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Experimental investigation of spanwise blowing on a 40 degree swept trapezoidal wing

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swept trapezoidal wing**

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San Jose State University, 1994

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EXPERIMENTAL INVESTIGATION OF SPANWISE BLOWING
ON A 40 DEGREE SWEPT TRAPEZOIDAL WING

A Thesis
Presented to
The Faculty of the Department of
Aerospace Engineering
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
Stephane L. Couillaud
May, 1994

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ABSTRACT

EXPERIMENTAL INVESTIGATION OF SPANWISE BLOWING ON A 40 DEGREE SWEPT TRAPEZOIDAL WING

by Stephane L. Couillaud

The concept of spanwise blowing was applied to a 40 degree swept trapezoidal wing in the 7- by 10- foot wind tunnel at NASA -Ames Research Center. A surface oil flow, schlieren optics, pressure sensitive paint and a laser Doppler velocimeter were used to study the effects of spanwise blowing on the flowfield of this wing. The results indicate that spanwise blowing helps in reattaching the flow and reestablishing a healthy leading-edge vortex on the upper surface of the wing, therefore increasing the lift. A panel code was also used to predict the aerodynamic characteristics of the wing for the case of no jet blowing. The code predictions agree with the measured values of the zero-lift angle and the lift-curve slope of the wing. Velocity predictions, however, tend to be lower than the measured values because viscous effects are not taken into account in the code.

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Special thanks to all those people, both from NASA & San Jose State University, who contributed in this investigation. A list of names of those who participated in the work presented here, would only result in an additional chapter. However, I wish to extend my thankfulness to two people, Mr. Richard Margason and Dr. Nikos Mourtos, for their effort to guide me through it all.

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NOMENCLATURE

English letter symbols:

A	coating sensitivity coefficient
B	coating sensitivity coefficient
B_{JK}	velocity potential influence coefficient at control point of panel J due to a uniform distribution of unit source on panel K
c	chord
CBAR	reference chord used for normalizing pitching moment
C_{JK}	velocity potential influence coefficient at control point of panel J due to a uniform distribution of doublet on panel K
C_L	total lift coefficient
C_{Lmax}	maximum lift coefficient
C_p	pressure coefficient
d	fringe spacing
dS	differential surface element on configuration
f_D	frequency of Doppler shift signal
$I_{\infty,0}$	luminescence at wind-off condition
I	luminescence at wind-on condition
N	number of cycles
$\bar{n}$	unit normal vector to surface
N_S	total number of surface panels
N_W	total number of wake panels
$p_{\infty,0}$	pressure at wind-off condition
p	pressure at wind-on condition
P	arbitrary point in space
q_j	jet dynamic pressure
q_{∞}	free stream dynamic pressure
RCORES	surface panel core radius
RCOREW	wake panel core radius
$\vec{r}$	vector between an arbitrary point P and a surface element dS
S	surface of the configuration

S_∞	imaginary surface at infinity
t	time
T	duration of an integral number N of cycles of the Doppler signal
u	streamwise velocity component
v	spanwise velocity component
V_e	effective velocity ratio, $V_e = \sqrt{\frac{\rho_\infty \cdot V_\infty^2}{\rho_j \cdot V_j^2}} = \sqrt{\frac{q_\infty}{q_j}}$
V_j	jet velocity
V_{norm}	velocity normal to the surface
V_∞	tunnel velocity
$\bar{V}_{\sigma_{PK}}$	velocity influence coefficient at point P due to a uniform distribution of unit source on panel K
$\bar{V}_{\mu_{PK}}$	velocity influence coefficient at point P due to a uniform distribution of unit doublets on panel K
$\bar{V}$	velocity vector
W	wake surface
w	downwash velocity component
x, y, z	Cartesian coordinates
X, Y, Z	Cartesian axes

Greek letter symbols:

Δt	time increment
λ	laser light wavelength
m	doublet singularity strength per unit area
F	total velocity potential
ρ	density
s	source singularity strength per unit area
q	angle between signal beam and reference beam

Subscripts:

i	interior region
-----	-----------------

j	jet
J	panel J or its control point
K	panel K or its control point
L	lower surface
o	off conditions
P	arbitrary point in space
w _L	wake lower surface
∞	freestream conditions

Abbreviations:

CCD	Charged Couple Device
FLAC	(Fighter Lift And Control)
GVS	General Visualization Software
LDV	Laser Doppler Velocimetry
LV	Laser Velocimeter
LVABI	Laser Velocimeter (Autocovariance) Buffer Interface
MRF	Multi Role Fighter
PC	Personal Computer
PMARC	Potential Method Ames Research Center
PSP	Pressure Sensitive Paint
S/N	Signal to Noise ratio
UV	Ultraviolet

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CHAPTER 1

INTRODUCTION

1.1 Motivation

At moderate to high angles of attack, the flow over a thin highly swept wing separates at the leading edge and forms a stable vortex over the wing. Such a vortex produces large vortex-lift increments. However, for moderately swept back wings, vortex breakdown occurs at rather low angles of attack. One remedy currently being investigated at the NASA-Ames Research Center 7- by 10- foot wind tunnel is that of spanwise blowing. Earlier experiments have found that spanwise blowing enhances the aerodynamic characteristics of moderately swept back wings at high angles of attack. This concept is applied and studied with the aid of a laser Doppler velocimeter on a 40 degree swept trapezoidal wing set at an angle of attack of 20 degrees with respect to the free stream. To further understand the action of spanwise blowing, pressure sensitive paint, schlieren optics, and surface oil flow visualization were used to analyze qualitatively the behavior of the flow about the wing. Finally, a panel method code (PMARC) was used to duplicate the results obtained experimentally in the wind tunnel for the case of no jet blowing.

1.2 Previous Work

The concept of strengthening and stabilizing the leading edge vortex of a delta wing planform by means of spanwise blowing has been studied by numerous investigators. Spanwise blowing originated in 1967 from studies performed at the Aerospace Science Research Laboratory of the Lockheed-Georgia Company at a time when vortex phenomena were being investigated[1-3]. Since then, it has been shown that lift augmentation by means of spanwise blowing is dependent on several factors. For instance, nozzle location and jet thrust coefficient have shown to affect the vortex lift augmentation [4]. Vortex enhancement is also dependent on the type of wing planform used. The case was documented for three different wing planforms (arrow, delta, and diamond) where it was found that wings with lower sweep angles generated more lift [5]. Other experiments have shown longitudinal aerodynamic performance by spanwise blowing to compare favorably with the performance of a wing strake [6]. Research by

Campbell [7] on a 44 degree swept trapezoidal wing showed spanwise blowing to be highly effective in delaying stall through a range of angles of attack and in improving the induced-drag polars. A more recent experiment [8], concerned with the stability and control of a current fighter using spanwise blowing, reinforced the importance of nozzle location, thrust coefficient, and wing planform.

1.3 Present Approach

The present spanwise blowing investigation, conducted in the wind tunnel, was performed on a wing planform resembling that of a proposed Multi Role Fighter (MRF), namely, a trapezoidal wing with a 40 degree leading edge sweep (Fig 1.1). The investigation consisted of the following three parts:

(1) Three flow visualization techniques were used to observe the flow on the upper surface of the wing: (a) Surface oil flow visualization: This technique involves dots of a mixture of oil and paint pigment, applied over the upper surface of the wing to observe the interaction of the leading edge vortex with the jet. (b) Schlieren optics: This technique helped to identify density gradients in the region of the jet. (c) Pressure sensitive paint: This is a recently developed technique that allowed to record pressure variations on the upper surface of the wing.

(2) Velocities near the wing were measured using a laser Doppler velocimeter (LDV). Two configurations were of special interest: one with the jet off and one with the jet blowing perpendicular to the root chord and near the leading edge of the wing to reinforce the leading edge vortex. Those velocity measurements were used to determine quantitatively part of the flowfield near the wing.

(3) Finally, a panel method was used to calculate velocities in the vicinity of the wing without a jet blowing and the results were compared with the velocities measured by the LDV system mounted in the test section of the 7- by 10- foot wind tunnel.

CHAPTER 2

SURFACE OIL FLOW VISUALIZATION

2.1 Tunnel Test Conditions

The experimental investigation was conducted in the NASA-Ames Research Center Low Speed Wind Tunnel. This facility has a closed throat, a single-return circuit operating at atmospheric pressure and a 7- by 10- foot test section [9]. The tunnel is powered by a motor generating 1600 hp such that airspeeds in the test section can reach close to 280 mph. Cooling is achieved by an air exchange tower. The test model, in this case the semi-span wing, was bolted to a ground plane which in turn was welded to the floor of the test section (Fig 2.1).

The test conditions varied with the flow visualization technique employed. The dynamic pressure in the wind tunnel remained constant at 12 lb/ft² (575 N/m²), corresponding to a Mach number of 0.09 and consequently, a Reynolds number, based on the mean aerodynamic root chord, equal to 1.54×10^6 . The effective velocity ratio Ve was 0.250 for the jet-on case.

2.2 Experimental Setup

For oil flow visualization a Plexiglas wing, originally built for the LDV experiment, was used. Plexiglas was chosen to permit propagation of the laser beams aimed through the wing, as will be explained in the LDV chapter. The geometry of the wing is configured much like the F-22 Fighter where both the leading edge and trailing edge of the wing have 40 degrees of sweep and a wing tip swept 7.18 degrees (Fig.2.2). This special sweep allows the airplane to evade radar by concentrating its limited radar response in four lobes well clear of the line of flight [10]. The low aspect ratio wing is trapezoidal in shape with a sharp leading edge and trailing edge. The root chord measures 3.58 feet and is one inch thick. The wing was held by two 2"x 2"x 1/4 " angle irons bolted to each side of the wing root chord. Both angle irons were bolted to an already existing ground plane built for a previous test [11] (Fig. 2.3). The wing was

positioned at an angle of 20 degrees with respect to the free stream to simulate an angle of attack. The ground plane, consisting of plywood enclosed by two aluminum sheets, measured 48" by 54" and was supported by four streamlined legs, bolted to the ground plane and welded to the floor. In addition, a streamlined brace was designed to support the ground plane and counteract the lift generated by the wing. A detailed stress analysis was done and is available as NASA Job Order No. T7509 Test Request No. 215 "Spanwise Blowing".

The plenum chamber was mounted below the ground plane enclosed in a fairing shaped like a symmetrical airfoil. The fairing consisted of a thin sheet of metal held by small angle irons bolted to the ground plane and to the floor.

2.3 Description and Methodology

To visualize quickly the streamlines on the surface of a model placed in a wind tunnel, a technique called surface oil flow visualization is often used. This method was of particular assistance for adjusting the jet to blow along the leading edge all the way to the tip of the wing. This method proved particularly handy in comparing qualitatively the surface flow patterns with the jet on and the jet off.

Drops, consisting of a mixture of oil and paint pigment, were applied on the upper surface of the Plexiglas wing to visualize the streamlines. Previous experiments have shown the best ratio of paint to oil to be two to one. This ratio is such that the oil will act as a vehicle for the paint pigment. Special care was taken to obtain pigments that would not only glow under ultraviolet lights but also mix in the presence of oil. For this purpose, Day-Glo® fluorescent pigments belonging to the T series were found to best suit the task.

Another important aspect of the surface oil flow technique revolved around the choice of oil. Because the wing was set vertically on top of the ground plane a highly viscous oil had to be applied to avoid dripping by the pull of gravity. Yet, the viscosity had to be low enough to allow the oil to act as a carrier for the paint when the tunnel was turned on. For this reason, regular gear oil (SAE-90) was chosen over other oils for its adequate viscosity.

Three different colors, from the Day-Glo® T-series pigment, were chosen: T-19 Horizon Blue, T-13 Rocket Red, and T-17 Saturn Yellow. The advantage of applying dots of different colors helped enhance the contrast of the final pattern. The droplets

were applied with the end of a toothpick, in line, chordwise, and spaced regularly about an inch apart. The diameter of the dots varied anywhere from 1/10 of an inch to 1/5 of an inch, but the distance between the droplets is determined by the experimenter. As a rule of thumb a denser line of droplets is advantageous near a stagnation line or near a region of separation where more information is needed. On the other hand, regions of the wing where the flow was more uniform required fewer dots.

Again to enhance the contrast, lines of dots alternated in color. For instance, a line of red dots was started at the wing tip, followed by a line of blue dots about an inch below then one line of yellow dots. The procedure was repeated until the whole wing or specific areas of the wing were covered.

To fluoresce the paint pigments on the model, lighting was provided by a set of ultraviolet lights positioned outside the test section of the 7- by-10- foot wind tunnel (Fig.2.4). The first lamp, clamped outside and above the test section, shone directly down through a Plexiglas window. The second U.V. light, set on a tripod outside the test section, shone through the Plexiglas side-window onto the upper surface of the wing. To improve visualization of the fluorescent dots of paints the tunnel lights and exterior lights remained turned off throughout the test.

Once the appropriate areas of the Plexiglas wing were covered with dots, the wind tunnel was immediately turned on to the desired speed to avoid run off of the droplets. The same procedure also applied when both the nozzle and the wind tunnel had to be turned on simultaneously. Once the tunnel was on condition the dots were allowed approximately 2 minutes to settle. But in most cases the tunnel (and the nozzle if it applied) was left on until no movement of the droplets was recorded by the human eye.

To record the pattern left by the flow over the wing, the tunnel (and the nozzle in the case it was on) was shut off. A photograph of the imprint on the wing, left by the oil streaks, was taken with a 35 mm camera mounted on a tripod using 1000 ASA film. After wiping off the oil smears from the model and re-applying new oil/pigment dots, the same procedure was repeated for the next test condition.

2.3.2 Results and Observations

Due to time constraints in the schedule of this investigation a limited number of conditions were recorded. The turn around time to test one set of conditions required anywhere from 45 minutes to 1 hour. This included preparing the model or wing with

the dots, bringing the tunnel to condition, observing the developing pattern on the upper surface of the wing, bringing down the tunnel, taking pictures of the wing and cleaning the model to ready it for the next set of conditions. For this reason, three separate sets of test conditions were performed two of them being identical to test for the consistency of the method.

The first test condition was recorded at a dynamic pressure of 12 lb/ft^2 with the jet off. From the color photograph (Fig. 2.5), one can observe two distinct regions. To facilitate visualization of the flow over the wing, the pattern was reproduced in figure 2.6. Region one is located at the tip of the wing and extends from the very tip of the wing to roughly a distance measuring one third of the span towards the root chord. Region two can be observed slightly behind the leading edge. Very little movement of the dots was observed in these regions, indicating separated flow. Furthermore, one can notice two separate stagnation lines running in a chordwise direction. The first one is located near the root chord two inches above the edge of the angle iron supporting the wing to the ground plane. The second stagnation line is located approximately two thirds down the span. From the above observations, it is seen that the wing is almost entirely stalled: a result expected for a trapezoidal wing with a sharp leading edge at high angle of attack.

The second test condition required the jet-on with a tunnel dynamic pressure of 12 lb/ft^2 and an effective velocity ratio of 0.250. From figure 2.7 an improvement in the flow can readily be observed particularly in the tip region of the wing. Again to facilitate the description of the flow over the wing an additional diagram is provided, separating the different regions of interest (Fig.2.8). From the figures a smaller separation region is present and is depicted as region one near the trailing edge of the wing. Likewise, well developed spanwise flow is observed in the region of the jet (region #2) where flow is fully attached. Adjacent streamlines such as the one found along the leading edge are entrained in a spanwise direction towards the jet due to the presence of a low pressure area. This low pressure area is typical for the core of a high speed jet. A similar phenomenon can be seen roughly at the midchord where the flow is also entrained into the jet (region #3). However, some of the flow downstream from the jet reattaches to the wing and flows streamwise (region #4). These two regions are separated by a reattachment line normal to the root chord. In effect, the free stream air goes over a step (the jet acts like a step) and reattaches itself downstream from the stagnation line. Figure

2.9 shows a close up of the stagnation line caused by the free stream air overcoming the step.

For reproducibility, the same set of test conditions was repeated for the case of jet-on. Figure 2.10 shows identical features as described in the above paragraph, thus showing the effectiveness of using surface oil flow visualization. Furthermore, by comparing the case of jet-off to jet-on, a net improvement of the flow is observed. By visual observation, the wing appears less stalled when subjected to a jet of air blowing spanwise towards the tip of the wing.

CHAPTER 3

SCHLIEREN OPTICS

3.1 Tunnel Test Conditions

The wind tunnel test conditions were very similar those tested during the surface oil flow visualization described in the previous chapter. The tunnel dynamic pressure was kept constant at 12.0 lbf/ft² while the effective velocity ratio V_e ranged from 0.076 to 0.275. The lowest value of V_e attained, allowed observation of shock waves in the plume of the jet.

3.2 Theory

Schlieren systems in general are used either for detecting density gradients or for detecting optical inhomogeneities that might be present in optical components [12] .

A slit source placed in the front focal plane of mirror 1 causes a collimated beam to proceed toward mirror 2 (Fig. 3.1). The second mirror produces an image of the light source in its back focal plane and the object is imaged as a silhouette on the viewing screen. Since the object and its image are conjugate points, any ray leaving a point in the object plane has to proceed to its conjugate point in the image plane. If the object is transparent and contains no density gradients, then all rays from all points will proceed parallel to the optics axis as dictated by the incoming parallel beam from the first mirror. These rays, after reflecting off of the second mirror, proceed through the image of the slit at the focal point and onto the viewing screen. If a density gradient is present in the object plane the rays passing through that region will be deflected, but must still arrive at the same (conjugate) point in the image plane. This means they no longer pass through the focal point of the second mirror. If a screen surrounds the focal point allowing only the undeviated rays through, then the deviated rays will be blocked by the screen resulting in a darkening of the conjugate point. Consequently, refractive index gradients can be visualized in the image plane.

3.3 Experimental Setup

The 7- by 10- foot wind tunnel optical system resembled a Z schlieren system (Fig 3.1). The light source consisted of a strobe light, Strobex model 236, shining through a positive lens, followed by a vertical slit. The resulting beam of light was then passed through a set of projector lens unto a mirror to reflect the light to the first concave mirror.

The first concave mirror measured 17.5" in diameter and had a focal length equal to 6.56'. The light was then collimated through the wind tunnel test section to a second concave mirror (same specification as the first mirror) located across the test section. The collimated beam, between the two mirrors, was aimed through the two optical glass side windows of the test section. Furthermore, the light beam passed through the Plexiglas wing and above the nozzle located midway between the two side windows. The region above the nozzle in effect consisted the object plane of interest for this test.

The light bouncing off the second mirror was brought to a focus at the knife edge. By adjusting the height of the knife edge, part of the deflected rays described earlier were essentially blocked off. The remaining light which passed through to the camera was then collected on a photographic plate to record the visible refractive index gradients in the region above the jet. The Schlieren system was set up to record only the portion of the wing in the region of the jet.

3.4 Results & Observations

The schlieren investigation covered eight different conditions, corresponding to eight different effective velocity ratios. The different values of V_e tested are listed in the last section of table 1 under schlieren run. From the table, it is observed that the tunnel dynamic pressure was kept constant at 12 lb/ft². However, the dynamic pressure of the jet was varied.

The first condition was tested at a V_e of 0.250 to confirm the path taken by the jet exiting the nozzle from the quarter-chord point (Fig 3.2). The free stream air flows from right to left on all the schlieren pictures taken. From the picture, one can observe a turbulent jet exiting the nozzle parallel to the leading edge of the wing (the leading edge of the wing shows up as a dark rectangular shade at a 40 degree angle near the right edge of the picture). The picture confirms the results obtained with the surface oil flow

visualization technique, namely that the plume of the jet flows parallel to the leading edge of the wing. The picture also reveals the existence of small vortices located at the edge of the plume. These vortices appear as bold lines snaking inboard and parallel to leading edge of the wing. The dark fringes running parallel to the root-chord of the wing are believed to be caused by the windows of the test section, in addition to the Plexiglas of the wing. Such fringes could be the result of variation in the index of refraction of the materials used for the windows and the wing. The dark concentric circles to the left of the picture is the byproduct of the optics used to guide the light source.

In figure 3.3, the plume of the jet is blown further back compared to the previous figure. This is explained by the fact that the jet's dynamic pressure was reduced to increase the magnitude of V_e with a constant free stream dynamic pressure. The higher the magnitude of V_e the more the plume is bent back by the free stream air flowing above the upper surface of the wing. Notice the addition of two black dots to the right and left of the jet plume. These dots are caused by the centers of the two concave mirrors used to collimate the light.

All subsequent conditions were taken by decreasing the effective velocity ratio in increments of roughly 0.025, however, only those pictures of interest are discussed and displayed in this section. Figure 3.4, denoted as condition 6 in table 1, was shot at a V_e of 0.150. The plume of the jet is starting to overshoot the leading edge of the wing. This was accomplished by raising the dynamic pressure of the jet. Figure 3.5 shows the jet completely over-shooting the leading edge of the wing at a V_e of 0.115. In these photographs, one observes the disappearance of the small vortices mentioned earlier on figures 3.2 and 3.3. The two bursts right above the nozzle appear to be the near formation of shock disks in the plume of the jet. The jet is almost choked.

Finally, Figure 3.6 shows the formation of shock waves or shock disks in the core of the jet. The shocks appear as a series of five equally spaced bright lines nearly perpendicular to the jet trajectory. Also of interest is the presence of parallel hair-like dark lines running along the leading edge of the wing planform. The author remains unclear about their meaning.

The schlieren set up proved a useful tool to not only visualize the jet on the upper surface of the wing, but also to confirm the results obtained with oil flow visualization in positioning the plume of the jet parallel to the leading edge of the wing. The additional test conditions confirmed the expected behavior of the jet as the effective velocity ratio was decreased.

CHAPTER 4

PRESSURE SENSITIVE PAINT

4.1 Tunnel Test Conditions

Unlike the surface oil flow visualization, the pressure sensitive paint experiment was run through a limited set of increasing dynamic pressures, to enable the use of the special paint. The lowest dynamic pressure was 75 lb/ft^2 and the highest 100 lb/ft^2 , corresponding to a Reynolds number (based on the mean aerodynamic chord) which ranged from 3.84×10^6 to 4.43×10^6 respectively. The effective velocity ratio V_e varied from a low value of 0.153 to as high as 0.351. This investigation was also performed in the 7- by 10- foot wind tunnel, with no changes to the model except for the substitution of the metal wing coated with the pressure sensitive paint (PSP) for a Plexiglas wing. The metal wing was structurally stronger for the high tunnel velocities required for the test.

4.2 Theory

Wind tunnel models usually require the use of pressure taps and transducers to measure the local pressure at discrete points. However, a recent joint effort by engineers at NASA-Ames Fluid Mechanics Lab and the chemistry department of the University of Washington have introduced an inexpensive tool to measure pressures with a so-called pressure sensitive paint (PSP) [13]. Briefly, this method involves painting certain areas of a wing or fuselage. When illuminated with ultraviolet lights the paint luminesces in proportion to the partial pressure of oxygen applied on its surface. The image is then recorded with a charged couple device (CCD) camera and stored in a digitized form on a personal computer. Finally, a false color pressure mapping of the painted surface was generated using an Iris workstation.

The barometric paint contains molecules of platinum octaethylporphyrin (PtOEP) dispersed in Genessee GP-197 polymer binder. These molecules are sensitive to ultraviolet light and are identified as probe molecules. By illuminating the paint with

ultraviolet light the probe molecules are excited to a higher energy state. Essentially, an electron located in the ground state absorbs a photon and is elevated to a higher energy state (Fig 4.1). Because electrons in such electronic state are rather unstable, the extra energy is then lost by either two processes: fluorescence and phosphorescence. Fluorescence occurs rapidly in the span of 10^{-9} to 10^{-7} seconds, where electrons transition from the first excited singlet state to the singlet ground state. On the other hand, phosphorescence has a longer life of 10^{-3} to 100 sec and arises from a triplet-singlet transition. On returning to the ground state, however, some electrons collide with oxygen molecules thereby releasing the excess energy. This absorption by the oxygen molecules is called dynamic quenching. Consequently, as the number of oxygen molecules increases, the luminescence decreases due to a shortage in emitted photons and inversely, as the number of oxygen molecules decreases, the luminescence increases. Because the paint luminesces in proportion to the surface pressure, regions of low brightness are associated with high pressures (oxygen molecules are present in large quantities) and brighter areas with low pressures.

