Measurements of the length of the zone of flow establishment in a jet using a Laser Doppler Anemometer

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Measurements of the length of the zone of flow establishment in a jet using a Laser Doppler Anemometer

Ventresca, James Joseph, M.S.
University of Nevada, Las Vegas, 1990
MEASUREMENTS OF THE LENGTH OF THE ZONE OF FLOW ESTABLISHMENT IN A JET USING A LASER DOPPLER ANEMOMETER

By
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A thesis submitted in partial fulfillment of the requirements for the degree of
Master of Science in Mechanical Engineering

Department of Mechanical Engineering
University of Nevada, Las Vegas
December, 1990
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ABSTRACT

The length of the zone of flow establishment in a submerged, turbulent, buoyant, axisymmetric jet issuing into a quiescent ambient fluid was investigated using a Laser Doppler Anemometer and microthermocouple probe. Also, velocity and temperature profiles were measured through various cross-sections of the jet.

A 3-dimensional traversing mechanism with feedback and interface circuitry was constructed and then controlled by an 80286 microcomputer. Software for computer aided data acquisition was written for the Laser Doppler Anemometer and traversing mechanism and was executed on the 80286 microcomputer.

An experimental setup was constructed to form axisymmetric jets and to allow for the addition of heat, seed particles, and the control of velocity and temperature. The jet nozzle was made in such a way as to allow for flow measurements at angles of inclination from 0 to 90 degrees.

The work conducted for this experimental thesis expands the existing data on jets. A new formula for the zone of
flow establishment was developed that relates its length to the Reynolds number in the nozzle. The length of the zone of flow establishment in an axisymmetric, vertical jet was found to vary according to the formula:

\[
\frac{S_{zfe}}{D} = \frac{5.03 \cdot Re_D}{Re_D - 361}
\]

\[450 < Re_D < 30,000\]
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NOMENCLATURE

D  diameter of nozzle
F  average densiometric Froude number
F.T.  fractional turbulence = $\frac{\sqrt{\bar{u}^2}}{u}$
G  Grashof number
L  fringe spacing
r  radial distance from centerline
R  radius of nozzle
ReD  Reynolds number based on nozzle diameter
s  distance from the exit of the nozzle along the streamwise axis
$s_0$  virtual origin of jet
T  average temperature
T.I.  turbulence intensity
$u, U$  average velocity, streamwise direction
V  average velocity, radial direction

Greek Symbols

$\alpha$  angle of intersection of lasers
$\lambda$  wavelength of laser light
$\rho$  density
\( v \)  
kinematic viscosity

**Subscripts**

- **0**  
  centerline value
- **a**  
  ambient condition
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CHAPTER 1
INTRODUCTION

Turbulent jets have industrial and military applications. In industry, jets are used for deep hole drilling, cutting tools, jet pumps, cleaning tools, and flow mixers such as fuel injectors.

For example, in a fuel injector it may be desirable to control the distribution of the fuel mixture in the combustion chamber. From the analysis of a turbulent jet, it may be possible to design the injector and control the flow parameters in a way that would increase the efficiency of the system.

Buoyant jets are pertinent to the study of heat exchangers and exhaust ports where the effluent may have an effect on the environment such as thermal or salinity fluctuations.

For example, smokestacks exhaust into the environment. If the flow from the smokestack could be modeled accurately, it would be possible to predict the dispersion of pollutants and thermal energy. This would allow the smokestack to be designed so that the properties of the effluent could be
controlled.

Military interests in the study of buoyant jets include the defense against thermal targeting, as in the thermal signature of submarines, tanks, ships and aircraft.

Most research on turbulent jets has been done in the last three decades. Analytical equations have been written that lead to the prediction of flow parameters in the jet. Some limited data has been collected, most of it in the zone of established flow. Experimental data is needed to compare with analytical models and for boundary conditions in these models.

The purpose of this experimental thesis is to expand the body of data related to the zone of flow establishment for a pure and buoyant jet. In particular, the lengths of the zone of flow establishment.

To do this, a submerged, axisymmetric, buoyant jet issuing into a quiescent ambient fluid was constructed (heated air was the fluid), and a Laser Doppler Anemometer (LDA) was used to construct the velocity and turbulence intensity profiles. A microthermocouple probe was used to measure temperature profiles.

A 3-dimensional traversing mechanism was constructed and interfaced with an 80286 microcomputer. Computer software was written for the acquisition of data and control of the traverse. Measurements were made of the various
profiles including centerline traverses which enabled the length of the zone of flow establishment to be calculated.
CHAPTER 2
LASER DOPPLER ANEMOMETRY

2.1 History of Laser Doppler Anemometry

The technique of using the optical Doppler shift from reflected laser light of small particles in a flow began in 1964 by Cummins and Yeh [20]. These first applications were very limited since they used spectrum analyzers to obtain the Doppler shift which is extremely small relative to the frequency of light. For example, for a fluid with a velocity of 10 m/s, the Doppler shift is approximately 7 parts in $10^8$. However, for supersonic velocities, the Doppler shift is large enough to distinguish.

The direct measurement of the frequency of light is often impossible since most equipment can't operate in that range. For instance, the frequency of light emitted from a He-Ne laser is about $4.7 \times 10^{14}$ Hz.

The technique of optical "beating" was developed to make it possible to measure small frequency shifts. In this technique, laser light is heterodyned at a point (measuring volume) so that a resulting "beating" phenomenon is measured as a particle moves through this point. This "beating"
frequency is relatively low and is equal to the Doppler shift. Thus, various signal processing equipment can be now be used.

Another method used is the reference beam mode. In this method, the Doppler frequency is detected by directly comparing shifted light with a reference source (laser) in a photodetector. A prism and mirror are used to split the source beam and to preserve the unshifted light.

A preferred method which has a higher signal to noise ratio, is called the differential Doppler technique. This technique is preferred in gas flow measurements where a smaller number of signals are available to be measured. This is due to the smaller concentration of seed particles in a gas flow. In this method, two equal intensity laser beams are focused at a point so that Doppler shifted light can be directly measured using a photodetector.

### 2.2 Advantages and Applications of Laser Doppler Anemometry

These are some of the advantages of using an LDA to make fluid measurements [8].

1. It is a non-invasive technique.
2. It has a very fast response time, which allows a variety of statistical calculations to be made.
This is important, especially for turbulent flows.

3. LDA's have a very high spacial resolution. The measuring volume has dimensions on the order of 1 micron to hundreds of microns.

4. LDA's are extremely well-suited to hostile environments such as where flames are present. These conditions exist in combustion chambers such as furnaces or internal combustion engines. Here, special optical windows must be installed in order to create an optical path for the laser beams.

Some biological applications include measurements in small vessels in plants or animals. For this purpose, special fiber-optic probes must be constructed in order to penetrate into the tissue where flow measurements are needed. The LDA can also be incorporated into a microscope to facilitate these measurements.

In humans, LDA measurements have been made in the retinal blood vessels by using low power laser light (on the order of a microwatt) [8].

2.3 Disadvantages of Laser Doppler Anemometry

These are some of the problems associated with using a Laser Doppler Anemometer.
1. Gas flow measurements are more difficult because seed particles must be entrained in the fluid using an external apparatus.

2. The laser beams must have a clear, unobstructed optical path.

3. In some situations where there are density variations in the fluid, calculations must be made to correct for the refraction of light and hence the change in geometry of the measuring volume.

4. The initial cost of LDA system is typically very high. Prices of some of the more complex systems may be over $200,000.

5. Some of the bigger systems also have large laser power requirements and must be externally cooled.

6. The large LDA systems are usually very difficult to transport making it necessary to provide facilities to perform experiments. Smaller, limited systems can be used if it is necessary to transport the LDA.
2.4 Theory of Laser Doppler Anemometry

2.4.1 The Differential Doppler Technique

The Laser Doppler Anemometer (LDA) that was used for this experimental thesis was constructed implementing the most common method in Laser Doppler Anemometry, the differential Doppler technique. This section describes this technique [7],[8].

In general, an LDA measures the Doppler shift of light scattered from particles in a moving fluid to determine the flow velocity. Commonly, the Doppler shift is measured by optically heterodyning light from two laser beams. The Doppler shift is detected as the difference in frequency of the two beams and is measured by a photodetector. Here, only the frequency difference, the Doppler shift, will be detected since the frequency of light is too high to be measured.

This technique has the advantages of being:

1. able to use large collection apertures without violating coherence requirements, which allows measurements of small single particles.
2. easy to keep in alignment.
3. flexible, since the Doppler frequency is independent of the location of the detection optics.
Also, this method has characteristics such as:

1. good signal to noise ratio for a single particle
2. moderate signal to noise ratio in flows of high particle concentration
3. poor signal to noise ratio in flows that have a high concentration of very small particles.

2.4.2 The Fringe Model

A simplistic but accurate description of this method can be made using a fringe model as shown in figure 1.

Two coherent, monochromatic laser beams intersect at a particular point in space (measuring volume) and create an array of plane interference fringes. The spacing of these fringes can be calculated from the angle of intersection and wavelength of the light. From figure 3:

\[ d = \frac{\lambda}{\cos \frac{\alpha}{2}} \]
\[ L = \frac{d}{2 \tan \frac{\alpha}{2}} \]

\[ L = \frac{\lambda}{2 \sin \frac{\alpha}{2}} \]  \hspace{1cm} (2.1)

where \( L \) is the distance between the fringes.

A particle moving through this intersection volume with a
Figure 1 Interference Fringes

Figure 2 Dimensions of Measuring Volume
Figure 3 Fringe Spacing
particular velocity normal to the fringe planes, will scatter light at a corresponding frequency.

The velocity of a particle moving through these fringes can now be found:

\[ u = fL \]  \hspace{1cm} (2.2)

where

- \( u \) = velocity normal to the plane of the fringes
- \( f \) = frequency of scattered light

The lasers beams involved must be in the TEM\(_{00}\) (Transverse Electromagnetic Mode). This gives a well defined variation in the spacial distribution of the electromagnetic field normal to the direction of travel of the beam. The TEM\(_{00}\) gives the laser beams a Gaussian intensity distribution.

Also, in order to create an array of regularly spaced fringes, the beam waist (smallest diameter of the beam) must be located in the intersection volume. Special optics can be used to achieve this condition which is met in the system used for this experiment.

The shape of the intersection volume is ellipsoidal, as shown in figure 2. Its boundaries are defined as the points where the amplitude of the optical fringe modulation reaches \( 1/e^2 \) of its centerline value. For a TEM\(_{00}\) laser beam, the
dimensions are [7]:

\[ 2a = \frac{d_f}{\cos \frac{\alpha}{2}} \]  \hspace{1cm} (2.3)

\[ 2b = d_f \]  \hspace{1cm} (2.4)

\[ 2c = \frac{d_f}{\sin \frac{\alpha}{2}} \]  \hspace{1cm} (2.5)

\[ d_f = \frac{4f\lambda}{\pi d_2} \]  \hspace{1cm} (2.6)

\[ d_2 = Ed_1 \]  \hspace{1cm} (2.7)

where:

- \( d_f \) is the beam waist of the focused laser beam
- \( d_1 \) is the waist diameter of the unfocused laser beam
- \( d_2 \) is the waist diameter of the expanded beam
- \( E \) is the expansion ratio (if a beam expander is used)
- \( f \) is the focal length of the focusing optics
- \( \lambda \) is the wavelength of the laser light

The number of fringes in the measuring volume is:

\[ N_f = 4 \cdot \frac{D_2}{\pi d_2} \quad D_2 = E D_1 \]  \hspace{1cm} (2.8)

\( D_2 \) is the beam separation in front of the beam expander and \( D_1 \) is the beam separation in front of the focusing optics.
2.5 Seeding Techniques

Good differential Doppler signals require the flow to be seeded with particles that have diameters of about 1-2 microns. When seeding flows, it is important to keep in mind the dynamics of the seed particle in use. The particle must be analyzed to be sure that it can respond to properties of the flow such as turbulence fluctuations [9]. The particles must remain neutrally buoyant (inertial effects can be neglected) and must have good optical properties as predicted by Mie scattering theory.

2.5.1 Seeding of Gas Flows

For gas flows, liquid aerosols are recommended (such as a water mist) because the following properties can easily be achieved:

1. non-abrasiveness
2. non-corrosiveness
3. non-toxicity

These particles may be produced by atomization, fluidization, condensation, combustion or by a chemical reaction [9]. For this experiment, atomization of water by an ultrasonic humidifier was used.

For flows subject to high temperatures, it may be
desirable to instead use solid particles. The usual method for introducing solid particles into a flow is by agitating a fine powder of the seeding material in a fluidized bed and injecting this mixture into the main flow.

Some of the most common solid materials used are:

1. Titanium dioxide powder
2. Aluminum powder
3. Magnesium oxide
4. PVC or polystyrene latex
5. dust from the environment

Some other methods of seeding with aerosols are:

1. the dispersion of chalk dust from a fluidized bed
2. the combustion of oil
3. condensation of di-octyl phthalate
4. combustion of tobacco or smoke pellets
5. the chemical reaction of ammonium hydroxide and hydrochloric acid to produce ammonium chloride
CHAPTER 3
TURBULENT JETS

3.1 History of Work with Turbulent Jets

The fundamental research in turbulent jets is founded on interest from the military and industry. A large number of the applications for buoyant jets regard either the design of propulsion systems or the biological effects from the effluent of heat exchangers.

The military has interest in turbulent jets because the hot exhaust from ships, aircraft, and tanks can be used in thermal targeting. Therefore, exhaust systems must be designed so that heat is dissipated in a way so that it is not concentrated in any area.

For fuel injection systems, it may be desirable to control properties such as the distribution of fuel in the jet or the velocity profile. Some environmental concerns are centered mainly on how pollutants are distributed from smokestacks or the way heat is released into a body of water or the atmosphere.

