FAA-74-19.IV

REPORT NO. FAA-RD-75-161,IV

PULSED ACOUSTIC VORTEX SENSING SYSTEM
Volume IV: PAVSS Program Summary and Recommendations

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JUNE 1977

FINAL REPORT

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Research and Development Service
Washington DC 20591

Technical Report Documentation Page

1. Report No.	FAA-RD-75-161,IV
2. Government Accession No.	
3. Recipient's Catalog No.	
4. Title and Subtitle	PULSED ACOUSTIC VORTEX SENSING SYSTEM Volume IV -- PAVSS Program Summary and Recommendations
5. Report Date	June 1977
6. Performing Organization Code	
7. Author(s)	Royal N. Schweiger*
8. Performing Organization Report No.	DOT-TSC-FAA-74-19,IV
9. Performing Organization Name and Address	Avco Corporation Systems Division 201 Lowell Street Wilmington MA 01887
10. Work Unit No. (TRAIS)	FA405/R7126
11. Contract or Grant No.	DOT-TSC-620-4
12. Sponsoring Agency Name and Address	U. S. Department of Transportation Federal Aviation Administration Systems Research and Development Service Washington DC 20591
13. Type of Report and Period Covered	Final Report August 1973 to June 1974
14. Sponsoring Agency Code	
15. Supplementary Notes	* Under contract to: U. S. Department of Transportation Transportation Systems Center Kendall Square, Cambridge MA 02142

16. Abstract

Avco Corporation's Systems Division designed and developed an engineered Pulsed Acoustic Vortex Sensing System (PAVSS). This system is capable of real-time detection, tracking, recording, and graphic display of aircraft trailing vortices.

This volume of the report summarizes the background and accomplishments of the PAVSS program carried out by Avco, and presents Avco's recommendation that further work on the PAVSS would not be economically sound.

Other volumes in this final report are as follows:

Volume I Hardware Design
Volume II Studies of Improved PAVSS Processing Techniques
Volume III PAVSS Operation and Software Documentation

17. Key Words	Pulsed Acoustic Vortex Sensor, Wake Vortex, Trailing Vortex Sensing System, Aircraft Vortex Tracking System
18. Distribution Statement	DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161
19. Security Classif. (of this report)	Unclassified
20. Security Classif. (of this page)	Unclassified
21. No. of Pages	50
22. Price	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

The problems related to aircraft trailing vortices are currently under intensive study for the Federal Aviation Administration (FAA) by the U. S. Department of Transportation. The Transportation Systems Center (TSC) of the U. S. Department of Transportation (DOT) initiated and is carrying out several programs in this area, including programs to develop acoustic systems for detecting, tracking, and measuring the strength of aircraft wake vortices. The system described in this report was designed, built, and tested by Avco Corporation's Systems Division (Avco/SD) for DOT/TSC under Contract DOT-TSC-620, dated 15 August 1973. It is an engineered extension of the pulsed acoustic multi-static radar concept developed by the Communications Branch of DOT/TSC at Cambridge, Massachusetts.

The Avco-engineered system is designed to permit simultaneous operation of two (of three) 8-element arrays deployed along an appropriate baseline, and to provide real-time detection, tracking, recording, and graphic display of vortex locations.

This volume of the final report summarizes the background of the program and program accomplishments, and presents Avco's recommendations regarding future PAVSS activities. Other aspects of the system are covered in additional volumes (I, II, and III).

The work performed under this contract was significantly enhanced by the close cooperation and contributions of Ralph Kodis, David Burnham, and Thomas Sullivan, all of DOT/TSC.

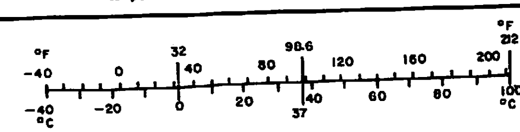
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

This introduction is presented in two parts. Paragraph 1.1 serves as an introduction to the complete final report; Paragraph 1.2 serves as an introduction to this volume (Volume IV) of that report.

1.1 INTRODUCTION TO THE FINAL REPORT

Trailing vortices from heavy jet aircraft represent a currently undefined hazard, particularly during landing and takeoff operations. Considerations of safety and the need to optimize airport operation make it essential to acquire positive information about the presence and locations of vortices generated by heavy aircraft.

The feasibility of using multi-static pulsed acoustic radar to detect and track wake vortices has been demonstrated by the U. S. Department of Transportation's Transportation Systems Center (DOT/TSC) in tests at Logan International Airport, New York, N. Y.; and at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, N. J. The hardware used during these tests consisted of laboratory models. The equipment was not engineered for long-term installation in the field, and was incapable of automatic real-time data processing and display.

This report describes a pulsed acoustic vortex sensing system (PAVSS) development program carried out by Avco Systems Division (Avco/SD) for DOT/TSC under Contract DOT-TSC-620. The goal of this program was to develop, build, and test an engineered wake vortex sensing system consisting of acoustic sensors and associated electronics; to acquire and process the sensed data; and to display this data visually in real time.

The complete final report on this program consists of this volume (Volume IV, PAVSS PROGRAM SUMMARY AND RECOMMENDATIONS) and three additional volumes as follows:

Volume I	HARDWARE DESIGN
Volume II	STUDIES OF IMPROVED PAVSS PROCESSING TECHNIQUES
Volume III	PAVSS OPERATION AND SOFTWARE DOCUMENTATION

1.2 INTRODUCTION TO VOLUME IV, PAVSS PROGRAM SUMMARY AND RECOMMENDATIONS

This volume of the final report on the pulsed acoustic vortex sensing system covers three major aspects of the program: the background of the program, program accomplishments, and recommendations regarding further actions.

a. Background

Avco/SD designed and developed a PAVSS capable of detecting and locating trailing (wake) vortices produced by aircraft during landings. The system generates, transmits, receives, and processes acoustic pulses in real time. Vortex position plots and diagnostic displays are also generated in real time. Both a cathode ray tube (CRT) terminal and a hard-copy printer are available for displaying data and diagnostic information.

The background of the program, program accomplishments, and Avco's recommendations regarding the PAVSS program are covered in this volume of the final report.

b. Organization of Volume IV

The remaining sections of this volume of the final report cover the areas indicated below:

Section 2	Describes the background of the PAVSS.

Section 3	Summarizes PAVSS program accomplishments in the areas of hardware features, software features, and the operation and performance of the system.
Section 4	Presents Avco's recommendations regarding PAVSS hardware and software improvements, and the course of future PAVSS activities.

2. BACKGROUND

The pulsed acoustic vortex sensing system (PAVSS) concept was developed and demonstrated by the U. S. Department of Transportation's Transportation Systems Center (DOT-TSC). The work began in 1970 and continued until mid-1973. This DOT-TSC effort proved that it was possible to locate trailing vortices from landing aircraft by analysis of acoustic data collected by a multi-element acoustic radar transceiver--although at this stage the locating was not being done on a real-time bases.

The technique employed is illustrated in Figure 2-1 upon which the following description of the PAVSS is based. The transmitter section of the transceiver at the left transmits a train of acoustic-frequency pulses that illuminate both vortices. Some of these pulses are refracted by the vortex and return to earth where they are detected by the receiving sections of the transceivers at the right (transceivers 1 and 2). By comparing the transit time of this refracted signal to the transit time of the same pulse train that reaches transceivers 1 and 2 directly from the transceiver to the left (the so-called line-of-sight, LOS, signal), the difference in the times of arrival can be determined. At the same time that this is taking place, similar pulse trains are being transmitted by transceivers 1 and 2, and both LOS and vortex-refracted signals are being received by the transceiver at the left. Ellipses based on this time data can then be constructed. Their intersection accurately defines the vortex location. Successful location of trailing vortices by this approach indicated its feasibility.

The next step in carrying the program beyond DOT-TSC's successful demonstration was to implement a fully automated engineered system capable of collecting and processing vortex location data in real time, and of providing cathode ray tube (CRT) and hard-copy displays of the processed data in either a real-time mode or a playback mode. Such a system would include three arrays of eight transceivers each. These constituted the field-located sensing system. DOT-TSC awarded a contract (DOT-TSC-620) for such an engineered system to Avco Corporation's Systems Division (Avco/SD) in August 1973. The performance

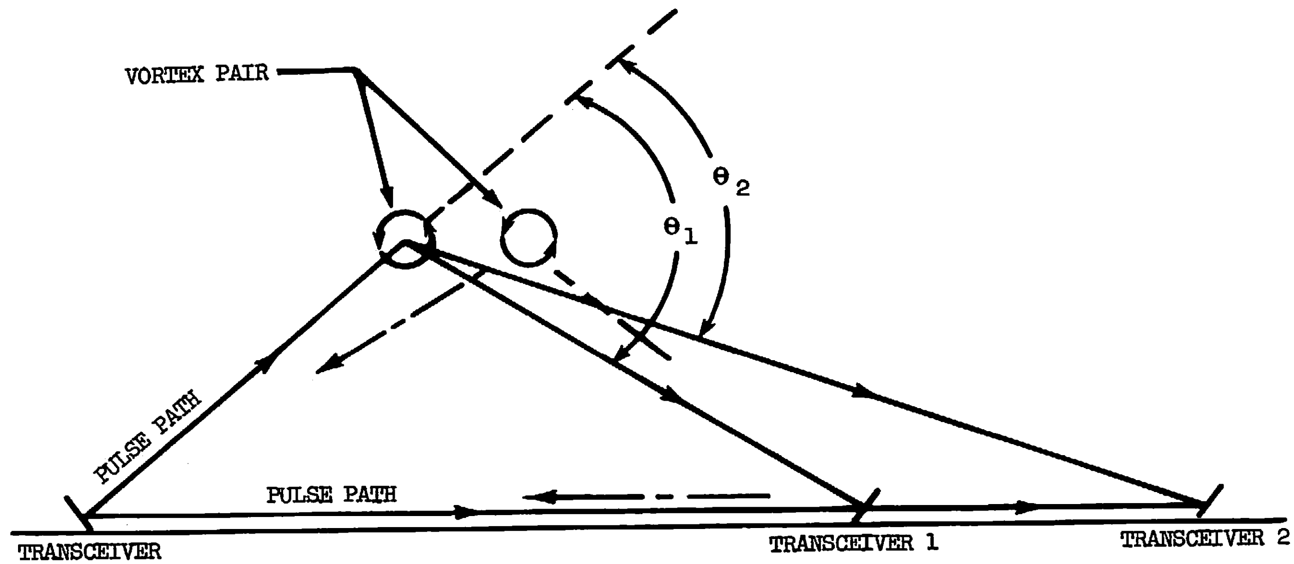


FIGURE 2-1 Bistatic Pulsed Acoustic Sensor

period for the contract was from August 1973 to May 1975. Table 2-1 lists important milestones in carrying out this contract.

The contract was amended several times to include work that substantially improved system performance and operation. These amendments, in the form of supplemental agreements (SA's), are listed in Table 2-2 along with a brief description of their content.

