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AVOSS Windline at Dallas/Ft.Worth Airport

Volume 2

Data Base of Ground-Based Anemometer Measurements of Wake Vortices

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13. ABSTRACT (Maximum 200 words)

A 259-meter array of horizontal and vertical single-axis anemometers mounted on 9-meter poles was installed at the Dallas/Ft. Worth Airport (DFW) under the approach to Runway 17C, as part of NASA's Aircraft VOrtex Spacing System (AVOSS) development program. Real-time processing algorithms were developed that based the vortex detection threshold on the turbulence level. Data from more than 70,000 landings have been recorded and processed. This report documents the current state of algorithm development and provides processed data for other researchers to analyze.

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PREFACE

The activities described in this report were conducted by the Volpe National Transportation Systems Center (Volpe Center) in support of the NASA Langley Research Center (NASA) and their development of the Aircraft VOrtex Spacing System (AVOSS). Dallas-Fort Worth (DFW) International Airport was selected by NASA as the primary test bed for the engineering model of AVOSS. AVOSS uses wake sensors to validate predicted wake behavior. A prior installation, also as part of the NASA AVOSS Program, but supported by the Federal Aviation Administration, was made in 1995 at Memphis Airport. Additional AVOSS-related test activities were conducted at the FAA/Volpe Center Wake Turbulence Test Site at Kennedy International Airport (JFK) in 1996 and 1997.

The Volpe Center deployed a windline at DFW under the approach to Runway 17C. The windline operates completely automatically and has been operating much of the time since initial installation in September 1997. The windline, which qualifies as a real-time, all-weather vortex sensor, provides vortex lateral position data and estimates of height and circulation under all weather conditions.

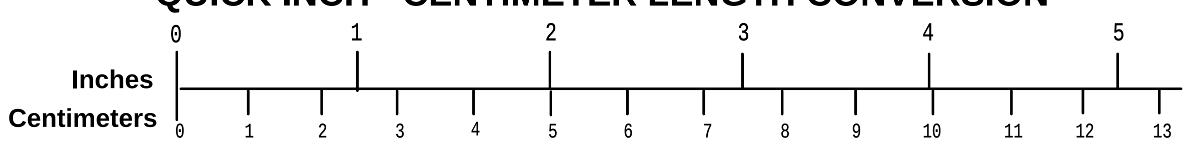
This report, Volume 2 of a two-volume report, describes some improvements in the processing algorithms that have had some success in extracting height and circulation values from such measurements, and presents analyses of more than 70,000 landings at DFW Airport over the time period 1997-1999.

The authors would like to acknowledge the support of Kevin Clark, Joe Ruggerio, Lynne Osovski, and Brian Berkwitz, who supported the data acquisition and real-time processing software; and David Hazen, who managed and validated the data files coming from the site.

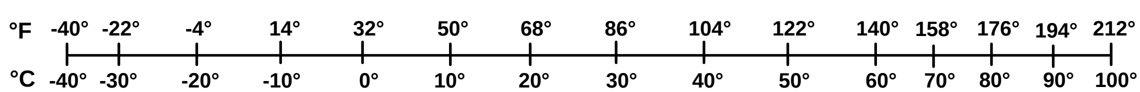
METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC		METRIC TO ENGLISH	
LENGTH (APPROXIMATE)		**LENGTH** (APPROXIMATE)	
1 inch (in)	= 2.5 centimeters (cm)	1 millimeter (mm)	= 0.04 inch (in)
1 foot (ft)	= 30 centimeters (cm)	1 centimeter (cm)	= 0.4 inch (in)
1 yard (yd)	= 0.9 meter (m)	1 meter (m)	= 3.3 feet (ft)
1 mile (mi)	= 1.6 kilometers (km)	1 meter (m)	= 1.1 yards (yd)
		1 kilometer (km)	= 0.6 mile (mi)
AREA (APPROXIMATE)		**AREA** (APPROXIMATE)	
1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)	1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)	1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)	10,000 square meters (m^2)	= 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)		
MASS - WEIGHT (APPROXIMATE)		**MASS - WEIGHT** (APPROXIMATE)	
1 ounce (oz)	= 28 grams (gm)	1 gram (gm)	= 0.036 ounce (oz)
1 pound (lb)	= 0.45 kilogram (kg)	1 kilogram (kg)	= 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)	1 tonne (t)	= 1,000 kilograms (kg)
			= 1.1 short tons
VOLUME (APPROXIMATE)		**VOLUME** (APPROXIMATE)	
1 teaspoon (tsp)	= 5 milliliters (ml)	1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	= 15 milliliters (ml)	1 liter (l)	= 2.1 pints (pt)
1 fluid ounce (fl oz)	= 30 milliliters (ml)	1 liter (l)	= 1.06 quarts (qt)
1 cup (c)	= 0.24 liter (l)	1 liter (l)	= 0.26 gallon (gal)
1 pint (pt)	= 0.47 liter (l)		
1 quart (qt)	= 0.96 liter (l)		
1 gallon (gal)	= 3.8 liters (l)		
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)	1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)	1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)		**TEMPERATURE** (EXACT)	
[(x-32)(5/9)] °F	= y °C	[(9/5) y + 32] °C	= x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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1. INTRODUCTION

