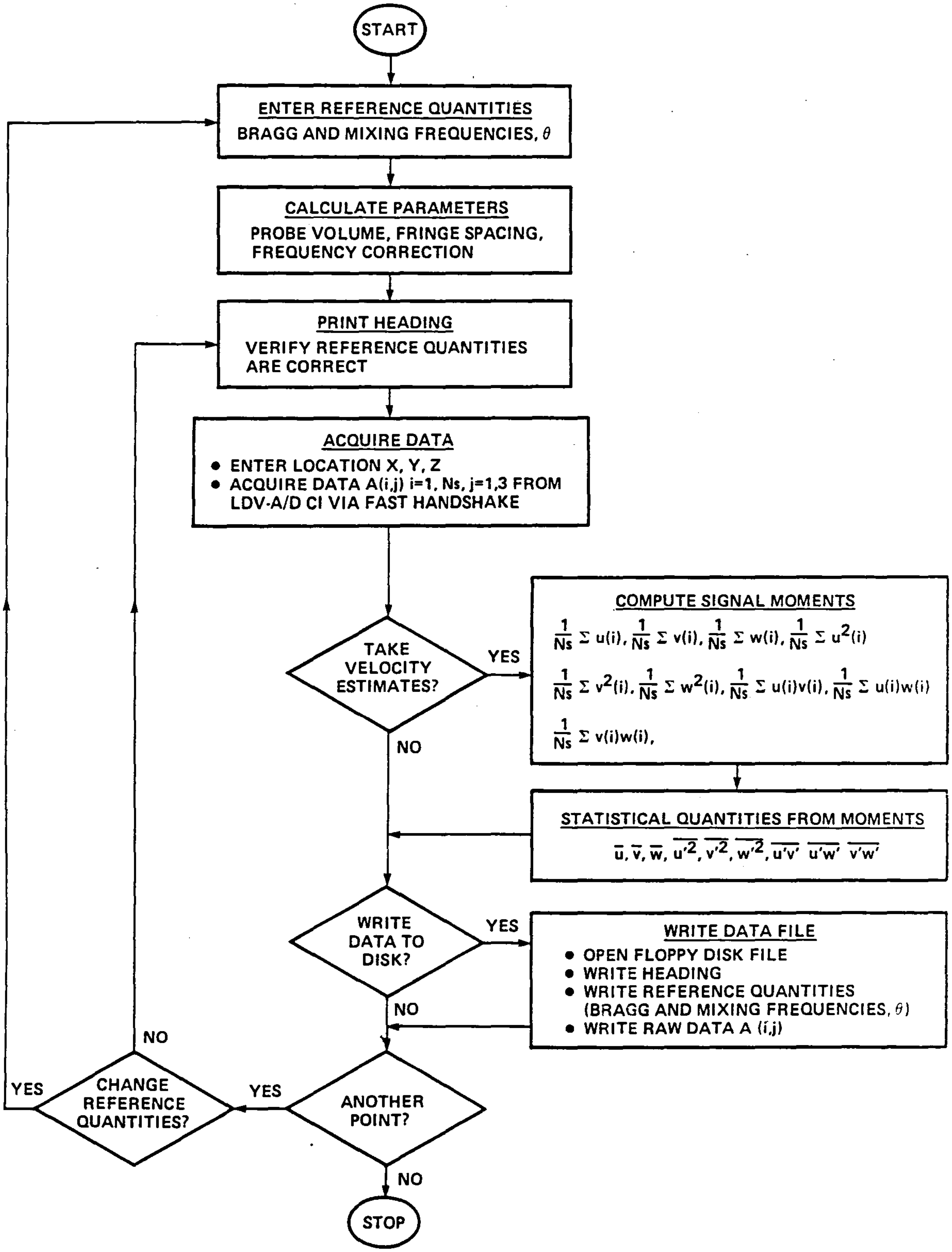


Fig. 8 Block diagram for data acquisition program.