Work under the basic contract and SA's 1 through 4 was completed in May 1975 by which time the system was operational at the J. F. Kennedy International Airport (JFK) Vortex Test Site at the end of Runway 31R.

TABLE 2-1 Significant PAVSS Program Milestones

Date	Event
15 August 1973	Award of contract
5 April 1974	Completion of hardware and factory demonstrations
16 April 1974	Completion of improved tracking techniques (by subcontractors, Scope Electronics, Inc. and Arcon Corporation)
16 April 1974	Shipment of system to J. F. Kennedy International Airport (JFK) Vortex Test Site (at end of runway 31R)
8 May 1974	Installation complete at JFK Vortex Test Site
15 July 1974	Completion of field testing and software optimization
19 July 1974	Successful completion of final acceptance test
27 May 1975	Completion of further software improvement

TABLE 2-2 PAVSS Contract (DOT-TSC-620) Supplementary Agreements

Supplementary Agreement	Description
1	Study of improved techniques for processing PAVSS data
2	Addition of identification data and hard-copy display to the system
3	Installation and extended testing of the PAVSS at JFK
4	Improvement of the software; reduction of the operating complexity

3. ACCOMPLISHMENTS

This section presents a brief account of the accomplishment made during conduct of the engineered PAVSS contract. It is centered primarily on the housed equipment used in the PAVSS. The remote, field-located pulsed acoustic radar subsystem, which includes the antenna elements, antenna support towers, cabling, etc., is very similar in concept to corresponding equipment developed prior to award of the contract for the engineered PAVSS. Hence that subsystem is not discussed here where attention is centered on accomplishments under the engineered PAVSS contract. All aspects of the hardware design, including that of the pulsed acoustic radar subsystem, are detailed in Volume I - HARDWARE DESIGN of this final report.

Avco chose to design the system around a Digital Equipment Corporation (DEC) GT-40 minicomputer complete with a keyboard unit and a cathode ray tube (CRT) display. This complement of equipment provides means for entering system control parameters, calculating vortex locations, and formatting and displaying data. The design philosophy that was adopted provides the system operator with the capability, via the keyboard unit, of altering any or all operating parameters at his discretion during testing.

This operational freedom and flexibility allows the system to be optimized in the field with minimum need for changes in the software. Displays were provided to assist the operator in monitoring performance, determining the effects of hardware adjustments, and assessing the results of changes in the processing parameters.

3.1 HARDWARE FEATURES

Figure 3-1 is a block diagram showing the basic configuration of the engineered PAVSS. The system is built around a DEC minicomputer, as noted above, and appropriate field-located antenna arrays and associated equipment (the pulsed acoustic radar subsystem). The minicomputer element of the GT-40 is basically a DEC PDP 11/05 unit in which a second central processing unit (CPU) is incorporated to provide CRT display capabilities. A CRT terminal, keyboard unit, and a light pen used with the CRT display are all included in the GT-40.

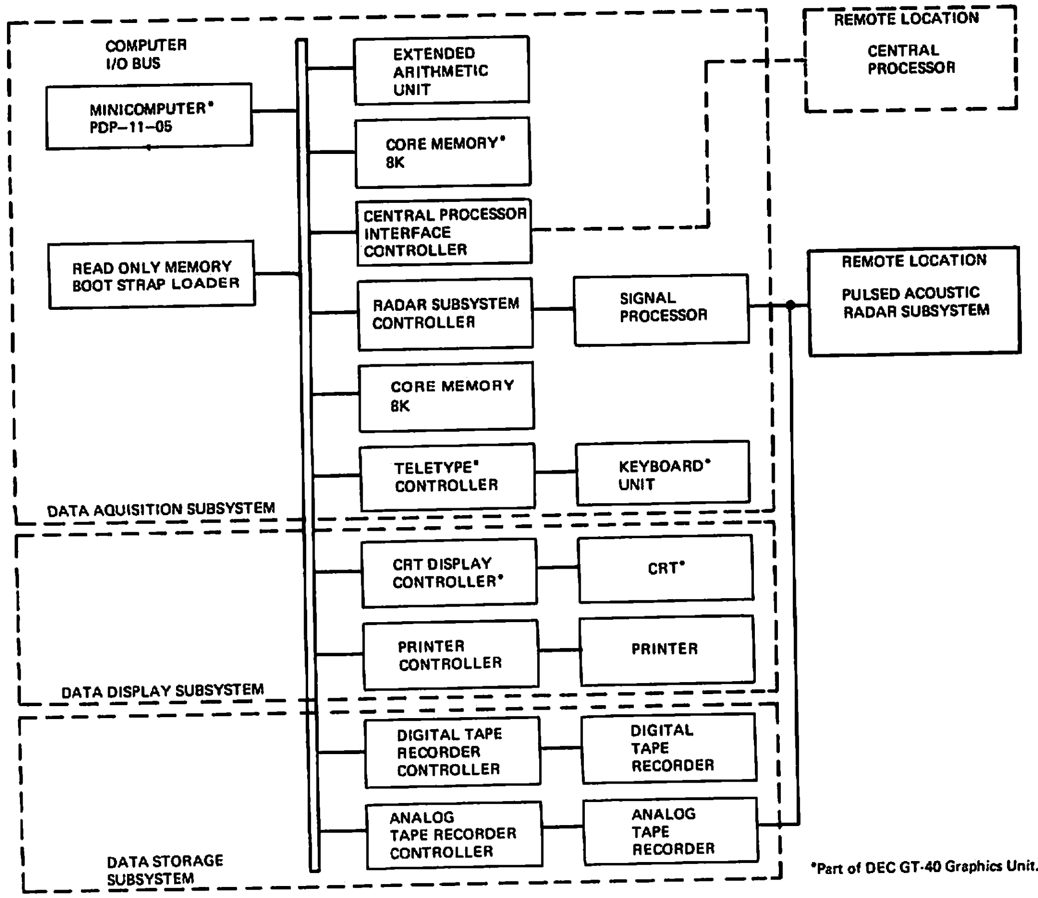


FIGURE 3-1 Block Diagram, Pulsed Acoustic Vortex Sensing System

Several additional items were added to the equipment complement to implement the required computer peripheral functions. These include: a 7-track digital magnetic tape unit (DEC TU-11) with an associated control unit (DEC TM-11), a 16K-word memory (DEC ME 11-L) external to the GT-40, a bootstrap loader (DEC MR-11-DB), and an extended arithmetic unit (DEC KE-11-A). A 14-track analog magnetic tape unit (Bell and Howell CPR-4010) is provided for data recording. A special-purpose Avco-built controller serves as the interface unit between the computer data bus, the PAVSS configuration control module, 12 signal processing modules, and the analog recorder. The interface between the 12 signal processing modules and the field-located antenna arrays is handled by an isolation module used: (1) to provide balanced inputs to minimize electromagnetic interference (EMI), and (2) to protect the system from lightning and other field-induced transients.

The principal features of the PAVSS hardware are summarized on Table 3-1.

3.2 SOFTWARE FEATURES

The software for the engineered PAVSS consists of two programs, each on magnetic tape. One program loads the system memory with the operating program. It permits the PAVSS to operate in either a real-time data collecting mode or in a playback mode. The other program is used to display--via either the CRT or a hard-copy printer--vortex data previously written by the PAVSS on digital tape. The software is written in the AVMOTS (Avco Modular Test System) assembly language, a language quite similar to PAL II. The software is described in Volume III of this final report and in the listings provided with the system.

Several outstanding features were included in the software. These are discussed briefly below.

3.2.1 Delay Pair Selection

Vortex position is determined in a multi-static array by measuring the propagation time-delay of vortex-refracted signals for different path lengths. Each time-delay measurement specifies

TABLE 3-1 PAVSS Hardware Features (Housed Equipment)

GRAPHICS UNITS (GT-40)

- PDP 11/05 Minicomputer
  - 16-bit data word
  - 16-bit address
  - Memory read/write cycle time - 950 nsec
  - Internal line clock
  - 8K word internal memory
  - 16K word external memory
  - Asynchronous serial interface
- CRT Display
  - Separate display central processing unit
  - 7-1/2-inch by 9-1/2-inch screen
  - 1024 by 768 raster unit area
  - 8 intensity levels
  - 6 by 8 dot matrix character font
  - 96 ASCE ASCII and characters
  - 31 special characters
- Alphanumeric Keyboard Unit
  - 96 ASCII characters
  - 31 special characters

TABLE 3-1 (Cont'd)

SIGNAL PROCESSOR

- Filtering
  - 2-pole bandpass, synchronous
  - Computer-controlled
- Detection
  - Double differentiation

CONTROLLER

- Interfaces with PDP 11/05 Unibus
- Provides system control
  - Run state
  - 200-second time-out
  - Selects acoustic frequencies
  - Feeds acoustic data to computer
  - Controls antenna array configuration
  - Formats and decodes identification words

7-TRACK MAGNETIC TAPE UNIT (DIGITAL)

- 0.5-inch wide industry-standard type
- 800 bits per inch packing density

14-TRACK MAGNETIC TAPE UNIT (ANALOG)

- 1.0-inch wide tape
- Head configuration per IRIG 106-71
- Tape speed: 15/16-inch per second to 60 inches per second (ips)

TABLE 3-1 (Concl'd)

HARD-COPY PRINTER

Printing Capability

96 characters

132 columns

12.5 dot matrix characters per inch

500 lines per minute

Plotting Capability

10.24-inch by 10.24-inch square writing area

1024 total writing points

122,880 dots per second

the location of the refracting target (in this case, the vortex) as a point somewhere on an ellipse whose foci are located at the particular transmitter and receiver used in making the time-delay measurements. This point is then completely defined by analytically determining the point of intersection of position ellipses based on pairs of time-delay measurements representing different path lengths. Clearly, a number of redundant measurements may be made in many regions of the array coverage.

Time-delay measurement errors are reflected in location-dependent position errors in bistatic and multi-static radar systems. That is, small time-delay errors may result in significant position errors when the position is defined in terms of the intersection of two highly eccentric position ellipses. In the engineered PAVSS, this sensitivity (of the actual position determination to time-delay measurement errors) is used to advantage by making that sensitivity the index for selecting the most accurate data in redundant sets of data. At any location point the best pair of time-delay measurements is, therefore, that which also represents the largest angular difference among the set of ellipses at the point of their intersection.

An error sensitivity analysis was performed to provide a basis for making the optimum choice among redundant time-delay measurements. The resultant choice criterion, in the form of a 'look-up' table, was then incorporated in the computer software. During operation, the PAVSS examines the available signal returns and previous data regarding the vortex whose position is being located, and then selects the appropriate delay pairs for use in calculating the vortex location.

