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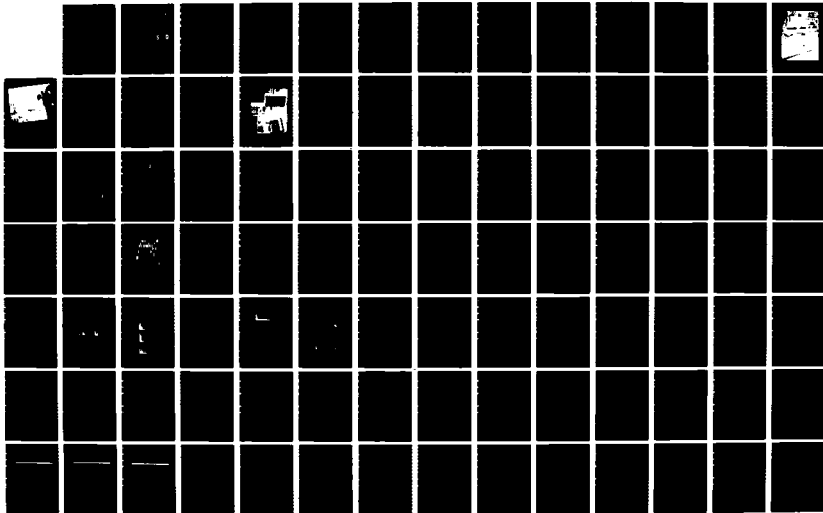
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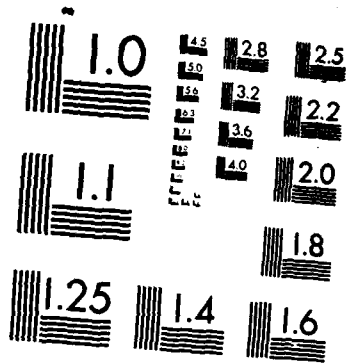
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# DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER



Bethesda, Maryland 20884

DTNSRDC THREE COMPONENT LASER  
DOPPLER VELOCIMETRY:  
MEAN VELOCITY DATA ANALYSIS

DAVID J. FRY

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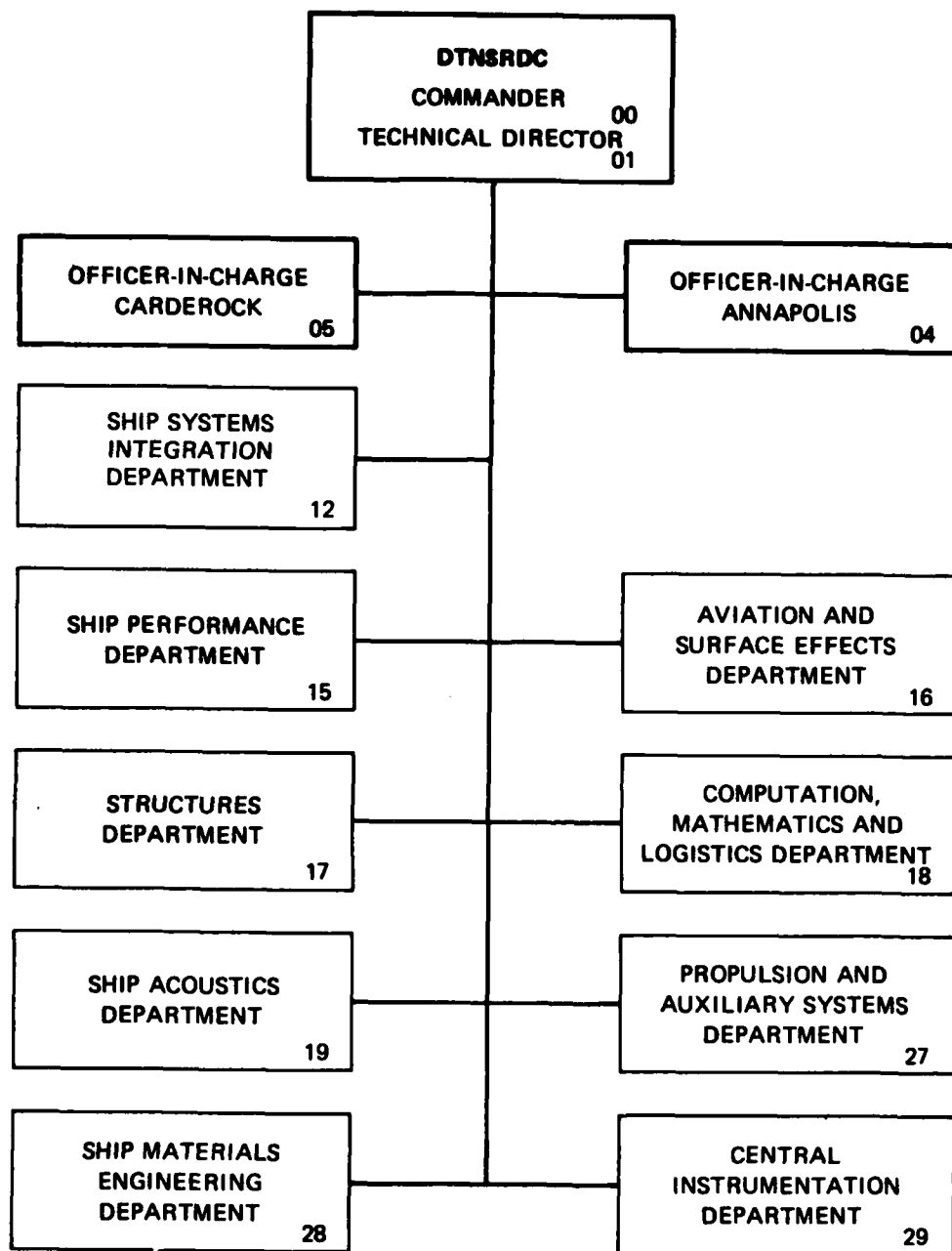
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**REPORT DOCUMENTATION PAGE**

1a REPORT SECURITY CLASSIFICATION <b>UNCLASSIFIED</b>		1b RESTRICTIVE MARKINGS	
2a SECURITY CLASSIFICATION AUTHORITY		3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release Distribution Unlimited	
2b DECLASSIFICATION/DOWNGRADING SCHEDULE		5 MONITORING ORGANIZATION REPORT NUMBER(S)	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) DTNSRDC SPD-1163-02		7a NAME OF MONITORING ORGANIZATION David Taylor Naval Ship Research and Development Center	
6a NAME OF PERFORMING ORGANIZATION David Taylor Naval Ship R & D Center	6b OFFICE SYMBOL (if applicable)	7b ADDRESS (City, State, and ZIP Code) Ship Performance Department (Code 15) Bethesda, Maryland 20084-5000	
6c ADDRESS (City, State, and ZIP Code) Ship Performance Department (Code 15) Bethesda, Maryland 20084-5000		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8a NAME OF FUNDING/SPONSORING ORGANIZATION 6.2 Ship & Submarine Tech. Program	8b OFFICE SYMBOL (if applicable)	10 SOURCE OF FUNDING NUMBERS	
8c ADDRESS (City, State, and ZIP Code)		PROGRAM ELEMENT NO. 62543N	PROJECT NO. TASK NO. SF43421
11 TITLE (Include Security Classification) DTNSRDC THREE COMPONENT LASER DOPPLER VELOCIMETRY: MEAN VELOCITY DATA ANALYSIS		WORK UNIT ACCESSION NO. 1506-130	
12 PERSONAL AUTHOR(S) David J. Fry			
13a TYPE OF REPORT Department Report	13b TIME COVERED FROM TO	14 DATE OF REPORT (Year, Month, Day) 1985, October, 10	15. PAGE COUNT 130
16 SUPPLEMENTARY NOTATION			
17 COSATI CODES		18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	
		Experimental Techniques; Velocity measurements; Laser Doppler Velocimetry; Fluid Flow; Error Analysis; Three Component Fluid Flow	
19 ABSTRACT (Continue on reverse if necessary and identify by block number) This report describes how the voluminous amount of data from Laser Doppler Velocimetry (LDV) experiments can be distilled to produce useful and comprehensible results. The procedures draw heavily on the experience and development work done in implementing three component LDV systems for the towing tanks and large wind tunnels of the David Taylor Naval Ship Research and Development Center. The standard procedures and computer software described are meant to reduce the time needed to analyze and report LDV experiments. The procedures address data collection, data calibration, measurement error estimation, data display graphics, and short and long term data storage.			
20 DISTRIBUTION AVAILABILITY OF ABSTRACT <input type="checkbox"/> UNCLASSIFIED UNLIMITED <input type="checkbox"/> SAME AS RPT <input type="checkbox"/> DTIC USERS		21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED	
22a NAME OF RESPONSIBLE INDIVIDUAL		22b TELEPHONE (Include Area Code)	22c OFFICE SYMBOL

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## NOTATION

$R, \theta, Z$	Measurement cylindrical coordinate system (radial, tangential, streamwise)
$U$	Streamwise velocity component
$V$	Vertical velocity component
$W$	Transverse or on-axis velocity component
$X, Y, Z$	Measurement rectangular coordinate system (vertical, transverse, streamwise)
$\theta_{FB}$	Traverse system front to back bending angle
$\theta_{SS}$	Traverse system side to side bending angle

## LIST OF ABBREVIATIONS

AFF	DTNSRDC Anechoic Flow Facility
ASCII	American Standard Code for Information Interchange
CID	Central instrumentation division computer system
DATA/B	Data taking RL02 hard disk
DEC	Digital Equipment Corporation of Marlboro, Mass.
DTNSRDC	David Taylor Naval Ship Research and Development Center
HDL	Harry Diamond Laboratory (U.S.Army) computer system
LAB	Laser Lab computer system
LAB/B	Laser Lab computer RL02 hard disk
KED	Keypad computer file editor
LDV	Laser Doppler Velocimeter
LDV	LDV measurement system computer
PDP 11/23	Computer manufactured by DEC
PDP 11/34	Computer manufactured by DEC
PMag	Magnetic tape storing printable data tables
REF/B	Data refinement RL02 hard disk
RL02	Hard disk for DEC PDP 11-23 computer storage
RMag	Magnetic tape storing raw data files
RT-11	DEC PDP 11-23 computer operating system
TEMP	Temporary storage RL02 hard disk
TT	DTNSRDC Towing Tank Facility
VAX	Computer manufactured by DEC
VMS	DEC VAX computer operating system

## ABSTRACT

This report describes how the voluminous amount of data from Laser Doppler Velocimetry (LDV) experiments can be distilled to produce useful and comprehensible results. The procedures draw heavily on the experience and development work done in implementing three component LDV systems for the towing tanks and large wind tunnels of the David Taylor Naval Ship Research and Development Center. The standard procedures and computer software described are meant to reduce the time needed to analyze and report LDV experiments. The procedures address data collection, data calibration, measurement error estimation, data display graphics, and short and long term data storage.

## ADMINISTRATIVE INFORMATION

The work described in this paper was done under a project for Laser Doppler Velocimeter System Development. The project was funded by the 6.2 Ship and Submarine Technology Program, Program Element 62543N, Task Area SF 43421, and DTNSRDC Work Unit 1506-253 (FY84) and 1506-130 (FY85).

## INTRODUCTION

### PURPOSE

Laser Doppler Velocimetry (LDV) experiments typically take a large amount of velocity data that must be carefully distilled to produce useful and comprehensible results. This is especially true of the three component mean velocity measurement systems currently available for the towing tanks and wind tunnels of DTNSRDC.

It is hoped that many DTNSRDC personnel will utilize the LDV technique on a variety of experiments. Standard, documented procedures and computer software are then an important way to reduce the cost and complexity of these experiments. They may be decisive in encouraging full and efficient usage of the expensive LDV equipment in the first place. Standard procedures on data storage have further value by insuring completeness and the ability for any researcher to easily access experimental results at a later date.

Three component LDV experience to date has only been on Towing Carriage No. 2 (Figure 1) and the Anechoic Flow Facility wind tunnel (Figure 2). However, the procedures described should apply directly or with some modification to any facility installation of the three component LDV system.

The reader should have some previous background in DEC computer operating systems (e.g. RT-11, VMS, etc.) and experience with the LDV measurement software provided by TSI Inc. The full value of some information in this report will not be realized without this background. In any case the actual process of LDV experimentation

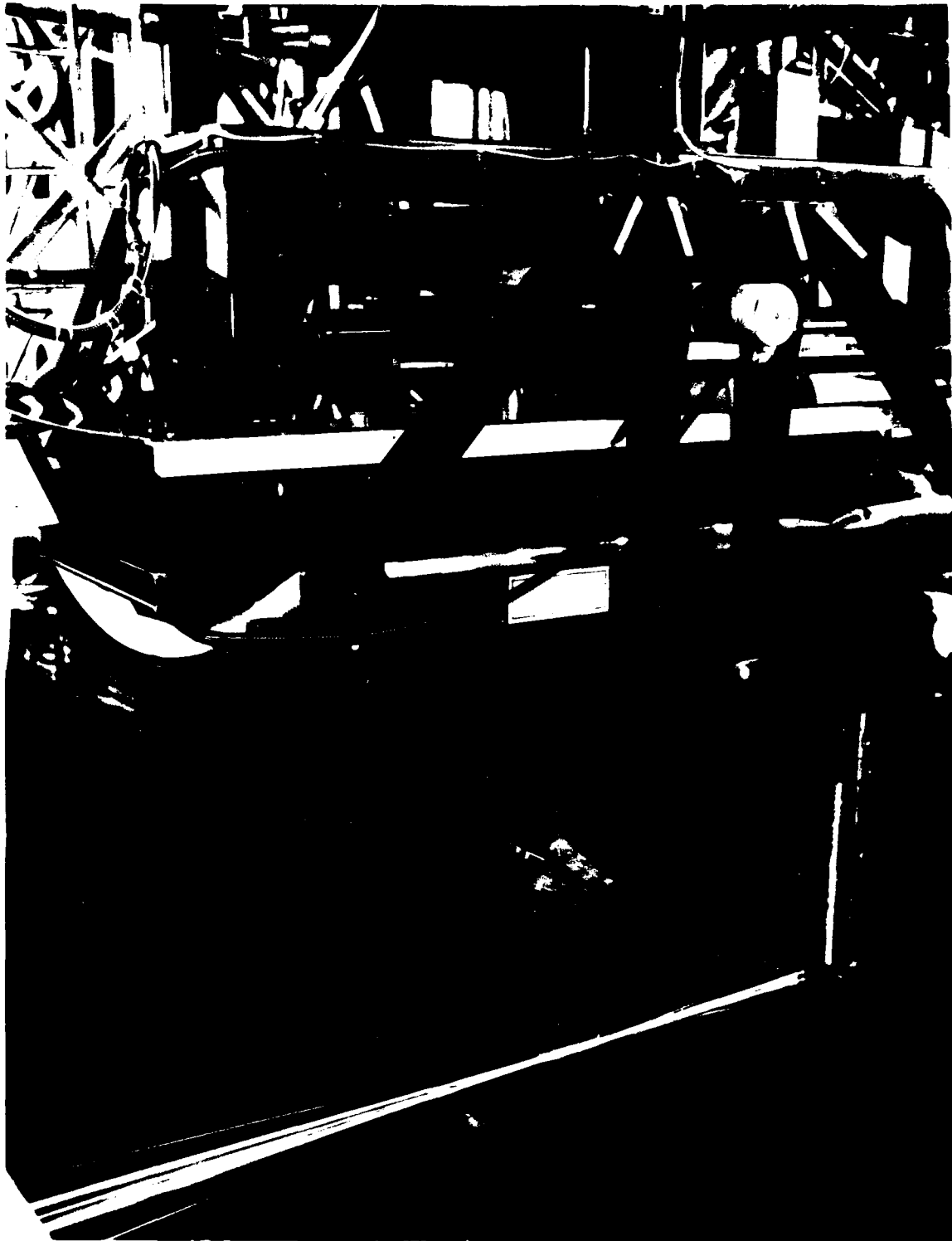


Figure 1: Towing Carriage Three Component LDV Installation.



Figure 2: AFF Wind Tunnel Three Component LDV Installation.

(as presently configured) requires this background.

#### DATA HANDLING PHASES

For descriptive purposes data handling procedures can be divided into four phases:

1. Testing Phase
2. Refinement Phase
3. Data Editing Phase
4. Data Plotting Phase

The procedures within these phases were developed from experience with the three component LDV systems in the Carriage #2 Towing Tank (TT) facility and the Anechoic Flow Facility (AFF) wind tunnel. Data handling for each facility is the same except for the initial testing phase where procedures are very analogous. The procedures described are intended to be a thorough and detailed series of data analysis steps. It is the experimenter's choice to simply use them as is or to use them as a starting point from which to make modifications.

Testing phase procedures include more than operating the data taking software. Data logs, data forms, information printouts, and data storage all contribute to experimental results that are efficiently produced, safely stored, and accurate.

Refinement phase procedures search through each individual velocity measurement and eliminate apparently erroneous ones. The corrected mean velocities are stored on magnetic tape along with the uncorrected values.

Data editing phase procedures first create ASCII computer files that contain a table of corrected velocity means and standard deviations. Then software programs and file editors modify the form of the mean velocity tables so that they match the form expected by the data plotting software programs. In this process some duplicate data points are eliminated while other valid data points are duplicated to properly fill out the table. Several versions of the mean velocity table (at various points in the editing phase) are safely stored on



magnetic tape.

Data plotting phase procedures use software built around DISSPLA\* graphics routines available on many VAX (and other) computer systems. Some data plots may suggest more mean velocity table editing. After this is done, the data plots and mean velocity table can be finalized.

#### EXPERIMENT REPORTS

The writing of experiment reports is not covered. Individual reports will generally differ too much for standards to be worthwhile. However, if some standard tests do emerge (e.g. propeller wake surveys), the effort may become worthwhile. In any event the output of the data plotting phase can serve as the primary graphics in most reports. Some of the developed graphics programs are intended for data error analysis.<sup>1,2</sup> These may be useful in detailed reports. Additional "DISSPLA-based" plotting programs will no doubt be developed by other experimenters and also be available.

---

\* A software library of plotting routines sold by ISSCO of San Diego, California

## DATA HANDLING EQUIPMENT

Data handling procedures require several computer systems and a variety of storage media. This section will define these hardware items to minimize confusion when procedures using them are described in later sections.

### COMPUTER SYSTEMS

Four separate computer systems will be referred to in this report. Each is essentially a Digital Equipment Corp. (DEC) machine that uses a common (or very similar) operating system and file editor. This helps a single experimenter to move easily between the computer systems.

#### LDV System

This is a PDP 11/23\* processor with the following peripherals:

1. Two DEC RL02\* hard disk drives
2. Kennedy\*\* 9-track tape drive
3. DEC LA34\* Dot matrix printer-plotter
4. DEC VT125\* Terminal

The computer has an RT-11\* operating system and a default keypad editor (KED).

This system generally accompanies the LDV optics to the experimental facility (Figure 3). Memory (128K), direct memory access (DMA), and serial port cards (in the computer bus) support LDV data taking software and control of the LDV traverse system. The newly acquired PDP 11/23 computers (12/84) to be permanently installed on the towing carriages can replace this system for towing tank tests. It has a compatible configuration except that a DMA card (DRV11B) must be added.<sup>3</sup>

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\* Product of Digital Equipment Corp. (Marlboro, Mass.)

\*\* Product of Magnetics and Electronics, Inc. (Monrovia, Cal.)

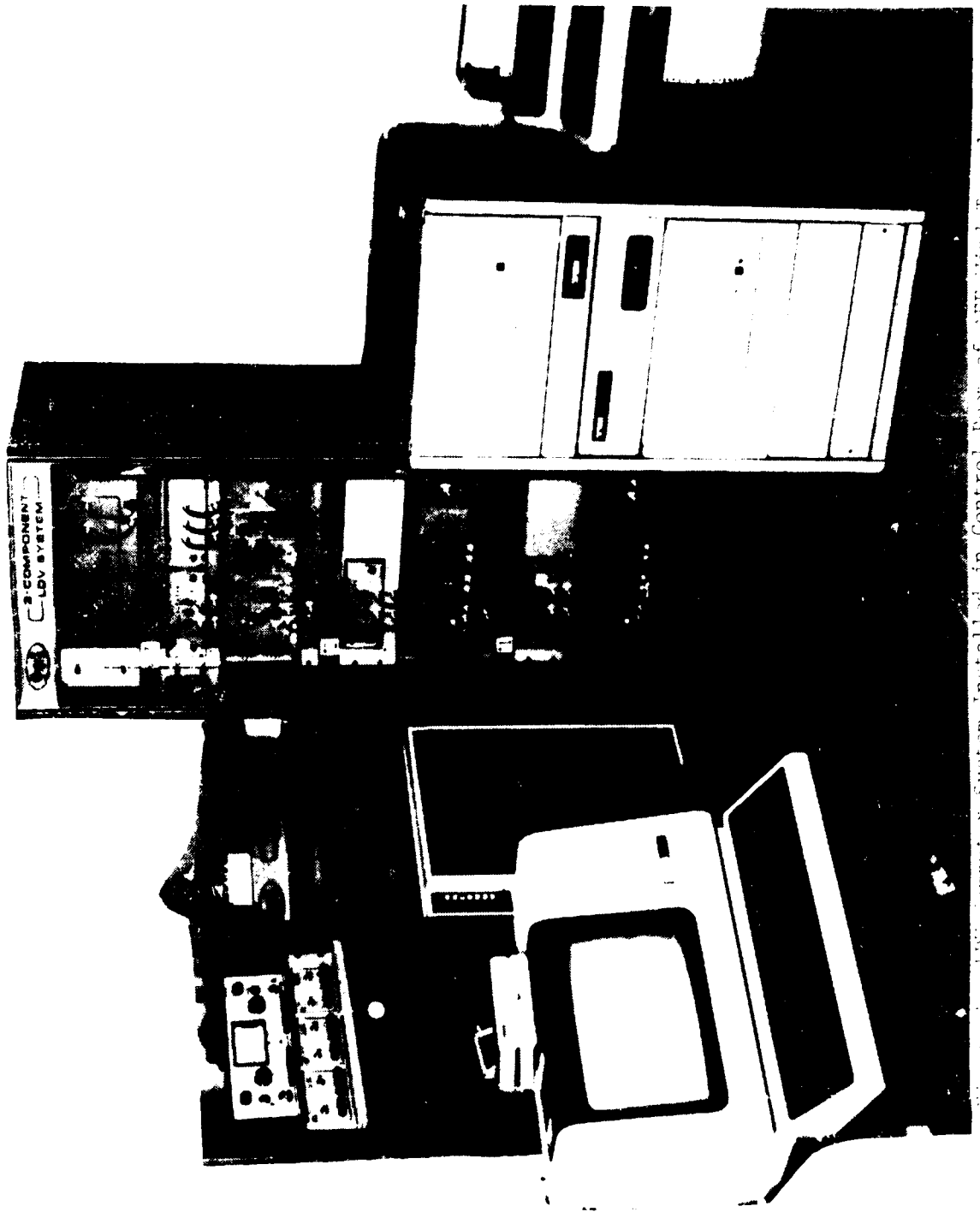


Figure 1-13 Computer System Installed in Control Room of AFF Wind Tunnel.

### Laser Lab (LAB) System

This is also a PDP 11/23 processor with the following peripherals:

1. One DEC RL02 hard disk drive
2. Kennedy 9-track tape drive
3. DEC Decwriter II\* dot matrix printer
4. DEC VT100\* Terminal
5. Graphics Terminal (Tektronix 4010 Emulator)
6. Modem and file transfer software

The computer has an RT-11 operating system and a default keypad editor (KED).

The LAB system is usually located in the basement of Building 3 (Room 32), though it is transportable. It can support LDV data taking software and control of the LDV traverse system, but lack of a second RL02 disk drive makes the system inconvenient for this purpose. The cards in its bus are duplicates of those in the LDV computer system. They can be used as spares or for troubleshooting LDV system breakdowns.

### Central Instrumentation Division (CID) System

This is a PDP 11/34\* processor with (among others) the following peripherals:

1. Two DEC RL02 hard disk drives
2. Centronics 6080 line printer

The computer has an TSX-PLUS multi-user operating system and an available keypad editor (KED). It is located permanently in Building 3 Room 110. With CID permission, it is used primarily for fast printouts of mean velocity data tables.

---

\* Product of Digital Equipment Corp. (Marlboro, Mass.)

## Harry Diamond Lab (HDL) System

This is a VAX 11-780\* system that has DISSPLA (Version 9.0), a versatile graphics routine library. The VMS\* operating system has many of the same commands and command structure as RT-11. The default editor (EDV) has a keypad editing mode almost exactly the same as KED on RT-11 systems.

This time sharing system is used through a remote terminal, modem, and phone (1200 baud). Access through a Tektronix terminal allows direct display of data plotting routines. A Versatec or Laser plotter with very high resolution, allow hardcopies to be created at HDL in Adelphi, Md. Arrangements must be made to pick them up or have them sent in the mail.

DTNSRDC has or is getting VAX systems that can also be used if the DISSPLA graphics library is implemented.

## DEC RL02 DISK CARTRIDGES

These cartridges store 10.4 Megabytes of memory and can be used in any of the RL02 hard disk drives of the above computers. Both the LDV and LL computers require RT-11 system software and any single experiment requires five separate disk cartridges to take and analyze the data.

## Data Aquisition Program/Bootable (DATA/B) disk

This disk contains the large software package that controls the LDV system and automatically takes data. It is generally used only during the experiment in Drive 0 of the LDV computer system. Several modified versions of the original (supplied by TSI Inc.; St. Paul, Minn.) exist on separate disk cartridges. The four versions are for different experimental setups:

1. TT traverse system; Cylindrical position coordinates

---

\* Product of Digital Equipment Corp. (Marlboro, Mass.)

2. TT traverse system; Rectangular position coordinates
3. AFF traverse system; Cylindrical position coordinates
4. AFF traverse system; Rectangular position coordinates

#### Refinement Programs/Bootable (REF/B) disk

This disk contains several modified versions of the original TSI Inc. software that can efficiently:

1. Create ASCII files of data tables
2. Eliminate bad data points
3. Calibrate velocity data
4. Normalize position coordinates

Generally it is used in the LDV computer system (Drive #0) for the refinement and data editing phases of data analysis.

#### Temporary Storage (TEMP) disk:

This disk can hold experimental data before it is stored on magnetic tape. For this purpose it is used during an experiment in Drive 1 of the LDV computer system. Several sets of data files (10 Megabytes) will fit on the disk, but it may not hold all of an experiment's data.

In another capacity this disk holds raw data files and data table files during the refinement and editing phases of data handling. It is placed in Drive 1 of the LDV computer system. It can be conveniently used to transport ASCII data table files to the CID computer for a fast printout. Again, nothing is permanently stored on this disk.

#### Laser Lab/Bootable (LAB/B) disk

This disk allows the LL computer system to run the same data editing programs as the LDV computer. However, more importantly the file transfer software ("FTERM") and modem controller allow the ASCII data table files to be sent over the phone to the HDL VAX computer at a rate of 1200 baud.

## MAGNETIC TAPES

Physically these are 9 track, 1600 bpi, 2000 foot tapes. They provide for permanent storage of LDV system data.

### Raw File Magnetic Tape (RMag)

This tape stores the raw data files that contain every individual velocity measurement. Completed sets of data files are transferred here from the TEMP disk cartridge during the experiment. Each tape can store somewhat more information than a completely filled RL02 disk cartridge. Long experiments may require several of these tapes.

### Printable File Magnetic Tape (PMag)

This tape stores the various versions of each ASCII data table file. One magnetic tape stores this condensed velocity information for each experiment. This tape provides one way to transport files from the LDV computer system to the LL computer system. It could also be used to directly transfer files to DTNSRDC VAX computers eliminating any need for the modem transfer process on the LL computer system.

## TESTING PHASE PROCEDURES

LDV data taking is greatly simplified by the data collection software developed by TSI Inc.<sup>3,4</sup>. This software and its slightly modified versions will be referred to as the TSI software. TSI software provisions for automatic positioning, data collection, data storage, and optional printouts are almost the only tools needed to organize testing phase procedures. The only experimental data handled outside this software environment are hand written data logs and the traverse bending formulation needed to correct for positioning errors.

The original TSI software package was specialized to position in cylindrical ( $R, \theta, Z$ ) coordinates and work with the DC servo-motor drive of the towing tank LDV system. This fits the envisioned, primary purpose of the system to take towing tank propeller wake surveys that historically use a cylindrical coordinate system (the "Z" axis being the propeller shaft axis).

There are now four versions of the software. Each is a slight modification of the original package. They were created to handle both cylindrical and rectangular ( $X, Y, Z$ ) coordinate positioning for the TT and AFF (no DC servo-motor drive) traverse systems. A separate DATA/B disk contains each of the four versions. The experimenter chooses the version most convenient for his traversing needs and inserts that DATA/B disk in Drive 0 of the LDV computer system.

1. "TOWR" : Towing Tank, cylindrical position coordinates
2. "TOWXR": Towing Tank, rectangular position coordinates
3. "TUNR" : AFF Tunnel, cylindrical position coordinates
4. "TUNXR": AFF Tunnel, rectangular position coordinates

A TEMP disk is inserted in Drive 1 of the LDV Computer to hold data as it is collected.

The TSI software (Figure 4) has two basic modes of data collection: automatic and manual. In the automatic mode, the user



LDV ANALYSIS SYSTEM : MAIN MENU  
DATE : 28-MAY-85  
TIME : 14:25:15

The Valid Keyboard Commands For The System Main Menu Are:

"M" = Display this menu.  
"F" = Data files management menu.  
"T" = Traverse table control menu.  
"P" = Data reduction parameters menu.  
"S" = Statistical analysis menu.  
"H" = Probability density histogram menu.  
"U" = Underwater tow tank menu.  
"D" = Counter output diagnostics menu.  
PF1 = Acquire and analyze one sample group.  
PF2 = Save raw data and/or data analysis.  
PF3 = Acquire and analyze multiple sample groups.  
PF4 = Acquire, analyze, and save multiple sample groups.  
RET = Analyze one previously acquired sample group.  
"X" = Immediate halt of analysis.  
"Q" = Quit.

Command ?

Figure 4: TSI Software Main Menu Display

initially enters a matrix of locations where he wants to collect data\*. Program options start an automatic sequence that moves the traverse to the first location, collects velocity data, moves to the second location, collects velocity data and so on until stopped by the user or upon collecting data at fifteen locations. After doing some calculations and storing the data, the program is ready to again collect data at any remaining points in the matrix of locations.

In manual mode the user first makes sure that the traverse is correctly positioned. A program option then allows him to open a computer file and fill it with an LDV data block. Program options allow more than one block (of user specified length) to be stored per file, or allow the user at any time to close the file and open up a new one. While normally all experimental data is acquired in the more time efficient automatic mode, the manual mode is useful in

---

\* The programs "ATM2ED", "ED2ATM", and the KED file editor may be helpful in creating and especially modifying traverse matrices outside the data collection software environment.<sup>5</sup>

creating some calibration data sets.

Testing Phase procedures consist of first acquiring certain calibration data, then collecting the experimental data, and finally safely storing the data for subsequent analysis steps.