In 1994, the John A. Volpe National Transportation Systems Center (Volpe Center) installed a ground-wind wake vortex tracking system[1] [now termed a "windline," for brevity] at New York's Kennedy Airport at the same Runway 31R approach region used for testing[2] in the 1970s. The new installation consisted[3] of an array of two-axis anemometers (vertical wind and crosswind). The headwind was also measured[4] at the ends of the array. The data collection system operated automatically. Aircraft arrivals were detected automatically with noise monitors; each arrival generated a data file containing data until the next arrival or 180 seconds later, whichever came first. A single report[5] documented data collection, processing algorithms and databases from the first JFK deployment (September 1994 to June 1995). The JFK report provided the model for this report.

Another windline was installed[6] at the Memphis, Tennessee airport after the termination of the first JFK deployment; it operated from August 1995 to December 1995. The JFK site was reestablished in August 1996 and used for the NASA JFK-1, JFK-2, and JFK-3 wake vortex sensor tests in November 1996, May 1997, and October 1998, respectively.

An anemometer array was installed at the Dallas/Ft. Worth (DFW) Airport in September 1997, as part of the NASA Langley Research Center AVOSS-1 test. The unique feature of the DFW deployment was completely automatic, real-time data processing. This report presents data collected during the AVOSS-1 test (September 17, 1997 – October 9, 1997), and in subsequent test periods. Each test period was approximately 1 month long and included data of consistent validity; many periods were terminated by lightning damage of the data acquisition system or by anemometer malfunctions.

The purpose of this report is to (1) document the changes in processing algorithms since the JFK report[5], (2) present preliminary results of the DFW wake vortex measurements and (3) make the wake vortex data set available to other researchers. Section 2 describes the data collection and Section 3 the data processing. Section 4 describes the databases provided on the CD ROM, which is in a pocket on the inside back cover of this report volume.

2. DATA COLLECTION

2.1 DATA DIGITIZATION

2.1.1 Sensor Descriptions

Table 1. Analog Sensors Recorded

Sensors	Units	Number	Total Channels
Two-Axis Anemometers	m/s	15	30
Three-Axis Anemometers	m/s	3	9
Noise	0.1 volt	1	1
Temperature	°C	1	1
Humidity	%	1	1
Wind Speed/Direction		2	2
TOTAL		23	44

The sensors listed in Table 1 were digitized by five Campbell Scientific data acquisition systems (CSDAS #n, n=1-5). CSDAS #1-3 report in low-resolution binary format (two bytes per channel) and record the propeller anemometer and aircraft noise data. CSDAS #4-5 report in ASCII format and record temperature, humidity and wind speed/direction. The first three CSDAS sample the sensors at 10 Hz and report 2-second averages every 2 seconds. Since the three CSDAS may not be synchronized, the data acquisition system prefixes the second the message was detected (in hundredths of a second) in standard Campbell low resolution format. Since the message channels are scanned every half second, the actual resolution on the message time tags is only 1/2 second (not the 1/18 second resolution of the computer clock). The wind units are meters/second/second. The aircraft noise units are 0.1 volts.