3.2.2 Ellipse Solution Algorithm

As noted above, the time delay (time difference between the vortex-refracted signal and the LOS, or ground, signal) of a vortex return defines an ellipse on which the vortex may be located. The relevant transmitter and receiver are the foci of that ellipse. One method of determining vortex position requires calculation of the intersection point of two ellipses generated on the basis of two vortex time delays. Typically, the straightforward geometric equations employed in this calculation include numerous square root terms. The square root operation, however, has to be implemented by special software and is normally a relatively slow operation. Avco, therefore, devised a unique iterative algorithm, one without square root terms, to avoid need for the exact geometric calculation. The approach is as follows. A starting altitude is selected. This altitude value is then incremented or decremented by successively smaller altitude intervals until the actual intersection altitude is converged upon with sufficient accuracy. The longitudinal intersection point is calculated as part of the iteration. The accuracy of the convergence is an inverse function of the number of altitude iterations executed. This approach saves considerable execution time as compared to use of the direct geometric formulas--and even this shortened execution time is controllable by appropriate selection of the number of altitude iterations to be used.

3.3 OPERATION AND PERFORMANCE

This section summarizes the operation and performance of the PAVSS. Details regarding system operation are presented in Volume III - PAVSS OPERATION AND SOFTWARE DOCUMENTATION.

3.3.1 Operation

System operation is initiated by loading the computer program into the PAVSS from magnetic tape. Once this is done the system is provided with a set of operating parameters previously determined to be optimum for generally prevailing conditions. (A short period of time is required following program loading to allow the operator to set the gain of each processing channel. Setting of the gains, which vary as a function of the meteorological conditions, is the only manual setting required for system operation.)

Real-time data collection is accomplished either manually (under operator control) or automatically (in response to commands initiated remotely). A READY command starts the recorders and hard-copy printer. When an aircraft (A/C) is over the location chosen for the start of the run, a suitable command (start-of-run, SOR) is executed. This command initates those functions by which the system selects, calculates, and solves for vortex positions. Hard-copy and CRT displays are produced as required. A new run begins either when a new READY command is issued, or after 200 seconds have elapsed following the previous SOR command.

Should the operator choose to modify one or more of the system parameters, he may do so via the keyboard unit. Examples of such modifications are changes in the array selection; a change of mode (real-time or playback); and entry of approximate wind, relative humidity, and temperature data.

Several displays are available on call by the operator during system operation. They may, for example, be selected to allow the operator to monitor data collection or to examine data after its collection. In addition, a data dump option is available to permit the vortex position data recorded on the digital magnetic tape to be reviewed. The CRT displays are summarized in Table 3-2. Examples of CRT displays are shown in the figures identified in that table (Figures 3-2 through 3-8). The hard-copy printout options that are available are listed in Table 3-3. Examples of the printout are shown in Figures 3-9 through 3-15.

3.3.2 Performance

The performance of the PAVSS varies greatly as a function of meteorological conditions and of aircraft type. Wind effects appear to have the most influence on the quality of the data. Most aircraft, other than Boeing 707 and McDonnell Douglas DC-8 types, are tracked well by the PAVSS under calm or light wind (less than 10 knots) conditions. For winds above 10 knots, vortex tracks deteriorate progressively as the wind increases, especially in respect to the horizontal location of the vortices. This may be due to more rapid breakup of the vortices, more erratic vortex behavior, an increase in ambient noise, or distortion of the acoustic path, etc. Such conditions amplify errors in defining accurately the point of intersection of the ellipse pairs used to determine the vortex position. Examples of good quality data are shown in Figures 3-16 and 3-17.

TABLE 3-2 CRT Displays

	Display Title	Reference Figure	Description
1.	Plot (P)	3-2	This display consists of a single page on which the height of each vortex is plotted versus time and the horizontal position of both vortices is plotted versus time. The header data contains pertinent run identification information, including array identification, run number, aircraft identification (ID), start-of-run (SOR) time, and mode. The time scales--which are in seconds and can be 60, 120, or 180 seconds--are keyboard selectable by the operator.
2.	Cross Plot (C)	3-3	This plot contains two grid presentations. The upper half of the display plots both vortices from one array in terms of horizontal distance versus elapsed time. The lower display plots both vortices from one array in terms of horizontal distance versus vertical height. This display includes the same header data as the Plot (P) display.
3.	Processing Parameters	3-4	This display shows either page 1 or page 2 of the current processing parameters. The first page contains the operating mode and tracker parameters and some of the header input data. The top of the page gives the number of the next run and the last wind calculation up-date for the two arrays currently operating in real time. Page 2 contains the antenna geometries and the data mask-out regions.
4.	Acoustogram Plot (A)	3-5	This display shows the acoustic data received by the selected receiver. The horizontal scale is in time (in terms of milliseconds from the transmit pulse). The vertical scale is in terms of frame number after the start-of-run. The horizontal broken line shown at frame 175 on Figure 3-5 denotes the mask-out region, with the solid portions of the line representing those time zones during which no data is allowed to enter the vortex processor.
5.	Tracking Acoustogram (T)	3-6	This display is the same as the acoustogram plot (A) described in 4., above, except that only the tracked data is displayed.
6.	Dot Grid	3-7	Each of the above CRT displays (A, T) includes a dot grid in the lower right-hand corner. This is shown, in enlarged form, on Figure 3-7a. This grid identifies those trackers currently tracking data. If the data is insufficient and cannot satisfy the tracker minimum requirements, a low-intensity spot will appear at the appropriate grid location. When there is sufficient data and the tracker is tracking, the appropriate spot increases in intensity. Figure 3-7b shows the layout of the dot grid. Each array has six active transceivers. Each receiver can receive a maximum of three line-of-sight (LOS) and three vortex returns. These have their origin in specific transmitters on the other side of the array. Therefore, the upper left dot is receiver 1's response to transmitter 4 and the lower right dot is the response of receiver 6 to transmitter 3. The four sets, or blocks, of grids represent the 2 LOS and 2 vortex returns for the two arrays as indicated in Figure 3-7b.
7.	Digital Tape Displays	3-8	The header and vortex location data recorded on digital tape may be displayed in playback mode operation on the CRT. A typical display is shown in Figure 3-8. Either manual page-by-page or automatic page-turning display is possible. The data displayed on the first page is the header date (Figure 3-8a). It presents all pertinent data for the run being covered. Subsequent records in the file contain the vortex location data, as shown in Figure 3-8b.

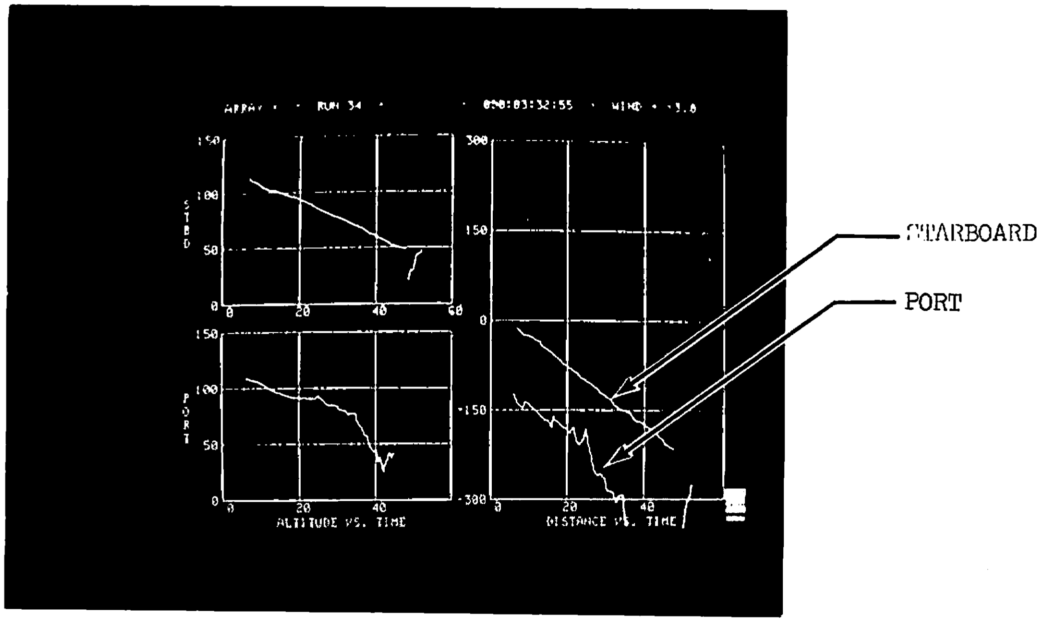


FIGURE 3-2 Plot (P), CRT Display

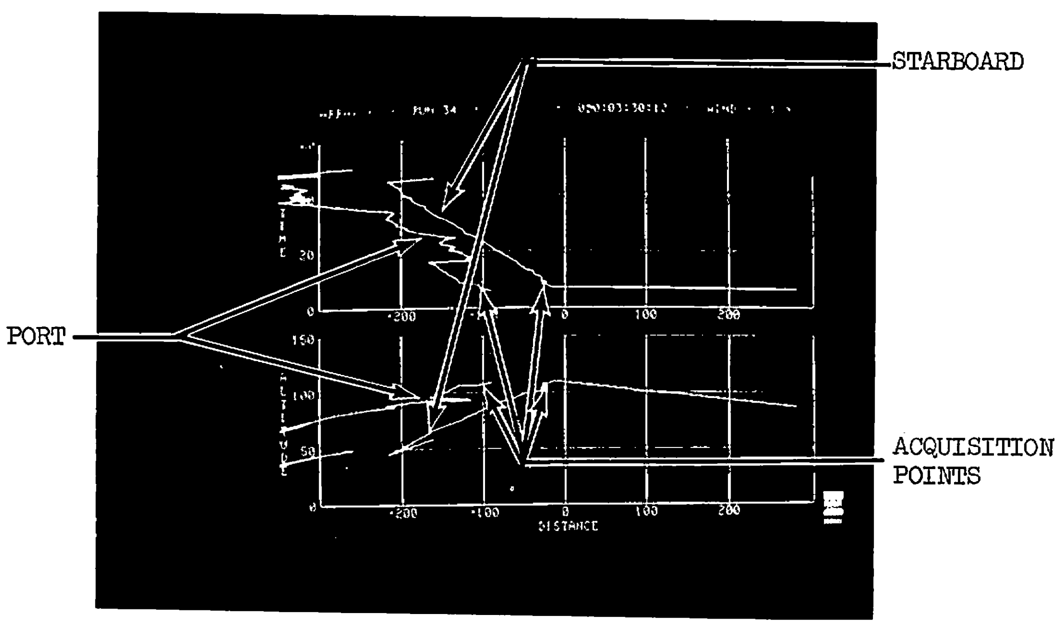
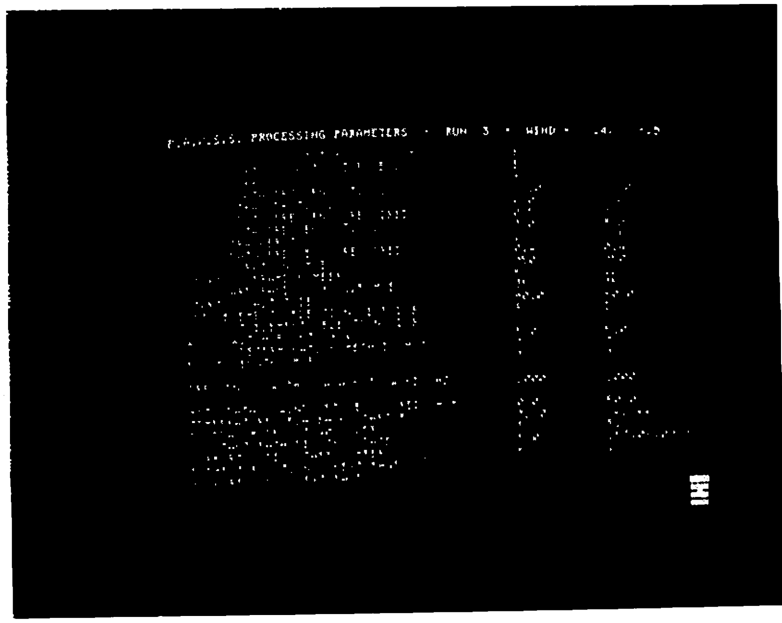


