MEASUREMENTS IN A MODEL LUNG BIFURCATION USING AN AUTOMATED LASER DOPPLER ANEMOMETER

by

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ABSTRACT

Aspects of flow in a human lung can be modeled by a series of simple bifurcations. A scaled-up which preserves dynamical similarity can be accomplished by using a fluid of higher viscosity and reducing the flow speed so that the Reynolds number is constant.

The experiment carried out here uses a Laser Doppler Anemometer System to measure velocity field in a three-quarter inch diameter tube which is a scaled-up typical bronchial bifurcation. Tap water seeded with alumina trihydrate is used as the working media. An ad-hoc calibration program is introduced to take care of the reflection problem caused by different reflective indice between water and the bifurcation which is constructed of plexiglas.

Measurement of tubewise velocity component is made with a He-Ne LDA system moved by a three dimensional traversing system which is controlled by an SDK-85 microprocessor. Signals processed through tracker are analyzed by a PDP-11 minicomputer. Serial interface between the minicomputer and the microprocessor is established so that the positioning of the laser system can be automated.

Evolution of the primary profiles through the bifurcation is investigated in detail at Reynolds number 320. The flow was found to have 'head-shoulder', second hump', and 'wing-like' features, etc. Plausible reasons are
given to interpret these features. A comparison of the flow pattern in major direction with Olson's hot-wire-measured data is made. The different situations between the two measurements are noted.
1.1 GENERAL STATEMENT OF THE WORK

The mechanics of breathing in human trachea and bronchia from the viewpoint of an engineer is just a flow going through various bifurcations. It is therefore believed that aspects of flow in a human lung can be modeled by a series of simple bifurcations. Because of the small sizes associated with the real lung, it is highly desirable in the laboratory to work with scale models which are larger. Dynamical simulation of the flow in the lung can be accomplished in these models using the principle of dynamic similarity, which requires that the Reynolds number of the model be the same as that in the lungs.

This study is an attempt to measure the flow field in a lung bifurcation using a computerized Laser Doppler Anenometer system. The scope of this work is two-fold:

(1) The investigation on the flow field

Care is taken to avoid possible errors due to the inherent characteristics of the laser system.

(2) The automation process

Efforts were made to have both the probe positioning and data acquisition/analysis process
Although the application of this investigation is to flow in the human lung, the methods developed and the results obtained are also applicable to piping systems where bifurcations occur.

1.2 RESEARCH BACKGROUND

Studies of flow patterns within the branching systems which attempt to mimic flow conditions within the body have been conducted for years. Leonardo Da Vinci, in about 1500, conducted experiments on branched channel flow for biological application. He sketched the flow patterns in his experiments which clearly show the division of the fluid stream into the two branches, an eddy formation on the surface of the flow divider, gradual disappearance of the large eddy as it moves downstream, and separation at the sharp inner wall of curvature, along with reattachment at a downstream position.

Naumann and Zeller \(^{170}\) conducted experimental studies on large scale model bifurcations with laminar flow for a range of Reynolds number from 400 to 1100 under steady and pulsatile conditions. They used colored dye streams to describe the basic patterns of flow and found secondary velocity components developing just downstream from the flow
Several researchers have used hot wires to measure velocity profile in model bifurcations. Schroter & Sudlow (1969) used a single hot wire to determine the velocity profile in the plane of the bifurcation and normal to the plane for a symmetrical bifurcation with a sharp flow divider, a total branching angle of 70 degrees, and a sharp curvature. They also used a smoke stream to visualize the secondary currents showing a secondary flow pattern downstream from the flow divider. At the inner wall of curvature they also showed separation occurring.

Schreck & Mockros (1970) also used single hot wire to measure the velocity profiles at each π/4 position in a series of bifurcations. The two symmetrical models used have total branching angles of 42 and 80 degrees. The velocity distribution obtained by Schreck & Mockros were in general similar to the measurements of Schroter & Sudlow.

Olson ( ) conducted more extensive hot wire measurements. He used a pulsed and a sensor wire together to measure all three components of the velocity field within a set of bifurcations. He used six bifurcations of which one is asymmetric and the branching angles were 50, 70, and 90 degrees. Olson recorded results at various Reynolds numbers between 300 and 1700. He found no separation from the outside wall since the wall in his model is gradually
All previous investigators used hot wires which we believe could have some disturbance on the flow fields. The experiment carried out here used Laser Doppler Anemometer to measure the flow fields. The major advantages for the laser system over hot-wires are:

1. It creates essentially no disturbance to the flow.
2. The relation between Doppler frequency and flow velocity is linear.
3. It is sensitive to only velocities in the measured direction.

Another advantage of the LDA over hot wires in measurement accuracy is its Gaussian intensity distribution which weights more on the center-point velocity than on the peripheral area in the 'control volume'.

Although the effectiveness of the LDA technique has been widely recognized, some of the problems associated with LDA have been noted in taking the measurement. (See Chapter 5.)

1.3 BASIC PRINCIPLES OF THE LDA SYSTEMS

As shown in Fig. 1.1, for the differential mode LDA system which we use here there is a well known Doppler
\[ f_{s_1} = f_{i_1} + \frac{\nabla \cdot (\hat{e}_{s_1} - \hat{e}_{i_1})}{\lambda_1} \quad (\text{Eq. 1.1.a}) \]
\[ f_{s_2} = f_{i_2} + \frac{\nabla \cdot (\hat{e}_{s_2} - \hat{e}_{i_2})}{\lambda_2} \quad (\text{Eq. 1.1.b}) \]

Where:

- \( f_{i_1}, \lambda_1, \hat{e}_{i_1} \) = frequency, wavelength, and unit vector of the first incident light
- \( f_{i_2}, \lambda_2, \hat{e}_{i_2} \) = frequency, wavelength, and unit vector of the second incident light
- \( f_{s_1}, \hat{e}_{s_1} \) = frequency and unit vector of the scattered light due to the first incident light
- \( f_{s_2}, \hat{e}_{s_2} \) = frequency and unit vector of the scattered light due to the second incident light
- \( \nabla \) = velocity vector of the scattering center
- \( \theta \) = scattering angle
- \( V_x \) = projection of the velocity vector \( V \) on the measuring direction, in the plane of the two incident beams and normal to the bisector of the angle between the two incident beams
Therefore we can detect a beating frequency:

\[ f_d = f_{\text{ss}} - f_{\text{sl}} \]
\[ = \left[ \frac{V \cdot (\hat{e}_{\text{ss}} - \hat{e}_{\text{sl}})}{\lambda_{\text{ss}}} - \frac{V \cdot (\hat{e}_{\text{sl}} - \hat{e}_{\text{li}})}{\lambda_{\text{li}}} \right] \]
\[ + \left[ f_{\text{is}} - f_{\text{il}} \right] \]  

---(Eq. 1.2)

This is a general case either with or without a frequency shift. In practice we have the 'optical frequency shift, \((f_0 = f_{\text{is}} - f_{\text{ii}})\) much much smaller than the incident frequency \((f_0 \sim 40 \text{ MHz}, f_i \sim 10^{14} \text{ MHz})\) so that Eq. 1.2 is then reduced to:
\[ f_d = \frac{V_x \cdot 2 \sin(\theta_x)}{\lambda} + f_o \]

\[ = f_D + f_o \]  

\[ \lambda = \lambda_1 = \lambda_2 = 632.8 \text{ nm the wavelength of the incident light for the Helium-Neon system} \]

\[ f_D = \text{the Doppler frequency} \]

and:

\[ V_x = C \cdot f_D \]  

\[ C = \frac{2 \sin \theta_x}{\lambda} \]

--- (Eq. 1.4)

--- (Eq. 1.5)

Note that based on Snell's law, different reflective indices of the fluids will not affect the calibration factor \( C \) because of the self-compensation between \( \lambda \) and \( \sin \frac{\theta}{2} \).

The detected frequency is encoded in the photocurrent by a photodetector in the following form:

\[ i_d \propto E_{s1}^2 + E_{s2}^2 + 2 E_{s1} E_{s2} \cos \left( 2\pi f_d t \right) \]  

--- (Eq. 1.6)

where:

\[ i_d = \text{photodetector current} \]

\[ E_{s1} = \text{amplitude of the light scattered from the first beam} \]

\[ E_{s2} = \text{amplitude of the light scattered from the} \]
second beam

t = time variable

Knowing $f_0$, $\theta$, and $\lambda$ we can thus obtain the velocity component by processing the photocurrent.
CHAPTER 2
EXPERIMENTAL DESCRIPTION

2.1 GENERAL DESCRIPTION

This chapter describes the experimental setup and how the facilities are working together. A schematic system configuration is shown in Fig. 2.1. The whole system is divided into the following sub-systems:

(1) The Flow System
(2) The Laser and Optics System
(3) The Data Acquisition/Analysis System
(4) The Traversing System

2.2 THE FLOW SYSTEM

As can be seen on Fig. 2.1, the working fluid is flowing in closed loop manner with constant head reservoirs to maintain a steady flow pressure across the bifurcation.
To maintain a slow and steady flow, the driving force of the liquid is the elevational difference between the upper and the lower tanks. The two tanks are situated on angle-iron racks which are bolted to a vertical steel frame. The relative elevation of the two tanks is adjustable from approximately -35 inches to +35 inches, but is set at +29 inches all through the experiment. Flow velocity is controlled by a velocity control valve right downstream the upper tank. A pump is used to provide the make-up water for the upper tank so that constant water levels on both upper and lower tanks can be maintained. The function of the four-way cock is to easily reverse the flow direction at any time without reassemble any portion of the flow system.

The bifurcation portion is constructed of two opposite and symmetric pieces of plexiglas in which the semi-circular grooves are carved. (See section 5.1 for more detail geometry of the bifurcation area.) Note that the long straight tubing is deliberately introduced right upstream and downstream of the interesting area to ensure a fully developed steady-state incoming flow. A calibrated rotameter is installed on the returning line to measure the volume flow rate.

All the piping is consisted of three quarters inch inside diameter tygon tubes. The diameter on the bifurcation area is also three quarters inch.
2.3 THE LASER & OPTICS SYSTEM

The laser system used is Helium-Neon laser, Model 124B, made by Spectral-Physics. Some specifications are included in Table 2.1. The transmitting optics is a DISA 55x modular system and is schematically shown on Fig.2.2.

The laser light enters the quarter wavelength retarders, of which one is connected on the laser head to convert the linearly (and vertically) polarized beam into circularly polarized beam, and the other, mounted onto the initial optical end, reverses the polarization back to vertical direction. This allows free rotation of the entire optics assembly without altering the polarization within the optics unit.

The entering beam is then split into two equal intensity beams in the beam splitter. When the two beams go through the Bragg cell section, one of them passes through the Bragg cell which up-shifts the beam by 40 MHz. The unshifted beam passes through a glass rod in order to maintain optically equal paths with the shifted beam. The next module, the beam displacer, displaces the shifted beam so that both beams can collimate into the ensuing backscatter section.

Pinhole section is situated next to the backscatter section to eliminate undesirable reflections or scattered light from front lens. The two beams pass through pinhole
section and then enter the beam translator where the beam separation is drawn closer to enter beam expander.

The function of the beam expander is to intensify the light at the latter focal point by a factor of approximately 14, resulting in an improvement of signal to noise ratio (SNR) by approximate 1/7 times. Lastly, the beams are brought to a focal point via a front lens.

In the backscatter mode, signal from the scattering center at the focal point penetrates back through front lens, beam expander, beam translator, pinhole section and then is reflected by the backscatter section into the photomultiplier. This mode was orginally designed but later abandoned because of the extremely low signal to noise ratio resulting from the reflected light from the plexiglas surface which is much higher than the backscattered Doppler signal.

In the forward scatter mode used, the photomultiplier (PM) tube is attached to a long bar which, in turn, fixed to the traversing system to compensate the movement of the beam intersection. (See Figure 2.5.)

The shifted Doppler signal is detected by the PM optics, transformed into current signal by the PM section, and then fed to the shifter for further processing.

A list of optical parameters is shown on Table 2.1.
Laser type: He-Ne $15\frac{1}{2}$ mW, polarized

Laser make: Spectral-physics, Model 124B

Wavelength, $\lambda$: 632.8 nm

Front lens type: DISA X57, Achromatic

Focal length, $f$: 310 mm

Focal length aperture, $D$: 79 mm

Beam diameter, $d$: 1.1 mm

Beam separation, $D$ (after beam expander): 25 mm

Expansion ratio, $E$: 1.9375

Half intersection angle, $\frac{\theta}{2}$ (in the air): 4.56 Deg.

Focused beam waist diameter, $d_f$: 0.1172 mm

Detector optics: imaging type with pinhole

Photodetector: Photomultiplier RCA 4526

Detector pinhole diameter, $r$: 0.1 mm

Probe volume diameters:

$2a = 1.475$ mm \hspace{1cm} (Convention as in Fig. 5.2)

$2b = 0.117$ mm

$2c = 0.117$ mm

Fringe spacing, $\delta_f$: 3.983 m

Fringe number, $N_f$: 15

Calibration factor, $C = \frac{\lambda}{2 \sin \left(\frac{\theta}{2}\right)}$: 3.983 ms$^{-1}$/MHz
2.4 DATA ACQUISITION AND ANALYSIS SYSTEM

2.4.1 Signal Nomenclature

The following symbols are used:

\( f_D \): Doppler frequency, directly proportional to particle velocity in the direction of measurement

\( f_o \): Optical frequency shift, introduced by Bragg cell \( (f_o = +40 \text{ MHz}) \)

\( f_d \): The detected frequency by PM tube

\( f_{lo} \): Electronic frequency shift, due to the local oscillator in the 55N10 DISA frequency shifter is consisted of two parts: \( (f_{lo} = 40 \text{ MHz} + f_s) \). The 40 MHz is to cancel out the optical shift \( f_o \), \( f_s \) is the net frequency shift.

\( f_t \): The tracker input frequency, also the shifter output frequency

2.4.2 Signal Processing Before Tracker

The frequency detected by PM is:

\[
\hat{f}_d = \left| f_d + f_o \right| \quad \text{(Eq. 2.1)}
\]

This signal is then fed to the frequency shifter where the electronic frequency shift is imposed.

Since \( f_o = 40 \text{ MHz} \) \& \( f_d > -40 \text{ MHz} \) all through the experiment, we have output from the shifter:
\[ f_T = |f_d - f_{ic}| = |f_0 - f_s| \quad \text{(Eq. 2.2)} \]

This signal is then fed into a DISA 55N20 frequency tracker.

2.4.3 Signal Processing In Tracker

Fig. 2.3 shows how signal is 'tracked' by a voltage controlled oscillator (VCO), and the various outputs of the tracker.
The core portion of a tracker is a phase lock loop whose task is to reproduce the original input signal while removing as much of the noise as possible.

A simplified phase lock loop is shown in Fig. 2.4. The input signal has a phase $\Theta_i(t)$ and the VCO output has a phase $\Theta_o(t)$. The two signals are compared in the phase detector and the 'error' signal, $\nu_d$, is produced proportional to the difference in phase between its inputs, i.e.:

$$\nu_d = k_d \cdot (\Theta_i - \Theta_o - \Phi) \quad \text{(Eq. 2.3)}$$

Where:

- $k_d$ = phase detector gain factor (volt/radian)
- $\Phi$ = the designed phase lag between $\Theta_i$ and $\Theta_o$

Phase error voltage, $\nu_d$, is filtered by a loop filter
where noise and high frequency signal components are suppressed and the control voltage, $V_c$ is produced.

The frequency of the VCO is controlled by $V_c$. We have:

$$\omega = k_0 \cdot V_c$$  \hspace{1cm} \text{(Eq. 2.4)}

where:

$k_0$ is the VCO gain factor (rad./sec. volt)

$\omega$ is VCO frequency (rad./sec.)

Eq. 2.4 can be rewritten as:

$$\frac{d\theta_c}{dt} = k \cdot V_c$$  \hspace{1cm} \text{(Eq. 2.5)}

Thus, by tracking the phase of input using output signal $\theta_i$, the VCO frequency is essentially the average frequency of the input signal when the loop is locked. Note that the time constant of the loop is so small that VCO frequency is actually an instant reflection of the input signal.

As shown in Fig. 2.3, the input signal is amplified and filtered leaving only frequencies in the set range before being fed into the phaselock loop. The 'SIN' output from the VCO is kept 90 degrees behind the input (i.e. $\phi = 90$ Deg.) when signal is locked, thus:

$$\int V_c \omega = \int T$$  \hspace{1cm} \text{(Eq. 2.6)}

is further processed in three ways:

(1) ANALOG OUTPUT
One branch goes through frequency-to-voltage (f/v) converter, output filter, sample β hold, and then output so that

$$V_{\text{analog \; out}} = \frac{10 V}{\text{RANGE}} \cdot f_T$$

--- (Eq. 2.7)

Where RANGE is the maximum frequency in the selected range.

(2) DIGITAL OUTPUT β DISPLAY MODULE

The second branch goes to the DIGITAL OUT Block (Fig. 2.3), where counting of the 'SINE' output of the VCO takes place at regular intervals.

The digital output is expressed as:

$$D = 2^{56} \cdot \frac{f_T}{\text{RANGE}}$$

--- (Eq. 2.8)

and is represented by an 8-bit word.

This signal was orginal used as a digital input to a PDP-11/34 minicomputer for data analysis but was substituted for by the analog output because of the non-functional serial buffer interface between the digital output and the computer.

The display module gets signal from the digital out. The following parameters are used to calculate
either the Doppler frequency or flow velocity:
a) net frequency shift \( f_s \), from shifter
b) frequency range \( R \), from front panel setting
c) calibration factor \( C \), from front panel setting

\[ C= \frac{\lambda}{2 \pi f_s} \text{ Display Doppler frequency} \]

\[ \text{Display velocity} \]

d) \( \frac{f_T}{f_D} \) setting, from front panel

When in \( f_T \) mode, \( f_s \) will be forced to be 0 in calculation.

e) \( f_D - f_s > 0 / f_D - f_s < 0 \) setting, from front panel

\[ f_D = f_s + f_T \text{ when } f_D - f_s > 0 \]

\[ f_D = f_s - f_T \text{ when } f_D - f_s < 0 \]

(3) LOCK DETECTOR

The third branch from VCO is presented in the 'COSINE' form. (i.e. \( \phi = 0 \) no phase lag to the input signal) This signal, together with a branch of the amplified input are first multiplied in a phase detector and then low-passed by a filter. The low-passed signal, \( \Delta V_L \) is compared with a preset reference level \( \Delta V_{LR} \) in the level detector. The result is:

(a) When \( \Delta V_s > \Delta V_{LR} \) the locked situation is determined.