Most of the work done on turbulent and buoyant jets started just after World War II. These early works gave
analytical models and some experimental data.

Some of the earliest work was done by Morton and Taylor [15] in 1956 who gave an analytical treatment and experimental data for turbulent and gravitational convection from point sources. Albertson [1] in 1950 was also one of the first experimentalists to research turbulent jets and presented much data on the velocity distribution in a turbulent jet.

Since a turbulent jet has much in common with the wake created by a body moving in a fluid, much of the analysis is the same. Wake and turbulence theories allow extensive analytical models of turbulent jets to be developed. Theories based on momentum and diffusion were developed by Prandtl, Taylor and Reichard. Prandtl's momentum transport theory, Taylor's vorticity transport theory and Reichard's inductive theory are used to solve for the velocity distributions and rates of spread. Solutions to equations developed from these theories were given by Tollmien [17] and Tomotika [18].

Some of the other important works were done by Batchelor, Schlichting, Hinze [10], and Ambramovich [2]. Work from these authors present some of the early analysis and experimental data for turbulent and buoyant jets.

More recently, models developed using integral equations for mass, energy and conservation of momentum were
developed by Hirst [11-13]. Some of the solutions given are for jet width, orientation and centerline distributions.

Chen and Rodi [4] in 1980 give a detailed review of experimental data and present these results in a uniform manner by using similarity and scaling laws. Results presented include data for rate of spread, lateral profiles of velocity, temperature, species concentration and turbulence quantities.

One of the problems that still remains is the lack of data that can be used for boundary conditions in analytical models. Models that are developed make assumptions about the boundary conditions that are not entirely founded. For example, the length of the zone of flow establishment is often taken as being constant. Albertson [1] used a constant of 6.2 nozzle diameters for this length in an axisymmetric jet. Hirst [12] also used the value of 6.2 nozzle diameters for a buoyant jet. Culbreth and Legoff gave the formula:

\[
\frac{S_{ZFE}}{D} \sim \frac{351}{\sqrt{Re_D}}
\]  

(3.0)

But in the case of a buoyant jet inclined at an angle, there is no known experimental data that exists on the length of the Z.F.E., and it is most likely not a constant for a varying Froude number.
3.2 Theory of Vertical Axisymmetric Buoyant Jets

Vertical, axisymmetric, buoyant jets are characterized by certain flow parameters shown in figure 4. A jet is buoyant when a density difference exists between the fluid in the jet and the ambient. When the buoyant force is directed back into the jet, as when the density of the jet effluent is greater than the ambient fluid, it is called a negative buoyant jet. If the buoyancy force can be neglected, it is a pure jet. The jet is a pure plume when the buoyancy force completely drives the flow.

For flows issuing into a quiescent ambient fluid, all buoyant jets eventually become pure plumes at the farthest region from their origin if a density difference still exists [4].
Figure 4 Turbulent, Buoyant, Axisymmetric Jet


3.2.1 The Zone of Flow Establishment

The first region in the effluent of a jet is called the zone of flow establishment. The most pronounced characteristic of this region is the existence of the potential core, where the properties closely match the flow in the nozzle of the jet. Here the parameters remain constant and equal to their exit values from the nozzle.

A fluid entering the zone of flow establishment keeps most of its characteristics from the internal flow in the nozzle. As the fluid reaches the zone of established flow, its properties are determined by the entrainment of ambient fluid.

Fluid in the zone of flow establishment outside of the potential core is in a region of turbulent mixing. Here, entrainment of ambient fluid occurs due to the formation of eddies on the surface of the flow [12].

3.2.2 Average Exit Properties

Average exit properties for the turbulent jet are frequently needed in calculations such as the Reynolds number and Froude number. These values are found from flow conditions just at the exit of the jet from the nozzle.

The average velocity is found by integration of the turbulent velocity distribution over the area of the jet.
A velocity profile taken from the equation of a logarithmic overlap layer in an internal flow [19] is:

\[ u(r) = u^*\left\{\frac{1}{\kappa} \ln\left(\frac{R-r}{v}\right) + B\right\} \]  \hspace{1cm} (3.1)

where

- \( u^* \) is the shear velocity = \( \sqrt{\frac{\tau_o}{\rho}} \)
- \( \kappa = 0.4 \), \( B = 5.0 \) (empirical constants)

\( R \) is the radius of the pipe

\( R - r \) is the radial distance from the wall

\( v \) is the kinematic viscosity of the fluid

A semiempirical formula used for internal turbulent flows and found to be very accurate [19] is:

\[ \frac{u(r)}{u_0} = \left[1 - 0.33\left(\frac{u}{R}\right)^2 - 0.67\left(\frac{u}{R}\right)^3\right] \]  \hspace{1cm} (3.2)

where

- \( u_0 \) is the centerline velocity

These equations are used to find the average exit velocity by integrating over the area of the nozzle:

\[ V_{ave} = \frac{Q}{A} = \frac{1}{A} \int_0^R u(r) 2\pi r dr \]  \hspace{1cm} (3.3)
In calculating the average Froude number, the average temperature must first be determined in order to calculate the average density. If the temperature at the wall of the jet is roughly the same as at the centerline, the temperature profile will be approximately constant. Thus, the average temperature can be closely approximated by the centerline temperature at the exit. This is especially true in a turbulent flow where there is a mixing of the fluid.

\[ F = \frac{\rho_0 V_0^2}{gD(\rho_a - \rho_0)} = \frac{Re^2}{G} \]  

(3.4)

\[ Re_p = \frac{V_0 D}{v} \]  

(3.5)

\[ G = \frac{g(\rho_a - \rho_0)D^3}{\rho_0 v^2} \]  

(3.6)

where:

- \( F \) -- densiometric Froude number
- \( \rho_0 \) -- average density at the exit
- \( \rho_a \) -- density of the ambient fluid
- \( V_0 \) -- average exit velocity
- \( g \) -- gravitational acceleration
- \( D \) -- diameter of the jet
- \( G \) -- Grashof number
3.2.3 The Zone of Established Flow

The zone of established flow is characterized by turbulent mixing and begins where turbulent mixing has reached the centerline of the jet. In this region the centerline velocity begins to decay inversely proportional to the square root of the Reynolds number.

In the zone of established flow, the flow parameters have attained the profile of a turbulent jet flow. At the outermost regions of the jet, referred to as the field zone, the momentum in the jet vanishes and buoyancy effects completely dominate. Here the jet behaves like a plume [12].

3.3 Techniques for Determining the Length of the Zone of Flow Establishment

The length of the zone of flow establishment is not a clearly defined point since the flow parameters change relatively slowly. The length of the Z.F.E. is basically the streamwise position along the centerline of the jet where the Z.F.E. ends and the Z.E.F. begins.

A few methods have been developed in order to create a systematic way of determining the length of Z.F.E. These methods are based on the change of flow parameters along the centerline as the flow begins to reach that of a fully
developed turbulent jet.

Albertson [1] determined the length of the zone of flow establishment by constructing log-log plots of velocity data versus the streamwise coordinate. The length of the zone of flow establishment was marked at the point of intersection of two lines drawn through data. One line through data in the zone of flow establishment, where the velocity is constant, and the other line through data in the zone of established flow.

A technique developed by Culbreth and Legoff [6] labeled the length of the zone of flow establishment as the inflection point in graphs of the first derivative of splined velocity and turbulence data taken along the centerline of the jet.

Since the centerline velocity begins to decay and the turbulence level increases as the fluid exits the Z.F.E., the various derivatives of these values will amplify the changes and will clearly define points that are of interest.

For velocity data, the length of the zone of flow establishment is taken as the minimum on the graph of the first derivative. For turbulence data, the maximum of the first derivative is located. This is the method used in this experimental thesis.
CHAPTER 4
EXPERIMENTAL SETUP

4.1 Laser Doppler Anemometer and Auxiliary Equipment

A 3-beam, 2-dimensional Laser Doppler Anemometer employing backscatter and the differential Doppler technique, was set up to make flow measurements over a turbulent, buoyant jet. The unit was manufactured by DANTEC, model #55x.

Colinear, multiline light from an argon/ion laser was transmitted through a TEM\(_{00}\) aperture into 2 color-sensitive prisms. These prisms isolated 2 wavelengths from the original beam to create 2 monochromatic beams. These 3 beams were launched into a fiber optic cable (figure 5).

The beams were launched into the cable using optical manipulators allowing the optimization of transmitted laser power. A laser probe with a converging lens was positioned over the axisymmetric jet. The laser beams were transmitted through this probe from the fiber optic cable.

Having passed through the converging lens, the beams intersected at the focal length. Due to the converging lens and the Gaussian nature of the laser beams, the minimum
Figure 5 LDA Schematic
diameter of these beams, beam waist, existed at the point of intersection (the measuring volume). This insured that the optical fringes were not distorted.

The 3 beams were transmitted from the probe in such a way so that 2 beams projected in a horizontal plane and 2 beams projected in a vertical plane. In this way, the original multiline beam could be heterodyned with each of the two monochromatic beams, enabling the Laser Doppler Anemometer to measure velocity in two orthogonal directions.

As a particle in the jet effluent passed through the interference fringes in the measuring volume, it created what is called a Doppler burst. Here, photopulses in 2 different wavelengths of light were created with a varying amplitude. The amplitude of the Doppler burst had a Gaussian distribution due to the Gaussian intensity distribution of the laser beams and, hence, the interference fringes. The Doppler bursts gave information on 2 components of the particle's velocity. These bursts were efficiently focused back into the probe and projected into the fiber optic cable.

When the signals reached the end of the fiber optic cable, they were passed through 2 optical filters to separate the 2 wavelengths of light. Each filter was placed over the input of a photomultiplier tube in order to create separate channels of information corresponding to each
wavelength of light and, hence, each component of velocity. Here, the Doppler burst was converted into a corresponding electric current and sent to a counter/processor which converted the signal into digital information (figure 6).

The processing of data by the counter/processor began once the first few cycles from the Doppler burst (figure 7) passed through a threshold window to insure it possessed a sufficient amplitude. After the minimum number of valid cycles had occurred, the rest of the burst was further validated and then converted into a digital pulse train. The Doppler frequency was then computed by accumulating the digital information in a register and counting the time in which a fixed number of pulses had occurred.

The counter/processor was equipped with high and low pass filters which allowed a desired portion of the frequency spectrum (corresponding to the Doppler burst) to be passed according to the range of velocities expected. The counters also allowed for adjustment of the threshold window and the accuracy of validation. Adjustment of the accuracy of validation was necessary when the turbulence level changed in the flow.

Data acquisition, using the microcomputer, allowed information on Doppler frequencies from each channel to be accumulated and flow statistics to be calculated. The flow velocity was calculated using the Doppler frequency and the
Figure 7
fringe spacing.

Some of the statistics obtained were:

1. average velocity
2. turbulence intensity
3. Reynolds stress

When acquired by serial polling of the DMA interface board on the 80286 computer, data was typically accumulated at rates of 20 to 100 Hz (depending on seeding of the flow and the arrangement of the experiment).

An instrument which facilitated the use of the Laser Doppler Anemometer was a digital oscilloscope. The oscilloscope allowed the quality and frequency of the Doppler bursts to be assessed so that adjustments in the counter/processors could be made to eliminate bias errors. The oscilloscope made it possible to set the high and low pass filters in order to bracket the Doppler frequency.

The LDA was used to obtain 2 and 3 dimensional velocity profiles throughout the axisymmetric jet. Average velocity and turbulence data was computed over a sample size of about 600.
4.2 Traversing Mechanism

A 3-dimensional traversing mechanism was constructed in order to automate the acquisition of data, figure 8. The mechanism was constructed from slotted steel angle, 2 milling tables, 4 ten-turn potentiometers, 4 brass pulleys, nylon coated wire and 4 reversible motors.

A feedback loop was constructed using 4 ten-turn potentiometers (one mounted to each degree of freedom of the milling table), a 5VDC power supply and the 80286 microcomputer. Brass pulleys were machined and glued onto the shafts of each potentiometer so that nylon coated wire could be wrapped around them and connected to the opposite ends of the milling tables. Feedback was achieved from this voltage dividing circuit when 5VDC was applied across the terminals of the potentiometers. In this way, a linear change in voltage was created for each corresponding displacement of the traversing mechanism. This voltage change was measured using data acquisition and translated in the computer to a change in position.

Housings were machined out of aluminum so that the probe of the Laser Doppler Anemometer could be rigidly mounted on the traversing mechanism. The probe was ultimately fastened to the traversing mechanism using a level so that the laser beams would project parallel to the ground.
Figure 8 Experimental Setup
The probe was then aligned with the centerline of the jet by positioning the traversing mechanism so that laser light, emanating from the measuring volume, reflected from a small nail protruding from a PVC end cap on the jet exit. This end cap was turned on a lathe so that the nail could be placed in the center as accurately as possible.

Four high torque reversible motors were attached to the shafts of the milling tables by machining couplings to fit onto the 0.25 inch shafts. Flanges were machined from sheet metal and attached to the milling tables in order to hold the motors in place.

The traversing mechanism was mounted onto a steel frame and anchored to the concrete floor.

4.3 Thermocouple and Temperature Sensor

A type-K microthermocouple probe was mounted onto the arm of the traversing mechanism in a glass capillary tube after the bulk of velocity data was taken. This probe was aligned with the centerline of the jet by positioning the junction of the microthermocouple over the nail. This microthermocouple probe was used to obtain various temperature profiles in the buoyant jet. The approximate junction diameter was 6 mils (150 microns).

A National LM3911 temperature sensor was attached to
the frame of the traversing mechanism and allowed to hang freely. This sensor was used to obtain the ambient room temperature needed in the calculation of the densiometric Froude number.