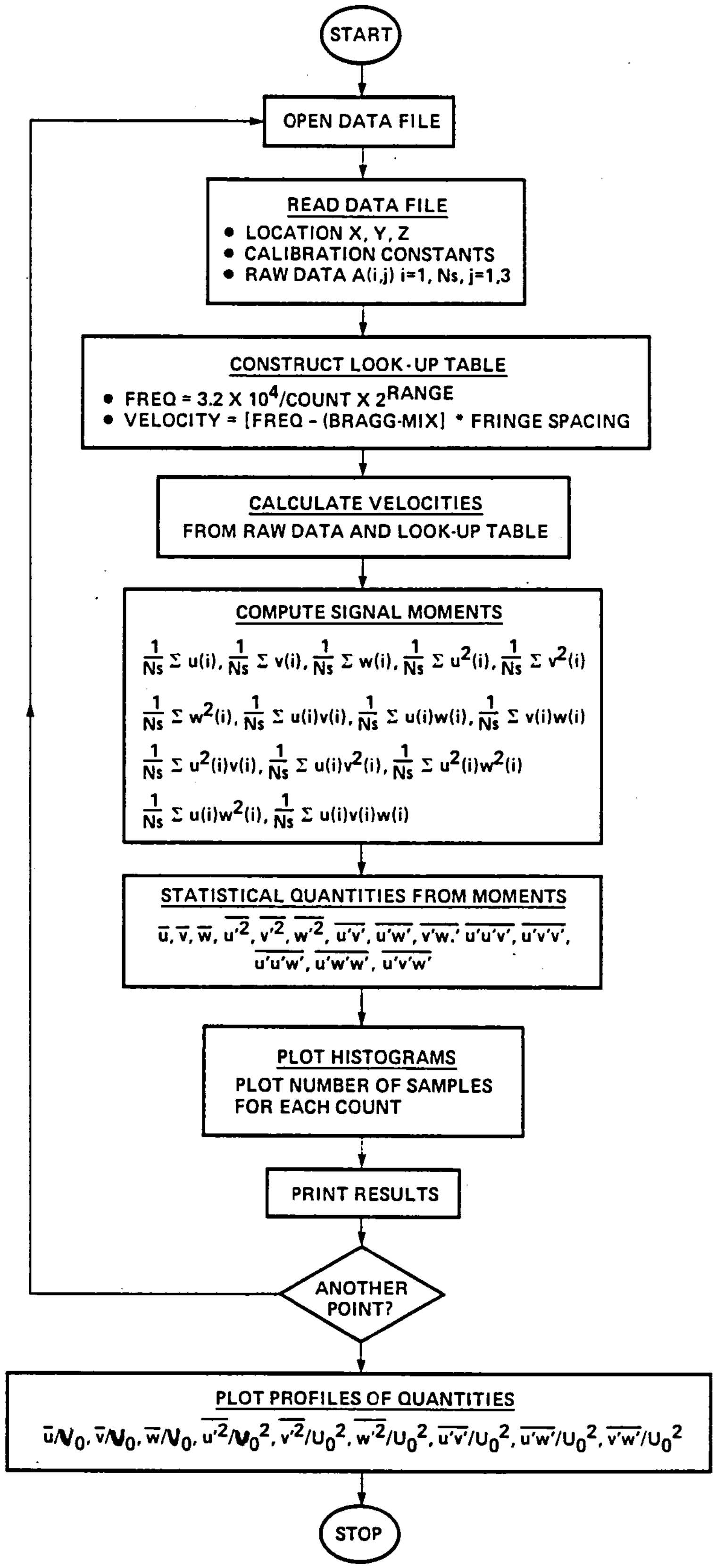


Fig. 9 Block diagram for data reduction program.