The LOCK output will show a TTL logic 0
(b) When \( \Delta V_L < \Delta V_R \) the unlocked situation is determined and the LOCK output will show a TTL logic 1. If the lock detector indicates out of lock, the analog as well as the digit outputs will immediately be frozen.

When signal is out of lock, a search circuit, which is triggered by a delay circuit 500 VCO periods after the initial unlock, will assume \((i.e. \quad =1)\). The phaselock loop will be interrupted by an electronic contact at the input of the loop integrator. The 'search' block will send an N' signal of alternately -0.22 V and +0.22 V to the loop integrator thus forcing the VCO frequency going up and down in the selected range until an agreement between tracker input and the search frequency is reached. At this time the lock detector will resume locked and the phaselock loop will lock in again.

2.4.4 Signal processing After Tracker

The ANALOG OUT and the LOCK signals are drawn from tracker and fed into a Phoenix analog to digital converter whereby the 'data' enter computer. These data are analyzed by a FORTRAN subroutine, ANA.FTN and the mean velocity, root mean square fluctuation, turbulence intensity for the locked, unlocked, and combined situations are calculated.
2.5 THE TRAVERSING SYSTEM

2.5.1 GENERAL DESCRIPTION

The function of the traversing system is to:

1. carry the bifurcation and move it in Z-direction
2. carry the laser and optics system, including receiving PM, and have two-dimensional maneuverability on the system (X & Y directions)
3. perform automatic as well as manual positioning of the LDA system
4. display current position of LDA in XYZ system.

By combining (1) and (2), the laser 'probe' has actually three dimensional maneuverability.

The traversing system can be divided into three portions:

a) The mechanical portion & its power drive
b) The translater and the translater interface
c) The SDK-85 microprocessor controller and position display
2.5.2 THE MECHANICAL PORTION

Fig. 2.5 shows a pictorial sketch of the mechanical parts. Note the position of the bifurcation and laser optics.

The vital parts of the mechanical portion are the three sets of stepper motors and shaft encoders which are distributed to the three axes. Each axis is moved by a stepper motor of which the internal windings are sequentially energized by its power drive. Each axis has also a shaft encoder assembly which is an optical-incremental type and provides a digital pulse train to the SDK-85 controller.

The encoder consists of an encoder plate attaching to the shaft and the body of the encoder is mounted to a fixed location. A matched photodiode and LED is mounted on the body. With a 5-pitch-per-inch lead screw and the 200-slot encoder plate, the system accuracy is approximately within 0.002 inch.

The stepper motor type is M062-FD09 made by Superior Electric and the encoder is made by Vernitech for robotics industry.
FIG. 2.6 TRAVERSING SYSTEM BLOCK DIAGRAM

MAN OPERATOR

SDK-85
μ-PROCESSOR

POSITION READOUT

POSITION COMMAND (X, Y, Z)

PDP-11/34
MINI-COMPUTER

FRONT PANEL SWITCHES

TRANSLATOR INTERFACE CARD

CONTROL WORD

STATUS WORD

PULSE TRAIN

SHAFT ENCODER

TRANSLATOR MODULE

PULSOUT

TRANSLATOR SIGNALS

SEQUENTIAL CONTROL SIGNAL

POWER DRIVE

MOTOR
2.5.3 THE TRANSLATER AND THE TRANSLATER INTERFACE

A functional block diagram of the traversing system is given in Fig. 2.6.

The function of the translater is to provide a sequential control signal in order to energize the motor sequentially. There are a variety of selections for the sequential control. (See Appendix 3.) However, due to the software and hardware arrangement, only the following control mode is being used:

a) For manual control: Base speed & Run speed (High speed)

b) For automatic control: Base speed only

The translater interface is at the system site where the switching of signals from the SDK-85 or the manual switch array from front pannel switches and the gating of proper combination of these signals onto the translater card occur.

Refer to Fig. 2.6. The PULSE OUT signal, a pulse train generated by the internal oscillator in the translater, is 'gated', in the translater interface card, according to the control switch on the front panel or a control word from SDK-85, in the translater interface card. This pulse train, included in the translater control
signals, is then fed back to either CW PULSE or CCW PULSE on the translator board to determine the motor direction.

A list of control bits is given in Table 2.2. Note all signals are TTL compatible. (Also refer to Appendix 2, TRANSLATOR & TRANSLATOR INTERFACE CONNECTION DIAGRAM for better understanding.)
<table>
<thead>
<tr>
<th>BIT</th>
<th>NAME</th>
<th>DESCRIPTION</th>
</tr>
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<tbody>
<tr>
<td>AUTO/MAN</td>
<td>Switch on front pannel determining auto or manual mode</td>
<td></td>
</tr>
<tr>
<td>A0, A1</td>
<td>Address codes for translators and their corresponding motors</td>
<td>A1, A0= 0,0 axis 1 i.e. Z axis 0,1 axis 2 Y axis 1,0 axis 3 x axis</td>
</tr>
<tr>
<td>NC BASE</td>
<td>Base speed for auto mode</td>
<td></td>
</tr>
<tr>
<td>NC RUN</td>
<td>High speed for auto mode</td>
<td></td>
</tr>
<tr>
<td>NC CW</td>
<td>Clockwise rotation of motor, auto mode</td>
<td></td>
</tr>
<tr>
<td>NC CCW</td>
<td>Counterclockwise rotation, auto mode</td>
<td></td>
</tr>
<tr>
<td>MAN BASE</td>
<td>Base speed, manual mode</td>
<td></td>
</tr>
<tr>
<td>MAN RUN</td>
<td>High speed, manual mode</td>
<td></td>
</tr>
<tr>
<td>MAN CW</td>
<td>Clockwise rotation, manual mode</td>
<td></td>
</tr>
<tr>
<td>MAN CCW</td>
<td>Counterclockwise rotation, manual mode</td>
<td></td>
</tr>
<tr>
<td>RUN</td>
<td>Run speed, active low</td>
<td></td>
</tr>
<tr>
<td>BASE</td>
<td>Base speed, active low</td>
<td></td>
</tr>
<tr>
<td>CCW PULSE</td>
<td>Triggering pulses for counterclockwise rotation, gated from PULSE OUT</td>
<td></td>
</tr>
<tr>
<td>CW PULSE</td>
<td>same as CCW PULSE but for clockwise rotation</td>
<td></td>
</tr>
<tr>
<td>PULSE OUT</td>
<td>Triggering pulse train from built-in oscillator in translator</td>
<td></td>
</tr>
</tbody>
</table>
2.5.4 THE SDK-85 CONTROLLER AND POSITION READOUT

Except for the expansion area and the readout portion, the micro-processor is, in general, the same as a standard SDK-85 micro-processor. (Refer to SDK-85 system design kit, Users manual.)

The functions of the controller are to:

(1) Determine mode of operation (auto/manual) by reading front pannel switch settings.

(2) Accept manual move command from front pannel switches when in manual mode.

(3) Accept position command (in XYZ format) from a PDP-11/34 executive computer when in auto mode.

(4) Decode the position information and activate the translator control word to drive the motors accordingly.

(5) Monitor position via a feedback loop closed by shaft encoders during motor operation.

(6) Update current position to the front pannel LED position-readouts.

(7) Stop drives by resetting the translator control word when the system reaches the desired position.
The translator status word is hardware wired but is not used by the software program.

An analysis of the execution time shows that at a feedback loop execution time of 90 seconds, the software counter can track both base speed pulse train (600 step/sec) and high speed pulse train (3000 step/sec) without a loss of data pulse.

A schematic block diagram of the SDK-85 is given in Fig. 2.7. For completeness, the following information is included in the Appendices:

SDK-85 EXPANSION AREA SCHEMATIC—Appendix 1
I/O PORT β BIT ASSIGNMENT—Appendix 4
PIN ASSIGNMENT—Appendix 5
LED INTERFACE SCHEMATIC—Appendix 6
CHAPTER 3
THE COORDINATE SYSTEMS AND THE CALIBRATION

3.1 THE BIFURCATION

Fig. 3.1 shows the detail geometry of the bifurcation under investigation. The bifurcation was milled symmetrically out of two pieces of rectangular plexiglas.

The major axes are defined in the $\pi/2$ or $3\pi/2$ direction on each plane ($s=$ constant). These axes also fall on the plane of bifurcation. The minor axes are defined perpendicular to the corresponding major axis on the same $s$ plane. In other words, it falls on $=0$ or $\pi$ position.

The lung is positioned upside down to avoid accumulation of the small air entrainment at low speed running.
NOTE:
* DIMENSION SHOWN ONLY
THE STRAIGHT PORTION
INSIDE BIFURICATION PLATE
TOTAL STRAIGHT LENGTHS
ARE ABOUT 37" AND 20"

CURVATURE BEGINS AT
S = 0 AND ENDS AT
S = 1.429"
3.2 THE COORDINATE SYSTEMS DEFINITION

Since the traversing system can only travel in the Cartesian coordinates and the probe point in bifurcation is better expressed in a 'cylindrical' coordinates, The two coordinates must be well defined and their relationship be established.

Fig. 3.1 sketches the relation between the 'cylindrical' coordinates \((s, r, \Theta)\) for beam intersection and the Cartesian coordinates on the LDA \((X, Y, Z)\). The origin of \((s, r, \Theta)\) system is set right at center line spot where the curvature begins. The +s direction is defined as streamwise (actually tubewise) displacement toward downstream of the lung bifurcation. The straight lines \(\Theta = 0\) are defined normal to the plane of bifurcation and toward LDA system. (i.e. Parallel to and toward +X direction.)

The \((X, Y, Z)\) coordinates on the LDA is defined such that the traversing system is at its origin when the beam intersection is at the origin of the \((s, r, \Theta)\) system. The +Y direction is parallel to the line, \(\Theta = \pi/2\) on \(s=0\) plane.

The programmed transformation from \((s, r, \Theta)\) system to \((X, Y, Z)\) system is established through optical as well as geometrical relationship. Thus accurate and automatic positioning of the probe point becomes possible.

The transformation from \((s, r, \Theta)\) to \((X, Y, Z)\) is established in the following ways:
(1) Case 1, s=0: Z=0 and transformation is detailed in section 3.2.

(2) Case 2, s<0: Same as case 1 except z=s.

(3) Case 3, s>0:

(a) Transformation from (s, r, Θ) to (x'', y'', z'') is first made in the same way as case 1 by presuming (x', y', z') as (X, Y, Z).

(b) Transform (x'', y'', z'') into (x', y', z') through a rotation angle as shown in Fig. 3.1.

Note x''=x'=X in the case.

(c) Transform (x', y', z') into (X, Y, Z) through a pure translation.
FIG 3.2 DEFINITION OF THE COORDINATES
3.3 THE RELATION BETWEEN THE TWO COORDINATES

---WHEN TWO BEAMS ARE IN VERTICAL PLANES

Fig. 3.2 shows how the probe point \( P(0,r,\Theta) \) and the position of LDA \( (X,Y,0) \) are related.

The reference \( R \), imbedded in the LDA, is arbitrarily chosen and thus defines \( 2b \) and \( A \) which is the distance from the reference point to the plexiglas surface. It is defined that when \( P \) goes to \( C(0,0,0) \) in \( (s,r,\Theta) \) system, \( R \) goes to Cartesian origin and \( A \) becomes \( A_b \).

The following equations can be solved for \( \Theta_i \) and \( \Theta_o \):

\[
N_2 \sin \Theta_i = N_3 \sin \Theta_o \quad \text{----(Eq. 3.1)}
\]

\[
\frac{r}{\sin \Theta_o} = \frac{R}{\sin [\pi - (\Theta-o) - \Theta_b]} \quad \text{----(Eq. 3.2)}
\]
Figure 3.3 Relation between $(0,r,\theta)$ and $(x,y,0)$
where:

\( n_2 = \text{reflective index of plexiglas} \ (1.489) \)

\( n_3 = \text{reflective index of working fluid (water} \ 1.33) \)

\( \theta_i = \text{incident angle in horizontal plane} \)

\( \theta_o = \text{reflected angle in horizontal plane} \)

\( R = \text{internal radius of the tube} \)

Introducing \( \Delta = \theta - \theta_i \), we have:

\[
\theta_i = \sin^{-1} \left( \frac{n_3 \cdot R \cdot \sin \Delta}{n_2 \sqrt{R^2 \cdot \sin^2 \Delta + (R - R \cdot \Delta \cdot \cos \Delta)^2}} \right) \quad \text{(Eq. 3.3)}
\]

\[
\theta_o = \sin^{-1} \left( \frac{R \cdot \sin \Delta}{\sqrt{R^2 \cdot \sin^2 \Delta + (R - R \cdot \Delta \cdot \cos \Delta)^2}} \right) \quad \text{(Eq. 3.4)}
\]

An iteration program was made to solve for \( \theta_i \) and \( \theta_o \).

From this the cartesian position of the LDA can be calculated:

And:

\[
Y = R \cdot \sin \theta_i = \frac{R \cdot n_3 \cdot r \cdot \sin \Delta}{n_2 \sqrt{R^2 \cdot \sin^2 \Delta + (R - R \cdot \Delta \cdot \cos \Delta)^2}} \quad \text{(Eq. 3.5)}
\]

Further we have:

\[
F = r \cdot \cos \left( \frac{\pi}{2} - (\theta + \theta_o) \right) + R \cdot \cos \theta_o \quad \text{(Eq. 3.6)}
\]

\[
D = F \cdot \cos (\theta_o - \theta_i) \quad \text{(Eq. 3.7)}
\]

\[
t = D \cdot \tan \theta_3 \quad \text{(Eq. 3.8)}
\]

\[
e = C - R \cdot \cos \theta_i \quad \text{(Eq. 3.9)}
\]

\[
L = t + e \cdot \tan \theta_2 \quad \text{(Eq. 3.10)}
\]

\[
A = (B - L) \cdot \tan \theta_1 \quad \text{(Eq. 3.11)}
\]

\[
X = A - A_0 \quad \text{(Eq. 3.12)}
\]

\[
N_1 \cdot \sin \theta_1 = N_2 \cdot \sin \theta_2 = N_3 \cdot \sin \theta_3 \quad \text{(Eq. 3.13)}
\]
Solving for X:

\[
x = \left[ B - \left[ R_{\omega} - k R_{\omega} (\Theta + \epsilon_0) \right] \omega \left( \Theta_0 - \Theta_1 \right) \right] \frac{R_{\gamma} \sin \Theta_1}{\sqrt{R_{\gamma}^2 - R_{\beta}^2 \sin^2 \Theta_1}} \\
+ (C - R_{\omega} \cos \Theta_1) \frac{R_{\gamma} \sin \Theta_1}{\sqrt{R_{\gamma}^2 - R_{\beta}^2 \sin^2 \Theta_1}} \right] \tan \Theta_1 - A_0 \quad \text{(Eq. 3.14)}
\]

Where \( \Theta_1, \Theta_2, \Theta_3 \) are the incident and reflective angles in vertical plane and all symbols are as shown on Fig. 3.3.

3.4 A DISCUSSION FOR PROBE POINT IN THE CURVED PORTION

In the course of transformation from the \((s, r, \Theta)\) system to the \((X, Y, Z)\) system when \(s > 0\), we have added a combination of pure rotation and pure translation to the basic transformation of case 1. This is exactly true when the two beams hit the straight tube portion, assuming the tube is perfectly milled. However, an offset from the 'modeled' position to the true position exists. This section estimates the error and discusses the legitimacy of neglecting this offset in practice.

Different perspectives of the beam hitting on the curved portion of the plexiglas and water interface are shown in Fig. 3.4. Note the exaggerated comparison on the actual beam locus (solid lines) and the model one (double dotted lines). The offset PQ can be decomposed into PQ1 as shown in sideview 1 and PQ2 shown in front view. Fig. 3.5 clarifies the difference between the modeled half-intersection angle, \( \Theta_2 \) and the actual ones, \( \Theta_{2,1} \) and \( \Theta_{2,2} \) in two perpendicular planes.
Considering a unit incident beam IK and taking $\theta_2 = 4.56$ deg. = 0.079587 , we can approximate:

$$\beta \sim \frac{\theta_2 R}{DCC} = 0.57^\circ \quad (\text{Eq. 3.14})$$

Also we can approximate:

$$\text{where } R=0.375 \text{ in.} \quad :\text{ID of the tube}$$

$$\text{DCC=3 in.} \quad :\text{Distance from center of the cured portion to centerline of the tube.}$$

All symbols are as shown on the figures.

and,

$$\text{HK=DCC} \sin \beta = 0.0298''$$

Also: $\text{AD=}\cos \theta_2 \quad (\text{Eq. 3.15})$

$$\text{KD=}\sin \theta_2 \cos \beta \quad (\text{Eq. 3.16})$$

$$\text{AK=}\sqrt{\cos^2 \theta_2 + \sin^2 \theta_2 \cos^2 \beta} \quad (\text{Eq. 3.17})$$

$$\cos \left( \frac{\pi}{2} - \theta_{2l} \right) = \frac{AK^2 + kD^2 - AP^2}{2 \cdot AK \cdot kD} \quad (\text{Eq. 3.18})$$

So, $\theta_{2l} = 4.5598$ deg. by substituting $\theta_2$ & $\beta$ into (Eq.'s 3.15 & 3.18).

Therefore the offset from sideview 1 is

$$PQ_1 = (\cot \theta_{2l}, -\cot \beta) \cdot \text{HK}$$

$$= 0.000494''$$

and the offset from front view is

$$PQ_2 = \text{HK} \tan \left[ \arcsin \left( \frac{\gamma_1}{\eta_1} \sin \beta \right) - \beta \right]$$

$$= 0.0000354''$$

The conclusion is that the error is of order
3.5 POSITION CALIBRATION IN PRACTICE

In addition to the analytical analysis, a second bifurcation which has exactly the same geometry but contains only the vicinity of the bifurcation area was made to perform the experimental calibration.