To relate the observed intensity measurements to the corresponding pressures the Stern-Volmer equation, shown below, is used.

$$\frac{I_{\infty,0}}{I} = A + B \frac{P}{P_{\infty,0}} \quad (4.1)$$

The variables $I_{\infty,0}$ and $p_{\infty,0}$ refer to wind-off condition whereas I and p are measured during wind-on condition. The coating sensitivity coefficients A and B are dependent on pressure and temperature. They are evaluated by taking the ratio of an image taken at two different pressure conditions. Typically, the ratio of wind-on condition to that taken in still air (or wind-off) is taken for a paint sample set in a pressure/temperature chamber. In a tunnel environment similar to the one encountered in this investigation, periodical recalibration of the paint is required due to the long exposure to UV light. UV light tends to degrade the luminescent property of the paint which in turn requires proper recalibration to avoid measuring spurious data.

The PSP has several advantages over the more common pressure taps. While taps measure pressures at discrete points on an aerodynamic surface, the PSP permits a complete mapping of the entire surface. Consequently, no-time is spent in transferring the database into a computer and interpolating between points as would be the case with

pressure taps data. Instead, the engineer can obtain close to real time pressure maps on a model surface. Furthermore, because the paint is applied like an ordinary paint, this method is far more cost effective and less time consuming. Pressure taps have the disadvantage of relying on a complex network of plastic tubing, transducers, and usually require extensive modification to the model.

4.3 Experimental Setup

Because the PSP required running at higher tunnel q_∞ 's, an aluminum wing was substituted for the Plexiglas one. The metal wing was structurally stronger. Before installation, in the 7- by 10- foot wind tunnel test section, the wing was sprayed with two different coats of paint. To increase the luminescence intensity signal recorded by the camera the wing was first sprayed with an epoxy based white enamel spray paint (Krylon glossy white No. 91501) prior to the application of PtOEP. Application of the white paint also reduced the presence of unwanted high contrast features that would normally show through the translucent PSP. Next the surface was carefully spray coated with a thin layer of PSP (5 to 15 μm) with the aid of an airbrush. After application of both paints the wing looked pink in appearance .

Previous tests have shown that oil contaminates the PSP [14,15]. Oil fluoresces when exposed to the UV light and consequently introduces errors in the pressure measurements. Because the plenum chamber contained oil to seed the tunnel for the LDV measurements performed for a previous test (unrelated to this investigation), the plenum chamber and nozzle were cleansed with a mixture of soap and water. The container previously filled with oil was replaced by the soap water mixture and blown out repeatedly four to five times until the air blown out the nozzle was judged to be free of oil. Furthermore, rubber gloves were required during the installation of the wing to avoid leaving any oil residue naturally found on a person's skin.

Some additional hardware located outside the test section of the wind tunnel was required to record the pressure intensity patterns on the surface of the wing. The wing was illuminated uniformly with a set of seven Electrolite ELC 250 ultra violet lamps through the optical glass wall of the test section. The UV lamps emitted in the 360nm region and were filtered to cut off wavelength in the visible spectrum. The PSP data was acquired with a standard CCD camera. The model used in this test was a Pulnix TM740 CCD video camera with an f1.4/16 mm lens. Like the UV light the camera was fitted

with a band-pass interference filter to insure only the passage of the paint's 650nm emission wavelength. The camera was linked to a PC 80386 using a Data Translation DT2861 framegrabber board. The digitized images were recorded with a spatial resolution of 512x480 pixel and an eight bit grey level resolution. Because the video monitor appended to the PC was used for both viewing the recorded images and for data processing, a second video monitor was plugged into the camera to observe the intensity pattern at all time (Fig. 4.2).

4.4 Methodology:

The PSP test plan was divided into three runs corresponding to three different tunnel dynamic pressures, 75 lb/ft², 90 lb/ft², and 100 lb/ft² respectively. Furthermore, each run was subdivided into various values of V_e (Table 1.). First the new wing was tested through a series of tunnel q_∞ 's to visually analyze the strength of the wing. The tunnel was slowly brought to a q_∞ of 50 lb/ft² and gradually increased to a peak of 100 lb/ft² where the wing showed no hints of structural failure or any sign of unwanted vibrations. The structural analysis was performed with the jet off and no PSP data was taken during that time.

The first run was performed at a dynamic pressure of 100 lb/ft² with the jet on whereas V_e varied from 0.190 to 0.350, in increments of 0.050. Data acquisition for individual values of V_e required only a few seconds - the time to take a picture and record it digitally on the PC's hard disk. Once, the desired values of V_e were recorded the jet was turned off and a picture was recorded. Next the tunnel was temporarily shut down to allow the PSP operators to take a picture of the wing during flow off condition. This last step was deemed important to recalibrate the paint for the post data processing phase.

The procedure was repeated for the same conditions (tunnel q_∞ and V_e) to check for consistency in the data acquisition. The next run was done at a lower dynamic pressure of 75 lb/ft², while V_e varied from 0.153 to 0.243. A jet off picture was taken followed by a picture under no flow condition to account for the degradation of the paint. The last run was performed at a constant dynamic pressure of 90 lb/ft² while varying the effective velocity ratio from 0.164 to 0.314. The last two pictures taken were with the jet off/tunnel on and both jet/tunnel off.

4.5 Results and Observations

Pictures of the wing taken at a free stream dynamic pressure of 100 lb/ft^2 were pasted together for comparison (Fig. 4.3). The following array of pictures is organized with the highest value of V_e at the top left hand corner of the page and the lowest value at the bottom right hand corner of the page. This particular set up helps visualize the behavior of the jet as the effective velocity ratio is decreased. Color denotes different pressure levels: red areas on the wing represent regions of low pressure whereas blue areas represent areas of high pressure.

The second picture of the wing, where $V_e = 0.351$, clearly shows the jet exiting the nozzle at the quarter chord point. As expected, the jet plume impinging on the upper surface of the wing shows up as a region of low pressure spanning from the root chord to roughly $3/4$ of the span. Also noticeable on the same wing is the formation of a leading edge vortex starting at the root chord and flowing inboard and parallel to the leading edge. Regions of higher pressure are present near the root chord and are represented by blue patches on the upper surface. These patches would agree with the surface oil flow pictures discussed in chapter 2, where stagnation regions were identified at those exact same locations.

The following set of wings shows a progression of the jet as V_e is decreased or similarly as the dynamic pressure of the jet is increased. From the figure one can see the jet progressively overcoming the incoming flow and finally overshooting the leading edge on the last four wings displayed. Increasing V_e results in larger regions of high pressure inboard of the trailing edge. This feature can be seen by observing an increasingly greater region of blue inboard the trailing edge of the wing. A stronger jet (or higher q_j) results in a narrower plume diameter near the nozzle exit and therefore in a decreased area of low pressure on the upper surface of the wing. Pictures of the jet taken with V_e set near 0.250 confirm the jet path to the tip of the wing; a result previously obtained with the surface oil flow visualization technique.

A similar sequence of pictures was repeated for a free stream dynamic pressure of 75 lb/ft^2 and pasted on figure 4.4. The first six pictures with the jet-on case reveal an interesting phenomenon, namely a significant loss in pressure in the jet plume impinging on the upper surface of the wing. Indeed, the surface area occupied by the jet plume, showing as a red patch in the previous figure, now shows up as a blue patch. Although,

the paint does a fairly good job in identifying the interaction of the jet with the wing upper surface, the paint fails to give a consistent estimate of the pressure caused by the impinging jet on the wing upper surface. One possible reason, for this unexpected pressure mapping in the plume of the jet might be due to a higher temperature in the plenum chamber. Data show an average temperature of roughly 42.4 °C at the time PSP data was taken. From theory, it is recalled that the coefficient A and B of the Stern-Volmer equation are temperature dependent. Because the temperature was assumed constant over the whole surface of the wing, the coefficient A and B might have yielded inaccurate results in the region where the jet impinges on the wing. Experiments have shown that temperatures above 35 °C resulted in marked variation in intensity I, and both coefficient A and B. Therefore, accurate knowledge of the surface temperature would seem rather important in such a case.

Although, the pressure estimates appear different from those recorded at a free stream dynamic pressure of 100 lb/ft², the same flow features are observed on the upper surface of the different wings. The jet exiting the nozzle continues to follow a curved path all the way to the wing tip at an effective velocity ratio in the neighborhood of 0.250. Higher values of V_e show the jet straightening up and overcoming the incoming free stream air by overshooting the wings leading edge.

The last free stream dynamic pressure tested was set at 90 lb/ft² where V_e was varied from 0.314 to 0.164. The pictures taken can be found in figure 4.5. Interestingly, pictures taken at V_e 's between 0.314 to 0.272 hardly show the impingement of the jet over the upper surface of the wing. It takes a value of V_e equal to 0.252 before the jet starts showing up as a small patch of red (or low pressure) above the nozzle. Subsequent values of V_e reveal a clearer imprint of the jet in the form of a red area covering a small portion of the wing inboard of the leading edge. Notice that the leading edge vortex forming at the root of the wing shows clearly on all the pictures except for the case of no-jet blowing. The results obtained at a free stream dynamic pressure of 90 lb/ft² resemble closely those recorded for the case at 100 lb/ft². However, figure 4.5 shows lower pressures than on figure 4.3 for values of V_e lower than 0.250. Where there used to be patches of blue patches inboard of the trailing edge near the root chord now show up as yellowish patches indicating low pressures. Because the dynamic pressures are so close to one another and those pictures (@ $q_\infty=90$ lb/ft²) were the last ones taken for this investigation, the discrepancy could be associated

to paint degradation. Long term exposure to U.V. decreases the accuracy of the paint as it was mentioned earlier in section 4.2.

Figure 4.6 represents three sets of wings tested at three different free stream dynamic pressures and at comparable effective velocity ratios. From the first set of data one would conclude spanwise blowing to be detrimental to the pressure distribution over the upper surface of the wing. Indeed, the wing with no blowing shows a much lower overall pressure distribution when compared to the next three wings tested at the same free stream dynamic pressure, namely 75 lb/ft². As it was noted earlier this might be due to an improper calibration of the paint. However, the next two series of data show a more common trend in the form of a low pressure area in the region impinged by the jet.

Because the free stream dynamic pressures were so close in magnitude one would expect very close correspondence, however different pressure mappings are observed for the same effective ratios. Perhaps proper calibration of the paint by closely monitoring the temperature variation across the wing will yield better results in the future. Furthermore, calibration of the paint is usually attained by measuring pressures in combination with the use of a few pressure taps on the model. Since, no pressure taps were available on the wing, calibration relied on data taken from previous tests. This lack of pressure taps might have also affected the reliability of the data taken. Nonetheless, the paint was a useful tool to visualize the area of the wing impinged by the jet and to identify the formation of a leading edge vortex near the root chord of the wing.

CHAPTER 5

LASER DOPPLER VELOCIMETRY

5.1 Tunnel Test Conditions

The laser doppler velocimetry (LDV) experiment was performed in the 7- by 10-foot wind tunnel much like the PSP investigation, though a few changes were done to the type of wing tested. The Plexiglas wing was substituted for the metal wing but the angle of attack remained at 20° . The test conditions were determined from the surface oil flow visualization where an effective velocity ratio of 0.250 was found to best suit the purpose of this test. The flow visualization showed the jet shooting right at the tip of the wing for this value of V_e , thus strengthening the leading edge vortex. The freestream dynamic pressure was kept at 10.3 lb/ft^2 (493 N/m^2) with jet off and 12.0 lb/ft^2 (575 N/m^2) with jet on. Those values correspond to tunnel velocities of 93 ft/sec (28.4 m/sec) and 100 ft/sec (30.5 m/sec) and Reynolds numbers of 1.42×10^6 and 1.53×10^6 , respectively.

5.2 Theory

LDV, as the name implies, uses the 'Doppler effect' to measure velocities of impurities, usually referred to as scattering centers, present in a fluid. This non-evasive technique was first demonstrated by Yeh and Cummins [16] in 1964 to measure the velocities of moving particles in a water flow. For the case of a wind tunnel, these moving particles can occur naturally in air in the form of dust or be produced artificially by seeding small particles into the flow. These particles, if small enough, are assumed to travel at the same velocity as the fluid of interest. Ideally, the particles should be of microscopic size, suitable for scattering (Mie scattering) the wavelength of the incident light, and have densities close to that of the surrounding fluid.

The 'Doppler effect' works much like the police car siren explained in physics books, only for this case high intensity light from a laser is used as the source [9,17-18]. To measure the velocity of a particle in a fluid, a laser beam, called the illuminating beam, is sent out from the source to the moving particle. Because the particle is moving it sees

the signal at a higher frequency than the original source. When the moving body scatters the incoming light, the light is re-emitted at the same frequency that it was received. However, an observer located at the source will record a higher still frequency because the particle is moving. If the Doppler shifted signal is mixed (or heterodyned) with a local oscillator, which could be the original laser signal, and is allowed to fall on a photodetector located at an angle with respect to the illuminating beam, one can then determine the frequency shift (Fig. 5.1). This technique called the heterodyne technique enables one to measure small frequency shifts. The photodetector detects a beat frequency equal to the Doppler shift frequency proportional to the flow velocity. The frequency shift in this case can be approximated to be of the order of $2v/c$, where v is the speed of the particle in the fluid and c is the speed of light. For the case where a particle is moving at a low speed of 15 m/sec the corresponding frequency shift is roughly 1 in 10 million. Assuming the frequency of light is approximately 5×10^{14} Hz, then a frequency shift of 1 part in 10 million corresponds to a shift of 50 MHz. Such a frequency can easily be recorded by existing electronic spectrum analyzers.

Although, simple in concept, the heterodyne system has its drawbacks. To obtain perfect 'heterodyne efficiency' requires both the reference beam and the illuminating beam, when beaten together, to overlap, be parallel and have the same curvature of their wavefront. For the beams to coincide with such precision, this system demands a precise alignment of all optical components (illuminating, reference and collection unit) on a rigid base virtually free of vibrations. Because a tunnel environment is prone to vibrations another system had to be considered for the purpose of this test, namely, a real fringe system.

The alignment criterion for the real fringe system requires two beams to focus upon and overlap at a common region in the flow. Light scattered by moving particles can be collected with various optical setups, however, only two will be discussed in this report. The first one is a forward scatter type setup, while the second one is a back scatter type setup. For the former the receiving optics and the photodetector are located across the test section (Fig. 5.2). Forward scatter, is usually the optical setup of choice for its higher signal strength as opposed to a back scatter setup. By comparison signal strength can be 100 to 1000 times higher, thus requiring a low-power laser such as helium neon (0.5-30 mW)[19]. One disadvantage however, is the need to steer the laser beams through the two windows of the test section which increases the chance of misalignment. For this reason, the windows are made out of a highly flat optical glass.

A back-scatter optical set up on the other hand, requires less hardware. This mode uses the focusing optics to collect the light scattered from the moving particles (Fig. 5.3). This has the advantage of having both the receiving optics and photodetector on the same side of the test section. However, as was mentioned earlier, a much weaker signal is collected compared to a forward scatter mode setup. Therefore, a high power laser is required. In most cases, an argon laser with a power output in the neighborhood of 10 W is the unit of choice.

In both modes, the original beam is split into two beams by means of a beam splitter. One beam is called the reference beam while the other is referred to as the signal beam. Both beams cross at a region in the fluid called the measurement volume or probe volume (Fig. 5.4). The measurement volume is an ellipsoidal region whose dimensions depend on the widths of the two crossing beams. The intersecting beams create an interference pattern in the form of alternating dark and bright fringes.

To measure velocities that might occur in flow reversal, such as highly turbulent regions in the wake of a wing, the reference beam is modulated. Therefore to determine whether a particle is moving in the forward or reverse direction the reference beam is passed through a Bragg cell which as a result shifts the frequency of the laser light. For the purpose of this test the Bragg cells shifted the frequency by 40 MHz. A frequency of 40 MHz recorded by the electronic spectrum analyzer would correspond to a stationary particle. Movement with the fringes would decrease the frequency while movement in the reverse direction would increase the frequency.

The transmitted beams are focused on a photodetector or photomultiplier tube with the receiving optics. The incoming signal are usually amplified with photomultiplier tubes due to the weak signal, especially in the back scatter mode. As a single particle crosses the measurement volume, a certain amount of light is blocked off as it passes the bright fringes. The light collected on the photodetector will fluctuate at the rate at which the particle crosses the bright fringes. Consequently, the light is modulated at a frequency of v/d where v is the component of velocity normal to the fringe system and d is the spacing between the fringes. The spacing d between the fringes can be approximated by the following equation:

$$d = \frac{\lambda/2}{\sin(q/2)} \quad (5.1)$$

λ is the wavelength of the laser light used and θ represents the angle between the two crossing beam at the measurement volume.

Upon falling on the photomultiplier tube the scattered light signal is converted to an electrical signal. Essentially, the photomultiplier tube absorbs the optical radiation from the receiving optics and converts it into electrons, or electron hole pairs in the case of semiconductors. The released electrons (or electron-hole pairs) constitute a current.

Because small frequency changes, relative to the 40 MHz frequency shift by the Bragg cell, are sometimes hard to resolve a downmixer is used to obtain an effective frequency shift. Existing downmixer have selectable "effective" frequency shift from 2 KHz to 10 MHz, a noticeable difference from the original frequency shift by the Bragg cell. Therefore, the signal processor sees this downmixed frequency as the real zero flow frequency.

Following the downmixing procedure, the signal is fed into a counter processor. To improve the signal to noise (S/N) ratio the signal is filtered out through a high pass and low pass filter to scan a predetermined frequency band. This task is usually performed either automatically by a computer or operated manually. The high pass filter removes the pedestal component or any dc component of the photodetector signal (Fig. 5.5), whereas the low-pass detector reduces high frequency noise on Doppler signals, improves the S/N ratio, improves count accuracy, and reduces the number of spurious data point caused by unwanted noise. After effective filtering of the photodetector signal, the operator is left with discrete bursts which appear as oscillatory signals. Those bursts correspond to multiple fringe passes by particles through the measurement volume. To estimate the frequency f_D of the Doppler shift signal the frequency counter processor times the duration T of an integral number N of cycles of the signal. The Doppler shift is then calculated by the following equation:

$$f_D = \frac{N}{T} \quad (5.2)$$

The timing scheme used in this process relies on measuring the duration between zero voltage crossing the Doppler shift signal. The logic circuitry of the counter processor digitizes the signal and counts the number of zero voltage crossings of the Doppler signal until the amplitude of the measured signal falls below an adjustable sensitivity threshold. The bursts, created by the particles passing through the measurement volume, can be

monitored by means of an oscilloscope or an analog frequency analyzer. Displaying the bursts provides the operator the flexibility of improving the S/N ratio.

Next the LV data from the counter processor is transferred over to the data acquisition system. The acquisition system will store the incoming LV signal or coincident data for vectorial analysis and the interarrival time. An autocorrelation function will store only those data points recorded within a specified time frame. All points falling outside this time window are ignored. This process is repeated until a predetermined number of bursts is reached.

Finally, the stored data can be retrieved by a microcomputer interface board for further analysis. Using specific software, the data can be interpreted statistically in the form of histograms, plots, or numbers.

5.3 Experimental Setup

The LDV investigation performed in the 7- by 10- foot wind tunnel used a fixed focus three-component dual beam-velocimeter system. This system was designed and assembled in house by NASA-Ames Research Center engineers, to allow uncoupled orthogonal measurement of the three Cartesian coordinates of velocity. The LDV system was controlled by means of an IBM compatible model Compaq 386/25 microcomputer with PC-AT expansion bus slots for peripheral devices. The menu driven software (LDV9QB), written solely for the purpose of this test, presented the user with different windows to adjust the proper settings for data acquisition and storage by remotely controlling the traverse system, and the LDV signal processing system (Fig. 5.6).

Traverse system

The optical setup in this case required mounting all optical components (Bragg cells, focusing optics and receiving optics) and the laser on a rigid optical aluminum frame suspended above the test section of the wind tunnel (Fig. 5.7). Two appendages extending down vertically were made up of thin walled square tubing to accommodate a set of mirrors to guide the laser beams in the test section.

The fixed focus design required the measurement volume location to be controlled by a traverse system. Consequently, the rigid optical frame supporting all the optics and the laser had the freedom of translating in three directions with stepper motors driven by

three LM-HPIB Shaw motor controllers and connected to a microcomputer via an IEEE 488 bus interface. Motion of the traverse system could also be controlled with an umbilical cord and switch box set by the tunnel's test section. A truck, supported on rails located on both sides of the test section roof, enabled the traverse to translate in the streamwise direction, while a second set of rails mounted on the streamwise carriage allowed lateral motion. Vertical motion used a counter balanced pulley system to relieve load on the motors. All three directions were actuated by means of fixed worm gears of the recirculating ball type. The worm gear pitch is 5 revolutions per inch resulting in motion either in the horizontal or vertical direction at a rate of 1/1000 inch per step. Calibration and positional repeatability based on the encoder resolution and lead screw pitch showed accuracy of the rig to fall within 0.001 inch.

Optical Setup

A 5 -Watt argon-ion laser, model 165 from Spectra Physics, provided the necessary illumination source for the system. This continuous wave output laser is water cooled and thus required proper plumbing to reach the top of the test section. The two dominant light lines of this laser were used for the purpose of LDV measurement. The different light lines were easily distinguishable by their colors. One was blue at 488 nm and the other was green at 514 nm. The different light lines were obtained by directing the main output of the laser through a prism, therefore generating two new beams at the two wavelengths described earlier. The weakest light lines remaining were blocked off and served no purpose for this test. The blue beam was further divided by means of a beam splitters to obtain two dual beam systems or a total of four individual beams. Each system had one of its beams shifted by 40 MHz with respect to the other through a Bragg cell. Similarly, the green beam was divided into two beams and had one of its beams steered through a Bragg cell.

The three-component dual-beam LDV system in this test utilized both forward scatter mode and backscatter mode. The back scatter mode was implemented to measure the cross wind component of velocity. For this reason the 488 nm dual beam system was aimed through a 4' x 6' x 1/2" plate glass window housed in the roof of the test section. Because no optics could be installed on the test section floor, the scattered light was collected by a backscatter set up where both the focusing optics and receiving optics were fixed side by side. The receiving optics consisted of a 10 inch Schmidt type reflecting

telescope with a focal distance of roughly 7 feet. The telescope lens was mounted at a slight angle relative to the focusing optics to avoid collecting the unscattered light of the illuminating beams.

On the other hand, the two other components of velocity, namely the streamwise component and vertical component of velocity, utilized a forward scatter type setup. Four beams were steered by adjustable mirrors down the right arm of the optical frame. At the end of the arm a mirror positioned at an angle of 45 degrees aimed both dual beam systems horizontally at a focus coincident with that of the backscatter setup. Both dual beam systems could be easily distinguished visually by their colors: one being green and the other blue. To obtain two velocities orthogonal to one another the plane of one horizontal beam pair was rotated by 90 degrees. As a result, two mutually perpendicular fringe patterns are found in the measuring volume and are nearly perpendicular to the fringe pattern induced by the backscatter setup. The scattered signals from both beam pairs was collected by the second Schmidt-Cassegrain collector. Like all typical forward scatter set ups, the collecting optics were located on the opposite side of the test section, off axis, and clamped to the left arm of the traverse system.

The light collected by each telescope was concentrated onto a multi-mode optical fiber located right behind the spatial filter. The opposite end of the optical fibers were connected to the photomultiplier tubes to convert the light signal into an electrical signal. Because the signal from both horizontal beam pairs was collected by the same Schmidt-Cassegrain collector and consequently, the same fiber optic, this required separating the colors through a dichromatic mirror prior to entering the photomultiplier tube. As a result, the photomultiplier tubes obtained three different signals one from the backscatter system and two from the forward scatter system. The strength of the signals were amplified by adjusting the power supply voltage prior to transferring the signals to their respective frequency mixers.

Signal Processing System

Since, small frequency changes are hard to resolve with respect to the 40 MHz frequency shift caused by the Bragg cells, downmixers were required. Each individual signal fed into their respective frequency mixer was mixed with a downmix signal generated by a signal generator (Model HP 8165A 1mHz - 50 MHz). The downmix was calculated from previous measurements by the software run on the microcomputer:

however, manual operation of the mixers was required to adjust to the proper "effective" frequency shift. Default values were set at 35 MHz for all three channels when data was acquired for the first data point. Refinements to the software and interface between the mixers and microcomputer should avoid involvement of the operator in future tests.

Next the signals were read by a counter processor (Macrodyne Model 3003). All three signals from all three channels were filtered through a high pass and low pass filter to maximize the signal to noise ratio. Default settings of 2 MHz and 8 MHz were used for the high pass and low pass filter respectively. Adjustments of the filters could be made manually according to the displayed calculations on the microcomputer's screen, however, the settings remained unchanged throughout the present test. The filtered signals, or bursts were monitored separately by means of an oscilloscope and an analog frequency analyzer. This capability enabled the operator to adjust the signal to noise ratio when judged necessary.