4.4 Construction of the Axisymmetric Jet Nozzle

Two squirrel cage fans were adapted to channel air flow into a 1 foot section of 4 inch diameter ABS pipe (refer to figure 9). This section was connected to a 1 foot long aluminum pipe that was fitted with a 2 kilowatt heating element. Power to the heating element was controlled with a voltage dividing circuit constructed from nichrome wire.

Heated air entered flexible aluminum/vinyl tubing that made a connection to a 3 foot section of 3 inch diameter PVC pipe. It then again entered the flexible tubing and into a tapered junction to a 3 foot long, 1 inch diameter PVC pipe. This final section served as the nozzle of the jet.

The nozzle was mounted onto a steel frame and anchored to the ground with bolts. A mechanism was constructed to allow the jet to be inclined from 0 to 90 degrees and to rigidly hold the nozzle in position. This structure was also supported by connecting it to the frame of the traversing mechanism with a piece of slotted steel angle.
4.5 Computer and Interfaces

Computer interfaces (figure 10) were constructed in order to allow the computer to control the motors on the traversing mechanism. Four interface circuits were constructed, each with one SN7406 Quad Nand Gate, one SN7400 Hex Buffer, one 100 Ohm quarter-watt resistor, two LED's and four 5 volt SPST Reed Relays. The circuits were soldered onto 55-pin edge connector cards and then connected to a plywood board containing a 20 Volt, 12 Volt and a 5 Volt power supply. This board contained I/O connectors to allow communication to a 12 bit high speed data acquisition card inserted into an 80286 microcomputer. This data acquisition board allowed 2 channels of D/A, 8 channels of differential input A/D, and 16 ports of DIO.

Two interface cards for the Laser Doppler Anemometer were supplied by DANTEC. These cards allowed high speed direct memory access, but since software for data acquisition was not supplied from DANTEC, it had to be written and high speed DMA was not achieved. The data was acquired by the serial polling of the peripheral interface adapter on the microcomputer.
Figure 10 Interface Circuit Diagram
An 80286 microcomputer was used for the data acquisition from the Laser Doppler Anemometer and the feedback loop. All software for data acquisition and automation of the traversing mechanism, was written by the author.
5.1 Calibration of the Traversing Mechanism

After the traversing mechanism was in position, the position feedback circuit was calibrated by notching the milling tables and running the following sequence of steps:

1. The data conversion value was read from the voltage drop across the potentiometer.
2. The traversing mechanism was repositioned after a few inches of displacement.
3. This displacement was measured using a vernier caliper.
4. The new conversion value was read from the computer.
5. The displacement and corresponding change in conversion value were tabulated.
6. Steps 1 through 5 were repeated for the maximum range of each milling table.
7. The average of the conversion values divided by the displacement was calculated and used in the programs to compute the position of the probe.
5.2 Calibration of the Thermocouple and Sensor

The type-K thermocouple and LM3911 temperature sensor were calibrated by placing them in an isothermal bath and reading the temperature from a Platinum RTD (Resistance Temperature Detector). The average value of 500 voltage samples taken at each temperature was calculated. This was done for 20 different temperature values ranging from 23 to 85 degrees Celsius.

A fourth-order polynomial and linear curve fit were made from the data by making a regression analysis. The resulting curve fits had a standard error of about 0.2. The linear curve fit was used in the computer programs because the results were expected to be more accurate in the case where a voltage outside the calibration range was encountered.

Since the LM3911 temperature sensor turned out to be inaccurate, the platinum RTD was used in its place. This was the same device used to calibrate the thermocouple.

5.3 Data Acquisition and Reduction

In the initial part of the experiment, data was obtained from the Laser Doppler Anemometer for the case of a pure, turbulent, vertical jet.

The jet's 2- and 3-dimensional velocity profiles at its
exit were measured by making measurements over a grid of points at 0.25 inches above the nozzle exit. For the construction of the 3-D velocity profile in the jet, 600 velocity and turbulence levels were obtained at 121 points in the traversing grid. The average velocity and standard deviation were calculated at each point. Contours were made from the data to determine if the flow was irregular or contained any swirl.

After the profiles were considered valid, 17 centerline traverses were made for Reynolds numbers ranging from 4,750 to 29,800. This data was normalized and then splined using a cubic spline program. From the inflection point in the graph of the first derivative of velocity and turbulence data with respect to the centerline position, the length of the Z.F.E. was determined and tabulated.

The Reynolds number for each flow was determined using the centerline velocity at the exit and integrating a turbulent velocity distribution over the cross sectional area of the nozzle (equations 3.2, 3.3 and 3.5).

After the velocity data for the pure turbulent jet was taken, heat was added to the flow from a 2 kilowatt heating element and the same procedure as above was repeated for five different Reynolds and Froude numbers. This time both temperature and velocity profiles were made.

The Froude number was calculated using the centerline
temperature at the exit to calculate the average density, using the equation of state for an ideal gas, and by using equation 3.4.

The data was again non-dimensionalized and splined to calculate the length of the Z.F.E.
6.1 Exit Profiles

2- and 3-dimensional velocity and temperature distributions were measured just above the nozzle of the jet. The velocity distribution was compared with a semiempirical formula for a fully developed turbulent flow in a channel [19].

\[
\frac{\bar{U}}{U_0} = 1 - 0.33 \left( \frac{r}{R} \right)^2 - 0.67 \left( \frac{r}{R} \right)^{32}
\]

The comparison is graphed in figure 13 (appendix B). The other profiles including contour plots are graphed in figures 14-22.

The profiles were determined to conform well to the expected distribution in a turbulent, axisymmetric jet. The assumption was made that the jet was fully developed and contained negligible swirl.

The centerline traverses were compared to traverses made by Culbreth and Legoff [6] and found to have similar characteristics.
6.2 The Length of the Zone of Flow Establishment in a Turbulent Jet

From velocity and turbulence data, the length of the zone of flow establishment was determined for a submerged, turbulent, vertical, axisymmetric, pure jet issuing into a quiescent ambient fluid for 17 Reynolds numbers ranging from 4,750 to 29,800.

In the work of Culbreth and Legoff [6], data exists only for low Reynolds numbers, mostly in the laminar region, and the length of the zone of flow establishment was estimated to be inversely proportional to the square root of the exit Reynolds number:

\[
\frac{S_{ZFE}}{D} \sim \frac{351}{\sqrt{Re_D}}
\]

(6.1)

It was found that this equation describes the length of the Z.F.E. incorrectly for turbulent flows.

Data from this experimental thesis was merged with data collected by Culbreth and Legoff and various least squares curve fits were made. A curve fit to the Michaelis-Mentor equation gave the smallest standard error of 2.33 \([S_{ZFE}/D]\) and is given by the equation:
\[
\frac{S_{ZE}}{D} = \frac{5.03 \cdot Re_D}{Re_D - 361}
\]  
(6.2)

This equation is valid for \(450 < Re_D < 30,000\).

The results are graphed in figure 11 and tabulated in appendix C along with data from Culbreth and Legoff [6].

Values of the length of the zone of establishment were taken in a region overlapping data from Culbreth and Legoff. This was in the transition region for laminar and turbulent flows. The values for the length of the zone of flow establishment were found to be in good agreement.

For higher Reynolds numbers, the results are also in good agreement with values given from other sources [4]. These sources give the length of the zone of flow establishment in a turbulent jet ranging from about \(s/D = 4\) to \(s/D = 6\).

6.3 The Length of the Zone of Flow Establishment in a Buoyant Jet

From velocity, turbulence, and temperature data the length of the zone of flow establishment was determined for a submerged, vertical, turbulent, buoyant jet issuing into a quiescent ambient fluid. The results for the length of the Z.F.E. from temperature data were not as consistent as from velocity and turbulence data. However, the temperature data taken from the microthermocouple was very smooth within each
Figure 11 Length of the Zone of Flow Establishment in a Turbulent, Vertical, Axisymmetric Jet
traverse and graphs of the first derivatives of this data were still relatively smooth.

The standard deviation in temperature data collected from the thermocouple was inconsistent and not used. This was due to the time constant of the microthermocouple being too large and data acquisition from the thermocouple being too slow to pick up the relatively fast fluctuations.

Values for the length of the Z.F.E were determined for 5 different Froude and Reynolds numbers. The results are graphed in figure 12 and tabulated in appendix C.
Length of the Zone of Flow Establishment in a Buoyant Jet

Figure 12 Length of The Zone of Flow Establishment in a Buoyant, Vertical, Axisymmetric Jet
CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

7.1 Discussion of the Results

The value for the length of the zone of flow establishment in a submerged, turbulent, axisymmetric, pure jet issuing into a quiescent ambient fluid was found to be an average of about $s/D = 5$ for exit Reynolds numbers of about 5,000 to 30,000. This result verified values given by other works [4] and also allowed a new formula to be developed to correct the one given by Culbreth and Legoff [6].

Data for the vertical buoyant jet was collected at relatively large Froude numbers, over 1,000, and gave results similar to the pure jet values for the length of the Z.F.E. No conclusions were made since the number of centerline traverses was relatively small, 5, and the Froude numbers were relatively high, indicating small buoyancy effects.

The temperature data resulted in smoother curves but less consistent values of the length of the Z.F.E. However, the results indicated that it may be possible to probe the buoyant jet inclined at an angle with a thermocouple to
determine the location of the centerline. This will then make it possible to accurately traverse the centerline and determine the length of the Z.F.E.

The main problem in getting consistent values was that any small deviation in the graph of the centerline distribution of a property is amplified in its derivatives with respect to centerline position, s. This may be smoothed somewhat by a splining program, but there still usually exists ambiguities in the inflection points. For example, there may exist multiple inflections.

This problem may have been caused in part by biasing errors that occurred when the Doppler frequency approached a value close to the bandwidth selected on the high and low pass filters.

7.2 Recommendations for Future Work

1. The results may be made more consistent by making smaller traversing increments, under 0.2 inches, and by taking more than 600 samples per point.

2. The centerline position should be probed from the exit of the nozzle to a value of s/D over 2 times the expected value of the length of the Z.F.E. to insure that the inflection will be accurate.

3. The biasing problem should be corrected either by
using a more advanced processor or by using a hot wire anemometer.

4. Samples should be taken over a sufficient time so that the measured parameters become ergotic (the time average will converge to the actual mean). NOTE: this will usually not be a problem unless data is received at a very high rate.

5. Only accept values from the LDA if the data validation is over 100 per thousand. This is suggested by DANTEC and seems to insure that a bias error is not occurring.

6. When performing experiments on buoyant jets, let the system run for over 45 minutes to reach steady state.

7. The fluid loop should be reconstructed out of a material such as aluminum to withstand the high temperatures needed for low Froude numbers.

8. Good quality seeding could be implemented by injecting chalk dust into the flow from a fluidized bed. Chalk dust seems to create very good quality Doppler bursts.

9. Other methods of determining the length of the Z.F.E. should be developed. For example, the length of the Z.F.E. could be defined in terms of the entrainment rate along the centerline.
BIBLIOGRAPHY


Appendix A -- Error Analysis

Estimate of Uncertainties

Estimates of the uncertainties in measurements were made based on specifications from manufacturers, standard errors from curve fits, and by using the Kline and McClintok method [2]:

\[ u_f = \sqrt{ \left( u_{x_1} \frac{\partial f}{\partial x_1} \right)^2 + \left( u_{x_2} \frac{\partial f}{\partial x_2} \right)^2 + \ldots } \]

where:

- \( f \) is a function of the variables \( (x_1, x_2, \ldots) \)
- \( u_f \) is the uncertainty in \( f \)
- \( u_{x_1} \) is the uncertainty in \( x_1 \)

1. \( V \) +/− 1%
2. \( T.I. \) +/− 1%
3. \( \text{Re}_p \) +/− 3%
4. \( F \) +/− 6%
5. \( x, y, z, s, r \) +/− 0.010 inches
6. \( S_{ZFE} \) +/− 2 [s/D]
7. \( D \) +/− 0.1%
8. \( T \) +/− 0.5%

The uncertainty for the \( S_{ZFE} \) was made based on the standard error of graphs of \( S_{ZFE} \) versus \( \text{Re}_p \). Deviations in this value were due mainly to random variations in the inflection points of graphs of the first derivative of the centerline parameters.
Velocity profile in a Pure, Turbulent Jet
$S / D = 0.25$ - without the ZFE.

Figure 13 2-D Velocity Profile in a Turbulent Jet
Temperature Distribution in a Buoyant Jet
Froude Number = 3,700 / Reynolds Number = 24,160
S / D = 2.5 - Within the Z.F.E.

Figure 14 2-D Temperature Distribution in a Buoyant Jet
Turbulence Distribution in a Pure, Turbulent Jet

\[ S/D = 0.25 \text{ - Without the ZFE} \]

Fractional Turbulence = \( T.I. / V \)

Figure 15 2-D Turbulence Distribution in a Turbulent Jet
Figure 16  Temperature Distribution in a Buoyant Jet
Appendix B - Graphs of Results

Velocity Profile in a Pure, Turbulent Jet
S / D = 0.25 - Within the ZEE.
(121 Data points)

Figure 17  Velocity Distribution in a Turbulent Jet
Figure 18 Centerline Turbulence Distribution in a Pure, Turbulent Jet
Appendix B - Graphs of Results

Figure 19 Centerline Velocity Distribution in a Turbulent Jet
Appendix B — Graphs of Data

Centerline Temperature Distribution in a Buoyant Jet

Froude number = 7,680 / Reynolds Number = 31,870

Figure 20 Centerline Temperature Distribution in a Buoyant Jet
Contour of the Velocity Profile Over a Pure, Turbulent Jet
\[ s/D = 0.25 - \text{within the } \pm \]
Contour of the Temperature Profile in a Buoyant Jet
Froude Number = 3,700 / Reynolds Number = 24,160
s / D = 2.5 - within the z=FE.