Scale lines on a grid enscribed on a thin film was put in the second (along with the working fluid) tube to see if the beam crossing actually hits the calculated positions. Excellent agreement between the computed transformation and the actual positioning was confirmed.

To assure that centerline of the optics is perpendicular to the bifurcation plane, a thin flat mirror was stuck onto the plexiglas. The spot where the reflected laser beam hits on the focal lens was carefully examined to be in the correct position at all turning angles, and all positions of the optics assembly.

The displacement in +X direction on LDA system is measured when their corresponding probe point is translated, in +X direction, from centerline of the miniature to its outer flat surface. This physical displacement, which agrees with the calculated one, is then applied back on the bifurcation to locate its origin. A measured symmetric velocity profile on 2.5 inches upstream the origin further confirms the calibration.
3.6 CALIBRATION ON TRACKER OUTPUTS

The voltage from the analog output was supposed to be:

\[ V_{\text{analog \ out}} = \frac{10V}{K_{\text{analog}}} \cdot f_T \quad \text{(Eq. 2.8)} \]

A drift on the output voltage was found. Therefore, calibration was necessary before \( V_{\text{analog \ out}} \) could be further processed.

Based on the data shown on the tracker display module, which we found to be working correctly, the following listing shows the relation between the \( V_{\text{analog \ out}} \) and the calibrated analog output \( V_{\text{ana \ out}} \):

\[ V_{\text{ana \ out}} = b_1 \cdot V_{\text{analog \ out}} + b_0 \quad \text{(Eq. 3.17)} \]

Where \( b_1, b_0 \) are constants and were determined by linear regression fitting over the ranges.

\[
\begin{align*}
  b_1, b_0 &= 0.973459, -0.036448 \quad \text{for Range: } 1 \sim 10 \text{ MHz} \\
  &= 0.991966, -0.091971 \quad \text{for Range: } 0.3 \sim 3.3 \text{ MHz} \\
  &= 0.988761, -0.080598 \quad \text{for Range: } 0.1 \sim 1 \text{ MHz} \\
  &= 0.988288, -0.072361 \quad \text{for Range: } 33 \sim 333 \text{ KHz} \\
  &= 0.979682, -0.103719 \quad \text{for Range: } 10 \sim 100 \text{ KHz} \\
  &= 0.979710, -0.068719 \quad \text{for Range: } 3 \sim 33 \text{ KHz} \\
  &= 0.979661, -0.095801 \quad \text{for Range: } 1 \sim 10 \text{ KHz}
\end{align*}
\]

A similar calibration on the LOCK output is also included in the software program ATOD.FTN. The lock percentage is then decided as:

\[ \text{Lock} \% = (1.0143 - LV/4.38) \times 100\% \quad \text{(Eq. 3.18)} \]
Where $LV =$ voltage measured on LOCK output and we have used 0.07 volt for full lock indication and 4.95 volts for full unlock situation.
CHAPTER 4
THE SUPPORTING SOFTWARE PROGRAMS

There are two big programs performing automatic positioning of LDA, data acquisition, data analysis, coordinate transformation, and data recording:

(1) MOVE.SRC

This program on SDK-85 was written by Bryan Howe and is modified by the present investigator on the portion which communicates with PDP-11. A simplified flow chart of this program is given in Fig. 4.1.

(2) LUNG.FTN

This main program carries 6 subroutines functions which are delineated below:

PARAM.FTN: * Initialization of tracker parameters

* Select parameters for analog output calibration

CAL.FTN : * Transformation of \((s, r, \Theta)\) to \((X, Y, Z)\)

ATOD.FTN : * Calls ADPHX.MAC to sample data from analog-to-digit converter

* Transformation of sampled data to velocity

\[ \phi \]

\[ \text{lock percentage} \]

ADPHX.MAC: * Samples data from A/D converter

ANA.FTN : * Calculates mean velocity, RMS fluctuation, and turbulence intensity for the
locked, unlocked, and combined signals

TALK.FTN : * Communicates with MOVE.SRC on SDK-85

The \((X,Y,Z)\) were expressed in thousandth of inches when they are sending out.

A flow chart showing the overall algorithm is given in Fig. 4.2.
FIG. 4.1 FLOW CHART FOR MOVE.SRC

START

Initialize Hardware, Data Buffer

Auto/manual mode?

Auto

Message From PDP-11 Ready?

Yes

Receive Position Command From PDP-11

Convert ASCII Code to BCD

Move the Axes & Update Positions at Front Panel

No
FIG. 4.2 FLOW CHART FOR LUNG.FTN

Start

Open File for Analyzed Data
Call Assign (3,'LP:')
Call Assign (4,'TT4:')

Call PARAM.FTN

IOPT1 = 4?
Yes
No

Initialization for Data Sampling

IOPT1 = 3?
Yes
No

Initialization for Traversing System

IOPT1 = ?

1: Move Probe Point
2: Sample Data
3: Change Sampling Rate
4: Change Parameters
5: Print Out Data
6: Exit Program

Print Out Data
FIG. 4.2 FLOW CHART FOR LUNG.FTN (P.3)

Which System to go? \((s,r,\theta)/(X,Y,Z)\)

\((X,Y,Z)\) \n\nCall TALK.FTN
(Send Message to MOVE.SRC)

A

\n\nCall ATOD.FTN
Call ADPHX.MAC

A

To Analyze Data?

\n\nYes

Call ANA.FTN

\n\nNo

\n\nD

Close (UNIT=2)
Call Close (3, 'LP:')
Call Close (4, 'TY4:')

Stop
CHAPTER 5

THE MEASURING TECHNIQUES AND LIMITATIONS

5.1 THE SEEDING PARTICLES

Tap water was used as working medium. There are natural 'seeding' particles in it, however, to enhance the signal receptance, Alumina Trihydrate from Alcoa were added. Approximately one quarter of a teaspoon for 18 gallons of water. Composition of the seeding particles is listed in TABLE 5.1.
### Table 5.1 Composition of the Seeding Particles

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂O₃</td>
<td>65.0 %</td>
</tr>
<tr>
<td>SiO</td>
<td>0.01</td>
</tr>
<tr>
<td>FeO</td>
<td>0.004</td>
</tr>
<tr>
<td>NaO</td>
<td>0.15</td>
</tr>
<tr>
<td>NaO(soluble)</td>
<td>0.02</td>
</tr>
<tr>
<td>Moisture (110°C)</td>
<td>0.4</td>
</tr>
<tr>
<td>Density</td>
<td>2.42 g/cc</td>
</tr>
<tr>
<td>Average particle size:</td>
<td>6.5 - 8.5 μm</td>
</tr>
</tbody>
</table>

#### 5.2 Limitations on the Laser Anemometry

There are a few factors affecting the performance of the LDA system. This portion is to discuss specifically how much these factors affect our measurement.

1. **Temporal Resolution**

   The temporal resolution is limited from two sides:

   a. The limited ability of the seeding particles to adapt to flow velocity without significant lag. This becomes more difficult when the flow has very high fluctuation and short cycle time.

   b. The response time of the signal processor, the frequency tracker, in our case. The processor will not be able to detect the signal if the cycle time of the flow or the the
residence time of the particle is shorter than the minimum transit time of the processor.

Noel Nee (1982) in his thesis set a criterion for maximum particle size. He assumed that particles act like a linear first order system. Therefore, the particle time constant can be evaluated as:

\[ \frac{1}{\tau_P} = \alpha = \frac{\gamma \kappa}{a^2} \quad \text{----(Eq. 5.1)} \]

Where \[ \kappa = \frac{2}{3/\nu + 1} \approx 1.5 \]
\[ \alpha \] is a measure of maximum frequency that particle is able to respond without a significant lag.
\[ \rho = \text{density of the working fluid (} = 1 \text{ in our case)} \]
\[ \rho' = \text{density of the particle (} \approx 2.5 \text{ in our case)} \]
\[ \nu = \text{viscosity of the fluid (} \approx 0.95 \times 10^{-6} \text{ ft/sec)} \]
\[ a = \text{radius of the particle} \]

Since mean particle diameter is 6.5 \( \sim \) 8.5 \( \mu \text{m} \), we can conservatively pick \( a = 5 \ \mu\text{m} \). Then:

\[ \alpha = 52950 \ \text{sec}^{-1} \text{ or } \tau_P = 1.89 \times 10^{-5} \ \text{sec} \]

Considering the bifurcation region which is the only acceleration zone in our problem, we have:

\[ \omega = \frac{V}{R} \text{ Where } \omega = \text{angular velocity (sec}^{-1}) \]

Since has a dimension of sec\(^{-1}\), we can imagine the flow frequency is of order of \( \omega \).

Let \( V = V_{\text{max}} = 3.24 \ \text{m/sec} \), \( R = .375 \ \text{in.} \).
then:

\[ W \sim 340 \text{ sec}^{-1} \text{, or } \tau_f \sim 2.94 \times 10^{-3} \text{ sec} \]

Seeing that \( \lambda \gg W \), we definitely do not have the velocity lag problem. In fact the difference is so great that even reasonably intense secondary flow regions should be 'traded' satisfactorily.

A check on the other side of the problem shows that the tracker time constant is of order 10 \( \mu \) sec. This is also much much smaller than \( \tau_f \) thus it may be concluded that there is no problem here either.

(2) The Signal Drop Out Problem

Signal dropout is a common problem in the continuous LDA processing. The physical reasons for the dropout are as follows:

(a) The signal amplitude is too low due to:

aa) Particle concentration too low or particle size too small

bb) Poor S/N ratio

cc) Phase cancellation among the particles

(b) The particle transit time is much too short relative to the loop response time of the tracking type processor.

Buchhave etc. (1979), according to their analysis, concluded that if the dropout time is small compared to the
turbulence integral scale and the tracker holds the last value, as in our case, all the moments of the velocity will be conserved.

It is desirable that dropout be less than 10% if we want to conserve higher order moments in the case of high-turbulence measurement. However, if we can assume that the dropout rate is independent of the velocity of the fluid and sufficient averaging time is used, the first moment of the velocity will be conserved even if we have higher dropout time.

Since our major concern is the first moment velocity (the flow is laminar) and seeing that the dropout rate was kept under 20% throughout our measurement, we concluded no problem in this regard.

(3) Spatial Resolution Probe Volume

Probe volume is defined as the volume within the $1/e^2$ boundary of the optical fringe modulation. For laser beams which have Gaussian intensity profile, the probe volume is an ellipsoid as shown in Fig. 5.2.

The intensity can be formulated as

$$W(\bar{x}) = \frac{1}{(2\pi)^{\frac{1}{2}}} \frac{1}{\sigma_x \sigma_y \sigma_z} \exp[\left(- \frac{\bar{x}^2}{2\sigma_x^2} + \frac{y^2}{2\sigma_y^2} + \frac{z^2}{2\sigma_z^2} \right)]$$

(Eq. 5.3)

Where: $\bar{x} = (x, y, z)$ is the position vector and $\sigma_x, \sigma_y, \sigma_z$ are the standard deviations of the corresponding Gaussian distributions
The spatial resolution of the LDA depends on the probe volume. The selected probe volume must be smaller than the shortest wavelength of the velocity to be measured.

In the system we have:

\[ \begin{align*}
2a &= 4 \frac{\Omega_x}{a} = \frac{d_f}{\sin \theta / 2} \quad \text{(Eq. 5.4)} \\
2b &= 4 \frac{\Omega_y}{b} = d_f \quad \text{(Eq. 5.5)} \\
2c &= 4 \frac{\Omega_z}{c} = \frac{d_f}{\omega \theta / 2} \quad \text{(Eq. 5.6)} \\
d_f &= \frac{4}{\pi} \frac{f \lambda}{c d_1} \quad \text{(Eq. 5.7)}
\end{align*} \]

where all symbols are as shown in Table 2.1.

**FIG. 5.2 THE PROBE VOLUME**

(4) The Curvature Effect

The finite extension of the probe volume resulted in a spatial integration of the flow field. If the flow field is
not uniform in the probe volume, the measured data will be different from the velocity at the center point of the volume. This is known as the curvature effect. The following estimates the worst error in our case due to curvature effect.

For multi-particle flows, the continuous Doppler signal relates to the true velocity as follows:

$$\text{Um}(t) = \frac{1}{N(t)} \iint W(x) \ U(x, t) \ g(x) \ d^3x \quad \text{-----(Eq. 5.8)}$$

Where: $W(x)$, given in Eq. 5.3, is a weighting function referring to the shape of the measuring volume.

$N(t)$ is the instantaneous number of particles in the probe volume.

$\text{Um}(t)$ is the measured velocity.

$U(x, t)$ is the velocity at point $x$.

$g(x)$ is a function which accounts for the presence or absence of a particle at a location. ($g(x) = 1$, presence; $g(x) = 0$, absence)

To simplify the problem, let's consider only $U_x$ direction. Assuming the principal gradient of $U_x$ to be in the $z$-direction and taking the ensemble average yields we can rewrite

$$\bar{U}_x(t) = \int I(z) \bar{U}_x(z, t) \ dz \quad \text{-----(Eq. 5.9)}$$

where

$$I(z) = \frac{1}{\sqrt{2\pi \sigma_z^2}} \exp\left(-\frac{z^2}{2\sigma_z^2}\right) \quad \text{-----(Eq. 5.10)}$$
Note that in Eq. 5.10, we have taken the ensemble average so that \( N(t) \) and \( g(t) \) are no longer present.

In the bifurcation coordinates, let center point of the probe be at \( r = r_c \). Then, Eq. 5.10 becomes:

\[
U_{\xi}(r_c, t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} \exp\left[ -\frac{(Y-Y_0)^2}{2\sigma^2} \right] U_{\xi}(r, t) \, dr \quad \text{(Eq. 5.11)}
\]

By substituting \( U_m \) for \( U_{\xi} \), using a Tailor series expansion of \( U_m \), and neglecting higher order terms, we have

\[
U_m(r_c, t) = U(r_c, t) + \frac{\partial^2 U}{\partial r^2} (r_c, t) \quad \text{(Eq. 5.12)}
\]

where double prime denotes twice differentiation over the \( r \) direction.

Thus the error due to the curvature effect is

\[
\text{Err}(r_c) = \frac{\partial^2 U}{\partial r^2} \frac{U}{\bar{U}} \quad \text{(Eq. 5.13)}
\]

\[
= 0.1844 \bar{U} \quad \text{(U in mm/sec)}
\]

To have an idea of how big the error is, consider the entrance flow which is Hagen-Poiseuille profile:

\[
U(r) = \frac{\bar{U}}{\xi} \left[ 1 - (r/R)^2 \right] \quad \text{(Eq. 5.14)}
\]

Substituting into Eq. 5.13 and putting the numbers in yields

\[
\text{Err}(r_c) = -\frac{\partial^2 U}{\partial r^2} \frac{U}{\bar{U}} = -0.0016 \frac{U}{\xi} \quad \text{everywhere}
\]

We therefore conclude that, unless very close to the wall, the curvature effect is insignificant.
(5) Measuring Point Effect On Photodector

The measuring volume is defined as the region in the space from which Doppler signals are received and detected by the system. The following are the important factors affecting the measuring volume:

(a) wavelength and the geometry of the receiving optics such as F-number, f/D.

(b) photomultiplier gain

(c) the position and the focusd point of the PM optics

We now focus on the last item since it has certain effect on the measured data.

The detector, placed at a definite angle to the optical axis of LDA, cut out a section of the probe volume given by the intersection of the probe volume and the cone defined by the view field of the detector. Theoretically, the best signal is obtained when the center of the measuring volume coincides with the center of the probe volume. However, in practice, it is not easy to assure this point, especially when lock percentage is lower. We found, instead of a point, there is a small region around centerline of the probe volume in which, when the measuring point is located, the best signal can be obtained. This error, due to the offset of the measuring point, which is often neglected, may become significant with high velocity gradient. Sometimes, this may account to approximately 3% of the centerline velocity. Some detail as to how this number was achieved
may not be appropriate. The adopted data is then the mean value of the data taken at several spots inside the small region.

(6) Doppler Ambiguity

LDA measurement with continuous Doppler signals is always affected by the random dispersion of particles in the fluid and the resulting random phase fluctuations of the scattered light. This phenomenon creates an ambiguity in the velocity measurement. It also has a bandwidth broadening effect in the spectral analysis.

Fortunately, Doppler ambiguity does not significantly affect the measurement of the first moment which concerns us.
CHAPTER 6
DATA AND RESULTS

6.1 GENERAL DESCRIPTIONS

The flow was measured in detail at a Reynolds number of 320. It was found that flow pattern of 650 Reynolds number is very close to that of 320 Reynolds number based on measurement over several planes.

Measurement were taken on each 30° as well as 45° intervals. The interval in the radial directions is either 0.05 or 0.1 inch depending on local situations. Data points are up to r=0.35 inch and sometimes less because of the inavailability of signals. A list of measured plane is given in Table 6.1.

Because of the symmetrical geometry, the ensuing paragraphs refer only to the right-hand branch of the bifurcation.

6.2 EVOLUTION OF THE FLOW PATTERN

Fig. 6.1 shows that the entrance flow is pretty close to a fully developed Hagen-Poiseuille flow with peak velocity of 2.43 mm/s.

Because of the divider ahead, the profile is gradually suppressed around the centerline area thus making it flatter. (This suppression becomes farther-reaching with higher velocity. )
At $S/D=0$, Fig. 6.2, a 'shoulder' in minor axis (0-180) is being brewing. As the expansion space lies ahead in major direction (90-270), the pattern is flatter around centerline in this direction than in either 0-180 or 45-225 directions.

Patterns for plane $S/D=0.628$ are drawn on Fig. 6.4. Note that the centerline of the tube direction deviates from the centerline of the bifurcation by 0.04 inch at this location, and makes little velocity difference.

Flow patterns for $S/D=1.256$ and 1.565 are given in Fig. 6.5, 6.6, and 6.7. Note: (1) the 'shoulder' is becoming apparent in 180-0 direction, (2) offset of the centerline of the tube is significant and velocity shown is tubewise direction everywhere. (3) a second hump is brewing on the right end of the 90-270, 45-225, and 30-210 curves. (Compare to next few planes.)