#### POSITIONING CORRECTION CALIBRATION

The towing tank traverse system is plagued by structural bending changes when the LDV system is traversed. This sometimes results in significant positioning errors. Analogous errors have not been measured in the AFF traverse system. A software fix has been incorporated into both towing tank data acquisition programs to correct these positioning errors.

#### Traverse Bending Correction

As detailed in Reference 1, accelerometers on the traverse system must be used to take data on the relation of traverse position and traverse bending angle. This is best done with the model in place and the carriage moving at its anticipated towing speed. The collected data ( $\theta_{SS}, Y$  or  $\theta_{FB}, Z$  data pairs, is input to a Fortran program, "BEND1", to calculate the best fit third degree polynomial for the data (Figure 5). The coefficients that "BEND1" produces must be input to the data collection software for proper positioning correction. Appendix A contains a Position Correction Polynomial Form that might be useful for this task.

Less frequently the positioning error of the towing tank traverse system will be checked directly in the dry dock. In this event, additional Fortran programs automatically calculate bending parameter "constants" (see Reference 1 for its Appendix 7). Programs "BEND2Y", "BEND2Z", and "BEND3" all require the input of the bending angle polynomial and a data set (traverse position versus positioning error). Appendix A contains a Traverse Bending Correction Form that might be useful for this task.

User  
Inputs:

```

→ .R BEND1
   Y TRAVERSE BALANCE VALUE? F10.4
→ 4.0
   HOW MANY POINTS? , 12
→ 10
   THETA, Y VALUES? ; F10.4,F10.4
→ -.059 18.
→ -.034 12.
→ -.022 6.
→ -.014 0.
→ .007 -6.
→ .037 -12.
→ .075 -18.
→ .086 -18.
→ .043 -12.
→ .018 -6.

0.1111E+09 -0.2146E+07 0.3810E+06 -0.7776E+06 -0.1490E+04
-0.2146E+07 0.3180E+06 -0.7776E+04 0.1512E+04 0.3978E+02
0.3810E+06 -0.7776E+04 0.1512E+04 -0.3600E+02 -0.5610E+01
-0.7776E+04 0.1512E+04 -0.3600E+02 0.1000E+02 0.1370E+00

→ 1
   ZERO THE THETA FUNCTION AT Y = YBAL? 0-NO; 1-YES
      A3      A2      A1      A0
-0.3619E-05 0.6112E-04 -0.2674E-02 0.9950E-02

→ 1
   CONVERT FROM DEGREES TO RADIANS? 1-YES; 0-NO;
      A3      A2      A1      A0
-0.6317E-07 0.1067E-05 -0.4667E-04 0.1737E-03

→ 4.0
   Y VALUE FOR THETA CALCULATION? 0.0 - DISCONTINUE
   "Y" VALUE = 4.0000      "THETA" VALUE = 0.0000E+00
. . . . .
. . . . .
→ 0.0

```

Figure 5: "BEND1" Input for Bending Polynomial Calculation.

### Correcting Relative Model Positions

Positioning corrections are most naturally done in the absolute coordinate system of the traverse system. However, the experimenter invariably wants a coordinate system referenced to the water's free surface and some ship model location. For this reason the position encoders can be manually zeroed at any point in their range. The experimenter however must carefully note where this is in the absolute coordinate system of the traverse system. The care is needed to allow returning to this "rezeroed" coordinate system if power is unexpectedly interrupted to the encoder readout module. Also, proper positioning correction by the data collection software

requires that these new coordinate zeroes be input by the experimenter.

An additional complication occurs if the experimenter wants to locate his measurement positions relative to many ship model points or a model surface. It is relatively simple to place the laser beam crossing point at physical locations on the ship model and then read the position encoders. However, because of positioning errors these encoder readouts may not be accurate enough. Therefore a Fortran program was written to calculate the actual measurement location from inputs of the position correction coefficients, the location of the coordinate system origin, and the encoder readouts. The program is called "ENC2RL" and a sample usage appears in Figure 6. Actual ship model locations can be plotted up and fluid measurement points accurately located in their vicinity. Actual measurement locations can also be transformed to the corresponding encoder readouts with the companion program "RL2ENC".

Appendix A contains a Body Positions Calculation Form that can be useful for this task.

#### VELOCITY COMPONENT CALIBRATIONS

In addition to the velocity measurements experimentally sought, certain velocity calibration data sets are needed to properly interpret the data.

##### Fringe Spacing

Fringe spacing for the streamwise and vertical components are determined by making measurements on a spinning wheel surface that travels at a very precise speed<sup>1,2</sup>. The standard LDV system software was used in the manual mode to collect the necessary data. One of the software parameter setups is shown in Table 1. This makes the measured velocities really signal frequencies in MHz. Figure 7 shows typical software generated histograms and data tables for fringe spacing determination.

The LDV user should take four or more fringe spacing

```

USER
INPUTS
-----> .R ENC2RL

          Default Y - O<SS> Polynomial:
          1.117E-07*Y*Y*Y + -1.377E-06*Y*Y + 4.527E-05*Y + -1.662E-04
          Do You Want Changes ? 1-Yes; 0-No;

-----> 1
          A3*Y*Y*Y :
-----> +6.317E-08
          A2*Y*Y :
-----> -1.067E-06
          A1*Y :
-----> +4.667E-05
          A0 :
-----> -1.737E-04

          Okay ? 1-Yes; 0-No;
-----> 1

          Default Z - O<FB> Polynomial:
          2.172E-06*Z*Z*Z + 1.154E-05*Z*Z + 4.215E-04*Z + 0.000E+00
          Do You Want Changes ? 1-Yes; 0-No;
-----> 0

          Default Absolute Position of Traverse Bending Point (in.)
          X = 105.2 in.; Y = 7.91 in.; Z = 0.00 in.
          Do You Want Changes ? 1-Yes; 0-No;
-----> 0

          Default Angle Proportionality Constants:
          K<SS> = +1.273; K<FB> = -0.778
          Do You Want Changes ? 1-Yes; 0-No
-----> 1
          K<SS> : (F8.4)
-----> 1.274
          K<FB> : (F8.4)
-----> -0.779
          Okay ? 1-Yes; 0-No
-----> 1

          Number of Real Points to be Calculated ? (I2)
-----> 4
          Enter Encoder Readout Coordinates (in.): X,Y,Z (3F9.4)
-----> 4.1007 -7.1002 2.00
-----> 3.1004 -6.8004 2.00
-----> 2.6010 -6.7213 2.00
-----> 2.1007 -6.5935 2.00
          <Parameters and Calculated Real Values Sent to LDV Printer>
          More Points ? 1-Yes; 0-No;
-----> 0
          .

```

Figure 6: "ENC2RL" Input for Encoder Readout Corrections.

```

*****
* DATA REDUCTION PARAMETERS *
* 04-AUG-84 19:00:09 *
* *****

```

```

EXPERIMENT IDENTIFIER:
STREAMWISE FRINGE CALIBRATION 606 FREERIAL 02/27/84

```

```

EXPERIMENT COMMENTS:
ONE ROTATION DIRECTION --- IN THE DIRECTION OF FLOW
NO EFFECTIVE FRINGES SHIFT
VELOCITY OF CALIBRATION WHEEL OUTSIDE CIRCUMFERENCE
OUTPUT IS IN MHZ

```

```

INPUT DATA SOURCE : RDE:COUNTR:RAH
OUTPUT DATA SOURCE : RDE:STHMO:1:PMH
MODE OF OPERATION : RANDOM
NUMBER OF COUNTERS : 3
TIME BETWEEN DATA : NO
DATA POINT GROUP : ALL
SAMPLE GROUP SIZE : 6 GROUPS OF 256 DPG

```

```

<< COUNTER 1 CONFIGURATION >>
TYPE : 1990
SETTING : TBC >>VEL BIAS
N-CYCLE = 8
FREQUENCY SHIFT : 0.000 MHZ
FRINGE SPACING : 1.000 M/SEC/MHZ

```

```

<< COUNTER 2 CONFIGURATION >>
TYPE : 1990
SETTING : TRC >>VEL BIAS
N-CYCLE = 8
FREQUENCY SHIFT : 0.050 MHZ
FRINGE SPACING : 1.000 M/SEC/MHZ

```

```

<< COUNTER 3 CONFIGURATION >>
TYPE : 1990
SETTING : TRC >>VEL BIAS
N-CYCLE = 8
FREQUENCY SHIFT : 0.050 MHZ
FRINGE SPACING : 1.000 M/SEC/MHZ

```

STREAMWISE (40 MHz) FRINGE SPACING DETERMINATION  
(using calibration wheel)

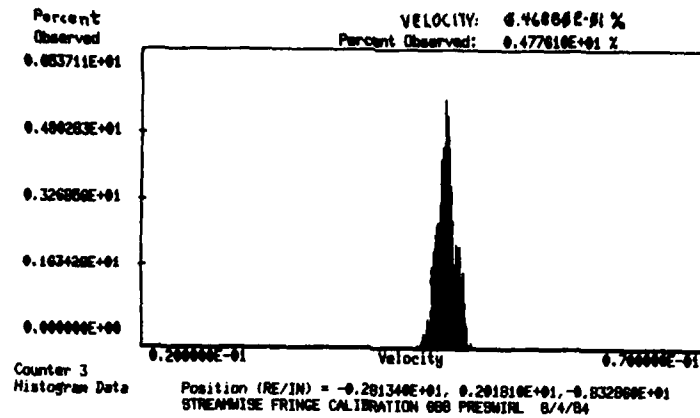
SAMPLE #	No. Pts.	Freq. KHz
1	1108	46.857
2	1075	46.813

Avg = 46.836 KHz

Wheel Speed = 2816 m/sec

Fringe Spacing = 2046 / 04884 = 46.018 μm

Table 1: TSI Software Parameters for Fringe Spacing Calibration.



SAMPLE GROUP STATISTICS  
DATA POSITION (RE/IN) = -7.8134 2.0181 -8.3286

< COUNTER STATISTICS >

	COUNTER 1	COUNTER 2	COUNTER 3
\TOTAL NBR PTS \	0.111000E+03	0.317000E+03	0.110800E+04
\NBR GOOD PTS \	0.111000E+03	0.317000E+03	0.110800E+04
\NBR BAD PTS \			
\VELOCITY MEAN \	0.509909E-01	0.214989E-04	0.468593E-01
\STAN DEVIATION \	0.303817E-03	0.670094E-03	0.790577E-03
\T INTENSITY(%) \	0.595825E+00	0.288430E+04	0.168713E+01
\3RD MOMENT \			
\SKEWNESS COEFF \			
\4TH MOMENT \			
\FLATNESS COEFF \			

STRM01 SAMPLE \*1

Figure 7: Histograms and Data Tables for Fringe Spacing Determination.

determinations. The determinations should be independent setups of the calibration wheel and occurring, if possible, at both the beginning and end of any optical alignment. The mean of these fringe spacing determinations is needed by the TSI software to convert experiment LDV signals to velocity data. The standard deviation of the fringe spacing determinations indicates the size of a source of measurement error and will be required later during data analysis.

Appendix A contains a Fringe Spacing Calculation Form that might be useful for this task.

#### Component Direction Relative to Model

The description of the velocity component directional error<sup>1,2</sup> included how "freestream" LDV measurements could be used to wholly or partially correct for several errors. In the TT LDV system, this is done by taking measurements on one or two passes without the model present. In the AFF LDV system, several measurements are taken at a location as far out into the freestream as possible.

These data sets can be taken by the standard software in the automatic data acquisition mode of operation. Typical file names for this data are: "FREA00", "FREB00", "FREC00", etc. These data files should be taken before the experiment and during the experiment (either weekly or whenever the LDV optics are adjusted).

Appendix A contains a Component Direction Error Form that might be useful for this task.

#### DATA TAKING ORGANIZATION

The software organizes experimental data (in automatic collection mode) into TEMP disk files with six character alphanumeric names. The first four characters are user chosen to define the ship model and "Z" (streamwise) measurement station for the data. Velocity data graphics programs are based on this idea of data collection being organized into sets, each taken at a unique "Z" location (i.e. single plane of measurement locations). Added to the four characters is a two digit number that shows the order in which data files were automatically collected (01 --> 85). Each data file is the result of one automatic data collection - traversing sequence. Many data files (though usually less than 85) are required to collect all the data for a given "Z" plane. The RT-11 file type for these data files is automatically ".RAW".

In addition, a velocity data summary file is created and then updated with each new ".RAW" file. Its file name is the same as the



associated data files except that the added number is "00". The summary file's data type is automatically ".PVD" for Position - Velocity Data. Note that both the data files and the data summary file contain binary numbers and not ASCII characters that can simply be printed out.

Manual mode files have a six character alphanumeric name that is completely chosen by the user. However, as before, the RT-11 file type must be ".RAW". There is nothing analogous to the summary file (".PVD" file) in this mode.

TSI software provides tabular printouts of both manual (Table 2) and automatic data collections (Table 3). The experimenter is

"RAW"

SAMPLE GROUP STATISTICS

Data Position (CY/IN) = 5.8000 4.7000 0.0000

< Counter Statistics >

	Counter 1	Counter 2	Counter 3
Total nbr pts	0.256000E+03	0.256000E+03	0.256000E+03
Nbr good pts	0.256000E+03	0.256000E+03	0.256000E+03
Nbr bad pts	0.000000E+00	0.000000E+00	0.000000E+00
Velocity mean	0.137561E+00	-0.489829E+00	0.313631E+01
Stan deviation	0.229437E-01	0.226339E+00	0.516874E-01
IT intensity(%)	0.166789E+02	0.462078E+02	0.164803E+01
3rd moment	0.170411E-05	-0.373297E-02	0.947480E-03
Skewness coeff	0.705468E-01	-0.160970E+00	0.343072E+01
4th moment	0.963499E-06	0.834747E-01	0.111780E-02
Flatness coeff	0.347695E+01	0.318065E+02	0.156612E+03

"REFINED"

SAMPLE GROUP STATISTICS

Data Position (CY/IN) = 5.8000 4.7000 0.0000

< Counter Statistics >

	Counter 1	Counter 2	Counter 3
Total nbr pts	0.256000E+03	0.256000E+03	0.256000E+03
Nbr good pts	0.255000E+03	0.249000E+03	0.251000E+03
Nbr bad pts	0.100000E+01	0.700000E+01	0.500000E+01
Velocity mean	0.137818E+00	-0.498072E+00	0.313401E+01
Stan deviation	0.225710E-01	0.142577E+00	0.396877E-01
IT intensity(%)	0.163774E+02	0.286258E+02	0.126636E+01
3rd moment	0.268528E-05	-0.230155E-03	-0.142684E-04
Skewness coeff	0.116764E+00	-0.397043E-01	-0.114123E+00
4th moment	0.864128E-06	0.150444E-02	0.803471E-05
Flatness coeff	0.332949E+01	0.364060E+01	0.323851E+01

Table 2: TSI Software Data Printouts ("Manual" Collection)

Position/Velocity Data: DBSD Tow Statistics  
 Exp Id: DESTROYER WHOLE BODY MAKE SURVEY 6 KNOTS 19-APR-84

Mat #	Z (in)	X (in)	Y (in)	Vertical (VM/VT)	Turbulence Intensity (%)	On-Axis (VM/VT)	Turbulence Intensity (%)	Stream-Wise (VM/VT)	Turbulence Intensity (%)	Raw Sp. F#	Sp. G#
53	0.00	4.30	16.30	0.104229E+00	0.475426E+02	-0.140372E+00	0.477413E+02	0.696305E+00	0.180373E+02	-6	6
54	0.00	4.30	16.50	0.115325E+00	0.395292E+02	-0.156366E+00	0.405236E+02	0.721363E+00	0.870826E+01	7	2
55	0.00	4.30	17.25	0.110285E+00	0.384079E+02	-0.151446E+00	0.405236E+02	0.676355E+00	0.982881E+01	7	3
56	0.00	4.30	17.45	0.111289E+00	0.391405E+02	-0.141171E+00	0.405870E+02	0.644412E+00	0.100074E+02	7	4
57	0.00	4.30	17.65	0.110707E+00	0.349032E+02	-0.136215E+00	0.456124E+02	0.626361E+00	0.970535E+01	7	5
58	0.00	4.90	6.00	0.452778E-01	0.221807E+02	-0.163861E+00	0.293650E+02	0.101368E+01	0.149436E+01	12	5
59	0.00	4.90	9.80	0.753625E-01	0.459849E+02	-0.146659E+00	0.389865E+02	0.913902E+00	0.499677E+01	5	3
60	0.00	4.90	11.80	0.624238E-01	0.743882E+02	-0.144555E+00	0.492573E+02	0.727883E+00	0.878324E+01	5	4
61	0.00	4.80	13.80	0.952113E-01	0.497362E+02	-0.152744E+00	0.434305E+02	0.706122E+00	0.122093E+02	5	5
62	0.00	4.80	14.80	0.972880E-01	0.530983E+02	-0.141971E+00	0.460515E+02	0.666979E+00	0.118080E+02	5	6
63	0.00	4.80	15.30	0.911389E-01	0.528099E+02	-0.137580E+00	0.495870E+02	0.633280E+00	0.122140E+02	6	1
64	0.00	4.80	15.80	0.645987E-01	0.571111E+02	-0.146335E+00	0.455304E+02	0.587834E+00	0.136693E+02	6	2
65	0.00	4.80	16.00	0.876036E-01	0.511481E+02	-0.129878E+00	0.482435E+02	0.570755E+00	0.116100E+02	6	3
66	0.00	4.80	16.20	0.841306E-01	0.578718E+02	-0.135751E+00	0.429445E+02	0.533674E+00	0.127582E+02	6	4
67	0.00	5.80	18.00	0.792548E-01	0.396526E+02	-0.179051E+00	0.268230E+02	0.101337E+01	0.157854E+01	19	1
68	0.00	5.80	-10.00	0.402382E-01	0.229617E+02	-0.183431E+00	0.261371E+02	0.101204E+01	0.144566E+01	17	5
69	0.00	5.80	-4.00	0.433192E-01	0.182202E+02	-0.185487E+00	0.264881E+02	0.100517E+01	0.129552E+01	16	1
70	0.00	5.80	2.00	0.347740E-01	0.232945E+02	-0.165553E+00	0.248726E+02	0.101498E+01	0.113849E+01	14	5
71	0.00	5.80	4.70	0.446809E-01	0.163774E+02	-0.161474E+00	0.286258E+02	0.101605E+01	0.126636E+01	13	1
72	0.00	5.80	4.70	0.413144E-01	0.115710E+02	-0.154544E+00	0.271937E+02	0.101483E+01	0.148385E+01	-1	1
73	0.00	5.80	6.70	0.399830E-01	0.905846E+02	-0.138768E+00	0.427583E+02	0.913140E+00	0.571723E+01	4	1
74	0.00	5.80	8.70	0.608945E-01	0.589839E+02	-0.138574E+00	0.434979E+02	0.841214E+00	0.556465E+01	4	2
75	0.00	5.80	9.20	0.679423E-01	0.607153E+02	-0.133650E+00	0.471250E+02	0.828436E+00	0.756765E+01	4	3
76	0.00	5.80	10.20	0.497686E-01	0.945307E+02	-0.170899E+00	0.506332E+02	0.726948E+00	0.105822E+02	4	4
77	0.00	5.80	10.70	0.511285E-01	0.908668E+02	-0.117771E+00	0.561939E+02	0.624438E+00	0.138597E+02	4	5
78	0.00	5.80	11.70	0.502151E-01	0.795763E+02	-0.124076E+00	0.490415E+02	0.651382E+00	0.114397E+02	4	6
79	0.00	5.80	11.40	0.602915E-01	0.647216E+02	-0.128690E+00	0.494027E+02	0.556326E+00	0.110838E+02	5	1
80	0.00	5.80	11.60	0.597564E-01	0.600213E+02	-0.129367E+00	0.407107E+02	0.546057E+00	0.124302E+02	5	2
81	0.00	7.80	2.00	0.294471E-01	0.319164E+02	-0.146054E+00	0.284597E+02	0.101809E+01	0.107602E+01	15	1
82	0.00	7.80	3.20	0.369235E-01	0.183770E+02	-0.146054E+00	0.309423E+02	0.101677E+01	0.160859E+01	1	2
83	0.00	7.80	4.30	0.392615E-01	0.38529E+02	-0.152648E+00	0.349058E+02	0.996355E+00	0.302024E+01	3	6
84	0.00	7.80	5.80	0.461976E-01	0.938130E+02	-0.134773E+00	0.423752E+02	0.873582E+00	0.642831E+01	3	5
85	0.00	7.80	5.80	0.444364E-01	0.107263E+03	-0.134172E+00	0.461819E+02	0.808761E+00	0.815564E+01	3	4
86	0.00	7.80	6.30	0.465714E-01	0.981075E+02	-0.120917E+00	0.538397E+02	0.714699E+00	0.946503E+01	3	2
87	0.00	7.80	6.50	0.491290E-01	0.946930E+02	-0.115233E+00	0.522931E+02	0.668439E+00	0.104351E+02	3	3
88	0.00	7.80	6.70	0.455195E-01	0.103792E+03	-0.110583E+00	0.441766E+02	0.604887E+00	0.134846E+02	3	1
89	0.00	8.80	-18.00	0.453744E-01	0.382762E+02	-0.167428E+00	0.249141E+02	0.101462E+01	0.172240E+01	18	1
90	0.00	8.80	2.10	0.730129E-01	0.715935E+02	-0.169217E+00	0.290448E+02	0.999336E+00	0.252110E+01	20	1
91	0.00	8.80	3.10	0.301967E-01	0.823561E+02	-0.133922E+00	0.392936E+02	0.942000E+00	0.378539E+01	1	3
92	0.00	8.80	4.10	0.455066E-01	0.595354E+02	-0.145448E+00	0.356468E+02	0.907534E+00	0.476032E+01	1	4
93	0.00	8.80	4.60	0.503152E-01	0.676994E+02	-0.153927E+00	0.368186E+02	0.880894E+00	0.540919E+01	1	5
94	0.00	8.80	5.10	0.420513E-01	0.973227E+02	-0.142872E+00	0.398244E+02	0.817154E+00	0.674357E+01	2	2
95	0.00	8.80	5.30	0.376606E-01	0.110321E+03	-0.131828E+00	0.412620E+02	0.775855E+00	0.752774E+01	2	2
96	0.00	8.80	5.50	0.384655E-01	0.127870E+03	-0.124003E+00	0.461119E+02	0.726045E+00	0.955952E+01	2	3

Table 3: TSI Software Data Printout ("Automatic" Collection)

allowed to immediately review the most recently collected data and check for obvious collection problems by using a TSI software table printout (for automatic data collections). These tables can then be thrown away in favor of a master table containing the entire measurement plane's data. This master table is also provided by the TSI software and it should be printed out and saved after the "Z" plane's measurements are complete.

#### EXPERIMENT RUN-TIME RECORDS

Certain hard copy records are recommended to the experimenter to organize and later interpret his data taking. They include hand written logs and TSI software printouts. These are in addition to master data tables mentioned above.

##### Run-Time Log

Hand written examples of this log appear in Table 4. Appendix A contains a blank, full page, Run-Time Log Form. An entry should be made after every automatic sequence of data taking. In the towing tank, this is after every carriage pass. In the AFF wind tunnel, this is usually after every 15 collected data points. The table keeps track of what data locations are in which stored data files. Environmental parameters and the freestream velocity for each automatic sequence are recorded. Also, a running record is made of the amount of seed particles added to the facility. Finally room is left for noting irregularities in the data acquisition process (e.g. equipment malfunctions, operating parameter changes, etc.)

##### Traverse Position Matrix

TSI software options allow the printing out of the matrix of locations used by the automatic data collection mode. This should be done for each plane of velocity data. Then the experimenter can follow and note on the printout where in the entire matrix he is after each data collection sequence.

SUBJECT DESTROYER HULL BOW FLOW STUDY 4 Kts

$Z_E = 157''$  AFT  $Z_E = -93682$   $Z_A = -849''$

SHEET NO. 1 OF 2 SHEETS

LINE NO.	COL. A Pass/Time	COL. B Swd Behv. Turb	COL. C Tow Speed #1 m/s	COL. D Tow Speed #2 m/s	COL. E # Points Matrix Loc	COL. F Tow Cont	COL. G	COL. H Comments	COL. I	COL. J
1	1/8 30	2	2.056		1-3	0543	$Z_E = 93682$	$Z_A = 849''$		
2	2/8 45	2	2.057	2.056	4-6	022		First stage = 18.15		
3	3/9 00	2	2.056		7-10	021				
4	4/9 15	0	2.056		11-18	020				
5	5/9 30	1	2.055		19-25	020				
6	6/9 45	0	2.056		26-35	060				
7	7/10 00	1	2.056		36-46	027				
8	8/10 15	1	2.056		47-57	028				
9				BREAK	back to 10 35					
10	9/10 44	1	2.056		58-70	029				
11										
12				NEW Z PLANE		NOMINALLY -6"				
13						$Z_E = 1.3040''$		$Z_A = 1.258''$		
14						moved	18.670''	East on Encoder & moved		
15	10/10 30	0	2.056		7	0542				
16	11/10 12	1	2.056		8-16	021				
17	12/10 26	0	2.056	2.056	17-27	023				
18				LUMEN	back to 12 35					
19	13/12 34	1	2.054	2.055	28-40	024				
20	14/12 49	0	2.056		41-51	025				
21	15/13 04	0	2.056		52-64	026				
22	16/13 19	0	2.056		65-72	027				
23										
24				Moved Mach West		Bow T. to $Z_E = -79612''$				
25						$Z_E = -79612''$		$Z_A =$		
26				End of Shocks						
27	17/14 40	1	2.052	2.052	71-77	025				
28	18/14 55	1	2.052		78-83	022				
29	19/15 10	1	2.052		84-91	023				
30	20/15 25	2	2.052		92-94	024				

D. FRY

D. Mullinax

S. McGuigan

Table 10 - Bowing to 30 m/s (10 kts)

### Daily Test Log

This log summarizes the data taking shift and does not contain all the detail of the Run-Time Log. It is primarily meant to contain information that will be input to data analysis programs after the test (Table 5). It also serves to summarize to the experimenter what has been done and how fast it has been done. This should help in planning the best use of what remains of his experiment time. Appendix A contains a blank, full page, Daily Test Log Form.

### Operating Parameter Tables

TSI software options can produce a printout of some of the current LDV system operating parameters (as set in the software). These parameters and some experimental identifiers are stored in every data file (".RAW" file) taken. The experimenter should carefully keep these items current with his data taking (improper parameters may mean collected data errors). A printout should be saved for each plane of data. An example appears in Table 6.

### Data Repeatability Measurements

Finally some data repeatability checks should be run during any experiment. Measurement repeatability can only be evaluated if measurements are repeated one or more times at a few locations (at least 20 for every optical alignment). The repeated data is collected in the usual automatic mode. It can consist of freestream measurements, experimental data, or both. For later convenience, all repeated measurements should be in the same Position - Velocity Data summary file (i.e. ".PVD" file) as the original measurements.

### PERMANENT DATA STORAGE

All data and data summary files should be stored on the RM tape after each plane of measurements is completed. Typical experiments can produce more ".RAW" files than the RMF disk can hold so that this transfer is often needed just to open up additional data

DAILY DATA LOG

DATA TAKEN

DATE	DATA SET	Start Time	DESCRIPTION	MODEL CONFIGURATION			VELOCITY CORRECTIONS				
				MODEL	PROP(S)	TOP SPEED	HOOR GAUGES	Streamwise	Vertical	On Axis	
4/18/84	FREB	08:40	No Motor Operation after turning Remotely and Probe loses Power Changing	NONE		5 MS		27951 U	V = 0066 U	W = 2045 U	
4/19/84	DSFI	08:00	08:00	DSFI	722	6 MS	1351	567	"	"	"
		08:56	08:56	DSFI	6 NT	6 NT			"	"	"
		10:54	10:54	DSFI	6 NT	6 NT			"	"	"
		13:27	13:27	DSFI	6 NT	6 NT			"	"	"
		13:31	13:31	DSFI	6 NT	6 NT			"	"	"
4/20/84	DSFI	08:22	08:22	DSFI	6 NT	6 NT	1351	567	"	"	"
		10:30	10:30	DSFI	6 NT	6 NT			"	"	"
		13:12	13:12	DSFI	6 NT	6 NT			"	"	"
		15:16	15:16	DSFI	6 NT	6 NT			"	"	"
4/21/84	DSFI	08:45	08:45	DSFI	6 NT	6 NT	1351	567	1946 U	V = 0066 U	W = 2284 U
		10:20	10:20	DSFI	6 NT	6 NT			"	"	"
		15:48	15:48	DSFI	6 NT	6 NT			"	"	"
4/23/84	DSFI	08:35	08:35	DSFI	6 NT ?	6 NT			"	"	"
		13:40	13:40	DSFI	6 NT	6 NT			"	"	"
4/24/84	DSFI	08:35	08:35	DSFI	6 NT	6 NT			"	"	"
		15:15	15:15	DSFI	6 NT	6 NT			"	"	"

Table 5: Example Daily Test Log.

```

*****
*
* DATA REDUCTION PARAMETERS *
* 30-MAY-85 09:05:29 *
*
*****

```

```

Experiment identifier:
DESTROYER WHOLE BODY WAKE SURVEY 6 KNOTS 19-APR-84

```

```

Experiment comments:
STRIPE NO. 13
"Z" PLANE AT Z = -8.6152" (ABS. ENCODER)
6 KNOTS PROPS OUTWARD AT 727 RPM RUDDERS IN PLACE
THIS PLANE INCLUDES THE PROPELLER SHAFT

```

```

Input data source : RDF:COUNTR.RAW
Output data source : RDF:DSSD13.RAW

```

```

Mode of operation : Random
Number of counters : 3
Time between data : No
Data point group : AP
Sample group size : 3 groups of 206 det

```

```

<< Counter 1 Configuration >>
Type : 1990
Settings : TBC >>vel bias
N-Cycle = 8
Frequency Shift : 0.500 Mhz
Fringe Spacing : 4.747 m/sec/Mhz

```

```

<< Counter 2 Configuration >>
Type : 1990
Settings : TBC >>vel bias
N-Cycle = 16
Frequency Shift : 0.500 Mhz
Fringe Spacing : 30.849 m/sec/Mhz

```

```

<< Counter 3 Configuration >>
Type : 1990
Settings : TBC >>vel bias
N-Cycle = 8
Frequency Shift : 0.000 Mhz
Fringe Spacing : 1.734 m/sec/Mhz

```

Table 6: TSI Operating Parameters Printout.

space on the TEMP disk. Data summary files should remain on the TEMP disk even after they are stored on magnetic tape. Most of the interesting data collection software outputs (data tables and plots) can be displayed from information on just the relatively small summary file. So, by keeping the ".PVD" files handy (on the TEMP disk), the experimenter still has easy access to the most important features of the data he has taken.

## DATA REFINEMENT PROCEDURES

Data refinement is merely the elimination of apparently erroneous individual velocity measurements. Either 768 (Towing Tank) or 1,536 (AFF) individual measurements are recommended for each data location<sup>1,2</sup>. This means that an experiment of any duration (1,000+ measurement locations) will generate a million or more individual measurements. Thus the elimination of bad measurements almost always has to be an automatic, computer controlled process.