Table 2. Anemometer Pole Locations

Pole	Distance (m) from Runway Centerline	Height(m)	Number Axes
01	-107	9	3
02	-91	9	2
03	-72	9	2
04	-61	9	2
05	-46	9	2
06	-31	9	2
07	-16	9	2
08	0	9	3
09	16	9	2
10	31	9	2
11	46	9	2
12	61	9	2
13	76	9	2
14	91	9	2
15	107	9	2
16	122	9	2
17	137	9	2
18	152	9	3

All propeller anemometers were installed at approximately 9-m height on 18 fiberglass poles at locations given in Table 2. The three-axis anemometers measure crosswind, vertical wind and headwind. The two-axis anemometers measure crosswind and vertical wind. The sign convention is defined with respect to a pilot landing on Runway 17C at DFW; positive lateral distances and crosswinds are toward the pilot's right hand. The array was installed 983 meters from the runway threshold.

The propeller anemometers were manufactured by the R. M. Young Company with a current Model No. of 27106R. The four-bladed propellers are made of black polypropylene, have a distance constant of 2.7 meters and a starting speed of 0.5 starting speed of 0.5 meters/second, and have an approximate cosine wind response. The calibration of each anemometer was checked for nominal response (17.2 meters/second per volt).

The aircraft detector consisted of a horn-type loudspeaker aiming upward toward the arriving aircraft. A drain hole was drilled in the horn to allow water to drain out. In the wintertime the mount of the horn was covered with plastic to keep out rain and snow. The signal from the horn loudspeaker was amplified and rectified to produce the noise signal that was digitized.

Table 3. 1994-1995 Data Acquisition System Channel Assignments, Parameter Names

Channel	CSDAS #1		CSDAS #2		CSDAS #3	
0	ID=1		ID=2		ID=3	
1	500 ft	V18	150 ft	V11	0 ft	ACNO
2	500 ft	H18	150 ft	C11	-200 ft	V04
3	500 ft	C18	100 ft	V10	-200 ft	C04
4	450 ft	V17	100 ft	C10	-235 ft	V03
5	450 ft	C17	50 ft	V09	-235 ft	C03
6	400 ft	V16	50 ft	C09	-300 ft	V02
7	400 ft	C16	0 ft	V08	-300 ft	C02
8	350 ft	V15	0 ft	H08	-350 ft	V01
9	350 ft	C15	0 ft	C08	-350 ft	H01
10	300 ft	V14	-50 ft	V07	-350 ft	C01
11	300 ft	C14	-50 ft	C07		
12	250 ft	V13	-100 ft	V06		
13	250 ft	C13	-100 ft	C06		
14	200 ft	V12	-150 ft	V05		
15	200 ft	C12	-150 ft	C05		

2.1.2 Parameter Names

Table 3 describes the channel assignments. The 3- or 4- character codes assigned to each sensor are included. The anemometer axes are labeled Cnn, Vnn or Hnn, where nn refers to the pole number and C, V, or H refer to the crosswind, vertical wind, or headwind component, repectively. ACNO is the aircraft noise.

The standard deviations of the wind component measurements are calculated every minute and are named by prefixing a "T" for turbulence, e.g., TVnn. According to Monin-Obukhof similarity theory[7], TVnn is a better indication of atmospheric turbulence in the boundary layer than TCnn or THnn, which are influenced by large scale eddies that affect the wind direction.

2.2 DATA ACQUISITION

The primary data acquisition system (DAS) is hosted in an industrial PC and was derived from an available weather data acquisition system. The DAS accepts data from up to 32 serial ports. The DAS software operates under the Desqview multitasking environment. The DAS operating information is specified in a configuration file, which defines the message format and storage requirements for each serial channel. The main data acquisition program is called WVx, where, e.g., x ='N,' is the version of the program (version N was installed in the summer of 1999). Version N features:

1. Clock time taken from fileserver to give uniform times for all data,
2. Aircraft arrival information broadcast over the network,[(Note 1)] and

[1] This capability was developed first at the JFK test site for the October 1998 JFK-3 test. Data from all four aircraft sensors (acoustic, RASS, lidar range finder and Mode-S receiver) were broadcast over the network and could be displayed and recorded anywhere on the network. At DFW, only acoustic detection is currently in use, but the lidar range finder may be deployed in the future to assess actual aircraft heights at the windline.

3. Real-time, averaged (5, 10, 15, and 20 minutes) turbulence data incorporated into run file headers so that run files can be processed without external turbulence values.

2.2.1 Equipment Layout

The five CSDAS were located in small shelters along the anemometer array to minimize cable lengths. The DAS was installed in a trailer located near the end of the anemometer array and was one node in a Novell Netware computer network. The network permitted real-time analysis of the data from the anemometer array.

The following four sections describe the various files recorded by the DAS. The third file format (reruns) was used for the wake vortex data analyzed in this report.