Flow patterns right on the plane of the divider are given in Fig. 6.8, 6.9. Note the 'head' is further suppressed on 0-180 line. Because of the inertia, the high velocity is toward the inner wall of bifurcation and the 'head' on minor direction becomes lower. This inertia seems to be a source of secondary flow, measured by Olson(37), which comes from center vicinity toward 270 direction, i.e. inner wall of bifurcation, and bounds back along either side of the tube. The author believes that it is this secondary flow which makes (1) the 'shoulder' become stronger thus
overcome the 'head', and (2) the existence of the second hump near the outer wall of bifurcation on the planes of $S/D=2.548$ and $3.635$. (Fig. 6.10 to 6.12)

Figures 6.13 and 6.14 show profiles of $S/D=4.135$. Note that double humps are apparent in all directions and the flow peaks are going closer.

On the planes of $S/D=5.333$, 6.905 (Fig. 6.15, 6.16), the flow is gradually getting used to its new direction and is on its way toward a fully developed flow.

The flow patterns for the major and minor directions are given in Fig. 6.17, 6.18. Note the abrupt closing up as well as speeding up of the 90-270 peak to the inner wall and then gradually slowing down and returning to the centerline of the tube. Also note the boundary layer developing on the inner wall right after the flow divider.

A comparison of equal velocity lines showing the evolution of the wing-like contours is given in Fig. 6.19.

The results are summarized as follows:

(1) Inlet parabolic flow pattern at $s=-3$ in. ($S/D=-4$)
(2) Flow gradually retarded down near the center areas. This effect is less apparent in major direction than in the minor direction when it is in the expansion zone.
(3) Because of inertia, the high velocity is toward inner wall of bifurcation and a secondary flow is developed right after the divider. This secondary flow is going from center portion to the inner wall and
bounds back along both banks of the tube. (4) The head-down-shoulder-up pattern in 0-180 direction is because of retardation around center area and of the strong secondary flow mentioned in (3). (5) Instead of the usual slowing down, the peak velocity is first speeding up and moving toward the inner wall very fast right after the divider, and then gradually slowing down as well as moving toward the tube center. (6) A second hump is gradually formed after divider in all but minor direction. This is due to the secondary flow mentioned in (3) above.

6.3 A COMPARISON WITH OLSON'S DATA

Using a hot wire anemometer, Olson conducted an extensive measurement on several model lung bifurcations. Velocity profiles of the major direction for the condition closest to ours is given in Fig. 6.20. Note that Olson used mean velocity and radius in the parent and daughter branches to nondimensionalize velocities and radial lengths in the parent and daughter tubes respectively.

The differences between Olson's experiment and this work is noted in Table 6.2. As geometries of the two bifurcation is not totally comparable, similar nondimensionalization is not drawn to compare with Olson's figure.

Although there are quite a few differences, the results
bear the following similar trends:

(1) High velocity is toward inner wall of bifurcation and gradually moving toward center. (2) Second hump appearance and wing-like velocity profile exist after the flow divider.

The conclusion is: The difference in inlet pattern seems to matter little downstream of the divider, although it does dominate upstream the divider.


<table>
<thead>
<tr>
<th>S (in.)</th>
<th>S/D</th>
<th>(S/D)₀*</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3</td>
<td>-4</td>
<td>-5.905</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>-1.905</td>
</tr>
<tr>
<td>.471</td>
<td>.628</td>
<td>-1.277</td>
</tr>
<tr>
<td>.942</td>
<td>1.256</td>
<td>-0.649</td>
</tr>
<tr>
<td>1.174</td>
<td>1.565</td>
<td>-0.34</td>
</tr>
<tr>
<td>1.429</td>
<td>1.905</td>
<td>0</td>
</tr>
<tr>
<td>1.911</td>
<td>2.548</td>
<td>0.643</td>
</tr>
<tr>
<td>2.726</td>
<td>3.635</td>
<td>1.73</td>
</tr>
<tr>
<td>3.101</td>
<td>4.135</td>
<td>2.23</td>
</tr>
<tr>
<td>4</td>
<td>5.33</td>
<td>3.425</td>
</tr>
<tr>
<td>5.179</td>
<td>6.905</td>
<td>5</td>
</tr>
</tbody>
</table>

* OLSON'S EQUIVALENT (S/D). SEE NOTES ON TABLE 6.2.
TABLE 6.2

COMPARISON OF PARAMETERS FOR OLSON'S AND SHEU'S DATA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Olson's</th>
<th>Sheu's</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparatus type</td>
<td>Hot-wire</td>
<td>LDA</td>
</tr>
<tr>
<td>Mother tube size</td>
<td>$2\pi$ I.D.</td>
<td>$0.75\pi$ I.D.</td>
</tr>
<tr>
<td>Daughter tube size</td>
<td>$1.5\pi$</td>
<td>$0.75\pi$</td>
</tr>
<tr>
<td>Total branch angle</td>
<td>70 deg.</td>
<td>73 deg.</td>
</tr>
<tr>
<td>Curvature ratio*</td>
<td>1/7</td>
<td>1/8</td>
</tr>
<tr>
<td>Reynolds No. (mother)</td>
<td>468</td>
<td>(\sqrt{320})</td>
</tr>
<tr>
<td>Reynolds No. (daughter)</td>
<td>311</td>
<td>(\sqrt{160})</td>
</tr>
<tr>
<td>Position of origin**</td>
<td>0 at divider</td>
<td>0 at beginning of curvature</td>
</tr>
</tbody>
</table>

NOTE: * Curvature Ratio = (radius of mother tube)/(radius of centerline curve)

** \(S_0 + 1.429 = S\)

\[(S/D)_0 + 1.905 = (S/D)\]

where \(S_0\), \(S\)=tubewise displacement for Olson's and Sheu's system (in.)

\((S/D)_0\), \((S/D)\)=nondimensionalized tubewise displacement for the two systems
E = -3
v = -4
FIG 6.9  $S = 1.429$, $S/D = 1.905$.  

\[ x \quad 210 - 30 \\
\circ \quad 240 - 60 \]
\text{FIG. 6.10} \quad D = 1.92, \quad \frac{S_0}{D} = 2.5kPa
FIG. 6.11  \[ S = 2.726, \frac{S}{D} = 3.635 \]

\[(180-0, 270-90, 225-45)\]
FIG. 6.13: $S = 3.10^1$, $S' = 4.185$
FIG. 618  EVOLUTION OF PATTERNS IN
(1P, -1) DIRECTION
FIG. 6.19
EVOLUTION OF EQUAL VELOCITY CONTOURS

*Numbers shown are velocities in m/s*
FIG. 6.20

CLSON'S DATA ON MAJOR AXES

Numbers in parentheses are (3/5), numbers in brackets are (3/6) based on Sherwood system.
CHAPTER 7
CONCLUSION AND FURTHER INVESTIGATIONS

7.1 SUMMARY AND CONCLUSIONS

A forward scattered LDA system with frequency shifter and tracking type signal processor is used here to measure the flow field in a model lung bifurcation. The system was established so that probe positioning and data acquisition are controlled by a PDP-11/34 minicomputer and a SDK-85 microprocessor, thus making on-line measurement possible.

The tubewise component of the laminar flow pattern with parabolic inlet condition at about 320 Reynolds number is measured. The divider was found to have a very dominant effect around its vicinity and within five diameters downstream. A higher velocity was detected near the inner wall of bifurcation. The flow was found to have 'head-shoulder', 'second hump', and 'wing-like' features. These features are contributed by flow inertia and its consequential secondary flow acting on the flow divider. A comparison of the flow pattern in the major direction with Olson's 'hot-wire' data is made. The different situations between the two measurements are noted. Discrepancies in the inlet flow pattern have far less effect on the downstream flow than the divider does.
7.2 SUGGESTED FURTHER INVESTIGATIONS AND COMMENTS

The following paragraphs are comments and suggestions for further investigations:

(1) Velocity measurement on the other two directions:

Measurement on the primary component of the flow field has been carried out here. The other two components can be expressed in either radial/tangential or major/minor axes directions.

According to the present apparatus arrangement, only the directions lying on the plane perpendicular to the axis of optics assembly can be measured. Therefore only one more component can be measured in either choice of coordinates. The third component may be obtained analytically through the continuity equation.

Following a similar approach shown in section 3.2, it is possible to pinpoint the beam intersection inside the tube when two beams are in the plane perpendicular to the tube axis. Care shall be taken to examine the actual direction measured, because the beam crossing has, in most cases, been tilted by the curved interface.

(2) Measuring the pulsatile respiration:

Measurement on the pulsatile inspiration/expiration conditions can be achieved through the following additional measures:

a) Couple the four-way cock in the flow system to a
bi-directional motor and link the motor to the microprocessor through any unused port.

b) Include a counting loop in SDK-85 program and periodically reverse the flow direction by alternately rotating the motor. The period can be included in the command sent from PDP-11.

c) Handshakings between the PDP-11 and the SDK-85 shall be established.
APPENDIX 3

STEPPER MOTOR DRIVING MODE

The stepper motor is controlled by its corresponding STM 103 SLO-SYN translator module.

The three modes are as follows:

(1) Full Step With Two Windings On

This mode drives the motor in steps of 1.8 degrees. The motor windings are energized in the following sequence for clockwise rotation:

<table>
<thead>
<tr>
<th>SWITCHING STEP</th>
<th>MOTOR LEAD OR TERMINAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RED (1)</td>
</tr>
<tr>
<td>1</td>
<td>ON</td>
</tr>
<tr>
<td>2</td>
<td>ON</td>
</tr>
<tr>
<td>3</td>
<td>OFF</td>
</tr>
<tr>
<td>4</td>
<td>OFF</td>
</tr>
<tr>
<td>1</td>
<td>ON</td>
</tr>
</tbody>
</table>

(2) Full Step With One Winding On

This mode drives the motor in steps of 1.8 degrees. The motor windings are energized in the following sequence for clockwise rotation:

<table>
<thead>
<tr>
<th>SWITCHING STEP</th>
<th>MOTOR LEAD OR TERMINAL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RED (1)</td>
</tr>
<tr>
<td>1</td>
<td>OFF</td>
</tr>
<tr>
<td>2</td>
<td>ON</td>
</tr>
<tr>
<td>3</td>
<td>OFF</td>
</tr>
<tr>
<td>4</td>
<td>OFF</td>
</tr>
<tr>
<td>1</td>
<td>OFF</td>
</tr>
</tbody>
</table>
(3) Half Step (One Winding On)

This mode drives the motor in steps of 0.9 degree.

The motor windings are energized in the following sequence for clockwise rotation:

<table>
<thead>
<tr>
<th>SWITCHING STEP</th>
<th>RED (1)</th>
<th>WHITE/RED (2)</th>
<th>WHITE/GREEN (4)</th>
<th>GREEN (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>2</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>3</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>4</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>5</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>6</td>
<td>OFF</td>
<td>ON</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>7</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>8</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>1</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
</tbody>
</table>

NOTE: a) Only mode (3) was hardware wired.

b) *(1),(3),(4),(5) correspond to M1,M3,M4,M5 on translator module (See Appendix 2.)*

c) If necessary, the direction of motor rotation convention can be reversed by reversing the motor lead connections at terminals M4 and M5.
APPENDIX 4

I/O PORT & BIT ASSIGNMENT FOR MICROPROCESSOR

I/O PORT ASSIGNMENT:

(1) ON 8251A (USART):

  SYSTEM PORT #
  #10
  #11

FUNCTION
   I/O to PDP-11
   Command/Mode/Status reg.

(2) ON 8155A#1:

  SYSTEM PORT #
  #20
  #21 (port A)
  #22 (port B)
  #23 (port C)
  #24, 25

FUNCTION
   C/S Reg.
   unused
   unused
   pulse analysis reg.
   (receive pulse from encoder)
   timer used by system monitor
to support LED's & keypad

(3) ON 8155A#2:

  SYSTEM PORT #
  #28
  #29 (port A)
  #2A (port B)
  #2B (port C)
  #2C, 2D

FUNCTION
   C/S Reg.
   translator status reg.
   translator control reg.
   multipurpose reg.
   (only pulse train select used)
timer, baud rate sel. for USART
(4) ON 8255#1 TO #3:

SYSTEM PORT #

#A0, A1, A2 (P A, B, C)

#A3

#B0, B1, B2 (P A, B, C)

#B3

#C0, C1, C2 (P A, B, C)

#C3

FUNCTION

ports for LED display, axis #1 (on 8255#1)
control for 8255#1
ports for LED display, axis #2 (on 8255#2)
control for 8255#2
ports for LED display, axis #3 (on 8255#3)
control for 8255#3

BIT ASSIGNMENT:

(1) PULSE TRAIN REGISTER (23H)

PULSE TRAIN INPUT

(2) TRANSLATOR STATUS REG. (29H)

AUTO/MAN
CCW3
CW3
CCW2
CW2
CCW1
CW1

(3) TRANSLATOR CONTROL REG. (2AH)

A1
A0
NCCCW
NCCW
NCBASE
NCRUN
MULTIPURPOSE REG. (2BH)

- PULSE TRAIN SELECT B
- PULSE TRAIN SELECT A
- TOGGLE BUFFER ENABLE*
- TOGGLE CLK0*
- TOGGLE CLK1*
- TOGGLE CLK2*

* UNUSED
APPENDIX 5
PIN ASSIGNMENT

NOTE: This section lists detail pin assignment on translator interface card and the blue flat cable socket connecting SDK-85 and translator cage.

ON TRANSLATOR INTERFACE:

<table>
<thead>
<tr>
<th>PIN NO.</th>
<th>FUNCTION</th>
<th>PIN NO.</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A,B</td>
<td>+5V</td>
<td>C</td>
<td>A0</td>
</tr>
<tr>
<td>D</td>
<td>A1</td>
<td>E</td>
<td>NCRUN</td>
</tr>
<tr>
<td>F</td>
<td>NCCBASE</td>
<td>H</td>
<td>NCCW</td>
</tr>
<tr>
<td>blank</td>
<td>NCCCW</td>
<td>K</td>
<td>UNUSED</td>
</tr>
<tr>
<td>M</td>
<td>AUTO/MANUAL</td>
<td>N</td>
<td>MAN RUN</td>
</tr>
<tr>
<td>P</td>
<td>MAN BASE</td>
<td>R</td>
<td>MAN CW</td>
</tr>
<tr>
<td>blank</td>
<td>MAN CCW</td>
<td>T~blank</td>
<td>UNUSED</td>
</tr>
<tr>
<td>U,W,X</td>
<td>UNUSED</td>
<td>Y,Z</td>
<td>GROUND</td>
</tr>
<tr>
<td>1</td>
<td>RUN (TO TRANSLATOR)</td>
<td>2</td>
<td>BASE(&quot; &quot;&quot;&quot;)</td>
</tr>
<tr>
<td>3</td>
<td>CCW(&quot; &quot;&quot;&quot;)</td>
<td>4</td>
<td>CW(&quot; &quot;&quot;&quot;)</td>
</tr>
<tr>
<td>5</td>
<td>PULSE TRAIN (FROM TRANSLATOR)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ON FLAT CABLE SOCKET (CAGE END):

<table>
<thead>
<tr>
<th>PIN NO.</th>
<th>FUNCTION</th>
<th>PIN NO.</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1~6</td>
<td>+5V</td>
<td>7</td>
<td>A0</td>
</tr>
<tr>
<td>8</td>
<td>A1</td>
<td>9</td>
<td>NCRUN</td>
</tr>
<tr>
<td>10</td>
<td>NCCBASE</td>
<td>11</td>
<td>NCCW</td>
</tr>
<tr>
<td>12</td>
<td>NCCCW</td>
<td>13~18</td>
<td>STATUS REG.</td>
</tr>
<tr>
<td>19,</td>
<td>AUTO/MAN</td>
<td>20</td>
<td>MAN RUN 1</td>
</tr>
<tr>
<td>21</td>
<td>MAN BASE 1</td>
<td>22</td>
<td>MAN CW 1</td>
</tr>
<tr>
<td>23</td>
<td>MAN CCW 1</td>
<td>24</td>
<td>JOG(UNUSED)</td>
</tr>
<tr>
<td>25</td>
<td>PULSE TRAIN FROM ENCODER 1</td>
<td>26</td>
<td>MAN RUN 2</td>
</tr>
<tr>
<td>28</td>
<td>MAN BASE 2</td>
<td>29</td>
<td>MAN CW 2</td>
</tr>
<tr>
<td>30</td>
<td>MAN CCW 2</td>
<td>31</td>
<td>UNUSED</td>
</tr>
<tr>
<td>32</td>
<td>PULSE TRAIN FROM ENCODER 2</td>
<td>33</td>
<td>MAN RUN 3</td>
</tr>
<tr>
<td>35</td>
<td>MAN BASE 3</td>
<td>36</td>
<td>MAN CW 3</td>
</tr>
<tr>
<td>37</td>
<td>MAN CCW 3</td>
<td>38</td>
<td>UNUSED</td>
</tr>
<tr>
<td>39</td>
<td>PULSE TRAIN FROM ENCODER 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40~44</td>
<td>UNUSED</td>
<td>45~50</td>
<td>GROUND</td>
</tr>
</tbody>
</table>
APPENDIX 5
PIN ASSIGNMENT

NOTE: This section lists detail pin assignment on translator interface card and the blue flat cable socket connecting SDK-85 and translator cage.