FIGURE 3-3 Cross Plot (C), CRT Display



PAGE 1

PAGE 2

FIGURE 3-4 Processing Parameters, CRT Display

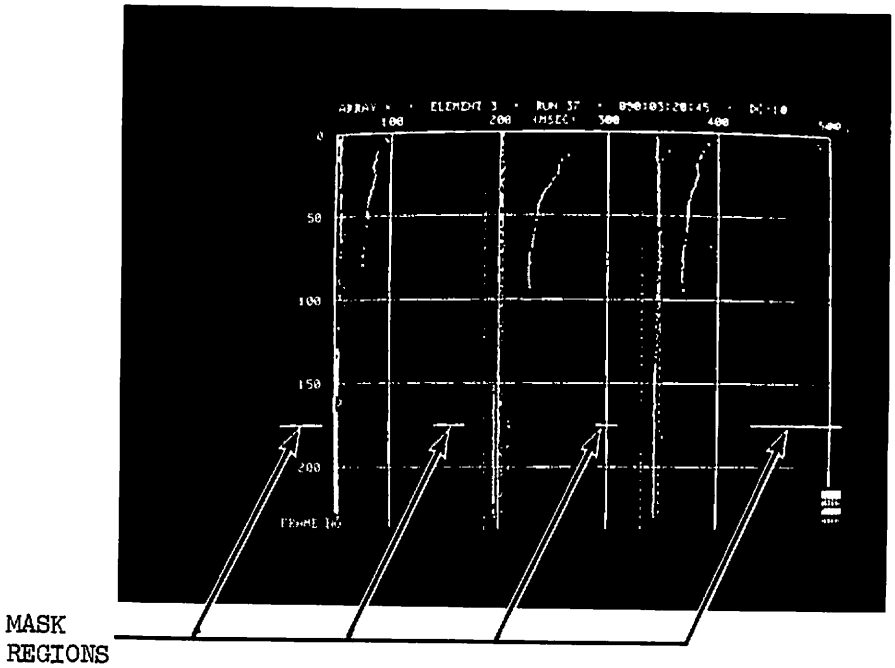


FIGURE 3-5 Acoustogram Plot (A), CRT Display

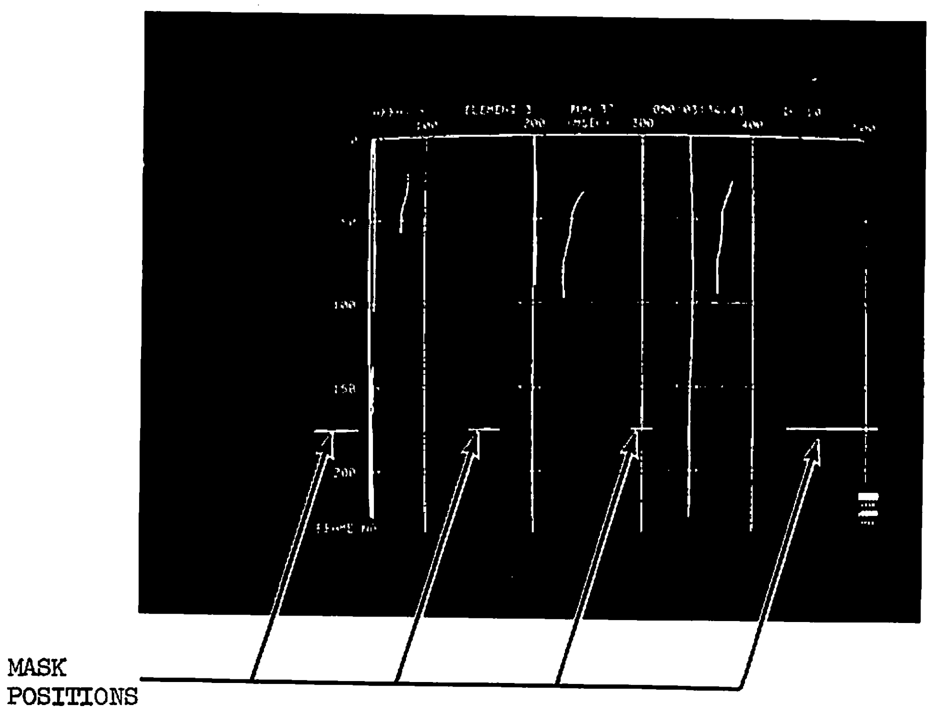
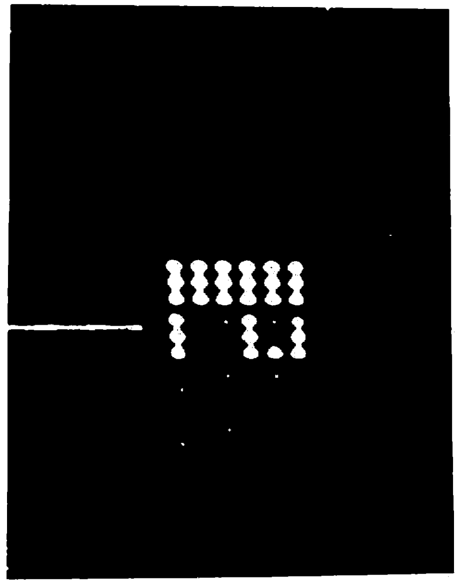
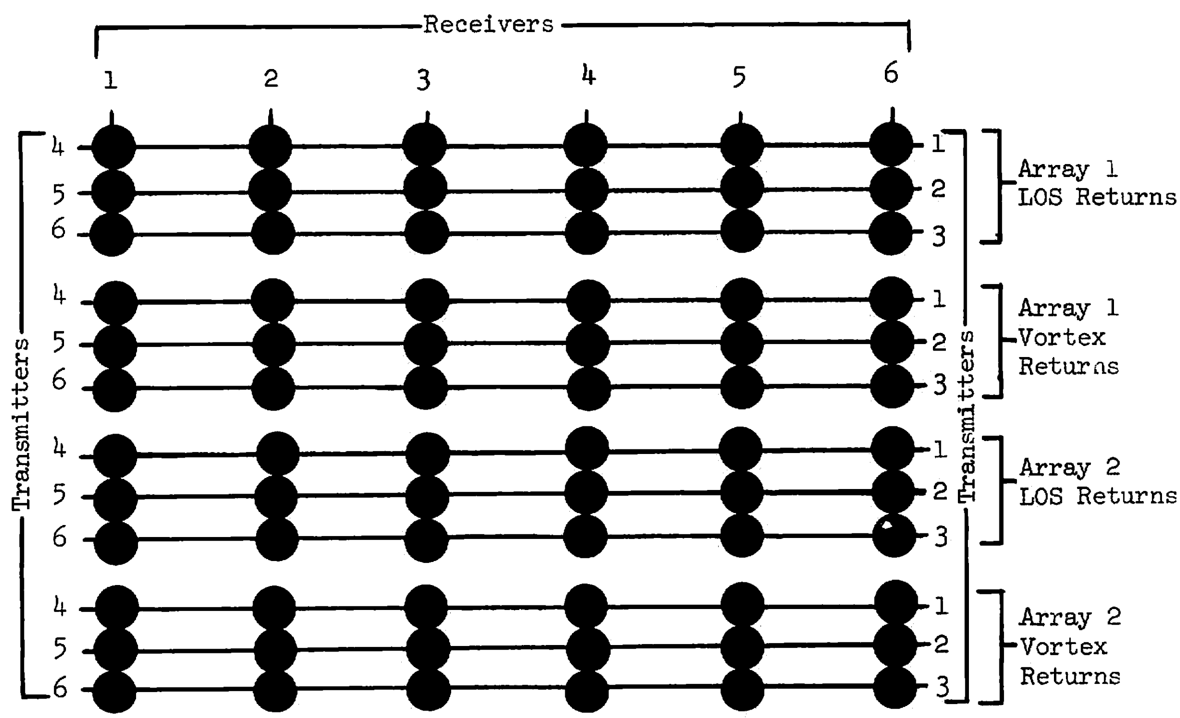