Chauvenet's criteria is applied blindly by the computer to eliminate velocity component measurements that are too many standard deviations from the measurement mean. The cutoff is a function of the number of individual velocity component measurements: 256 measurements - 3.1 standard deviations; 512 measurements - 3.3 standard deviations; etc. The basis for this criteria is that valid measurements assume a gaussian distribution about the mean velocity component. Measurement locations that are crossed by the fluctuating edge of a turbulent boundary layer or wake are examples of when this refinement process may not be justified.

### COMPUTER SETUP

The TSI software package provides for data refinement, but not in a practical way. About a minute's worth of user entries are required to refine one measurement location. The refinement process itself also takes one or two minutes per data location. A typical experiment would require nearly constant user entry of file names and software menu selections for on the order of 50 hours (1000 locations / 20 locations per hour).

An alternative has been developed for the user who can determine which data files (".RAW" files) he wants to refine. The user installs the REF/B disk in Drive 0 of the LDV computer system. The TEMP disk is inserted into Drive 1 and loaded (from RMag Tape) with the raw data and data summary files of interest.

The alternative data refinement processes do not speed up the refinement procedure itself. They merely provide for a certain



measure of automatic refinement without constantly requiring user inputs. The 50 hours of processing is still needed, but it can be done overnight or without the user's constant attention or even presence.

Both of the refinement programs that will now be described go through the Chauvenet's criteria data elimination process twice. That is, a raw data mean and standard deviation are calculated and then values outside the standard deviation cutoffs eliminated. A new mean and standard deviation are calculated from the remaining data and a final elimination made based on their values.

#### "REFINR" REFINEMENT PROGRAM

The TSI software was modified to automatically step through the refinement of all data locations on a single data file. The summary data file is also automatically updated with the refined velocity means and standard deviations.

#### Description

The REF/B disk contains command files to compile ("REFINC.COM"), link ("REFINL.COM"), and run ("REFINR.COM") this program. The executable file is named "TOWRTT.SAV". The program runs much like the standard TSI software with the user able to access most of the parameter setting and the file opening menus. Only those options in the statistical analysis ("S") menu and in the underwater tow ("U") menu are inaccessible.

#### Usage

Upon entry into the program, the user should first set the refinement standard deviation cutoffs appropriate for his data. This is done (as in the standard software) by entering the Data Reduction Parameter Menu and selecting "R" for refinement boundary constants. In order to avoid this step for subsequent runs of "REFINR" the entered cutoffs can be made the default ones by now selecting "W" (Write to default parameter file, "MASTER.MAD") in the Data Reduction

Parameter Menu.

Next the File Management Menu should be entered to open up the data or ".RAW" file of interest. Note that in the standard TSI software the opening of any old data file means that all data reduction parameters revert to the values used when the data was originally collected. However, this program is modified such that refinement boundary constants and histogram limits are not changed from the most recently entered or default values.

Finally the user presses the function key "PF1" and sits back as the program automatically sequences through the menus and menu options to refine all the data locations in the opened file. The associated data summary file is updated to include the refined velocity data means and standard deviations. After completing the refinement the user should reenter the File Management Menu to close the finished file and perhaps open the next file to be refined. Note that the data files (".RAW" files) are unchanged. Only the data summary file (".PVD" file) is different. In this way the computer remotely handles the refinement process of a whole data file (between 6 and 15 measurement locations) at a time.

#### "REMOTR" REFINEMENT PROGRAM

The TSI software was also modified to automatically step through the refinement steps for all data locations on a "SS" disk file named "INP.RAW". The summary data file is also automatically updated with the refined velocity means and standard deviations.

#### Description

The REF/B disk contains command files to compile ("REMOTC.COM"), link ("REMOTL.COM"), and run ("REMOTR.COM") this program. The executable file is named "REMRTT.SAV". Upon executing the "REMOTR.COM" command file, the program immediately takes full control and does the refinement of "INP.RAW" and updating of the associated summary data ".PVD" file. The program is automatically exited when the process is over.

## Usage

Because the computer (once the program is started) allows no user interaction, there is no opportunity for the user to modify or even check the refinement cutoffs. The default values previously stored (in file MASTER.MAD) by the last run of "REFINR" are used. So, generally the user should first execute "REFINR" to properly set these values for all subsequent runs of "REMOTR".

After copying the data file of interest to "INP.RAW", the command file "REMOTR.COM" executes the program. Without further user inputs, all the data locations in the data file are sequentially refined and the data summary file (".PVD" file) updated.

A whole series of data files can be refined without user input if a master command file, such as "NITEWK.COM" (Figure 8), is used. Master command files, if made long enough, can run day and night until the data is refined with the user entirely free to do something else.

An abridged version of the TSI software data statistics table is sent to the LDV computer system printer for each data location. "NITEWK.COM" also prints the file name being refined to keep the printouts straight after long sessions. It is recommended that the

```
DIR DL1:DATA01.RAW/PRINTER
COPY DL1:DATA01.RAW DLO:INP.RAW
@REMOTR
DEL INP.RAW/NOQ

DIR DL1:DATA02.RAW/PRINTER
COPY DL1:DATA02.RAW DLO:INP.RAW
@REMOTR
DEL INP.RAW/NOQ

DIR DL1:DATA03.RAW/PRINTER
COPY DL1:DATA03.RAW DLO:INP.RAW
@REMOTR
DEL INP.RAW/NOQ

DIR DL1:DATA04.RAW/PRINTER
COPY DL1:DATA04.RAW DLO:INP.RAW
@REMOTR
DEL INP.RAW/NOQ
```

Figure 8: Listing of Example "NITEWK.COM" File.

number of points eliminated by the refinement process be recorded for each data location and each velocity component. Large numbers of eliminated measurements may mean erroneous or unusable data. A worksheet such as shown in Table 7 is suggested. When questionable data appears in later plotting routines, it is good to have such a table around to check immediately if the cause was very noisy or non-gaussian data. Appendix A contains a blank, full page, Bad Measurement Tally Form for experiment usage.

#### DATA STORAGE

When all the data files belonging to a data plane or summary data file have been refined, the ".PVD" file on the TEMP disk really contains refined rather than raw data. It should be stored on the RMag tape as "????00.REF"\* so as not to have the same file type as the raw data summary file. Note that if this file is to be subsequently used by the TSI software (or any of its modified versions), then it must be copied back into the Drive #1 RL02 disk and renamed "????00.PVD".

---

\* The "????" stands for the 4 character alphanumeric that is unique to the measurement plane being refined.

File Name	Good Pts per Run	Iterations	LDV DATA REFINEMENT DESTROYER BOW FLOW STUDY													
			DSØ2; normally .5" Aft at Bul Top; 6 NE.													
			CHAUVENET'S CRITERIA Sample Group "Bad" Pts. V-W-U													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
DØ2Ø1	4	2	0-3-6	2-8-1	3-3-3	3-9-4										
" 02	4	2	1-6-6	1-3-3	0-6-2	0-4-6										
" 03	6	2	2-9-4	4-4-6	1-2-3	2-8-3	0-4-4	1-3-1								
" 04	8	2	1-6-4	2-4-6	0-2-2	1-5-1	1-4-3	0-2-4	0-6-1	1-8-6						
" 05	9	2	0-3-5	3-8-5	0-7-7	0-6-2	1-4-3	1-6-1	4-4-7	4-3-6	1-7-9					
DØ2Ø6	8	2	1-4-4	3-4-3	1-5-4	1-3-3	1-6-5	0-6-1	1-4-4	2-6-6						
" 07	10	2	1-9-2	3-5-5	0-6-1	1-3-3	1-3-4	0-4-4	3-6-3	1-6-5	2-7-3	1-4-2				
" 08	10	2	3-8-9	0-4-3	1-7-5	3-7-2	0-5-3	1-7-4	1-5-3	0-6-4	1-5-6	2-8-6				
" 09	8	2	1-5-2	1-2-8	2-6-6	0-7-7	0-8-3	1-4-3	0-6-4	2-3-7						
" 10	10	2	2-6-3	4-5-6	1-5-4	4-4-5	2-8-5	2-6-4	3-5-5	1-4-4	1-6-0	1-5-5				
DØ2Ø11	8	2	3-5-2	0-8-1	2-2-7	2-4-3	2-9-1	4-7-7	2-6-4	2-10-4						
" 12	8	2	1-5-3	2-6-6	0-6-1	0-7-1	0-2-6	0-2-3	2-5-5	2-5-2						
" 13	8	2	2-7-6	2-8-1	0-4-2	0-5-1	1-3-0	0-5-3	0-6-0	0-5-2						
" 14	7	2	4-5-2	0-4-5	0-4-8	4-2-3	4-6-7	1-5-4	2-3-5	3-3-5	5-3-6					
" 15	8	2	2-4-6	1-8-3	3-5-7	4-6-4	4-3-6	3-4-6	4-8-3	3-3-1						
DØ2Ø16	6	2	1-6-5	1-8-0	3-3-1	0-3-1	0-2-0	2-3-1								
" 17	8	2	0-4-2	1-6-0	1-2-0	2-1-5	3-0-2	1-7-3	2-6-2	4-7-3						
" 18	7	2	1-3-5	4-2-3	3-1-5	1-6-7	1-6-6	0-5-4	0-4-1							
" 19	5	2	1-4-2	1-4-2	7-2-14	7-5-30	13-9-32									
" 20	9	2	2-1-1	0-3-3	1-2-4	4-5-4	2-3-3	4-0-6	4-8-2	1-8-4	1-7-2					
DØ2Ø21	7	2	0-2-1	1-5-4	4-3-6	5-4-4	1-4-5	6-5-3	4-4-2							
" 22	10	2	0-3-4	3-5-4	0-6-2	2-2-2	7-3-1	2-0-8	4-3-3	2-1-3	4-4-3	3-1-1				
" 23	10	2	1-2-6	1-4-7	4-3-2	0-2-4	1-3-1	2-4-3	3-3-6	1-2-5	6-7-1	5-4-1				
" 24	2	2	2-6-3	3-5-5												

Table 7: Example of Bad Measurement Tally Sheet.

## DATA EDITING PROCEDURES

This data analysis phase prepares the refined data for various plots. The velocity data values are unchanged, except for a correction of velocity component direction. The origin and unit of measure of the location coordinate system are changeable during this phase. The main purpose of this phase is to create position - velocity data files that are convenient to read and to incorporate into reports and data plotting programs.

All steps, but the last, involve computer programs written and tested on the two PDP 11-23 computer systems previously described (LDV and LAB). In addition to the description here, each program source file contains a paragraph at the top explaining program inputs and functions. The last step is transferring the readied data files to the HDL-VAX computer where the final Data Plotting phase takes place.

### "EDITABLE" FILE CREATION

The data summary files created by the TSI software contain all the information required for plotting. Although TSI software can access and print out that information, the binary character of the summary file is a big disadvantage if the file needs modification or must be accessed by other software. Therefore the first step is to decode these binary files. A new computer file is needed that looks exactly like the TSI Software master data tables (Table 3) when opened by a computer program or file editor.

Programs on the REF/B disk do this job very easily. The programs are modified versions of the TSI software. They send the data summary table into a new computer file instead of to the printer. The new file, named "FTN6.DAT", is created on the REF/B disk. It should be renamed to "????.WRF" where "????" is the 4 character data plane identifier and "WRF" stands for Written Refined File. This new file should be printed out (the CID computer system offers the quickest printer) and also stored on the PMag tape.

The user must choose from four programs the one that handles the

position coordinates of his data files. A command file is provided on the REF/B disk to properly setup and start each program.

1. "FILERI.COM" uses the "RECIN" program to decode data files with rectangular coordinates in units of inches;
2. "FILERM.COM" uses the "RECM" program to decode data files with rectangular coordinates in units of millimeters;
3. "FILECI.COM" uses the "CYLIN" program to decode data files with cylindrical coordinates in units of inches;
4. "FILECM.COM" uses the "CYLMM" program to decode data files with cylindrical coordinates in units of millimeters;

The program has the same menus as the standard TSI software<sup>3</sup>. The user should enter the "U" or Underwater Tow menu, select the proper data plane (tow name), and select "2" to output the entire summary statistics table.

After exiting the program, the user should open the file with an editor to examine it. A number of linefeed characters must also be replaced by carriage return characters (Figure 9). Several of these occur among the titles for each page of data. The user must also place at the very top (on a line by itself) the total number of data locations in the file. The number must have four digits with zeroes or spaces to the left for numbers under 1000.

#### CYLINDRICAL VELOCITY COMPONENTS (OPTIONAL)

If data is recorded in cylindrical position coordinates (as in wake surveys), very often the user is interested in radial and tangential velocity components. The LDV technique naturally measures rectangular components of velocity<sup>1,2</sup>. However, it is a simple calculation (given a coordinate sign convention) to convert mean velocities to cylindrical components. Note only the "V" and "W" components are combined to calculate radial and tangential mean velocities. The sign convention used is found in Appendix B.

The program used in this step is "RCOMP" and it is found on both the LAB computer system (LDVPRG subdirectory) and the LDV computer

Keyboard Entries	Comments
.<SET-UP> 9 <SET-UP> .EDIT DATA.WRF <RET>	Change screen to 132 ch. lines Edit File "DATA.WRF"
[GOLD] [BOTTOM] [GOLD] [TOP] <SP> 3 3 1 [DELCHR] <RET> [BLINE] [BLINE] [DELCHR] [DELCHR] <RET> <RET> [BLINE] [BLINE] [DELCHR] <RET> <↑> <↑> <↑> <↑> <↑> <SP> <SP> ... <SP> . W R F [GOLD] [FIND] <CTRL> L [ADVANCE]	Note last point number; eg 331 For a file with 331 points  Center ".WRF" under the titles Find next <FF>
<←> <RET> [BLINE] [BLINE] [BLINE] [DELCHR] [DELCHR] <RET> <RET> [BLINE] [BLINE] [DELCHR] <RET> <↑> <↑> <↑> <↑> <↑> <SP> <SP> ... <SP> .WRF [FINDNXT]	} Do for each page of Data (i.e. for each block of 52 data points)
[GOLD] [COMMAND] E X I T [ENTER]	

[ ] Special Keypad Key for KED Editor  
<SET-UP> Set-up Key  
<SP> Space Bar  
<RET> Return Key  
<↑> Up Arrow Key  
<CTRL> Control Key  
<←> Left Arrow Key

Figure 9: "KED" Editing Session for <LF> Elimination.

system (REF/B disk). The "?????.WRF" file is copied into a file named "IN.WRF". The program is then run with the converted velocity component table output to the file "OUT.RAD". This file should be immediately renamed "?????.RAD" to avoid being destroyed by the next run of "RCOMP". If this file is of particular interest, it may be printed out and stored on the PMag tape.

#### NORMALIZED AND CORRECTED DATA FILES

This step in the refinement phase applies the velocity component direction correction and can change the origin and units of the position coordinate system. Any combination of the three changes chosen



by the user is applied at once to entire data planes (i.e. ".WRF" files).

The program used in this step is "NORMLZ" and it is found on both the LAB computer system (LDVPRG subdirectory) and the LDV computer system (REF/B disk). The previously created "?????.WRF" file is copied into a file named "IN.WRF". The user creates or edits a normalizing data file, "NORMLZ.DAT" according to the coordinate zeroes, length scales, and correction factors appropriate to his data. Nine values must be present on the file before running the program. Each number (F8.4 formatting) appears alone on a line:

1. Zero<sub>1</sub> ..... added to 1<sup>st</sup> coordinate value;
2. Zero<sub>2</sub> ..... added to 2<sup>nd</sup> coordinate value;
3. Zero<sub>3</sub> ..... added to 3<sup>rd</sup> coordinate value;
4. L.Scale<sub>1</sub> ..... divided into 1<sup>st</sup> coordinate value;
5. L.Scale<sub>2</sub> ..... divided into 2<sup>nd</sup> coordinate value;
6. L.Scale<sub>3</sub> ..... divided into 3<sup>rd</sup> coordinate value;
7. Correct<sub>U</sub> .....  $U = U * \text{Correct}_U$
8. Correct<sub>V</sub> .....  $V = V + U * \text{Correct}_V$
9. Correct<sub>W</sub> .....  $W = W + U * \text{Correct}_W$

The program is then run and the user is interactively asked if any or all of the normalizations should be done. The normalized position - velocity data table is output to the file "OUT.NRM". This file should be immediately renamed "?????.NRM" to avoid being destroyed by the next run of "NORMLZ". The file should also be printed out and saved on the PMag tape.

#### CYLINDRICAL, NORMALIZED VELOCITY COMPONENTS (OPTIONAL)

The earlier description for Cylindrical Velocity Components applies here as well. this time however, "RCOMP" will work on a data file with corrected velocities and normalized position coordinates. The only difference between this and the previous procedure is that "?????.NRM" (not "?????.WRF") is copied into "IN.WRF".

## PLOT-READY DATA FILES

Several features of the "?????.NRM" data files are changed for the plotting programs. ".NRM" files can contain multiple measurements at the same location. Also, table headings and titles that appear every page require extra work when the data is input to a program. Finally some data plotting programs (Contour plots) need data planes with an equal number of measurement points at each depth (rectangular position coordinates) or at each radius (cylindrical position coordinates).

The program "TABLE" accomplishes the first two tasks automatically. Duplicate and bad data points (denoted by negative "IA" values, Table 3) are simply dropped. Thus the user must first check his data file to insure that locations with multiple measurements have a positive "Raw Fi#" value for only the most accurate one. To use the program the user copies his normalized and checked data file, "?????.NRM" to "IN.NRM". The program is run and a newly formatted table is created with the name "OUT.PLT". This file should be immediately renamed "?????.PLT" to avoid being destroyed by the next run of "TABLE".

Because velocity contour plots are usually an objective, the user must edit his "?????.PLT" files so that they consist of a series of data blocks each with an equal number of measurements. Ideally each data block consists of all measurements taken at one depth (rectangular coordinates) or one radius (cylindrical coordinates). The user enters the number of data blocks and points per block into the file on the same line as the total number of data points. Like the total data point number, these are four digit integers (zeroes or spaces are used to the left if the numbers are under 1000) with no separating commas. Dummy values are required even if the contour plotting programs will not be used.

For many reasons, the data may not fit naturally into equal length data blocks. The user then must decide on a strategy to create such a file if he wants to later graph velocity data contours. The suggested method is not to delete any measurements, but to

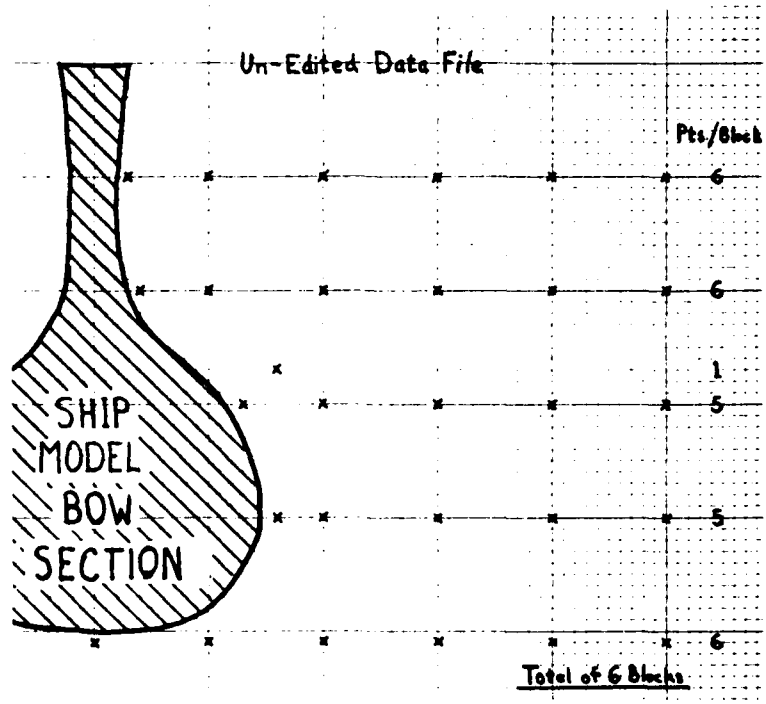
duplicate existing ones to satisfy the requirement. The KED editor (or any other) can be used to make the required changes. The contouring programs (described later) do not mind having two or more measurements at the same location as long as they have the same velocity data values. Also, the programs do not strictly require that each data block have points with only one depth or radius value. The programs simply draw contour lines between each data location and four adjacent points. The program assumes that the locations just before and just after a point in the data block are adjacent. Also, the preceding and following data blocks each have an adjacent point at the corresponding location within the block.

An example strategy appears in Figure 10. Note that the total number of data points now includes both the deletions by running "TABLE" and any duplicate point additions. Also, it is a good idea to label duplicate points by uniformly making their "Raw Fi#" and "Smp Gr#" values something implausible (e.g. 99). Some data plotting programs will recognize these "Raw Fi#" and "Smp Gr#" values of 99 and not use the duplicate points in the plots produced.

The "?????.PLT" file is now ready to serve as input for the plotting programs. The user should print out the file for his records and permanently save it on the PMag tape.

#### FILE TRANSFER OVER THE PHONE

In order to take advantage of already developed graphics programs, the user must get those programs and the "?????.PLT" data files to a computer system on which DISSPLA graphics routines are implemented. The Harry Diamond Laboratory's (CAD-CAM Group) VAX 11-780 Computer is one such system available to DTNSRDC personnel. The procedures here send files over the phone (1200 baud) from the LL Computer System to this VAX 11-780.



KEY:

- x Measurement Point
- o Duplicated Meas. Point
- Adjacent Point Links

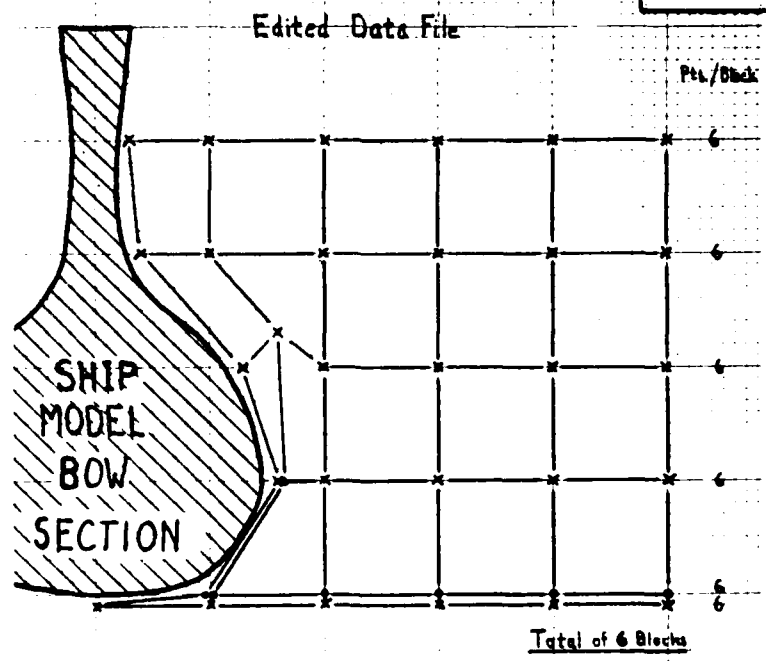


Figure 10: Data Block Editing Strategy for Contour Plots.

After booting the LAB Computer System, the user loads the modem controller (RD) and runs the control software (FTERM<sup>\*</sup>). The terminal inputs are completely detailed in Figure 11. Note that the 132 column data files ("?????.PLT") do not work with the software's default burst width ("BW") and burst delay ("BD") values. Also, each system must see the terminal as a 132 column display device.

If a data repeatability plot is required, the user must make a composite data file from all the ".NRM" files with repeated data points. Non-repeated data points within this file may be deleted as they will not be used in the repeatability plotting program. This composite file must also be transferred to the VAX 11-780 computer

VAX COMMANDS	RT-11 COMMANDS	COMMENTS
{Phone Call and Login Procedure}	.<Setup> 9 .LOAD RD .R FTERM <RET>	Only for 132 char. files Load Modem Handler Run FTERM Program Enable Modem Communication
\$SET TERM/WID=132 \$CREATE FILE.HDL <CTRL>P		Only for 132 char. files File Name on HDL Comp. Back to FTERM
	H BW 100 BD 020 S FILE.LDV <RET>	Lists all FTERM commands Only for 132 char. files Only for 132 char. files Send File File Name on LAB Comp. Enable Modem Communication
{After Completed Transfer} <CTRL>C <CTRL>P		Close FILE.HDL Back to FTERM
	E .	Exit FTERM RT-11 Command Prompt

Figure 11: "FTERM" File Transfer (to HDL) Session Listing.

\* FTERM is a communications software package licensed to DTNSRDC (No. 268) by Glenn A. Barber Associates Inc. of Sherman Oaks, Calif.

for plotting.

Although some slight procedure modification may be necessary, the FTERM software should be able to send files over the phone to any remotely accessible computer.

## DATA PLOTTING PHASE

This phase finally produces the graphs necessary for LDV data interpretation and display. The use of existing plotting programs will be detailed and typical results displayed. Users developing new plotting programs in Fortran may find the data input sections and DISSPLA setups of these programs useful as a starting point. After obtaining the desired plots, data tables are stored away for convenient access in the future.

The plotting programs are divided into three groups depending on whether their primary output involves error analysis information, rectangular velocity component data plots, or cylindrical velocity component data plots. Each program description will consist of three sections:

1. General description
2. User Interaction
3. Program Output

Fortran source code listings appear in Reference 5.

### VAX - DISSPLA ERROR ANALYSIS PLOTS

#### SCATR1 & SCATR2: Mean Velocity Component SCATteR Plots

These two programs take "Plot-Ready" LDV data files and mark all data points on a graph whose axes are two velocity components. SCATR1 plots data for "U" (streamwise component) and "V" (vertical component) axes. SCATR2 plots data for "T" ( $(U^2+V^2)^{1/2}$  component) and "W" (on-axis component). The program is written in Fortran, but includes calls to the plotting package, DISSPLA. The program has been run on the HDL VAX computer.

This program is useful in conjunction with error contour plots output by ERROR1 (an error calculation computer program described in Reference 1 and 2). Together they show an estimate of the range of measurement errors for any component. Also, the plots may be used in estimating velocity component ranges for future, similar experiments.

User Interaction. The user copies the data file of interest to a file named "XWAKE.DAT" and then just runs the program on a Tektronix or other graphics display terminal. The axes are labeled in velocity components divided by the towing speed,  $U_0$ . If the user wishes other than the default axes' bounds, than he need only change the "Call GRAF(.....)" program statement (see listing in Reference 5).

Program Output. The program outputs a graph with "X"s marking the location of each data point in the LDV data file. The axes are automatically set and labeled. An error should result if data points are far outside the plot boundaries. Figure 12 presents example plots of both "SCATR1" and "SCATR2".

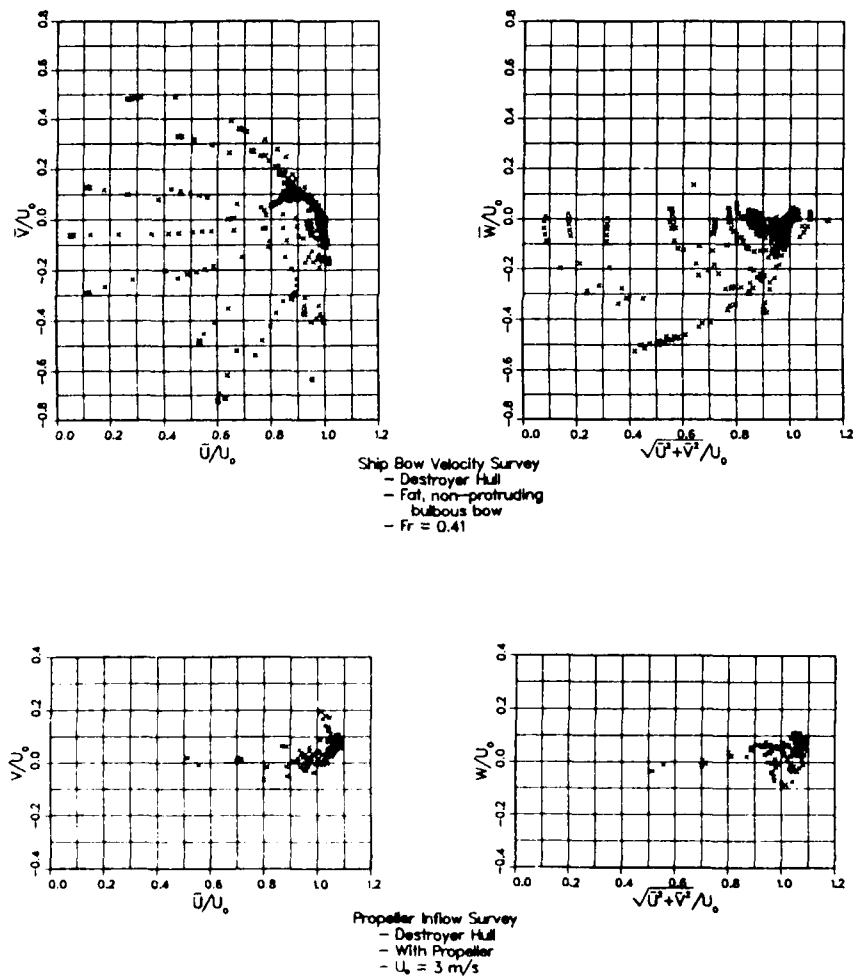


Figure 12: "SCATR1" and "SCATR2" Plots.



#### BGRAF1: Velocity Fluctuation Magnitude Bar GRaph

This program looks at the standard deviations of any of the measured velocity components as found on a standard "Plot-Ready" data file. A bar graph is produced that plots percent occurrence as a function of the standard deviation magnitude. The user chooses the velocity component that is plotted. The program is written in Fortran, but includes calls to the plotting package, DISSPLA. The program has been run on the HDL VAX computer.

The plots (especially the vertical standard deviation) may be useful in establishing velocity component fluctuation magnitudes for future, similar experiments. Reliable estimation of errors during the planning of experiments, requires an accurate estimate of the velocity component fluctuation magnitudes.

User Interaction. The user copies the data file of interest to a file named "XWAKE.DAT" and then runs the program on a Tektronix or other graphics display terminal. The program asks for the component standard deviation to be plotted. The upper bounds of both the standard deviation and the percent occurrence axes are entered by the user after he is prompted by the computer with the maximum values for the data set.

Program Output. The program outputs a bar graph like that shown in Figure 13.

#### BGRAF2: Data Repeatability Bar GRaph

This program looks at the repeatability of the measured mean velocity components as found on any TSI Software Format data file. The file must contain some locations where two or more valid measurements were made. The composite file of repeated data points was created and transferred to the plotting computer system to serve as input to this program.