ON TRANSLATOR INTERFACE:

<table>
<thead>
<tr>
<th>PIN NO.</th>
<th>FUNCTION</th>
<th>PIN NO.</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A,B</td>
<td>+5V</td>
<td>C</td>
<td>A0</td>
</tr>
<tr>
<td>D</td>
<td>A1</td>
<td>E</td>
<td>NCRUN</td>
</tr>
<tr>
<td>F</td>
<td>NCBASE</td>
<td>H</td>
<td>NCCW</td>
</tr>
<tr>
<td>blank</td>
<td>NCCCW</td>
<td>K</td>
<td>UNUSED</td>
</tr>
<tr>
<td>M</td>
<td>AUTO/MANUAL</td>
<td>N</td>
<td>MAN RUN</td>
</tr>
<tr>
<td>P</td>
<td>MAN BASE</td>
<td>R</td>
<td>MAN CW</td>
</tr>
<tr>
<td>blank</td>
<td>MAN CCW</td>
<td>T~blank</td>
<td>UNUSED</td>
</tr>
<tr>
<td>U,W,X</td>
<td>UNSED</td>
<td>Y,Z</td>
<td>GROUND</td>
</tr>
<tr>
<td>1</td>
<td>RUN(ETO TRANSLATOR)</td>
<td>2</td>
<td>BASE(&quot;&quot;&quot;&quot;)</td>
</tr>
<tr>
<td>3</td>
<td>CCW(&quot;&quot;&quot;&quot;)</td>
<td>4</td>
<td>CW(&quot;&quot;&quot;&quot;)</td>
</tr>
<tr>
<td>5</td>
<td>PULSE TRAIN (FROM TRANSLATOR)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ON FLAT CABLE SOCKET (CAGE END):

<table>
<thead>
<tr>
<th>PIN NO.</th>
<th>FUNCTION</th>
<th>PIN NO.</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-6</td>
<td>+5V</td>
<td>7</td>
<td>A0</td>
</tr>
<tr>
<td>8</td>
<td>A1</td>
<td>9</td>
<td>NCRUN</td>
</tr>
<tr>
<td>10</td>
<td>NCBASE</td>
<td>11</td>
<td>NCCW</td>
</tr>
<tr>
<td>12</td>
<td>NCCCW</td>
<td>13-18</td>
<td>STATUS REG.</td>
</tr>
<tr>
<td>19</td>
<td>AUTO/MAN</td>
<td>20</td>
<td>MAN RUN 1</td>
</tr>
<tr>
<td>21</td>
<td>MAN BASE 1</td>
<td>22</td>
<td>MAN CW 1</td>
</tr>
<tr>
<td>23</td>
<td>MAN CCW 1</td>
<td>24</td>
<td>JOG(UNUSED)</td>
</tr>
<tr>
<td>25</td>
<td>PULSE TRAIN FROM ENCODER 1</td>
<td>26</td>
<td>UNUSED 2</td>
</tr>
<tr>
<td>28</td>
<td>MAN BASE 2</td>
<td>29</td>
<td>MAN CW 2</td>
</tr>
<tr>
<td>30</td>
<td>MAN CCW 2</td>
<td>31</td>
<td>UNUSED</td>
</tr>
<tr>
<td>32</td>
<td>PULSE TRAIN FROM ENCODER 2</td>
<td>33</td>
<td>UNUSED</td>
</tr>
<tr>
<td>35</td>
<td>MAN BASE 3</td>
<td>36</td>
<td>MAN CW 3</td>
</tr>
<tr>
<td>37</td>
<td>MAN CCW 3</td>
<td>38</td>
<td>UNUSED</td>
</tr>
<tr>
<td>39</td>
<td>PULSE TRAIN FROM ENCODER 3</td>
<td>40-44</td>
<td>UNUSED</td>
</tr>
<tr>
<td>45-50</td>
<td>UNUSED</td>
<td>GROUND</td>
<td></td>
</tr>
</tbody>
</table>
COMMON /POS/N1,N2,N3,B,A0/CAL
COMMON /MAXMIN,XMIN,MAX,YMIN,YMAX,ZMIN,ZMAX/CAL
COMMON /SITE/,X,Y,Z,XT,XT1,XT11,XT2,XT21,XT3,YP,YP1,YP2,YP3
COMMON /ANGLES/THET1,THET2,THET3/CAL,PARAM
COMMON /XDATA,FACT,SHIFT,FRQ(T),DATA(T),VEL(T),CLOCK/PARAM,ATOD
COMMON /DATA1,ISIZE,DATA(1024)/ATOD,ANA
COMMON /PARAM,WAVE,WAVE(7),ISIGN,B1,B0/PARAM,ATOD
COMMON /INDEX,XCHAN,BRANCH,CHG2/CAL,ATOD,PARAM

CHG2 FOR SAMPLING PARAM's, i.e. SAMPLING RATE, # OF SAMPLE/CHAN.

COMMON /SAMPLE,CHAN1,NSAMPL,ICODE1,ICODE2,IFROM/ATOD,ANA

C***
COMMON S(3)
DIMENSION W(3)

C***
DIMENSION XLOCK(T),FRQ(T)
EQUIVALENCE (FRQ(1),FRQ(1))
EQUIVALENCE (DATA(1),DATA(1))
LOGICAL*1 ANS,BRANCH
INTEGER CLOCK

REAL N1,N2,N3
IPFRQ=0
CHG2='Y'
OPEN(UNIT=2,NAME='ANALY.DAT',TYPE='NEW',FORM='formatted')
DATA FILE FOR ANALYZED DATA.

CALL ASSIGN (3,'LF:')
CALL ASSIGN (4,'TT:')
WRITE (2,79) XMARK
79 FORMAT (I3,F7.2)

---- INITIALIZATION FOR OPTICAL & TRACKER PARAMETERS---
1050 TYPE *, Enter REFLECTIVE INDICES N1,N2,N3

THET1=.079512 !BEAM SEPARATION SET AT MIDDLE ON BEAM EXPANDER

THET1=11.5 SIN(THET1)*N1/N2
IF(TT1.GE.1)GO TO 333
XT1=TT1/SQRT(1-TT1**2)
THET2=ATAN(XT1)
TT2=5SIN(THET2)*N2/N3
IF(TT2.LT.1.0)GO TO 222

333 TYPE *, INCIDENT ANGLE TOO BIG. NO BEAM CROSSING EXIST.

TYPE *, Try changing THET1 or N3

222 XT2=TT2/SQRT(1-XT2**2)

XT2=TAN(THET2)
CALL PARAM
IF (IOPT1 .EQ. 4) GOTO 1100

C
C ---INITIALIZATION FOR DATA SAMPLING---

1040 WRITE(5,103)
103   FORMAT(/,' ENTER FIRST CHANNEL: ',*1)
      ACCEPT *,ICHAN1
      IF (ICHAN1 .GT. 10) GOTO 1040
      ICHAN=2
      ICODE=1

C ---INITIALIZATION FOR TRAVERSING SYSTEM (THEREAFTER REFERRED AS LDA)
XMIN=-6.
XMAX=6.
YMIN=-5.5
YMAX=5.5
ZMIN=-5.3
ZMAX=5.5
E=.9725
A0=11.69482

C
1100 WRITE(5,1001)
1001 FORMAT(/,' TYPE:  1 --TO RELOCATE PROBE PT.'
C   '/,8X,'2 --TO SAMPLE DATA',/,'8X,'3 --TO CHANGE SAMPLING RATE'
C   '/,8X,'4 --TO CHANGE OPTICAL OR TRACKER PARAMETERS',/
C   '/,8X,'5 --TO PRINT OUT THE ANALYZED DATA',/
C   '/,8X,'6 --TO EXIT PROGRAM',/) READ *,IOPT1
      TYPE *,!'ILLEGAL OPTION. TRY AGAIN!'
      GO TO 1100

1010 WRITE(5,880)
880 FORMAT(1X,'TYPE: X--TO GO ALONG WITH (X,Y,Z) SYSTEM ONLY.'
C   '/,7X,'R--TO RELOCATE PROBE WITH (STD,r,THETA) SYSTEM')
      ACCEPT 155,ANS
      IF (ANS .EQ. 'R') GOTO 1510
      IF (ANS .EQ. 'X') GOTO 1610
      GO TO 1010

1610 TYPE *,!'ENTER (X,Y,Z) in INCHES.'
      ACCEPT *,X,Y,Z
      GO TO 2222

1510 TYPE *,!'CHECK WHICH BRANCH TO BE LOCATED. [R/N/L]'
      ACCEPT 155,BRANCH
      CALL CAL

2222 IF (X .LT. XMIN .OR. X .GT. XMAX) GOTO 550
      IF (Y .LT. YMIN .OR. Y .GT. YMAX) GOTO 550
      IF (Z .LT. ZMIN .OR. Z .GT. ZMAX) GOTO 550

C** THIS PORTION TO BE DELETED
W(1)=X
W(2)=Y
W(3)=Z
NSTP=0
   DO 677 I=1,3
   IF (S(I) .LT. 0.0) GOTO 677
   IF (ABS(W(I)) .GT. ABS(S(I))) GOTO 129
   IF (ABS(W(I)) .GT. 20.0) GOTO 677
   IF (ABS(S(I)) .LT. 0.0999 .OR. ABS(S(I)) .LT. 0.0799) GOTO 677
      GOTO 766
   129 IF (ABS(S(I)) .LT. 0.20) GOTO 677
   IF (ABS(W(I)) .LT. 0.0999 .OR. ABS(W(I)) .LT. 0.0799) GOTO 677
   766 IF (S(I) .LT. 0.) W(I) = -0.5
      IF (S(I) .LT. 0.) W(I) = -0.5
      NSTP = 1
CONTINUE
IF(NSTP .NE. 1)GOTO 1100
WRITE(5,666)
666 FORMAT(1X,'***TO CONTINUE, HIT ANY KEY***','')
ACCEPT 153,ANS

CALL TALK(X,Y,Z)
GO TO 1100

C
43 TYPE *, 'ENTER FUNCTION SELECT VALUE: '
TYPE *, ' 1=INTERNAL 150 KHz CLOCK'
TYPE *, ' 2=EXTERNAL 150 KHz CLOCK'
TYPE *, ' 3=GENERAL GENERATION CLOCK'
ACCEPT *,ICODE2
IF(ICODE2 .EQ. 2)GOTO 63
IF(ICODE2 .NE. 4)GOTO 43

53 WRITE(5,143)
143 FORMAT(1X,'ENTER SAMPLING RATE--100KHz MAX: ',1X)
ACCEPT *,CLOCK
IF(CLOCK .GT. 100)GOTO 53

63 WRITE(5,153)
153 FORMAT(1X,'ENTER NUMBER OF SAMPLES/CHANNEL: ',1X)
ACCEPT *,NSAMPL
IF(NSAMPL .GT. 512)GOTO 63
CHG2='N'

1020 IF(CHG2 .EQ. 'Y')GOTO 43
C
---NBLOCS OF SAMPLING BEGINS---
CALL ATOD
IF(IERR .NE. 0)GOTO 1100
IF(CHG2 .NE. 'Y')GOTO 1025
GOTO 43

C
1025 TYPE *, 'WANT TO ANALYZE DATA? Y/N: '
ACCEPT 155,ANS
IF(ANS .EQ. 'N')GOTO 1100
CALL ANA
GO TO 1100

155 FORMAT(A1)
C
550 TYPE *

550 TYPE *, 'OUT OF MANIPULATION RANGE. TASK NEGLECTED.'
GO TO 1100

C
1800 REWIND 2
1810 READ(2,1700)X10
1700 FORMAT(1X,F7.2)
IF(X10 .EQ. XMARK)GOTO 1100
READ(2,800)X1,X2,X3,X4,X5,X6,D1 !X1--X10 & D1 ARE TEMPORARY MEMORY SPACES

800 FORMAT(1X,4F7.3,F6.3,F4.0,A1)
T800 WRITE(3,850)X1,X2,X3,X4,X5,X6,D1
850 FORMAT(1X,'(X,Y,Z)='F13.3,')', '('S,R,THET)=('F7.3,F6.3,F4.0
c ','X1,A1)
READ(2,900)X1,X2,X3,X4,X5,X6,X7,X8,X9
900 FORMAT(1X,2(E11.3,E11.3,E8.2),/),1X,E11.3,E11.3,E8.2,/
WRITE(3,950)X1,X2,X3,X4,X5,X6,X7,X8,X9,X10
950 FORMAT('LOCKED: VEL=','1PE11.3,' RMS FLUCT=','1PE11.3,
C TURB. INTEN.=','F8.2,/,' UNLOCKED: VEL=','1PE11.3,' RMS FLUCT=','
C ','1PE11.3,' TURB. INTEN.=','F8.2,/,' COMBINED: VEL=','1PE11.3,
C ',' RMS FLUCT=','1PE11.3,' TURB. INTEN.=','F8.2,' LOCK X=','F7.2,/)
GOTO 1810

2000 CLOSE(UNIT=2)
SUBROUTINE CAL.

COMMON /POSCAR/N1,N2,N3,E,A0
COMMON /SMLIN/SMIN,XMAX,YMIN,YMAX,ZMIN,ZMAX
COMMON /ANGLES/THET1,THET2,THET3
COMMON /INDEX/ANS,BRANCH,CHG2

REAL N1,N2,N3

LOGICAL*1 ANS,BRANCH

C=0.716
R=0.375
DCC=3

C---------WRITE (5,124)

WRITE (5,124)

124 FORMAT (1X,'ENTER NEW POSITION WITH FORMAT (S,R,THETA)'')

C

C---------NOTE : TWO WAYS ARE USED FOR DETERMINING THETI

C 1) ITERATED RECURSION  2) MULTIPLE SHOOTING (BACK & FORTH)

C AS 1) DOES NOT WORK FOR DTHETA BETWEEN <-65, +65> DEGREES FOR
C RD NEAR .375 (i.e. HIGHER r), (2) IS INTRODUCED FOR THIS REGION

REF=1.0
DEC=0.01
IND=0

IF (DTHETA.LT.295.) IND=1
IF (IND.EQ.0) GOTO 660

IF (DTHETA.LT.65.) GOTO 669

THETI=THET-8*ATAN(1.)-DEC

GOTO 100

THETI=THETI+DEC

GOTO 100

THETI=THETI-DEC

THETI=THETI/3.

DELTA=THETI-THETI

FF=RD*RD+R*R-2*R*RD*CO(S(DELTA))
F=SORT (FF)
FX=RD*SIN(DELTA)/F
TXF=FX/SORT (1-FX*FX)
THETO=ATAN (TXF)

SXI=N3*SIN (THETO)/N2

TXI=SXI/SORT (1-SXI*SXI)

THETI1=ATAN (TXI)

ABS=ABS (THETI-THETI1)

IF (ABS .LT. 0.0001) GOTO 200
IF(REF .LE. ABSS) DEC = -1*DEC/5.  'IF OVERSHOT, SHORTEN SHOOTING
" INTERVAL BY FIVE TIMES AND SHOOT BACKWARDS
C   REF=ABSS
" UPDATE REFERENCE VALUE BY ABSS
IF(DTHETA .LT. 65.) GOTO 670
IF(DTHETA .GT. 295.) GOTO 680
700
THETII = THETI
GO TO 100
200
YC = R*SIN(THETI)
E = C - R
'ONLY IN THE CASE Y=THETI=0
IF (THETI .NE. 0.00) E = C - YC*COS(THETI)/SIN(THETI)
D = F*COS(THETO-THETI)
SL = D*SIN(THET3)/COS(THET3)
YL = SL + E*SIN(THET2)/COS(THET2)
A = (B-YL)*COS(THET1)/SIN(THET1)
XC = A - A
YY = YC*COS(SKUW)
ZZ = -YC*SIN(SKUW)
IF(STD .GT. 0.637045*DCC) GOTO 1000
OVERY = 0.
OVERZ = 0.
GOTO 2000
1000
OVERY = (STD-0.637045*DCC)*ABS(SIN(SKUW))
OVERZ = (STD-0.637045*DCC)*COS(SKUW)
2000
OFFY = DCC*(1.-COS(SKUW))+OVERY
IF(BRANCH .EQ. 'L') OFFY = -1.*OFFY
OFFZ = DCC*ABS(SIN(SKUW))+OVERZ
Y = YY + OFFY
IF(STD .LE. 0.) Z = STD
IF(STD .GT. 0.) Z = ZZ + OFFZ
X = XC
C -------
C TYPE *, 'UPDATED POSITION:'
C TYPE 500, X, Y, Z, STD, BRANCH, DSKUW, RD, THET, DTHETA
500
FORMAT(' FOR LDA: X=', F7.3, ', Y=', F7.3, ', Z=', F7.3,
C ', ' FOR PROBE: S=', F7.3, ', A1=', F4.0, ', r=',
C F6.3, ' THET=', F7.4, ', RAD=', F4.0, ', DEG')
IF(RD .GT. R) TYPE *, 'WARNING: RADIAL DIST. out of range.'
RETURN
END
SUBROUTINE PARAM
COMM /PRAM/IRANGE, RANGE(7), ISIGN, B, Bo
COMM /DATA/FACT, SHIFT, FREQ(512), DATA(1024), CLOCK
COMM /ANGLES/THET1, THET2, THET3
COMM /INDEX/AN, BRANCH, CHG1, CHG2

LOGICAL*1 AN, BRANCH, CHG1, CHG2

RANGE(1) = 10.
RANGE(2) = 33.3333
RANGE(3) = 100.
RANGE(4) = 333.33
RANGE(5) = 1000.
RANGE(6) = 3333.3
RANGE(7) = 10000.