The data acquisition system was accomplished with a Macrodyne model 3030 Laser Velocimeter (Autocovariance) Buffer Interface (LVABI). The unit linked to the counter processor stored the LV signals in addition to the interarrival times for later data reduction. The data block size recorded by the LVABI was fixed from the software run on the host computer. The data acquisition process was designed to time out after a preset time in case of malfunction. Normal data blocks consisted of five hundred samples for each point taken. The data was finally downloaded in the host computer and stored on a hard disk for later analysis.

Seeding apparatus

LDV measurement would not be possible without proper seeding of the wind tunnel. Consequently, a Rosco 4500 vapor condensation smoke generator provided the proper seeding in the tunnel's test section. The particle generator was located in the settling chamber upstream of the test section. The smoke exited the machine through a hose aimed along the center line of the test section. Proper adjustment of the hose was possible by entering the settling chamber while the tunnel was operating and aiming the smoke downstream to the desired location.

Seeding of the tunnel was accomplished remotely with an umbilical cord outside the test section. Seeding was done intermittently for a period of 20 to 30 seconds until the beam, and more importantly the measurement volume, was visible to the naked eye.

The operation was repeated when either the occurrence of particle bursts was low or the outline of the beams were judged difficult to see visually.

The smoke was allowed to circulate through the tunnel circuit approximately three to four times before any measurements were done. This resulted in a more evenly seeded test section and reduced the possibility of having clumps of particles saturate the measuring volume. Seeding of the tunnel was performed with the air-exchange doors closed to minimize loss of smoke.

5.4 Methodology

Data acquisition by the LDV operator located near the test section was coordinated with the tunnel operators located in the control room of the wind tunnel. Wind tunnel data and plenum chamber data, such as time and date, wind tunnel velocity, barometric pressure, effective velocity ratio and jet mass flow rate (Fig. 5.8), were monitored and recorded by the tunnel operators, while the duty of the LDV operator consisted in collecting LV data only. Tunnel conditions were stored on the local VAX system to be correlated and analyzed with those stored on the hard disk of the microcomputer. No physical connections existed between the data acquisition in the control room and the microcomputer. Therefore, a numbering scheme (i.e., run numbers) common to both acquisition systems was devised to match both sets of data for post-data processing. The clocks on both computer were synchronized and served as a back-up scheme to correlate the data.

A typical run would require preparation of an input file to be later read by the menu driven software customized for this investigation. Briefly, the input file informs the traverse system where to start and end a series of measurement points (Fig. 5.9). Next the active LVABI channels and coincident channels are defined. Finally, a few parameters such as the fringe spacings, downmix directions and others are entered to convert the recorded frequencies into velocities. Most editing, in the different input files, involved modifying the path of the traverse system while all other parameters remained essentially the same throughout the test.

Before starting the test, the argon ion laser was turned on at least half an hour to an hour prior to any measurements. This precautionary measure allowed all optical components in the laser to reach a steady state temperature and thus minimize optical property variations. The remaining components of the LDV system were set to their

default values, starting with the traverse system. A diagnostic program, called SHAWRUN, was written to test the motor controllers, and encoders by positioning the measurement volume at its reference position. This task was achieved by focusing the probe volume at the center of an iris fixed 4 inches above the nozzle. From then on control of the traverse was taken over by the main program LV3D9.QB which would then translate the measurement volume to its initial traverse position or initial point. The remaining components of the signal processing system were given default values to be corrected during operation of the software. For instance, the downmix was always set at 35 MHz for all three channels at the initial start of a run. Similarly, all high pass filters and low pass filters were set at 2 MHz and 8 MHz respectively.

Once the traverse system and the signal processing system was checked, the tunnel was brought to condition (those conditions are described at the beginning of each initialization file). For the case, where the jet needed to be on, the tunnel was turned on first followed by the jet to avoid blowing debris on the top window of the test section. Once the desired dynamic pressure was attained, the fog machine was turned on remotely from outside the test section until a uniform seeding was judged adequate by the operator to start LDV measurements. A series of menus were brought up on the screen to confirm each default setting on either the traverse position, the downmix, or the filter settings before actual data acquisition. Next the operator was given the option to commence the measurements. Once initiated the operator tracked each signal with a frequency analyzer connected alternately to the three channels. In general, data acquisition terminated within a specified number of samples defined in the input file, usually 500 samples, or timed out after a specified time, in most cases, 2 minutes.

Before saving the collected samples, the operator was presented with statistics on the last point to determine if the data was worth keeping. The statistics displayed were mean Doppler frequency and standard deviation for all three channels. The major criterion for accepting the data was based on the magnitude of the standard deviation. As a rule of thumb, data samples with a standard deviation higher than 0.8 MHz were rejected. Should the point be rejected then the same procedure was repeated over at the same point or location. Acceptable data were transferred and saved on the microcomputer's hard drive. The traverse was then moved to the next position for further LDV measurements. This procedure was repeated until the final position was reached at which point the traverse was brought back to its reference position and readied for the next run.

In this investigation several traverses near the wing were of interest. Data located half an inch behind the trailing edge and half an inch ahead of the leading edge of the Plexiglas wing were collected for both the jet-on case and the jet-off case. Traverses in the upwash of the wing were taken parallel to the leading edge in a plane perpendicular to the wing's upper surface. Similarly, traverse in the downwash of the wing were collected parallel to the trailing edge in a plane normal to the upper surface of the wing. A total of 6 parallel traverses (corresponding to 6 different runs), each spaced 0.5 inch apart, in the plane normal to the wing were considered.

The data for the jet-off condition was performed at a tunnel dynamic pressure of 10.3 lb/ft², whereas the jet-on condition required a tunnel dynamic pressure of 12.0 lb/ft² and a V_e fixed at 0.250. Jet-off data was taken first followed by the jet-on data. To position the jet at the very tip of the wing to strengthen the leading edge vortex required surface oil flow visualization as described in chapter 2 of this report. Discrepancy in the tunnel q_∞ 's between the jet-on and jet-off condition arose because fine tuning the tunnel q_∞ would in affect change the effective velocity ratio. Recall that

$$V_e = \sqrt{\frac{\rho_\infty \cdot V_\infty^2}{\rho_j \cdot V_j^2}} = \sqrt{\frac{q_\infty}{q_j}} \quad (5.3)$$

In other words, when the tunnel operators attempted adjusting the tunnel Q to 10.3 lb/ft² the jet would undershoot the tip. As a trade off and to minimize the time spent to match the tunnel Q at jet off condition, a tunnel Q of 12.0 lb/ft² was deemed acceptable.

5.5 Data Reduction

A statistical program called HISTOGRA (see appendix A) was written by the author for this investigation to verify the validity of the data collected. The FORTRAN program was devised to display graphically a histogram history of the three components of velocity. The plots displayed the number of samples versus frequency. In addition, standard deviations, and mean values were calculated for each component of velocity and printed next to the plots (Fig. 5.10). This menu driven software gave the user the choice of manipulating the data by eliminating any spurious data within specifications. For this investigation an acceptance threshold was estimated to be of the order of 5% of the

number of samples found in the peak value. In other words, any bin with a number of samples less than 5% of the highest bin was judged spurious data and ignored for the velocity calculations. Furthermore, if three consecutive bins were found to be less than 5% of the peak on either side of the highest bin then all the remaining bins were ignored, even if those bins were higher than the peak value. The scheme adopted in this investigation is discussed in detail in reference [20]. HISTOGRAM also allowed the user to control the bin sizes and the desired frequency bands. A summary of the displayed histograms for each data point can be found in appendix B.

Once screened by the program HISTOGRAM, the new data files were then manipulated by yet another FORTRAN program called LDVSUM (see appendix C). This program had three major options:

- (1) To retrieve the first fifteen lines from each of the data files and save them onto one file. This option provided a compilation of all the data points measured in the wind tunnel.
- (2) To retrace the traverse pattern of each run and save it as TRAVERSE.DAT. In other words, the coordinates of each point in a run were collected and put in a table format.
- (3) To convert mean frequencies to velocities and save it as a data file. The data files were such that they could be used with various Macintosh software such as Kaleidagraph, Excel or Word for graphical analysis.

A summary of all the datapoints processed by program LDVSUM can be found in appendix D. Appendix D includes the nondimensionalized components of velocity with respect to the different spanwise stations defined as $y/(b/2)$.

5.6 Results and Observations

Various traverses, measured half an inch behind the trailing edge, were plotted. Namely, traverses measured one inch, and half an inch above the center line of the wing, in addition to those measured one inch and half an inch below the center line of the wing. The sign convention used in this investigation is as follow: the positive x-axis points downstream, the positive y-axis points normal to the root chord towards the wing tip and the positive z-axis points up normal to the wing's upper surface. This unusual sign convention was adopted from the panel method code (PMARC), discussed in Chapter 6, for later comparison between experimental and computational data. Figure 5.11 displays

the spanwise distribution of the non dimensional quantity u/V_∞ for the case where the jet is off and on. The blowing caused the magnitude of u/V_∞ to be higher than the jet off case. However, for the traverse measured half an inch above the upper surface the opposite was observed where the magnitude of the jet off points were higher than those measured with the jet on. The values measured below the upper surface of the wing in graph (a) & (b) are fairly close in magnitude as one would expect since the two traverses were only spaced half an inch apart. However, the traverses measured above the upper surface showed totally different trends. Not only were the values for the jet off case higher than the jet on case (graph c), but also a sign reversal was observed. Because the traverses in graphs (c) & (d) were spaced by only half an inch, one would expect fairly similar plots of equal magnitude. There is reason to believe that spurious data was measured during those runs. Aside from the last two graphs, spanwise blowing seemed to facilitate a stronger flow in the chordwise direction. Furthermore, the distribution of points was similar whether or not the jet is turned on.

Similarly, the non-dimensional quantity v/V_∞ was plotted with respect to $y/(b/2)$ again along the trailing edge of the wing (Fig. 5.12). The magnitudes of the spanwise component of velocity (graph (a)) were scattered in both cases (jet on & jet off) between spanwise locations of 0.5 and 0.8. Beyond the semispan location 0.8, the data were more orderly. A different trend was observed in graph (b) where all the data had nearly the same magnitude along the whole traverse. Yet the jet off case had a larger negative spanwise component. While the two sets of data measured below the wing and plotted in graph (a) & (b) were collected only half an inch apart, the results were inconclusive. On the other hand, the two sets of LDV measurements taken above the wing upper surface showed similar behaviors. Both sets of data, graph (c) and (d), followed the same trend and had very similar magnitudes. The jet on case showed a more positive spanwise velocity component than the jet off case; in these data it was close to zero. This would correlate with the oil flow visualization where a region of stagnation was observed halfway between the tip and the half span of the wing. Interestingly for the jet on case, higher v/V_∞ were observed near the tip, most probably due to the presence of a tip vortex. However, this phenomenon was absent for the jet off case. This suggests that blowing laterally reinforces the tip vortex.

Finally, the non-dimensional downwash component of velocity w/V_∞ was plotted as a function of the non-dimensional quantity $y/(b/2)$ (Fig 5.13). From observation, a larger upwash velocity was present below the wing's upper surface (graph

(a) & (b)) for the jet off case. Indeed, from a spanwise location of 0.5 to roughly 0.8 both cases had fairly close magnitudes. Outboard of the 0.8 spanwise location, the jet on case appeared to have a smaller downwash velocity component while the jet off case dipped into higher velocities; a typical behavior due to the formation of tip vortices (Fig. 5.14). A synonymous behavior was plotted in graph (c) representing a traverse measured 0.5 inches above the wing's center line, 0.5 inches behind the trailing edge. The points had fairly constant magnitude midspan to about a spanwise location of 0.8 for both cases. Further out the points were more spread out indicating again the presence of a tip vortex. Notice that the components of downwash was stronger for the jet off case and weaker for the jet on case. A weaker downwash component for the jet on case is favorable in reducing the drag associated with high angles of attack and makes the wing more efficient, however, a weaker downwash is associated with a lower lift coefficient C_L . Interestingly, a traverse measured half an inch higher than the one discussed previously showed a different trend (graph (d)). Points measured midspan to a spanwise location of 0.9 increased in downwash and dipped down to a value $w/V_\infty = -1$. On the other hand, values measured for the jet off case decreased in downwash all the way to the tip. This would suggest blowing to increase the lift coefficient of the wing. However, the previous traverse tended to show otherwise. These two graphs show the inconsistency of the measurements although done only a half an inch apart.

CHAPTER 6

PANEL METHOD CODE

6.1 Introduction

The objective of this investigation is to compare part of the experimental data obtained with the LDV system in the 7- by 10- foot wind tunnel to those calculated with PMARC (Panel Method Ames Research Center). Only the case of no jet blowing is treated in this chapter. The jet on case was ignored due to the complexity of representing a jet. Jets usually require higher order potential-flow codes, if not complicated computational flow dynamic codes. The velocities in the upwash and downwash regions near the trapezoidal wing set at a 20 degrees angle of attack were analyzed using the code and compared with experimental data. This comparison, in effect, evaluates the accuracy of the code for a wing with a sharp leading edge set at a high angle of attack.

6.2 Theory of PMARC code

The code as its name implies is currently being developed at NASA-Ames from an already existing panel method code called VSAERO. Like VSAERO, PMARC uses a low-order potential-flow panel method to estimate flow fields around three dimensional bodies. PMARC was chosen over other codes for its simplicity and its speed. Experience has shown that high-order codes yield comparable results to those obtained with low-order codes, though at a higher cost and higher computational time.

This low-order method uses singularities (sources and doublets) distributed with constant strength over each panel. The flow around the three dimensional geometry is considered to be inviscid, irrotational, and incompressible. An arbitrary three dimensional body, such as a wing or a wing-body combination, is modeled by two different regions: an internal region and an external region (Fig 6.1). The internal region is usually modeled with a fictitious flow. Typically, the velocity potentials in either regions obey Laplace's equation:

$$\nabla^2 F = 0 \quad (6.1)$$

$$\nabla^2 F_i = 0 \quad (6.2)$$

Applying Green's theorem, the potential at any point P in either region is evaluated by the following equation:

$$\Phi_P = \frac{1}{4\pi} \iint_{S+W+S_\infty} (\Phi - \Phi_i) \bar{n} \cdot \nabla \frac{1}{\bar{r}} dS - \frac{1}{4\pi} \iint_{S+W+S_\infty} \frac{1}{\bar{r}} \bar{n} \cdot (\nabla \Phi - \nabla \Phi_i) dS \quad (6.3)$$

$\bar{n}$ represents a unit vector normal to the surface, and $\bar{r}$ is a vector between an arbitrary point P in space and a surface element dS . The first integral in this equation describes the disturbance potential caused by the surface distribution of doublets with strength $(\Phi - \Phi_i)$ per unit area whereas the second integral describes a surface distribution of sources with strength $-\bar{n} \cdot (\nabla \Phi - \nabla \Phi_i)$ per unit area. The above equation can be simplified by appropriate assumptions. The derivation is presented in depth in references [21] and [22] and only outlined below. The basic panel element in this method has a constant strength source or doublet. Also the boundary condition applied in this method is of the Dirichlet type where no flow goes through the surface. Consequently, the following set of linear algebraic equations are obtained:

$$\sum_{K=1}^{N_S} (\mu_K C_{JK}) + \sum_{K=1}^{N_S} (\sigma_K B_{JK}) + \sum_{L=1}^{N_W} (\mu_{W_L} C_{JL}) = 0 \quad \left\{ \begin{array}{l} J=1 \text{ to } N_S \end{array} \right. \quad (6.4)$$

where

$$B_{JK} = \iint_K \frac{1}{\bar{r}} dS \quad (6.5)$$

and

$$C_{JK} = \iint_K \bar{n} \cdot \nabla \frac{1}{\bar{r}} dS \quad (6.6)$$

C_{JK} and B_{JK} are velocity potential influence coefficient at control point of panel J due to a uniform distribution of unit doublet and unit source on panel K respectively. The above equations are assembled together in the form of a matrix. From the steps, leading from equation (6.3) to equation (6.4), it can be proven that the source strengths on the surface are defined as

$$\sigma = \frac{1}{4\pi}(\mathbf{V}_{\text{norm}} - \bar{\mathbf{n}} \cdot \bar{\mathbf{V}}_{\infty}) \quad (6.7)$$

where $\mathbf{V}_{\text{norm}}$, the velocity normal to the surface, is set to zero for the purpose of this investigation (no flow through the surface). All the variables to the right of equation (6.7) are known values, therefore σ can easily be calculated. Furthermore, the velocity potential influence coefficients C_{JK} and B_{JK} are functions of geometry only. Because the source strengths are known values, they can be transferred over to the right of the matrix, thus leaving the doublet strengths to be calculated by means of the matrix solver coded in PMARC. Once the doublet strengths are determined and all the singularities on all the panels are known, velocities and pressure data can be obtained at each control point. The following equation is used:

$$C_{PK} = 1 - \frac{V_K^2}{V_{\infty}^2} + \frac{2 + 4\pi}{V_{\infty}^2} \cdot \frac{\mu(t) - \mu(t-1)}{Dt} \quad (6.8)$$

The last term in the equation represents the unsteady term, $d\Phi/dt$.

Similarly, off-body data, such as velocities at an arbitrary point in the flow field, can readily be obtained by taking the gradient of the potential equation at any point P. Once the equation for velocity is obtained; a set of discretized equations, much like the one derived for the on-body equations, are used by PMARC:

$$\bar{\mathbf{V}}_P = \bar{\mathbf{V}}_{\infty} - \sum_{K=1}^{N_S} (\mu_K \cdot \bar{\mathbf{V}}_{\mu_{PK}}) - \sum_{L=1}^{N_W} (\mu_{WL} \cdot \bar{\mathbf{V}}_{\mu_{PL}}) - \sum_{K=1}^{N_S} (\sigma_K \cdot \bar{\mathbf{V}}_{\sigma_{PK}}) \quad (6.9)$$

where

$$\bar{V}_{\sigma_{PK}} = \iint_K \nabla \left(\frac{1}{r} \right) dS$$

(6.10)

and

$$\bar{V}_{\mu_{PK}} = \iint_K \nabla \left(\bar{n} \cdot \nabla \left(\frac{1}{r} \right) \right) dS$$

(6.11)

where $\bar{V}_{\sigma_{PK}}$ and $\bar{V}_{\mu_{PK}}$ are the velocity influence coefficients per unit singularity strength for panel K acting on the point P. Panel K can either be a panel on the surface of the geometry or a panel forming the wake. These coefficients are dependent on the geometry of the body and its wake. Equation (6.9) is solved with a matrix solver much like the one described for equation (6.4). The solution to equation (6.9) through (6.11) are used to compute velocities at defined points in space. These points are usually referred to as scan points in PMARC.

6.3 Methodology

PMARC provides the user with an input file that can be modified according to the parameters of interest. The input files (see appendix E) used for the purpose of this investigation are divided into four major sections:

- Basic input section
- Surface geometry section
- Time-stepping wakes section
- Scan volume section

The basic input section is further divided into subsections consisting of namelist definitions. For instance, the namelist labeled BINP2 pertains to job control where the user can define the type of input and output needed. Various printing options are

available by simply modifying the existing namelist (BINP2 & BNP3). Three of the namelists (BINP4 through BNP6) involve different sets of parameters (i.e., solver parameter, time-step parameter and symmetry and computation parameters) required to compute the desired results. Namelist BNP7 defines the free stream conditions namely, the free stream velocity and the velocity of sound. The next two namelists (BINP8 & BNP9) involve angular position (i.e., angle of attack) and rotation rate and reference dimensions. The remaining namelists (BINP10 through BNP13) were not needed for this investigation.

The surface geometry section, as its name implies, provides information on the diverse coordinate axis locations, and on the physical points describing the shape of the geometry. In this investigation, the geometry of the trapezoidal wing described earlier in figure 2.2 of chapter two is used. For simplicity, the origin of both coordinate systems (global and assembly) were located at the leading edge of the root chord. The x-axis pointed upstream, the y-axis pointed spanwise and the z-axis was normal to the upper surface of the wing. All the coordinates entered in this section are expressed in terms of feet.

The trapezoidal wing was defined by a folded patch (Fig. 6.2(a)) constructed of three different sections - a section is referred to as a cross-sectional cut through the modeled geometry. The first section was located at the root chord, the second at a distance of 21.5 inches along the span and the third at the tip chord. All the sections were subdivided with panels with varying density depending on the modeled region. The wing geometry had a total of 800 panels: 20 divisions in the chordwise direction (upper and lower surfaces) and 20 divisions in the spanwise direction. For instance, a higher panel density was required near the leading edge and trailing edge (Fig. 6.2(b)) because aerodynamic quantities (i.e., C_p 's) tend to vary drastically in these regions. The code used a cosine spacing both at the leading edge and trailing edge.

The time-stepping wakes section is fashioned much like the surface geometry section. A wake was convected downstream from the wake separation line at a distance of 20 chord lengths. In this case, the wake separation line started on the side of the patch forming the trailing edge of the wing. In addition, the total number of panels in the spanwise direction defining the wake corresponded to the number of panels found along the trailing edge of the wing.

The scan volume section was used to calculate velocities induced by the wing. Scan points within the scan volume were defined by the user. The rectangular scan

volume were specified in terms of three direction vectors emanating from a common point. The side of each vector corresponded to the length of one side of the rectangle. Therefore, to replicate the LDV results, scan volumes were placed half an inch ahead of the leading edge and half an inch behind the trailing edge. However, all scan volumes had one side of zero length which resulted into planes normal to the wing (Fig. 6.2(c)). The scan points distributed on these planes were located in the same region as those defined for the LDV investigation described in chapter 5, section 5.4 of this report. The two scan volumes located behind the trailing edge were separated to avoid the wake from running into one of the scan volumes.

The geometry of the wing, the wake and the scan volumes were analyzed with a software called GVS (General Visualization Software) developed at NASA-Ames. This software runs on SiliconGraphics Iris workstations. This proved to be a very useful tool to confirm that the geometry parameters were adequately entered in the input file of PMARC. The observed geometry can be translated and rotated on the computer screen to observe the model at different angles. By the same token, one can generate time stepping wakes and visualize the location of the scan volumes. Some additional features, include C_p distributions and visualization of both on-body and off-body streamlines.

For the purpose of this investigation, the input file was edited on an Iris workstation. The jobs were submitted to the CRAY Y-MP supercomputer located in the Central Computer Facility (CCF) of NASA-Ames. However, the jobs could have been processed just as well on an Iris workstation or VAX system, but for reduced computer run time more rapid job execution the CRAY was judged to be best. Once the job was processed, the output files were returned to the Iris workstation and the results were visualized graphically on GVS. The calculated results (i.e., velocities) were processed in the appropriate format by a FORTRAN program called SCANVOL (appendix F) and then plotted with the graphic software Kaleidagraph on a Macintosh personal computer.

6.4 Results and Observations

Force data measured in the 7- by 10- foot wind tunnel were compared to various PMARC output files which reproduced the same flow conditions. The results indicate that the low order panel method code could predict flow field conditions with some precision for the jet off case. The force data were obtained from a parallel test on a FLAC

(Fighter Lift And Control) model wing which was similar in geometry to the one built for the LDV investigation. Force data for the FLAC model provided experimental lift coefficient values (Fig. 6.3). These values were plotted and compared to the lift coefficients calculated by PMARC through a range of angles of attack. The experimental C_L increases steadily until it reaches a stall angle close to 25 degrees where $C_{L_{max}}$ is roughly equal to one. The lift coefficient calculated by PMARC agrees fairly closely up to an angle of attack of 25 degrees. Beyond this angle PMARC continues to show a linear increase of C_L with the angle of attack and fails to predict wing stall. Because the PMARC results seemed promising in predicting rather accurately the lift coefficient of the wing for angle of attacks up to 20 degrees, flow field conditions calculated by this low order panel method were compared to those measured by the LDV set up in the 7-by-10 wind tunnel.

The data calculated by PMARC was done only for the jet off condition. To start with, the non dimensional quantity u/V_∞ was plotted versus the nondimensional quantity $y/(b/2)$. From the first two plots of figure 6.4, representing traverses measured 0.5 inch behind the trailing edge, one inch and 0.5 inch below the center line of the wing, PMARC underpredicts the experimental data points. However, both plots (a) & (b) follow the same trend from a spanwise location of 0.5 to 0.9. The same type of plot was generated for a traverse 0.5 inches above the center line of the wing, and 0.5 inches behind the trailing edge. Once more, PMARC underpredicts the LDV results but nevertheless follows the same trend including near the tip where both sets of points decrease in magnitude. In any case, freestream velocity components calculated by PMARC are C_L 0.1 to 0.2 V_∞ less than the experimental results.