At repeated locations, the difference of each component measurement from the mean measured value is computed. A bar graph is

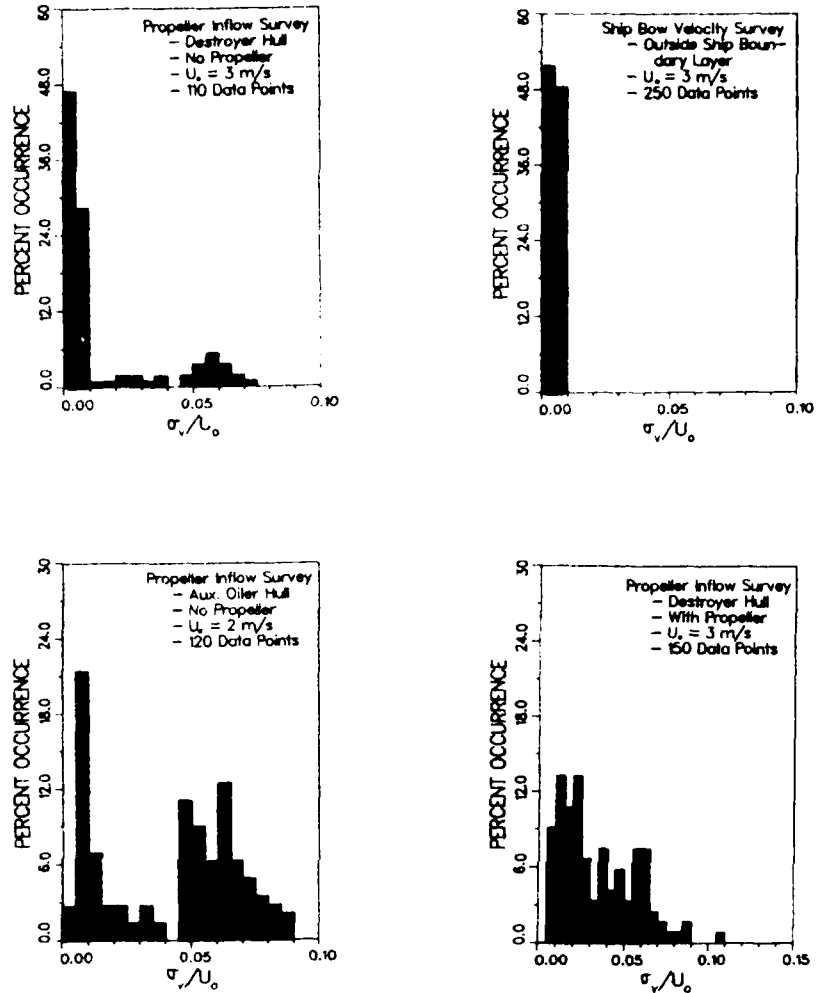


Figure 13: "BGRAPH1" Bar Graph for Measurement Standard Deviations.

produced that plots percent occurrence as a function of these measurement differences (absolute value). The velocity component plotted is chosen by the user. The program is written in Fortran, but includes calls to the plotting package, DISSPLA. The program has been run on the HDL VAX computer.

The plots are useful in demonstrating the quality of the velocity measurements and the steadiness of model conditions over different carriage passes, different days, or different experiments.

User Interaction. The user copies the repeated data file of interest to a file named "REPEAT.DAT" and then runs the program on a Tektronix

or other graphics display terminal. The program expects "REPEAT.DAT" to have the same page format found in ".NRM" files. The program asks for the component for which repeatability is to be plotted. The upper bounds of both the data difference magnitude and the percent occurrence axes are entered by the user after he is prompted by the computer with the maximum values for the data set.

Program Output. The program outputs a bar graph like that shown in Figure 14.

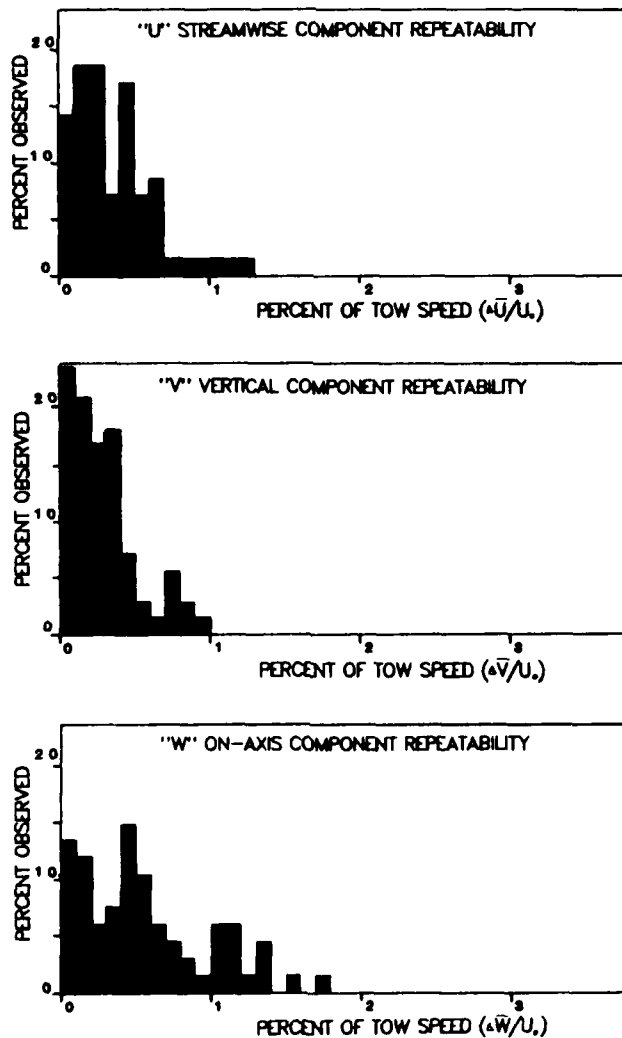


Figure 14: "BGRAF2" Bar Graph for Data Repeatability.

### BGRAF3: Streamwise Fringe Crossings Bar Graph

This program looks at the frequency of occurrence of different numbers of fringe crossings for the streamwise LDV velocity component. The data is taken from calibration runs (no ship model) when the velocity direction is essentially streamwise. The plot is in the form of a histogram or bar graph. The program is written in Fortran, but includes calls to the plotting package, DISSPLA. The program has been run on the HDL VAX computer.

The input file called "FRINGE.DAT" must be obtained by examining the Raw Data files for a calibration run. The data must have been recorded with the streamwise signal processor in TBC or TBM mode.

User Interaction. The user cannot use any of the normal data table files, but must somehow decode the octal words of raw data files. He must extract the total fringe crossing number<sup>5</sup> from streamwise component octal words. A Fortran program "FRING" was written for the LDV computer system to do this job. "FRING" supplies only a hard copy output from which the user must generate a "FRINGE.DAT" file formatted for input to "BGRAF3" (see listing in Reference 5). Afterwards the user runs the program on a Tektronix or other graphics display terminal. The upper bounds of the both the fringe crossings and the percent occurrence axes are entered by the user after he is prompted by the computer with the maximum values that occur in the data set.

Program Output. The program outputs a bar graph like that shown in Figure 15.

### ERROR2: Final ERROR Estimation

This program takes "Plot-Ready" LDV data files and estimates the component errors for each data point. The calculations are based on the error formulations of Reference 1 and the LDV system developed for the DTNSRDC towing tanks. ERROR2 needs no estimate of velocity mean and standard deviation, it directly uses each data point's

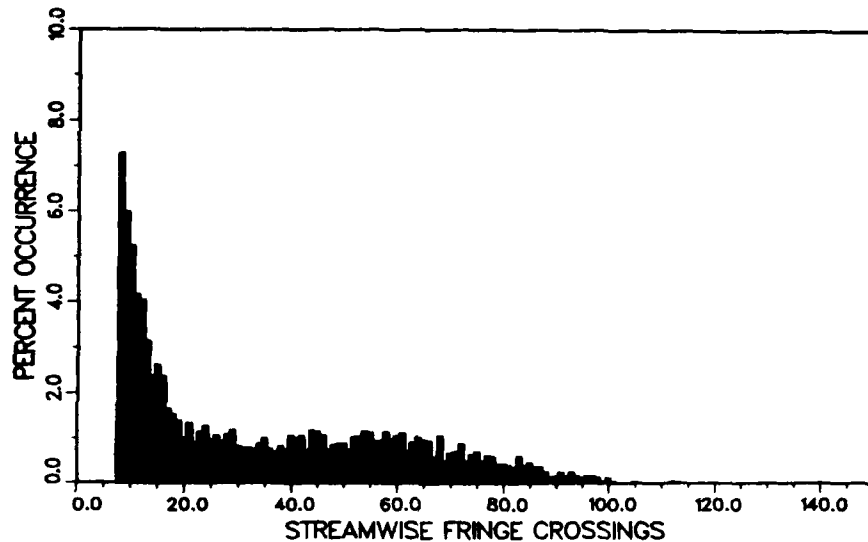


Figure 15: "BGRAF3" Bar Graph for Total Fringe Crossings.

measurements. The program is written in Fortran, but includes calls to the plotting package, DISSPLA. The program has been run on the HDL VAX computer.

This program gives the best possible estimate of the errors present in each velocity component at each measurement point.

User Interaction. The user copies the data file of interest to a file named "LDV.DAT" and then runs the program on a Tektronix or other graphics display terminal. The user is asked to enter LDV system operating parameters and which errors are to be summed (as with ERROR1; see Reference 1 and 2). The user is also asked for estimates of freestream component standard deviation magnitudes. Also, a standard deviation of the repeated fringe spacing calibrations is entered for each velocity component. Both of these last two inputs come directly from procedures followed during the Testing Phase (refer to Fringe Spacing and Component Direction calibration sections).

Program Output. Output is in two possible forms. A bar graph can be displayed that plots any component's total error magnitude versus frequency of occurrence (Figure 16). Also, a revised data table

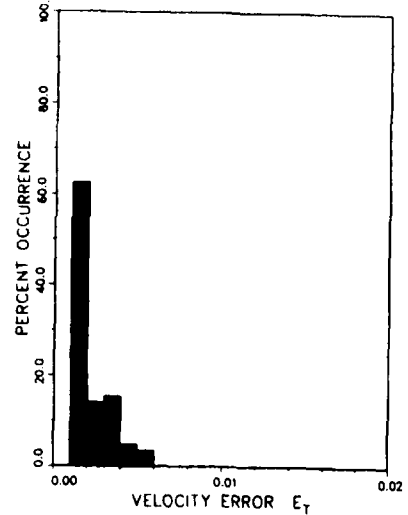
Data File "DSNO"

	U Comp.	V Comp.	W Comp.
Free Stream S.D.	0.000	0.004	0.035
Fringe Spac. S.D	0.004	0.004	0.004
Freq Shift (MHz)	0.000	0.500	0.500
LP Filter (MHz)	2.000	1.000	1.000
Fringe Count Mf	8	8	16
Meas. Count N	256	256	256
Comb. Correction	X	X	X
V Bias Correction	X	X	X

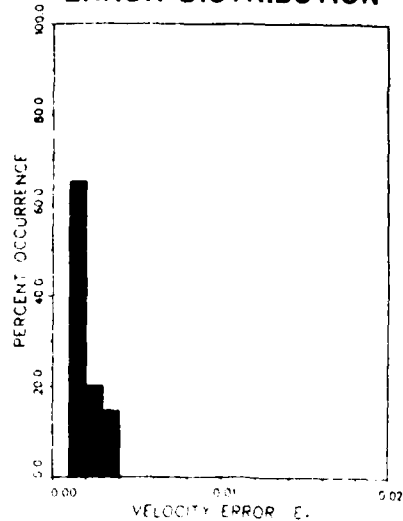
Tow Speed = 3.086 (m/s)

Signal Noise Error.....E(n) X  
 Time Digitization Error.....E(d) X  
 Fringe Spacing Error.....E(f) X  
 Frequency Shift Error.....E(a) X  
 Particle Lag Error.....E(L) X  
 Velocity Fluctuation Error...E(u) X  
 Filter Bias Error.....E(F,B) X  
 Carriage Speed Error.....E(c) X  
 Flow Disturbance Error.....E(i) X  
 Velocity Bias Error.....E(UB) X  
 Fringe Bias Error.....E(FB) X  
 Vel. Comp. Direction Error...E(e) X

STREAMWISE COMPONENT  
ERROR DISTRIBUTION



VERTICAL COMPONENT  
ERROR DISTRIBUTION



ON-AXIS COMPONENT  
ERROR DISTRIBUTION

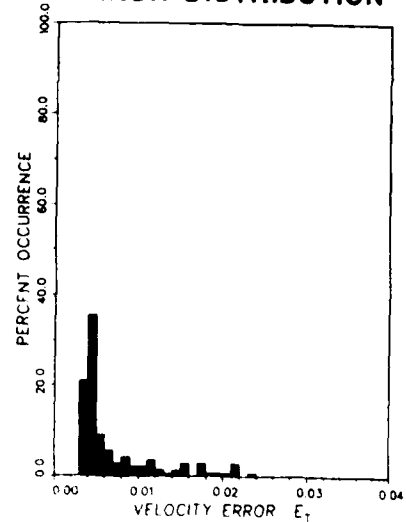


Figure 16: "ERROR2" Bar Graphs for Error Magnitude Distribution.

(ErLDV.DAT) can be output with measured velocity standard deviations replaced by estimates of the total error; total error being the standard deviation expected for measured component means about the true velocity component mean.

The data table ErLDV.DAT should be quite useful in making report plots from the LDV data. Reference to this table gives error "bars" or limits for the velocity components at each individual measurement point.

#### ERROR3: Final ERROR Estimation

This program takes "Plot-Ready" LDV data files and estimates the component errors for each data point. The calculations are based on the error formulations of Reference 2 and the LDV system used in the AFF wind tunnel. ERROR3 needs no estimate of velocity mean and standard deviation, it directly uses each data point's measurements. The program is written in Fortran, but includes calls to the plotting package, DISSPLA. The program has been run on the HDL VAX computer.

This program gives the best possible estimate of the errors present in each velocity component at each measurement point. The user interaction and output descriptions for ERROR2 fit this program as well.

#### VAX - DISSPLA XYZ VELOCITY FIELD PLOTS

There are only two basic types of plots under this section. Each type shows data on a single physical plane. Data files with rectangular position coordinates are plotted. "Arrow" plots show a directed arrow at each measurement point in the plane. The arrow direction and magnitude come from the vector sum of the two mean velocity components in that physical plane. "Contour" plots display the mean velocity component that is directed perpendicular to the physical plane. Contour lines are calculated based on linear interpolation between data location values. The actual data measurement locations do not appear on these graphs.

Different versions of each type of plot exist to achieve the

best plotted page orientation and to plot different physical planes. Shorthand for the location coordinate system axes are: X - Vertical direction; Y - On-Axis or Cross-stream direction; Z - Streamwise direction; A Horizontal Page Plot puts the Y (or Z) coordinate axis along the long side of the page and the X (vertical axis) along the short side. A Vertical Page Plot does the opposite. Page dimensions are a standard 8.5 by 11 inches.

XARRO1: Horizontal Page, X-Y Plane, Arrow Plot

This program displays arrows that define the measured crossflow in a X-Y plane (i.e. transverse to the towing direction). The X or vertical axis is oriented along the short (8.5 in.) side of the paper and the Y or on-axis direction is along the long side. Model sections in this plane can be plotted as a cross-hatched area. The water's free surface, if measured, can be plotted as well.

The user must rename his plot-ready file "XWAKE.DAT" before running "XARRO1". Ship model sections in the plane must be entered as a series of X,Y points in the file "BODY.DAT" and "XTRA.DAT". The water surface data must appear in file "SURF.DAT" in order to be included in the plot. All files must be present, although they can consist of zero points if either no ship section exists (on the plane) or the free surface was not measured.

User Interaction. After starting the program, the user is asked for eight or nine sets of inputs that affect the final plot.

The program first asks the user for X axis limits for the plot. The user enters two numbers (in format: 2F10.4) for the minimum and maximum axis values. The user is then asked for the step between labeled grid marks, the lowest valued grid mark, and the number of tick marks between labeled grid marks (in format: 2F10.4,I2). The program then requires the same information for the Y axis. Note that the ratio of Y axis range to X axis range must be about 1.385 for the plot and arrows to come out undistorted.

The user is then asked for the sign of his Y values so that the



correct half plane (where data was taken) can be plotted. Also, the user can indicate if he actually wants velocity vectors plotted or just a simple "X" at each measurement location. For vector plots, the program calculates the largest plotted velocity magnitude and displays it to the user. The user must then input a vector size factor (units of inches/tow speed in format: F6.3).

Finally the user enters a minimum "Y" spacing between adjacent vectors. Measurement points with a closer spacing are not plotted. He also indicates whether final "Filled" characters are to be used in titles. "Filled" characters give the graph a pleasing appearance but are very time consuming to display.

Program Output. Figure 17 shows an example of an XARRO1 plot. The vector magnitude scale is in the upper left hand corner of the plot.

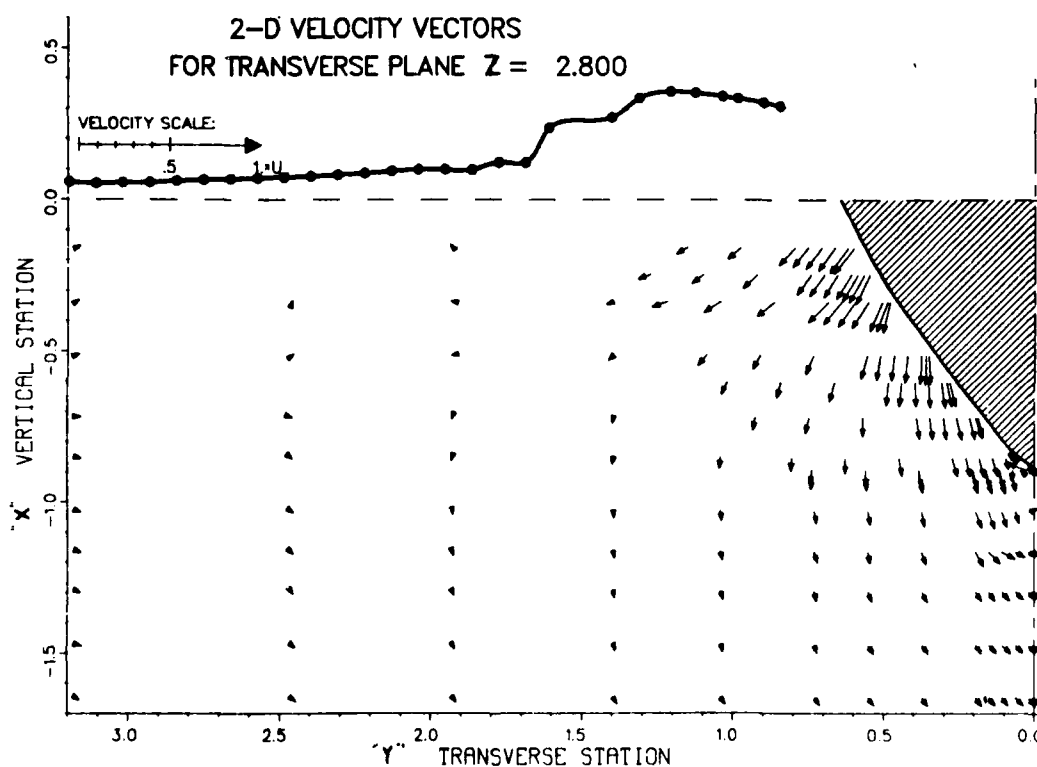


Figure 17: "XARRO1" Velocity Vector Plot Example.

#### XARRO2: Vertical Page, X-Y Plane, Arrow Plot

The other version of the X-Y plane arrow plots does the same job just described except on a vertical page. The user interaction is exactly the same as for "XARRO1". Note that the ratio of Y axis range to X axis range must now be about 0.722 (instead of 1.385) for the plot and arrows to come out undistorted. Depending on the position ranges over which data was taken, this may use page space better than "XARRO1"

Appendix C displays examples of "XARRO2" plots. The user inputs and auxiliary data files ("SURF.DAT" and "BODY.DAT") needed to create the plots are also listed.

#### XCONT1: Horizontal Page, X-Y Plane, Contour Plot

This program can display equal value contours of various, user chosen, velocity quantities. Adjacent data points with values higher and lower than a given contour value determine a location for that contour. A linear interpolation between these adjacent data points, yields a location that the program forces the contour through. Spline smoothing of the contour between these locations is possible, but the locations themselves are fixed.

Successive values of contour lines alternate between a solid, labeled (where possible) line style and a dashed, unlabeled line style. A horizontally oriented, X-Y plane of measurements are displayed.

The user must rename his plot-ready file "XWAKE.DAT" before running "XCONT1". Ship model sections in the plane must be entered as a series of X,Y points in the file "BODY.DAT" and "XTRA.DAT". The water surface data must appear in file "SURF.DAT" in order to be included in the plot. All files must be present, although they can consist of zero points if either no ship section exists (on the plane) or the free surface was not measured.

User Interaction. After starting the program, the user is asked for twelve sets of inputs that affect the final plot.

The initial input sets define the axes bounds and labeling, just as was done for "XARRO1". The same restriction on the ratio of Y range to X range applies (1.385).

The user is then asked for the sign of his Y values so that the correct half plane (where data was taken) can be plotted.

The next five inputs all concern the contours themselves. A contour "tension" is inputted first. A high integer tension makes the contours almost a series of line segments between the established locations. A low integer tension smoothes the contour out by means of a spline fit. The user is then asked if he wants some special contours plotted. The values of the main contours are determined by the next two inputs of the lowest contour value and the step between contour values. A maximum of 30 total contours are plotted. Finally the user is asked for the number of decimal digits that should appear in the contour labels. Only solid contours are labelled.

The user also indicates whether final "Filled" characters are to be used in titles. "Filled" characters give the graph a pleasing appearance but are very time consuming to display.

Program Output. Figure 18 shows an example of a XCONT1 contour plot. The inputs used for the plot are listed in order.

After the user erases the plot from his terminal screen, the program outputs a contour summary table. Each of the 30 possible contour values is listed next to the number of contour locations found by the program. The user should observe if either the highest or lowest contour value has a non-zero number of locations. If either does, then contours outside the user specified range may also belong on the plot.

XCONT2: Vertical Page, X-Y Plane, Contour Plot

The only other contour plotting program, "XCONT2", plots the same plane as "XCONT1" but on a vertical rather than a horizontal page. The user interaction is exactly the same for both implemented versions. As with "XARRO2" the ratio of Y range to X range must be

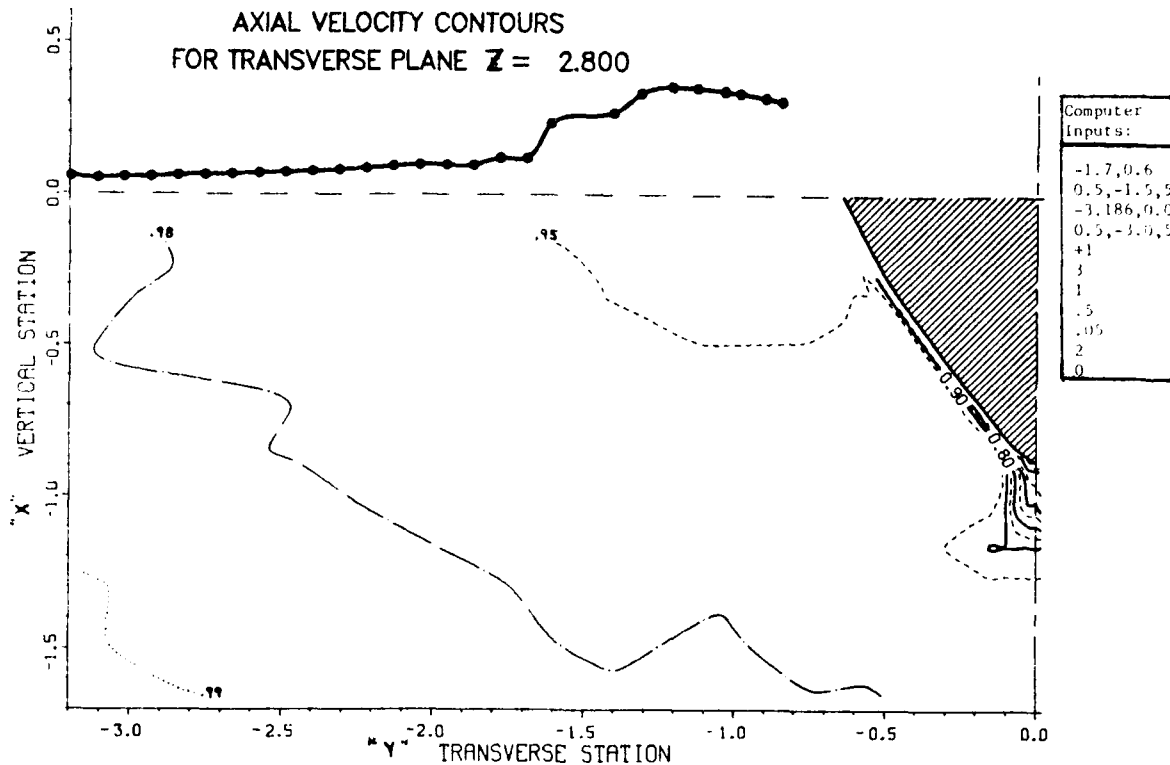


Figure 18: "XCONT1" Velocity Contour Plot Example.

0.722 for an undistorted plot.

Appendix C displays plots of both contour programs. The user inputs and auxiliary data files ("SURF.DAT" and "BODY.DAT"), needed to create the plots, are also listed.

#### VAX - DISSPLA R0Z VELOCITY FIELD PLOTS

There are only two basic types of plots under this section. Each show data on a single physical plane at a fixed Z or streamwise value. "Arrow" plots show a directed arrow at each measurement point in the plane. The arrow is the vector sum of the two mean velocity components ("V" and "W") in that physical plane. "Contour" plots display the mean velocity component ("U") that is directed perpendicular to the physical plane. Contour lines are calculated based on linear interpolation between data location values. The actual data

measurement locations do not appear on these graphs.

Different versions of each type of plot exist to better fit the data ranges to the plotted page. Data plotted by these programs must have cylindrical coordinate positions. Different versions of the programs plot data with  $\theta$  angular positions between either:

1.  $0^\circ - 360^\circ$ ;
2.  $180^\circ - 360^\circ$ ;
3.  $0^\circ - 180^\circ$ ;
4.  $270^\circ - 360^\circ$ ;
5.  $0^\circ - 90^\circ$ ;

Because of some of the options of the contour plots, four values must be added to each data file to be plotted. The values depend on the dimensional or dimensionless unit chosen for the radial and streamwise position coordinates. On the first line, next to the three previously inserted integers, two decimal numbers must be added which are respectively the propeller radius and propeller hub radius in data file coordinate units. A new line is inserted below this line with the tunnel or tow speed (in coordinate units per second) and the propeller speed (in cycles per second). Each of the four numbers and surrounding blanks must take up 10 spaces including the decimal point (i.e. input Fortran format "F10.4"). There should be no commas between the entries.

RARRO1: Angular Range  $0^\circ - 360^\circ$ , Arrow Plot

This program displays arrows that define the measured crossflow velocity vector in a coordinate plane parallel to the propeller plane. A full circle or  $360^\circ$  of measurements is displayed. The user must rename his plot-ready file "RWAKE.DAT" before running "RARRO1".

User Interaction. After starting the program, the user is asked for either six or seven inputs that affect the final plot.

The program first asks for a vector size factor. A decimal number (less than 7 digits and a decimal point) should be entered that is linearly proportional to plotted vector magnitude scale. A

value of 1.0 means that a vector magnitude of the tow speed,  $U_0$ , will have a plotted length of 1.0 plot length scales. The plot length scale is either the propeller radius or the largest measured radius (whichever is greater).

The next input allows the user to "thin out" his data if plotted arrows excessively overlap each other. The user specifies a minimum angle in degrees (less than 7 digits and a decimal point) by which data at the propeller hub radius must be separated. A related minimum separation also applies to any other radius. It is the same arc length specified at the hub. If the user wants to display all his data, he simply inputs a very low minimum separation angle.

The user then enters a number that determines the graph type: 1-Propeller Plane; 2-Propeller Wake; 3-Normal Plane; In Propeller Plane graphs both the propeller radius and hub region are shown on the plot. Propeller Wake graphs are intended for measurement planes that do not intersect body or propeller hub because they are so far aft. Finally Normal Planes are intended to help visualize flow around axisymmetric bodies. Generally these bodies have a radius that grows smaller as the propeller is approached. The resulting negative radial velocity often masks flow structures of interest to the user. Normal Plane plots with the input of a mean flow inclination (to the streamwise direction) allows subtraction of this mean radial flow at all data points before arrow plotting.

The user decides with the final three inputs whether certain labels, titles, and printing will be included in the plot. Any finished plot will want these labels, titles, and "filled" characters, but their absence in initial plots reduces significantly the required plotting time.

Program Output. Figure 19 and 20 show two examples of Propeller Plane plots. Note the vector magnitude scale in the upper right hand portion of Figure 19. In Figure 20, the user has input a very small vector size factor ( $< 0.2$ ) so that all vectors have no discernable length and only the crossflow direction is shown. However, this allows the maximum number of data points to be clearly displayed.

## 2-D VELOCITY VECTORS IN THE PROPELLER PLANE

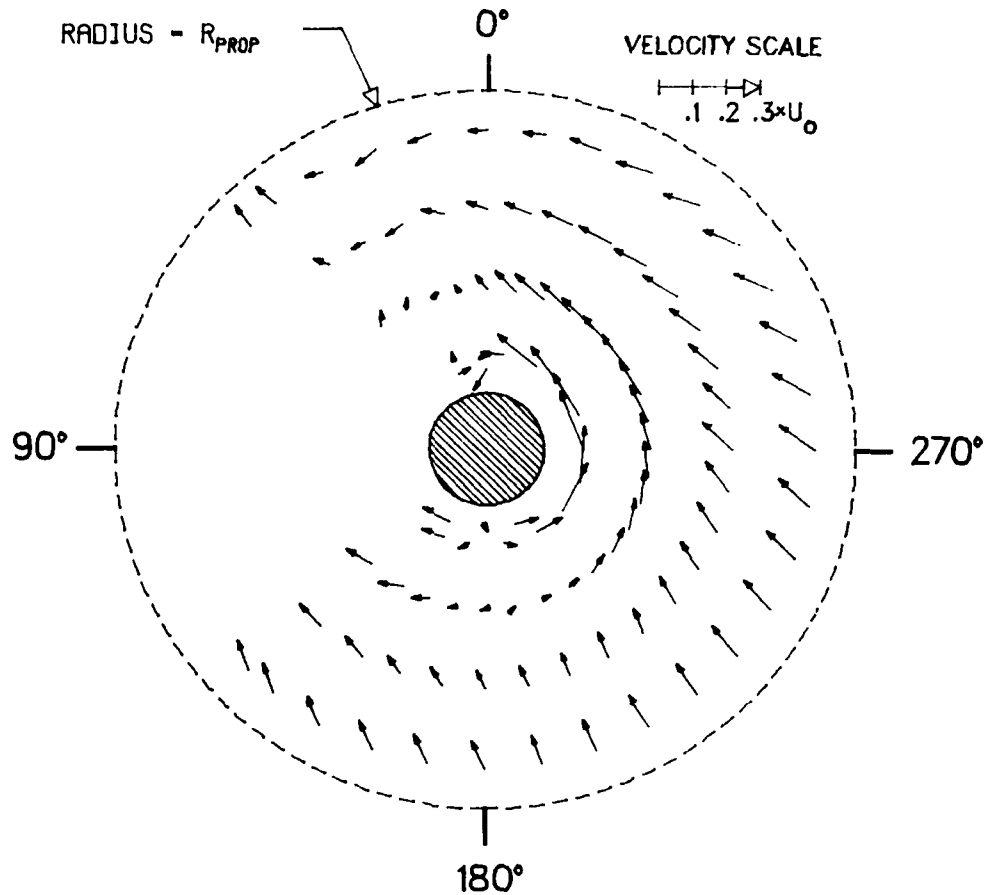


Figure 19: "RARRO1" Velocity Vector Plot Example.