Figure 22 Contour Plot of Temperature in a Buoyant Jet
### EXPERIMENTAL DATA

**Pure, Turbulent, Vertical Jet**

**Length of the Zone of Flow Establishment**

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### Data Obtained by Culbreth - Legoff [6]

**Length of the Zone of Flow Establishment**

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### Buoyant, Turbulent, Vertical Jet

**Length of the Zone of Flow Establishment**

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### Pure, Turbulent, Vertical Jet

#### 2-D Velocity Profile at s/D = 0.25

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## Pure, Turbulent, Vertical Jet

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Pure, Turbulent, Vertical Jet

Centerline Velocity Distribution

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## Pure, Turbulent, Vertical Jet

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Appendix C - Tabular Data

Buoyant, Turbulent, Vertical Jet

Centerline Temperature Distribution

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Pure, Turbulent, Vertical Jet

2-D Temperature Profile

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**Buoyant, Turbulent, Vertical Jet**

**3-D Temperature Profile**

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</table>
Appendix D — Program "VelJet"

DECLARE SUB soundout (value!)  
DECLARE SUB presetpos ()  
DECLARE SUB movemotor (motor.value)  
DECLARE SUB centerline (p2(), s.pos)  
DECLARE SUB getdata (x, y, z)  
DECLARE SUB pause ()  
DECLARE SUB nextpoint (x, y, z, c.1, c.2, c.3, c.4,  
    point.count!, p2!)  
DECLARE SUB analog (zchannel.number!, avalue!)  
DECLARE SUB direction (dir$, m.num!)  
DECLARE SUB board.reset ()  
DECLARE SUB digital.out (port!, value!)  
DECLARE SUB setdio (port!)  
DECLARE SUB codes (motor.number!, status$, mvalue!)  
DECLARE SUB position (c.1, c.2, c.3, c.4, x!, y!, z!, mag$)  
DECLARE SUB map (theta!, qx!, qy!, qz!, p2!(), scale!)  
DECLARE SUB startpoint (c.1, c.2, c.3, c.4, j.angle,  
    strt.scale, p2!)  

REM  
REM Jim Ventresca  
REM Fall and Summer 1990  
REM  
REM Program to collect velocity data from the LDA and  
REM traverse along grid or centerline.  
REM  
REM Data is received from the LDA by serial polling of  
REM the 82C55A Programmable Peripheral Interface on the  
REM DMA interface card.  
REM  
REM Feedback is supplied from the potentiometers on the  
REM traversing mechanism.  
REM  
REM The motors are controled using the feedback and the  
REM DIO ports on the Data Translation DT2801-A board.  
REM  
REM The traverse is made using coordinates in the p2()  
REM array. The p0() array in the MAP subprogram supplies  
REM the basis for the matrix operators which in turn  
REM supply the p2() array.  
REM  
REM The p2() array must be selected by uncommenting the  
REM initialization blocks in the MAP subprogram.  
REM
Appendix D — Program "VelJet"

CLS

REM The value DATUM is added to the x position in the following routines and only appears in the output written to the data file.
REM
REM THE X VALUE WRITTEN TO THE SCREEN DOES NOT REFLECT THIS OFFSET VALUE.
REM
LOCATE 4, 10
INPUT "Enter the height above jet exit in inches"; datum

REM Set maxgrid to the number of points in the grid-- (cols. in p0())
REM maxgrid = 1 for a centerline traverse
REM IT WON'T WORK UNLESS YOU SET THIS CORRECTLY!!!!
REM
maxgrid = 1
DIM p2(4, 121)
s.pos = 0

LOCATE 5, 10
INPUT "Enter name for data file"; file$
out$ = "b:\NEWDATA\LD" + file$ + ".dat"
OPEN out$ FOR OUTPUT AS #1

Move to start point manually. Construct the grid.
Scale the grid to the starting size
This is only for the very first grid at the jet exit

'For a vertical jet only
j.angle = 0
strt.scale = .1
CALL startpoint(c.1, c.2, c.3, c.4, j.angle,
strrt.scale, p2())

point.count = 0
jet1:
Appendix D — Program "VelJet"

'Go through all points

WHILE point.count < maxgrid
    point.count = point.count + 1
    Move to next point
    CALL nextpoint(x, y, z, c.1, c.2, c.3, c.4, point.count, p2())

'-------------------
' Collect data
    CALL getdata(x + datum, y, z)
WEND
point.count = 0

'-------------------
' Move to next centerline position
' Calculate angle for the grid (tan theta = y/x)
' Re-calculate the grid points based on new position

    CALL centerline(p2(), s.pos)

'-------------------
'-------------------
    IF (s.pos + datum) >= 15 THEN GOTO jetstop
    GOTO jet1

jetstop:
    CLOSE
    STOP
    END

SUB centerline (p2(), s.pos)

'Calculate the new grid points based on the centrlne position
-------------------
    s.increment = .2
    s.pos = s.pos + s.increment

'Values for a vertical jet only
    s.x = s.pos
    s.y = 0
    s.z = 0
    theta = 0

'-------------------
'scale, translate and rotate the grid according to
Appendix D -- Program "VelJet"

' the
' position along the centerline
CALL map(theta, s.x, s.y, s.z, p2(), .1)

END SUB

SUB movemotor (motor.value)

   CALL setdio(0)
   CALL digital.out(0, motor.value)

END SUB

SUB nextpoint (nx, ny, nz, c.1, c.2, c.3, c.4, point.count, p2())

' Move to next point in the p2() array - grid
'---------------------------------------------------------------
  x.required = p2(1, point.count)
  y.required = p2(2, point.count)
  z.required = p2(3, point.count)

' LPRINT "Array Index (Grid) = ";
' LPRINT USING "###.##"; point.count
'---------------------------------------------------------------
' Dummy
mag$ = ""
'---------------------------------------------------------------
  tol = .01
'---------------------------------------------------------------
' x-direction

   CALL pause
   CALL board.reset
   CALL position(c.1, c.2, c.3, c.4, x, y, z, mag$)
   x.error = x.required - x

xl:   WHILE ABS(x.error) >= tol
     IF x.error > 0 THEN mag$ = "+" ELSE mag$ = "-"
     x.error = x.error - tol
     CALL pause
     CALL board.pos(x, y, z, mag$)
     CALL board.position(x, y, z, mag$)
     CALL board.reset
     CALL position(c.1, c.2, c.3, c.4, x, y, z, mag$)
     CALL pause
     CALL board.pos(x, y, z, mag$)
     CALL board.position(x, y, z, mag$)
     CALL board.reset
     CALL position(c.1, c.2, c.3, c.4, x, y, z, mag$)
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     CALL board.position(x, y, z, mag$)
     CALL board.reset
     CALL position(c.1, c.2, c.3, c.4, x, y, z, mag$)
     CALL pause
Appendix D -- Program "VelJet"

CALL direction("x", m.num)
CALL codes(m.num, mag$, motor.value)
'----------------------
CALL movemotor(motor.value)
soundout (motor.value)
CALL position(c.1, c.2, c.3, c.4, x, y, z, mag$)
'----------------------
x.error = x.required - x
WEND

CALL digital.out(0, 0)
CALL pause
CALL position(c.1, c.2, c.3, c.4, x, y, z, mag$)
x.error = x.required - x
'------
IF ABS(x.error) >= tol THEN GOTO x1

'y-direction

CALL board.reset
CALL position(c.1, c.2, c.3, c.4, x, y, z, mag$)
y.error = y.required - y

y1: WHILE ABS(y.error) >= tol
    IF y.error > 0 THEN mag$ = "+" ELSE mag$ = "-"
    CALL direction("y", m.num)
    CALL codes(m.num, mag$, motor.value)
    '----------------------
    CALL movemotor(motor.value)
    soundout (motor.value)
    CALL position(c.1, c.2, c.3, c.4, x, y, z, mag$)
    '----------------------
    y.error = y.required - y
WEND

CALL digital.out(0, 0)
CALL pause
CALL position(c.1, c.2, c.3, c.4, x, y, z, mag$)
y.error = y.required - y
'------
IF ABS(y.error) >= tol THEN GOTO y1

'z-direction

CALL board.reset
CALL position(c.1, c.2, c.3, c.4, x, y, z, mag$)
z.error = z.required - z
Appendix D — Program "VelJet"

z1: WHILE ABS(z.error) >= tol
   IF z.error > 0 THEN mag$ = "+", ELSE mag$ = "-",
   CALL direction("z", m.num)
   CALL codes(m.num, mag$, motor.value)
   CALL movemotor(motor.value)
   CALL soundout(motor.value)
   CALL position(a, b, c, d, x, y, z, mag$)
   CALL pause
   CALL board.reset
   CALL position(a, b, c, d, x, y, z, mag$)
   'values to write to the data file
   nx = x: ny = y: nz = z

CALL pause
CALL board.reset
CALL position(a, b, c, d, x, y, z, mag$)
'values to write to the data file
nx = x: ny = y: nz = z

CLS
SCREEN 0
COLOR 15, 1

LOCATE 7, 10
PRINT "Grid Point = "; point.count

LOCATE 8, 10
PRINT "The last required points were (x,y,z) ";
PRINT USING " ##.### "; x.required; y.required;
z.required

LOCATE 9, 10
PRINT "x = ";
PRINT USING " ##.### "; x;

PRINT "y = ";
PRINT USING " ##.### "; y;

PRINT "z = ";
PRINT USING " ##.### "; z

'pause
Appendix D -- Program "VelJet"

'pause
pause
'--------------------------------------

END SUB

SUB pause
'Pause for 1 second

st.time = TIMER
WHILE t < 1
  t = (TIMER - st.time)
WEND
END SUB

SUB presetpos
'------------------

CLS
LOCATE 4, 10
  PRINT "Enter the pot values of the desired (0,0,0)
  position"

'------------------

LOCATE 5, 10
k1 = 2035
  PRINT "Pot #1 value = "; k1
LOCATE 6, 10
k2 = 1895
  PRINT "Pot #2 value = "; k2
LOCATE 7, 10
k3 = 3539
  PRINT "Pot #3 value = "; k3
LOCATE 8, 10
k4 = 2533
  PRINT "Pot #4 value = "; k4
PRINT

'------------------

  x.required = 0
  y.required = 0
  z.required = 0

'------------------

'Dummy
  mag$ = ""

Appendix D -- Program "VelJet"

'---------
tol = .01
'---------
x-direction

CALL pause
CALL board.reset
CALL position(k1, k2, k3, k4, x, y, z, mag$)
x.error = x.required - x

px1: WHILE ABS(x.error) >= tol
    IF x.error > 0 THEN mag$ = "+" ELSE mag$ = "-"
    CALL direction("x", m.num)
    CALL codes(m.num, mag$, motor.value)
    CALL movemotor(motor.value)
    soundout (motor.value)
    CALL position(k1, k2, k3, k4, x, y, z, mag$)
    x.error = x.required - x
WEND

CALL digital.out(0, 0)
CALL pause
CALL position(k1, k2, k3, k4, x, y, z, mag$)
x.error = x.required - x

'---------
IF ABS(x.error) >= tol THEN GOTO px1

'---------
y-direction

CALL board.reset
CALL position(k1, k2, k3, k4, x, y, z, mag$)
y.error = y.required - y

py1: WHILE ABS(y.error) >= tol
    IF y.error > 0 THEN mag$ = "+" ELSE mag$ = "-"
    CALL direction("y", m.num)
    CALL codes(m.num, mag$, motor.value)
    CALL movemotor(motor.value)
    soundout (motor.value)
    CALL position(k1, k2, k3, k4, x, y, z, mag$)
    y.error = y.required - y
WEND

CALL digital.out(0, 0)
CALL pause
Appendix D — Program "VelJet"

CALL position(k1, k2, k3, k4, x, y, z, mag$)
y.error = y.required - y
'------------------------
IF ABS(y.error) >= tol THEN GOTO pyl

'------------------------
'z-direction

CALL board.reset
CALL position(k1, k2, k3, k4, x, y, z, mag$)
z.error = z.required - z

pz1: WHILE ABS(z.error) >= tol
    IF z.error > 0 THEN mag$ = "+", ELSE mag$ = "-"
    CALL direction("z", m.num)
    CALL codes(m.num, mag$, motor.value)
    '------------------------
    CALL movemotor(motor.value)
soundout (motor.value)
    CALL position(k1, k2, k3, k4, x, y, z, mag$)
    '------------------------
    z.error = z.required - z
    WEND

CALL digital.out(0, 0)
CALL pause
CALL position(k1, k2, k3, k4, x, y, z, mag$)
z.error = z.required - z
IF ABS(z.error) >= tol THEN GOTO pz1

'------------------------

LOCATE 20, 10
INPUT "Press <Enter> to continue"; dum$
CLS

END SUB

SUB soundout (value)
' 0 >= value <= 255

SOUND (value * 10) + 1000, 1
Appendix D -- Program "VelJet"

SUB startpoint (c.1, c.2, c.3, c.4, j.angle, strt.scale, p2())

'---------------------------------------------------------------
'Move the traverse to the centerline position just
'above the jet exit.
'Read the pot values and set the position to (0,0,0).
'---------------------------------------------------------------
'SCREEN 0
COLOR 15, 1

CLS
LOCATE 4, 10
INPUT "Would you like to start at preset pot-values "; q$
IF LEFT$(q$, 1) = "y" THEN
CALL presetpos
GOTO js1
END IF

CLS
LOCATE 4, 10
PRINT "  Move the probe to the reference position"

LOCATE 5, 10
INPUT "  Direction (x,y,z) "; dir$
LOCATE 6, 10
INPUT "  + or - "; mag$

'Convert (x,y,z) to motor number
CALL direction(dir$, m.num)
'Convert +/- and (x,y,z) to a value for writing to
'digital output
CALL codes(m.num, mag$, motor.value)
CALL soundout(motor.value)

WHILE INKEY$ <> "s"
'Moving the traverse
CALL movemotor(motor.value)
WEND

'Stop Moving
CALL digital.out(0, 0)

LO D E 8, 11
INPUT "Move Again? (y/n)"; q$
IF q$ = "y" THEN 1

js1:
'REad the pots
CALL pause
CALL board.reset

CALL analog(0, p1!)
CALL analog(1, p2!)
CALL analog(2, p3!)
CALL analog(3, p4!)