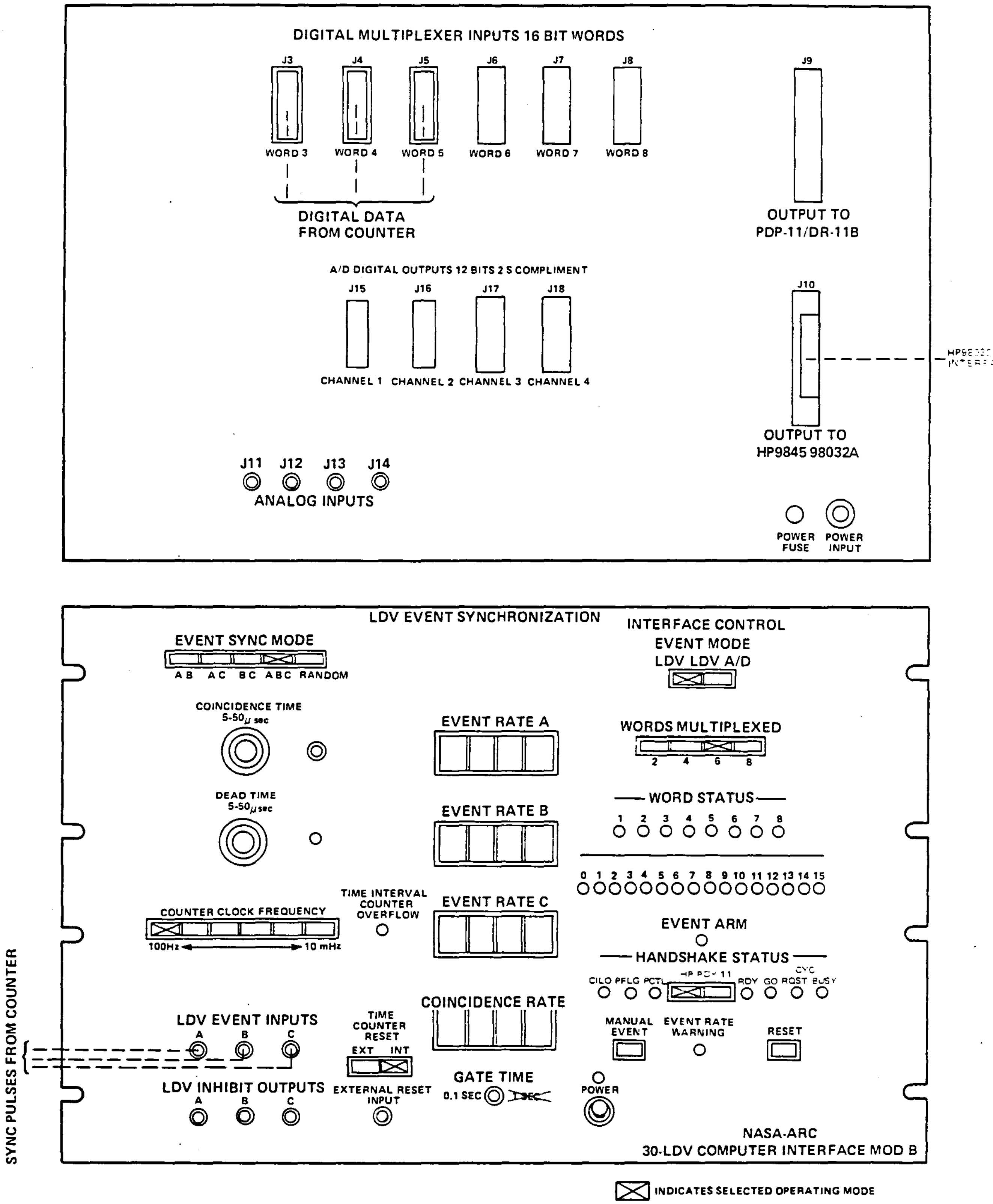
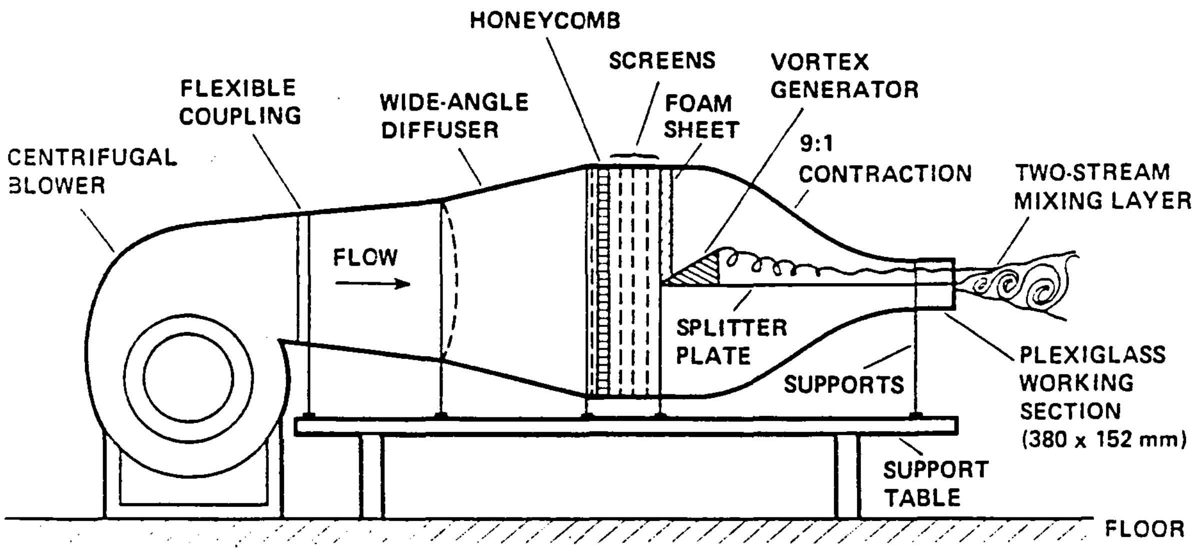
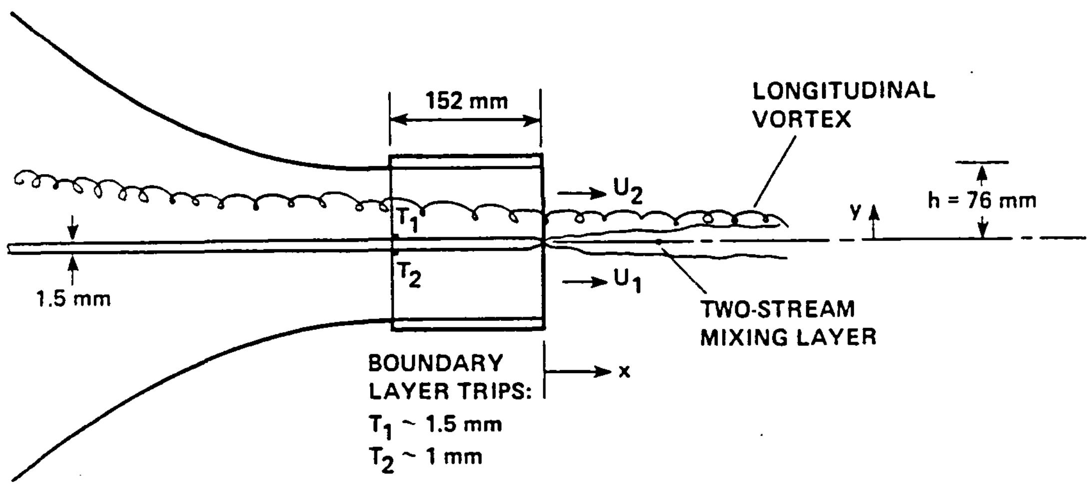