### Other RARRO? Versions

The four other versions of the cylindrical coordinate arrow plots simply display a smaller sector of the measurement plane than "RARRO1". The user interaction is exactly the same for all five implemented versions. A list follows of all the "RARRO?" programs and the measurement plane sectors that are plotted.

## 2-D VELOCITY VECTORS IN THE PROPELLER PLANE

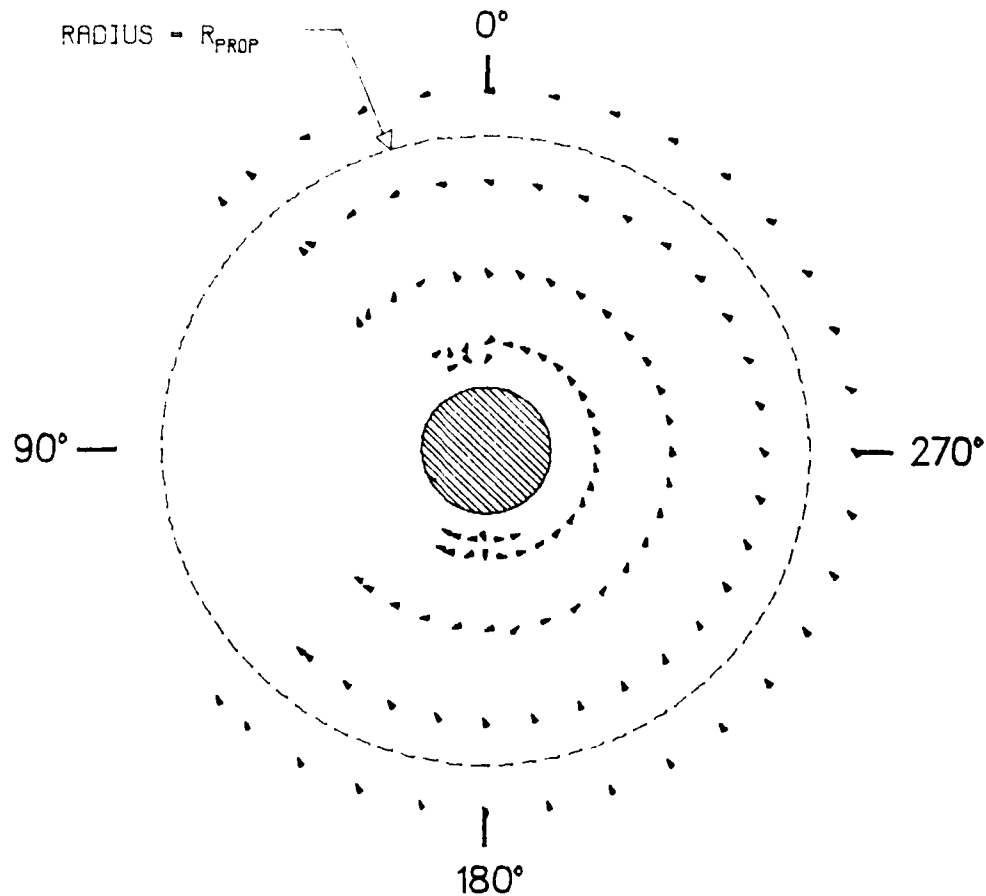


Figure 20: "RARRO1" Velocity Direction Plot Example.

1. RARRO1: Angular Range  $0^\circ - 360^\circ$ , Arrow Plot
2. RARRO2: Angular Range  $180^\circ - 360^\circ$ , Arrow Plot
3. RARRO3: Angular Range  $0^\circ - 180^\circ$ , Arrow Plot
4. RARRO4: Angular Range  $270^\circ - 360^\circ$ , Arrow Plot
5. RARRO5: Angular Range  $0^\circ - 90^\circ$ , Arrow Plot

Appendix C displays examples of "RARRO1", "RARRO2", "RARRO3", "RARRO4", and "RARRO5".



RCONT1: Angular Range  $0^{\circ}$  -  $360^{\circ}$ , Contour Plot

This program can display equal value contours of various, user chosen, velocity quantities. Adjacent data locations with values higher and lower than a given contour value determine a location for that contour. A linear interpolation between these adjacent data locations, yields a location that the program forces the contour through. Spline smoothing of the contour between these locations is possible, but the locations themselves are fixed.

Successive values of contour lines alternate between a solid, labeled (where possible) line style and a dashed, unlabeled line style. A full circle or  $360^{\circ}$  of measurements are displayed.

The user must rename his plot-ready file "RWAKE.DAT" before running "RCONT1".

User Interaction. After starting the program, the user is asked for ten inputs that affect the final plot.

The program first asks the user to indicate if the data covers the full  $360^{\circ}$  of the propeller plane. If this is the case then the contouring program will assume that the first and last measurement locations in a block (i.e. at a given radius) are adjacent to each other.

The program requires four inputs to characterize the contours. The reader is first asked successively for two decimal numbers (9 digits and a decimal point each) that will be the lowest contour value plotted and the value difference between successive contours. These inputs indirectly set the highest possible contour value because the program plots a maximum of 15 contours. The user is then asked to define the contour label format. Finally by input of a contour "tension" the user can control the degree of smoothness by which contours are drawn through contour locations. A two digit integer is entered where "10" produces a nearly straight line interpolation between contour locations (determined by the program from the data) and "00" introduces the greatest degree of spline smoothing<sup>6</sup>. Unsmoothed or "spiked" contours are unrealistic, but

overly smoothed contours can cross themselves or other contour values (even more unrealistic).

The user then enters a number that determines the graph type: 1-Propeller Plane; 2-Propeller Wake; In Propeller Plane graphs both the propeller radius and hub region are shown on the plot. Propeller Wake graphs are intended for measurement planes that do not intersect body or propeller hub because they are so far aft.

The user decides, with the next two and the last inputs, whether certain labels, titles, and printing will be included in the plot. Any finished plot will want these labels, titles, and "filled" characters, but their absence in initial plots reduces significantly the required plotting time.

Finally the user is asked which velocity quantity he wants contoured on the plot: 1-"U" or streamwise mean velocity; 2-BETA or propeller blade inflow angle; 3-"UMT" or streamwise velocity standard deviation; 4-"VMT" or vertical velocity standard deviation; After making his selection, the chosen contours are calculated and plotted.

Program Output. Figure 21 show an example of a Propeller Plane plot. The nine inputs that were used for this plot are listed in Appendix C.

After the user erases the plot from his terminal screen, the program outputs a contour summary table. Each of the 20 possible contour values are listed next to the number of contour locations found by the program. The user should observe if either the highest or lowest contour value has a non-zero number of locations. If either does, then contours outside the user specified range may also belong on the plot.

#### Other RCONT? Versions

The four other version of the cylindrical coordinate contour plots simply display a smaller sector of the measurement plane than "RCONT1". The user interaction is exactly the same for all five

## AXIAL VELOCITY CONTOURS IN THE PROPELLER PLANE

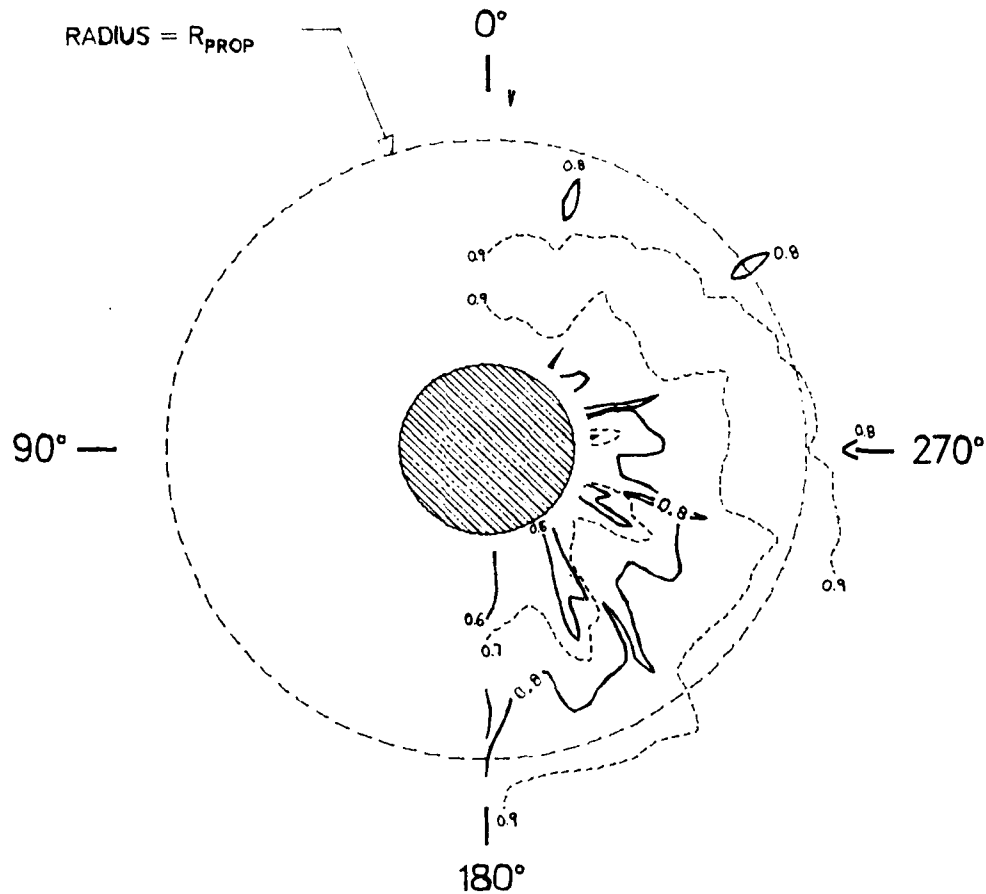


Figure 21: "RCONT1" Velocity Contour Plot Example.

implemented versions. A list follows of all the "RCONT?" programs and the measurement plane sectors that are plotted.

1. RCONT1: Angular Range  $0^\circ - 360^\circ$ , Contour Plot
2. RCONT2: Angular Range  $180^\circ - 360^\circ$ , Contour Plot
3. RCONT3: Angular Range  $0^\circ - 180^\circ$ , Contour Plot
4. RCONT4: Angular Range  $270^\circ - 360^\circ$ , Contour Plot
5. RCONT5: Angular Range  $0^\circ - 90^\circ$ , Contour Plot

Appendix C displays examples of "RCONT1", "RCONT2", "RCONT3", "RCONT4", and "RCONT5".

The initial strategy used in creating equal sized data blocks in the ".PLT" data summary files, may not produce satisfactory contour plots. Improperly chosen adjacent points may cause unrealistic spikes in the contours or send contours through solid body surfaces. After observing the contours produced by a first attempt, the user may make additional modifications to his Plot-Ready file. If data was recorded in equal sized data blocks, then no changes need to be made unless an erroneous data value has become apparent.

#### FINALIZED DATA TABLE STORAGE

After satisfactory FiNaL data plots have been created, the summary data file "?????.PLT" should be renamed "?????.FNL". This file should be transferred back to the LDV computer system over the phone. Figure 22 lists the terminal entries necessary for such a transfer

VAX COMMANDS	RT-11 COMMANDS	COMMENTS
	.<Setup> 9 .LOAD RD .R FTERM <RET>	Only for 132 char. files Load Modem Handler Run FTERM Program Enable Modem Communication
{Phone Call and Login Procedure}		
\$SET TERM/WID=132 <CTRL>P		Only for 132 char. files Back to FTERM
	H BW 100 BD 020 P FILE.LDV <RET>	Lists all FTERM commands Only for 132 char. files Only for 132 char. files Receive a File File Name on LAB Computer Enable Modem Communication
\$TYPE FILE.HDL {After Completed Transfer} <CTRL>P		File Name on HDL Computer  Back to FTERM
	C E .	Close LDV Computer File Exit FTERM RT-11 Command Prompt

Figure 22: "FTERM" File Transfer (from HDL Session Listing).

using the "FTerm" software. The finalized data file may be printed out and kept for quick reference with the other versions of the data summary table. It should be saved on the "PMag" magnetic tape with the other data summary files. There it will be conveniently available to other researchers or for the user to redo plots.

## SUMMARY

For descriptive purposes data handling procedures were divided into four phases:

1. Testing Phase
2. Refinement Phase
3. Data Editing Phase
4. Data Plotting Phase

The steps within these phases were developed from experience with the three component LDV systems in the Carriage #2 Towing Tank (TT) facility and the Anechoic Flow Facility (AFF) wind tunnel. Data handling for each facility is the same except for the initial testing phase where procedures are very analogous. The steps described are intended to be a thorough and detailed data analysis procedure. It is the experimenter's choice to simply use them as is or to use them as a starting point from which to make modifications.

Tables 8 and 9 summarize the individual steps and when they are used. Computer systems and software that help accomplish these steps are also listed. Blank versions of all the forms noted (except for the Data Block Diagram; see figure 10) appear in Appendix A.

Testing phase steps include more than operating the data taking software. Data logs, data forms, information printouts, and data

1 --> 5	Experiments per Fiscal Year
1 --> 2	Optical Setups per Experiment .....
5 --> 10	Work Shifts per Optical Setup .....
1 --> 7	Measurement Planes per Work Shift .....
10 --> 30	Data Sequences per Measurement Plane .....

Table 8: General LDV Time Scale Hierarchy.

SOFTWARE SUPPORT			COMPUTER STORAGE			FORMS	
COMPUTER SYSTEM	PROGRAM	DISK CARTRIDGES DRIVE 0 DRIVE 1	COMPUTER	OPERATION	MEDIA	NAME	FREQ. OF ENTRY
--- TESTING PHASE ---							
1	LDV	BEND1	DATA/B	TEMP	---	Position Corr.	Each Experiment
2	LDV	BEND2Y	DATA/B	TEMP	---	Traverse Bend.	Each Fiscal Year ?
	LDV	BEND2Z	DATA/B	TEMP	---		
	LDV	BEND3	DATA/B	TEMP	---		
3	LDV	ENC2RL	DATA/B	TEMP	---	Body Positions	Each Meas. Plane
4	LDV	TOWR,TOWXR, TUNR,TUNXR	DATA/B	TEMP	RMag RMag	Fringe Calc. Each Optical Setup Component Dir. Parameter Table Run-Time Log Each Data Sequence Traverse Pos. Test Log	Each Optical Setup Each Meas. Plane Each Data Sequence Each Data Sequence Each Work Shift
5	LDV	REFINR,REMOTR	REF/B	TEMP	---	Bad Meas. Tally	Each Data Sequence
--- REFINEMENT PHASE ---							
--- DATA EDITING PHASE ---							
6	LDV	FILERI,FILERM, FILECI,FILECH	REF/B	TEMP	LDV CID	COPY COPY ".WRF" File PRINT ".WRF" File	RMag Paper
7	LDV	RCOMP	REF/B	TEMP	LDV LAB CID	COPY COPY ".RAD" File PRINT ".RAD" File	RMag Paper
8	LDV	NORHLZ	REF/B	TEMP	LDV LAB CID	COPY COPY ".NRM" File PRINT ".NRM" File	RMag Paper
9	LDV	TABLE	REF/B	TEMP	LDV LAB CID	COPY COPY ".PLT" File PRINT ".PLT" File	RMag Paper
10	LAB	FTERM	LAB/B	---	HDL	STORE ".PLT" File	Disk
--- DATA PLOTTING PHASE ---							
11	HDL	SCATR1,SCATR2	---	---	HDL	HARDCOPY Graphs	Paper
	HDL	BGRAFT1,BGRAF2	---	---	HDL	SAVE "ERLDV.DAT"	Disk
	HDL	ERROR2	---	---			
12	HDL	XARRO?,RARRO?	---	---	HDL	HARDCOPY Graphs	Paper
	HDL	XCONTI?,RCONTI?	---	---	HDL	EDIT ".FNL" File	Disk
13	LAB	FTERM	LAB/B	---	LAB LAB CID	STORE ".FNL" File COPY ".FNL" File PRINT ".FNL" File	LAB/B RMag Paper

Table 9: Summary Chart for Data Analysis Steps.

storage all contribute to experimental results that are efficiently produced, safely stored, and accurate.

Refinement phase steps search through each individual velocity measurement and eliminate apparently erroneous ones. The corrected mean velocities are stored on magnetic tape along with the uncorrected values.

Data editing phase steps first create ASCII computer files that contain a table of corrected velocity means and standard deviations. Then software programs and file editors modify the form of the mean velocity tables so that they match the form expected by the data plotting software programs. In this process some duplicate data points are eliminated while other valid data points are duplicated to properly fill out the table. Several versions of the mean velocity table (at various points in the editing phase) are safely stored on magnetic tape.

Data plotting phase steps use software built around DISPLA graphics routines available on many VAX (and other) computer systems. Some data plots may suggest more mean velocity table editing. After this is done the data plots and mean velocity table can be finalized.

Laser Doppler Velocimetry (LDV) experiments typically take a large amount of velocity data that must be carefully distilled to produce useful and comprehensible results. This is especially true of the three component mean velocity measurement systems currently available for the towing tanks and wind tunnels of DTNSRDC.

It is hoped that many DTNSRDC personnel will utilize the LDV technique on a variety of experiments. Standard, documented procedures and computer software are then an important way to reduce the cost and complexity of these experiments. Standard procedures on data storage have further value by insuring completeness and the ability for any researcher to easily access experimental results at a later date.

Three component LDV experience to date has only been on towing Carriage No. 2 (Figure 1) and the Anechoic Flow Facility wind tunnel



(Figure 2). However, the procedures described should apply directly or with some modification to any facility installation of the three component LDV system.

001 002 003 004 005 006 007 008 009 010 011 012 013 014 015 016 017 018 019 020 021 022 023 024 025 026 027 028 029 030 031 032 033 034 035 036 037 038 039 040 041 042 043 044 045 046 047 048 049 050 051 052 053 054 055 056 057 058 059 060 061 062 063 064 065 066 067 068 069 070 071 072 073 074 075 076 077 078 079 080 081 082 083 084 085 086 087 088 089 090 091 092 093 094 095 096 097 098 099 100

#### ACKNOWLEDGMENTS

The author wishes to thank the other members of a team that implemented and debugged the DTNSRDC's three component LDV systems. They are Mr. Steve McGuigan (Code 1521), Mr. Dennis Mullinix (Code 1521), Ms. Toby Nagle (1522), and Mr. Kenneth Remmers (Code 1522). Some long experimental hours and contract procedures came before any displayed measurements.

The engineers of TSI Inc. (St. Paul, Minn.) also deserve acknowledgment for the careful construction and support given to the LDV equipment and basic software (provided under contract to DTNSRDC). They include Mr. Richard Chlebecek, Ms. Karen Dahlerup, and Mr. Ralph Kiland.

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APPENDIX A  
DATA ANALYSIS BLANK FORMS

1. Position Correction Polynomial Form
2. Traverse Bending Correction Forms
3. Body Positions Calculation Form
4. Fringe Spacing Calculation Forms
5. Component Direction Error Form
6. Run-Time Logs
7. Daily Test Log
8. Bad Measurement Tally Form

**POSITION CORRECTION POLYNOMIAL**

"BEND1.FOR"

DATE

SUBJECT **EXPERIMENT:**

**Tow SPEED:**

**"Z" PLANE:**

SHEET NO. OF SHEETS

LINE NO.	Run #	Condition (S/T)*	Side to Side Angle		Front to Back Angle		X <sub>E</sub>	Y <sub>E</sub>	Z <sub>E</sub>
			θ <sub>SS</sub> ' (Deg)	θ <sub>SS</sub> (Deg)	θ <sub>FB</sub> ' (Deg)	θ <sub>FB</sub> (Deg)	Vertical (in)	N-S (in)	E-W (in)
1									
2									
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100									

Y - θ<sub>SS</sub>    θ<sub>SS</sub>'    · Y<sup>3</sup> +    · Y<sup>2</sup> +    · Y +    Radians  
 Z - θ<sub>FB</sub>    θ<sub>FB</sub>'    · Z<sup>3</sup> +    · Z<sup>2</sup> +    · Z +    Radians

\* S: Static Instrument Zero @ Balance Point<sup>\*\*\*</sup>; T: Measurement under Towed Conditions  
 \*\* Balance Point: θ<sub>FB</sub> = θ<sub>SS</sub> = 0° @ X<sub>E</sub> = Z<sub>E</sub> = 0 & Y<sub>E</sub> = 4.0'  
 \*\*\* θ<sub>FB</sub> & θ<sub>SS</sub> are introduced accelerometer (angle) readouts

# X-Y TRAVERSE BENDING ERROR

SUBJECT **EXPERIMENT:**

$SY = SY' - SY'(\theta_{SS} = 0); \delta X'' = \delta X' - 286 \sin \theta_{SS}'; \delta X = \delta X'' - \delta X''(\theta_{SS} = 0);$

SHEET NO. \_\_\_\_\_ OF \_\_\_\_\_ SHEETS

LINE NO.	COL. A $X_E$ Absolute Encoder Value (in)	COL. B $Y_E$ Absolute Encoder Value (in)	COL. C	COL. D $\theta_{SS}'$ Optics Platform Angle (Deg)	COL. E $\delta X'$ $X_E - X_{strat}$ (in)	COL. F $\delta X''$ $\delta X' - 286 \sin \theta_{SS}'$ (in)	COL. G $\delta Y'$ $Y_E - Y_{strat}$ (in)	COL. H $\theta_{SS}$ Zeroed Platform Angle ( $10^{-3}$ Rad.)	COL. I $\delta X$ Zeroed & Computed Error (in)	COL. J $\delta Y$ Zeroed & Computed Error (in)
3										
4										
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BENDZY BEND3

→	$X_c =$	in	Vertical Separation of Meas. Point and Idealized Trav. Bending Pt.
	$Y_0 =$	7.91 in	$Y_E$ Value when Meas Point is on X Traverse Vertical Axis
	$Z_0 =$	0.0 in	$Z_E$ Value when " " " " " " " "
→	$K_{SS} =$		Angle Correction Factor
	$K_{FB} =$		Angle Correction Factor

# X-Z TRAVERSE BENDING ERROR

SUBJECT EXPERIMENT:

$\delta X = \delta X' - \delta X'(Z_E = 0")$  ;  $\delta Z = \delta Z' - \delta Z'(Z_E = 0")$

SHEET NO. \_\_\_\_\_ OF \_\_\_\_\_ SHEETS

LINE NO.	$X_E$ Absolute Encoder Value (in)	$Z_E$ Absolute Encoder Value (in)	$\theta_{FB}$ Optics Platform Angle (Deg)	$\delta X'$ $X_E - X_{strut}$ (in)	$\delta Z'$ $Z_E - Z_{strut}$ (in)	$\theta_{FB}$ Zeroed Platform Angle (10 <sup>-3</sup> Rad)	$\delta X$ Zeroed & Computed Error (in)	$\delta Z$ Zeroed & Computed Error (in)
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BENDZ FOR

$X_0 =$  \_\_\_\_\_ in Vertical Separation of Meas Point and Idealized Trav Bending Point

$Y_0 =$   $\frac{1}{2}$  7.91 in  $Y_E$  value when Meas Point is on X Traverse Vertical Axis

$Z_0 =$  0.0 in  $Z_E$  value when Meas. Point is on X Traverse Vertical Axis

$K_{\theta} =$  \_\_\_\_\_ Angle Correction Constant

$K_{FB} =$  \_\_\_\_\_ Angle Correction Constant (BENDZ)      ②  $K_{FB} = \frac{16.2}{10^3} / \theta_{FB} \cdot X_0 =$

# BODY POSITION CALCULATIONS

DATE

SUBJECT **EXPERIMENT:**

**"Z" PLANE:**

SHEET NO. OF SHEETS

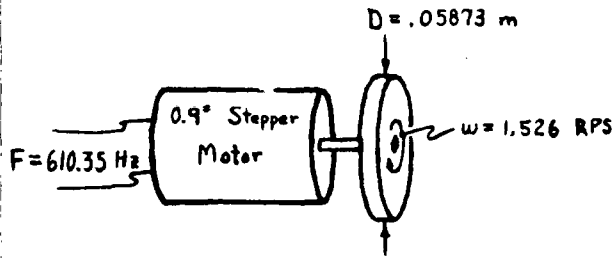
LINE NO.	X <sub>E</sub> Absolute Encoder Value	Y <sub>E</sub> Absolute Encoder Value	Z <sub>E</sub> Absolute Encoder Value	COMMENTS:
1	(inches)	(inches)	(inches)	
2				
3				
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EXPERIMENT:

OPTICAL SETUP:

RECORDED BY:

STREAMWISE FRINGE SPACING, "S<sub>v</sub>"



$V = \pi D \omega = .2815 \text{ m/s}$

AFF <sub>18</sub> S <sub>v</sub>	≈ 5.5	μm
AFF <sub>12</sub> S <sub>v</sub>	≈ 4.4	μm
TT S <sub>v</sub>	≈ 1.7	μm
FOP S <sub>v</sub>	≈	μm

Date / Time	Indepen? (Y/N)	Wheel Measurements			Wheel Speed, V (m/s)	Fringe Spacing S <sub>v</sub> = V/f (μm)
		Pts. (No.)	Mean, f (MHz)	Std. Dev. (MHz)		
					.2815 m/s	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	

$$\sum_{i=1}^n S_{v,i} = \quad \quad \quad \sum_{i=1}^n S_{v,i}^2 =$$

$$\text{Mean of } S_v = \sum_{i=1}^n S_{v,i} / n =$$

$$\text{Std. Dev. of Mean } S_v = \left\{ \left[ \sum_{i=1}^n S_{v,i}^2 - \left( \sum_{i=1}^n S_{v,i} \cdot \sum_{i=1}^n S_{v,i} \right) / n \right] / (n-1) \right\} =$$



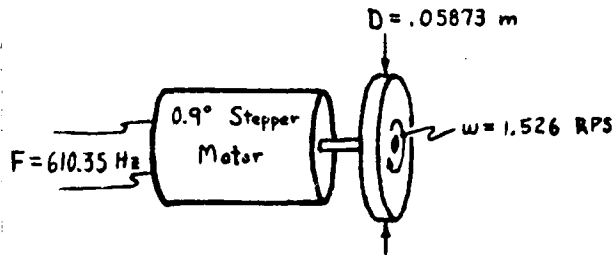
EXPERIMENT:

OPTICAL SETUP:

RECORDED BY:

VERTICAL FRINGE SPACING, "S."