'Make these values the (0,0,0) position

CALL position(p1!, p2!, p3!, p4!, x, y, z, "+")
c.1 = p1!: c.2 = p2!: c.3 = p3!: c.4 = p4!
'LP RINT "Zero Pots = "; c.1, c.2, c.3, c.4

LOCATE 13, 25
PRINT USING "##.### x; y; z

'Jet angle of inclination = angle of the grid at
'start
'j.angle = jet angle
'strt.scale = scale the 11x11 matrix

'map(theta, qx, qy, qz, output, scale)
'p2() is the transformation of the p0() grid
'p0() is a -5 to 5 grid

'--------------------------------------------
CALL map(j.angle, 0, 0, 0, p2(), strt.scale)
'--------------------------------------------
CLS

END SUB
Appendix D -- Program "VelJet"

DECLARE SUB pause()
DECLARE SUB cerror()
DECLARE SUB analog(channel, value!)
DECLARE SUB board.reset()
DECLARE SUB stopclear()

SUB analog(zchannel.number, avalue!)
' Read data from the A/D ports on the Data Translation data
' acquisition board.

FOR b = 1 TO 700: NEXT b

DEFINT A-Y

BASE.ADDRESS = &H2EC
COMMAND.REGISTER = BASE.ADDRESS + 1
STATUS.REGISTER = BASE.ADDRESS + 1
DATA.REGISTER = BASE.ADDRESS
COMMAND.WAIT = &H4
WRITE.WAIT = &H2
READ.WAIT = &H5
'-------------------
CSTOP = &HF
CCLEAR = &H1
CADIN = &HC
'-------------------
'This is the start of data aquisition
'-------------------

stl: 'Check for legal Status Register.

STATUS = INP(STATUS.REGISTER)
IF NOT ((STATUS AND &H70) = 0) THEN
  'PRINT "Analog: no L.S.R"
  CALL board.reset
  GOTO stl
END IF

'Stop and clear
CALL stopclear

GAIN.CODE = 1
' Write READ A/D IMMEDIATE command.
WAIT STATUS.REGISTER, COMMAND.WAIT
OUT COMMAND.REGISTER, CADIN

' Write A/D gain byte.
WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
Appendix D -- Program "VelJet"

OUT DATA.REGISTER, GAIN.CODE

' Write A/D channel byte.
WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
OUT DATA.REGISTER, zchannel.number

'------------------------
' Read two bytes of A/D data from the Data Out
' Register,
' and combine the two bytes into one word.
WAIT STATUS.REGISTER, READ.WAIT
LOW = INP(DATA.REGISTER)
WAIT STATUS.REGISTER, READ.WAIT
HIGH = INP(DATA.REGISTER)
data.value! = CSNG(HIGH) * 256 + CSNG(LOW)

IF data.value! > 32767 THEN data.value! = data.value! - 65536!

' Check for ERROR.
WAIT STATUS.REGISTER, COMMAND.WAIT
STATUS = INP(STATUS.REGISTER)
IF (STATUS AND &H80) THEN
'PRINT "Analog: error being cleared"
CALL cerror
CALL board.reset
GOTO stl
END IF

'------------------------
avalue! = data.value!
'------------------------
END SUB

DEFSNG A-Y
SUB board.reset

' Reset the A/D board.
'-------------------reset-------------------
DEFINT A-Z

BASE.ADDRESS = &H2EC
COMMAND.REGISTER = BASE.ADDRESS + 1
STATUS.REGISTER = BASE.ADDRESS + 1
Appendix D -- Program "VelJet"

DATA REGISTER = BASE ADDRESS
COMMAND WAIT = &H4
WRITE WAIT = &H2
READ WAIT = &H5

CRESET = &H0
CSTOP = &HF

bsl:

' Check for legal Status Register value.

STATUS = INP (STATUS REGISTER)
IF NOT ((STATUS AND &H70) = 0) THEN
PRINT "Board.Reset: no L.S.R"
CALL cerror
CALL pause
GOTO bsl
PRINT "Problem with reset command"
END IF

' Stop the DT2801.

OUT COMMAND REGISTER, CSTOP
temp = INP (DATA REGISTER)

' Write RESET command.

WAIT STATUS REGISTER, COMMAND WAIT
OUT COMMAND REGISTER, CRESET

' Read ID byte.

WAIT STATUS REGISTER, READ WAIT
CODE BYTE = INP (DATA REGISTER)

' Wait for READY, check ERROR.

WAIT STATUS REGISTER, COMMAND WAIT
STATUS = INP (STATUS REGISTER)
IF (STATUS AND &H80) THEN
' PRINT "Board.Reset: error being cleared"
CALL cerror
GOTO bsl
PRINT "Problem with reset"
END IF

END SUB
Appendix D -- Program "VelJet"

DEFSNG A-Z
SUB stopclear

    BASE.ADDRESS = &H2EC
    COMMAND.REGISTER = BASE.ADDRESS + 1
    STATUS.REGISTER = BASE.ADDRESS + 1
    DATA.REGISTER = BASE.ADDRESS
    COMMAND.WAIT = &H4
    '---------------------
    CSTOP = &HF
    CCLEAR = &H1
    '---------------------

    OUT COMMAND.REGISTER, CSTOP
    temp = INP(DATA.REGISTER)
    WAIT STATUS.REGISTER, COMMAND.WAIT
    OUT COMMAND.REGISTER, CCLEAR

END SUB


Appendix D — Program "VelJet"

DECLARE SUB board.reset ()
DECLARE SUB cerror ()

SUB cerror

    DEFINT A-Z
    BASE.ADDRESS = &H2EC
    COMMAND.REGISTER = BASE.ADDRESS + 1
    STATUS.REGISTER = BASE.ADDRESS + 1
    DATA.REGISTER = BASE.ADDRESS
    COMMAND.WAIT = &H4
    WRITE.WAIT = &H2
    READ.WAIT = &H5
    CCLEAR = &H1
    CSTOP = &HF

    crl:  // Check for legal Status Register.
        STATUS = INP(STATUS.REGISTER)
        IF NOT ((STATUS AND &H70) = 0) THEN
           'PRINT "Cerror: no L.S.R"
           CALL board.reset
           GOTO crl
        END IF

        ' // Stop and clear DT2801.
        OUT COMMAND.REGISTER, CSTOP
        TEMP = INP(DATA.REGISTER)

    ' // Wait Status Register, Command.Wait
        OUT COMMAND.REGISTER, CCLEAR

    ' // Check for ERROR.
        WAIT STATUS.REGISTER, COMMAND.WAIT
        STATUS = INP(STATUS.REGISTER)
        IF (STATUS AND &H80) THEN
           'PRINT "Cerror: error being cleared"
           CALL cerror
           CALL board.reset
           GOTO crl
        END IF

END SUB
Appendix D -- Program "VelJet"

DECLARE SUB mm (a!, b!, c!, rows!, cols!, n!)
DECLARE FUNCTION rads! (theta!)
DECLARE SUB map (theta!, qx!, qy!, qz!, p2(), scale)

SUB map (theta!, qx!, qy!, qz!, p2(), scale)

REM Jim Ventresca
REM June 24, 1990
REM
REM MAP subroutine

DIM p0(4, 121), temp(4, 121)

'-----------------------
' Define the grid points.
' 4 by 121 matrix of points

| x1  x2  x3    x4    ...    xn |
| y1  y2  y3    y4    ...    yn |
| z1  z2  z3    z4    ...    zn |
| 1   1   1     1      ...     1 |

'------This is an 11x11 grid -------
REM
REM THERE ARE 121 POINTS IN THIS ARRAY!!!!
REM
'increment = 1:
' c = 0
' FOR i = -5 TO 5
'   FOR j = -5 TO 5
'       c = c + 1
'       p0(1, c) = scale * (0)
'       p0(2, c) = scale * (j * increment)
'       p0(3, c) = scale * (i * increment)
'       p0(4, c) = 1
'   NEXT j
' NEXT i

'------This is a grid for a 2D traverse over the jet
REM
REM NOTE THE NUMBER OF POINTS IN THE P0() ARRAY
REM
'increment = .5:
' c = 0
' FOR j = -5 TO 5 STEP increment
Appendix D -- Program "VelJet"

\[
C = C + 1
\]
\[
p_0(1, c) = \text{scale} \times (0)
\]
\[
p_0(2, c) = \text{scale} \times (j)
\]
\[
p_0(3, c) = \text{scale} \times (0)
\]
\[
p_0(4, c) = 1
\]
\[
\text{NEXT } j
\]

--- This is a 1 point grid for centerline traverses

REM
REM THERE IS 1 POINT IN THE ARRAY!

\[
p_0(1, 1) = 0
\]
\[
p_0(2, 1) = 0
\]
\[
p_0(3, 1) = 0
\]
\[
p_0(4, 1) = 1
\]

ang = rads(theta)

---

This is the translation transformation matrix

\[
t(1, 1) = 1: t(1, 2) = 0: t(1, 3) = 0: t(1, 4) = qx
\]
\[
t(2, 1) = 0: t(2, 2) = 1: t(2, 3) = 0: t(2, 4) = qy
\]
\[
t(3, 1) = 0: t(3, 2) = 0: t(3, 3) = 1: t(3, 4) = qz
\]
\[
t(4, 1) = 0: t(4, 2) = 0: t(4, 3) = 0: t(4, 4) = 1
\]

---

This is the rotation transformation matrix

\[
r(1, 1) = \cos(\text{ang}): r(1, 2) = -\sin(\text{ang}): r(1, 3) = 0: r(1, 4) = 0
\]
\[
r(2, 1) = \sin(\text{ang}): r(2, 2) = \cos(\text{ang}): r(2, 3) = 0: r(2, 4) = 0
\]
\[
r(3, 1) = 0: r(3, 2) = 0: r(3, 3) = 1: r(3, 4) = 0
\]
\[
r(4, 1) = 0: r(4, 2) = 0: r(4, 3) = 0: r(4, 4) = 1
\]

---

This sequence of routines will rotate then translate the grid
' p2 is the output........p0 is the origanal grid

---

'CHANGE P0.COL WHEN CHANGING GRIDS
'LEAVE THE REST ALONE!!!!!

p0.col = 1: 'This is the number of columns in the p0 matrix

CALL mm(r(), p0(), temp(), 4, p0.col, 4)
CALL mm(t(), temp(), p2(), 4, p0.col, 4)
Appendix D -- Program "VelJet"

FUNCTION rads (theta)
    pi = 3.13159
    rads = pi / 180 * theta
END FUNCTION

DECLARE SUB cerror ()
DECLARE SUB stopclear ()
DECLARE SUB board.reset ()
DECLARE SUB digital.out (port, motor.value)
DECLARE SUB setdio (port)
DECLARE SUB codes (motor.number, STATUS$, motor.value)

SUB codes (motor.number, STATUS$, mvalue)

    IF motor.number = 1 THEN
        IF STATUS$ = "off" THEN mvalue = 0
        IF STATUS$ = "-" THEN mvalue = 1
        IF STATUS$ = "+" THEN mvalue = 2
    END IF

    IF motor.number = 2 THEN
        IF STATUS$ = "off" THEN mvalue = 0
        IF STATUS$ = "-" THEN mvalue = 8
        IF STATUS$ = "+" THEN mvalue = 4
    END IF

    IF motor.number = 3 THEN
        IF STATUS$ = "off" THEN mvalue = 0
        IF STATUS$ = "+" THEN mvalue = 32
        IF STATUS$ = "-" THEN mvalue = 16
    END IF

    IF motor.number = 4 THEN
        IF STATUS$ = "off" THEN mvalue = 0
        IF STATUS$ = "-" THEN mvalue = 64
        IF STATUS$ = "+" THEN mvalue = 128
    END IF
Appendix D -- Program "VelJet"

END SUB

SUB digital.out (port, value)
'
  This subroutine feeds out a value from 0 to 255 to one of the three 1-byte wide digital output ports. (port = 0, 1, or 2) (value = 0 to 255).
'
  DIOPORT = port
  data.value! = INT(value)

'-----------------------
'-----------------------
'    BASE.ADDRESS = &H2EC
'    COMMANDREGISTER = BASE.ADDRESS + 1
'    STATUSREGISTER = BASE.ADDRESS + 1
'    DATAREGISTER = BASE.ADDRESS
'    COMMANDWAIT = &H4
'    WRITEWAIT = &H2
'    READWAIT = &H5
'
'    CCLEAR = &H1
'    CDIOOUT = &H7
'    CSTOP = &HF

'-----------------------
dost:
  STATUS = INP(STATUS.REGISTER)
  IF NOT ((STATUS AND &H70) = 0) THEN
    PRINT "Digital.out: no L.S.R"
    CALL board.reset
    CALL setdio(0)
    GOTO dost
  END IF

'-----------------------
'  Stop and Clear
'  CALL stopclear

'-----------------------
dol:

  IF DIOPORT = 0 THEN
    DIO.DATA0 = data.value!
  END IF

  IF DIOPORT = 1 THEN
    DIO.DATA1 = data.value!
    DIO.DATA0 = data.value!
  END IF
Appendix D -- Program "VelJet"

DIO.DATA2! = DIO.DATA1 * 256 + DIO.DATA0
COMMAND = 0

'--------------------------------------------
'  Write WRITE DIGITAL OUTPUT IMMEDIATE.
'
WAIT STATUS.REGISTER, COMMAND.WAIT
OUT COMMAND.REGISTER, CDIOOUT + COMMAND

'--------------------------------------------
'  Write DIGITAL PORT SELECT byte.
'
WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
OUT DATA.REGISTER, DIOPORT

'--------------------------------------------
'  Write the first data byte.
'
WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
OUT DATA.REGISTER, DIO.DATA0

'--------------------------------------------
'error

WAIT STATUS.REGISTER, COMMAND.WAIT
STATUS = INP(STATUS.REGISTER)
IF (STATUS AND &H80) THEN
   'PRINT "Digital.out: error being cleared"
   CALL cerror
   CALL board.reset
   CALL setdio(O)
   GOTO dol
END IF

END SUB

DEFINT A-Z
SUB setdio (port)
'--------------------------------------------
'  THE FOLLOWING SETS THE PORT "port" FOR OUTPUT
'  Jim V. 6/8/90
'--------------------------------------------

DEFINT A-Z
Appendix D -- Program "VelJet"

BASE.ADDRESS = &H2EC
COMMANDREGISTER = BASE.ADDRESS + 1
STATUSREGISTER = BASE.ADDRESS + 1
DATAREGISTER = BASE.ADDRESS
COMMANDWAIT = &H4
WRITEWAIT = &H2
READWAIT = &H5

CCLEAR = &H1
CSOUT = &H5
CSTOP = &HF

sdl: Check for legal Status Register.