WAVELN=632.8

FACT = 1.E-3 * WAVELN / (2. * SIN(THET1))

TYPE *, 'Enter frequency shift in kHz.'
ACCEPT *, SHIFT

WRITE(5, 171)
170 FORMAT(' ENTER 1 --IF DOPPLER FREQ GREATER THAN OR EQUAL TO FREQ
* SHIF ', '/.' , ' 0 --IF DOPPLER FREQ LESS THAN FREQ SHIFT', ' /,*
**NOTE** COUNT FOR POSITIVE-NEGATIVE CONDITONS FOR BOTH FREQS')
ACCEPT *, ISIGN

IF(ISIGN .EQ. 0 .OR. ISIGN .EQ. 1) GO TO 2
TYPE *, 'INVALID NUMBER. TRY AGAIN!'
GO TO 170

2 TYPE *, 'Set the tracker range by entering:'
TYPE *, ' 1 :  1.0   -   10.  kHz'
TYPE *, ' 2 :  3.3   -   33.    ''
TYPE *, ' 3 : 10.0   -  100.    ''
TYPE *, ' 4 : 33.3  -  333.    ''
TYPE *, ' 5 :  0.1   -    1.0 MHz'
TYPE *, ' 6 :  0.33  -    3.3   ''
TYPE *, ' 7 :  1.0   -   10.0   ''

ACCEPT *, IRANGE

IF(IRANGE .GE. 1 .AND. IRANGE .LE. 7) GO TO 5
TYPE *, 'IMPROPER RANGE SETTING. TRY AGAIN.'
GO TO 2

5 GOTO (910, 920, 930, 940, 950, 960, 970) IRANGE

910 B1=.97986
B0=- .09580
GOTO 3

920 B1=.97971
B0=- .06872
GOTO 3

930 B1=.97968
B0=- .10372
GOTO 3

940 B1=.98829
B0=- .07236
GOTO 3

950 B1=.98876
B0=- .05060
GOTO 3

960 B1=.99197
B0=- .09197

!SEE ATOD.FTN FOR MEANING OF B1, B0
**NOTE:** THE READING FROM ANALOG OUTPUT PORT ON TRACKER IS CONSISTENTLY HIGHER THAN THE CORRESPONDING DIGITAL DISPLAY. IT WAS DETERMINED THAT ANALOG O/P SHOULD BE CORRECTED BY THE FOLLOWING EQ:

\[ Y = b_1x + b_0 \]

WHERE \( Y \) = CORRECTED ANALOG O/P (BASED ON DIGITAL DISPLAY)

\( x \) = THE MEASURED ANALOG O/P

\( b_1, b_0 \) = CONSTANTS FOR LINEAR REGRESSION

DECISION BASED ON: 1) THE PROVEN TRUTH OF LINEARITY BETWEEN \( x \) & \( y \)

2) THE DIGITAL DISPLAY ON TRACKER IS CONSISTENT BY ITSELF WHEN PLAYING AROUND WITH VARIOUS FREQ. SHIFT

3) COUNTER READING = C * TRACKER READING

WHERE \( C = 1.273 \) (ALWAYS)

4) TRACKER READOUT IS CONSISTENT WITH OSCILLOSCOPE

===================================

**SUBROUTINE ATOD**

COMMON /XDATA/FACT,SHIFT,FRQ(512),DATA(512),VEL(512),CLOCK
COMMON /DATA1/ISIZE,IDXAM(1024)
COMMON /PARAMS/MANAGE,RANGE(7),ISIGN,B1,B0
COMMON /INDEX/ANS,IRANGE,CHG2
COMMON /SAMPLE/ICHANS,ICHAN1,NSAMPL,ICODE1,ICODE2,IERR
DIMENSION XLOCK(512),FRQD(512)
EQUIVALENCE (FRQD(1),FRQT(1))
EQUIVALENCE (DATA1(1),XLOCK(1))
LOGICAL*1 ANS,IRANGE,FLNAME(20)
INTEGER CLOCK
DATA 1010,KB,FLNAME(20)/1,15,1,FALSE,
ISIZE = 1024

IF(ICODE2 .EQ. 4) GO TO 999
TYPE *, 'SAMPLING RATE = 150 Khz'
GOTO 1010
999 WRITE(5,1000)CLOCK
1000 FORMAT(1X, 'SAMPLING RATE=', 1X, 13)
1010 TYPE *, 'No. OF SAMPLES/CHANNEL= ', NSAMP
TYPE *, 'ARE YOU HAPPY WITH THIS? Y/N'
ACCEPT 220, ANS
IF(ANS .EQ. 'Y') GOTO 1020
1040 CHG2 = 'Y'
 !CHG2=Y TO CHANGE SAMPLING PARA.
RETURN
1020 IERR = 0
CALL ADPHX(ICHANS, ICHAN1, NSAMP, ICODE1, ICODE2, IERR)
IF(IERR .NE. 0) GO TO 500
N = ICHANS*NSAMP

TYPE *, 'ANA O/P(V) FREQ(KHz) VEL(M/S) LOCK'
DO 1050 I = 1, N/2
80 DATA(I) = 10. * FLOAT(IDATA(2*I-1))/FLOAT('37777')
C !DATA(I)=ACTUAL VOLTAGE MEASURED (FOR VEL SIGNAL)
TYPE *, 'ANA O/P = ', DATA(I)
DATA(I) = D1*DATA(I) + B0 'CORRECTED ANALOG O/P FROM TRACKER
TYPE *, 'CORRECTED ANALOG O/P = ', DATA(I)
FRQT(I) = DATA(I)*RANGE / (IRANGE) / 10. 'TRACKER I/P FREQ.'
TYPE *, 'FRQT=', FRQT(I)
IF(ISIGN .EQ. 0) FRQD(I) = SHIFT - FRQT(I) !WHEN FsubD<SHIFT
IF(ISIGN .EQ. 1) FRQD(I) = SHIFT + FRQT(I) !WHEN FsubD>SHIFT
VEL(I) = FACT*FRQD(I)/1000
 !DOPPLER FREQ SHOULD BE IN MHZ
 ! IN ORDER TO GET VEL IN m/sec
C  !LOCK SIGNAL OUTPUT
XLOCK(I)=1.0143443-XLOCK(I)/4.88 !1=FULL LOCKED ,0=FULL UNLOCKED
C  !LOCK VOLTAGE RANGE: <,.07,4.95>
IF(XLOCK(I) .GT. 1.)XLOCK(I)=1.0
IF(XLOCK(I) .LT. 0.)XLOCK(I)=0.0
WRITE(5,3100)DATA(I),FRD(I),VEL(I),XLOCK(I)
3100  FORMAT(3X,F6.2,6X,1PE11.3,3X,1PE11.3,9X,F4.2)
1030  CONTINUE

C
90  WRITE(5,190)
190  FORMAT(1X,'DO YOU WISH TO TAKE MORE DATA ? [Y/N]: ',*)
     ACCEPT 220,ANS
     IF(ANS .EQ. 'N') RETURN
     WRITE(5,200)

200  FORMAT(1X,'DO YOU WISH TO CHANGE PARAMETERS ? [Y/N]: ',*)
     ACCEPT 220,CHG2
     IF(CHG2 .EQ. 'Y') RETURN
     GOTO 1020

C
500  IF(IERR .EQ. 1)TYPE *, 'POWER NOT ON TO A/D.'
     IF(IERR .EQ. 2)TYPE *, 'A/D REMOTE SWITCH NOT SET.'
     IF(IERR .EQ. 3)TYPE *, 'FHEONIX IS NOT RESETING C
(DSTAT C not clearing)
     IF(IERR .EQ. 4)TYPE *, 'TOO MANY SAMPLES REQUESTED.'
     IF(IERR .EQ. 4)GOTO 1040
     IF(IERR .EQ. 5)TYPE *, 'ILLEGAL FUNCTION BITS (DSTAT C SET)'
     TYPE *, 'DO YOU WANT TO TRY AGAIN ?'
     WRITE(5,210)
210  FORMAT(1X,'TYPE [Y/N] WHEN READY.',*)
     ACCEPT 220,ANS
220  FORMAT(A1)
     IF(ANS .EQ. 'Y')GO TO 1020
     RETURN
END
This is a driver for the TRL Phoenix A/D converter which is designed for use with RSX-11 in a mapped system. It assumes that the memory management registers and the DMA registers can be accessed through a device partition which must be included in the LINK instructions.

This program must be called by a Fortran program containing the following COMMON BLOCK and CALL statements:

```fortran
CALL ADPHX(ICHANS,ICHAN1,NSAMPL,ICODE1,ICODE2,IERR,CLOCK)
```

where

- `ICHANS` = number of channels
- `ICHAN1` = first channel in scan
- `NSAMPL` = number of samples/channel
- `ICODE1` = 1 for single word transfer, 0 for double word transfer
- `ICODE2` = 2 for internal clock, 3 for external clock, 4 for software clock
- `IERR` = 0 if all OK, 1 if power off, 2 if A/D not in remote mode, 3 if Phenix not resetting properly, 4 if too many samples, 5 if illegal function bits
- `CLOCK` = software clock count down word

The common block is defined by

```fortran
COMMON / DATA1 / ISIZE, IDATA
```

This program was written by Scott Woodward for general use. DLS, 7/19/83

```
.TITLE ADPHX

.GLOBL ADPHX,LKS
.GLOBL DRWC,DRBA,DRST,DRDB
.GLOBL PARU0,PARU1,PARU2,PARU3
.GLOBL PARU4,PARU5,PARU6,PARU7

.PSEG DATA1,D,GBL,OVR
ISIZE: .BLKW 1
IDATA: .BLKW 1
.PSEG

STORE REGISTERS ON STACK

ADPHX: MOV R0,-(SP)
       MOV R1,-(SP)
       MOV R2,-(SP)
       MOV R3,-(SP)
       MOV R4,-(SP)

GET ARGUMENTS

       MOV @2(R5),ICHANS ;NUMBER OF CHANNELS
       MOV @4(R5),ICHAN1 ;FIRST CHANNEL
       MOV @6(R5),NSAMPL ;NUMBER OF SAMPLES/CHANNEL
       MOV @10(R5),ICODE1 ;DOUBLE/SINGLE WORD CODE
```
MOV COUNTER, #0012 ;CLOCK MODE
MOV @14(R5), #0001 ;CLOCK COUNT DOWN WORD
MOV NSAMPL, NSAMPL ;DUPLICATE NUMBER OF SAMPLES FOR LATER USE

RESET PHOENIX AND DISABLE LINE CLOCK

CLR LKS ;DISABLE LINE CLOCK, NO INTERRUPTS
MOV #1, DRST ;RESET PHOENIX

CHECK IF PHOENIX IS WORKING PROPERLY

MOV DRST, #0 ;GET STATUS WORD
BIT #2000, #0 ;CHECK FOR POWER ON
BNE SKIP

JMP ERR1 ;IF NOT SET BRANCH

SKIP: BIT #4000, #0 ;CHECK IF REMOTE
BEQ SKIP2

JMP ERR2 ;IF SET BRANCH

SKIP2: BIT #1000, #0 ;ILLEGAL FUNCTION BITS
BEQ SKIP3

JMP ERR3 ;PHENIX IS NOT RESETTING PROPERLY

SKIP3: MOV ICHANS, #0
MOV NSAMPL, R1
MUL R0, R1 ;REQUIRED MEMORY
MOV R1, NSAMPL ;STORE IN NSAMPL
TST ICODE1 ;CHECK IF DOUBLE WORD
BNE FLAG1 ;SKIP IF SINGLE WORD

ASL NSAMPL ;DOUBLE NUMBER

FLAG1: CMP ISIZE, NSAMPL ;CHECK IF ARRAY BIG ENOUGH
BGT SKIP4 ;IF NOT BRANCH

JMP ERR4 ;IF NOT BRANCH

SKIP4: NEG NSAMPL ;2'S COMPLEMENT
MOV NSAMPL, DWRC ;LOAD WORDCOUNT REGISTER

DETERMINE ABSOLUTE ADDRESS OF IDATA

Determine Displacement in Blocks (DIB)

MOV #IDATA, R3 ;Get virtual address
BIC #177700, R3 ;Keep 6 lowest bits. DIB in R3

Determine Block Number (BN)

MOV #IDATA, R4 ;Get virtual address again
BIC #160077, R4 ;Keep bits 6 - 12
ASL R4 ;Prepare for shift right

ASL R4 ;
SWAP R4 ;Finish shift right. BN in R4.

Determine Active Page Field (APF)

MOV #IDATA, R1 ;Get virtual address again
BIC #17777, R1 ;Keep bits 13 - 15
TST R1 ;Clear carry bit
ROL R1 ;Start shift to bits 0 - 2
ROL R1 ;Remember carry bit
ROL R1 ;is included.
ROL R1 ;Finished. APF in R1.

Determine Physical Address Register (PAR)

MOV PAR0,(R1), R1
ADD R1, R1 ;Construct Physical Block Number
GET TWO MSB'S FOR STATUS REGISTER

MOV R4,R2 ;SETUP STATUS WORD IN R2
BIC #1171777,R2 ;CLEAR ALL BUT 2 MSB'S
SWAB R2 ;PREPARE SHIFT TO BITS 4 & 5
ASL R2
ASL R2 ;DONE BUT STILL NEED FUNCTION

FINISH UP AND LOAD ADDRESS REGISTER

ASL R4 ;Need to shift to bits 6 - 17
ASL R4
ASL R4
ASL R4
ASL R4
ASL R4 ;Finished with 6 left shifts
ADD R3,R4 ;Add DIB to get Physical Address
MOV R4,DRBA ;Load Address Register in DMA

SETUP AND LOAD PHOENIX DATA WORDS

CLR R0 ;PREPARE R0 FOR DATA WORD
TST ICODE1 ;SINGLE OR DOUBLE WORD
BEQ FLAG2 ;IF DOUBLE SKIP
BIS #1000000,R0 ;BIT 15 SINGLE/DUPLICATE 1 - SINGLE WORD
BIS #7000000,R0 ;BIT 14 SEQUENTIAL SRT PNT 1 PROG START CHAN
ADD ICHAN1,R0 ;ADD START CHANNEL
MOV R0,DRDB ;LOAD DATA BUFFER REGISTER
MOV #3,DRST ;STROBE PHOENIX

FLAG2: MOV R0,DRDB ;FIRST STROBE LOADS THE FIRST CHANNEL ADDRESS
MOV R0,DRDB ;SECOND STROBE LOADS THE LAST CHANNEL ADDRESS
CMP #1,ICHA5 ;IF BIT 12 RAND/SEQU IS 0-SEQUENTIAL.
BEQ FLAG3 ;ONE EACH CTC WILL CONVERT CHANNEL JUST LOADED
BIC #10017,R0 ;CLEAR BITS 0 - 3 AND 12
ADD ICHAN1,ICHA5 ;DETERMINE LAST CHANNEL PLUS ONE
DEC ICHA5 ;SUBTRACT THE ONE
ADD ICHA5,R0 ;ADD LAST CHANNEL
MOV R0,DRDB ;LOAD DATA BUFFER REGISTER AGAIN
MOV #3,DRST ;STROBE PHOENIX

FLAG3: MOV ICODE2,R4 ;GET CLOCK CODE
ASL R4 ;SHIFT TO FUNCTION BITS (1-3)
INC R4 ;ADD #1 FOR GO BIT
ADD R4,R2 ;R2 CONTAINS 2 MSB OF DATA BUF + FUNC & GO BITS
CMP ICODE2,#4 ;BRANCH TO SOFTWARE CLOCK ROUTINE
BEQ SFCLK ;IF ICODE2 = 4
MOV R2,DRST ;TELL PHOENIX TO GO

WAIT: MOV DRST,R0 ;LOAD STATUS REG TO
BIT #200,R0 ;CHECK READY BIT 7
BEQ WAIT ;DONE WHEN SET
BR DONE

SOFTWARE CLOCK TIMING LOOP

SFCLK: MOV R2,DRST ;TELL PHOENIX TO SAMPLE
DEC NSMPL ; KEEP TRACK OF SAMPLES TAKEN
BMI DONE ; LOAD COUNT DOWN WORD
TIMELP: DEC R0 ; WAIT LOOP
BR TIMELP ; CONTINUE WAITING
;
DONE: MOV DST,R0 ; LOAD STATUS REG
BIT #1000,R0 ; CHECK FOR ILLEGAL FUNCTION BITS
BNE ERR5 ; IF DSTAT C IS SET BAD FUNC BITS
BR FLAG4 ; SKIP IF OK

ERR1: MOV #1,IERR ; POWER OFF
BR FLAG4
ERR2: MOV #2,IERR ; REMOTE NOT SET
BR FLAG4
ERR3: MOV #3,IERR ; PHENIX NOT CLEARING DSTAT C ON RESET
BR FLAG4
ERR4: MOV #4,IERR ; TOO MANY SAMPLES
BR FLAG4
ERR5: MOV #5,IERR ; ILLEGAL FUNCTION BITS
;
FLAG4: MOV #100,LKS ; RESTORE LINE CLOCK
MOV (SP)+,R4
MOV (SP)+,R3
MOV (SP)+,R2
MOV (SP)+,R1
MOV (SP)+,R0
MOV IERR,E14(R5) ; RETURN ERROR CODE TO PROGRAM
RTS PC ; GO BACK TO MAIN

ICHANS: .WORD 0
ICHAN1: .WORD 0
NSAMPL: .WORD 0
NSMPL: .WORD 0
ICODE1: .WORD 0
ICODE2: .WORD 0
IERR: .WORD 0
CLOCK: .WORD 0

.END
SUBROUTINE ANA
COMMON /DATA/FACT, SHIFT, FRot(512), DATA(512), VEL(512), ...
COMMON /DATAI/ISIZE, IDATA(1024)
COMMON /SAMPLE/ICHAINS, ICHAIN,NUM,ICODE1, ICODE2, INRX
COMMON /SIE/Vx, y, z, u, v, w, o, THERMAL, SKWSTD, XMARK
COMMON /INDEX/INDEX, INDEX, CHG2
LOGICAL ANS, BRANCH
DIMENSION XLOCK(512)
EQUIVALENCE (IDATA(1), XLOCK(1))
DOUBLE PRECISION DVEL, SVEL, TVL, TVUL, TV, TVSL, TVSUL, TSV
DOUBLE PRECISION AVL, AVUL, AV, ASVL, ASVUL, ASV
TSVL = 0. ! TOTAL SQUARE VEL, LOCKED
TVL = 0. ! TOTAL VEL, LOCKED
TVUL = 0. ! TOTAL VEL, UNLOCKED
TSVUL = 0. ! TOTAL SOR. VEL, UNLOCKED
TV = 0. ! TOTAL VEL LOCKED & UNLOCKED
TSV = 0. ! TOTAL SOR VEL LOCKED & UNLOCKED
LOK = 0 ! NUMBER OF LOCKED VEL
TLOCK = 0.