FIGURE 3-6 Tracking Acoustogram (T), CRT Display

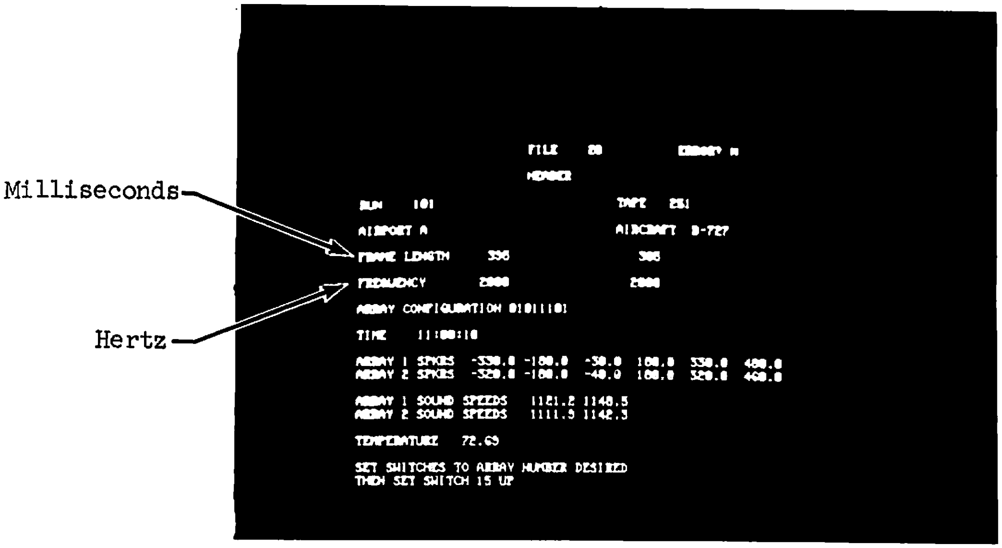


(a) Photograph of Display

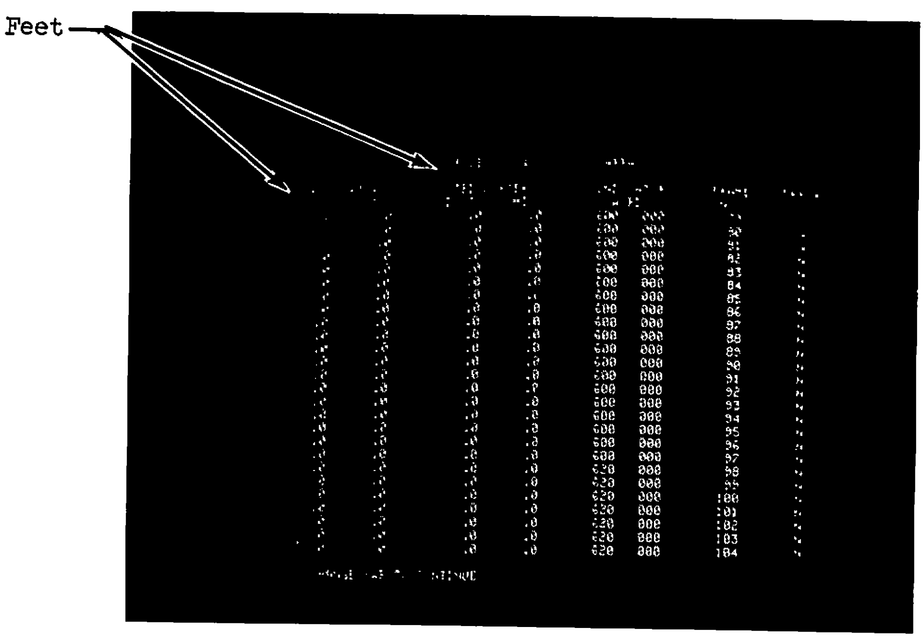


(b) Tracker Indicator Layouts

FIGURE 3-7 Dot Grid, CRT Display: (a) Photograph of Display, (b) Tracker Indicator Layouts



(a) Header Page



(b) Data Page

FIGURE 3-8 Digital Tape, CRT Display: (a) Header Page, (b) Data Page

TABLE 3-3 Hard-Copy Displays

	Display Title	Reference Figure	Description
1.	Processing Parameters	3-9	Upon appropriate command, the hard-copy printer will print out all of the processing parameters currently entered in the machine. During printout, all other system functions halt until the printout is completed.
2.	Plot (P)	3-10. 3-11	Plot (P) Printout. The plot (P) printout is the same as the Plot (P) CRT display. The header data is the same as the CRT display except that the time scale is included and the start-of-run time is entered at the end of the plot. The total time scale of the CRT plot (P) display is limited to the input on Line A Column 2 of the processing parameters. The hard-copy time scale changes with this entry, but the printout continues until the run is stopped. Figure 3-11 shows the hard-copy display of both arrays on the same grid.
3.	Acoustogram Printout (A)	3-12, 3-13, 3-14	This printout is the same as the CRT acoustogram display; that is, the data received is plotted against time into the frame and the frame number. The hard-copy printout, however, may display one, three, or six receiver acoustograms from one selected array.
4.	Digital Tape Data Dump Printout	3-15	The digital tape containing vortex location solutions can be printed out on the hard-copy printer for quick review. Each file can be printed sequentially in either an automatic (continuous) or manual (page-by-page) mode.

```
    P.A.V.S.S. PROCESSING PARAMETERS  -  RUN  6  -  WIND = -8.7,   -.0

A = MODE (R,P) - PLOT TIME (1,2,3 MIN)                      R          2
B = AUTO START  -  AUTO STOP (E,D)                          E          E
C = ACTIVE ARRAYS                                           X          Y
D = L.O.S. DATA FREQUENCY T. C.                             12.0       12.0
E = L.O.S. TRACKER T. C.                                    6.0        6.0
F = L.O.S. DATA FREQUENCY REQUIRED                          0.5        0.5
G = DELAY DATA FREQUENCY T. C.                              3.0        3.0
H = DELAY TRACKER T. C.                                     1.5        1.5
I = DELAY DATA FREQUENCY REQUIRED                           0.4        0.4
J = FRAME DURATION (MSEC)                                   950        950
K = STARTING FRAME NUMBER                                   8          12
L = LOS GUARD BANDS -/+ (.25 MSEC)                          25         35
M = STARTING ALTITUDE                                       80.0       80.0
N = MET. ELEMENT SELECTION (E,F,L,R)                        R          L
O = LOCK OUT ELEMENT SELECTION (L,R,S,C)                    S          S
P = WIND SWITCH POINT (+ & -)                               5.0        5.0
Q = L.O.S. DETERMINATION METHOD (M,T)                       T          T
R = PULSE LENGTH (MSEC)                                     3          3

S = FREQUENCY (WITH - AGAINST) WIND (HZ)                    2000       2000

T = MET. DATA - WIND (FT/SEC) - REL. HUM. (%)               0.0        50.0
U = TEMPERATURE, PLAYBACK STARTUP                           32.0        32.67
V = DISPLAY MODE (GT-40) (VERS)                             A1-3       P1
W = CONSTANT PATH LENGTH - DATE                             5.0        001:08:42:33
X = AIRPORT CODE - TAPE NUMBER                              K          1
```

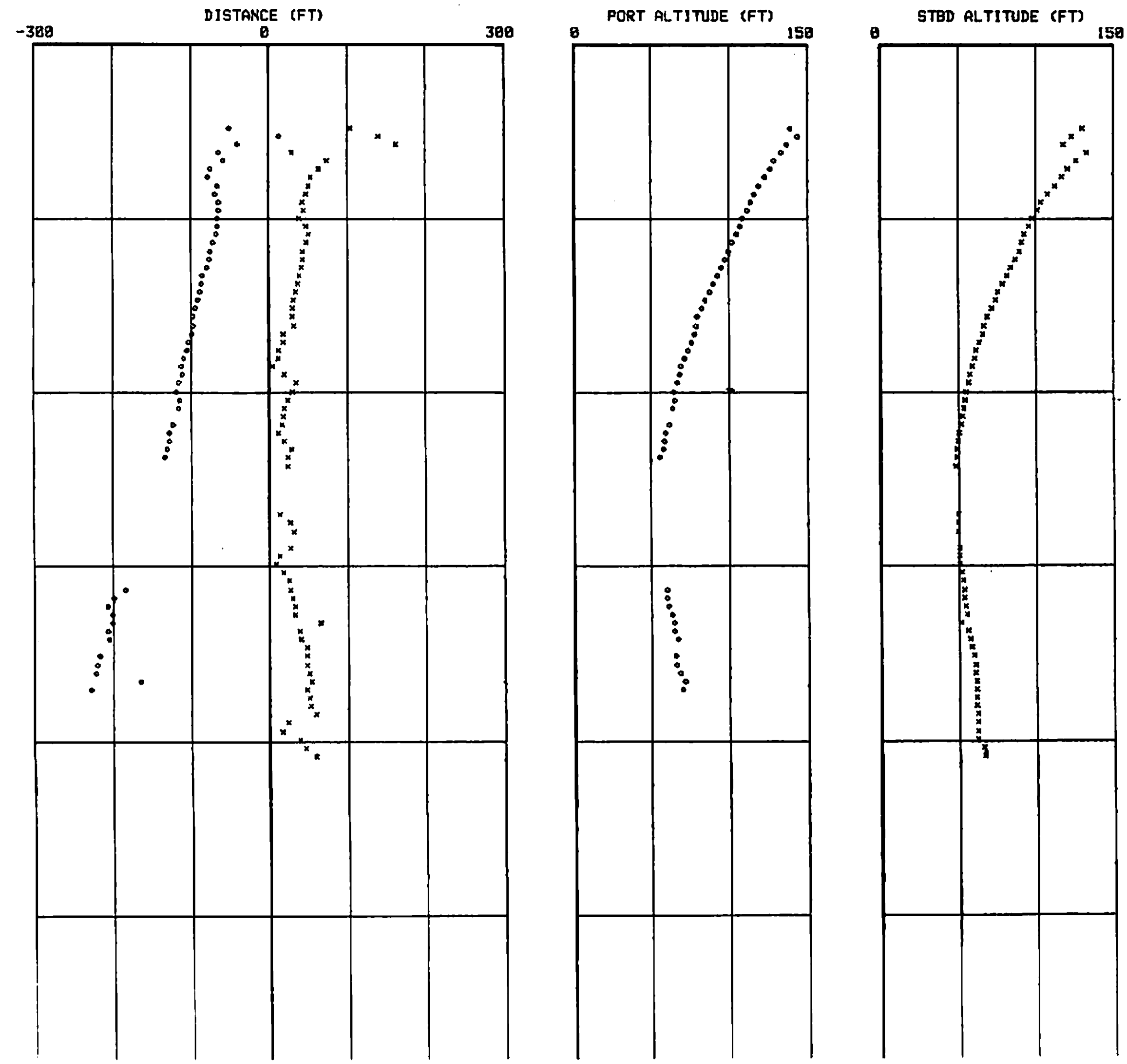
Page 1

```
    X - ELEMENT POSITIONS, X ARRAY
    -480.0   -330.0   -180.0   -30.0    30.0     180.0    330.0    480.0

    Y - ELEMENT POSITIONS, Y ARRAY
    -460.0   -320.0   -180.0   -40.0    40.0     180.0    320.0    460.0

    Z - ELEMENT POSITIONS, Z ARRAY
    -460.0   -320.0   -180.0   -40.0    40.0     180.0    320.0    460.0

    MASK POSITIONS - ARRAY 1
    500  940  0                       400  940  0
    300  940  0                       300  940  0
    400  940  0                       500  940  0

    MASK POSITIONS - ARRAY 2
    500  940  0                       400  940  0
    300  940  0                       300  940  0
    400  940  0                       500  940  0
```