PMARC calculations of the nondimensional quantity v/V_∞ , along the spanwise traverses located below the upper surface of the wing, are lower than the experimental data collected with the LDV (Fig. 6.5). In graph (c) and (d) v/V_∞ calculated by PMARC is fairly constant along the whole traverse from a spanwise location of 0.5 to 0.9. Beyond 0.9 the magnitude of v/V_∞ increases probably due to the rolling of a tip vortex. On the other hand, the LDV data behaves rather erratically in graph (a) from a spanwise location of 0.5 to 0.8. Because this behavior is absent in graph (b), which represents a traverse only 0.5 inch away from the previous traverse it is expected that the data collected from spanwise location 0.5 to 0.8 for graph (a) is invalid. Traverses measured above the upper surface of the wing on the other hand, result in a higher estimation of v/V_∞ for a spanwise location inboard of 0.9. Beyond the 0.9 spanwise location,

PMARC underestimates the experimental values. Again this sudden shift in magnitude close to the wingtip might be attributed to the formation of a tip vortex.

The third and final component of velocity, the downwash component, was plotted as the nondimensional quantity w/V_∞ , spanwise, 0.5 inches behind the trailing edge of the wing (Fig 6.6). In the first two graphs, graph (a) and (b), experimental and computational data show the same trend. However, the magnitude of the two sets of data are off by close to $0.2V_\infty$ along most of the traverse. A steep increase in downwash would be expected in the region near the tip due to a great pressure differential, but the data points for both methods suggest only a small increase in magnitude near the tip. The two traverses measured behind the trailing edge and above the upper surface agree very closely from midspan to a value of $y/(b/2)$ equal to 0.7. Past station 0.7 the LDV data decreases in magnitude while the low order panel method data remains fairly constant along the remaining portion of the traverse.

The core radius of both the surface panels and the wake panels were tested through a range of values to study the effect of RCORES and RCOREW (referred as RCORE values) on the precision of the velocity measurements in comparison to the LDV data. The nondimensional quantities expressed as a fraction of CBAR, found in BINP9 of the input file, was varied from a low value of 0.01 to a high value of 0.07 (0.05 is the default value found in the PMARC input file) while keeping all remaining variables and conditions identical. The effect of varying both values made the velocity calculations behind the trailing edge more or less sensitive to both the surface panel edge and the wake panel edge. The first traverse studied was taken 0.5 inches behind the trailing edge and 1.0 inch below the wing's center line. The three different graphs of figure 6.7 involved the three nondimensional quantities u/V_∞ , v/V_∞ and w/V_∞ versus the nondimensional quantity $y/(b/2)$.

From the first graph (a) setting the both RCORE values to 0.01 resulted in the best estimate of the experimental data until a value of $y/(b/2)$ equal to 0.9 where it failed to estimate the sharp drop in u/V_∞ . The other values of RCORE underestimated the LDV data. All three remaining values of RCORE appeared to reach an asymptotic value as the nondimensional values were increased. Note however, the behavior of RCORE's = 0.07 past spanwise station 0.085 where a drop in velocity is followed by an increase in velocity. This phenomena could be due to the presence of a tip vortex, however it is absent for all other RCORE values tested. In graph (b), the default value of 0.05 resulted in similar phenomena, where the spanwise quantity v/V_∞ deviated from the other

RCORE values past a spanwise station of 0.09. Whereas all the other RCORE values followed what seems to be an asymptotic value centered around $v/V_\infty = -0.05$, the default values resulted in an increase of magnitude in the region near the wing tip. The downwash component of velocity represented in graph (c), reached an asymptotic value as the magnitude of the core radii were increased. Setting the RCORE's at 0.07 yielded the closest results to the LDV measurements.

The second traverse studied was located 0.5 inches behind the trailing edge and 0.5 inches above the wing's center line. The results plotted in figure 6.8 showed similar trends to the ones observed in the previous figure. Setting the RCORE's at 0.01 in graph (a) resulted in the best estimate of the streamwise nondimensional value u/V_∞ along the spanwise traverse. All four curves generated by PMARC revolved around an asymptotic value around 0.85, except for the default values which again resulted in a higher streamwise component near the wingtip. The experimental value of v/V_∞ was best represented when the setting for the core radius was left to the default values. Otherwise, all other values of RCORE approached an asymptotic curve of v/V_∞ equal to -0.1 except at the tip where the nondimensional quantity was slightly higher. The downwash component of velocity was best represented by the default values but failed to predict any increase in downwash in the region close to the wingtip.

From observation of figure 6.7 to 6.8, fine tuning of RCOREW and RCORES results in a rather crude matching of the experimental results. The default values set at 0.05 for the two different core radii seemed to yield the closest results to the LDV data points. One reason, for the discrepancies in both the experimental and computational results is explained by the fact that PMARC assumed attached flow over the upper surface of the wing (figure 6.9). However, from the flow visualization figures discussed in chapter two, regions of stagnation and detached flow were observed on the upper surface of the trapezoidal wing. All cases considered, the C_L 's calculated by PMARC (Fig 6.3) would then appear fortuitous considering the potential flow code assumed attached flow.

CHAPTER 7

CONCLUSIONS & RECOMMENDATIONS

The surface oil flow visualization, consisting of a mixture of oil with a fluorescent paint pigment, proved to be an invaluable tool in the assessment of the flow pattern on the upper surface of the trapezoidal wing. This technique helped determine regions of stagnation and flow separation, otherwise impossible to determine by the human eye.

The schlieren provided extra information in the flow field near the nozzle exit of the jet. The schlieren photograph confirmed the path of the jet and divulged the existence of small vortices at the edge of the plume. Moreover, decreasing V_e revealed shock disks in the core of the jet. Because most pictures were taken only in a small area above the nozzle exit, a wider field of view might be desirable in the future to picture the flow over the entire wing's upper surface.

The pressure sensitive paint was revolutionary in determining qualitatively the location of areas of low and high pressure on the upper surface of the wing with the jet on. Some inconsistencies were observed for different effective velocity ratios tested and was attributed in the improper calibration of the paint. Calibration of the paint, with pressure taps and proper monitoring of the temperature for the Stern-Volmer equation, should be given more attention in future tests.

The laser Doppler velocimeter enabled the measurement of velocities in the wake of the wing for the case of jet off and jet on. However, some of the results were inconsistent in most part. Graphical representation of the measurements shortly after data acquisition would greatly enhance the quality of the results by quickly identifying any spurious data that might otherwise be present.

Finally, the panel method code called PMARC failed to predict the flow characteristics near the highly swept trapezoidal wing. PMARC assumed attached flow over the upper surface of the wing which is inconsistent with two of the flow visualization techniques used in this investigation.

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FIGURES

Figure 1.1 Artist concept of a Multi Role Fighter (MRF) configuration

Figure 2.1. Plexiglas wing in 7-by 10 -foot wind tunnel

Figure 2.2. Wing specifications

Figure 2.3. Cut out of ground plane

Figure 2.4. Location of U.V. lamps around test section

Figure 2.5 Surface oil flow visualization of MRF wing with jet-off and dynamic pressure set at 12.0 lb/ft²

Figure 2.6 Diagram dividing regions of interest from figure 2.5

Figure 2.7. Surface oil flow visualization of MRF wing with jet-on ($V_e = 0.250$) and freestream dynamic pressure set at 12.0 lb/ft^2

Figure 2.8 Diagram dividing regions of interest from figure 2.7

Figure 3.1. Basic schlieren system setup in the 7-by 10-foot wind tunnel

Figure 3.2. Schlieren photograph of jet blowing spanwise on MRF wing ($Ve = 0.250$)
Freestream flows from right to left

Figure 3.3. Schlieren photograph of jet blowing spanwise on MRF wing ($Ve = 0.275$)
Freestream flows from right to left

Figure 3.4. Schlieren photograph of jet blowing spanwise on MRF wing ($Ve = 0.150$)
Freestream flows from right to left

Figure 3.5. Schlieren photograph of jet blowing spanwise on MRF wing ($Ve = 0.115$)
Freestream flows from right to left

Figure 3.6. Schlieren photograph of jet blowing spanwise on MRF wing ($Ve = 0.076$)
Freestream flows from right to left

Figure 4.1. Schematic of the energy level transition

Figure 4.2. Hardware setup to record and process pressure sensitive paint data

pressure Sensitive Luminescent Paint

Trapezoidal Wing with Spanwise Blowing $\alpha = 20^\circ$ deg

NASA Ames 7x10 Wind Tunnel No. 1

unimolecular Paoletti, B.G., Glöckle, A., L.H., Bell, J.M., Espinoza, R.J., Morrison, S.L., Confield, B., Dennis

Figure 5.1. Heterodyne system

Figure 5.2. Forward-scatter real fringe system

Figure 5.3. Backscatter optical system

Figure 5.4. Measurement volume

Figure 5.5. Photodetector signal components

Figure 5.6. LDV acquisition system diagram

Figure 5.7. Traverse system and test section cross-sections


```

SPANWISE BLOWING CFD VERIFICATION TEST -- TEST NO. 746
7 X 10 FOOT WIND TUNNEL
VERSION: 2

RUN 101    POINT 4    DATE ACQUIRED: 4/30/92    DATE PRINTED: 4/30/92
TIME ACQUIRED: 8:16: 0    TIME PRINTED: 11:44:09

RAW DATA -- POINT 4

MEAS. ID    VALUE    MEAS. ID    VALUE    MEAS. ID    VALUE    MEAS. ID    VALUE    MEAS. ID    VALUE    MEAS. ID    VALUE
-----
BARO        14701.    PGNDP1      302.    PGNDP5     -500.    PSRINGM    -2426.    RHUM       5785.    TTRAV      -6891.
PIAIRM      1114.    PGNDP2     -1914.    PGNDP6     4025.    PTBDM     -1319.    TSAIR      -6172.
P2AIRM      2797.    PGNDP3     -1575.    PRETURNM   -57.    PTJTM     -239.    TTEM       6105.
PDIFAIR      76.    PGNDP4     -1629.    PSBUM     -1287.    PTPROB1M   -78.    TIJET     -6485.

MODEL GEOMETRY -- MEAS = 1
CONF = 1
SEMI SPAN = 23.829 INCHES    JETS = 0
CHORD = 29.237 INCHES    AJET = 3.1416 SQ. INCHES    DJET = 2.0 INCHES
SWING = 3.804 SQ. FEET

TEST SECTION CONDITIONS
TT = 41.0 DEG. F    BARO = 14.70 PSI    RH = 57.8 %
PSBU = 2105.73 PSF    PTBU = 2116.89 PSF    PSRING = 2106.43 PSF    PRETURN = 2116.70 PSF
QTUN = 1.25 PSF    CQ = 10.45 PSF    VFPS = 94.4 FT/SEC    RMOS = 0.23472E-02 SLUG/FT**3
RNFT = 1.193 MILLION    CS = 1118.5 FT/SEC    MTUN = 0.084    RMU = 0.1210E-04 LB/FT-SEC

```

Figure 5.8. Sample VAX output file

```

LDV Initialization File: INITDB.DAT
Test 746

1. Run number: 100
2. Date: 4/29/92
3. Mode: 2 --
4. Remarks:
   Jet survey : Jet Off
   Wind Tunnel Testing With Plexiglass Wing On
   Traverse Along T.E. of Wing
   Tunnel q = 10.3 lbf/ft2
   Tunnel seeding on - smoke
   Jet seeding off - mineral oil
5. Traverse operation (automatic or manual):..Automatic.
   a. Traverse units (in or cm):..in
   b. Traverse reference position (x, y, z):
      +000.000, +000.000, +004.000
   c. Initial survey position (x, y, z):
      017.296, +008.268, +018.103
   d. Final survey position (x, y, z):
      022.553, +010.182, +012.000
   e. Traverse increment: 0.500
6. Active LVABI Channels (0, 2, 4, 6): 1 1 1 0 *
7. Coincident Channels (0, 2, 4, 6): 0 0 0 0 *
8. Downmix IEEE-488 addresses: 0, 701, 702, *
9. Data Block Size (200, 500, or 1000): 500
10. Maximum time/data block (seconds): 300
11. Maximum time/location (seconds): 900
12. Maximum number of data blocks (<11): 1
13. Desired confidence in mean velocity, per channel (m/s): 0.2
14. Frequency-to-velocity conversion factors (m/s/MHz):
    18.829 0.000 0.000 0.000
    0.000 0.000 -19.708 0.000
    0.000 -17.638 0.000 0.000
    0.0 0.0 0.0 0.000
15. Fringe spacing, per channel (microns):
    18.829 -19.708 -17.638
16. Average frequency tolerance to reset downmix(bandwidth +/-): .10
17. Sample rejection criteria (standard deviation +/-): 3.0
18. Bandwidth tolerance: 4.000
19. Downmix direction factors (+1.0 or -1.0): -1.0, +1.0, +1.0
20. Bragg cell frequencies (40.0 or 0.0): 40.0, 40.0, 40.0

```

Figure 5.9. Sample initialization file for LDV's system software

Figure 5.10. Sample histograms generated with program HISTOGRAM

Fig. 5.11 (a) Traverse taken 0.5" behind trailing edge, 1.0" below wing's center line

Fig. 5.11 (b) Traverse taken 0.5" behind trailing edge, 0.5" below wing's center line

Fig. 5.11 (c) Traverse taken 0.5" behind trailing edge, 0.5" above wing's center line

Fig. 5.11 (d) Traverse taken 0.5" behind trailing edge, 1.0" above wing's center line

Fig. 5.12 (a) Traverse taken 0.5" behind trailing edge,
1.0" below wing's center line

Fig. 5.12 (b) Traverse taken 0.5" behind trailing edge,
0.5" below wing's center line

Fig. 5.12 (c) Traverse taken 0.5" behind trailing edge,
0.5" above wing's center line

Fig. 5.12 (d) Traverse taken 0.5" behind trailing edge,
1.0" above wing's center line

Fig. 5.13 (a) Traverse taken 0.5° behind trailing edge,
1.0° below wing's center line

Fig. 5.13 (c) Traverse taken 0.5° behind trailing edge,
0.5° above wing's upper surface

Fig. 5.13 (b) Traverse taken 0.5° behind trailing edge,
0.5° below wing's center line

Fig. 5.13 (d) Traverse taken 0.5° behind trailing edge,
1.0° above wing's center line

Figure 5.14. Downwash velocity vectors behind wing

Figure 6.1. PMARC'S potential flow model

Wire frame of MRF's wing upper surface

Blow up of MRF's wing tip geometry

MRF's wing with scan volumes

Figure 6.2. MRF's wing geometry generated by PMARC & displayed with GVS (General Visualization Software)

Figure 6.3. Comparison of computed C_L (PMARC) and experimental C_L for a range of angles of attack

Fig. 6.4 (a) Traverse taken 0.5° behind trailing edge,
1.0° below wing's center line

Fig. 6.4 (c) Traverse taken 0.5° behind trailing edge,
0.5° above wing's center line

Fig 6.4 (b) Traverse taken 0.5° behind trailing edge,
0.5° below wing's center line

Fig. 6.5 (a) Traverse taken 0.5" behind trailing edge,
1.0" below wing's center line

Fig. 6.5 (c) Traverse taken 0.5" behind trailing edge,
0.5" above wing's center line

Fig. 6.5 (b) Traverse taken 0.5" behind trailing edge,
0.5" below wing's center line

Fig. 6.5 (d) Traverse taken 0.5" behind trailing edge,
1.0" above wing's center line

Fig. 6.6 (a) Traverse taken 0.5" behind trailing edge,
1.0" below wing's center line

Fig. 6.6 (c) Traverse taken 0.5" behind trailing edge,
0.5" above wing's center line

Fig. 6.6 (b) Traverse taken 0.5" behind trailing edge,
0.5" below wing's center line

Fig. 6.6 (d) Traverse taken 0.5" behind trailing edge,
1.0" above wing's center line

Fig. 6.7 (b) Spanwise/Freestream versus $y/(b/2)$

Figure 6.7: Nondimensional components of velocity versus $y/(b/2)$ for different core radii or RCORES's. Traverse taken 0.5" behind trailing edge, 1.0 inch below wing's center line

Fig. 6.8 (a) Downstream/Freestream versus $y/(b/2)$

Fig. 6.8 (b) Spanwise/Freestream versus $y/(b/2)$

Fig. 6.8 (c) Downwash/Freestream versus $y/(b/2)$

Figure 6.8: Nondimensional components of velocity versus $y/(b/2)$ for different core radii or RCORES's. Traverse taken 0.5" behind trailing edge, 0.5 inch above wing's center line

Figure 6.9. Onbody streamlines generated by PMARC on a trapezoidal wing set at an angle of attack of 20 degrees

TABLES

	SPANWISE BLOWING TEST PLAN		
--	-----------------------------------	--	--

LDV RUNS			
RUN NUMBER	Q-TUNNEL (lbf/ft ²)	Ve-JET	COMMENTS
100	10.3	OFF	Traverse along T.E., @ 0.5 inch away
101	10.3	OFF	Repeat of run 100
102	10.3	OFF	Traverse along T.E., @ y = +0.5
103	10.3	OFF	Traverse along T.E., @ y = -0.5
104	10.3	OFF	Traverse along T.E., @ y = +1.0
105	10.3	OFF	Traverse along T.E., @ y = -1.0
106	10.3	OFF	Traverse along L.E., @ 0.5 inch away
108	12.0	0.250	Traverse along T.E., @ 0.5 inch away
109	12.0	0.250	Traverse along T.E., @ y = +0.5
110	12.0	0.250	Traverse along T.E., @ y = -0.5
111	12.0	0.250	Traverse along T.E., @ y = +1.0
112	12.0	0.250	Traverse along T.E., @ y = -1.0
113	12.0	0.250	Traverse along T.E., @ y = -2.0
114	12.0	0.250	Traverse along T.E., @ y = -2.0
115	12.0	OFF	Traverse along T.E., @ y = -2.0

DUMMY RUN			
RUN NUMBER	Q-TUNNEL (lbf/ft ²)	Ve-JET	COMMENTS
107	12.0	0.250	Run to determine ultimate path of jet

OIL FLOW RUN			
RUN NUMBER	Q-TUNNEL (lbf/ft ²)	Ve-JET	COMMENTS
116	12.0	OFF/0.250	1 pt jet off / 2 pts jet on

P.S.P. RUNS			
RUN NUMBER	Q-TUNNEL (lbf/ft ²)	Ve-JET	COMMENTS
120	50.0	OFF	Structural analysis (no P.S.P. taken)
	75.0	OFF	Structural analysis (no P.S.P. taken)

RUN NUMBER	Q-TUNNEL (lb/ft2)	MFLOW	COMMENTS
	100.0	OFF	Structural analysis (no P.S.P. taken)
121	100.0	0.200	
	100.0	0.190	
	100.0	0.250	
	100.0	0.300	
	100.0	0.300	
	100.0	0.350	
	100.0	0.250	
	100.0	0.200	
	90.0	0.200	
	90.0	0.250	
	90.0	0.300	
122	100.0	OFF	Jet off
	100.0	0.351	
	100.0	0.322	
	100.0	0.298	
	100.0	0.275	
	100.0	0.256	
	100.0	0.24	
	100.0	0.223	
	100.0	0.208	
	100.0	0.194	
	100.0	0.184	
	100.0	0.172	
	75.0	0.243	
	75.0	0.224	
	75.0	0.207	
	75.0	0.196	
	75.0	0.184	
	75.0	0.164	
	75.0	0.156	
	75.0	0.153	
	75.0	OFF	Jet off
	75.0	OFF	Jet off and wind off
	90.0	OFF	Jet off
	90.0	0.314	
	90.0	0.292	
	90.0	0.272	
	90.0	0.252	
	90.0	0.234	
	90.0	0.22	
	90.0	0.208	

<i>RUNNUMBER</i>	<i>Q-TUNNEL(lbf/ft2)</i>	<i>MFLOW</i>	<i>COMMENTS</i>
	90.0	0.195	
	90.0	0.182	
	90.0	0.176	
	90.0	0.164	
	90.0	OFF	Jet off and wind off

SCHLIEREN RUN			
<i>RUNNUMBER</i>	<i>Q-TUNNEL(lbf/ft2)</i>	<i>Ve-JET</i>	<i>COMMENTS</i>
130	12.0	0.250	Condition 1 / Pictures : 24
	12.0	0.275	Condition 2 / Pictures: 35, 28
	12.0	0.225	Condition 3 / Pictures: 29, 27, 25
	12.0	0.200	Condition 4 / Pictures: 31, 21
	12.0	0.175	Condition 5 / Pictures: 34, 30
	12.0	0.150	Condition 6 / Pictures: 20
	12.0	0.115	Condition 7 / Pictures: 32
	12.0	0.076	Condition 8 / Pictures: 33, 26

APPENDICES

APPENDIX A

PROGRAM HISTOGRAM

```

      PROGRAM HISTOGRA
c*****
c Histogram Program, VERSION 2.0
c Date first created: April 1, 1992
c Date last edited: June 24, 1992
c Written by Stephane Couillaud
c Copyright (c), 1992. All rights reserved.
c*****
c
c PROGRAM HISTOGRA PROVIDES A GRAPHICAL METHOD TO DISPLAY THE DATA
c ACQUIRED FROM THE LDV SYSTEM. THE PROGRAM PLOTS OUT THREE
c HISTOGRAMS CORRESPONDING TO THE THREE VELOCITY COMPONENTS U0,U2,&U4.
c THE PLOTS ARE # OF SAMPLES VERSUS FREQUENCY. IN ADDITION, STANDARD
c DEVIATION AND MEAN VALUES ARE CALCULATED FOR EACH COMPONENT OF
c VELOCITY AND ARE INCLUDED ON THE GRAPHS.
c THIS PROGRAM CALLS OUT SIX DIFFERENT SUBROUTINES IN THE PROCESS
c - SUBROUTINE FILE
c - SUBROUTINE GRAPH
c - SUBROUTINE HISTOG
c - SUBROUTINE SORT
c - SUBROUTINE SPURIOUS
c - SUBROUTINE STATS
c
c*****
      character OPTION*1,CHECK*1,FILENAM*11,TYPE*1,FILEIMG*11,CLEAR*1 real
      dF(3),yfn(3),ytemp(150,3)
      integer nbar(3),FLAG,NEWN(3)
      integer*2 iwork1(32000), iwork2(32000)
      common FHI(4),FLO(4),IRUN,IPT,DM(4),DMDIR(4),BINMAX(4),
      # FSPACE(4),BRAG(4),F(1000,4),N,NACTIV,PEAKNUM(4),FNEW(1000,4)
c
c CALL FILE SUBROUTINE TO RETRIEVE FILE OF INTEREST
c
c 10      call FILE(OPTION,FILENAM,TYPE)
c          if(OPTION.EQ.'V'.OR.OPTION.EQ.'v') go to 55
c          if(OPTION.EQ.'Q'.OR.OPTION.EQ.'q') go to 60
c
c CALL SORT SUBROUTINE AND DO BUBBLE SORT OF THE DATA TO BE PROCESSED
c
c          write(*,305)
c          call SORT
c
c NEXT SEQUENCE OF LINES DEFINES INPUT INFORMATION FOR THE BAR CHARTS
c
c 20      call HISTOG(nbar,ytemp,yfn,dF,FLAG,OPTION,TYPE)
c
c CHECK IF OPERATOR WANTS TO CORRECT SPURIOUS DATA
c
c 30      if(OPTION.EQ.'C'.OR.OPTION.EQ.'c')then
c          call SPURIOUS(nbar,ytemp,dF,FILENAM,NEWN,OPTION)
c      endif
c
c CALL GRAPHIC SUBROUTINE TO PLOT HISTOGRAM
c
c          call GRAPH(FILENAM,nbar,ytemp,yfn,dF,FLAG,NEWN,OPTION,TYPE)
c
c INPUT FORMATS
c
c 300      format(A1)
c 305      format(/,1x,'Be patient, the histograms are on the way !!!')
c 310      format(/,1x,'HISTOGRAM DISPLAY PROGRAM, VERSION 2.0',////)