DO 100 I = 1, NUM ! NUM = NO. OF SAMPLES
   DVEL = VEL(I) ! CONVERT INTO DOUBLE PRECISION TO AVOID!
                ! TRUNCATION ERROR WHEN VEL**2 OCCURS.
   C IF(XLOCK(I) .LT. 0.5) GOTO 1000
   LOK = LOK + 1
   TVL = TVL + DVEL
   TVUL = TVUL + DVEL**2
   GOTO 1100
1000
   TVUL = TVUL + DVEL
   TSVUL = TSVUL + DVEL**2
   C TV = TV + DVEL.
   TSV = TSV + DVEL**2
   TLOCK = TLOCK + XLOCK(I)
100 CONTINUE

C --- Compute mean quantities ---
C --- FOR LOCKED & UNLOCKED DATA ---
AV = TV / NUM ! AVG. VEL, LOCKED & UNLOCKED
ASV = TVS / NUM ! AVG. SOR. VEL, COMBINED
ASF = ASV - AV**2 ! AVG. SOR. FLUCT. VEL, COMBINED
RMS = SQRT(ASF) ! RMS FLUCT. VEL, COMBINED
TRBI = 100.*RMS / ABS(AV) ! TURBULENCE INTENSITY (%), COMBINED
C --- FOR LOCKED DATA ---
IF (LOK .EQ. 0) GOTO 600 ! IF NO LOCK AT ALL OMIT IT!
AVL = TVL / LOK ! AVERAGED VEL, LOCKED (i.e. 'MEAN' VEL)
ASVL = TVSL / LOK ! AVG. SOR. VEL, LOCKED
ASFL = ASVL - AVL**2 ! MEAN SOR. FLUCT. VEL, LOCKED
RMSL = SQRT(ASFL) ! ROOT MEAN SOR. FLUCT., LOCKED
TRBIL = 100.*RMSL / ABS(AVL) ! TURBULENCE INTENSITY (%), LOCKED
C --- FOR UNLOCKED DATA ---
IF (NUM .EQ. LOK) GOTO 700 ! ALL LOCKED, OMIT THE UNLOCKED

600
AVUL = TVUL / (NUM - LOK) ! AVG. VEL, UNLOCKED
ASVUL = TVSUL / (NUM - LOK) ! AVG. SOR. VEL, UNLOCKED
ASFUL = ASVUL - AVUL**2 ! AVG. SOR. FLUCT. VEL, UNLOCKED
RMSUL = SQRT(ASFUL) ! RMS FLUCT. VEL, UNLOCKED
TRBIUL = 100.*RMSUL / ABS(AVUL) ! TURBULENCE INTENSITY, UNLOCKED
C
C
700
PLock = 100.*TLOCK / NUM ! LOCK PERCENTAGE
WRITE(5, 200)
200 FORMAT(10X, 'MEAN VEL m/s RMS FLUCT. TURB. INTENSITY %')
WRITE(5, 250)
250 FORMAT(1X, '------------------------')
IF (LOK .EQ. 0) GOTO 610
WRITE (5, 300) AVL, RMSL, TRBIL
   FORMAT (' LOCKED   ', 1PE11.3, 3X, 1PE11.3, 7X, F8.2, ' %')
WRITE (5, 250)
C
IF (NUM .EQ. LOK) GOTO 710
WRITE (5, 400) AVL, RMSL, TRBIUL
   FORMAT (' UNLOCKED  ', 1PE11.3, 3X, 1PE11.3, 7X, F8.2, ' %')
WRITE (5, 250)
C
WRITE (5, 450) AV, RMS, TRBI
   FORMAT (' COMBINED  ', 1PE11.3, 3X, 1PE11.3, 7X, F8.2, ' %')
WRITE (5, 250)
C
WRITE (5, 500) PLOCK
   FORMAT (' LOCK PERCENTAGE = ', F7.2, ' %')
WRITE (5, 190)
   FORMAT (1X, 'DO YOU WANT TO STORE THE DATA? [Y/N]')
ACCEPT 155, ANS
155 FORMAT (A1)
   IF (ANS .EQ. 'N') RETURN
BACKSPACE 2
WRITE (2, 800) PLOCK, X, Y, Z, STD, RD, DTHETA, BRANCH
   FORMAT (1X, F7.2, /, 1X, 4F7.3, F6.3, F4.0, A1)
WRITE (2, 810) AVL, RMSL, TRBIL, AVL, RMSL, TRBIUL, AV, RMS, TRBI
WRITE (2, 79) XMARK
79 FORMAT (1X, F7.2)
RETURN
END
C:-------------------------TALK.FTN-----------------------------
C THIS SUBROUTINE IS USED TO TALK WITH SDK-85 CONTROLLER
C TO MOVE THE LDA SYSTEM(i.e. TRAVERSING SYSTEM)
C NOTE: 1) X,Y,Z ARE MULTIPLIED BY 1,000, BEFORE SENDING TO
C SDK-85
C 2)X CORRESPONDS TO AXIS #3 ON THE TRAVERSING SYS.
C
Y " " " #2 " " "
Z " " " #1 " " "
C DATE:5/4/83'     D. SHEU IN TRL
C----------------------------------------------------------------------
C SUBROUTINE TALK(X,Y,Z)
C------------------------------------------------------------------------
C ***
C *** COMMON S(3)
C ***
C IF(X .GE. 0.) IX=1000*X+0.49999 ! TO ROUND OFF (AVOID
C IF(X .LT. 0.) IX=1000*X-0.49999 ! TRANCATION ERROR ALSO TAKE
C IF(Y .GE. 0.) IY=1000*Y+0.49999 ! CARE OF NEGATIVE CONDITIONS
C IF(Y .LT. 0.) IY=1000*Y-.49999 !
C IF(Z .GE. 0.) IZ=1000*Z+.49999 !
C IF(Z .LT. 0.) IZ=1000*Z-.49999 !
C WRITE(4,200) IZ,IY,IX
C 200 FORMAT(1x,'/',16,'*/',16,'*/',16,'*/',16,'*/',16,'*')
C ***
C S(1)=X
C S(2)=Y
C S(3)=Z
C ***
C RETURN
C END
;=====================================================================
; PROGRAM FOR SDK-85  4-14-83
; T.R.L.  RM 309 ENGINEERING EAST  SONYAR
;=====================================================================

ORG 2000H

PTCHAR: PUSH PSW ; SAVE CHARACTER
VDM1: IN 11H ; GET STATUS
ANI 01 ; TX DONE?
JZ VDM1 ; NO, POLL AGAIN
POP PSW ; YES, SEND IT

OUT 10H

BOA: MVI A,40H ; 8155 #2 TO OUTPUT
OUT 2DH ; CONTINUOUS SQUARE
MVI A,28H ; 3.072MHz/(64*1200BAUD)=
OUT 2CH ; LOW BYTE OF TIMER CNT
MVI A,0EH ; LOAD MODE AND HIGH 6-10
OUT 28H ; PORT #28 IS COMMAND/ST
RET

;8251-A INITIALIZATION :

US: MVI A,00 ; COMMAND NOP
OUT 11H ; FORCE TO
OUT 11H ; KNOWN COMMAND S
OUT 11H ; PORT #11 IS COM/MODE
OUT 11H ; INTERNAL RESET

MVI A,40H ; MODE INSTRUCTION (1 S
MVI A,4FH ; 8-BIT WORD, BAUD
MVI A,37H ; COMMAND INSTRUCTION
OUT 11H ; ENABLE Rx,Tx,etc.
OUT 11H

ORG 2800H ; 8155 RAM FOR STORAGE
; 6116 RAM FOR ALGORITHM

ORG 3000H

; 8155#2 RAM LOCATIONS
STACK EQU 28FFH
SDKS5 EQU 0000H
ASCII EQU 2FH
ASCIIH EQU 3FH
ZERO EQU 00H
ONE EQU 01H
NNINE EQU 99H
NZER EQU 10H
BLNKB EQU 40H
UPDAD EQU 0363H
UPDDT EQU 036EH

; TRANSLATOR INTERFACE CONTROL PORT LOCATIONS

TRCR EQU 28H
TRSTS EQU 29H
TRWRD EQU 2AH
PLSE NP EQU 2BH
TRIWR EQU 0EH

; TRANSLATOR INTERFACE CONTROL WORDS

AXIS1 EQU 00H
AXIS2 EQU 10H
AXIS3 EQU 20H
CWB EQU 06H
CCWB EQU 0AH
DEAD EQU 00H
OFF EQU 00H
CH1 EQU 01H
CH2 EQU 04H
CH3 EQU 10H
CCW1 EQU 02H
CCW2 EQU 08H
CCW3 EQU 20H

; TRANSLATOR INTERFACE STATUS WORDS
105 0000 MANC EQU 00H
106 00C0 AUTOC EQU 0C0H
107 116 PULSE ANALYSIS WORDS
108 117 POSITION UPDATE (LED) INTERFACE CONTROL WORDS AND LOCATIONS
109 119 PULSE1 EQU 08H ; INIT WORD
110 PULSE2 EQU 18H ; 8155#2 CONTROL REGISTER
111 PULSE3 EQU 28H ; PULSE ANALYSIS REGISTER
112 120 PULPREG EQU 26H ; PULSE TRAIN1 SELECT
113 POLFRT EQU 23H ; PULSE TRAIN2 SELECT
114 121 LED1 EQU 0A0H ; PULSE TRAIN3 SELECT
115 LED2 EQU 0B0H
116 LED3 EQU 0C0H
117 122 INITIALIZATION WORD
118 ; ARRAY FOR AXIS1
119 123 ; ARRAY FOR AXIS2
120 124 ; ARRAY FOR AXIS3
121 R3D2 CONTROL ALGORITHM
122 125 FIRST: LXI SP,STACK ; INITIALIZE THE STACK
123 126 3000 31 FF 28 R3D2: CALL INITP ; INITIALIZE #2 PORTS
124 127 3003 21 07 30 CALL INITD ; INITIALIZE DATA BUFFERS
125 128 3006 E9 CALL INITSP ; INITIALIZE COMMUNICATION LINK
126 129 3007 CD F1 30 AUTO: CALL SWITCH ; AUTO/MAN SWITCH
127 130 300A CD 09 31 MOV B,A ; COMPARE WITH B
128 131 300D CD 02 31 TEST: MOV 00H,B ; 00H = MANU MODE
129 132 3010 CD 35 31 CMP B ; FALL THROUGH IF AUTO MODE
130 133 3013 47 JZ MAN0P ; CHECK TO BE SURE
131 134 3014 3E 00 CMP B ; IF NOT READ SWITCH AGAIN
132 135 3016 B8 JNZ TEST ; TALK TO PDP
133 136 3017 CA 31 31 CALL LINK ; START OF ASCII BUFFER IN DE
134 137 301A 3E 01 CALL L,ASCIIX ; HL LOCATES BCD STRING BUFFER
135 138 301C B8 CALL H,NECDX ; START OF BCD BUFFER IN Tmphl
136 139 301D C2 10 30 JMP AUTO ; START OF ASCII BUFFER IN TMPDE
137 140 3020 CD E5 31 ; CONVERT TO BCD AND STORE IT
138 141 3023 11 00 28 \( ASCII\)
139 142 3026 21 18 28 \( ASCII\)
140 143 3029 22 34 28 \( ASCII\)
141 144 302C EB \( ASCII\)
142 145 302D 22 36 28 \( ASCII\)
143 146 3030 EB \( ASCII\)
144 147 3031 CD 61 31 \( ASCII\)
145 148 3034 11 07 28 \( ASCII\)
146 149 3037 21 24 28 \( ASCII\)
147 150 303A 22 34 28 \( ASCII\)
148 151 303D EB \( ASCII\)
149 152 303E 22 36 28 \( ASCII\)
150 153 3041 EB \( ASCII\)
151 154 3042 CD 61 31 \( ASCII\)
152 155 3045 11 0E 28 \( ASCII\)
153 156 3048 21 2D 28 \( ASCII\)
SHLD TMPHDL
SHLD TMPDF
CALL ASCBCD
XMOV: LXI B,TBCDX
LXI H,TMPHDL
MOV M,C
INX H
MOV M,B
LXI D,NECDX
LXI H,TMPDE
MOV M,E
INX H
MOV M,D
LXI H,AXIS
MVI M,AXIS1
LXI H,LED
MVI M,LED1
LXI H,OBDCDX
MVI A,PULSE1
OUT PLSENP
CALL MOVE
MVI C,0CH
LXI D,OBDCDX
LXI H,NECDX
CALL SWAPP

PROGRAM CONTROL IS RETURNED HERE WHEN THE AXIS IS SUCCESSFULLY POSITIONED AND POSITION IS UPDATED ON FRONT PANEL.
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207 30AA CD 12 32 CALL MOVE
210 30AD 0E 03 MVI C,03H
211 30AF 21 24 28 LXI H,NBCDZ
212 30B2 11 1E 28 LXI D,OBCDZ
213 30B5 CD 1D 31 CALL SWAPP
214
215 30B8 01 2A 28 ZMOV: LXI B,TBCDZ
216 30B8 21 34 28 LXI H,TMPHL
217 30BE 71 MOV M,C
218 30BF 23 INX H
219 30C0 70 MOV M,B
220 30C1 11 2D 28 LXI D,NBCDZ
221 30C4 21 36 28 LXI H,TMPDE
222 30C7 73 MOV M,E
223 30C8 23 INX H
224 30C9 72 MOV M,D
225 30CA 21 3A 28 LXI H,AXIS
226 30CD 36 20 MVI M,AXIS3
227 30CF 21 3B 28 LXI H,LED
228 30D2 36 C0 MVI M,LED3
229 30D4 21 27 28 LXI H,OBSDZ
230 30D7 3E 28 MVI A,PULSE3
231 30D9 D3 28 OUT PLSENPE
232 30DB CD 12 32 CALL MOVE
233 30DE 0E 03 MVI C,03H
234 30E0 21 2D 28 LXI H,NBCDZ
235 30E3 11 27 28 LXI D,OBCDZ
236 30E6 CD 1D 31 CALL SWAPP
237
238 ; THE CORE ALGORITHM GOES HERE
239
240 30E9 3E 44 MVI A,44H
241 30ED CD 00 20 CALL PITCHAR
242 30EE C3 10 30 JMP TEST
243
244 ;
245 ; INITIALIZE ALL PARALLEL PORTS ON 8155 AND 8255 CHIPS
246 30F1 3E 02 INITP: MVI A,PLLIP
247 30F3 D3 20 OUT PLREG
248 30F5 3E 0E OUT MVI A,TRIWR
249 30F7 D3 28 OUT TRCR
250 30F9 3E 20 MVI A,LEDIP
251 30FB D3 A3 OUT LED1+3
252 30FD D3 B3 OUT LED2+3
253 30FF D3 C3 OUT LED3+3
254 3101 C9 RET
255 3102 CD 16 20 INITSP: CALL BAUD
256 3105 CD 23 20 CALL USET
257 3108 C9 RET
258 3109 21 00 28 INITD: LXI H,ASCII
259 310C 0E 40 MVI C,BLNFBE
260 310C AF XRA A

; PARALLEL PORTS. INITIALIZED
; INITIALIZE PARA...
; BLNLPC: MVI M, ZERO
; DCR C
; INX H
; CMP C
; JNZ BLNLPC
; "NEGATIVE" ZERO IN THE NZERO BUFFER
; LOOP ALL CHAR ZERO
; SUBROUTINE SWAPP ...
; # OF BUFF CHARACTERS IN REG C
; HL HAS POINTER TO NEW POSITIONS
; DE HAS POINTER TO OLD POSITION BUFFER
; B HAS NEW POSITION
; TURN NEW POSITION POINTER
; SWAP IT WITH OLD POSITION POINTER
; MOVE TO THE OLD POSITION BUFFER
; TURN OLD POSITION POINTER
; HL HAS NEW POINTER
; DE HAS OLD POINTER
; COUNT CHARACTERS
; LAST CHARACTER ?
; LOOP TIL BUFFER SWAPPED
; RETURN WHEN DONE

; TELL PDP YOU ARE DONE
; D MEANS DONE
; GO CHECK THE SWITCHES
; D COUNTS PASSES THROUGH MAN
; E THROUGH AUTO
; SAVE IN B
; SAVE ANDED RESULT IN C
; GET STATUS WORD
; WAS IT MANUAL ?
; USE C TO FIND OUT
; COMPARE WITH MANUAL
; IF NOT MANUAL OR AUTO SWITCH
; IS BROKEN ... SEND ERROR TO PDP

; 08H IS LASTLOOP COUNT
313 3153 C2 39 31             JNZ IN
314 3156 C9                    RET
315 3157 1D       AUTO: DCR E
316 3158 3E 00             MVI A,00H
317 315A BB                 CMP E
318 315B C2 39 31             JNZ IN
319 315E 3E 01             MVI A,01H
320 3160 C9                    RET

; TMPDE HAS START OF ASCII STRING
; TMPHL HAS START OF BCD BUFFER
; S1.XXX BECOMES MNL WHERE M= SIGN, TENS OF INCHES
; N= INCHES, TENTHS
; L= HUNDREDTH, THOUSANDTHS

; RESULT IS RETURNED IN THE BCD BUFFER

330 3161 2A 36 28 ASCBCD: LHLD TMPDE ; SCAN ASCII FOR SIGNS
331 3164 0E 06             MVI C,06H
332 3166 CD C4 31             CALL SIGN ; - SIGN = 10H IN ACCUMULATOR
333 3169 EB                 XCHG
334 316A 2A 34 28             LHLD TMPHL ; + SIGN = 00H
335 316D 77                MOV M,A
336 316E EB                ABSVAL: XCHG
337 316F 2A 36 28             LHLD TMPDE ; STORE SIGN IN BCD BUFFER
338 3172 23                 INX H ; DE POINTS TO BCD BUFFER
339 3173 0E 05             MVI C,05H ; GET LEADING ASCII LOCATION AGAIN
340 3175 CD 9D 31             CALL DATAS ; FIVE CHARACTERS LEFT IN ASCII BUFFER
341
342 3178 0D                DCR C ; GET THE NEXT ASCII CHARACTER - RETURN
343 3179 EB                 XCHG
344 317A 86                ADD M ; WITH BCD IN ACCUMULATOR
345
346 317B 77                MOV M,A
347 317C 23                 INX H ; ADD LOW AND HIGH NIBBLES TO FORM MSB
348 317D EB                 XCHG ; OF THE BCD REPRESENTATION
349 317E 23                INX H ; SAVE IN THE MSB OF THE BCD BUFFER
350 317F CD 9D 31 LOP2: ; TURN BCD BUFFER POINTER
351 3182 0D                DCR C ; SWAP REG - POINT AT ASCII
352 3183 37                CALL DATAS ; TURN POINTER TO NEXT ASCII CHARACTER
353 3184 3F                RAL
354 3185 17                RAL
355 3186 17                RAL
356 3187 17                RAL
357 3188 17                RAL
358 3189 EB                 XCHG
359 318A 77                MOV M,A
360 318B EB                 XCHG ; BCD IS MOVED INTO THE TOP NIBBLE
361 318C 23                 INX H ; POINT TO NEXT BCD STORAGE LOCATION
362 318D CD 9D 31             CALL DATAS ; STORE TOP NIBBLE HERE
363 3190 0D                DCR C
364 3191 EB                 XCHG