STATUS = INP(STATUSREGISTER)
IF NOT ((STATUS AND &H70) = 0) THEN
   PRINT "Set.dio: no L.S.R."
   CALL board.reset
   GOTO sdl
END IF

Stop and clear the DT2801.
CALL stopclear

DIOPORT = port
Write SET DIGITAL PORT FOR OUTPUT command.

WAIT STATUSREGISTER, COMMANDWAIT
OUT COMMANDREGISTER, CSOUT

Write DIGITAL PORT SELECT byte.

WAIT STATUSREGISTER, WRITEWAIT, WRITEWAIT
OUT DATAREGISTER, DIOPORT

3300 Check for ERROR.

WAIT STATUSREGISTER, COMMANDWAIT
STATUS = INP(STATUSREGISTER)
IF (STATUS AND &H80) THEN
   PRINT "Set.dio: error being cleared"
   CALL cerror
   CALL board.reset
   GOTO sdl
END IF

END SUB
Appendix D -- Program "VelJet"

DECLARE SUB direction (dir$, m.num!)
DECLARE SUB board.reset ()
DECLARE SUB position (c.1, c.2, c.3, c.4, x!, y!, z!, mag$)
DECLARE SUB direction (dir$, m.num)
DECLARE SUB digital.out (port!, value!)
DECLARE SUB setdio (port!)
DECLARE SUB codes (motor.number!, status$, mvalue!)

SUB direction (dir$, m.num)

    SELECT CASE dir$
    CASE IS = "x"
        m.num = 3
    CASE IS = "y"
        m.num = 2
    CASE IS = "z"
        m.num = 4
    CASE ELSE
        'error
        m.num = 0
    END SELECT

END SUB
Appendix D -- Program "VelJet"

DECLARE SUB pause ()
DECLARE SUB dataout (x, y, z, h.ave, h.sigma, v.ave, v.sigma, r.stress, hor(), ver(), time.hor(), time.ver(), imax!, jmax!)
DECLARE SUB getdata (x, y, z)
DECLARE SUB pdata (h.ave, h.sigma, v.ave, v.sigma, r.stress, time.hor(), time.ver(), imax!, jmax!, hor(), ver!, mwin, h.yval(), v.yval())
DECLARE SUB stats (v.time, time.hor(), time.ver(), d1, d2, d3, d4, h.yval(), v.yval(), c$, velocity!, i, j, hor(), ver!, imax, jmax, mwin, inv.samples)
DECLARE SUB param (scw!, imax, jmax, mwin, fr$)
DECLARE SUB fspace (f1, f2)
DECLARE SUB writeout (c$, velocity!, ht.time, vt.time, v.time)
DECLARE SUB translate (nf!, c$, pt!, velocity, f1, f2)
DECLARE SUB setuplda (sew!)
DECLARE SUB readlda (v.time, start.time, dl, d2, d3, d4)
DECLARE SUB processlda (d1, d2, d3, d4, nf, c$, pt, fr$, ht.time, vt.time)

REM Jim Ventresca
REM July 1990
REM Data acquisition from LDA

SUB dataout (x, y, z, h.ave, h.sigma, v.ave, v.sigma, r.stress, hor(), ver(), time.hor(), time.ver(), imax, jmax)

'FOR i = 1 TO imax
 'PRINT #1, time.hor(i), hor(i)
'NEXT i

'FOR j = 1 TO jmax
 'PRINT #2, time.ver(j), ver(j)
'NEXT j

PRINT #1, USING "  ###.## x, y, z, h.ave, h.sigma, v.ave, v.sigma, r.stress";
END SUB
Appendix D -- Program "VelJet"

SUB fspace (f1, f2)

'----------------------------------------
'Counter #1 -- wavelength -- nanometers
green = 514.5
'Counter #2
blue = 488
'----------------------------------------

beam.spacing = .02659
focal.length = .16

theta.over2 = ATN((beam.spacing / 2) / focal.length)

'----------------------------------------
' Fringe spacing in microns

f1 = green / (2 * SIN(theta.over2))
f2 = blue / (2 * SIN(theta.over2))

'----------------------------------------

END SUB

SUB getdata (x, y, z)

SCREEN 0
CLS
COLOR 15, 1

start.time = TIMER

'---------------------
' Enter Parameters
CALL param(scw!, imax, jmax, mwin, fr$)

'---------------------
' Set DMA interface board for input
CALL setuplda(scw!)

'---------------------
' Calculate fringe spacing
CALL fspace(f1, f2)
Appendix D -- Program "VelJet"

\[
\begin{align*}
\text{DIM hor(imax), ver(jmax), h.yval(imax), v.yval(jmax)} \\
\text{DIM time.hor(imax), time.ver(jmax)} \\
\end{align*}
\]

inv.samples = 0
max.time = 3
i = 0
j = 0
cnst = TIMER

WHILE (i <= imax) AND (j <= jmax)
   IF i = imax AND j = jmax THEN GOTO jump
   current.time = TIMER - cnst
   t.samples = inv.samples + i + j
   IF t.samples = 0 THEN t.samples = 1
   percent.valid = (i + j) / t.samples * 100
   LOCATE 23, 21
   PRINT "Percent Valid Samples = "; INT(percent.valid)
   END IF
   IF (current.time > max.time) AND percent.valid < 0 THEN
      bad.flag = 1
      GOTO jump
   ELSE
      bad.flag = 0
      END IF
END IF

\begin{align*}
\text{----- read data} \\
\text{CALL readlda(v.time, start.time, d1, d2, d3, d4)} \\
\text{----- process it} \\
\text{CALL processlda(d1, d2, d3, d4, nf, c$, pt, fr$,} \\
\text{ht.time, vt.time)} \\
\text{----- translate data} \\
\text{CALL translate(nf, c$, pt, velocity, f1, f2)} \\
\text{----- write data to screen} \\
\text{CALL writeout(c$, velocity, ht.time, vt.time,} \\
\text{v.time)} \\
\text{----- Accumulate statistic on data} \\
\text{CALL stats(v.time, time.hor(), time.ver(), d1, d2,} \\
\text{d3, d4, h.yval(), v.yval(), c$, velocity, i, j,} \\
\text{hor(), ver(), imax, jmax, mwin, inv.samples)}
\end{align*}
Appendix D — Program "VelJet"

WEND
jump:

'-----------------------
'----- Reset Board so that a data rate continues to
'register on the counters
           OUT &H301, 3
'-----------------------
'----- Process Data if time has not expired
IF bad.flag = 1 THEN GOTO ldal
CALL pdata(h.ave, h.sigma, v.ave, v.sigma, r.stress,
    time.hor(), time.ver(), imax, jmax, hor(), ver(),
    mwin, h.yval(), v.yval())

ldal:
'---- Write data to file
    IF bad.flag = 1 THEN
        h.ave = 0: h.sigma = 0: v.ave = 0: v.sigma = 0:
        r.stress = 0:
    END IF
    CALL dataout(x, y, z, h.ave, h.sigma, v.ave,
        v.sigma, r.stress, hor(), ver(), time.hor(),
        time.ver(), imax, jmax)
'-----------------------
SCREEN 0
COLOR 15, 1
CLS
END SUB

SUB param (scw!, imax, jmax, mwin, fr$)

'-----------------------

        CLS
'-----------------------
'Right Nibble of Static Control Word
        scw.temp! = 10
'-----------------------
Appendix D -- Program "VelJet"

'Left Nibble of Static Control Word -- Coincidence time
coincidence! = 0
----------------------------------------
SELECT CASE coincidence!
CASE IS = 0
   IF scw.temp! AND 8 = 8 THEN
      ctime = 0
   ELSE
      ctime = 788.66
   END IF
CASE IS = 1
   ctime = 401.6
CASE IS = 2
   ctime = 179.66
CASE IS = 3
   ctime = 159.66
CASE IS = 4
   ctime = 99
CASE IS = 5
   ctime = 90
CASE IS = 6
   ctime = 74.33
CASE IS = 7
   ctime = 71
CASE IS = 8
   ctime = 48
CASE IS = 9
   ctime = 46.33
CASE IS = 10
   ctime = 42.66
CASE IS = 11
   ctime = 41.66
CASE IS = 12
   ctime = 36.66
CASE IS = 13
   ctime = 36
CASE IS = 14
   ctime = 33.66
CASE IS = 15
   ctime = 32.66
CASE ELSE
   ctime = 0
END SELECT

'----------------------------------------

'------------------
'Maximum number of samples for each component
imax = 0: 'Channel 2
Appendix D -- Program "VelJet"

jmax = 600: 'Channel 1
'Maximum velocity allowed in m/s
mwin = 40
'Fixed number of fringes?
fr$ = "y"

'Add coincidence time and turn off DMA
scw! = scw.temp! OR (coincidence! * 16) OR 4

'----------
dma.test = 4 AND scw!
IF dma.test = 4 THEN dma$ = "No DMA " ELSE dma$ = "DMA Enabled "
'----------
co.test = 8 AND scw!
IF co.test = 8 THEN co$ = "No Coincidence "
ELSE
co$ = "Coincidence Enabled "
END IF
'----------
ch1.test = 1 AND scw!
IF ch1.test = 1 THEN ch1$ = "Channel 1 -- Off "
ELSE
ch1$ = "Channel 1 -- On ">
END IF
'----------
ch2.test = 2 AND scw!
IF ch2.test = 2 THEN ch2$ = "Channel 2 -- Off "
ELSE
ch2$ = "Channel 2 -- On ">
END IF
'----------

LOCATE 5, 21
PRINT dma$
LOCATE 6, 21
PRINT co$
LOCATE 7, 21
PRINT "Coincidence Interval = ";
PRINT USING "####.##"; ctime;
PRINT " usecs"
SUB pdata (h.ave, h.sigma, v.ave, v.sigma, r.stress, 
time.hor(), time.ver(), imax, jmax, hor(), ver(), 
mwin, h.yval(), v.yval())

CLS
DIM ibad(imax), jbad(jmax)

max.it = 3
FOR m = 1 TO max.it

'Compute the Averages

sum = 0
FOR i = 1 TO imax
    sum = sum + hor(i)
NEXT i
IF imax <> 0 THEN h.ave = sum / imax

sum = 0
FOR j = 1 TO jmax
    sum = sum + ver(j)
NEXT j
IF jmax <> 0 THEN v.ave = sum / jmax

'Compute the Standard deviation = turbulence
'intensity = RMS value

temp1 = 0
FOR i = 1 TO imax
    temp1 = temp1 + (hor(i) - h.ave) ^ 2
NEXT i

IF imax <> 0 THEN h.sigma = SQR(temp1 / imax)
Appendix D — Program "VelJet"

`tempi = 0
FOR j = 1 TO jmax
    tempi = tempi + (ver(j) - v.ave)^2
NEXT j`

`IF jmax <> 0 THEN v.sigma = SQR(tempi / jmax)`

`IF m = max.it THEN
    GOTO stp
END IF`

`ibc = 0: jbc = 0`

`h.rlim = h.ave + (3 * h.sigma)
v.rlim = v.ave + (3 * v.sigma)
h.llim = h.ave - (3 * h.sigma)
v.llim = v.ave - (3 * v.sigma)`

`FOR i = 1 TO imax
    IF (hor(i) > h.rlim) OR (hor(i) < h.llim) THEN
        ibc = ibc + 1
        ibad(i) = 1
    END IF
NEXT i`

`FOR j = 1 TO jmax
    IF (ver(j) > v.rlim) OR (ver(j) < v.llim) THEN
        jbc = jbc + 1
        jbad(j) = 1
    END IF
NEXT j`

`it = 0
FOR i = 1 TO imax
    IF ibad(i) <> 1 THEN`
Appendix D -- Program "VelJet"

it = it + 1
hor(it) = hor(i)
time.hor(it) = time.hor(i)
END IF
NEXT i

imax = imax - ibc

______________________________
jt = 0
FOR j = 1 TO jmax
  IF jbad(j) <> 1 THEN
    jt = jt + 1
    ver(jt) = ver(j)
time.ver(jt) = time.ver(j)
  END IF
NEXT j

jmax = jmax - jbc

'-----------------------------------
hb.cnt = hb.cnt + ibc
vb.cnt = vb.cnt + jbc

NEXT m

stp:

'-----------------------------------
' Compute the Reynolds stress
'-----------------------------------

IF imax <> 0 AND jmax <> 0 THEN
  tempi = 0
  IF imax < jmax THEN m = imax ELSE m = jmax
  FOR i = 1 TO m
    u.prime = hor(i) - h.ave
    v.prime = ver(i) - v.ave
    tempi = tempi + (u.prime * v.prime)
  NEXT i
  r.stress = tempi / m
END IF