```

```

312 format(/,1x,'You now have the following options:',
# /,10X,' Enter either an A for frequency band autoscalling',
# /,10X,'          or a B to select a different number of bins',
# /,10X,'          or a C to correct spurious data',
# /,10X,'          or an M to select a wider band manually',
# /,10X,'          or a P to plot a different datafile',
# /,10X,'          or a Q to quit the program',
# /,10X,'          or an S to save new data file w/o spurious #',
# /,10X,'          or a T to both autoscale/maximize bin number',
# /,10X,'          or a V to view a saved screen',
# /,1X,'Enter selection')
320 format(A1)
322 format(/,1x,'Enter the new high pass frequencies starting with th
#e lowest channel.',
# /,1x,'Use following formats: xx.x xx.x xx.x')
324 format (3F5.2)
326 format(/,1x,'Enter the new low pass frequencies starting with the
# lowest channel.',
# /,1x,'Use following formats: xx.x xx.x xx.x')
328 format(/,1X,'Any other options (enter option or <CR>)?')
330 format(/,1X,'See you later alligator!!!!!!!!!!',/)
340 format(/,1X,'Are you sure you want to quit (Y/N)?')
350 format(/,1x,'Reenter your option.')
c
c OPTIONS GIVEN TO THE OPERATOR (I.E. SELECT DIFFERENT FREQUENCY BAND OR
c TO PLOT DIFFERENT FILE OR QUIT PROGRAM)
c
35          write(*,310)
          write(*,312)
40          read(*,320) OPTION
c OPTION A
          if(OPTION.EQ.'A'.OR.OPTION.EQ.'a'.OR.OPTION.EQ.'T'.OR.OPTION
# .EQ.'t') then
              do 50 i = 1, 4
                  FLO(i) = INT(F(n,i)) + 1.0
                  FHI(i) = INT(F(1,i))
50          continue
              if(OPTION.EQ.'A'.OR.OPTION.EQ.'a')then write(*,328)
                  read(*,320) OPTION
              endif
              go to 20
          endif
c OPTION B
          if(OPTION.EQ.'B'.OR.OPTION.EQ.'b') go to 20
c OPTION C
          if(OPTION.EQ.'C'.OR.OPTION.EQ.'c') go to 30
c OPTION M
          if(OPTION.EQ.'M'.OR.OPTION.EQ.'m') then
              write(*,322)
              read(*,324) (FHI(i), i = 1, 3)
              write(*,326)
              read(*,324) (FLO(i), i = 1, 3)
              write(*,328)
              read(*,320) OPTION
              go to 20
          endif
c OPEN FILE STAT.DAT IN ORDER TO CLOSE IT AND DELETE IT
          open(unit=10,file='STAT.DAT',status='old')
c OPTION P
          if(OPTION.EQ.'P'.OR.OPTION.EQ.'p')then
              close(unit=10,status='delete')

```

```

        go to 10
    endif
c  OPTION S
        if(OPTION.EQ.'S'.OR.OPTION.EQ.'s')then
            call SPURIOUS(nbar,ytemp,dF,FILENAM,NEWN,OPTION) go to 40
        endif
c  OPTION V
        if(OPTION.EQ.'V'.OR.OPTION.EQ.'v')then call
            FILE(OPTION,FILENAM,TYPE)
        endif
55      if(OPTION.EQ.'V'.OR.OPTION.EQ.'v')then
            FILEIMG = FILENAM
            FILEIMG(1:1) = 'I'
            call qsmode(16)
            call qcolor(0,0)
            call QLodScr(FILEIMG,iwork1,iwork2) call qcmov(0,24)
            read(*,320) CLEAR
            call qsmode(2)
            go to 35
        endif
c  OPTION Q
        write(*,340)
        read(*,300) CHECK
        if(CHECK.EQ.'N'.OR.CHECK.EQ.'n')then
            write(*,350)
            go to 40
        endif
        close(unit=10,status='delete')
        call qsmode(2)
        write(*,310)
60      write(*,330)
        stop
        end

```

```

        SUBROUTINE FILE (OPTION,FILENAM,TYPE)
c*****
c
c  THIS SUBROUTINE REQUESTS INFORMATION REGARDING THE DATAFILE TO BE
c  PROCESSED (I.E. THE RUN NUMBER, POINT NUMBER, AND A BACKUP NUMBER IF
c  NEEDED) THEN RETRIEVES ALL RELEVANT INFORMATION FOR THE HISTOGRAMS
c*****
        character*11 FILENAM,R*1,RUN*3,P*1,PNT*2,DAT*4,OPTION*1,B*2,
        # BAK*2,EXTENSN*1,TYPE*1
        common FHI(4),FLO(4),IRUN,IPT,DM(4),DMDIR(4),BINMAX(4),
        # FSPACE(4),BRAG(4),F(1000,4),N,NACTIV,PEAKNUM(4),FNEW(1000,4)
        logical check
        data P,R,DAT,B/'P','R',' .DAT',' .B'/
c
c  I/O FORMATS
c
100      format(/,lx,,
        #'      II',/,
        #'HH HH II SSSSS TTTTTT OOOOOO GGGGGG RRRRRR AAAAAA MM MM ',/,
        #'HH HH II SSS TT OO OO GG RR RR AA AA MMM MMM',/,
        #'HHHHHH II SS TT OO OO GG GG RRRRRR AAAAAA MM M MM',/,
        #'HH HH II SSS TT OO OO GG GG RR R AA AA MM MM',/,
        #'HH HH II SSSSS TT OOOOOO GGGGGG RR R AA AA MM MM ',/,)
110      format(///,
        #' *****',/,
        #' Histogram Program, VERSION 2.0',/,

```

```

# ' Date first created: April 1, 1992',/,
# ' Date last edited:   June 24, 1992',/,
# ' Written by Stephane Couillaud',/,
# ' Copyright (c), 1992. All rights reserved.',/,
# ' *****')
120 format(/,1x,'Enter <CR> to continue')
130 format(A1)
140 format(/,1x,'Enter the type of data to be analyzed ( W for wing o
#r J for jet).')
200 format(/,1x,'HISTOGRAM DISPLAY PROGRAM, VERSION 2.0',/)
210 format(/,1x,'Enter the data file extension (D for .DAT or B for .
#BAK):')
220 format(A1)
230 format(/,1x,'Enter the back up file number:')
240 format(I2)
250 format(/,1x,'Enter the run number: ')
260 format(I3)
270 format(/,1x,'Next enter the point number: ')
280 format(I2)
290 format(/,1x,'The data file "',A1,'" does not exist.',
# /,10X,'Enter either an S to select a different data file',
# /,10X,'          or a Q to quit the program',
# /,1x,'Enter selection')

300 format(/,1x,'The data file "',A1,'" was selected.',
# /,10X,'Enter either an S to select a different data file',
# /,10X,'          or a Q to quit the program',
# /,10X,'          or a P to plot the histograms',
# /,10X,'          or a V to view a saved screen',
# /,1x,'Enter selection')
310 format( A1 )
315 format(//,20X,I4,8X,I4,////)
320 format(18X,I5,30X)
322 format(36X,I4,6x,/)
325 format(4X,2F9.1,9X,F9.2,F6.1,30X)
330 format(////////,3F8.3)
340 format(24X,3F6.1,/)
350 format(24X,3F8.2,22X)

c
c OPEN AND READ DATAFILE
c
      call qsmode(2)
      if (OPTION.EQ.'P'.OR.OPTION.EQ.'p') go to 10
      if (OPTION.EQ.'V'.OR.OPTION.EQ.'v') go to 10 write(*,100)
      write(*,110)
      write(*,120)
      read(*,130) TYPE
10    call qsmode(2)
20    write(*,200)
      write(*,140)
      read(*,130) TYPE
      write(*,210)
      read(*,220) EXTENSN if(EXTENSN.EQ.'B'.OR.EXTENSN.EQ.'b') then
        write(*,230)
        read(*,240) IBAK
      endif
      write(*,250)
      read(*,260) IRUNUM
      write(*,270)
      read(*,280) IPTNUM

```



```

write(RUN,'(I3)') IRUNUM      write(PNT,'(I2)') IPTNUM
if(EXTENSN.EQ.'B'.OR.EXTENSN.EQ.'b') then
  write(BAK,'(I2)') IBAK
  FILENAM = R//RUN//P//PNT//B//BAK
if(FILENAM(10:10).EQ.' ') FILENAM(10:10) = '0'
else
  FILENAM = R//RUN//P//PNT//DAT
endif
if(FILENAM(2:2).EQ.' ') FILENAM(2:2) = '0'
if(FILENAM(3:3).EQ.' ') FILENAM(3:3) = '0'
if(FILENAM(6:6).EQ.' ') FILENAM(6:6) = '0'
check=.true.
inquire(file=FILENAM,exist=check)
if(.not.check) then
  call qsmode(2)
  write(*,200)
  write(*,290) FILENAM
  read(*,310) OPTION
  if(OPTION.EQ.'S'.OR.OPTION.EQ.'s') go to 10
  if(OPTION.EQ.'Q'.OR.OPTION.EQ.'q') return
  go to 20
endif
if (OPTION.EQ.'V'.OR.OPTION.EQ.'v') return
call qsmode(2)
write(*,200)
open(unit=8,file=FILENAM,status='old')
write(*,300) FILENAM
read(*,310) OPTION
if(OPTION.EQ.'S'.OR.OPTION.EQ.'s') go to 10
if(OPTION.EQ.'Q'.OR.OPTION.EQ.'q') return
if(OPTION.EQ.'V'.OR.OPTION.EQ.'v') return
c
c READING DATAFILE SELECTED
c
  read(8,315) IRUN,IPT
  read(8,320) n
  read(8,322) NACTIV
  read(8,325) (FHI(i),FLO(i),DM(i),DMDIR(i), i=1,NACTIV)
  read(8,330) (FSPACE(i), i=1,3)
  read(8,340) (BRAG(i), i=1,3)
  do 30 i=1,n
    read(8,350,ERR=40) F(i,1),F(i,2),F(i,3)
30  continue
    close(unit=8,status='keep')
    return
40  stop40
    end

      SUBROUTINE GRAPH(FILENAM,nbar,ytemp,yfn,df,FLAG,NEWN,OPTION,TYPE)
c*****
c
c THIS SUBROUTINE CALLS OUT SUBROUTINES FOUND IN THE GRAPHICS PACKAGE
c CALLED GRAFMATIC. INFORMATION CAN BE FOUND IN THE GRAFMATIC MANUAL
c PUT OUT BY MICROCOMPATIBLES, INC.
c   ADDRESS: 301 Prelude Drive
c             Silver Spring, MD 20901
c   TECHNICAL SUPPORT: (301) 593-5151
c
c SOME VARIABLES OF INTEREST ARE LISTED BELOW

```

```

C
C   ytemp    = ARRAY CONTAINING NUMBER OF SAMPLES/BIN# FOR THE THREE
C             COMPONENTS OF VELOCITY
C   dF       = INTERVAL SIZE
C   FLO      = MAXIMUM VALUE ON X-AXIS
C   FHI      = MINIMUM VALUE ON X-AXIS
C   YFN      = MAXIMUM VALUE ON Y-AXIS
C   YST      = MINIMUM VALUE ON Y-AXIS
C   ZMEAN    = MEAN VALUE
C   ZSTDEV   = STANDARD DEVIATION VALUE
C
C*****
      character VERSION*38,PROMPT*26,OPTION*1,TYPE*1
      character*7 U0,U2,U4,char*1,dFS*3,LDV*23,SAMPLE*12,FREQ*5,SAMP
      character*7 meanu,meanv,meanw,stdvu,stdvv,stdvw,WARNING*33
      character ZFILE*5,CHAN*11,STREAM*10,SPAN*8,DOWN*8,SCREEN*1
      character*11 FILEIMG,FILENAM
      real yval(150,3),zy(150),zmean(3),zstdev(3),dF(3),yfn(3)
#     ,UHI(4),ULO(4),ytemp(150,3)
      integer nbar(3),jcol1(3),jcol2(3),jrow1(3),jrow2(3),FLAG,NEWN(3)
      integer*2 iwork1(32000),iwork2(32000)
      common FHI(4),FLO(4),IRUN,IPT,DM(4),DMDIR(4),BINMAX(4),
# FSPACE(4),BRAG(4),F(1000,4),N,NACTIV,PEAKNUM(4),FNEW(1000,4)
      data LDV,FREQ/'LDV DISPLAY INFORMATION','(MHz)'/
      data SAMPLE,dFS,SAMP/'# OF SAMPLES','dF=','SAMPLES'/
      data WARNING/'*** WARNING DATA OUT OF RANGE ***'/
      data PROMPT,ZFILE/'ENTER <CR> TO EXIT DISPLAY','FILE: '/
      data meanu,meanv,meanw/'MEAN U0','MEAN U2','MEAN U4'/
      data stdvu,stdvv,stdvw/'STDV U0','STDV U2','STDV U4'/
      data U0,U2,U4/'U0, M/S','U2, M/S','U4, M/S'/
      data VERSION/'HISTOGRAM DISPLAY PROGRAM, VERSION 2.0'/
      data CHAN,STREAM/'CHANNEL OFF','STREAMWISE'/
      data SPAN,DOWN/'SPANWISE','DOWNWASH'/

C
C   JCOL1,ETC. DEFINE WINDOWS FOR HISTOGRAM CHART OF U0, U2,& U4
C
      data jcol1(1),jcol2(1),jrow1(1),jrow2(1)/100,300,180,300/
      data jcol1(2),jcol2(2),jrow1(2),jrow2(2)/360,560,180,300/
      data jcol1(3),jcol2(3),jrow1(3),jrow2(3)/100,300,20,140/

C
C   INPUT FORMATS
C
300  format(/,1x,'Would you like the next screen saved to a file(Y/N)?
      #')
310  format(A1)

C
C   CHECK IF USER WANTS SCREEN SAVED TO A FILE
C
      write(*,300)
      read(*,310) SCREEN
      if(SCREEN.EQ.'Y'.OR.SCREEN.EQ.'y')then
          FILEIMG = FILENAM
          FILEIMG(1:1) = 'I'
      endif

C
C   NEXT SEQUENCE OF LINES DEFINES INPUT INFORMATION FOR THE SCREEN DISPLAY
C
      do 20 nchart=1,3
          nbars = nbar(nchart)
          do 10 i=1,nbars yval(i,nchart)=ytemp(i,nchart)
10          continue

```

```

20          continue
c
c ENTER HIGH RESOLUTION GRAPHICS MODE
c
          call qsmode(16)
          call qcolor(0,0)
c INFORMATION ON TOP OF SCREEN DISPLAY
          call qgtxt(38,VERSION,15,10,320,0)
          call qgtxt(5,ZFILE,15,430,320,0)
          call qgtxt(11,FILENAM,15,470,320,0)
c
c CLOSE PLOT FRAME USING QLINE SUBROUTINE
c   - QLINE(jcol1,jrow1,jcol2,jrow2,kolor)
c
          call qline(2,2,2,347,7)
          call qline(2,347,637,347,7)
          call qline(637,347,637,2,7)
          call qline(637,2,2,2,7)
c
c DRAW EACH HISTOGRAMS
c
          do 100 nchart=1,NACTIV
             nbars=nbar(nchart)
             do 30 i=1,nbars
30              zy(i)=yval(i,nchart)
                 jc1=jcol1(nchart)
                 jc2=jcol2(nchart)
                 jr1=jrow1(nchart)
                 jr2=jrow2(nchart)
                 ylast=yfn(nchart)
c
c ndim AND mdim ARE THE DIMENSIONS USED IN yval AND y.
c
                 ndim=25
                 mdim=3
                 ntic=1
                 call qbar(jc1,jc2,jr1,jr2,ndim,mdim,nbars,1,
# yst,ylast,ntic,zy,1,2)
c
c CLOSE INDIVIDUAL PLOT FRAME
c
                 if(nchart.eq.1) then
                     call qline(100,300,300,300,7)
                     call qline(300,300,300,180,7)
                 endif
                 if(nchart.eq.2) then
                     call qline(360,300,560,300,7)
                     call qline(560,300,560,180,7)
                 endif
                 if(nchart.eq.3) then
                     call qline(100,140,300,140,7)
                     call qline(300,140,300,20,7)
                 endif
c
c NEXT SEQUENCE OF LINES SETS UP THE Y AXIS FOR THE HISTOGRAMS
c
                 label=1
                 minor=1
                 ndec=1
                 ntic=4
                 ymajor=abs((ylast-yst)/ntic)

```

```

        call qyaxis(yst,ylast,ymajor,label,minor,ndec)
100      continue
c
c DRAW DUMMY HISTOGRAM FRAME FOR CHANNEL 4 IF NACTIV EQUAL 3
c
      if(NACTIV.LT.3) then
        call qline(100,140,300,140,7)
        call qline(300,140,300,20,7)
        call qline(300,20,100,20,7)
        call qline(100,20,100,140,7)
        call qgtxt(11,CHAN,15,150,70,0)
      endif
c
c POSITION DASH LINES CORRESPONDING TO THE MEAN AND THE STANDARD
c DEVIATION FOR ALL 3 HISTOGRAMS
c   - QDASH(ndots,icol1,irow1,icol2,irow2,kolor)
c
      call STATS(zmean,zstdev,NEWN,OPTION)
c
c COMPONENT U (MEAN & THREE STANDARD DEVIATION TO THE RIGHT AND LEFT)
c
      if(zmean(1).LT.FHI(1).OR.zmean(1).GT.FLO(1)) go to 105
      icol1=100+(200/(FLO(1)-FHI(1)))*(zmean(1)-FHI(1))
      icol2=icol1
      call qdash(5,icol1,180,icol2,300,15)
105    continue
c
      if(zstdev(1)+zmean(1).GT.FLO(1).OR.zmean(1)-zstdev(1).LT.FHI(1))
# go to 110
      icol1=100+(200/(FLO(1)-FHI(1)))*((zmean(1)+zstdev(1))-FHI(1))
      icol2=icol1
      call qdash(5,icol1,180,icol2,300,14)
c
      icol1=100+(200/(FLO(1)-FHI(1)))*((zmean(1)-zstdev(1))-FHI(1))
      icol2=icol1
      call qdash(5,icol1,180,icol2,300,14)
110    continue
c
c COMPONENT V (MEAN & THREE STANDARD DEVIATION TO THE RIGHT AND LEFT) c
      if(zmean(2).LT.FHI(2).OR.zmean(2).GT.FLO(2)) go to 115
      icol1=360+(200/(FLO(2)-FHI(2)))*(zmean(2)-FHI(2))
      icol2=icol1
      call qdash(5,icol1,180,icol2,300,15)
115    continue
c
      if(zstdev(2)+zmean(2).GT.FLO(2).OR.zmean(2)-zstdev(2).LT.FHI(2))
# go to 120
      icol1=360+(200/(FLO(2)-FHI(2)))*((zmean(2)+zstdev(2))-FHI(2))
      icol2=icol1
      call qdash(5,icol1,180,icol2,300,14)
c
      icol1=360+(200/(FLO(2)-FHI(2)))*((zmean(2)-zstdev(2))-FHI(2))
      icol2=icol1
      call qdash(5,icol1,180,icol2,300,14)
120    continue
c
      if(NACTIV.EQ.3) then
c
c COMPONENT W (MEAN & THREE STANDARD DEVIATION TO THE RIGHT AND LEFT)
c
      if(zmean(3).LT.FHI(3).OR.zmean(3).GT.FLO(3)) go to 125

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```

        icol1=100+(200/(FLO(3)-FHI(3)))*(zmean(3)-FHI(3))
        icol2=icol1
        call qdash(5,icol1,20,icol2,140,15)
125    continue
c
        if(zstdev(3)+zmean(3).GT.FLO(3).OR.zmean(3)-zstdev(3).LT.FHI(3))
# go to 130
        icol1=100+(200/(FLO(3)-FHI(3)))*((zmean(3)+zstdev(3))-FHI(3))
        icol2=icol1
        call qdash(5,icol1,20,icol2,140,14)
c
        icol1=100+(200/(FLO(3)-FHI(3)))*((zmean(3)-zstdev(3))-FHI(3))
        icol2=icol1
        call qdash(5,icol1,20,icol2,140,14)
130    continue
        endif
c
c PLACE TEXT IN PLOT FRAME USING THE FOLLOWING SUBROUTINES
c - QQNPUT(jcol,jrow,xval,ndec)
c - QGTXT(nchar,char,kolor,jcol,jrow,iorien)
c
c LABEL THE UNITS ON THE BOTTOM X-AXIS SCALE IN TERMS OF FREQUENCIES call
        qqnput(50,165,FHI(1),1)
        call qqnput(250,165,FLO(1),1)
        call qqnput(310,165,FHI(2),1)
        call qqnput(510,165,FLO(2),1)
        if(NACTIV.EQ.3) then
            call qqnput(50,5,FHI(3),1)
            call qqnput(250,5,FLO(3),1)
        endif
c LABEL THE UNITS ON THE TOP X-AXIS SCALE IN TERMS OF VELOCITIES
        do 150 j=1,NACTIV
            UHI(j)=FSPACE(j)*(DMDIR(j)*FHI(j)+DM(j)-BRAG(j))
            ULO(j)=FSPACE(j)*(DMDIR(j)*FLO(j)+DM(j)-BRAG(j))
150    continue
        call qqnput(60,305,UHI(1),1)
        call qqnput(240,305,ULO(1),1)
        call qqnput(320,305,UHI(2),1)
        call qqnput(500,305,ULO(2),1)
        if(NACTIV.EQ.3) then
            call qqnput(60,145,UHI(3),1)
            call qqnput(240,145,ULO(3),1)
        endif
c X-AXIS LABELS (TOP AND BOTTOM)
        call qgtxt(7,U0,7,170,300,0)
        call qgtxt(7,U2,7,430,300,0)
        call qgtxt(7,U4,7,170,140,0)
        call qgtxt(3,dFS,7,200,165,0)
        call qgtxt(5,FREQ,7,150,165,0)
        call qqnput(190,165,dF(1),2)
        call qgtxt(3,dFS,7,460,165,0)
        call qgtxt(5,FREQ,7,410,165,0)
        call qqnput(450,165,dF(2),2)
        call qgtxt(5,FREQ,7,150,5,0)
        if(NACTIV.EQ.3) then
            call qgtxt(3,dFS,7,200,5,0)
            call qqnput(190,5,dF(3),2)
        endif
c Y-AXIS LABEL
        call qgtxt(12,SAMPLE,1,10,250,-1)
        if(TYPE.EQ.'W'.OR.TYPE.EQ.'w') then

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        call qgtxt(10,STREAM,13,110,285,0)
        call qgtxt(8,SPAN,13,370,285,0)
        call qgtxt(8,DOWN,13,110,125,0)
    endif
c LDV DISPLAY INFORMATION
    call qgtxt(23,LDV,2,380,140,0)
    call qgtxt(7,meanu,15,420,125,0)
    call qqnp(470,125,zmean(1),5)
    call qgtxt(7,meanv,15,420,110,0)
    call qqnp(470,110,zmean(2),5)
    if(NACTIV.EQ.3) then
        call qgtxt(7,meanw,15,420,95,0)
        call qqnp(470,95,zmean(3),5)
    endif
    call qgtxt(7,stdvu,14,420,80,0)
    stdev0 = zstdev(1)/3.0
    call qqnp(470,80,stdev0,5)
    call qgtxt(7,stdvv,14,420,65,0)
    stdev2 = zstdev(2)/3.0
    call qqnp(470,65,stdev2,5)
    if(NACTIV.EQ.3) then
        call qgtxt(7,stdvw,14,420,50,0)
        stdev4 = zstdev(3)/3.0
        call qqnp(470,50,stdev4,5)
    endif
    call qgtxt(7,SAMP,1,420,35,0)
    xval = N
    call qqnp(490,35,xval,0)
    if(FLAG.EQ.1) then
        call qgtxt(33,WARNING,15,350,20,0)
    endif
c
c EXIT HISTOGRAM DISPLAY AND CLEAR THE SCREEN BY ENTERING A CARRIAGE c RETURN
c
    if(SCREEN.EQ.'Y'.OR.SCREEN.EQ.'y')then
        call QSavScr(FILEIMG,iwork1,iwork2)
    endif
    call qbeep
    call qcmov(0,24)
    call qgtxt(26,PROMPT,15,375,5,0)
    read(*,160) char
160    format(A1)
    FLAG = 0
    call qsmode(2)
    return
end

SUBROUTINE HISTOG(ZINUM,BINNUM,YMAX,SZINT,WARN,OPTION,TYPE)
c*****
c
c THIS SUBROUTINE ASSIGNS THE FREQUENCY DATA F(I,J) TO THE APPROPRIATE
c BINS FOR ALL THREE COMPONENT OF VELOCITY. IT ALSO CALCULATES PARAMETERS
c SUCH AS dF, FBAND, AND I.
c
c FHI = HIGH FILTER FREQUENCY
c FLO = LOW FILTER FREQUENCY
c FBAND = FREQUENCY BAND
c ZINUM = NUMBER OF INTERVAL IN FBAND,ALSO USED AS NUMBER OF BARS
c WHEN PASSED TO MAIN PROGRAM