Fig. 10 NASA LDV-A/D computer interface connections and settings.

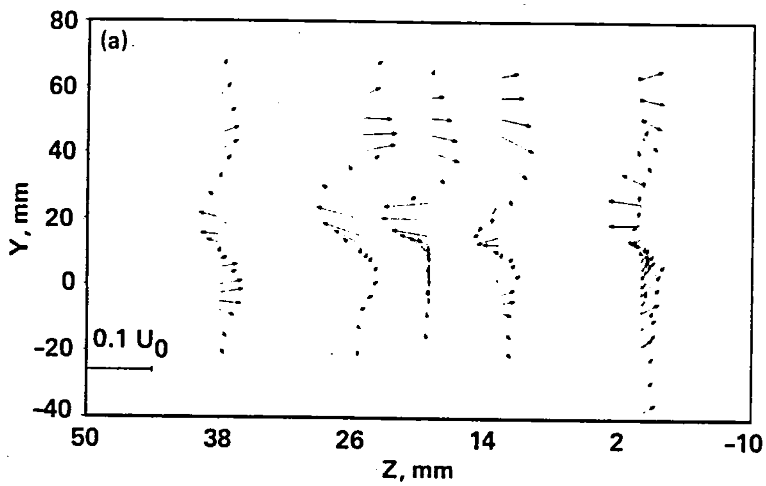


(a) Overall schematic

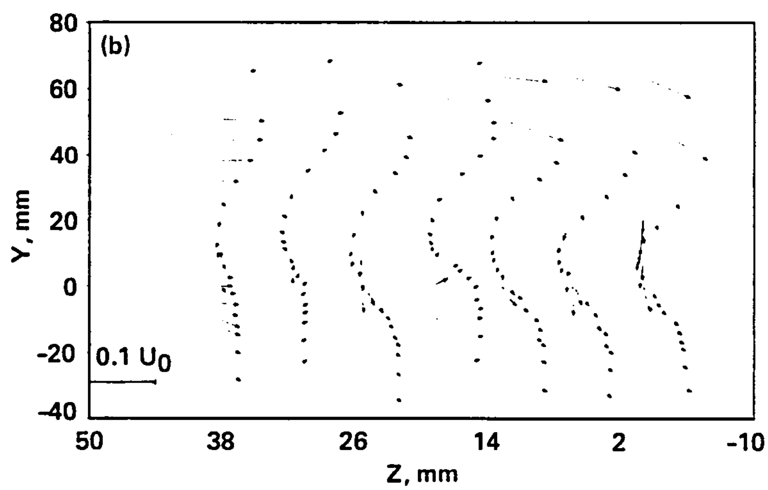


(b) Details of boundary layer trips and coordinate system

Fig. 11 Experimental rig.