AFF <sub>18</sub>	S <sub>v</sub> =	5.2	μm
AFF <sub>12</sub>	S <sub>v</sub> =	4.2	μm
TT	S <sub>v</sub> =	4.7	μm
FOP	S <sub>v</sub> =	4m	



$$V = \pi D \omega = .2815 \text{ m/s}$$

Date / Time	Indepen? (Y/N)	Wheel Measurements			Wheel Speed, V (m/s)	Fringe Spacing S <sub>v</sub> = V/f (μm)
		Pts. (No.)	Mean, f (MHz)	Std. Dev. (MHz)		
					.2815 m/s	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	
					"	

$$\sum_{i=1}^n S_{v_i} = \quad \quad \quad \sum_{i=1}^n S_{v_i}^2 =$$

$$\text{Mean of } S_v = \sum_{i=1}^n S_{v_i} / n =$$

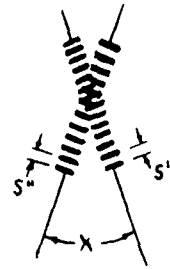
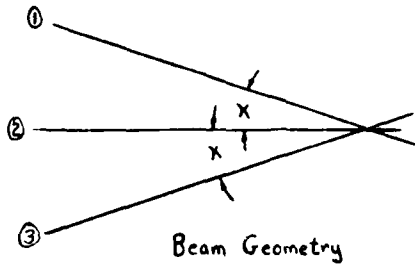
$$\text{Std. Dev. of Mean } S_v = \left\{ \left[ \sum_{i=1}^n S_{v_i}^2 - \left( \sum_{i=1}^n S_{v_i} \cdot \sum_{i=1}^n S_{v_i} / n \right) / (n-1) \right] \right\} =$$

EXPERIMENT:

OPTICAL SETUP:

RECORDED BY:

ON-AXIS FRINGE SPACING,  $S_w$



AFF <sub>11</sub>	$S_w \approx 59 \mu\text{m}$
AFF <sub>12</sub>	$S_w \approx 38 \mu\text{m}$
T.T.	$S_w \approx 30 \mu\text{m}$

$S'$  = Fringe Spacing for Beams 1 & 3 ( $S_w$  for TT)  
 $S''$  = Fringe Spacing for Beams 2 & 3 ( $S_w$  for AFF)

Formulas:

—  $\frac{x}{2} = \frac{1}{2} \sin^{-1}(\lambda_0 / 2S')$   
 $= \sin^{-1}(\lambda_0 / 2S'')$

—  $S'' = \lambda_0 / 2 \sin \frac{x}{2}$

—  $S_w = S' / 2 \sin \frac{x}{2} = S''^2 / \lambda_0$

—  $\lambda_0 = .5145 \mu\text{m} / n$

where  $n$  is the media's index of refraction

Air:  
 $n = 1$

Water

$n = 1.3335$  (19°C)

$n = 1.3330$  (20°C)

$n = 1.3322$  (26°C)

$S'$ ( $\mu\text{m}$ )	$S''$ ( $\mu\text{m}$ )	$S_w$ ( $\mu\text{m}$ )

Mean  $S_w$  =

Std. Dev.  $S_w$  =

EXPERIMENT:

RECORDED BY:

### COMPONENT DIRECTION ERROR

$$U_c \cos \theta = A_u U_r + B_u^c$$

$$U_c \sin \theta = V_r + A_v U + B_v^c$$

$$0 = W_r + A_w U + B_w^c$$

Corrections Used	Free Stream Reference File	Reason for Change	Files Corrected
$U = ( \quad ) U_r$ $V = V_r + ( \quad ) U$ $W = W_r + ( \quad ) U$			
$U = ( \quad ) \cdot U_r$ $V = V_r + ( \quad ) \cdot U$ $W = W_r + ( \quad ) \cdot U$			
$U = ( \quad ) \cdot U_r$ $V = V_r + ( \quad ) \cdot U$ $W = W_r + ( \quad ) \cdot U$			
$U = ( \quad ) \cdot U_r$ $V = V_r + ( \quad ) \cdot U$ $W = W_r + ( \quad ) \cdot U$			
$U = ( \quad ) \cdot U_r$ $V = V_r + ( \quad ) \cdot U$ $W = W_r + ( \quad ) \cdot U$			



DATA CALCULATIONS  
NDM GEN-5900

WIND TUNNEL "RUN-TIME" LOG


LINE NO.	FILE	Z Pos. mm	Radius mm	Angles (°)	Pilot Pres. Pa	T <sub>amb</sub> °F	T <sub>oew</sub> °F	PATH in H <sub>2</sub>	V <sub>TUNNEL</sub> m/s	SHEET NO. OF SHEETS		
										COL. I	COL. J	COL. K
1										Comments	Time/Date	
2												
3												
4												
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19												
20												
21												

RECORDED BY

CALCULATED BY

CHECKED BY

GPO 887-028


 22 21 18 SHEETS 3 SQUARE  
 22 21 18 SHEETS 3 SQUARE  
 22 21 18 SHEETS 3 SQUARE

# "DAILY" DATA LOG

## Data Taken

DATE	DATA SET	START TIME	DESCRIPTION	Model Configuration			Velocity Corrections			
				Model Prop (s)	Tau Speed	Moat Gages Bow Stern	Streamwise "U"	Vertical "V"	On-Axis "W"	



APPENDIX B  
CYLINDRICAL VELOCITY COMPONENT SIGN CONVENTION



CONVENTIONS FOR LDV  
COORDINATES AND VELOCITY COMPONENTS

-X - Y - Z COORDINATES

Coord./Vel.	Name	Positive Direction	Examples
"X" / "V"	Vertical	Ship Model "Up"	Carriage #2: Up AFF Submarine: Down
"Y" / "W"	On-Axis	Ship Model "Port"	Carriage #2: South AFF Submarine: South
"Z" / "U"	Streamwise	Model "Downstream"	Carriage #2: East AFF Submarine: West

-R -  $\theta$  - Z COORDINATES

Coord./Vel.	Name	Positive Direction	Examples
"R" / "V" <sub>r</sub>	Radial	Increasing Radius	$\theta = 0^\circ$ +R is Up $\theta = 180^\circ$ +R is Down
" $\theta$ " / "V" <sub>t</sub>	Tangential	Counter-Clockwise (facing forward)	$\theta = 270^\circ$ +V <sub>t</sub> is Up $\theta = 90^\circ$ +V <sub>t</sub> is Down
"Z" / "V" <sub>s</sub>	Streamwise	Model "Downstream"	Carriage #2: East AFF Submarine: West

- CONVERSIONS BETWEEN SYSTEMS

$$Z = Z$$

$$R = X \cos(\theta) + Y \sin(\theta)$$

$$\begin{aligned} \theta &= \tan^{-1}(Y/X) && \text{for } X > 0; Y > 0 \\ &= \tan^{-1}(Y/X) + 180^\circ && \text{for } X < 0 \\ &= \tan^{-1}(Y/X) + 360^\circ && \text{for } X > 0; Y < 0 \end{aligned}$$

$$V_s = U$$

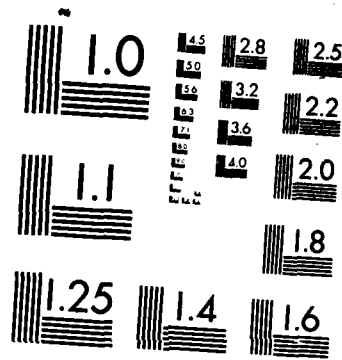
$$V_r = W \sin(\theta) + V \cos(\theta)$$

$$V_t = W \cos(\theta) - V \sin(\theta)$$

APPENDIX C  
EXAMPLE VELOCITY DATA PLOTS

1. Cartesian Arrows: XARRO1, XARRO2
2. Cartesian Contours: XCONT1, XCONT2
3. Cylindrical Arrows: RARRO1, RARRO2, RARRO3, RARRO4,  
RARRO5
4. Cylindrical Contours: RCONT1, RCONT2, RCONT3, RCONT4,  
RCONT5





MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

Main Program Name: XARRO1

Subroutines: XKEY1, SHIP, SURFAC

Computer System: HDL VAX 11-780

Compile Commands: \$FOR XARRO1

\$FOR XKEY1

\$FOR SHIP

\$FOR SURFAC

Linking Command: \$LINK XARRO1,XKEY1,SHIP,SURFAC,DISSPLA/LIB,GH/LIB

Program Input Files: XWAKE.DAT; BODY.DAT; SURF.DAT

Execute Command: \$RUN XARRO1

Example:

Data Files Used: DSSD.FNL; BODYPT.DAT; SURFEL.DAT

Keyboard\* Input:

-20.,6.433; 5.,-20.,5; -.6,36.; 5.,0.,5; -1; 1; .1; 1

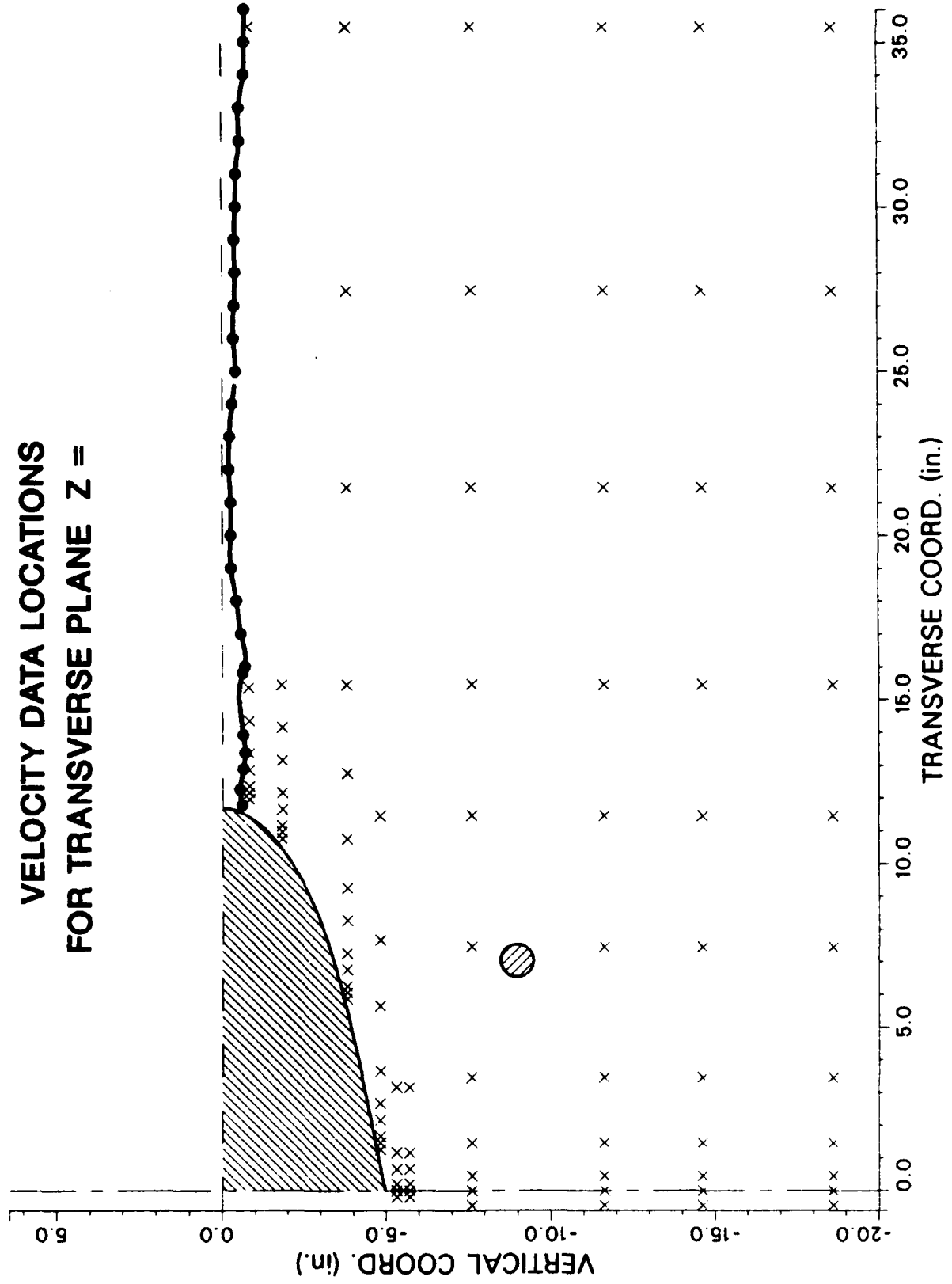
AND

-20.,6.433; 5.,-20.,5; -.6,36.; 5.,0.,5; -1; 0; 2.; .1; 1

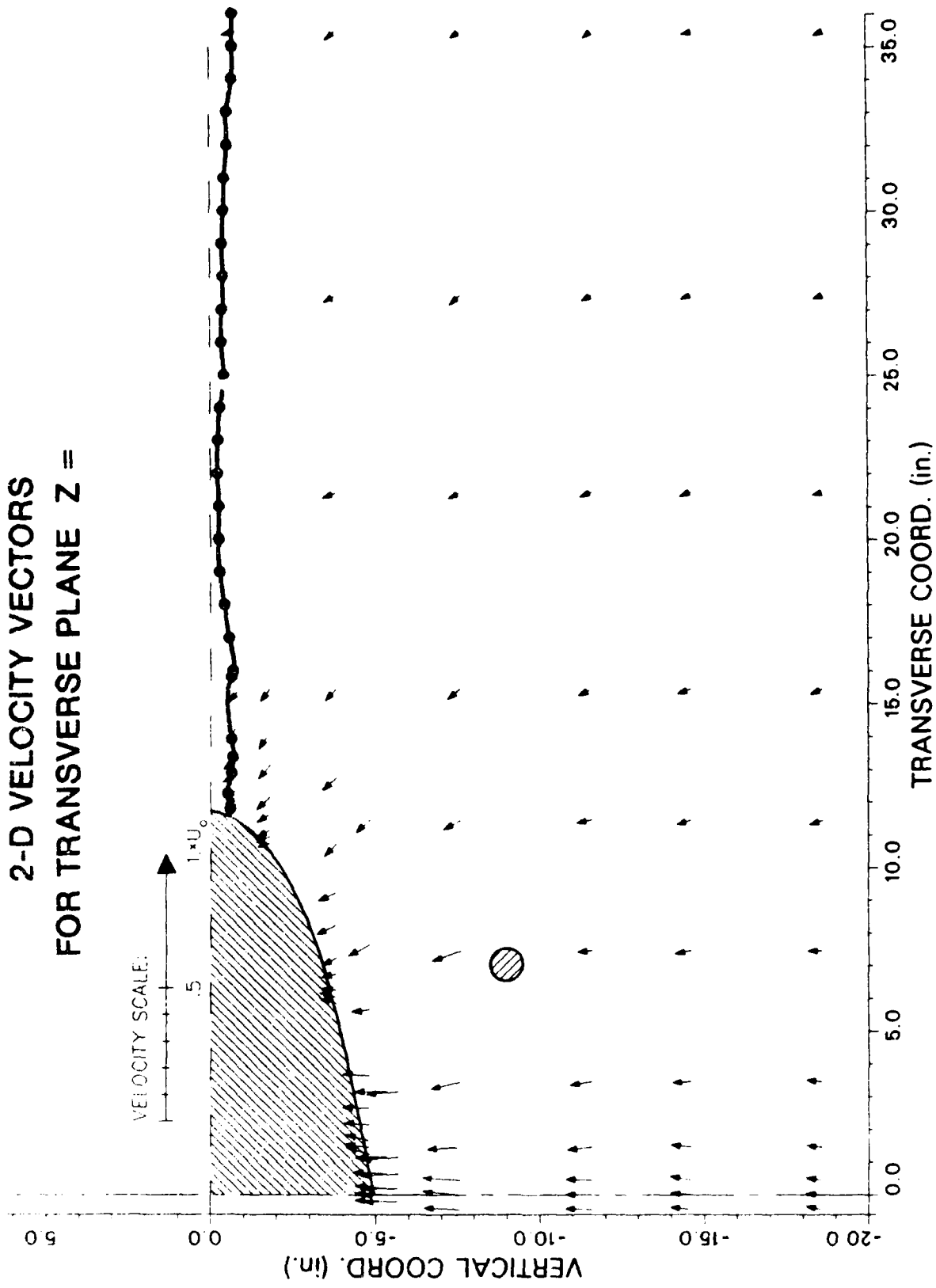
---

\* ";" separates different keyboard inputs; "\$" HDL command prompt;

VELOCITY DATA LOCATIONS  
FOR TRANSVERSE PLANE Z =



2-D VELOCITY VECTORS  
FOR TRANSVERSE PLANE Z =



Main Program Name: XARRO2

Subroutines: XKEY2, SHIP, SURFAC

Computer System: HDL VAX 11-780

Compile Commands: \$FOR XARRO2

\$FOR XKEY2

\$FOR SHIP

\$FOR SURFAC

Linking Command: \$LINK XARRO2,XKEY2,SHIP,SURFAC,DISSPLA/LIB,GH/LIB

Program Input Files: XWAKE.DAT; BODY.DAT; SURF.DAT

Execute Command: \$RUN XARRO2

Example:

Data Files Used: DSSD.FNL; BODYPT.DAT; SURFEL.DAT

Keyboard\* Input:

-20.,2.985; 5.,-20.,5; -0.6,16.; 5.,0.,5; -1; 1; .1; 1;

AND

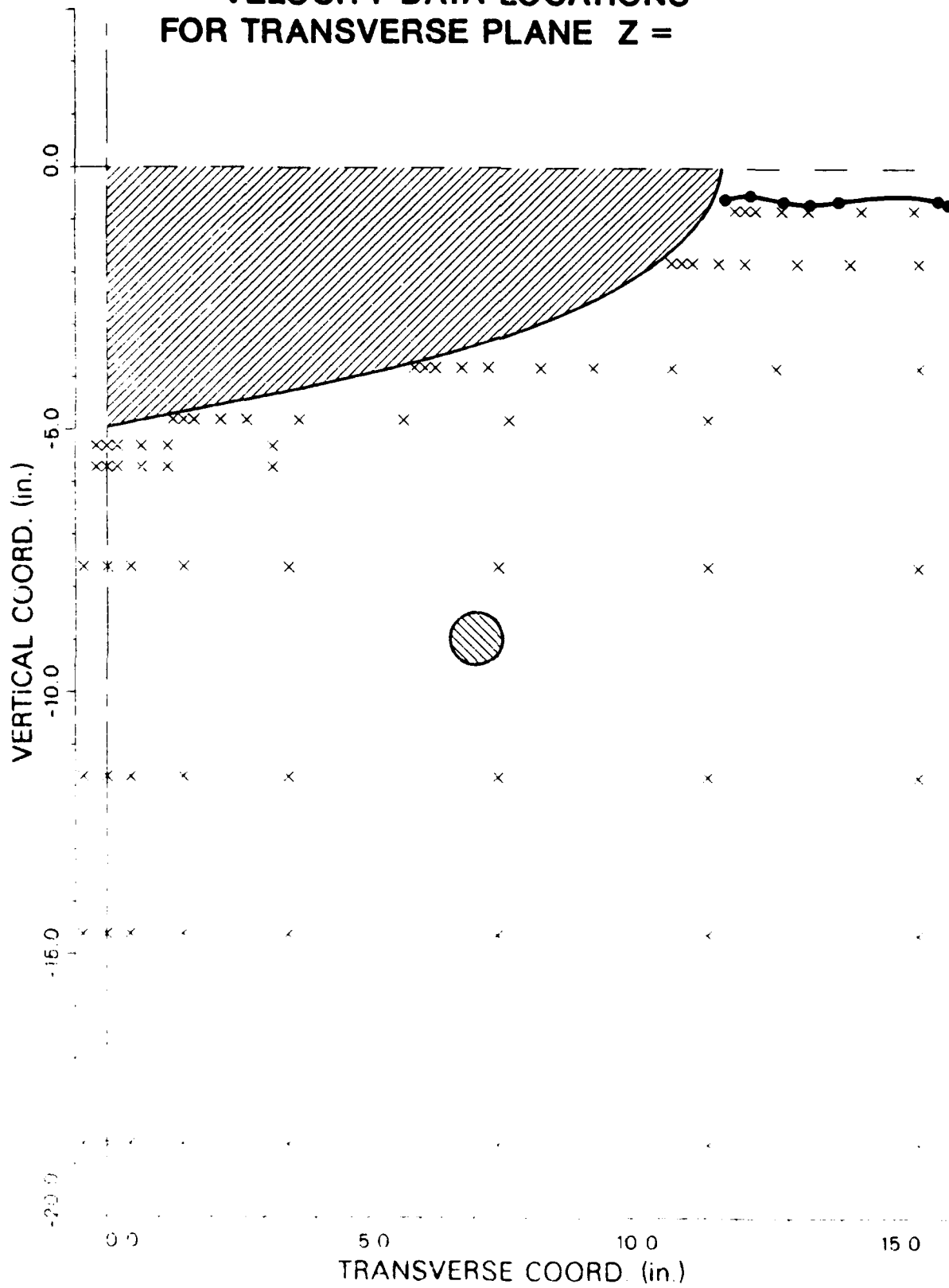
-20.,2.985; 5.,-20.,5; -0.6,16.; 5.,0.,5; -1; 0; 2.; .1; 1;

---

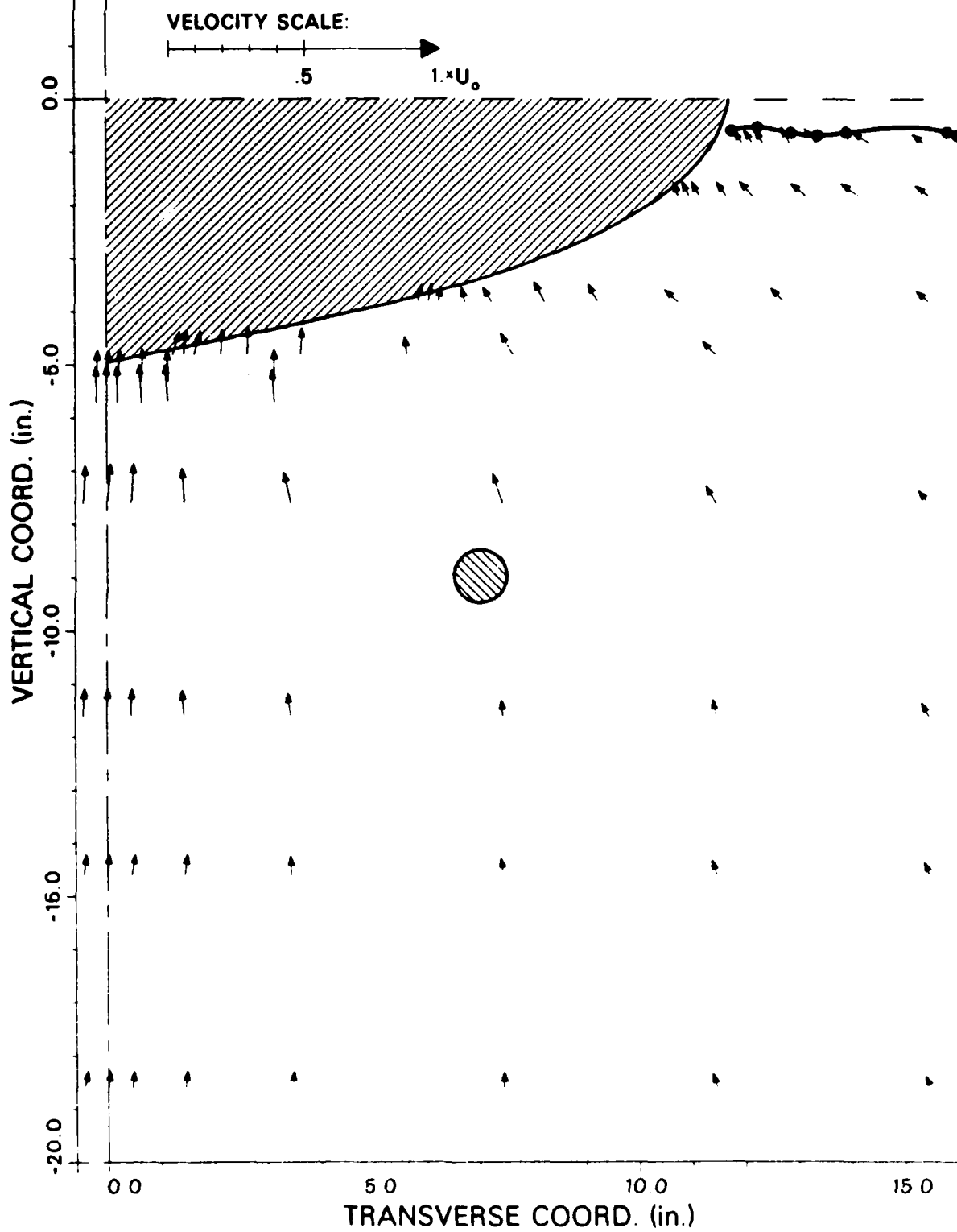
\* ";" separates different keyboard inputs; "\$" HDL command prompt;



# VELOCITY DATA LOCATIONS FOR TRANSVERSE PLANE Z =



# 2-D VELOCITY VECTORS FOR TRANSVERSE PLANE Z =



Main Program Name: XCONT1

Subroutines: XTRACE, XYZPT, SHIP, SURFAC

Computer System: HDL VAX 11-780

Compile Commands: \$FOR XCONT1

\$FOR XTRACE

\$FOR XYZPT

\$FOR SHIP

\$FOR SURFAC

Linking Command:

\$LINK XCONT1,XTRACE,XYZPT,SHIP,SURFAC,DISSPLA/LIB,GH/LIB

Program Input Files: XWAKE.DAT; BODY.DAT; SURF.DAT

Execute Command: \$RUN XCONT1

Example:

Data Files Used: DSSD.FNL; BODYPT.DAT; SURFEL.DAT

Keyboard\* Input:

-20.,6.433; 5.,-20.,5; -.6,36.; 5.,0.,5; -1; 3; 1; 0; .5; .05; 1; 1

;

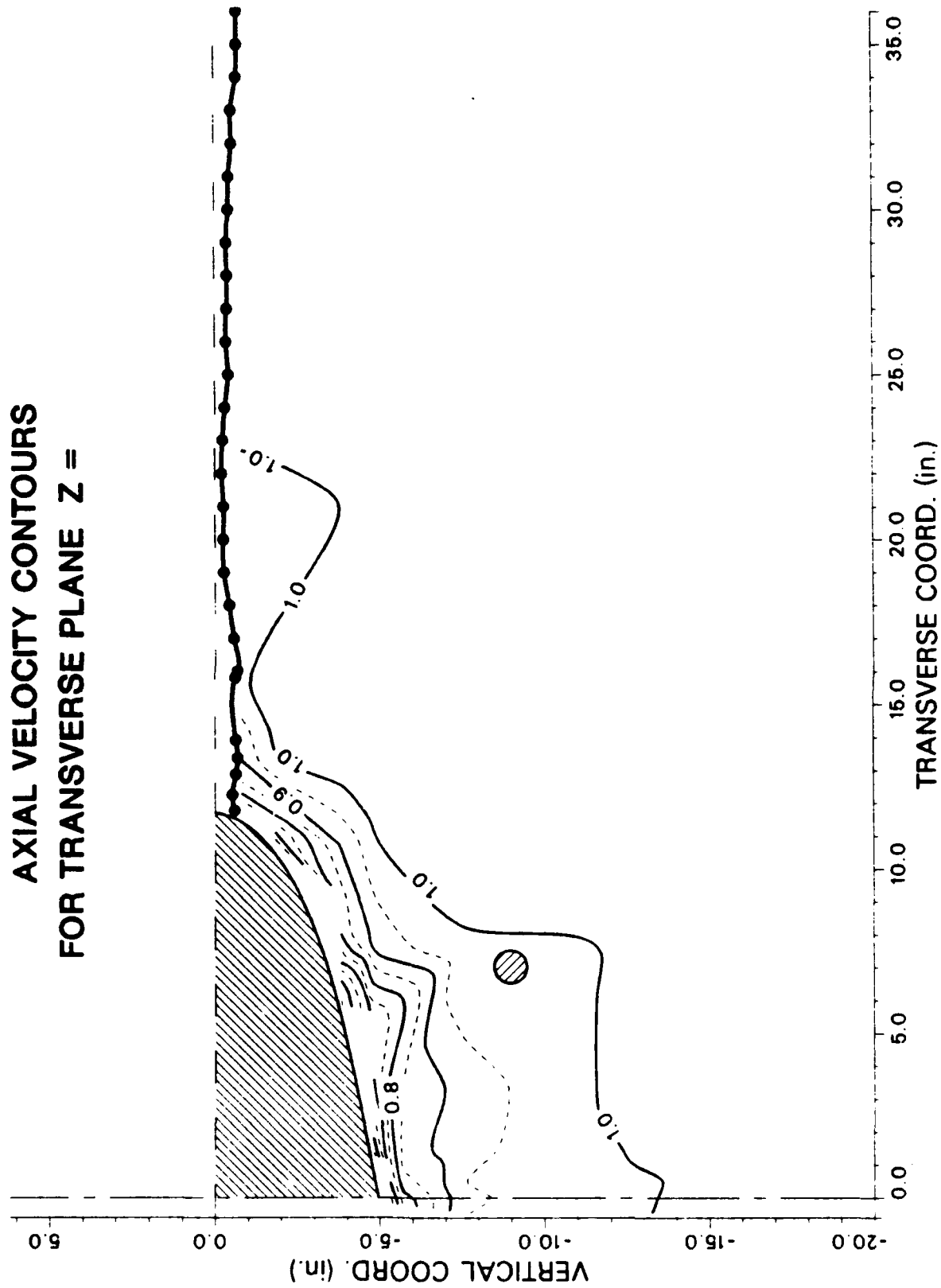
AND

-20.,6.433; 5.,-20.,5; -.6,36.; 5.,0.,5; -1; 3; 1; 0; 0.; 0.5; 0; 1

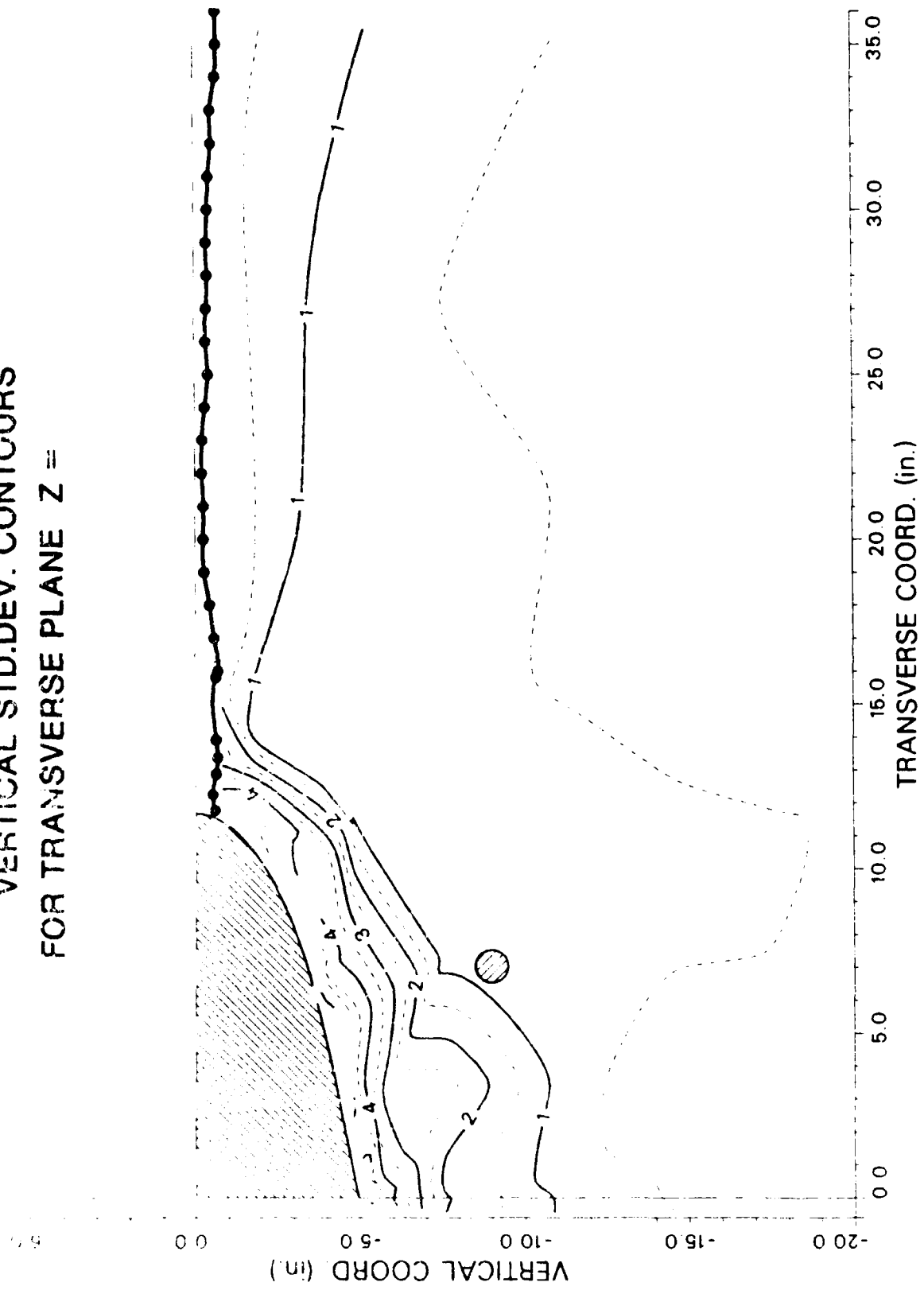
:

-----  
\* ";" separates different keyboard inputs; "\$" HDL command  
prompt;

AXIAL VELOCITY CONTOURS  
FOR TRANSVERSE PLANE Z =



VERTICAL STD.DEV. CONTOURS  
FOR TRANSVERSE PLANE Z =



Main Program Name: XCONT2

Subroutines: XTRACE, XYZPT, SHIP, SURFAC

Computer System: HDL VAX 11-780

Compile Commands: \$FOR XCONT2

\$FOR XTRACE

\$FOR XYZPT

\$FOR SHIP

\$FOR SURFAC

Linking Command:

\$LINK XCONT2,XTRACE,XYZPT,SHIP,SURFAC,DISSPLA/LIB,GH/LIB

Program Input Files: XWAKE.DAT; BODY.DAT; SURF.DAT

Execute Command: \$RUN XCONT2

Example:

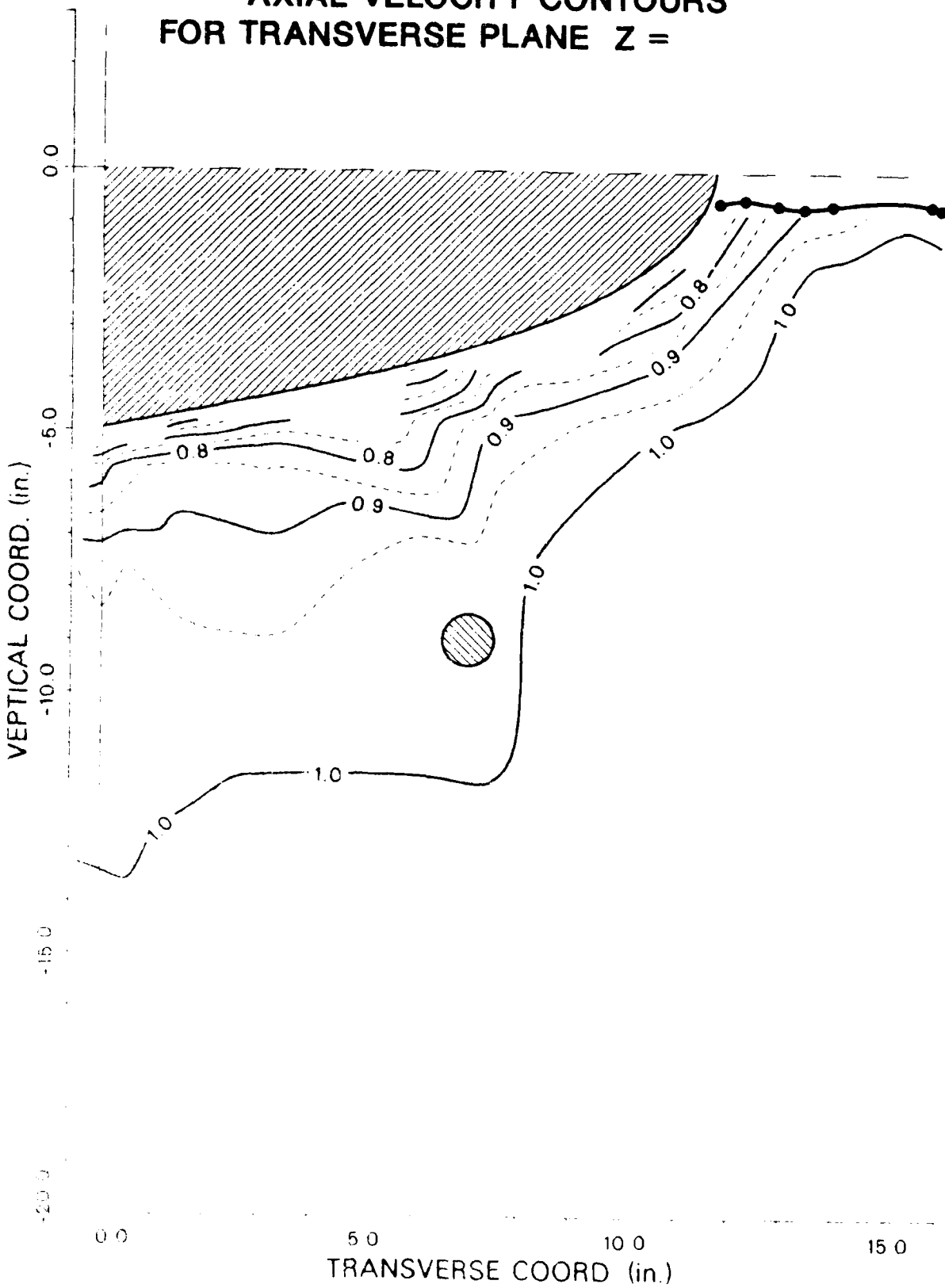
Data Files Used: DSSD.FNL; BODYPT.DAT; SURFEL.DAT

Keyboard\* Input:

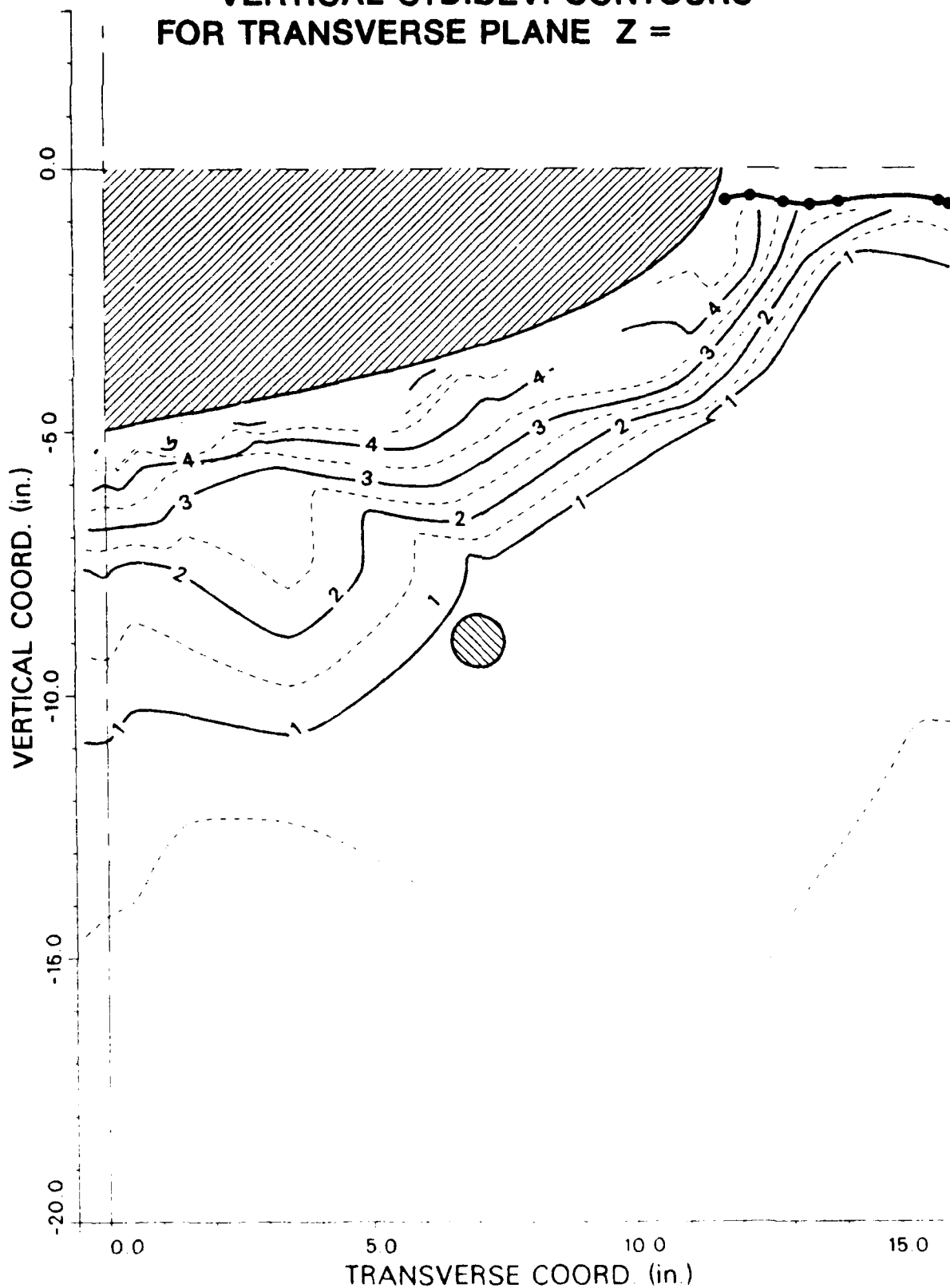
```
-20.,2.985; 5.,-20.,5; -0.6,16.; 5.,0.,5; -1; 3; 1; 0; .5; .05; 1;
1;
AND
-20.,2.985; 5.,-20.,5; -0.6,16.; 5.,0.,5; -1; 3; 2; 0; 0.0; .5; 0;
1;
```

-----  
\* ";" separates different keyboard inputs; "\$" HDL command prompt;

# AXIAL VELOCITY CONTOURS FOR TRANSVERSE PLANE Z =



# VERTICAL STD.DEV. CONTOURS FOR TRANSVERSE PLANE Z =





Main Program Name: RARRO1

Subroutines: RKEY1, RDAT1

Computer System: HDL VAX 11-780

Compile Commands: \$FOR RARRO1

\$FOR RKEY1

\$FOR RDAT1

Linking Command: \$LINK RARRO1,RKEY1,RDAT1,DISSPLA/LIB,GH/LIB

Program Input Files: RWAKE.DAT

Execute Command: \$RUN RARRO1

Example:

Data Files Used: DSP0.FNL;

Keyboard\* Input:

1.0; 5.0; 1; 1; 1; 1;

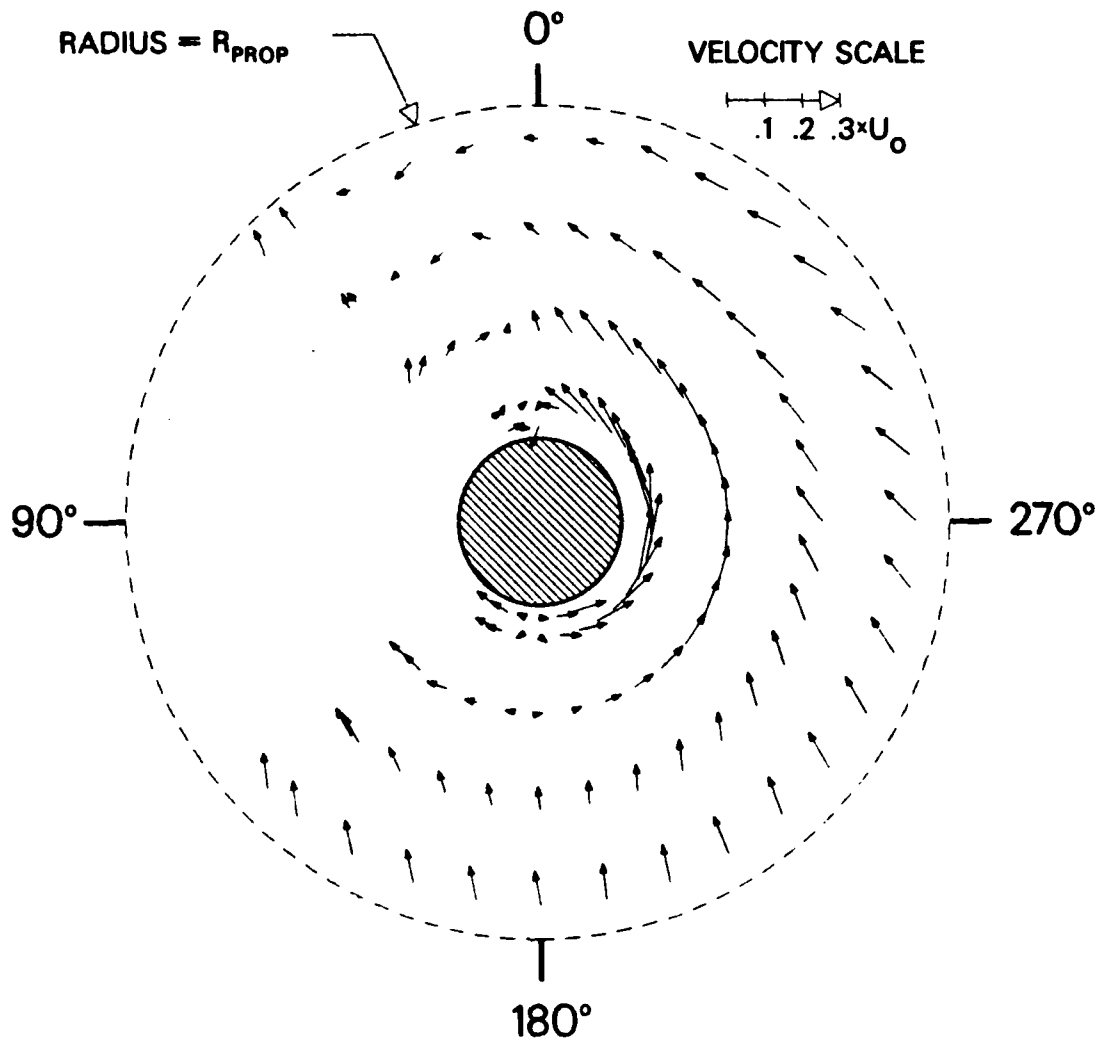
AND

0.1; 1.0; 1; 1; 1; 1;

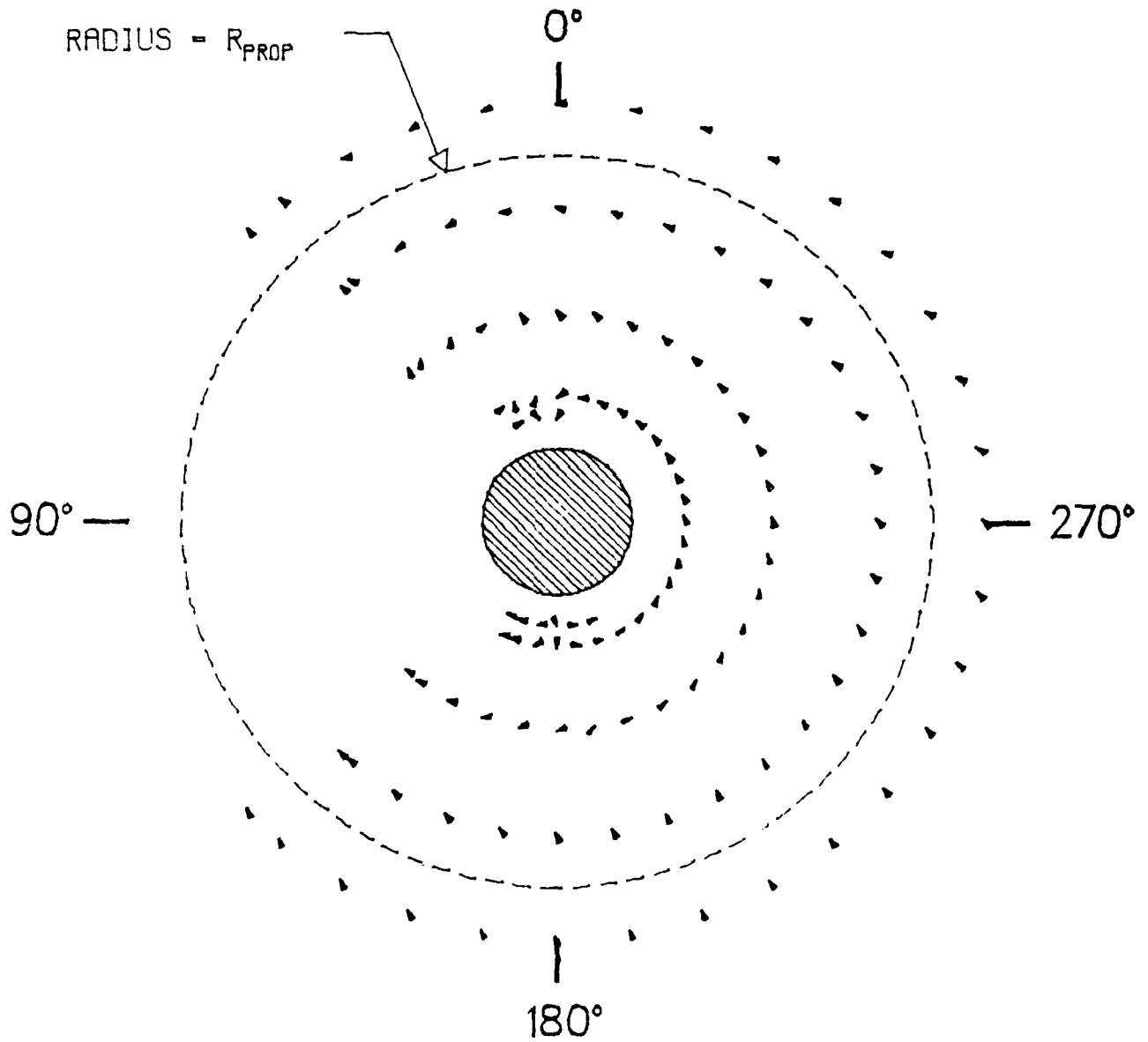
---

\* ";" separates different keyboard inputs; "\$" HDL command prompt;

## 2-D VELOCITY VECTORS IN THE PROPELLER PLANE



# 2-D VELOCITY VECTORS IN THE PROPELLER PLANE



Main Program Name: RARRO2

Subroutines: RKEY2, RDAT1

Computer System: HDL VAX 11-780

Compile Commands: \$FOR RARRO2

\$FOR RKEY2

\$FOR RDAT1

Linking Command: \$LINK RARRO2,RKEY2,RDAT1,DISSPLA/LIB,GH/LIB

Program Input Files: RWAKE.DAT

Execute Command: \$RUN RARRO2

Example:

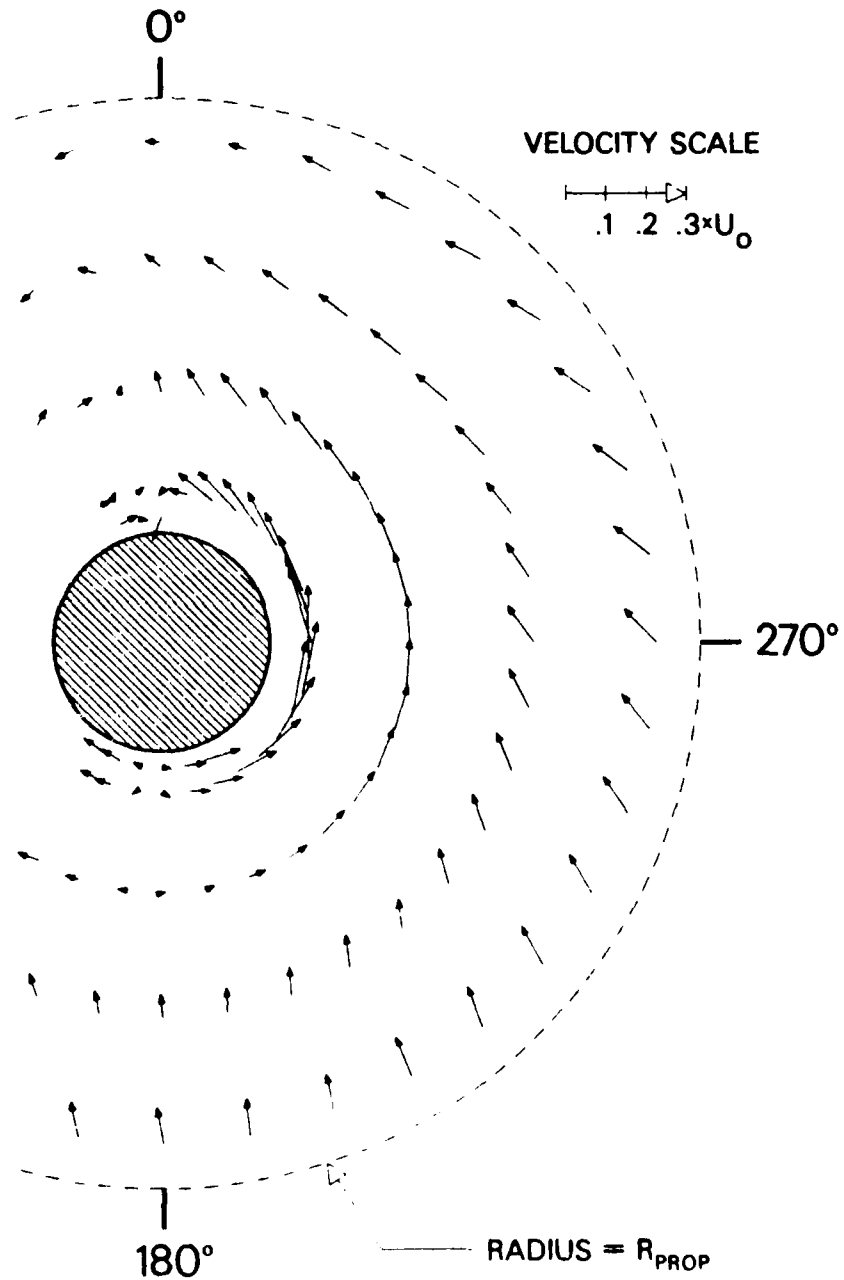
Data Files Used: DSP0.FNL;

Keyboard\* Input:

1.0; 5.0; 1; 1; 1; 1;

-----  
\* ";" separates different keyboard inputs; "\$" HDL command prompt;

# 2-D VELOCITY VECTORS IN THE PROPELLER PLANE



Main Program Name: RARRO3

Subroutines: RKEY3, RDAT1

Computer System: HDL VAX 11-780

Compile Commands: \$FOR RARRO3

\$FOR RKEY3

\$FOR RDAT1

Linking Command: \$LINK RARRO3,RKEY3,RDAT1,DISSPLA/LIB,GH/LIB

Program Input Files: RWAKE.DAT

Execute Command: \$RUN RARRO3

Example:

Data Files Used: DSP0.FNL;

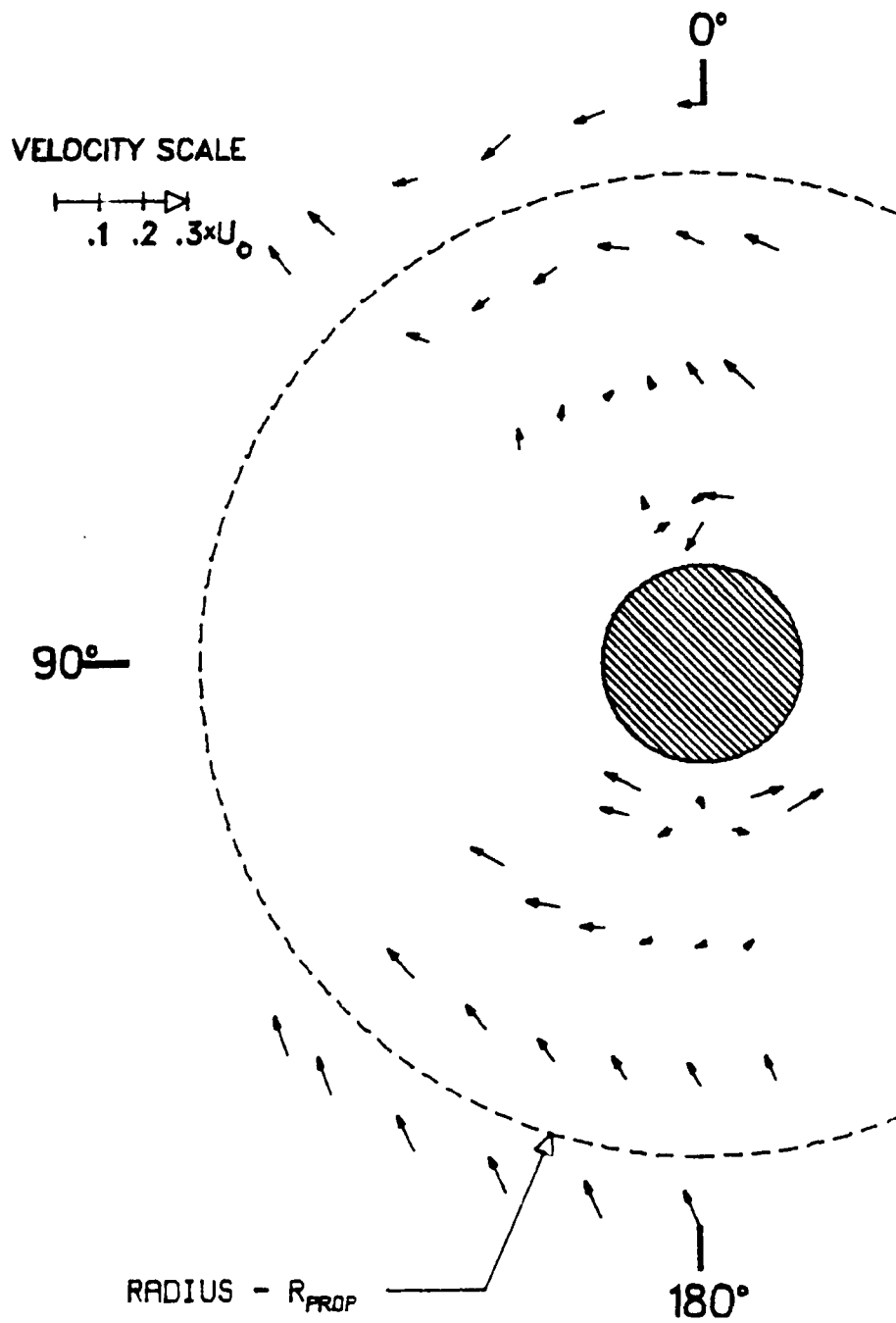
Keyboard\* Input:

1.0; 30.0; 1; 1; 1; 1;

---

\* ";" separates different keyboard inputs; "\$" HDL command prompt;

# 2-D VELOCITY VECTORS IN THE PROPELLER PLANE



Main Program Name: RARRO4

Subroutines: RKEY4, RDAT1

Computer System: HDL VAX 11-780

Compile Commands: \$FOR RARRO4

\$FOR RKEY4

\$FOR RDAT1

Linking Command: \$LINK RARRO4,RKEY4,RDAT1,DISSPLA/LIB,GH/LIB

Program Input Files: RWAKE.DAT

Execute Command: \$RUN RARRO4

Example:

Data Files Used: DSP0.FNL;

Keyboard\* Input:

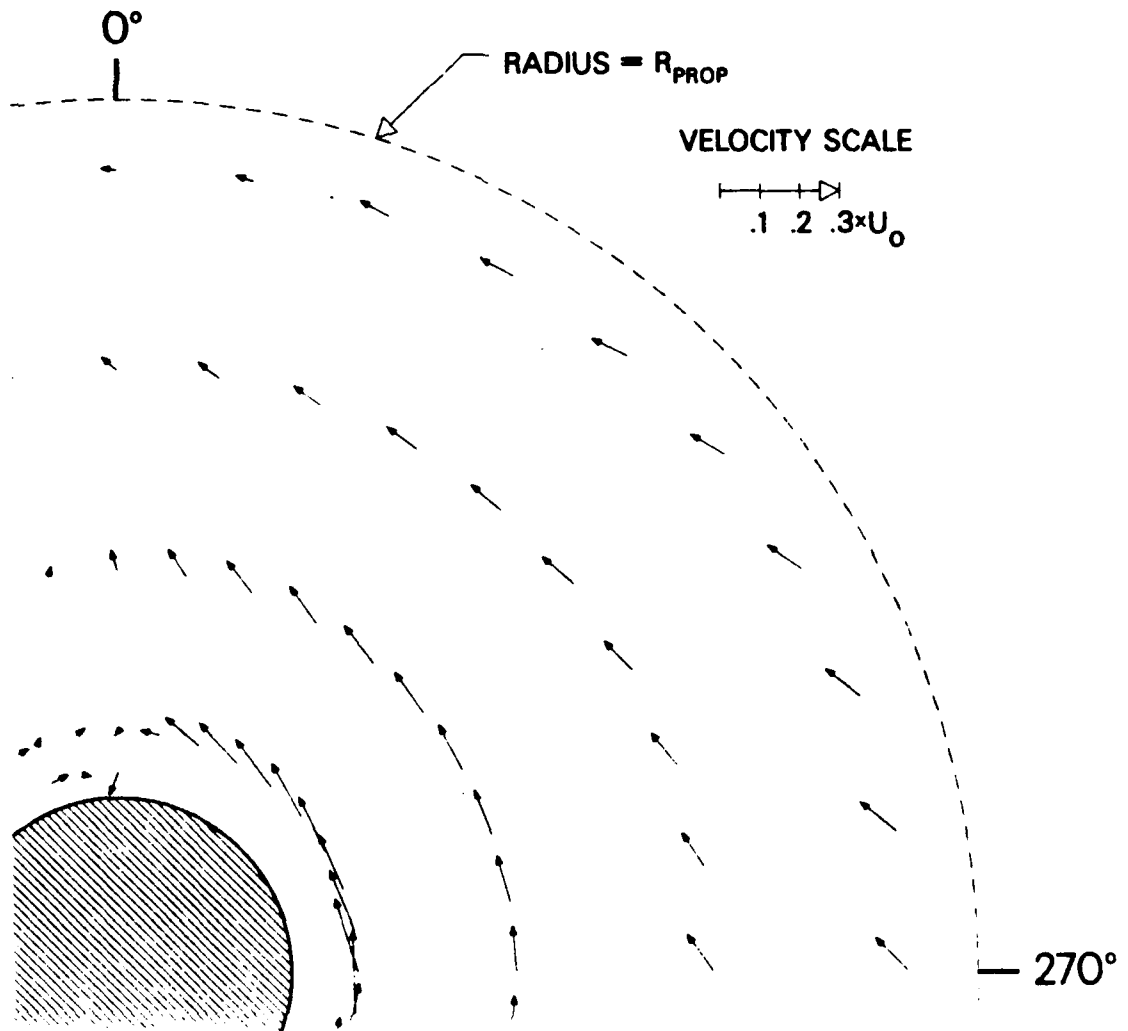
1.0; 5.0; 1; 1; 1; 1;

---

\* ";" separates different keyboard inputs; "\$" HDL command prompt;



## 2-D VELOCITY VECTORS IN THE PROPELLER PLANE



Main Program Name: RARRO5

Subroutines: RKEY5, RDAT1

Computer System: HDL VAX 11-780

Compile Commands: \$FOR RARRO5

\$FOR RKEY5

\$FOR RDAT1

Linking Command: \$LINK RARRO5,RKEY5,RDAT1,DISSPLA/LIB,GH/LIB

Program Input Files: RWAKE.DAT

Execute Command: \$RUN RARRO5

Example:

Data Files Used: DSP0.FNL;