```

```

C      SZINT   = SIZE OF FREQUENCY INTERVAL
C      BINNUM  = ZINUM X 3 ARRAY CONTAINING NUMBER OF SAMPLES/BIN #;
C                COLUMN 1 REPRESENTS GRAPH INFORMATION FOR U0 AND THE
C                OTHER TWO COLUMNS ARE U2 AND U4.
C      BINMAX  = NUMBER PASSED OUT TO LABEL MAXIMUM Y VALUE OF GRAPH IN
C                IN MAIN PROGRAM
C C***** C
C      dimension BINNUM(150,3),FBAND(3),SZINT(3),YMAX(3),ZINUM(3)
C      character OPTION*1,TYPE*1
C      integer PEAKNUM,WARN,ZINUM
C      real BINMAX
C      common FHI(4),FLO(4),IRUN,IPT,DM(4),DMDIR(4),BINMAX(4),
C      # FSPACE(4),BRAG(4),F(1000,4),N,NACTIV,PEAKNUM(4),FNEW(1000,4)
C
C INPUT FORMATS
C
C 200  format(/,
C      #/, ' Enter the number of bins for each plot frame. One per line.',
C      #/, ' The number of bins per plot should not exceed 100.',
C      #/, ' The current values are:')
C 210  format(1x,' plot U0 =',I3'      plot U2 =',I3'      plot U4 =',I3)
C 220  format(/,1x,'The bin numbers are out of range. Please reenter the
C      # correct values.')
C
C OPEN FILE AND READ NUMBER OF SAMPLES AND ARRAY F(N,4)
C
C      open(unit=10,file='STAT.DAT',status='old')
C      read(10,10) n
C 10   format(I5)
C      read(10,20) ((F(i,j), j=1,3), i=1,n)
C 20   format(3F8.2)
C
C CALCULATE NUMBER OF INTERVALS REQUIRED FOR THE THREE HISTOGRAMS
C
C      FBAND(1) = FLO(1)-FHI(1)
C      FBAND(2) = FLO(2)-FHI(2)
C      FBAND(3) = FLO(3)-FHI(3)
C
C ENTER THE NUMBER OF BINS MANUALLY
C
C      if(OPTION.EQ.'B'.OR.OPTION.EQ.'b')then
C        write(*,200)
C        write(*,210) ZINUM(1),ZINUM(2),ZINUM(3)
C 22      read(*,*) (ZINUM(j),j =1,NACTIV)
C        do 25 j=1,NACTIV
C          if(ZINUM(j).GT.100.OR.ZINUM(j).LT.1)then
C            ERROR = 1
C          endif
C 25      continue
C          if(ERROR.EQ.1)then
C            write(*,220)
C            ERROR = 0
C            go to 22
C          endif
C          do 30 j=1,NACTIV
C            SZINT(j) = (FBAND(j))/ZINUM(j)
C 30      continue
C
C USE THE LARGEST NUMBER OF BINS
C
C      else if(OPTION.EQ.'T'.OR.OPTION.EQ.'t')then

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```

        do 40 j=1,NACTIV
            ZINUM(J)=50.0
            SZINT(J)= (FBAND(j))/ZINUM(j)
40        continue
c
c CALCULATE THE NUMBER OF BINS
c
        else
            do 50 j=1,NACTIV
                if(FBAND(j).LT.4) then
                    TEMP = 20.0
                else if(FBAND(j).GE.4.AND.FBAND(j).LT.12) then
                    TEMP = 30.0
                else if(FBAND(j).GE.12.AND.FBAND(j).LT.16) then
                    TEMP = 40.0
                else
                    TEMP = 50.0
                endif
                ZINUM(j) = TEMP
                SZINT(j) = (FBAND(j))/ZINUM(j)
50            continue
        endif
c
c TEST THAT ALL ENTRIES OF F(N,3) ARE WITHIN LIMITS
c
        WARN=0
        do 60 j=1,NACTIV
            if(F(n,j).GT.FLO(j).OR.F(1,j).LT.FHI(j)) then
                WARN=1
            endif
60        continue
c
c ASSIGN SAMPLES TO CORRESPONDING BIN NUMBER FOR ALL THREE COMPONENTS
c
        do 70 j=1,150
            BINNUM(j,1) = 0
            BINNUM(j,2) = 0
            BINNUM(j,3) = 0
70        continue
c
        do 90 k=1,NACTIV
            do 80 j=1,n
                L = (F(j,k)-FHI(k))/SZINT(k) + 1.0
                BINNUM(L,k) = BINNUM(L,k) + 1
80            continue
90        continue
c
c FIND THE MAXIMUM # OF SAMPLES IN ARRAY BINNUM. FIND THE CLOSEST MULTI
c PLE OF 5 HIGHER THAN BINMAX. THE NUMBER IS TO BE PASSED OUT TO THE
c MAIN PROGRAM AS THE Y UPPER LIMIT ON THE Y-AXIS (OR # OF SAMPLES AXIS)
c
        BINMAX(1)=0
        BINMAX(2)=0
        BINMAX(3)=0
        do 110 j=1,NACTIV
            do 100 i=1,ZINUM(j)
                if(BINNUM(i,j).GE.BINMAX(j)) then
                    BINMAX(j) = BINNUM(i,j)
c PEAKNUM DENOTES THE LOCATION OF THE HIGHEST BIN TO BE LATER USED
c IN SUBROUTINE SPURIOUS
                    PEAKNUM(j) = i

```



```

        endif
100      continue
110    continue
c
      if (TYPE.EQ.'W'.OR.TYPE.EQ.'w') then
        do 120 i=1,3
          ZYMAX=20.0
          do while (BINMAX(i).GE.ZYMAX)
            ZYMAX=ZYMAX+20.0
          end do
          YMAX(i)=ZYMAX+20.0
120      continue
        else
          do 125 i=1,3
            ZYMAX=5.0
            do while (BINMAX(i).GE.ZYMAX)
              ZYMAX=ZYMAX+5.0
            end do
            YMAX(i)=ZYMAX+5.0
125      continue
          endif
c
          rewind 10
          end

      SUBROUTINE SORT
c*****
c
c  THIS SUBROUTINE SORTS THE COLUMNS OF AN N X 3 ARRAY IN ASCENDING ORDER
c  BY USING A BUBBLE SORT METHOD
c
c*****
      logical done
      common FHI(4),FLO(4),IRUN,IPT,DM(4),DMDIR(4),BINMAX(4),
      # FSPACE(4),BRAG(4),F(1000,4),N,NACTIV,PEAKNUM(4),FNEW(1000,4)
c
      open(unit=10,file='STAT.DAT',status='new')
c
c  DO BUBBLE SORT ON ARRAY F(n,3) FOR EACH COLUMN WHERE EACH COLUMN
c  CORRESPONDS TO A COMPONENT OF VELOCITY (I.E. U(1)=F(n,1))
c
      do 30 j=1,3
        m = n - 1
        done = .false.
c
c  WHILE NOT DONE DO THE FOLLOWING
c
15      if(.not. done) then
        done = .true.
c
c  SCAN THE LIST COMPARING CONSECUTIVE ITEMS
c
        do 20 i=1,m
          if(F(i,j).gt.F(i+1,j)) then
c
c  NUMBER OUT OF RANGE, SO INTERCHANGE THEM
c
            temp = F(i,j)
            F(i,j) = F(i+1,j)

```

```

        F(i+1,j) = temp
        done = .false.
    endif
20  continue
c
c  LARGEST NUMBER HAS SUNK INTO PLACE SO ELIMINATE IT ON NEXT PASS
c
        m = m - 1
        go to 15
    end if
30  continue
c
c  PRINT SAMPLE OUTPUT FILE
c
        write(10,40) n
40    format(I5)
        do 60 i=1,n
            write(10,50) F(i,1),F(i,2),F(i,3)
50        format(3F8.2)
60    continue
        rewind 8
        close(unit=8)
        close(unit=10,status='keep')
        return
    end

        SUBROUTINE SPURIOUS(ZINUM,BINNUM,SZINT,FILENAM,NEWN,OPTION)
c*****
c
c  THIS SUBROUTINE IS USED TO REMOVE ANY SPURIOUS DATA GENERATED BY
c  ELECTRONIC NOISE. THE USER IS GIVEN THE OPTION TO DEFINE THE ACCEPTANCE
c  THRESHOLD. GENERALLY, AN ACCEPTANCE THRESHOLD IS CALCULATED TO BE 5
c  PERCENT OF THE NUMBER OF MEASUREMENTS WITHIN THE PEAK OR THE VALUE
c  OF 3 WHICHEVER IS GREATER (THESE NUMBERS HAVE BEEN APPROXIMATED
c  FROM STATISTICS AND PROBABILITY CALCULATIONS).
c  Ref: James F. Meyers (1988) Laser Velocimeter Data Acquisition and
c        Real Time Processing Using a Microcomputer. Fourth International
c        Symposium on Applications of Laser Anemometry To Fluid Mechanics
c        July 11-14, 1988 Lisbon, Portugal
c  c*****
        dimension ZBINNUM(150,3),BINNUM(150,3),TRSHOLD(3)
        character*11 FILESPR,FILENAM,OPTION*1,CHECK*1
        integer NEWN(3),PEAKNUM,ZINUM(3)
        real SZINT(3),BINMAX
        common FHI(4),FLO(4),IRUN,IPT,DM(4),DMDIR(4),BINMAX(4),
        # FSPACE(4),BRAG(4),F(1000,4),N,NACTIV,PEAKNUM(4),FNEW(1000,4)
c
c  INPUT FORMATS
c
200  format(/,1X,A11,/)
203  format(1X,'THRESHOLD(1)',3X,'THRESHOLD(2)',3X,'THRESHOLD(3)',/)
205  format(4X,F5.2,10X,F5.2,10X,F5.2,/)
207  format(4X,'N',6X'NEWN(1)',3X,'NEWN(2)',3X,'NEWN(3)',/)
210  format(2X,I4,6X,I4,6X,I4,6X,I4,/)
220  format(1X,'The first NEWN samples of each column is good data the
        # rest is spurious data'//)
230  format(1X,3F8.2)
240  format(/,1X,'File saved. Enter your next option')
245  format(/,1X,'HISTOGRAM DISPLAY PROGRAM, VERSION 2.0',////)

```

```

250  format(/,1X,'Accept default threshold value of 5% of peak(Y/N)')
255  format(A1)
260  format(/,1X,'Enter the',I2,' threshold values (F5.2).')
270  format(F5.2)
c
      if(OPTION.EQ.'S'.OR.OPTION.EQ.'s')then
c
c  SAVE NEW DATA FILE UNDER NEW NAME BY REPLACING FIRST LETTER R OF THE
c  ORIGINAL DATA FILE NAME BY AN S. WHEN READING THE NEWDATA FILE ONLY
c  THE FIRST NEWN SAMPLES OF EACH COLUMN ARE TO BE CONSIDERED THE REST
c  IS SPURIOUS DATA.
      FILESPR      = FILENAM
      FILESPR(1:1) = 'S'
      open(unit=12,file=FILESPR,status='new')
      write(12,200) FILESPR
      write(12,203)
      write(12,205) TRSHOLD(1),TRSHOLD(2),TRSHOLD(3)
      write(12,207)
      write(12,210) N,NEWN(1),NEWN(2),NEWN(3)
      write(12,220)
      do 5 J = 1, N
        write(12,230) FNEW(J,1),FNEW(J,2),FNEW(J,3)
5      continue
      write(*,240)
      close(unit=12,status='keep')
      go to 300
    endif
c
c  PROMPT THE USER TO ACCEPT THE DEFAULT THRESHOLD VALUE OR TO ENTER ONE
c  OF HIS/HER CHOICE
c
      callqsmode(2)
      write(*,245)
      write(*,250)
      read(*,255) CHECK
      if(CHECK.EQ.'N'.OR.CHECK.EQ.'n')then
        write(*,260) NACTIV
        read(*,270) (TRSHOLD(I),I=1,NACTIV)
      else
c
c  CALCULATE THRESHOLD VALUE
c
        do 10 J=1,NACTIV
          TRSHOLD(J) = BINMAX(J) * 0.05
          if(TRSHOLD(J).LT.3.0) TRSHOLD(J) = 3.0
10      continue
        endif
c
c  REMOVE ALL SPURIOUS DATA STARTING FROM PEAK TO HIGHER FREQUENCIES
c
        do 30 J=1,NACTIV
          COUNT1 = 0
          COUNT2 = 0
          COUNT3 = 0
          do 20 I=PEAKNUM(J),ZINUM(J)
            if(BINNUM(I,J).LT.TRSHOLD(J))then
              COUNT1 = COUNT1 + 1
            endif
            COUNT2 = COUNT2 + 1
            if(COUNT1.EQ.COUNT2)then
              COUNT3 = COUNT3 + 1
            endif
          enddo
        enddo
      enddo

```

```

c CHECK IF THREE SUCESSIVE BINS ARE LESS THAN THRESHOLD. IF CONDITION
c IS TRUE THEN SET CONTENT OF REMAINING BINS TO ZERO.
      if(COUNT3.EQ.3)then
        do 15 K=I,ZINUM(J)
          BINNUM(K,J) = 0
15      continue
        endif
      else
        COUNT1 = 0
        COUNT2 = 0
        COUNT3 = 0
      endif
20      continue
30      continue
c
c REMOVE ALL SPURIOUS DATA STARTING FROM PEAK TO LOWER FREQUENCIES
c
      do 60 J=1,NACTIV
        COUNT1 = 0
        COUNT2 = 0
        COUNT3 = 0
        do 50 I=PEAKNUM(J),1,-1
          if(BINNUM(I,J).LT.TRSHOLD(J))then
            COUNT1 = COUNT1 + 1
          endif
          COUNT2 = COUNT2 + 1
          if(COUNT1.EQ.COUNT2)then
            COUNT3 = COUNT3 + 1
c CHECK IF THREE SUCESSIVE BINS ARE LESS THAN THRESHOLD. IF CONDITION
c IS TRUE THEN SET CONTENT OF REMAINING BINS TO ZERO.
            if(COUNT3.EQ.3)then
              do 40 K=I,1,-1
                BINNUM(K,J) = 0
40          continue
              endif
            else
              COUNT1 = 0
              COUNT2 = 0
              COUNT3 = 0
            endif
50          continue
60        continue
c
c CHECK FOR SPURIOUS DATA AND SAVE IT AS A NEW DATAFILE
c
      do 70 L = 1,150
        ZBINNUM(L,1) = 0
        ZBINNUM(L,2) = 0
        ZBINNUM(L,3) = 0
70      continue
c
      do 90 K = 1, NACTIV
        NEWN(K) = N
        M = 1
        do 80 J = 1, N
          L = (F(J,K)-FHI(K))/SZINT(K) + 1.0
          ZBINNUM(L,K) = ZBINNUM(L,K) + 1
c COMPARE OLD BINNUM TO NEW BINNUM IF THEY DIFFER THROW AWAY DATA
          if(ZBINNUM(L,K).GT.BINNUM(L,K))then
            FNEW(NEWN(K),K) = F(J,K)
            NEWN(K) = NEWN(K) - 1
          endif
        enddo
      enddo

```

```

                else
                    FNEW(M,K)    = F(J,K)
                    M            = M + 1
                endif
80          continue
90          continue
c
300         return
           end

SUBROUTINE STATS(AVRG,STDEV,NEWN,OPTION)
c*****
c
c  THIS SUBROUTINE CALCULATES THE AVERAGE AND THE STANDARD DEVIATION OF
c  THE THREE VELOCITY COMPONENTS (IE U0,U2,& U4))
c
c*****
      dimension avrg(4),stdev(4),SUMU(4),VARU(4)
      character OPTION*1
      integer NEWN(3)
      common FHI(4),FLO(4),IRUN,IPT,DM(4),DMDIR(4),BINMAX(4),
# FSPACE(4),BRAG(4),F(1000,4),N,NACTIV,PEAKNUM(4),FNEW(1000,4)
c
      if(OPTION.EQ.'C'.OR.OPTION.EQ.'c')then
c
c  CALCULATE THE MEAN FOR ALL THREE COMPONENTS
c
      do 15 j= 1,NACTIV
          SUMU(j) = 0
          do 10 i= 1,NEWN(j)
              SUMU(j) = SUMU(j) + FNEW(i,j)
10          continue
          avrg(j) = SUMU(j)/NEWN(j)
15          continue
c
c  CALCULATE THE STANDARD DEVIATION FOR ALL THREE COMPONENTS
c
      do 30 j = 1,NACTIV
          VARU(j) =0
          do 20 i = 1,NEWN(j)
              VARU(j) = (FNEW(i,j) - avrg(j))**2 + VARU(j)
20          continue
          stdev(j) = 3 * sqrt(VARU(j)/NEWN(j))
30          continue
      else
c
c  OPEN FILE AND READ n and ARRAY F(n,3)
c
          open(unit=10,file='STAT.DAT',status='old')
          read(10,40) n
          format(I5)
          read(10,50)((F(i,j), j=1,3), i=1,n)
          format(3F8.2)
c
c  CALCULATE THE MEAN FOR ALL THREE COMPONENTS
c
          do 65 j = 1,NACTIV
              SUMU(j)=0
              do 60 i=1,n

```

```

        SUMU(j) = SUMU(j) + F(i,j)
60      continue
        avrg(j) = SUMU(j)/n
65      continue
c
c  CALCULATE THE STANDARD DEVIATION FOR ALL THREE COMPONENTS
c
      do 75 j = 1, NACTIV
        VARU(j)=0
        do 70 i=1,n
          VARU(j) = (F(i,j) - avrg(j))**2 + VARU(j)
70        continue
          stdev(j) = 3 * sqrt(VARU(j)/n)
75      continue
c
      close(unit=10,status='keep')
    endif
  end

```

APPENDIX B

SUMMARY OF ALL HISTOGRAMS

LDV HISTOGRAM SUMMARY

LEGEND:

B/D = BAD DATA

BM = BIMODAL

C/O = CHANNEL OFF

F/G = FAT GAUSSIAN

LOP = LEFT OF PEAK

N/C = NO COMMENTS

N/G = NARROW GAUSSIAN

O/R = OUT OF RANGE

ROP = RIGHT OF PEAK

RUN100	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	NOISY LOP	ZERO'S	NOISY
1.B01	N/C	N/C	NOISY
2.DAT	NOISY LOP	N/C	NOISY
3.DAT	NOISY LOP	N/C	ZERO'S
3.B01	NOISY LOP	N/C	F/G
4.DAT	NOISY LOP	ZERO'S	F/G
4.B01	NOISY LOP	BM?	NOISY
5.DAT	NOISY LOP	F/G	NOISY
6.DAT	NOISY LOP	F/G	C/O
7.DAT	NOISY LOP	F/G	C/O
8.DAT	NOISY LOP	NOISY	C/O
9.DAT	NOISY LOP	F/G	C/O
10.DAT	NOISY LOP	F/G	C/O
11.DAT	NOISY LOP	F/G	C/O
12.DAT	BM?	BM?	C/O
13.DAT	NOISY LOP	NOISY	C/O
14.DAT	NOISY LOP	NOISY	C/O
15.DAT	NOISY LOP	NOISY	C/O
16.DAT	NOISY	NOISY	C/O
17.DAT	NOISY	NOISY	C/O

RUN 101	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	NOISY	N/C	N/C
1.B01	N/C	NOISY O/R	ZERO'S
1.B02	N/C	N/C	N/C
2.DAT	FLAT TOP	N/C	N/C
3.DAT	N/C	N/C	N/C
4.DAT	N/C	NOISY O/R	N/C
4.B01	NOISY O/R	BM	BM
5.DAT	NOISE LOP	N/C	N/C
5.B01	BM	FLAT TOP	N/C
5.B02	N/C	BM	N/C
5.B03	N/G	N/G	N/C
5.B04	N/C	ZERO'S	B/M

5.B05	N/G	N/G	N/C
5.B06	N/G	BM	BM
5.B07	N/G	N/C	BM

RUN 102	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	N/C	TRIMODAL	NOISE LOP
2.DAT	N/C	BM	NOISE LOP
3.DAT	N/C	BM	NOISE LOP
4.DAT	N/G	BM	NOISE LOP
5.DAT	N/G	BM	NOISE LOP
5.B01	N/G	BM	NOISE LOP
5.B02	N/G	BM	NOISE LOP
5.B03	N/G	N/C	NOISE LOP
5.B04	N/G	N/C	NOISE LOP
5.B05	N/G	N/C	NOISE LOP
6.DAT	N/G	N/C	NOISE LOP

RUN103	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	NOISY LOP	N/C	N/C
2.DAT	N/C	N/C	N/C
3.DAT	N/C	N/C	N/C
4.DAT	N/C	N/C	N/C
5.DAT	N/C	N/C	N/C
5.B01	N/C	N/C	N/C
5.B02	N/C	BM?	N/C
5.B03	N/C	N/C	N/C
5.B04	N/C	NOISY LOP	NOISY
5.B05	N/C	N/C	N/C
6.DAT	N/C	NOISY LOP	NOISY LOP

RUN 104	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	NOISE LOP	N/C	N/C
2.DAT	BM?	BM?	N/C
3.DAT	N/C	BM?	BM?
4.DAT	N/C	BM?	N/C
5.DAT	N/C	BM?	NOISE LOP
5.B01	N/C	BM?	NOISE LOP
5.B02	ZERO'S	ZERO'S	BM?
5.B03	N/C	BM?	NOISE LOP
5.B04	N/C	BM?	NOISE LP
5.B05	N/C	BM?	BM?
5.B06	N/C	NOISE LOP	BM?
6.DAT	N/C	BM?	BM?

RUN 105	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	F/G	F/G	F/G
2.DAT	F/G	F/G	F/G
3.DAT	F/G BM?	F/G	F/G
4.DAT	F/G	F/G	F/G
5.DAT	F/G	F/G	F/G
6.DAT	F/G	F/G	F/G BM?
7.DAT	NOISY	F/G	F/G
8.DAT	F/G	F/G	F/G
9.DAT	F/G	F/G	N/C
10.DAT	F/G	F/G	F/G
11.DAT	NOISY	F/G	NOISY

RUN 106	STREAMWISE	SPANWISE	DOWNWASH
2.DAT	N/C	N/C	BM?
2.B01	N/G	N/G	BM
3.DAT	N/G BM?	N/G	N/G
4.DAT	N/G	N/G	N/G
5.DAT	N/G	N/G	N/G
6.DAT	ZERO'S	ZERO'S	BM
6.B01	N/G	N/G	N/G
7.DAT	N/G	N/G	N/G
9.DAT	N/G	N/G	N/G
10.DAT	N/G	N/G	N/G
11.DAT	NOISE	NOISE	NOISE
11.B01	N/G	N/G	N/G
12.DAT	N/G BM?	N/G	N/G
13.DAT	N/G BM?	N/G	N/G
14.DAT	N/G BM?	N/G	N/G
15.DAT	N/G BM?	N/G	N/G
16.DAT	ZERO'S	ZERO'S	N/G
16.B01	N/G	N/G	N/G

RUN 108	STREAMWISE	SPANWISE	DOWNWASH
2.DAT	NOISY	N/C	NOISY
2.B01	BM?	N/C	NOISY
3.DAT	BM?	N/C	F/G
4.DAT	BM? NOISY	N/C	NOISY ROP
5.DAT	NOISY LOP	NOISY LOP	NOISY
6.DAT	N/C	BM	BM?
7.DAT	N/C	N/C	BM?
8.DAT	BM?	N/C	BM?

9.DAT	N/C	N/C	BM?
10.DAT	N/C	N/C	BM?
11.DAT	N/C	N/C	NOISY?
12.DAT	N/C	N/C	NOISY LOP?
13.DAT	N/C	N/C	NOISY LOP?
14.DAT	N/G	NOISE LOP?	BM NOISE LOP
15.DAT	N/G	BM NOISE LOP	NOISY
16.DAT	N/G	BM NOISE LOP	N/C

RUN 109	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	N/G	N/G	N/G
2.DAT	N/G	N/G	N/G
3.DAT	N/G	N/G	N/G
4.DAT	N/G	N/G	N/G
5.DAT	N/G	N/G	N/G
6.DAT	N/G	N/G	N/G
7.DAT	N/G	N/G	N/G
8.DAT	N/G	N/G	N/G
9.DAT	N/G	N/G	N/G
10.DAT	N/G	N/G	N/G
11.DAT	N/G	N/G	N/G

RUN 110	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	N/C	N/C	N/C
2.DAT	N/C	N/C	N/C
3.DAT	N/C	BM?	N/C
4.DAT	N/C	BM?	N/C
5.DAT	N/C	BM?	N/C
6.DAT	N/C	BM?	N/C
7.DAT	N/C	N/C	N/C
8.DAT	N/C	N/C	N/C
9.DAT	N/C	N/C	N/C
10.DAT	N/C	N/C	N/C
11.DAT	N/C	N/C	F/G

RUN 111	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	NOISY	NOISY	NOISY
2.DAT	NOISY	NOISY	NOISY
3.DAT	NOISY	NOISY	NOISY
4.DAT	NOISY	NOISY	NOISY
5.DAT	NOISY	N/C	N/C
6.DAT	NOISY	NOISY	NOISY
7.DAT	NOISY	NOISY	NOISY

8.DAT	NOISY	F/G	F/G
9.DAT	NOISY	F/G	F/G
10.DAT	NOISY	F/G	F/G BM?
11.DAT	NOISY	F/G	N/C
12.DAT	NOISY	NOISY	NOISY

RUN 112	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	N/C	N/C	N/C
2.DAT	N/C	N/C	N/C
3.DAT	N/G	N/G	N/G
4.DAT	N/G	N/G	N/G
5.DAT	N/C	N/C	N/C
6.DAT	N/C	N/C	N/C
7.DAT	N/C	N/C	O/R BM?
8.DAT	N/C	N/C	BM?
9.DAT	N/G	N/G	F/G
10.DAT	N/G	N/C	NOISY LOP
11.DAT	N/C	N/C	BM?