Page 2

FIGURE 3-9 Processing Parameters, Versatec Printout

P.A.V.S.S. - VORTEX POSITION VS. TIME (1 DIVISION = 20 SEC.) - ARRAY X - RUN 2 - B-727 - WIND = .8

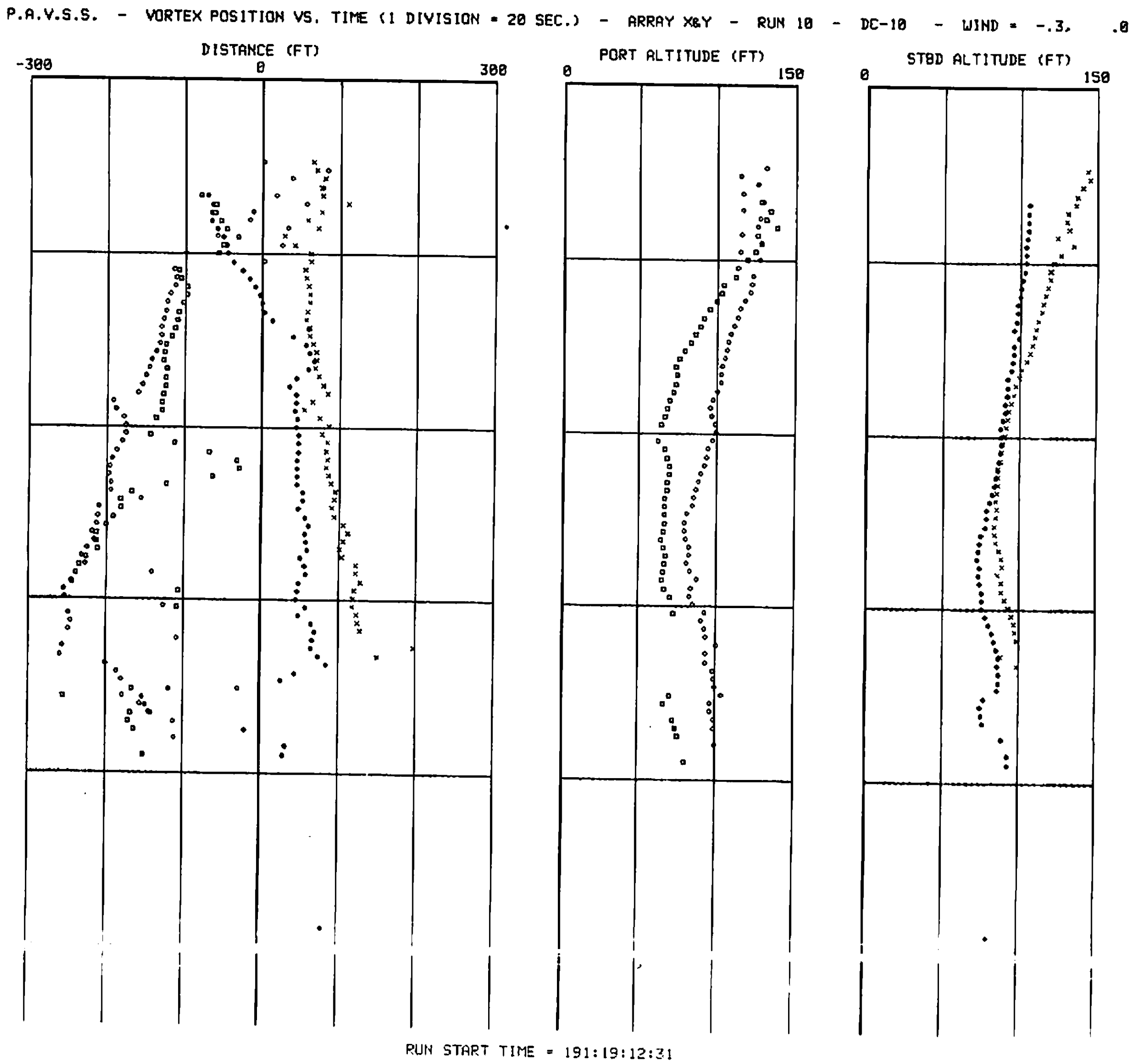


RUN START TIME = 153:08:09:33

NOTE: Port (left) and starboard (right) are used to designate directions relative to the runway center-line as viewed by a pilot landing on the runway. The following-listed symbols are used:

o = Port
x = Starboard
- = Port
+ = Starboard

FIGURE 3-10 Plot (P), Versatec Printout



NOTE: Port (left) and starboard (right) are used to designate directions relative to the runway center-line as viewed by a pilot landing on the runway. The following-listed symbols are used:

o = Port
▢ = Port
x = Starboard
● = Starboard
- = Port
+ = Starboard

FIGURE 3-11 Plot (P) for Both Active Arrays, Versatec Printout

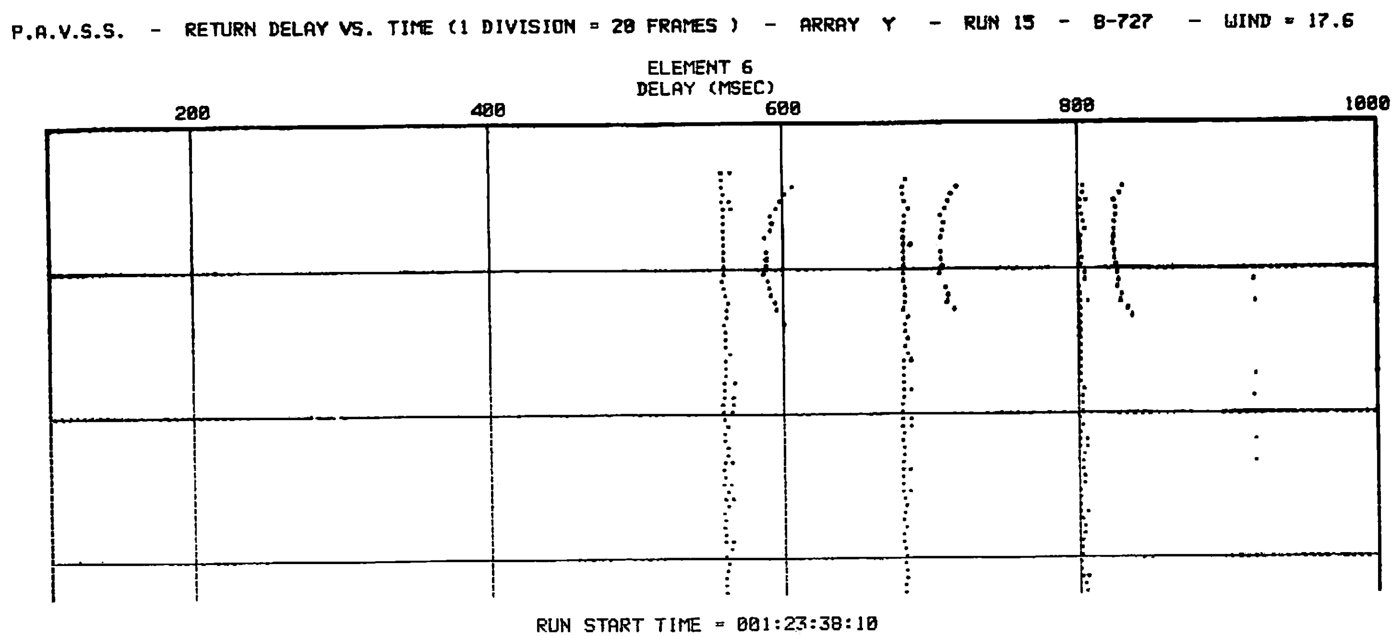


FIGURE 3-12 Single Acoustogram (A), Versatec Printout

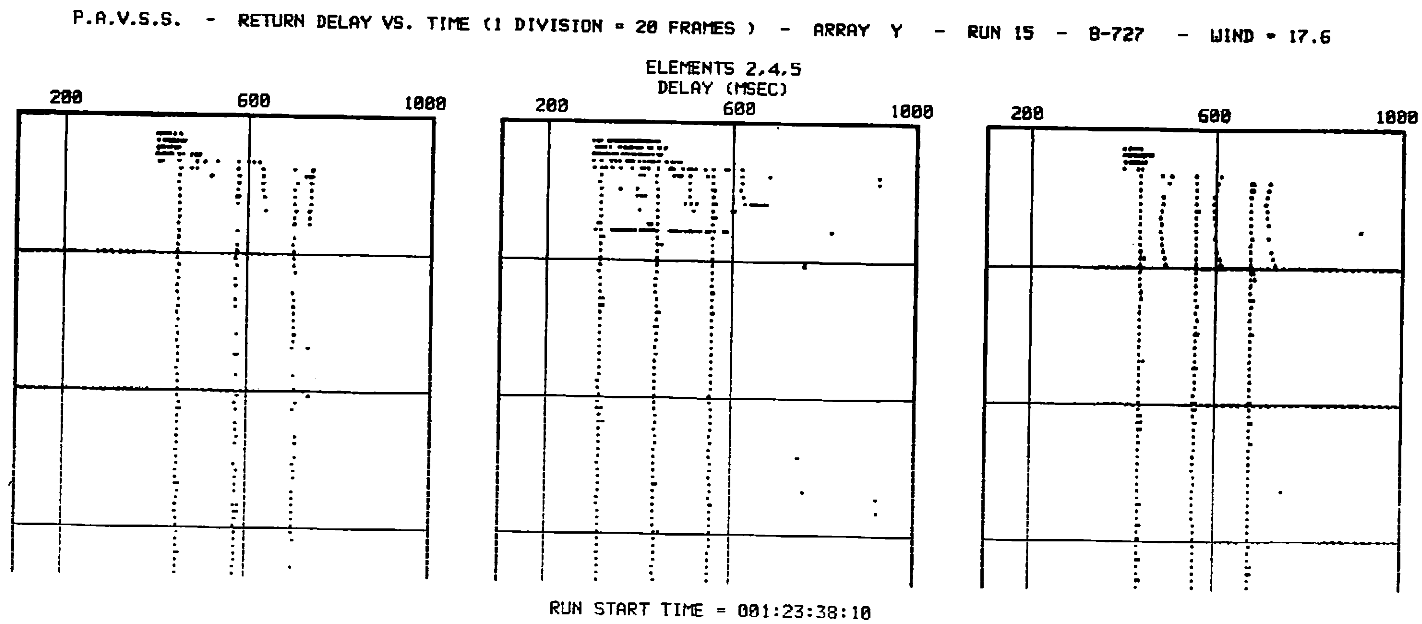


FIGURE 3-13 Three Acoustograms (A), Versatec Printout

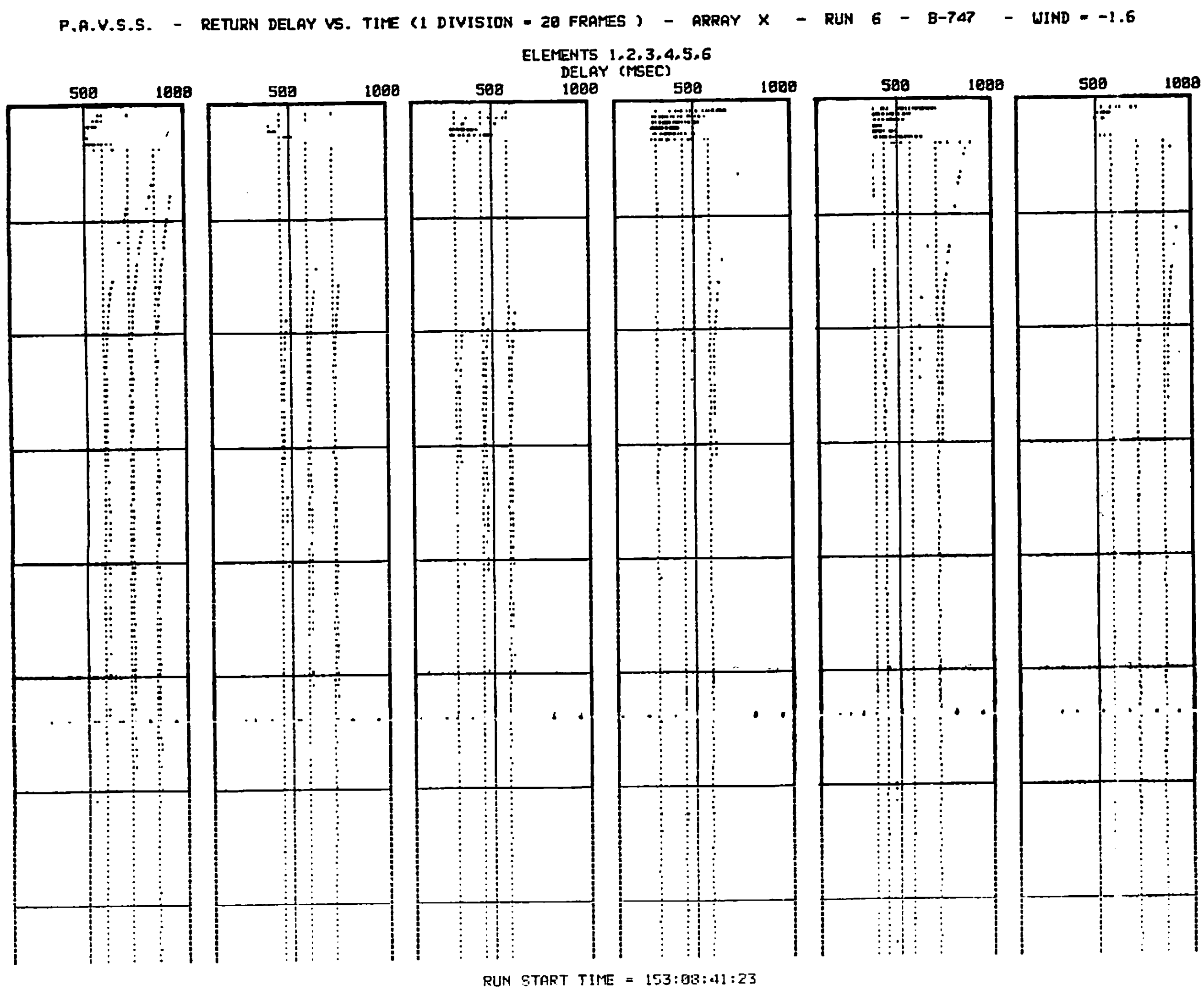


FIGURE 3-14 Six Acoustograms (A), Versatec Printout

FILE 2 ERROR? N

HEADER

RUN 17 TAPE 1

AIRPORT K AIRCRAFT B-747

Milliseconds — FRAME LENGTH 950 950

Hertz — FREQUENCY 2000 2200

ARRAY CONFIGURATION 00001101

TIME 10:36:44

Feet — ARRAY 1 SPKRS -480.0 -330.0 -180.0 180.0 330.0 480.0
ARRAY 2 SPKRS -460.0 -320.0 -180.0 180.0 320.0 460.0

Feet Per Second — ARRAY 1 SOUND SPEEDS 1122.5 1136.9
ARRAY 2 SOUND SPEEDS 1125.8 1135.4

Degrees, F. — TEMPERATURE 70.00

Feet

FILE 2 ARRAY 1

PORT VORTEX DIST	PORT VORTEX HT	STBD VORTEX DIST	STBD VORTEX HT	INDICATOR WORDS		FRAME NO.	ERROR?
.0	.0	.0	.0	000	000	1	N
.0	.0	.0	.0	000	000	2	N
.0	.0	.0	.0	000	000	3	N
.0	.0	.0	.0	000	000	4	N
.0	.0	.0	.0	000	000	5	N
.0	.0	.0	.0	000	000	6	N
.0	.0	.0	.0	000	000	7	N
.0	.0	.0	.0	000	020	8	N
.0	.0	.0	.0	200	020	9	N
.0	.0	.0	.0	000	004	10	N
.0	.0	.0	.0	000	080	11	N
.0	.0	.0	.0	000	002	12	N
.0	.0	.0	.0	100	000	13	N
.0	.0	.0	.0	000	042	14	N
.0	.0	.0	.0	000	051	15	N
12.9	159.7	.0	.0	000	045	16	N
-11.8	156.7	.0	.0	100	065	17	N
-15.9	152.1	.0	.0	100	074	18	N
-53.5	147.5	.0	.0	100	047	19	N
99.0	129.4	.0	.0	100	066	20	N
113.7	122.3	.0	.0	000	076	21	N
-44.0	129.9	.0	.0	000	065	22	N
2.7	120.6	.0	.0	100	077	23	N
34.5	113.6	.0	.0	000	067	24	N
42.3	108.5	.0	.0	100	076	25	N
6.4	106.4	.0	.0	000	077	26	N

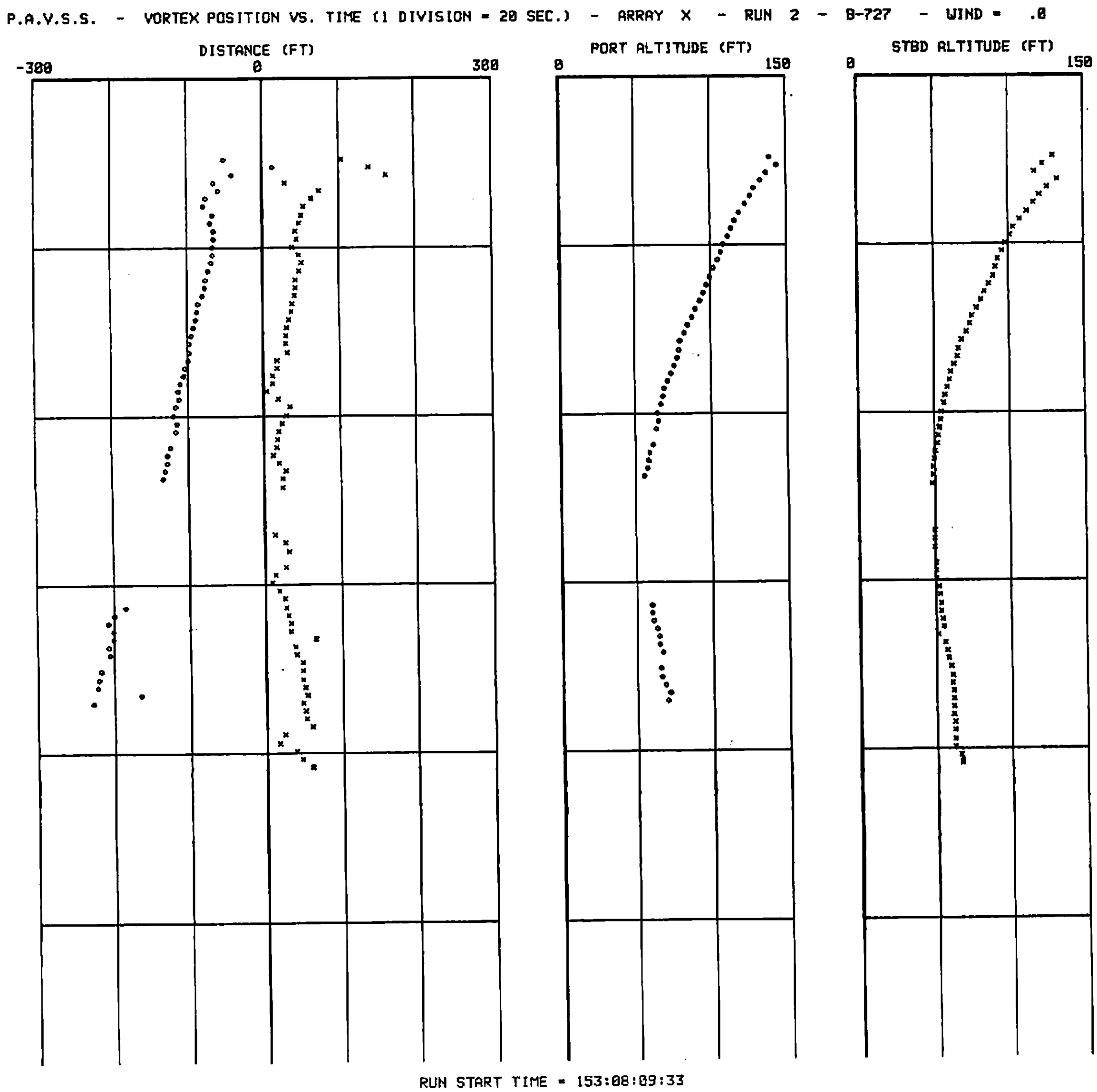
FILE 2 ARRAY 1

PORT VORTEX DIST	PORT VORTEX HT	STBD VORTEX DIST	STBD VORTEX HT	INDICATOR WORDS		FRAME NO.	ERROR?
57.5	97.5	.0	.0	100	077	27	N
61.2	92.9	.0	.0	100	677	28	N
100.4	88.7	.0	.0	100	677	29	N
107.3	85.8	.0	.0	100	677	30	N
111.1	82.3	.0	.0	100	477	31	N
115.7	79.0	.0	.0	100	477	32	N
115.4	78.0	.0	.0	100	077	33	N
128.5	76.4	.0	.0	120	077	34	N
137.9	73.0	.0	.0	100	077	35	N
144.1	70.4	.0	.0	100	077	36	N
163.9	66.8	.0	.0	100	077	37	N
168.0	65.3	.0	.0	100	073	38	N
145.9	66.2	.0	.0	100	073	39	N
143.1	64.5	.0	.0	100	071	40	N
159.7	62.6	.0	.0	000	070	41	N
202.9	56.0	.0	.0	000	070	42	N
209.0	53.4	.0	.0	000	070	43	N
198.7	53.6	.0	.0	000	070	44	N
192.5	53.5	.0	.0	000	070	45	N
193.6	52.3	.0	.0	000	070	46	N
252.9	41.9	.0	.0	000	070	47	N
272.9	36.6	.0	.0	000	070	48	N
301.9	26.0	.0	.0	000	070	49	N
310.0	23.4	.0	.0	000	070	50	N
235.7	44.9	.0	.0	000	070	51	N
247.1	43.7	.0	.0	000	070	52	N