CLS
SCREEN 9
COLOR 15, 1
Appendix D -- Program "VelJet"

PSET (10, 20)
DRAW "R610; D150; L610; U150;"

PSET (10, 175)
DRAW "R610; D150; L610; U150;"

LOCATE 3, 16
PRINT USING "####.## h.ave;"
PRINT "(m/s) U.bar -- Horizontal Component;"

LOCATE 14, 16
PRINT USING "####.## 1 1 ;  v.ave;"
PRINT "(m/s) V.bar -- Vertical Component;"

'-------------------------------------------------------------

" Horizontal Component

IF imax <> 0 THEN
    VIEW (180, 45)-(380, 145), , 15
    WINDOW (0, 0)-(mwin, imax)
    FOR i = 1 TO imax
        LINE (INT(hor(i)), h.yval(INT(hor(i))))-(INT(hor(i)),
    NEXT i
END IF

'-------------------------------------------------------------

" Vertical Component

IF jmax <> 0 THEN
    VIEW (180, 200)-(380, 300), , 15
    WINDOW (0, 0)-(mwin, jmax)
    FOR j = 1 TO jmax
        LINE (INT(ver(j)), v.yval(INT(ver(j))))-(INT(ver(j)),
    NEXT j
END IF

'-------------------------------------------------------------

LOCATE 12, 23
PRINT "0"
LOCATE 12, 30
PRINT "Vel (m/s)"

LOCATE 12, 45
PRINT mwin

LOCATE 5, 49
PRINT USING "##.##"; h.sigma;
PRINT "  m/s - Turb. Intensity"

'-----------------------------------------------

LOCATE 23, 23
PRINT "0"

LOCATE 23, 30
PRINT "Vel (m/s)"

LOCATE 23, 45
PRINT mwin

LOCATE 16, 49
PRINT USING "##.##"; v.sigma;
PRINT "  m/s - Turb. Intensity"

'-----------------------------------------------

LOCATE 17, 50
PRINT "R. Stress = ";
PRINT USING "##.###"; r.stress;
PRINT " (mA^2/s^2)"

LOCATE 6, 50
PRINT "R. Stress = ";
PRINT USING "##.###"; r.stress;
PRINT " (mA^2/s^2)"

'-----------------------------------------------

LOCATE 7, 50
PRINT "Samples kicked Out = "; hb.cnt

LOCATE 18, 50
PRINT "Samples kicked Out = "; vb.cnt

CALL pause:
'CALL pause:
'CALL pause:
'CALL pause:
Appendix D -- Program "VelJet"

'CALL pause:

SCREEN 0
CLS

END SUB

SUB processlda (d1, d2, d3, d4, nf, c$, pt, fr$, ht.time, vt.time)

'----------------------
'Number of fringes
IF fr$ = "y" OR fr$ = "Y" THEN
    nf = 8
ELSE
    nf = d1
END IF
'----------------------

    d2.temp$ = HEX$(d2)
    a$ = LEFT$(d2.temp$, 1)
    b$ = RIGHT$(d2.temp$, 1)
    length = LEN(d2.temp$)

    IF length = 2 AND a$ = "8" THEN
        counter$ = "Horizontal"
    ELSEIF (length = 1) THEN
        counter$ = "Vertical"
    END IF

    IF length > 2 THEN counter$ = "Invalid"
    IF length < 1 THEN counter$ = "Invalid"
    IF length = 2 AND a$ <> "8" THEN counter$ = "Invalid"
    IF d3 > 3 THEN counter$ = "Invalid"

    c$ = counter$

'----------------------
    a$ = RIGHT$(d2.temp$, 1)

SELECT CASE a$
    CASE IS = "A"
        byte = 10
Appendix D -- Program "VelJet"

CASE IS = "B"
    byte = 11
CASE IS = "C"
    byte = 12
CASE IS = "D"
    byte = 13
CASE IS = "E"
    byte = 14
CASE IS = "F"
    byte = 15
CASE ELSE
    byte = VAL(a$)
END SELECT

passage.exponent = byte

passage.mantissa = (d3 * 256) + d4

p = passage.mantissa * (2 ^ (passage.exponent))

'This time is in nanoseconds
passage.time = .125 * p

pt = (passage.time)

IF LEFT$(c$, 1) = "H" THEN ht.time = pt
IF LEFT$(c$, 1) = "V" THEN vt.time = pt

END SUB

SUB readlda (v.time, start.time, d1, d2, d3, d4)

base.address = &H300
pa = base.address + 0: 'data
pb = base.address + 1: 'mode selection

' read 4 bytes

d1 = INP(pa)
Appendix D -- Program "VelJet"

\[
\begin{align*}
d2 &= \text{INP}(pa) \\
d3 &= \text{INP}(pa) \\
d4 &= \text{INP}(pa)
\end{align*}
\]

\[
\begin{align*}
\text{'-----------------------------} \\
v.time &= \text{TIMER} - \text{start.time} \\
\text{'-----------------------------} \\
\text{END SUB}
\end{align*}
\]

SUB setuplda (scw!)

\[
\begin{align*}
\text{'-----------------------------} \\
\text{base.address} &= \&H300 \\
pa &= \text{base.address} + 0: \text{'data} \\
pb &= \text{base.address} + 1: \text{'mode selection} \\
pc &= \text{base.address} + 2: \text{'control input/output} \\
control &= \text{base.address} + 3: \text{'control the port functions} \\
\text{'-----------------------------} \\
\text{LOCATE 3, 21} \\
\text{PRINT} \text{"Static Control Word = "; scw!}
\end{align*}
\]

\[
\begin{align*}
\text{'Program board for Port A -- input, Port B -- output} \\
\text{OUT control, 181}
\end{align*}
\]

\[
\begin{align*}
\text{'RESET board} \\
\text{OUT pb, 3}
\end{align*}
\]

\[
\begin{align*}
\text{'Set board for Coincidence interval and Counters.} \\
\text{OUT pb, scw!}
\end{align*}
\]

\[
\begin{align*}
\text{'Enable DMA} \\
\text{'OUT control, 9}
\end{align*}
\]

\[
\begin{align*}
\text{'-----------------------------}
\end{align*}
\]

END SUB

SUB stats (v.time, time.hor(), time.ver(), d1, d2, d3, d4,
Appendix D -- Program "VelJet"

h.yval(), v.yval(), c$, velocity, i, j, hor(), ver(), imax, jmax, mwin, inv.samples)

IF (LEFT$(c$, 1) = "H") AND (i < imax) AND (velocity < mwin) THEN
  i = i + 1
  LOCATE 22, 20
  PRINT i;
  PRINT " Number of Channel 2 (valid) Samples"

  hor(i) = velocity
  time.hor(i) = v.time
  h.yval(INT(hor(i))) = h.yval(INT(hor(i))) + 1

ELSEIF (LEFT$(c$, 1) = "V") AND (j < jmax) AND (velocity < mwin) THEN
  j = j + 1
  LOCATE 21, 20
  PRINT j;
  PRINT " Number of Channel 1 (valid) Samples"

  ver(j) = velocity
  time.ver(j) = v.time
  v.yval(INT(ver(j))) = v.yval(INT(ver(j))) + 1

ELSEIF LEFT$(c$, 1) = "I" THEN

  LOCATE 18, 20
  inv.samples = inv.samples + 1
  PRINT " Number of Invalid Data Samples ";
  PRINT inv.samples
  'LOCATE 19, 21
  'PRINT HEX$(d1); " "; HEX$(d2); " "; HEX$(d3);
  " "; HEX$(d4)

END IF

END SUB

SUB translate (nf, c$, pt, velocity, f1, f2)

  IF LEFT$(c$, 1) = "H" THEN
Appendix D — Program "VelJet"

fringe.spacing = f2
ELSEIF LEFT$(c$, 1) = "V" THEN
  fringe.spacing = f1
END IF

IF pt <> 0 THEN velocity = (nf / pt) * (fringe.spacing)

END SUB

SUB writeout (c$, velocity, ht.time, vt.time, v.time)
'-----------------------------------
'Horizontal Component
IF LEFT$(c$, 1) = "H" THEN
  LOCATE 12, 20
  PRINT " "; c$; " Cptn. (m/s)"
  LOCATE 12, 45
  PRINT USING "####.## "; velocity

  LOCATE 13, 20
  PRINT " Transit time usecs "
  LOCATE 13, 45
  PRINT USING " #.#### "; ht.time / 1000

'-----------------------------------
'Vertical Component
ELSEIF LEFT$(c$, 1) = "V" THEN
  LOCATE 15, 20
  PRINT " "; c$; " Cptn. (m/s)"
  LOCATE 15, 45
  PRINT USING "####.## "; velocity

  LOCATE 16, 20
  PRINT " Transit time - usecs "
  LOCATE 16, 45
  PRINT USING " #.#### "; vt.time / 1000

'-----------------------------------
Appendix D -- Program "VelJet"

'Bad data
ELSE
',
END IF
'-----------------------------------

END SUB
Appendix D -- Program "VelJet"

DECLARE FUNCTION rtimc! (a!(), b!(), i!, j!, n!)
DECLARE SUB mm (a!(), b!(), c!(), rows!, cols!, n!)

REM  c = product of a and b

'----------------------
REM  Jim Ventresca
REM  June 23, 1990
REM
REM  Multiply two Matrices

'----------------------

SUB mm (a(), b(), c(), rows, cols, n)

    FOR i = 1 TO rows
        FOR j = 1 TO cols
            c(i, j) = rtimc(a(), b(), i, j, n)
        NEXT j
    NEXT i

END SUB

FUNCTION rtimc (a(), b(), i, j, n)

    sum = 0

    FOR l = 1 TO n
        sum = sum + (a(i, l) * b(l, j))
    NEXT l

    rtimc = sum

END FUNCTION
Appendix D — Program "VelJet"

DECLARE SUB potalarm (pot!, value!)
DECLARE SUB digital.out (port!, value!)
DECLARE FUNCTION trans (c.1, c.2, c.3, c.4, valuea!, pot, valueb!, mag$)
DECLARE SUB analog (zchannel.number!, avalue!)
DECLARE SUB board.reset ()
DECLARE SUB position (c.1, c.2, c.3, c.4, x, y, z, mag$)

COMMON SHARED lpot1!, lpot2!, lpot3!, lpot4!

SUB position (c.1, c.2, c.3, c.4, x, y, z, mag$)

' x,y,z in inches
'---------------------------------
' read the 4 pots
ps1:

    CALL analog(0, pot1!)
    CALL analog(1, pot2!)
    CALL analog(2, pot3!)
    CALL analog(3, pot4!)

'---------------------------------

'Check for Bad Values

IF lpot1! = 0 THEN lpot1! = pot1!
IF lpot2! = 0 THEN lpot2! = pot2!
IF lpot3! = 0 THEN lpot3! = pot3!
IF lpot4! = 0 THEN lpot4! = pot4!

IF ABS(pot1! - lpot1!) >= 50 THEN
    'LPRINT "Possible D/A error"
    CALL board.reset
    lpot1! = pot1!
    GOTO ps1
ELSE lpot1! = pot1!
END IF

IF ABS(pot2! - lpot2!) >= 50 THEN
    'LPRINT "Possible D/A error"
    CALL board.reset
    lpot2! = pot2!
    GOTO ps1
ELSE lpot2! = pot2!
END IF

IF ABS(pot3! - lpot3!) >= 50 THEN
    'LPRINT "Possible D/A error"
    CALL board.reset
    lpot3! = pot3!
Appendix D -- Program "VelJet"

GOTO ps1
ELSE lpot3! = pot3!
END IF

IF ABS(pot4! - lpot4!) >= 50 THEN
  'LPRINT "Possible D/A error"
  CALL board.reset
  lpot4! = pot4!
  GOTO ps1
ELSE lpot4! = pot4!
END IF

'-----------------------------
LOCATE 15, 25: PRINT "  p1  p2  p3  p4"
LOCATE 16, 25
PRINT USING "  ####  ?; pot1!; pot2!; pot3!; pot4!