RUN113	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	NOISY	NOISY	F/G
1.B01	NOISY	NOISY	F/G
1.B02	NOISY	NOISY	F/G
2.DAT	NOISY	NOISY	NOISY
2.B01	NOISY	NOISY	NOISY
3.DAT	NOISY	NOISY	NOISY
4.DAT	NOISY	NOISY	ZERO'S
4.B01	NOISY	NOISY	F/G
5.DAT	NOISY	NOISY	NOISY BM?
6.DAT	NOISY	NOISY	NOISY BM?
7.DAT	NOISY ROP	F/G	F/G
8.DAT	NOISY	NOISY	NOISY
9.DAT	NOISY	NOISY	NOISY
10.DAT	NOISY	NOISY	NOISY
11.DAT	F/G	NOISY	NOISY

RUN 114	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	F/G	F/G	F/G
2.DAT	NOISY	NOISY	NOISY
3.DAT	NOISY	NOISY	NOISY
4.DAT	NOISY	NOISY	NOISY
5.DAT	NOISY	NOISY	NOISY
6.DAT	F/G	F/G	B/M

7.DAT	NOISY	NOISY	NOISY
8.DAT	NOISY	NOISY	NOISY
9.DAT	NOISY	NOISY	NOISY
10.DAT	NOISY	NOISY	NOISY
11.DAT	NOISY	NOISY	NOISY

RUN 115	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	NOISY	NOISY	NOISY
2.DAT	NOISY	NOISY	NOISY
3.DAT	NOISY	NOISY	NOISY
4.DAT	NOISY	F/G	NOISY
5.DAT	F/G	F/G	NOISY
6.DAT	F/G	F/G	NOISY BM?
7.DAT	BM?	F/G	F/G
8.DAT	F/G	NOISY	NOISY
9.DAT	B/D	B/D	B/D

RUN 131	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	N/G	NOISY LOP	NOISY
2.DAT	N/G	NOISY LOP	NOISY
3.DAT	N/C	BM	NOISY

RUN 132	STREAMWISE	SPANWISE	DOWNWASH
1.DAT	NOISY	NOISY	NOISY

APPENDIX C

PROGRAM LDVSUM

```

      PROGRAM LDVSUM
*****
*
* THIS PROGRAM IS DESIGNED TO DO SEVERAL TASKS TAKEN FROM A MENU
* (1) TO RETRIEVE THE FIRST FIFTEEN LINES OF EACH DATAFILE AND SAVE
*     IT AS OUTPUT.DAT
* (2) TO RETRACE THE TRAVERSE PATTERN FOR EACH RUN AND SAVE IT AS
*     TRAVERSE.DAT
* (3) TO CONVERT MEAN FREQUENCIES TO VELOCITIES AND SAVE IT AS A DATA
*     FILE NAME OF YOUR CHOICE
*
*234567*****
      CHARACTER FILENAM*11,R*1,RUN*3,P*1,PNT*2,DAT*4,B*2,BAK*2
      CHARACTER ZOPTION*1,VELDATA*15,VALUE*1
      DIMENSION X(4),Y(4),Z(4),ICLC(4),FHI(4),FLO(4),FCEN(4),DMSV(4),
#DMDIR(4),FAVG(4),FDEV(4),NBAD(4)
      REAL LAMBDAG,LAMBDA
      LOGICAL CHECK
      DATA P,R,DAT,B/'P','R','.DAT','.B'/
C CONVERSION FACTORS RADIAN TO DEGREE AND VIS VERSA
      RADDEG = 57.2957795
      DEGRAD = 0.01745329
      ALPHA = 20.0*DEGRAD
      FREESTR = 28.36
      SEMISP = 23.847
C
C I/O FORMATS
C
100  FORMAT (//,10X,I4,6X,I4,8X,I4,8X,2(I2,1H/),I4,8X,2(I2,1H:),
#I2,/)
110  FORMAT (36X,F8.3,7X,F8.3,7X,F8.3)
115  FORMAT (35X,F8.3,7X,F8.3,7X,F8.3)
120  FORMAT (/ ,18X,I5)
130  FORMAT (36X,I4,27X,3(I2,1H:),I2,/)
140  FORMAT (1X,I3,2F9.1,4X,F5.1,F9.2,F6.1,F10.3,F11.1,I9)
C
150  FORMAT (33X,'LDV OUTPUT FILE',3X,A11)
160  FORMAT (/ ,6X,'TEST',I4,3X,'RUN',I4,3X,'POINT',I4,3X,
# 'DATE:',2(I2,1H/),I4,3X,'TIME:',2(I2,1H:),I2,/)
170  FORMAT (' INITIAL POSITION:',14X,'X = ',F8.3,3X,
# 'Y = ',F8.3,3X,'Z = ',F8.3)
180  FORMAT (' CURRENT POSITION:',14X,'X = ',F8.3,3X,
# 'Y = ',F8.3,3X,'Z = ',F8.3)
190  FORMAT (' FINAL POSITION:',16X,'X = ',F8.3,3X,
# 'Y = ',F8.3,3X,'Z = ',F8.3,/)
200  FORMAT (' DATA BLOCK SIZE: ',I5)
210  FORMAT (' LVABI:',6X,'NO. OF ACTIVE CHANNELS:',I4,6X,
# 'COINCIDENT CHANNELS: ', 3(I2,1H:),I2)
220  FORMAT (5X,'COUNTER PROCESSOR SETTINGS',11X,'SHIFT AVG FREQ.',
# ' STANDARD NO. BAD',/, 'LVABI HIGH PASS LOW PASS CENTER',
# ' DOWNMIX DIR. MHZ DEVIATION SAMPLES')
230  FORMAT (1X,I3,2F9.1,4X,F5.1,F9.2,F6.1,F10.3,F11.1,I9)
240  FORMAT (/ ,1X,'*****
#*****',/)
250  FORMAT (1X,'FILE ',A11,' COMPLETED')
260  FORMAT (/ ,1X,'YOU HAVE THE FOLLOWING OPTIONS',
# / ,8X,'Enter either an S to get a summary of all the datafiles',
# / ,8X,' or a T to get a summary of all traverses',
# / ,8X,' or a V to get a summary of all velocities',
# / ,8X,'Please enter your option')
270  FORMAT (A)

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280     FORMAT (/////,35X,F8.3,7X,F8.3,7X,F8.3)
285     FORMAT (1X,'TRAVERSE PATTERN FOR RUN # ',I3,/)
290     FORMAT (1X,'X = ',F8.3,3X,'Y = ',F8.3,3X,'Z = ',F8.3)
300     FORMAT (/////,35X,F8.3,7X,F8.3,7X,F8.3,/////)
305     FORMAT (1X,'FILENAME',5X,'X-COORD',2X,'Y-COORD',2X,'Z-COORD',
# 3X,'U-COMP',3X,'V-COMP',3X,'W-COMP',3X,'RESULT',2X,'X-ANGLE',
# 2X,'Y-ANGLE',2X,'Z-ANGLE')
308     FORMAT (16X,'(in)',5X,'(in)',5X,'(in)',5X,'(m/s)',4X,'(m/s)',
# 4X,'(m/s)',4X,'(m/s)',3X,'(deg)',4X,'(deg)',4X,'(deg)',/)
310     FORMAT (31X,F9.2,6X,F10.3,20X)
315     FORMAT (1X,'FILENAME',',',',',Y/(b/2)',',',',',DOWN',',',',Vdownwash/Vf
# reestream',',',',SPAN',',',',RESULTANT')
C 320     FORMAT (1X,A11,3(2X,F7.3),7(1X,F8.2))
C 320     FORMAT (1X,T2,A11,T15,F7.3,T24,F7.3,T33,F7.3,T42,F8.2,T51,F8.2,
C # T60,F8.2,T69,F8.2,T78,F8.2,T87,F8.2,T96,F8.2)
C320     FORMAT (1X,A11,',',',',3(1X,F7.3,',','),7(F8.2,',','))
320     FORMAT (1X,A11,',',',',1X,F7.3,',',',',7(F8.2,',','))
330     FORMAT (/ ,1X,'Enter the range of files to be processed starting
#with the lowest run #')
340     FORMAT (/ ,1X,'Lowest run # ?')
350     FORMAT (/ ,1X,'Highest run # ?')
360     FORMAT (/ ,1X,'Enter the name of the file you wish to create.')
370     FORMAT (A15)
380     FORMAT (/ ,1X,'Would you like the menu again (Y/N)?')
390     FORMAT (/ ,1X,'Mission accomplished')
400     FORMAT (I3)
410     FORMAT (/ ,1X,'Calculation with measured or calculated values (M/
#C)?')
C
5     WRITE(*,260)
    READ(*,270) ZOPTION
    IF(ZOPTION.EQ.'S'.OR.ZOPTION.EQ.'s') THEN
        OPEN(UNIT=9,FILE='OUTPUT.DAT',STATUS='NEW')
    ENDIF
    IF(ZOPTION.EQ.'T'.OR.ZOPTION.EQ.'t') THEN
        OPEN(UNIT=10,FILE='TRAVERSE.DAT',STATUS='NEW')
    ENDIF
    IF(ZOPTION.EQ.'V'.OR.ZOPTION.EQ.'v') THEN
        WRITE(*,360)
        READ(*,370) VELDATA
        WRITE(*,410)
        READ (*,270) VALUE
        OPEN(UNIT=11,FILE=VELDATA,STATUS='NEW')
        WRITE(11,315)
    ENDIF
C CHANGE THE RANGE OF THE 'I' DESCRIPTOR TO FIT THE NECESSARY REQUIREMENT
    WRITE(*,330)
    WRITE(*,340)
    READ(*,400) IFIRST
    WRITE(*,350)
    READ(*,400) ILAST
    DO 50 I = IFIRST,ILAST
        FLAG1 = 0
        IRUNUM = I
        IPTNUM = 0
        ICOUNT = 0
10     IF(ICOUNT.EQ.0) THEN
        IBAK = 0
15     IPTNUM = IPTNUM + 1
        WRITE(RUN,'(I3)') IRUNUM
        WRITE(PNT,'(I2)') IPTNUM

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      FILENAM = R//RUN//P//PNT//DAT
      IF (FILENAM(2:2).EQ.' ') FILENAM(2:2) = '0'
      IF (FILENAM(3:3).EQ.' ') FILENAM(3:3) = '0'
      IF (FILENAM(6:6).EQ.' ') FILENAM(6:6) = '0'
      ICOUNT = ICOUNT + 1
      CHECK=.TRUE.
      INQUIRE(FILE=FILENAM,EXIST=CHECK)
      IF (.NOT.CHECK.AND.ICOUNT.EQ.1) GO TO 15
      IF (.NOT.CHECK.AND.ICOUNT.EQ.2) GO TO 50
ELSE
      IBAK = IBAK + 1
      WRITE(BAK,'(I2)') IBAK
      FILENAM = R//RUN//P//PNT//B//BAK
      IF (FILENAM(2:2).EQ.' ') FILENAM(2:2) = '0'
      IF (FILENAM(3:3).EQ.' ') FILENAM(3:3) = '0'
      IF (FILENAM(6:6).EQ.' ') FILENAM(6:6) = '0'
      IF (FILENAM(10:10).EQ.' ') FILENAM(10:10) = '0'
      CHECK=.TRUE.
      INQUIRE(FILE=FILENAM,EXIST=CHECK)
      IF (.NOT.CHECK) THEN
        ICOUNT = 0
        GO TO 10
      ENDIF
ENDIF
OPEN(UNIT=8,FILE=FILENAM,STATUS='OLD')
C PRINT DESCRIPTION OF ALL THE DATA FILES
      IF (ZOPTION.EQ.'S'.OR.ZOPTION.EQ.'s') THEN
C READ DATA FILES
      READ(8,100) ITEST,IRUN,IPT,IMON,IDAY,IYR,IHR,IMIN,ISEC
      READ(8,110) X(1),Y(1),Z(1)
      READ(8,115) X(2),Y(2),Z(2)
      READ(8,110) X(3),Y(3),Z(3)
      READ(8,120) IDBS
      READ(8,130) NCHAN, (ICLC(J), J=1,4)
      DO 30 J = 1,NCHAN
        READ(8,140) ILVABI,FHI(J),FLO(J),FCEN(J),DMSV(J),
# DMDIR(J),FAVG(J),FDEV(J),NBAD(J)
30      CONTINUE
C WRITE TO NEW FILE CALLED OUTPUT.DAT
      WRITE(9,150) FILENAM
      WRITE(9,160) ITEST,IRUN,IPT,IMON,IDAY,IYR,IHR,IMIN,ISEC
      WRITE(9,170) X(1),Y(1),Z(1)
      WRITE(9,180) X(2),Y(2),Z(2)
      WRITE(9,190) X(3),Y(3),Z(3)
      WRITE(9,200) IDBS
      WRITE(9,210) NCHAN, (ICLC(J), J=1,4)
      WRITE(9,220)
      DO 40 J = 1,NCHAN
        WRITE(9,230) ILVABI,FHI(J),FLO(J),FCEN(J),DMSV(J),
# DMDIR(J),FAVG(J),FDEV(J),NBAD(J)
40      CONTINUE
      WRITE(9,240)
      CLOSE(UNIT=8,STATUS='KEEP')
      WRITE(*,250) FILENAM
      GO TO 10
    ENDIF
C PRINT TRAVERSE SUMMARY OF ALL DATA FILES
      IF (ZOPTION.EQ.'T'.OR.ZOPTION.EQ.'t') THEN
      READ(8,280) XT,YT,ZT
      IF (FLAG1.EQ.0) THEN
        WRITE(10,240)

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        WRITE(10,285) IRUNUM
    ENDIF
    FLAG1 = 1
    WRITE(10,290) XT,YT,ZT
    CLOSE(UNIT=8,STATUS='KEEP')
    WRITE(*,250) FILENAM
    GO TO 10
ENDIF
IF(ZOPTION.EQ.'V'.OR.ZOPTION.EQ.'v') THEN
C INITIALIZE THE FOLLOWING CONSTANTS
    LAMBDAG = 5.15E-7
    LAMBDAB = 4.88E-7
    HANGLE = 0.85
    VANGLE = 0.735
    THETA = 2.5567
    GAMMA = 0.238
    PHI = 1.3605
    BRAGG = 40.0
    IF(VALUE.EQ.'C'.OR.VALUE.EQ.'c') THEN
C CALCULATE FRINGE SPACING
        DELXGH = (LAMBDAG)/(2*SIN(HANGLE*DEGRAD))*1E6
        DELXBH = (LAMBDAB)/(2*SIN(HANGLE*DEGRAD))*1E6
        DELXGV = (LAMBDAG)/(2*SIN(VANGLE*DEGRAD))*1E6
    ELSE
C MEASURED FRINGE SPACING
        DELXGH = 18.82
        DELXBH = -17.60
        DELXGV = -19.72
    ENDIF
C READ POSITION,MEAN AND DOWNMIX FOR ALL THREE CHANNELS FROM DATAFIL
    READ(8,300) XT,YT,ZT
    READ(8,310) (DMSV(J),FAVG(J), J=1,3)
C CALCULATE FREQUENCY COEFFICIENTS
    FGH = FAVG(1)-(BRAGG-DMSV(1))
    FGV = FAVG(2)-(BRAGG-DMSV(2))
    FBH = FAVG(3)-(BRAGG-DMSV(3))
C CALCULATE VELOCITY COMPONENT
    UT = DELXGH*FGH
    V1 = SIN(PHI*DEGRAD)*DELXBH*FBH
    V2 = COS(THETA*DEGRAD)*DELXGV*FGV
    V3 = COS(THETA*DEGRAD)*COS(PHI*DEGRAD)
    V4 = SIN(THETA*DEGRAD)*SIN(PHI*DEGRAD)
    VT = (V1-V2)/(V3-V4)
    W1 = COS(PHI*DEGRAD)*FBH*DELXBH
    W2 = SIN(THETA*DEGRAD)*DELXGV*FGV
    W3 = SIN(THETA*DEGRAD)*SIN(PHI*DEGRAD)
    W4 = COS(PHI*DEGRAD)*COS(THETA*DEGRAD)
    WT = (W1-W2)/(W3-W4)
C THE ABOVE VELOCITY COMPONENTS ARE IN TERMS OF THE WIND TUNNEL COORDINATE SYSTEM
WHERE
C THE X-AXIS POINTS DOWNSTREAM, THE Y-AXIS POINTS TOWARDS THE CONTROL ROOM AND THE
C Z-AXIS POINTS UP TOWARDS THE CEILING. A COORDINATE TRANSFORMATION IS PERFORMED
C SO THAT THE X-AXIS LINES UP WITH THE ROOT CHORD OF THE WING AND THE Y-AXIS IS
NORMAL
C TO THE WING (THE Z-AXIS POINTS IN THE SAME DIRECTION). IN OTHER WORDS, THE TUNNEL
C COORDINATE AXIS IS ROTATED BY AN ANGLE EQUAL TO THE ANGLE OF ATTACK (20 DEGREES)
IN
C THE XY PLANE. THE VALUES OBTAINED ARE THEN NONDIMENSIONALIZED BY THE FREESTREAM
C VELOCITY VALUE.
    UW = (UT*COS(ALPHA) + VT*SIN(ALPHA))/FREESTR      !DOWNSTREAM COMPONENT
    VW = (-UT*SIN(ALPHA) + VT*COS(ALPHA))/FREESTR      !DOWNWASH COMPONENT

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      WW = WT/FREESTR                                !SPANWISE COMPONENT
C THE SAME PROCEDURE IS DONE WITH THE COORDINATES OF EACH POINT ON THE DESIRED
C TRAVERSE.
C FINALLY, LET THE Y-AXIS DEFINED IN THE WIND TUNNEL BE THE Z-AXIS AND VIS-VERSA LET
C THE
C Z-AXIS BE THE Y-AXIS (THE X-AXIS REMAINS THE SAME). THIS SWITCH IS DONE TO OBTAIN
C THE
C SAME COORDINATE SYSTEM AS DEFINED IN THE PMARC INPUT FILE. NOW, THE X-AXIS POINTS
C DOWNSTREAM ALONG THE CHORD OF THE WING, THE Y-AXIS POINTS ALONG THE SPAN OF THE
C WING
C AND THE Z-AXIS IS NORMAL TO THE PLANE OF THE WING. YW IS NONDIMENSIONALIZED BY THE
C SEMI-SPAN OF THE WING.
      XW = (XT*COS(ALPHA) + YT*SIN(ALPHA))
      YW = ZT/SEMISP
      ZW = (-XT*SIN(ALPHA) + VT*COS(ALPHA))
C CALCULATE RESULTANT
      RESLT = SQRT(UT**2+VT**2+WT**2)
C WRITE INFORMATION TO DATAFILE
      IF(IFIRST.NE.ILAST) THEN
        IF(FLAG1.EQ.0) THEN
          WRITE(11,240)
          WRITE(11,285) IRUNUM
          WRITE(11,305)
          WRITE(11,308)
        ENDIF
        ENDIF
        FLAG1 = 1
        WRITE(11,320) FILENAM,YW,UW,VW,WW,RESLT
        CLOSE(UNIT=8,STATUS='KEEP')
        WRITE(*,250) FILENAM
        GO TO 10
      ENDIF
50  CONTINUE
      IF(ZOPTION.EQ.'S'.OR.ZOPTION.EQ.'s') THEN
        CLOSE(UNIT=9,STATUS='KEEP')
      ELSEIF(ZOPTION.EQ.'T'.OR.ZOPTION.EQ.'t') THEN
        CLOSE(UNIT=10,STATUS='KEEP')
      ELSE
        CLOSE(UNIT=11,STATUS='KEEP')
      ENDIF
      WRITE(*,380)
      READ(*,270) ZOPTION
      IF(ZOPTION.EQ.'Y'.OR.ZOPTION.EQ.'y') GO TO 5
      WRITE(*,390)
      END

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APPENDIX D

LDVSUM CALCULATIONS

FILENAME	Y/(b/2)	Downstream	Downwash	Spanwise	Resultant
R100P01.DAT	0.759	0.10	-2.82	-0.35	80.71
R100P01.B01	0.759	1.11	-0.78	-0.41	40.17
R100P02.DAT	0.744	1.04	-0.86	-1.09	49.22
R100P03.DAT	0.728	0.96	-0.83	-3.16	96.55
R100P03.B01	0.728	0.91	-0.85	-1.72	60.11
R100P04.DAT	0.713	0.36	-2.32	-2.26	92.40
R100P04.B01	0.713	0.87	-0.85	-2.37	75.49
R100P05.DAT	0.697	0.97	-0.83	-2.97	91.86
R100P06.DAT	0.682	0.95	-0.78	-6.19	179.08
R100P07.DAT	0.666	0.95	-0.70	-9.30	265.95
R100P08.DAT	0.651	0.97	-0.63	-12.41	353.53
R100P09.DAT	0.635	0.92	-0.58	-15.52	441.20
R100P10.DAT	0.620	0.94	-0.44	-18.63	529.21
R100P11.DAT	0.605	0.92	-0.48	-21.74	617.12
R100P12.DAT	0.589	1.01	-0.34	-24.84	705.19
R100P13.DAT	0.574	0.87	-0.30	-27.33	775.61
R100P14.DAT	0.558	0.93	-0.23	-29.82	846.18
R100P15.DAT	0.543	0.89	-0.21	-32.31	916.60
R100P16.DAT	0.527	0.94	-0.04	-34.80	987.28
R100P17.DAT	0.512	0.82	-0.04	-37.28	1057.61

R101P01.DAT	1.006	-0.49	-0.21	-0.59	22.56
R101P01.B01	1.006	-1.41	-0.35	-3.17	98.90
R101P01.B02	1.006	-1.47	-0.51	-1.11	54.20
R101P02.DAT	0.976	-2.32	-0.90	-1.71	85.63
R101P03.DAT	0.945	-3.08	-1.28	-2.37	115.98
R101P04.DAT	0.914	-3.65	-1.43	-3.06	141.10
R101P04.B01	0.914	-0.19	-0.81	-1.11	39.28
R101P05.DAT	0.883	0.67	-0.68	-1.88	59.79
R101P05.B01	0.821	0.45	-0.96	-2.46	76.03
R101P05.B02	0.759	1.02	-0.82	-3.14	96.59
R101P05.B03	0.697	1.09	-0.75	-3.73	112.22
R101P05.B04	0.635	0.83	-1.32	-0.46	46.18
R101P05.B05	0.635	1.03	-0.82	-0.17	37.59
R101P05.B06	0.574	0.94	-0.89	-0.50	39.44
R101P05.B07	0.543	0.96	-0.78	-0.48	37.70

R102P01.DAT	1.006	0.91	-1.04	-0.28	40.01
R102P02.DAT	0.976	0.98	-0.85	-0.34	37.99
R102P03.DAT	0.945	0.90	-1.14	-0.23	41.77
R102P04.DAT	0.914	1.03	-0.87	-0.23	38.87

FILENAME	Y/(b/2)	Downstream	Downwash	Spanwise	Resultant
R102P05.DAT	0.883	1.00	-0.96	-0.34	40.41
R102P05.B01	0.821	1.05	-0.86	-0.27	39.22
R102P05.B02	0.759	1.06	-0.82	-0.34	39.29
R102P05.B03	0.697	1.05	-0.83	-0.33	38.94
R102P05.B04	0.635	1.03	-0.78	-0.45	38.91
R102P05.B05	0.574	0.99	-0.77	-0.33	36.86
R102P06.DAT	0.543	0.98	-0.76	-0.32	36.33

R103P01.DAT	1.006	0.62	-0.69	0.01	26.20
R103P02.DAT	0.976	1.00	-0.90	0.01	38.13
R103P03.DAT	0.945	1.04	-0.91	0.02	39.15
R103P04.DAT	0.914	1.08	-0.92	0.02	40.21
R103P05.DAT	0.883	1.71	-1.13	0.04	58.24
R103P05.B01	0.821	1.10	-0.91	0.05	40.62
R103P05.B02	0.759	1.08	-0.92	0.05	40.31
R103P05.B03	0.697	1.08	-0.87	0.03	39.37
R103P05.B04	0.635	1.03	-0.88	0.01	38.38
R103P05.B05	0.574	0.99	-0.81	-0.02	36.38
R103P06.DAT	0.543	0.96	-0.82	-0.17	36.17

R104P01.DAT	1.006	0.70	-0.59	-0.01	26.11
R104P02.DAT	0.976	0.84	-0.89	-0.02	34.69
R104P03.DAT	0.945	0.97	-0.84	-0.17	36.58
R104P04.DAT	0.914	1.00	-0.87	-0.15	37.71
R104P05.DAT	0.883	1.00	-0.86	-0.15	37.53
R104P05.B01	0.821	1.03	-0.82	-0.13	37.43
R104P05.B02	0.759	-2.96	-2.52	-0.38	110.65
R104P05.B03	0.759	1.05	-0.78	-0.16	37.28
R104P05.B04	0.697	1.04	-0.76	-0.41	38.41
R104P05.B05	0.635	1.02	-0.75	-0.58	39.63
R104P05.B06	0.574	1.00	-0.75	-0.76	41.46
R104P06.DAT	0.543	0.92	-0.76	-1.37	51.48

R105P01.DAT	1.006	-0.15	-0.17	0.04	6.54
R105P02.DAT	0.976	-0.28	-0.34	0.04	12.59
R105P03.DAT	0.945	-0.26	-0.34	-0.06	12.28
R105P04.DAT	0.914	-0.35	-0.39	0.04	14.87
R105P05.DAT	0.883	-0.38	-0.41	0.06	16.09
R105P06.DAT	0.821	-0.38	-0.49	0.09	17.66
R105P07.DAT	0.759	-0.36	-0.54	0.06	18.33
R105P08.DAT	0.697	-0.31	-0.59	0.05	19.01
R105P09.DAT	0.635	-0.23	-0.55	0.00	16.91

FILENAME	Y/(b/2)	Downstream	Downwash	Spanwise	Resultant
R105P10.DAT	0.574	-0.14	-0.54	0.00	15.93
R105P11.DAT	0.503	-0.01	-0.57	-0.11	16.49
R106P02.DAT	0.094	0.96	-0.44	0.15	30.11
R106P02.B01	0.094	0.99	-0.42	-0.12	30.71
R106P03.DAT	0.155	0.91	-0.48	0.26	30.14
R106P04.DAT	0.216	0.84	-0.53	0.31	29.45
R106P05.DAT	0.278	0.78	-0.61	0.34	29.65
R106P06.DAT	0.339	-2.56	-2.75	0.15	106.66
R106P06.B01	0.339	0.77	-0.59	0.35	29.40
R106P07.DAT	0.400	0.75	-0.62	0.36	29.45
R106P09.DAT	0.523	0.70	-0.65	0.38	29.25
R106P10.DAT	0.584	0.67	-0.69	0.38	29.37
R106P11.DAT	0.645	-2.63	-1.69	-2.65	116.12
R106P11.B01	0.645	0.91	-0.01	-0.27	26.77
R106P12.DAT	0.706	0.88	-0.02	-0.27	26.17
R106P13.DAT	0.768	0.86	-0.04	-0.28	25.70
R106P14.DAT	0.829	0.61	-0.71	0.33	28.21
R106P15.DAT	0.890	0.60	-0.76	0.33	29.11
R106P16.DAT	0.951	-2.36	-1.39	0.35	78.30
R106P16.B01	0.951	0.63	-0.79	0.29	29.88
R108P02.DAT	0.094	0.13	-0.18	-0.27	9.95
R108P02.B01	0.094	0.25	-0.20	-0.92	27.52
R108P03.DAT	0.155	0.35	-0.25	-1.53	45.11
R108P04.DAT	0.216	0.28	-0.42	-0.26	16.21
R108P05.DAT	0.278	0.50	-0.59	-0.88	33.12
R108P06.DAT	0.339	0.70	-0.77	0.11	29.74
R108P07.DAT	0.400	0.75	-0.65	0.15	28.44
R108P08.DAT	0.461	0.64	-0.68	0.23	27.24
R108P09.DAT	0.523	0.69	-0.70	0.20	28.32
R108P10.DAT	0.584	0.66	-0.73	0.17	28.45
R108P11.DAT	0.645	0.65	-0.74	0.09	27.91
R108P12.DAT	0.706	0.54	-0.79	0.28	28.34
R108P13.DAT	0.768	0.58	-0.77	0.31	28.65
R108P14.DAT	0.829	0.53	-0.86	0.23	29.54
R108P15.DAT	0.890	0.77	-0.69	-0.21	29.96
R108P16.DAT	0.951	0.82	-0.71	-0.47	33.44
R109P01.DAT	1.006	0.60	0.16	-0.23	18.86
R109P02.DAT	0.976	1.07	-0.67	-0.22	36.40
R109P03.DAT	0.945	1.12	-0.68	-0.19	37.60
R109P04.DAT	0.914	1.16	-0.72	-0.13	38.78

FILENAME	Y/(b/2)	Downstream	Downwash	Spanwise	Resultant
R109P04.DAT	0.914	1.16	-0.72	-0.13	38.78
R109P05.DAT	0.883	1.17	-0.74	-0.11	39.32
R109P06.DAT	0.821	1.17	-0.79	-0.09	40.04
R109P07.DAT	0.759	1.16	-0.79	-0.10	39.85
R109P08.DAT	0.697	1.14	-0.79	-0.10	39.55
R109P09.DAT	0.635	1.12	-0.76	-0.12	38.47
R109P10.DAT	0.574	1.06	-0.76	-0.15	37.27
R109P11.DAT	0.503	1.06	-0.71	-0.19	36.73
R110P01.DAT	1.006	0.00	0.39	0.43	16.45
R110P02.DAT	0.976	1.07	-0.68	-0.16	36.16
R110P03.DAT	0.945	1.03	-0.93	-0.12	39.45
R110P04.DAT	0.914	1.10	-0.82	-0.11	38.98
R110P05.DAT	0.883	1.14	-0.75	-0.10	38.90
R110P06.DAT	0.821	1.14	-0.79	-0.09	39.37
R110P07.DAT	0.759	1.14	-0.76	-0.09	39.09
R110P08.DAT	0.697	1.13	-0.75	-0.10	38.50
R110P09.DAT	0.635	1.11	-0.74	-0.12	37.90
R110P10.DAT	0.574	1.08	-0.71	-0.15	36.98
R110P11.DAT	0.503	1.06	-0.69	-0.18	36.21

R111P01.DAT	1.006	0.43	-0.64	-0.20	22.67
R111P02.DAT	0.976	0.43	-0.72	-0.22	24.45
R111P03.DAT	0.945	0.47	-0.69	-0.11	23.90
R111P04.DAT	0.914	0.37	-0.47	-0.05	16.84
R111P05.DAT	0.883	0.54	-0.58	-0.01	22.51
R111P06.DAT	0.852	0.78	-0.70	0.01	29.61
R111P07.DAT	0.821	0.65	-0.70	-0.02	27.17
R111P08.DAT	0.759	0.74	-0.73	-0.02	29.36
R111P09.DAT	0.697	0.76	-0.77	-0.01	30.62
R111P10.DAT	0.635	0.56	-0.66	-0.01	24.51
R111P11.DAT	0.574	0.53	-0.66	-0.02	24.14
R111P12.DAT	0.503	0.51	-0.77	-0.03	26.15

R112P01.DAT	1.006	1.05	-0.68	-0.14	35.73
R112P02.DAT	0.976	1.09	-0.70	-0.14	36.81
R112P03.DAT	0.945	1.13	-0.69	-0.12	37.68
R112P04.DAT	0.914	1.15	-0.70	-0.11	38.31
R112P05.DAT	0.883	1.16	-0.73	-0.20	39.34
R112P06.DAT	0.821	1.16	-0.77	-0.24	40.03
R112P07.DAT	0.759	1.16	-0.76	-0.54	42.10
R112P08.DAT	0.697	1.15	-0.74	-0.60	42.41

FILENAME	Y/(b/2)	Downstream	Downwash	Spanwise	Resultant
R112P09.DAT	0.635	1.13	-0.74	-0.43	40.11
R112P10.DAT	0.574	1.11	-0.71	-0.37	38.75
R112P11.DAT	0.503	1.09	-0.70	-0.83	43.74
R113P01.DAT	1.006	0.37	-0.90	-0.18	28.16
R113P01.B01	1.006	-0.66	0.07	0.42	22.34
R113P01.B02	1.006	-0.31	-0.62	-0.19	20.34
R113P02.DAT	0.976	0.88	-1.24	-0.18	43.45
R113P02.B01	0.976	0.24	-1.02	-0.15	30.03
R113P03.DAT	0.945	0.17	-0.84	-0.17	24.74
R113P04.DAT	0.914	0.03	-0.55	-1.58	47.52
R113P04.B01	0.914	0.03	-0.52	-0.11	15.02
R113P05.DAT	0.883	-0.01	-0.32	-0.06	9.22
R113P06.DAT	0.821	-0.14	-0.43	-0.06	12.92
R113P07.DAT	0.759	-0.18	-0.46	-0.06	13.96
R113P08.DAT	0.697	-0.14	-0.53	-0.09	15.77
R113P09.DAT	0.635	-0.08	-0.56	-0.09	16.21
R113P10.DAT	0.574	-0.07	-0.65	-0.13	18.96
R113P11.DAT	0.503	0.08	-0.73	-0.13	21.20

R114P01.DAT	1.006	0.44	-1.23	-0.12	37.26
R114P02.DAT	0.976	0.26	-1.40	-0.08	40.37
R114P03.DAT	0.945	0.10	-1.08	-0.05	30.88
R114P04.DAT	0.914	-0.01	-0.77	-0.01	21.91
R114P05.DAT	0.883	-0.04	-0.56	0.00	16.06
R114P06.DAT	0.821	-0.15	-0.47	-0.11	14.37
R114P07.DAT	0.759	-0.16	-0.47	-0.09	14.26
R114P08.DAT	0.697	-0.06	-0.44	-0.09	12.89
R114P08.B01	0.697	-0.02	-0.45	-0.16	13.72
R114P09.DAT	0.635	-0.04	-0.57	-0.19	16.99
R114P10.DAT	0.574	-0.01	-0.58	-0.20	17.38
R114P11.DAT	0.503	0.10	-0.57	-0.18	17.26

R115P01.DAT	1.006	0.16	0.52	0.64	23.72
R115P02.DAT	0.976	-0.20	-0.15	0.05	7.14
R115P03.DAT	0.945	-0.28	-0.26	0.07	10.94
R115P04.DAT	0.914	-0.31	-0.26	0.05	11.63
R115P05.DAT	0.883	-0.36	-0.28	0.09	13.17
R115P06.DAT	0.821	-0.38	-0.36	0.04	14.92
R115P07.DAT	0.759	-0.40	-0.42	0.02	16.47
R115P08.DAT	0.697	-0.38	-0.44	0.00	16.62
R115P09.DAT	0.635	-0.15	-0.08	0.52	15.58

APPENDIX E

SAMPLE PMARC INPUT FILE

MRF WING TEST