FILE 2 ARRAY 1

PORT VORTEX DIST	PORT VORTEX HT	STBD VORTEX DIST	STBD VORTEX HT	INDICATOR WORDS		FRAME NO.	ERROR?
302.4	29.0	.0	.0	000	070	53	N
227.0	50.7	.0	.0	000	070	54	N
158.9	62.3	.0	.0	000	072	55	N
160.5	62.8	.0	.0	000	071	56	N
174.6	61.9	.0	.0	000	071	57	N
192.3	59.0	.0	.0	000	073	58	N
193.5	60.5	.0	.0	000	073	59	N
201.7	60.5	.0	.0	000	073	60	N
208.3	60.7	.0	.0	000	077	61	N
218.0	60.0	.0	.0	000	077	62	N
212.5	62.6	.0	.0	000	077	63	N
202.5	66.0	.0	.0	000	077	64	N
219.9	63.7	.0	.0	000	077	65	N
250.4	57.2	.0	.0	000	077	66	N
243.1	60.3	.0	.0	000	077	67	N
213.9	58.4	.0	.0	000	077	68	N
210.7	70.4	.0	.0	000	077	69	N
213.0	71.1	.0	.0	000	077	70	N
209.9	72.4	.0	.0	000	077	71	N
212.3	71.5	.0	.0	000	077	72	N
218.1	70.8	.0	.0	000	077	73	N
224.6	70.6	.0	.0	000	073	74	N
223.7	71.9	.0	.0	000	073	75	N
226.8	72.0	.0	.0	000	033	76	N
227.5	72.4	.0	.0	000	023	77	N
250.1	71.4	.0	.0	000	003	78	N

FIGURE 3-15 Digital Data Dump, Versatec Printout



NOTE: Port (left) and starboard (right) are used to designate directions relative to the runway center-line as viewed by a pilot landing on the runway. The following-listed symbols are used:

o = Port
x = Starboard
- = Port
+ = Starboard

FIGURE 3-16 Vortex Tracks, Boeing 727 (Fog, Calm)

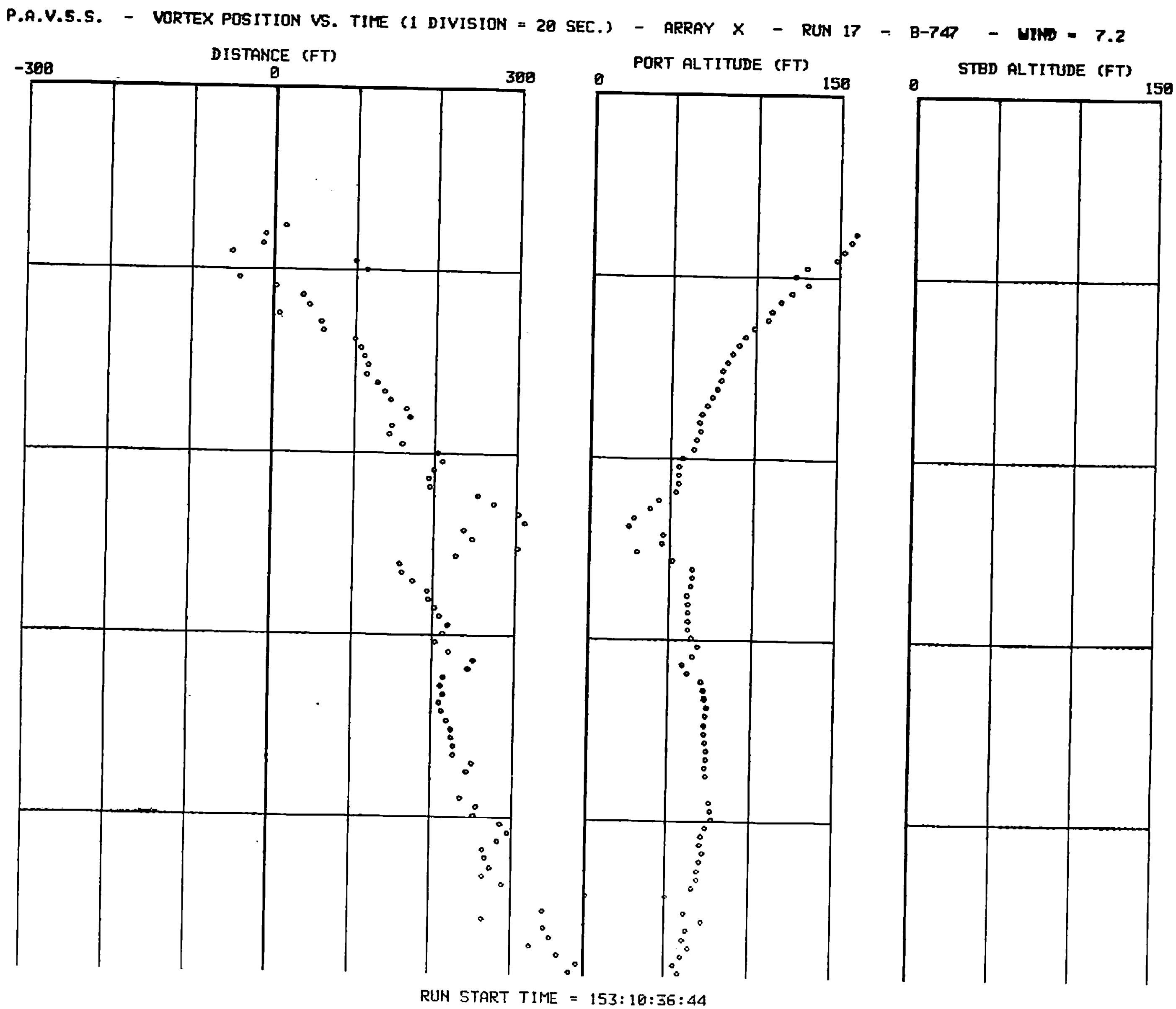


FIGURE 3-17 Vortex Tracks, Boeing 727 (Fog, 7.2 fps Crosswind)

Figure 3-16 shows the tracks of vortices produced by a Boeing 727 landing under foggy, calm conditions. Note that the header data for the plot shows that the crosswind was zero. It must be realized that the wind value is calculated by the system just prior to the start of the run. It appears, however, from the horizontal position data for the starboard vortex, that there was a slight wind in the negative direction--a wind that held the vortex close to the runway centerline extension. Since the system sets up guard bands to keep the vortex trackers from acquiring the LOS signals, the wind shift caused a momentary system blackout at about 50 seconds into the run. This occurs when the difference between the transit time for the vortex-refracted signal and the transit time for the LOS signal is very small (typically, when the vortex is at a low altitude).

Figure 3-17 shows the vortex tracks for a Boeing 747 landing later on the same day. By that time a cross-wind of +7.2 feet per second had developed. This caused the starboard vortex to move out of the field of view of the PAVSS before the system could track its motion. The port vortex, however, under the influence of the crosswind moved across the runway centerline extension. When it interacted with the ground, there was a rapid horizontal acceleration that resulted in the vortex bouncing up and returning to its original path. By the time 90 seconds had elapsed following passage of the aircraft, the vortex had moved 300 feet from the runway centerline.

3.3.3 Other Considerations

Work was done in two areas--software improvement and meteorological effects--additional to those discussed above during the conduct of the PAVSS program.

Avco carried out an investigation to determine whether or not the PAVSS data could provide better vortex tracking capability than that provided by the initially designed software. Problems of false signal rejection, spurious responses, ground clutter, and multiple tracks were all considered. Two subcontractors were engaged to investigate more advanced software approaches. The results of these efforts are reported in Volume II - STUDIES OF IMPROVED PAVSS PROCESSING TECHNIQUES.

Avco also examined the effect of meteorological conditions on PAVSS signal performance. In carrying out this effort, a study was started to determine the validity of using LOS signal characteristics as a measure of the sensitivity of system performance to meteorological conditions. Data from a special array of thermal, humidity, and wind instruments was multiplexed with PAVSS LOS signals and recorded on analog tape. The taped data was then demodulated and the LOS signals digitized to obtain data regarding such characteristics as pulse shape, intensity, and delay as a function of the received frequency and environmental conditions. The PAVSS was fully calibrated when it was relocated at JFK. After that had been completed, but before the system was again operational following the move, the instrumentation trailer at the test site was struck by lightning. This caused damage so extensive that the PAVSS had to be completely reworked. Financial limitations then prevented further work on the meteorological study. One of the anticipated results of the study was definition of an automatic gain setting approach that would automatically compensate for those meteorological conditions that have been found to affect system operation. Since the study was not completed, this result was not achieved. Thus, solution of most of the gain variation problem remains the operator's responsibility (with resultant need for skilled operators).

4. RECOMMENDATIONS

This section presents Avco/SD's recommendations regarding further PAVSS development.

The performance of the engineered PAVSS fully meets, and in fact in many areas exceeds, contractual requirements. It does have several advantages as well as certain disadvantages and limitations. These, along with brief comments regarding each, are noted in Table 4-1.

Avco/SD feels that further work on the PAVSS to overcome these problems would not be economically sound. The technical benefits that would be gained would not be sufficient to offset the disadvantages and limitations inherent in the PAVSS.

TABLE 4-1 PAVSS Advantages and Disadvantages

A. ADVANTAGES

1. Real-Time Capability

The system has outstanding real-time capability for most aircraft types.

2. Hardware Simplicity

The simplicity of the hardware is reflected in very low maintenance requirements.

3. Operator Skills

Less skill is required to operate the pulsed acoustic vortex sensing system than is required to operate the Doppler acoustic vortex sensing system (DAVSS).

4. Produces Smoother Data

The software tracker approach used in the PAVSS results in smoother data presentations than that for the DAVSS.

TABLE 4-1 (Cont'd)

B. DISADVANTAGES AND LIMITATIONS

1. Large Real Estate Requirements

There appears to be no feasible way of reducing the real estate requirements. Baselines of 900 feet are needed to provide appropriate tracking zones.

2. Noise Pollution

Since the antenna design must be kept simple (because of the relatively large number of antennas needed), good side-lobe rejection is difficult to achieve. Thus, there exists a noise pollution problem in the site area. This problem is aggravated by the fact that performance is better at a transmitting frequency of 2000 Hz. (Unfortunately, this is the frequency of maximum ear response.)

3. Does Not Track All Aircraft Vortices

The PAVSS does not track vortices generated by Boeing 707 and McDonnell Douglas DC-8 aircraft probably because of the large diameter (and resultant low refraction angles) of these vortices. Capability for tracking vortices generated by these aircraft could probably not be incorporated without making substantial

TABLE 4-1 (Concl'd)

changes in the design of the antennas and in their deployment. Although the tracking capability of the system can be bettered by software improvements, the PAVSS will remain incapable of tracking all aircraft vortices.

4. Requires Skilled Operators

The PAVSS's sensitivity to environmental conditions requires operator skill to set the receiver gain levels. This could be corrected via hardware/software modifications based on using presence of the LOS signal as a criterion for computerized setting of the gain levels. This approach assumes, however, that the LOS signals are always present and that their levels are sufficient to permit meaningful gain setting. This would have to be confirmed by appropriate tests. This single improvement does not appear practical in the light of the other disadvantages of the PAVSS and the existence and advantages of the monostatic Doppler acoustic vortex sensing system.

5. Cannot Produce Vortex Circulation Data

Since the PAVSS detects refracted signals, Doppler shifts due to vortex circulation velocities cannot be detected. The system, therefore, cannot define the degree of hazard presented by the vortex being tracked.

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