; GET BCD CHARACTER
; COUNT IT
; SET CARRY BEFORE THE RAL INSTRUCTION
; COMPLIMENT IT TO BE SURE IT IS CLEARED

; COUNT THE CHARACTER
; POINT TO BCD BUFFER
; ADD LOW AND HIGH NIBBLES TO FORM MSB
; OF THE BCD REPRESENTATION
; SAVE IN THE MSB OF THE BCD BUFFER
; TURN BCD BUFFER POINTER
; SWAP REG - POINT AT ASCII
; TURN POINTER TO NEXT ASCII CHARACTER
; GET BCD CHARACTER
ADD M
ADD M, A
INX H
XCHG
INX H
XRA A
CMP C
JNZ LOP2
RET

DATAS:
MOV A, M
MOV B, A
MVI A, ','
CMP B
JNZ NTST
RKWRD:
MVI A, ZERO
RET

NTST:
MVI A, ','
CMP B
JZ RKWRD
MOV A, B
CALL NUMBER
RET

NUMBER:
MOV B, A
MVI A, ASCIIIL
CMP B
JP ERR
MVI A, ASCIIH
CMP B
JM ERR
MOV A, B
SUI 30H
RET

SIGN:
MOV B, M
MVI A, ','
CMP B
JZ MINUS
DCR C
MVI A, ZERO
CMP C
INX H
JNZ SIGN
RET
MINUS:
MVI A, 10H
RET

ERR:
MVI A, 'E'
CALL FTCHAR
JMP SDKS5
REDY:
MVI A, 'R'
CALL FTCHAR
RET
SEND C TO PDP-11/34
SEND R TO PDP-11/34
COMMUNICATION LINK WITH POP-11/34 EXECUTIVE COMPUTER

; BUFFER LOCATION HL
; GET MESSAGE IN BUFFER

; PUTS A STRING OF CHARACTERS IN A BUFFER POINTED TO BY HL

; IS THIS A LINE FEED?
; 2FH='/'

; GET A CHARACTER AND TEST IT
; 2AH='*'  

; IF NOT <LF> STORE IN MEMORY

; BRING IN MASKED SIGN BIT
; DE POINTS TO OLD
; HL POINTS TO NEW

; MOVE IS COMPLETE
; DE POINTS TO OLD
; HL POINTS TO NEW

; MOVE COMPLETE
; DE POINTS TO OLD
; HL POINTS TO NEW

; ALL AXES MOVES ARE FILTERED AND
; PERFORMED
469 323A 7E  MASI:  MOV A, M  ; STRIP TO LEAVE SIGN
470 323B E6 10  ANI 10H
471 323D 47  MOV B, A
472 323E AF  XRA A
473 323F B8  CMP B
474 3240 C9  RET
475
476  ; POS00 TAKES CARE OF MOVES WITH BOTH POSITIONS ON NEGATIVE AXIS
477
478 3241 7E  POS00:  MOV A, M  ; GET OLD MSB
479 3242 E6 0F  ANI 0FH  ; STRIP THE SIGN
480 3244 4F  MOV C, A  ; SAVE IN REG B
481 3245 B9  CMP C  ; FLASH ON ERROR
482 3246 FA B0 35  JM FLSHR
483 3249 EB  XCHG
484 324A 7E  MOV A, M  ; DE=OLD, HL=NEW
485 324B E6 0F  ANI 0FH  ; STRIP THE SIGN
486 324D 47  MOV B, A
487 324E 3E 01  MVI A,01H
488 3250 B8  CMP B
489 3251 FA B0 35  JM FLSHR  ; C CAN'T BE >1 EITHER
490 3254 C2 62 32  JNZ TSTZ  ; IF NOT ONE MUST BE ZERO
491 3257 AF  XRA A  ; C IS ONE
492 3258 B9  CMP C  ; C=0?
493 3259 CA 9D 32  JZ LPA01
494 325C 3E 01  MVI A,01H
495 325E B9  CMP C
496 325F CA 6B 32  JZ LPA11  ; IF SO BOTH ARE 1X.XXX
497  ; DO FURTHER TESTS
498 3260 3E 01  TSTZ:  MVI A,01H
499 3264 B9  CMP C
500 3265 CA AC 32  JZ LPA10
501 3268 C3 93 32  JMP LPA00
502 3268 EB  LPA11:  XCHG
503 326C 23  INX H  ; HL=OLDBUF NSB
504 326D 13  INX D  ; DE = NEWBUF NSB
505 326E 4E  MOV C, M  ; PUT NSB IN C
506 326F 3E 1F  MVI A,1FH  ; >12 INCH TRAVERSE ?
507 3271 B9  CMP C
508 3272 FA B0 35  JM FLSHR
509 3275 EB  XCHG
510 3276 46  MOV B, M
511 3277 3E 1F  MVI A,1FH
512 3279 B8  CMP B
513 327A FA B0 35  JM FLSHR
514 327D EB  XCHG
515 327E 78  ENTRYA:  MOV A, B  ; DE=NEWBUF+1, HL=OLDBUF+1
516 327F B9  CMP C
517 3280 C2 8A 32  JNZ NXTMOV  ; R&C NE IS ENOUGH TO MOVE AXIS
518 3283 23  INX H  ; HL=OLDBUF+2
519 3284 13  INX D  ; DE=NEWBUF+2
520 3285 4E  MOV C, M
521 3286 EB XCHG B,M
522 3287 46 MOV A,B
523 3288 78 MOV C
524 3289 B9 CMP C
525 328A CA 79 33 NTRMOV: JZ NOMOVE
526 328D FA 5D 33 JM DCRCCW
527 328F C3 4F 33 JMP INCCW
528 3290 EB LPA00: XCHG H
529 3292 46 INX D
530 3294 13 MOV C,M
531 3296 4E XCHG M
532 3297 EB MOV B,M
533 3298 46 XCHG E
534 3299 EB LPA01: ENTRYA
535 329A C3 7E 32 JMP FLSHR
536 329D EB INX H
537 329E 23 INX D
538 329F 13 MOV B,M
539 32A0 EB XCHG C,M
540 32A1 46 MOV A,1FH
541 32A2 3E 1F CMP B
542 32A3 B9 JM INCCW
543 32A4 FA B0 35 JMP LPA10:
544 32A5 EB XCHG C
545 32A6 C3 4F 33 JMP INCCW
546 32A7 EB LPA10: XCHG C
547 32A8 23 INX H
548 32A9 13 INX D
549 32AA 4E MOV B,M
550 32AB 3E 1F MVI A,1FH
551 32AC EB CMP C
552 32AD 23 JM FLSHR
553 32AE 13 JM DCRCWW
554 32AF 4E MOV C,M
555 32B0 3E 1F MVI B,M
556 32B1 B9 CMP C
557 32B2 FA B0 35 JM FLSHR
558 32B3 EB XCHG B,M
559 32B4 7E MOV A,M
560 32B5 EB ANI 0FH
561 32B6 4F MOV C,A
562 32B7 3E 01 MVI A,01H
563 32B8 29 CMP C
564 32B9 FA B0 35 JM FLSHR
565 32BA EB MOV A,M
566 32BB E6 0F ANI 0FH
567 32BC 4F MOV C,A
568 32BD 3E 01 MVI A,01H
569 32BE 29 JMP DCRCWW
570 32BF FA B0 35 JM FLSHR
571 32C0 80 XRA A
572 32C1 0F CMP C
573 32C2 CA 17 33 JZ LPA01
574 32C3 3E 01 MVI A,01H
575 32C4 0F CMP C
576 32C5 E6 0F ANI 0FH
577 32C6 4F MOV C,A
578 32C7 3E 01 MVI A,01H
579 32C8 29 MOV A,B
580 32C9 FA B0 35 JM FLSHR
581 32CA EB MOV A,M
582 32CB E6 0F ANI 0FH
583 32CC 4F MOV C,A
584 32CD 3E 01 MVI A,01H
585 32CE 29 MOV B,A
586 32CF FA B0 35 JM FLSHR
587 32D0 80 XRA A
588 32D1 0F CMP C
589 32D2 CA 17 33 JZ LPA01
58A 32D3 3E 01 MVI A,01H
58B 32D4 0F CMP C
625  332B 4E
626  3332A 3F 1F
627  3332C B9
628  3332D FA B0 35
629  33330 C3 6B 33
630
631  ; POS01 FOR MOVE FROM NEG TO POS AXIS
632
633  3333 CD 20 35
634  ; POS01: CALL CCWDCZ
635  ; HL IS OLD BUFF POINTER
636  ; DE IS NEW
637  3336 CD 41 33
638  CALL INCCCW
639  RET
640
641  333A CD 64 35
642  POS10: CALL CWDCZ
643
644  333D CD 4F 33
645  CALL INCCCW
646  RET
647
648  3341 2A 34 28
649  INCCW: LHLD TMPHL
650
651  3344 3A 3A 28
652  LDA AXIS
653
654  3347 C6 0A
655  ADI CCWB
656
657  3349 D3 2A
658  OUT TRWRD
659
660  334B CD 7A 33
661  CALL INCNT
662  RET
663
664  334E C9
665  ; INCNW: LHLD TMPHL
666
667  3350 3A 3A 28
668  LDA AXIS
669
670  3355 C6 0A
671  ADI CCWB
672
673  3357 D3 2A
674  OUT TRWRD
675
676  3359 CD 7A 33
677  CALL DCRNT
678  RET
679
680  335C C9
681  ; DCRCCW: LHLD TMPHL
682
683  3360 3A 3A 28
684  LDA AXIS
685
686  3363 C6 0A
687  ADI CWB
688
689  3365 D3 2A
690  OUT TRWRD
691
692  3367 CD D6 33
693  CALL DCRNT
694  RET
695
696  336A C9
697  ; DCRCW: LHLD TMPHL
698
699  336B 2A 34 28
700  LDA AXIS
701
702  336E 3A 3A 28
703  ADI CWB
704
705  3371 C6 06
706  OUT TRWRD
707
708  3373 D3 2A
709  CALL DCRNT
710  RET
711
712  3375 CD D6 33
713  ; NOMOVE: RET
714
715  3379 C9
716
717  3379 C9
718
719  INCNT: MOV B,M
720  ; TEST THE POSITION FIRST
721
722  3373 56
723
724  3378 23
725
726  337D 45
727
728  337E 23
729
730
677 337E 4E  MOV  C,M
678 337F  C3 A4 33  JMP  CMPSR
679
680 3382 CD 32 34  INCTI1: CALL POLL
681 3385  56  MOV  D,M
682 3386  23  INX  H
683 3387  46  MOV  B,M
684 3388  23  INX  H
685 3389  4E  MOV  C,M
686 338A  79  MOV  A,C
687 338B  C6  01  ADI  ONE
688 338D  27  DAA
690 338F  D2  9F 33  JNC  SKIP
691 3392  78  MOV  A,B
692 3393  C6  01  ADI  ONE
693 3395  27  DAA
694 3396  47  MOV  B,A
695 3397  D2  9F 33  JNC  SKIP
696 339A  7A  MOV  A,D
697 339B  C6  01  ADI  ONE
698 339D  27  DAA
699 339E  57  MOV  D,A
700 339F  71  SKIP: MOV  M,C
701 33A0  2B  DCX  H
702 33A1  70  MOV  M,B
703 33A2  2B  DCX  H
704 33A3  72  MOV  M,D
705
706 33A4  2A  36 28  CMPSI: LHLH  TMPE
707 33A7  7E  MOV  A,M
708 33A8  60  NOP
709 33A9  BA  CMP  D
710 33AA  C2  DE 33  JNZ  UPLEDA
711 33AD  23  INX  H
712 33AE  7E  MOV  A,M
713 33AF  B8  CMP  B
714 33B0  C2  BD 33  JNZ  UPLEDB
715 33B3  23  INX  H
716 33B4  7E  MOV  A,M
717 33B5  B9  CMP  C
718 33B6  C2  BC 33  JNZ  UPLED C
719 33B9  C3  CA 33  JMP  STOPR
720 33BD  2B  UPLEDC: DX  H
721 33BE  2B  UPLEDB: DCX  H
722 33BF  2A  34 28  UPLEDA: LHLD  TMFHL
723 33C1  CD  59 34  CALL  UPDATE
724 33C4  2A  34 28  LHLD  TMFHL
725 33C7  C3  82 33  JMP  INCTI1
726 33CA  CD  A8 35  STOPR: CALL  STOP
727 33CD  2B  DCX  H
728 33CE  2B  DCX  H
781 3420 2A 34 28
782 3423 C3 DE 33
783 3426 CD A8 35
784 3429 2B
785 342A 2B
786 342B 2A 34 28
787 342E CD 59 34
788 3431 C9
789 3432 1E 00
790 3434 CD 51 34
791 3437 C2 34 34
792 343A 1C
793 343B 3E 02
794 343D BB
795 343E C2 34 34
796 3441 1E 00
797 3443 CD 51 34
798 3446 CA 43 34
799 3449 1C
800 344A 3E 02
801 344C BB
802 344D C2 43 34
803 3450 C9
804 3451 DB 23
805 3453 E6 02
806 3455 47
807 3456 AF
808 3457 BB
809 3458 C9
810 3459 3A 3B 28
811 345C 5F
812 345D 3E A0
813 345F BB
814 3460 CA E7 34
815 3463 3E 30
816 3465 BB
817 3466 CA A8 34
818 3469 7E
819 346A E6 10
820 346C 5F
821 346D AF
822 346E BB
823 346F CA 8A 34
824 3472 7E
825 3473 E6 0F
826 3475 5F
827 3476 3E 01
828 3478 BB
829 3479 CA 83 34
830 347C 3E 42
831 347E D3 C2
832 3480 C3 9F 34

MOVE.SRC

LHLD TNLPHL
JMP DCRNT1
STOP: CALL STOP
INC H
DCX H
LHLD TNPHL
CALL UPDATE
RET
MVI E,00H
; USE E TO COUNT POLL
CALL GETDTA
JNZ LOOP
JNZ LOOP
MVI E,00H
CALL GETDTA
JZ LOOP2
JNZ LOOP2
RET
IN POLPRT
ANI 02H
MOV B,A
XRA A
CMP E
MVI A,LED1
JZ AX1
JZ AX1
JZ AX2
MOV A,M
ANL 10H
MOV E,A
XRA A
CMP E
JZ PLUS3
MOV A,M
ANI 0FH
MOV E,A
MVI A,01H
CMP E
JZ NEG31
MVI A,42H
OUT LED3+2
JMP AX3C
385 34E0 D3 B1  OUT LED2+1
386 34E2 23  INX H
387 34E3 7E  MOV A,M
388 34E4 D3 B0  OUT LED2:
389 34E6 C9  RET
390 34E7 7E  AX1: MOV A,M
391 34E8 E6 10  ANI 10H
392 34E9 5F  MOV E,A
393 34EA AF  XRA A
394 34EB 8E  CMP E
395 34EC CA 02 35  JZ PLUS1
396 34F0 7E  MOV A,M
397 34F1 6F 0F  ANI 0FH
398 34F2 5F  MOV E,A
399 34F4 0E 42  MVI A,42H
400 34F6 D3 A2  OUT LED1+2
401 34F8 C3 17 35  JMP AX1C
402 34F9 3E 4E  NEGI1: MVI A,4EH
403 34FA D3 A2  OUT LED1+2
404 34FF C3 17 35  JMP AX1C
405 3502 7E  PLUS1: MOV A,M
406 3503 E6 0F  ANI 0FH
407 3505 5F  MOV E,A
408 3506 3E 01  MVI A,01H
409 3508 BB  CMP E
410 3509 CA 13 95  JZ PLUS11
411 350C 3E 40  MVI A,40H
412 350E D3 A2  OUT LED1+2
413 3510 C3 17 35  JMP AX1C
414 3513 3E 4C  PLUS11: MVI A,4CH
415 3515 D3 A2  OUT LED1+2
416 3517 23  AXIC: INX H
417 3518 7E  MOV A,M
418 3519 D3 A1  OUT LED1+1
419 351B 23  INX H
420 351C 7E  MOV A,M
421 351D D3 A0  OUT LED1
422 351F C9  RET
423 3520 2A 36 28  CCWDCZ: LHLD TMPDE
424 3523 E5  PUSH H
425 3524 21 36 28  LXI H,TMPDE
426 3527 11 30 28  LXI D,NZERO
427 352A 73  MOV M,E
428 352B 23  INX H
429 352C 72  MOV M,D
430 352D 2A 34 28  LHLD TMPH
431 3530 7E  MOV A,M
432 3531 E6 0F  ANI 0FH
433 3533 47  MOV B,A
434 3534 AF  XRA A
435 3535 B8  CMP B
436 3536 C2 48 35  JNZ EXIT

; LOAD HL WITH NEW BUFFER POINTER

; PUT ZERO IN TEMP BUFFER FOR NOW

; TEST MSB FOR ZERO
; STRIP THE SIGN
; STORE IN B FOR TEST
; CLEAR ACCUMULATOR
INX    H
MOV    B,M
CMP    B
JNZ    EXIT
INX    H
MOV    B,M
; TEST NSB
CMP    B
JNZ    EXIT
; AND LSB ALSO
EXIT:  LHLD  TMPHL
JMP    END1
; RELOAD OLD POSITION POINTER
LDA    AXIS
ADI    CCWB
OUT    TRWRD
CALL   DCRNT
END1:  POP   D
; RETRIEVE NEW POSITION FROM STACK
LXI    H,TMPDE
MOV    M,E
INX    H
MOV    M,D
LHLD  TMPHL
; NOW TURN THE SIGN TO A POSITIVE ZERO POSITION
MOV    A,M
ANI    0FH
MOV    M,A
RET
LHLD  TMPDE
PUSH   H
LXI    H,TMPDE
LXI    D,PZERO
MOV    M,E
INX    H
MOV    M,D
LHLD  TMPHL
MOV    A,M
ANI    0FH
MOV    B,A
XRA    A
CMP    B
JNZ    EXIT2
INX    H
MOV    B,M
CMP    B
JNZ    EXIT2
INX    H
MOV    B,M
CMP    B
JMP    ENDC
EXIT2:  LHLD  TMPHL
LDA    AXIS
ADI    CCWB
OUT    TRWRD
NOW TURN THE SIGN TO A NEGATIVE ZERO
REFERENCES

DISA Information Department: 55X Modular LDA Optics, Instruction Manual

DISA Information Department: 55N10 LDA Frequency Shifter

DISA Information Department: 55N20 Doppler Frequency Tracker, Instruction Manual

DISA Information Department: 55N20 Doppler Frequency Tracker, Service Manual