```

&BINP2  LSTINP=2,    LSTOUT=0,    LSTFRQ=0,    LENRUN=0,    LPLTYP=1,    &END
&BINP3  LSTGEO=1,    LSTNAB=1,    LSTWAK=3,    LSTCPV=0,    LSTJET=0,    &END
&BINP4  MAXIT=150,    SOLRES=0.0005,    &END
&BINP5  NTSTPS= 10,    DTSTEP=0.002,    &END
&BINP6  RSYM=0.0,    RGPR=0.0,    RFF=5.0,    RCORES=0.050,    RCOREW=0.050 , &END
&BINP7  VINP= 93.0,    VSOUND=1123.0,    UNIT=1,    &END
&BINP8  ALDEG= -20.0,    YAWDEG=0.0,    PHIDOT=0.0,    THEDOT=0.0,    PSIDOT=0.0, &END
&BINP8A PHIMAX= 0.0,    THEMAX=0.0,    PSIMAX=0.0,
        WRX=0.0,    WRY=0.0,    WRZ=0.0,    &END
&BINP8B DXMAX=0.0,    DYMAX=0.0,    DZMAX=0.0,
        WTX=0.0,    WTY=0.0,    WTZ=0.000,    &END
&BINP9  CBAR= 2.4022,    SREF= 3.8029,    SSPAN= 1.9873,
        RMPX=0.25,    RMPY= 0.0000,    RMPZ= 0.0000,    &END
&BINP10 NORSET=0,    NBCHGE=0,    NCZONE=0,
        NCZPCH=0,    CZDUB=0.0,    VREF= 93,    &END
&BINP11 NORPCH=0,    NORF=0,    NORL=0,
        NOCF=0,    NOCL=0,    VNORM=0.0,    &END
&BINP12 KPAN=0,    KSIDE=0,    NEWNAB=0,    NEWSID=0,    &END
&BINP13 NBLIT = 0,    &END

&ASEM1  ASEMXX= 0.00,    ASEMY= 0.00,    ASEMZ= 0.00,
        ASCAL= 1.00,    ATHET= 0.00,    NODEA= 5,    &END
&ASEM2  APXX= 0.00,    APYY= 0.00,    APZZ= 0.00,
        AHXX= 0.00,    AHYY= 0.00,    AHZZ= 0.00,    &END

&COMP1  COMPX= 0.00,    COMPY= 0.00,    COMPZ= 0.00,
        CSCAL= 1.00,    CTHET= 0.00,    NODEC= 5,    &END
&COMP2  CPXX= 0.00,    CPYY= 0.00,    CPZZ= 0.00,
        CHXX= 0.00,    CHYY= 1.00,    CHZZ= 0.00,    &END

&PATCH1 IREV= 0, IDPAT= 1, MAKE= 0, KCOMP= 1, KASS= 1, IPATSYM=0,
        IPATCOP=0,    &END
WING
&SECT1  STX= 0.0000,    STY= 0.0000,    STZ= 0.0000,    SCALE= 1.0000 ,
        ALF= 0.0,    THETA= 0.0,
        INMODE= 4,    TNODS= 0,    TNPS= 15 ,    TINTS= 3,    &END
        3.5833    0.0000    0.0000
        3.2708    0.0000    -0.0417
&BPNODE  TNODE=2,    TNPC=6,    TINTC=1,    &END
        0.3125    0.0000    -0.0417
&BPNODE  TNODE=2,    TNPC=10,    TINTC=3,    &END
        0.0000    0.0000    0.0000

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```

&BPNODE  TNODE=2,      TNPC=6,      TINTC=2,      &END
      0.3125      0.0000      0.0417
&BPNODE  TNODE=2,      TNPC=6,      TINTC=1,      &END
      3.2708      0.0000      0.0417
&BPNODE  TNODE=2,      TNPC=10,     TINTC=3,      &END
      3.5833      0.0000      0.0000
&BPNODE  TNODE=3,      TNPC=6,      TINTC=2,      &END

&SECT1   STX= 0.0000, STY=0.0000,      STZ= 0.0000,  SCALE=  1.0000 ,
      ALF=  0.0, THETA=  0.0,
      INMODE=  4, TNODS=  2,  TNPS= 15 ,  TINTS=  3,      &END
      2.1041      1.7628      0.0000
      1.7918      1.7628      -0.0417
&BPNODE  TNODE=2,      TNPC=6,      TINTC=1,      &END
      1.7917      1.7628      -0.0417
&BPNODE  TNODE=2,      TNPC=10 ,     TINTC=3,      &END
      1.4792      1.7628      0.0000
&BPNODE  TNODE=2,      TNPC=6,      TINTC=2,      &END
      1.7917      1.7628      0.0417
&BPNODE  TNODE=2,      TNPC=6,      TINTC=1,      &END
      1.7918      1.7628      0.0417
&BPNODE  TNODE=2,      TNPC=10 ,     TINTC=3,      &END
      2.1041      1.7628      0.0000
&BPNODE  TNODE=3,      TNPC=6,      TINTC=2,      &END

&SECT1   STX= 0.0000, STY= 0.0000,      STZ= 0.0000,  SCALE=  1.0000 ,
      ALF=  0.0, THETA=  0.0,
      INMODE=  4, TNODS=  5,  TNPS=  5 ,  TINTS=  3,      &END
      1.9158      1.9873      0.0000
      1.9157      1.9873      0.0000
&BPNODE  TNODE=2,      TNPC=6,      TINTC=1,      &END
      1.6383      1.9523      0.0000
&BPNODE  TNODE=2,      TNPC=10 ,     TINTC=3,      &END
      1.6382      1.9523      0.0000
&BPNODE  TNODE=2,      TNPC=6,      TINTC=2,      &END
      1.6383      1.9523      0.0000
&BPNODE  TNODE=2,      TNPC=6,      TINTC=1,      &END
      1.9157      1.9873      0.0000
&BPNODE  TNODE=2,      TNPC=10 ,     TINTC=3,      &END
      1.9158      1.9873      0.0000
&BPNODE  TNODE=3,      TNPC=6,      TINTC=2,      &END

&WAKE1   IDWAK=1,      IFLXW=1,      &END
      T.E. WAKE
&WAKE2   KWPACH=1,      KWSIDE=4,      KWLINE=0,      KWPAN1=0,
      KWPAN2=0,      NODEW=5,      INITIAL=1,      &END
&SECT1   STX= 75.0000, STY=  0.0000, STZ=  0.0000, SCALE=  1.000,
      ALF= -20.0,  THETA=  0.0,
      INMODE=-1,  TNODS=  3,  TNPS= 15,  TINTS=  1,      &END

&ONSTRM  NONSL =8,  KPSL = 22,102,182,262,342,422,502,582,      &END

&BLPARAM RN =0,  VISC = 0, NSLBL =0,      &END

&VS1     NVOLR=4,      NVOLC= 0,      &END
&VS2     X0=  3.6153,  3.6153, -0.0320,  2.7931
      Y0=  0.0268,  0.0268,  0.0268,  1.0204
      Z0=  0.1667, -0.0417,  0.0833, 17.9165      &END
&VS3     X1=  1.9709,  1.9709,  1.6597,  0.0000

```

	Y1=	2.0140,	2.0140,	2.0428,	0.0000		
	Z1=	0.1667,	-0.0417,	0.0833,	0.0000	NPT1= 16,16,16,1	&END
&VS4	X2=	3.6153,	3.6153,	-0.0320,	2.7931		
	Y2=	0.0268,	0.0260,	0.0268,	1.0204		
	Z2=	0.0417,	-0.1667,	-0.0833,	-17.9165	NPT2= 4,4,3,20	&END
&VS5	X3=	0.0000,	0.0000,	0.0000,	0.0000		
	Y3=	0.0000,	0.0000,	0.0000,	0.0000		
	Z3=	0.0000,	0.0000,	0.0000,	0.0000	NPT3= 0,0,0,0	&END
&SLIN1	NSTLIN= 0,						&END
&SLIN2	SX0=	-0.8333,	SY0=	1.6667,	SZ0=	2.333,	
	SU=	2.0833,	SD=	10.0000,	DS=	1.00,	&END
&SLIN2	SX0=	-0.8333,	SY0=	1.6667,	SZ0=	2.000,	
	SU=	2.0833,	SD=	10.0000,	DS=	1.00,	&END
&SLIN2	SX0=	-0.8333,	SY0=	1.6667,	SZ0=	1.667,	
	SU=	2.0833,	SD=	10.0000,	DS=	1.00,	&END
&SLIN2	SX0=	-0.8333,	SY0=	1.6667,	SZ0=	1.333,	
	SU=	2.0833,	SD=	10.0000,	DS=	1.00,	&END
&SLIN2	SX0=	-0.8333,	SY0=	1.6667,	SZ0=	1.000,	
	SU=	2.0833,	SD=	10.0000,	DS=	1.00,	&END
&SLIN2	SX0=	-0.8333,	SY0=	1.6667,	SZ0=	0.667,	
	SU=	2.0833,	SD=	10.0000,	DS=	1.00,	&END
&SLIN2	SX0=	-0.8333,	SY0=	1.6667,	SZ0=	0.333,	
	SU=	2.0833,	SD=	10.0000,	DS=	1.00,	&END
&SLIN2	SX0=	-0.8333,	SY0=	1.6667,	SZ0=	0.000,	
	SU=	2.0833,	SD=	10.0000,	DS=	1.00,	&END
&SLIN2	SX0=	-0.8333,	SY0=	1.6667,	SZ0=	-0.333,	
	SU=	2.0833,	SD=	10.0000,	DS=	1.00,	&END
&SLIN2	SX0=	-0.8333,	SY0=	1.6667,	SZ0=	-0.667,	
	SU=	2.0833,	SD=	10.0000,	DS=	1.00,	&END

APPENDIX F

PROGRAM SCANVOL

```

PROGRAM SCANVOL
*****
* THIS PROGRAM IS DESIGNED TO READ THE PMARC OUTFILE. THE SCAN VOLUMES      *
* ARE OF PARTICULAR INTEREST IN THIS PROGRAM. THE VELOCITY COMPONENTS      *
* ARE STORED IN AN ARRAY SO AS TO BE READ BY EXCEL OR KALEIDaGRAPH          *
*****
C23456789
  DIMENSION XP(100),YP(100),ZP(100)
  DIMENSION VX(100),VY(100),VZ(100)
  CHARACTER FILENAM*20,ANSWER*3

C
  SPAN    = 1.9873
  FRSTRM  = 93.0

C FORMAT INPUT
30  FORMAT(1X,'ENTER PMARC OUTPUT FILE NAME',/)
40  FORMAT(A20)
50  FORMAT(////,33X,I5,/)
60  FORMAT(33X,I5,////////)
70  FORMAT(1X,'ENTER THE TRAVERSE NUMBER OF INTEREST',/)
80  FORMAT(I5)
85  FORMAT(6X,I5,15X,F10.4,30X,F10.4)
90  FORMAT(///,6X,I5,15X,F10.4,30X,F10.4)
110 FORMAT(1X,'  Y/(b/2)',5X,'Vdownwash/Vfreestream')
120 FORMAT(2F10.4)
130 FORMAT(1X,'ENTER NEW FILE NAME',/)
140 FORMAT(A20)
150 FORMAT(1X,'DO YOU WANT TO CONTINUE WITH A DIFFERENT TRAVERSE(Y/N)?
    #',/)
160 FORMAT(A3)
170 FORMAT(1X,'SAME PMARC OUTPUT FILE(Y/N)?',/)

C
480 WRITE(*,30)
    READ(*,40) FILENAM
    OPEN(UNIT=7,FILE=FILENAM,STATUS='OLD')
490 READ(7,50) NPT1
    READ(7,60) NPT2

C LOOK FOR DOWNWASH VELOCITY AND SPANWISE LOCATION
    WRITE(*,70)
    READ(*,80) NTRAV
    I=1
    READ(7,85) NTEST,YPTEST,VZTEST
    GO TO 505
500 READ(7,90) NTEST,YPTEST,VZTEST
505 IF(NTEST.EQ.NTRAV) THEN

C CONVERT VELOCITIES AND LOCATIONS TO DIMENSIONLESS PARAMETERS AND STORE
C IN ARRAY FOR EXCEL
    YP(I) = YPTEST/SPAN
    VZ(I) = VZTEST/FRSTRM
    I=I+1
    IF(I.EQ.NPT1+1) THEN
      GO TO 510
    ELSE
      GO TO 500
    ENDIF
  ELSE
    GO TO 500
  ENDIF
510 WRITE(*,130)
    READ(*,140) FILENAM
    OPEN(UNIT=9,FILE=FILENAM,STATUS='NEW')
    WRITE(9,110)

```

```

        WRITE(9,120) ( YP(I),VZ(I), I=1,NPT1)
        CLOSE(UNIT=9,STATUS='KEEP')
C  PROMPT USER TO CONTINUE
        WRITE(*,150)
        READ(*,160) ANSWER
        IF(ANSWER.EQ.'N'.OR.ANSWER.EQ.'n') GO TO 520
        WRITE(*,170)
        READ(*,160) ANSWER
        IF(ANSWER.EQ.'Y'.OR.ANSWER.EQ.'y') THEN
            REWIND 7
            GO TO 490
        ELSE
            CLOSE(UNIT=7,STATUS='KEEP')
            GO TO 480
        ENDIF
        CLOSE(UNIT=7,STATUS='KEEP')
520  STOP
      END

```