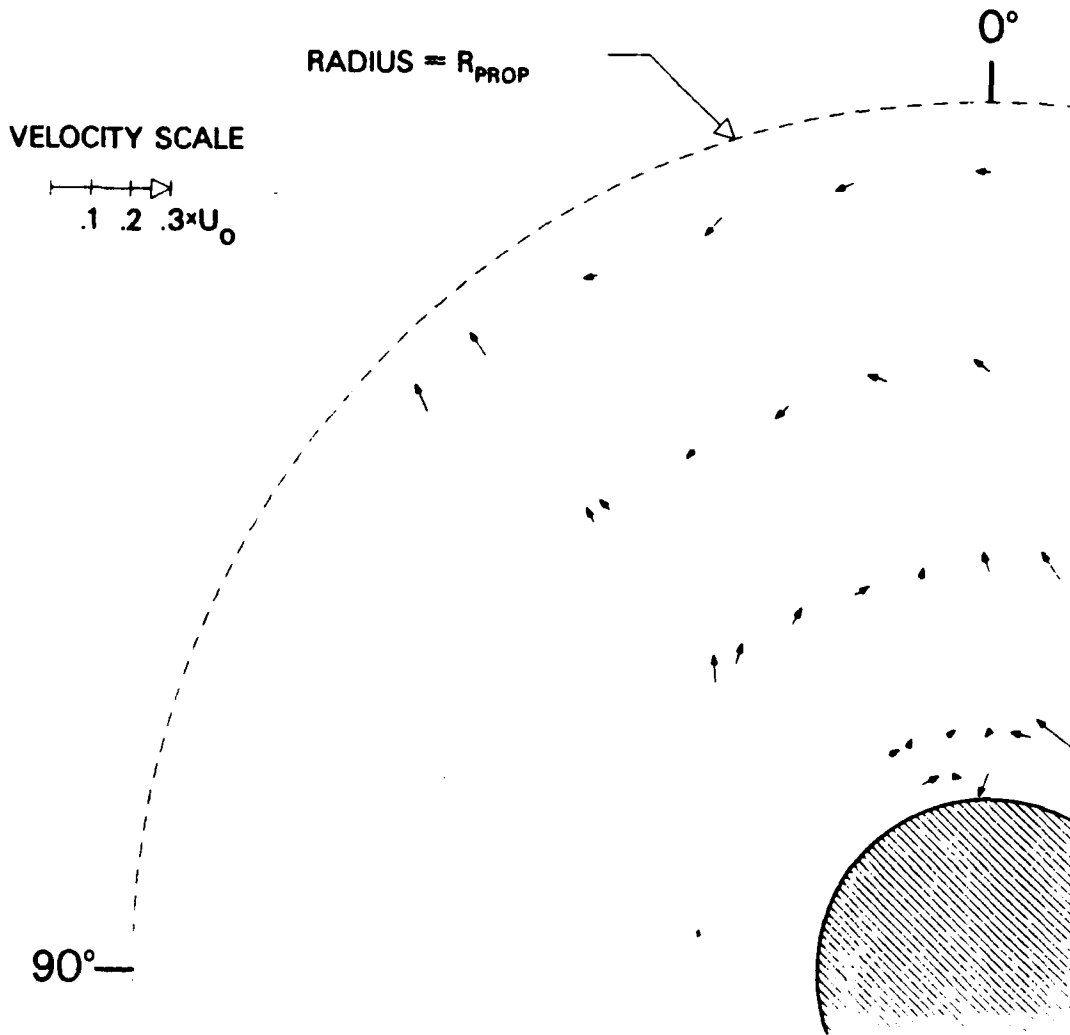
Keyboard\* Input:

1.0; 5.0; 1; 1; 1; 1;

---

\* ";" separates different keyboard inputs; "\$" HDL command prompt;

# 2-D VELOCITY VECTORS IN THE PROPELLER PLANE



Main Program Name: RCONT1

Subroutines: RTRACE,RTZPT

Computer System: HDL VAX 11-780

Compile Commands: \$FOR RCONT1

\$FOR RTRACE

\$FOR RTZPT

Linking Command: \$LINK RCONT1,RTRACE,RTZPT,DISSPLA/LIB,GH/LIB

Program Input Files: RWAKE.DAT

Execute Command: \$RUN RCONT1

Example:

Data Files Used: DSP0.FNL;

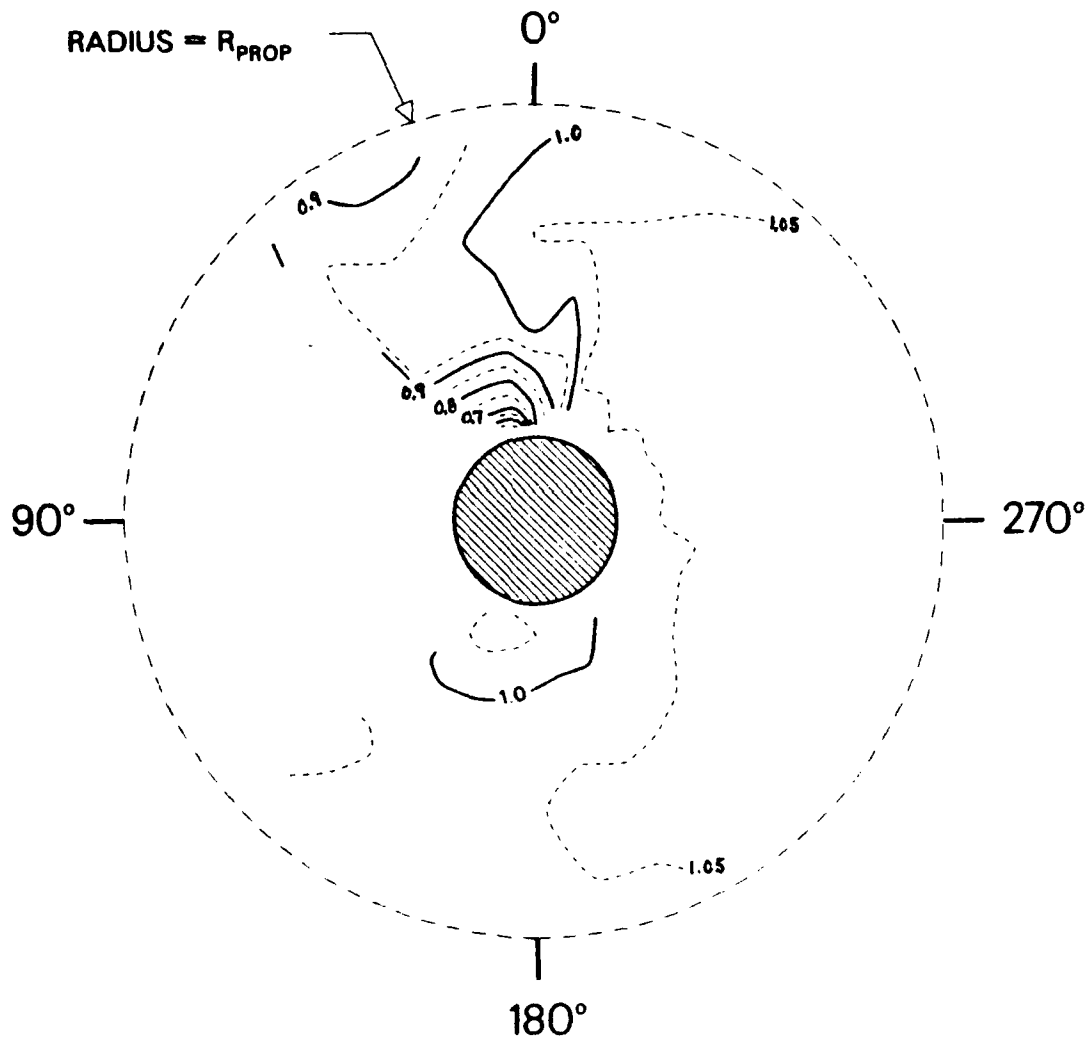
Keyboard\* Input:

0; .5; .05; 1; 03; 1; 1; 1; 1; 1;

---

\* ";" separates different keyboard inputs; "\$" HDL command prompt;

# AXIAL VELOCITY CONTOURS IN THE PROPELLER PLANE



Main Program Name: RCONT2

Subroutines: RTRACE,RTZPT

Computer System: HDL VAX 11-780

Compile Commands: \$FOR RCONT2

\$FOR RTRACE

\$FOR RTZPT

Linking Command: \$LINK RCONT2,RTRACE,RTZPT,DISSPLA/LIB,GH/LIB

Program Input Files: RWAKE.DAT

Execute Command: \$RUN RCONT2

Example:

Data Files Used: DSP0.FNL;

Keyboard\* Input:

0; .4; .05; 1; 03; 1; 1; 1; 1; 1;

AND

0; 0.0; .5; 0; 03; 1; 1; 1; 3; 1;

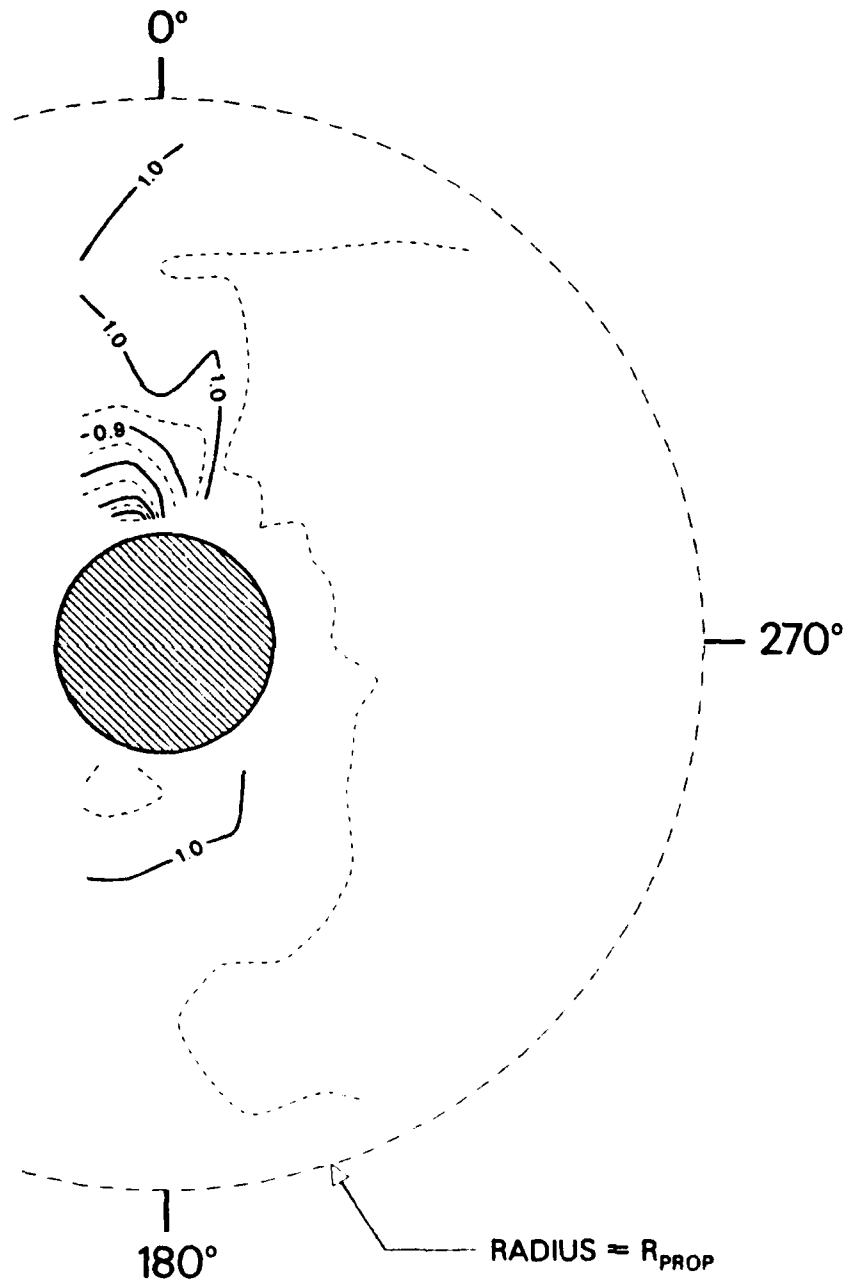
AND

0; 10.; 5.; 0; 03; 1; 1; 1; 2; 1;

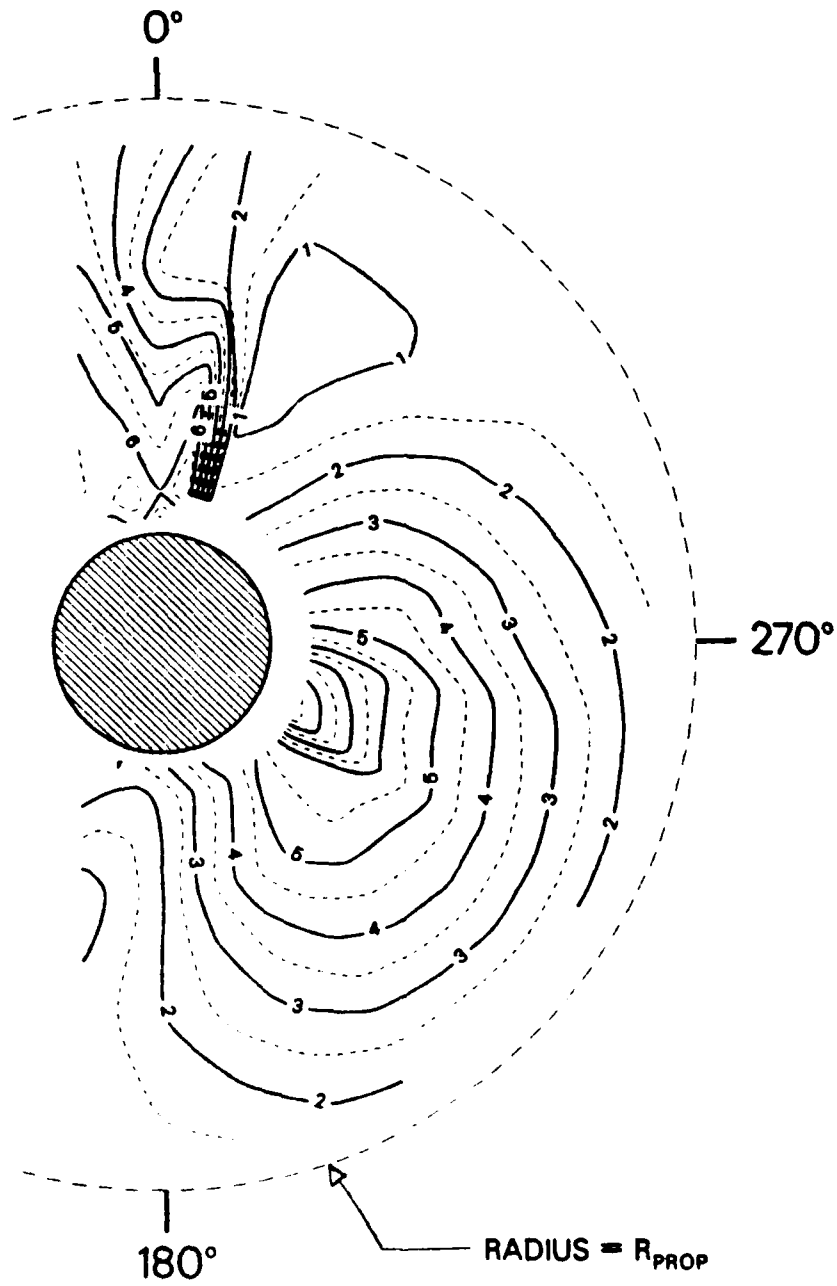
---

\* ";" separates different keyboard inputs; "\$" HDL command prompt;

# AXIAL VELOCITY CONTOURS IN THE PROPELLER PLANE

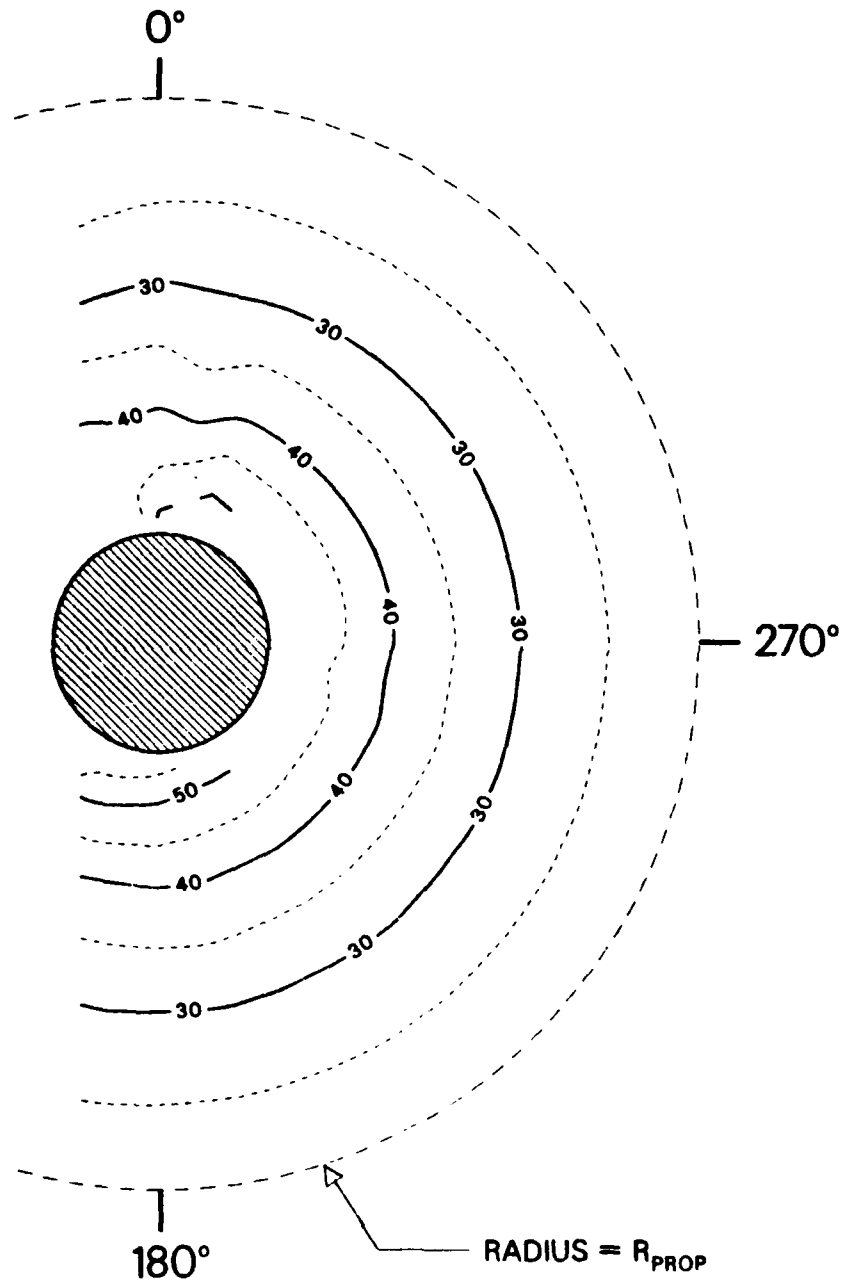


# VELOCITY FLUCTUATIONS CONTOURS IN THE PROPELLER PLANE





# AVG. INFLOW ANGLE, $\beta$ , CONTOURS IN THE PROPELLER PLANE



Main Program Name: RCONT3

Subroutines: RTRACE,RTZPT

Computer System: HDL VAX 11-780

Compile Commands: \$FOR RCONT3

\$FOR RTRACE

\$FOR RTZPT

Linking Command: \$LINK RCONT3,RTRACE,RTZPT,DISSPLA/LIB,GH/LIB

Program Input Files: RWAKE.DAT

Execute Command: \$RUN RCONT3

Example:

Data Files Used: ATSl.FNL;

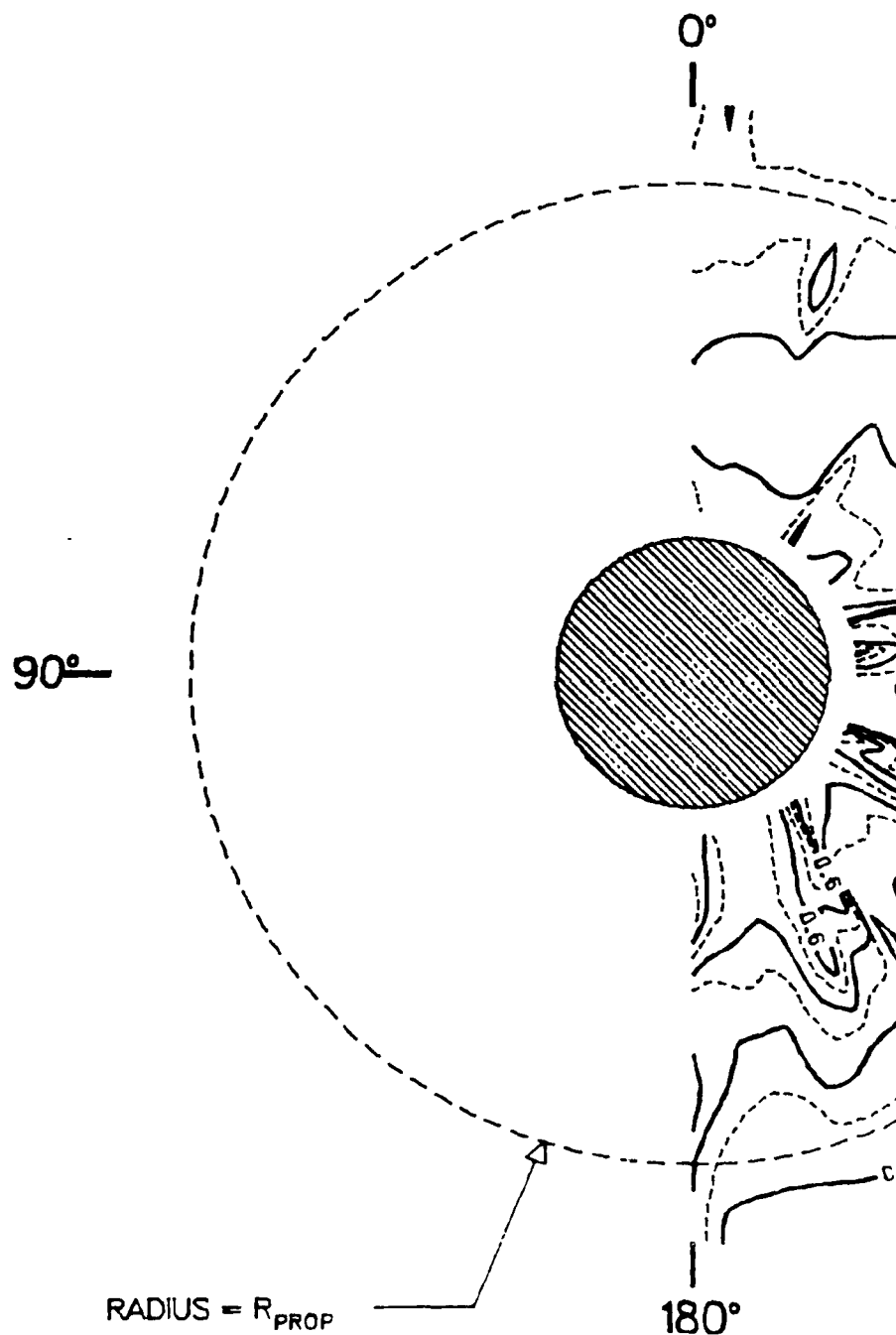
Keyboard\* Input:

0; .4; .05; 1; 03; 1; 1; 1; 1; 1;

---

\* ";" separates different keyboard inputs; "\$" HDL command prompt;

# AXIAL VELOCITY CONTOURS IN THE PROPELLER PLANE



Main Program Name: RCONT4

Subroutines: RTRACE,RTZPT

Computer System: HDL VAX 11-780

Compile Commands: \$FOR RCONT4

\$FOR RTRACE

\$FOR RTZPT

Linking Command: \$LINK RCONT4,RTRACE,RTZPT,DISSPLA/LIB,GH/LIB

Program Input Files: RWAKE.DAT

Execute Command: \$RUN RCONT4

Example:

Data Files Used: ATSl.FNL;

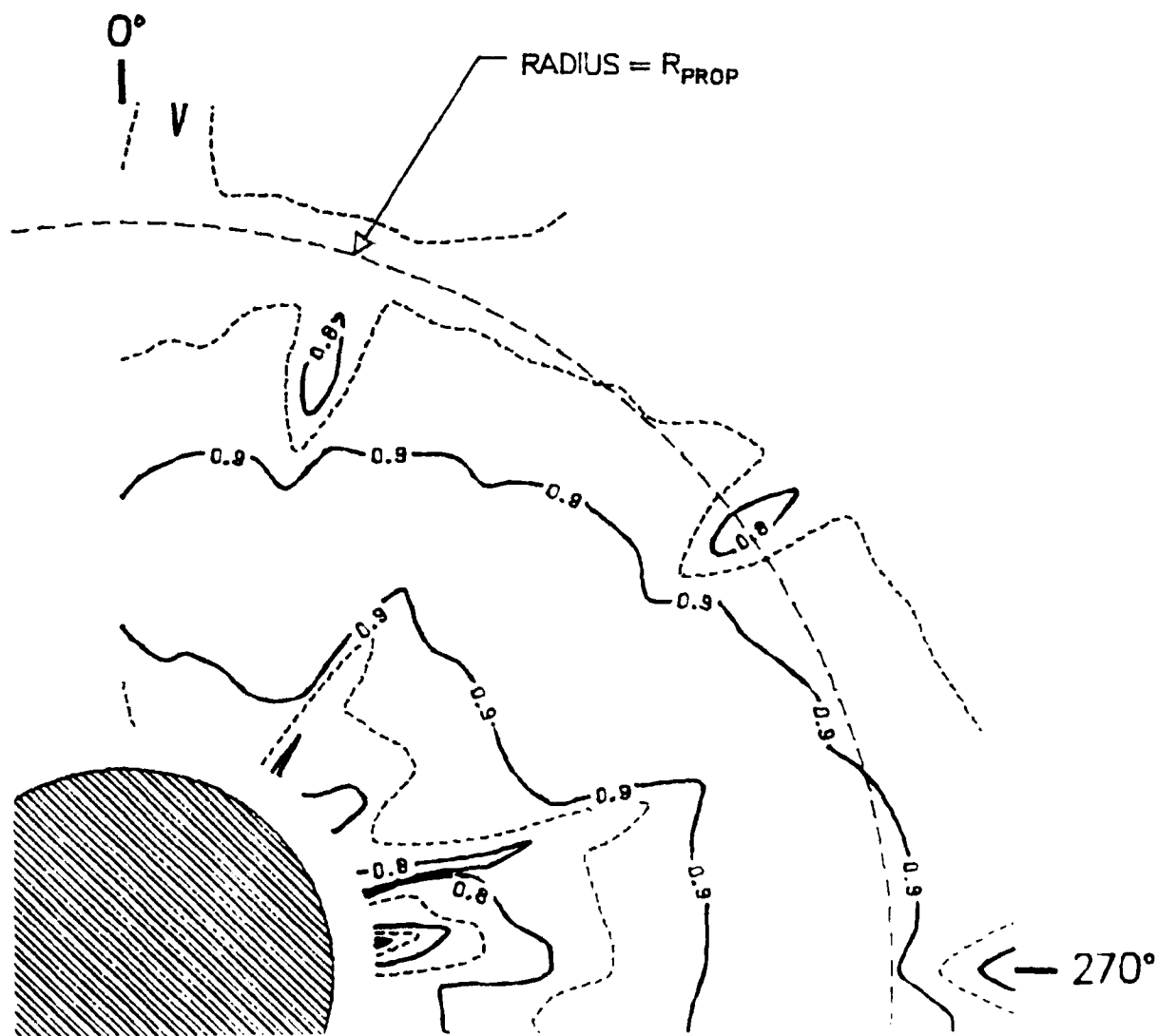
Keyboard\* Input:

0; .4; .1; 1; 03; 1; 1; 1; 1; 1;

---

\* ";" separates different keyboard inputs; "\$" HDL command prompt;

# AXIAL VELOCITY CONTOURS IN THE PROPELLER PLANE



Main Program Name: RCONT5

Subroutines: RTRACE,RTZPT

Computer System: HDL VAX 11-780

Compile Commands: \$FOR RCONT5

\$FOR RTRACE

\$FOR RTZPT

Linking Command: \$LINK RCONT5,RTRACE,RTZPT,DISSPLA/LIB,GH/LIB

Program Input Files: RWAKE.DAT

Execute Command: \$RUN RCONT5

Example:

Data Files Used: ATSl.FNL;

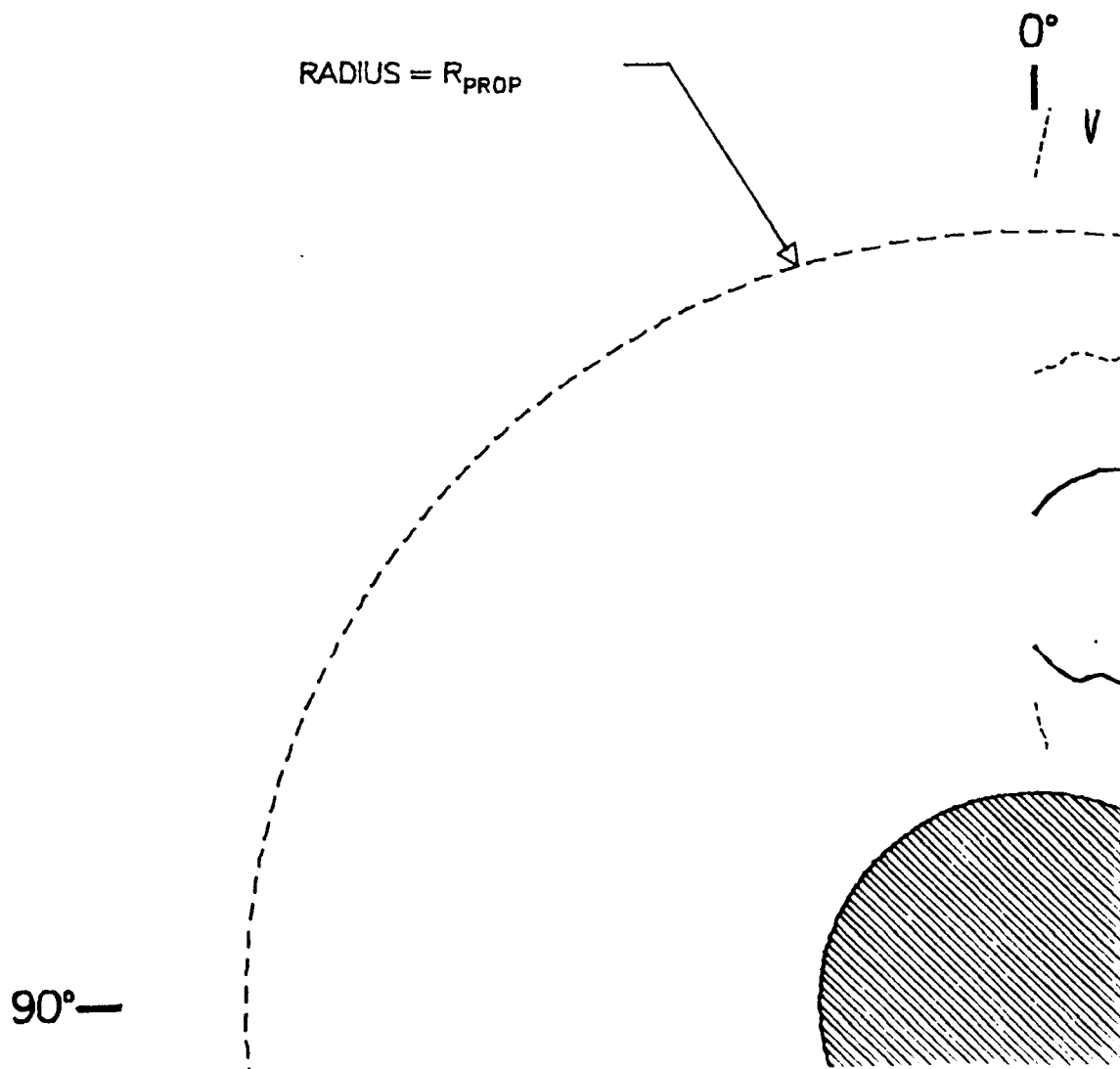
Keyboard\* Input:

0; .4; .05; 1; 03; 1; 1; 1; 1;

---

\* ";" separates different keyboard inputs; "\$" HDL command prompt;

# AXIAL VELOCITY CONTOURS IN THE PROPELLER PLANE



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