'-----------------------------
' translate the values the coordinates in the system
x = trans(c.1, c.2, c.3, c.4, pot4!, 4, 0, mag$)
y = trans(c.1, c.2, c.3, c.4, pot2!, 2, 0, mag$)
z = trans(c.1, c.2, c.3, c.4, pot3!, 3, pot1!, mag$)

'-----------------------------
END SUB

SUB potalarm (pot, value)

FOR i = 1 TO 10
  SOUND 40, 1
  SOUND 4000, 1
NEXT i

LOCATE 2, 4
PRINT "Motor Has Gone Too Far -- ERROR -- Pot # "; pot; " "; value

'LPRINT "Motor Has Gone Too Far -- ERROR -- Pot # "; pot; " "; value

STOP
Appendix D -- Program "VelJet"

END SUB

FUNCTION trans (c.1, c.2, c.3, c.4, valuea!, pot, valueb!, mag$)

' Converts raw A/D data to position in inches

'------------------------
' (c.n) pot values for the (0,0,0) position of the probe
' (m.n) linear transformation constants (inches)

m.1 = 305.1:  ' for pot 1 -- motor 1 -- z dir
m.2 = 304.5:  ' for pot 2 -- motor 2 -- y dir
m.3 = 292.8:  ' for pot 3 -- motor 4 -- z dir
m.4 = 299.4:  ' 8/7/90 -- for pot 4 -- motor 3

-- x dir

'------------------------
pot2.highlim = 2785
pot2.lowlim = 1144

'------------------------
pot3.highlim = 4090
pot3.lowlim = 2828

'------------------------
pot4.highlim = 3149
pot4.lowlim = 50

'------------------------
SELECT CASE pot

CASE IS = 2
  ' y value

  '------------------------
  IF (valuea! >= pot2.highlim) AND (mag$ = "+")
  THEN
    CALL digital.out(0, 0)
    CALL potalarm(pot, valuea!)
  END IF

  IF (valuea! <= pot2.lowlim) AND (mag$ = "-"
  THEN
    CALL digital.out(0, 0)
    CALL potalarm(pot, valuea!)
  END IF

  '------------------------
  trans = (valuea! - c.2) / m.2
Appendix D -- Program "VelJet"

CASE IS = 4
' x value
'-----------------------------------------------
IF (valuea! >= pot4.highlim) AND (mag$ = "-") THEN
  CALL digital.out(0, 0)
  CALL potalarm(pot, valuea!)
END IF
IF (valuea! <= pot4.lowlim) AND (mag$ = "+") THEN
  CALL digital.out(0, 0)
  CALL potalarm(pot, valuea!)
END IF
trans = (-1) * (valuea! - c.4) / m.4
CASE IS = 3
' z value
'-----------------------------------------------
IF (valuea! >= pot3.highlim) AND (mag$ = "+") THEN
  CALL digital.out(0, 0)
  CALL potalarm(pot, valuea!)
END IF
IF (valuea! <= pot3.lowlim) AND (mag$ = "-") THEN
  CALL digital.out(0, 0)
  CALL potalarm(pot, valuea!)
END IF
'-----------------------------------------------
temp1 = (valuea! - c.3) / m.3
temp2 = (valueb! - c.1) / m.1
trans = temp1 + temp2
CASE ELSE
  STOP
END SELECT

END FUNCTION
Appendix E -- Programs "GHdata" and "GYdata"

REM Jim Ventresca
REM Summer and Fall 1990
REM
REM This program accepts data from the HEATJET program
REM
REM Program to ready data for splining, graphing and to
REM estimate the Reynolds Number

CLS
DIM x(100), t.bar(100), tur(100)

'----------------------------------------
INPUT "file "; file$
in$ = file$ + ".dat"
OPEN in$ FOR INPUT AS #1

tmpout$ = "d:\jim\graphs\q" + MID$(file$, 3, 6) + ".dat"
OPEN tmpout$ FOR OUTPUT AS #2

turbout$ = "d:\jim\graphs\r" + MID$(file$, 3, 6) + ".dat"
OPEN turbout$ FOR OUTPUT AS #3

'----------------------------------------
d.jet = 1.023

i = 0
WHILE NOT EOF(1)
i = i + 1
INPUT #1, x(i), y, z, t.bar(i), tur(i)

PRINT #2, USING 
"####.##"; x(i) / d.jet,
t.bar(i) / t.bar(1)
PRINT #3, USING 
"####.##"; x(i) / d.jet,
tur(i) / t.bar(i)

WEND
max = i

'----------------------------------------
COLOR 15, 1
CLS
LOCATE 4, 10
PRINT "Number of Samples = "; max

LOCATE 5, 10
PRINT "File = "; file$

CLOSE
Appendix E -- Programs "GHdata" and "GVdata"
Appendix E — Programs "GHdata" and "GVdata"

Jim Ventresca
Summer and Fall 1990

This program accepts data from the VELJET subprogram
Program to ready data for splining, graphing and to
estimate the Reynolds Number

CLS
DIM x(100), v.bar(100), v.tur(100)

'-----------------------------------------------
INPUT "file "; file$
in$ = file$ + ".dat"
OPEN in$ FOR INPUT AS #1

vout$ = "d:\jim\graphs\v" + MID$(file$, 3, 6) + ".dat"
OPEN vout$ FOR OUTPUT AS #2

tout$ = "d:\jim\graphs\t" + MID$(file$, 3, 6) + ".dat"
OPEN tout$ FOR OUTPUT AS #3

'-----------------------------------------------
d.jet = 1.023

i = 0
WHILE NOT EOF(1)
i = i + 1
INPUT #1, x(i), y, z, u.bar, u.tur,
v.bar(i), v.tur(i), r.stress

WEND
max = i

v.exit = v.bar(1)

FOR i = 1 TO max
n.pos = x(i) / d.jet
n.vel = v.bar(i) / v.exit
f.tur = v.tur(i) / v.bar(i)

PRINT #2, USING ":.## "; n.pos; n.vel
PRINT #3, USING ":.## "; n.pos; f.tur

NEXT i
Appendix E -- Programs "GHdata" and "GYdata"

'-------------------------------------------------
COLOR 15, 1
CLS
LOCATE 4, 10
PRINT "Number of Samples = "; max
LOCATE 5, 10
PRINT "File = "; file$
CLOSE
END
Appendix F — Program "LenZFE"

DECLARE SUB flatc()

REM Written by Jim Ventresca - August 1990
REM
REM This is a smoothing cubic spline program written
REM originally by Helmuth Spath and adapted to calculate
REM the length of the zone of flow establishment in a
REM jet.
REM
REM The input file should have two columns of data:
REM column 1 contains values of S/D
REM column 2 contains either v/v.exit data or turbulence
REM data
REM
REM The array "p()" holds the weights for each spline
REM
REM '-------------------------------------
REM COMMON SHARED n, x(), u(), p(), a(), b(), c(), d(),
y2()

max = 60
DIM x(max), u(max), p(max), y2(max)
DIM a(max), b(max), c(max), d(max)

st: COLOR 15, 1
CLS

'-------------------------------------
INPUT "Input Filename "; file$
infile$ = "d:\jim\spline\temp\" + file$ + ".dat"
outfile$ = "d:\jim\spline\temp\" + file$ + ".dat"

OPEN infile$ FOR INPUT AS #1
OPEN outfile$ FOR OUTPUT AS #2

'-------------------------------------
data.type$ = LEFT$(file$, 1)
PRINT "Data Type = "; data.type$

INPUT "Weight Factor (k): <500>"; k.con
IF k.con = 0 THEN k.con = 500

' 'These are the weights
FOR k = 1 TO max
  p(k) = k.con
NEXT k
Appendix F -- Program "LenZFE"

'----------------------------------------
'Read the data from a file
  k = 0
  WHILE NOT EOF(1)
    k = k + 1
    INPUT #1, x(k), u(k)
    'PRINT x(k), u(k)
  WEND
  n = k
'----------------------------------------

'Spline fit the data
CALL flatc

'----------------------------------------
'Find the inflections in the first derivative
  minflection = c(1): maxflection = c(1)
  FOR i = 1 TO n
    test = c(i)
    IF test < minflection THEN
      minflection = test
      index.min = i
    END IF
    IF test > maxflection THEN
      maxflection = test
      index.max = i
    END IF
  NEXT i
'----------------------------------------

'Print S/D, splined and smoothed data, first
derivative, second der.
  FOR k = 1 TO n
    PRINT #2, USING "#####.##; d(k); c(k); y2(k)
  NEXT k
'----------------------------------------

'Plot the data on screen
pmax = 0
pmin = 0
  FOR i = 1 TO n
    t1 = d(i)
    t2 = c(i)
    t3 = y2(i)
Appendix F — Program "LenZFE"

IF t1 > pmax THEN pmax = t1
IF t2 > pmax THEN pmax = t2
IF t3 > pmax THEN pmax = t3

IF t1 < pmin THEN pmin = t1
IF t2 < pmin THEN pmin = t2
IF t3 < pmin THEN pmin = t3

NEXT i

SCREEN 9
COLOR 15, 4
CLS

ymin = pmin: ymax = pmax
xofs = 90: yofs = 70

WINDOW (x(1), ymin)-(x(n), ymax)
VIEW (30 + xofs, 30 + yofs)-(400 + xofs, 200 + yofs), 8, 15
LINE (x(1), 0)-(x(n), 0), 7

'splined and smoothed data
PSET (x(1), d(1))
FOR i = 1 TO n
  LINE -(x(i), d(i)), 1
NEXT i

'Data that was splined
FOR i = 1 TO n
  PSET (x(i), u(i)), 15
NEXT i

'First derivative
PSET (x(1), c(1))
FOR i = 1 TO n
  LINE -(x(i), c(i)), 14
NEXT i

'Second derivative
PSET (x(1), y2(1))
FOR i = 1 TO n
  LINE -(x(i), y2(i)), 12
NEXT i

'Line to the minimum of the first derivative
PSET (x(index.min), minflection), 15
LINE -(x(index.min), d(index.min)), 2
Appendix F — Program "LenZFE"

'Line to the maximum of the first derivative
PSET (x(index.max), maxflection), 15
LINE -(x(index.max), d(index.max)), 2

LOCATE 3, 10: PRINT "Data Points = white dots"
LOCATE 4, 10: PRINT "Splined Curve = blue"
LOCATE 5, 10: PRINT "First Derivative = yellow"
LOCATE 6, 10: PRINT "Second Derivative = red"
LOCATE 21, 10: PRINT "Minimum Inflection at s/D = ";
   x(index.min)
LOCATE 22, 10: PRINT "Maximum Inflection at s/D = ";
   x(index.max)

'Calculate the length of the zone of flow establishment
IF (LEFT $(data.type$, 1) = "v" OR LEFT $(data.type$, 1) = "q") THEN
   s.zfe = x(index.min)
ELSE
   s.zfe = x(index.max)
END IF

LOCATE 23, 10: PRINT "S.ZFE = " ; s.zfe

LPRINT file$; " (" ; data.type$ ; " data) s.zfe = ";
LPRINT USING " ##.## "; s.zfe;
LPRINT " inches (k = "; k.con; ")"

CLOSE
END

SUB flatc

'-----------------------------------------------
max = 60
DIM y(max), dx(max)
y2(1) = 0: y2(n) = 0
'-----------------------------------------------
eps = .0005
ww = 1
ww1 = 0
nl = n - 1
Appendix F -- Program "LenZFE"

n2 = n - 2

\[ c(1) = 0 \]
\[ d(1) = 0 \]

rr1 = y2(1)

rr2 = y2(n)

b(1) = 0

b(n) = 0

\[ dx(n) = 1 \]

\[ h1 = x(2) - x(1) \]

\[ dx(1) = h1 \]

FOR k = 2 TO n1

\[ h2 = x(k + 1) - x(k) \]

\[ dx(k) = h2 \]

\[ d(k) = \frac{1}{(2 * (h1 + h2) - h1 * h1 * d(k - 1))} \]

\[ h1 = h2 \]

NEXT k

2

FOR k = 1 TO n

\[ y2(k) = 0 \]

\[ y(k) = u(k) \]

NEXT k

4

\[ w = ww \]

\[ w1 = 1 - w \]

FOR k = 1 TO n1

\[ h2 = dx(k) \]

\[ r2 = (y(k + 1) - y(k)) / h2 \]

IF k = 1 THEN GOTO 5

\[ h = 6 * (r2 - r1) \]

IF k = 2 THEN h = h - h1 * b(1)

IF k = n1 THEN h = h - h2 * b(n)

\[ c(k) = d(k) * (h - h1 * c(k - 1)) \]

\[ h1 = h2 \]

\[ r1 = r2 \]

NEXT k

5

b(n1) = c(n1)

IF n1 <= 2 THEN GOTO 8

FOR j = 2 TO n2
Appendix F — Program "LenZFE"

\[
k = n - j \\
b(k) = c(k) - d(k) \times dx(k) \times b(k + 1)
\]

NEXT j

8

FOR k = 2 TO n1
\[
b(k) = w \times b(k) + w1 \times y2(k)
\]
NEXT k

j1 = 1
h5 = 0

FOR k = 1 TO n
j2 = k + 1
IF k = n THEN j2 = n
\[
h = (((b(j2) - b(k)) / dx(k)) - (b(k) - b(j1)) / dx(j1)) / p(k)
\]
IF w = 1 THEN a(k) = -h
IF w <> 1 THEN a(k) = w * (u(k) - h) + w1 * y(k)

h5 = h5 + ABS(a(k))
j1 = k

NEXT k

h5 = 1 / h5

IF w <> 1 THEN GOTO 13

h1 = 0
h2 = 0

FOR k = 1 TO n
h = y(k)
h1 = h1 + a(k) * h
h2 = h2 + h * h

NEXT k

ww2 = h1 / h2

IF ABS(ww2 - wwl) < (eps * ABS(ww2)) THEN GOTO 12

ww1 = ww2
GOTO 15

12

ww = 2 / (1 + SQR(1 - ww2))
b(1) = rrl
Appendix F -- Program "LenZFE"

\[ b(n) = \pi r^2 \]
GOTO 2

13
\[
\begin{align*}
h2 &= 0 \\
h3 &= 0 \\
h4 &= 0
\end{align*}
\]

FOR k = 1 TO n
\[
\begin{align*}
h2 &= h2 + \text{ABS}(a(k) - y(k)) \\
h3 &= h3 + \text{ABS}(b(k)) \\
h4 &= h4 + \text{ABS}(b(k) - y2(k))
\end{align*}
\]
NEXT k

IF (h2 * h5 + h4 / h3) < eps THEN
GOTO 17
ELSE
LOCATE 2, 55
PRINT USING "####.#### "; (h2 * h5) + (h4 / h3)
END IF

h5 = 1

15
FOR k = 1 TO n
\[
\begin{align*}
y2(k) &= b(k) \\
y(k) &= a(k) \times h5
\end{align*}
\]
NEXT k

GOTO 4

17
FOR k = 1 TO n1
\[
\begin{align*}
j2 &= k + 1 \\
d(k) &= a(k) \\
a(k) &= (b(j2) - b(k)) / (6 \times dx(k)) \\
c(k) &= (a(j2) - d(k)) / dx(k) \times dx(k) \times (b(j2) + 2 \times b(k)) / 6 \\
b(k) &= 0.5 \times b(k)
\end{align*}
\]
NEXT k

\[ d(n) = a(n) \]
\[ b(n) = 0.5 \times b(n) \]

END SUB