(a) Cross-wire measurements



(b) LDV measurements

Fig. 12 Secondary velocity plots.

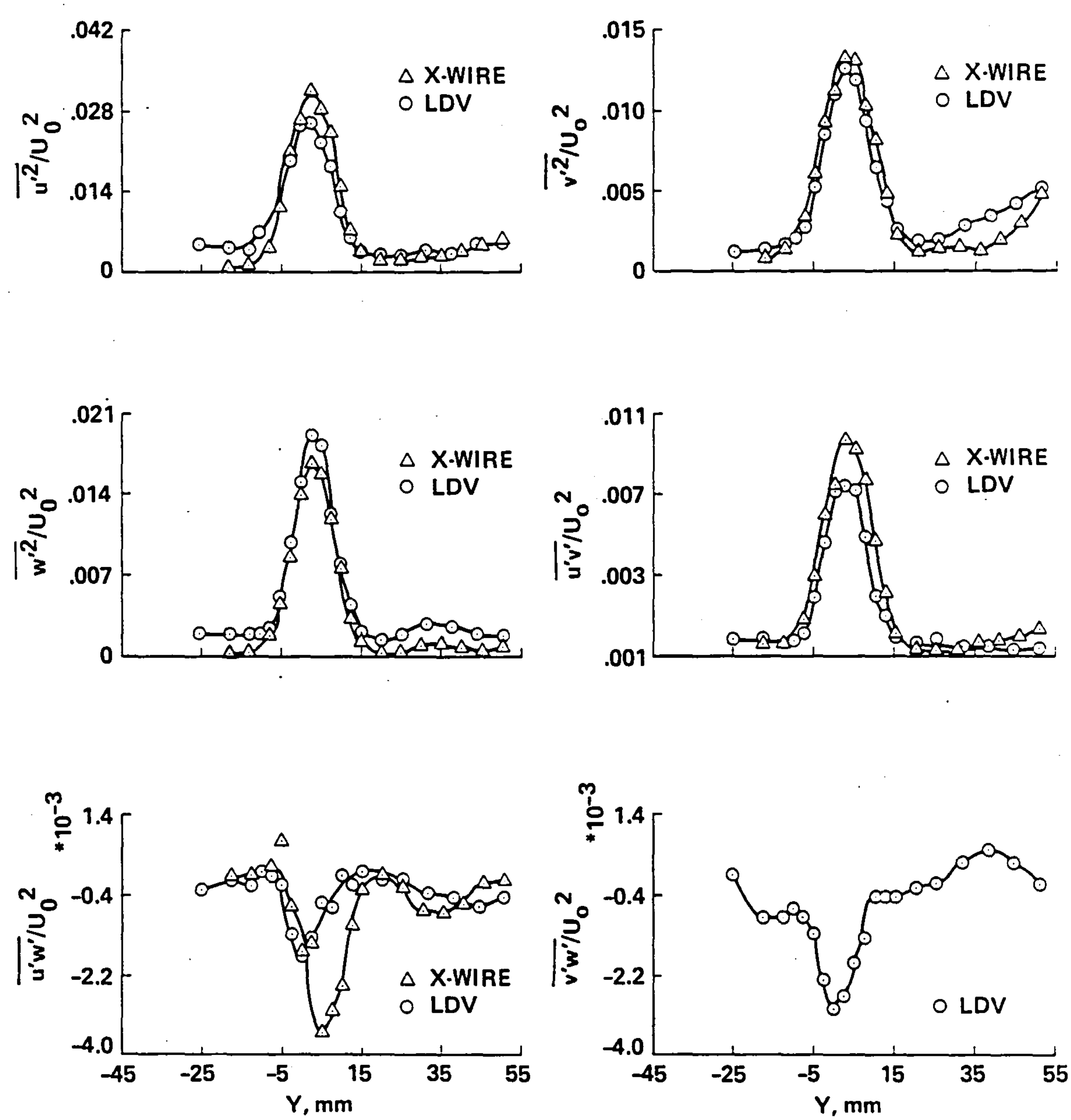


Fig. 13 Comparison of X-wire and LDV measurements in a vortex/mixing layer interaction.

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