2.2.2 Raw Wake Vortex Data Storage

The daily data file is named "WMmmDdd.Yyy," where the capital letters are fixed in the file name and mm is the month, dd is the day and yy is the year. This file stores 1-minute data blocks and is saved on both the local DAS hard drive and the network fileserver. The configuration file used each day is copied to a file named "XMmmDdd.Yyy." Because of the amount of 2-second averaged data, the complete WM file for 1 day contains more than 4 Mbytes. To reduce this file size by eliminating uninteresting data, two options were specified for the amount of data saved in the WM file: (a) all data, or (b) the minute before and 4 minutes after each aircraft arrival, which was detected by measuring aircraft noise near the middle of the anemometer array. Normally, the complete data file was recorded locally and the reduced data file was recorded on the fileserver.

2.2.3 Meteorological Data Storage

A secondary data acquisition program called META receives each 1-minute data block as a mail message (under Desqview) from the primary data acquisition program. It saves the non-binary data as received, but processes the 2-second binary data into 1-minute means and standard deviations, which are stored as ASCII. The meteorological file is named "DMmmDdd.Yyy," and stores all 1-minute data blocks for the day. It is recorded on both the local hard drive and the network fileserver. The configuration file for this file is named "CMmmDdd.Yyy," and was generated by manually editing the file XMmmDdd.Yyy rather than by automatic computer processing, since it was fixed for long periods of time.

The current version of META also processes the windline data to determine averaged, crosswind turbulence values (taken from the low turbulence end of the array, see Section 3.3.1) which are saved in a file called CURRTURB.DAT and also passed back to WVN to be incorporated into the run file headers.

2.2.4 Wake Vortex Run

The traditional wake vortex run file name was "RMmmDdd.nnn," where the capital letters are fixed in the file name and mm is the month, dd is the day and nnn is the number of the aircraft arrival for that day. In March 1998, the file name was changed to include the year (yy): RMyymmdd.nnn. The start of run is defined by the 2-second average of aircraft noise reaching a peak (i.e., noted by a decrease in the next 2-second average) that is above a detection threshold. The start of the next run is suppressed

suppressed for 20 seconds to prevent multiple triggers on the same aircraft (more likely on a 35C departure than a 17C arrival because of the higher altitude). The run file records 2-second data blocks from 10 seconds before the arrival until the next arrival or until 180 seconds has elapsed since the start of the run.

2.2.5 Wake Vortex Rerun Files

Some real-time run files suffered from problems caused by other functions of the real-time data collection software. In April 1998, new software was developed to reprocess the WM files into run files. The generated run files use the newer form for the filename, RMyymmdd.nnn, which includes the year. Several alternative reprocessing programs were developed. One option increases the delay time before another run can occur from the normal 20 seconds to 45 seconds. This change prevents another run from being triggered by thrust-reverser noise. This option is not needed at DFW since the noise sensor was shielded from runway noise by a plywood panel. A second option includes two arrivals in the run file if the second arrival occurs less than 180 seconds after the first; the filename for this option is RTyymmdd.nnn. The signal for the new arrival is that the vortex age drops to 2 seconds when the new arrival is detected. The two-arrival files permit the wake vortices from the first arrival to be tracked after the second. Modifications in the processing software are needed to exercise this option. This report will not consider two-arrival files.

2.2.6 Real-Time Analysis

The data collection program also outputs three files to the network fileserver that can be used for real-time analysis. They will not be discussed in this report.

2.2.7 Clock Time

The data collection clock time was defined by the clock on the fileserver. This clock was set for GMT as derived from a GPS receiver. The data collection computer reboots at midnight and obtains an updated clock time when it logs into the fileserver. As mentioned above, the fileserver clock was read directly by the data acquisition software after the summer of 1999.

2.3 KNOWN SENSOR/SYSTEM FAILURES

The validity of the windline anemometer data was determined by examining daily plots of the mean and standard deviation values saved in the DM files (Section 2.2.3).

1. During the first test period (17-Sep-1997 through 9-Oct-1997) the data from CSDAS #1 was occasionally lost. These times were identified by zero values for H10 and C18 and were flagged as invalid. The first test period terminated on 9-Oct-1997 with lightning damage to much of the data collection system.

2. The second test period started on 5-Feb-1998 and was terminated on 22-Feb-1998 with lightning damage. The days of valid data are from 5-Feb-1998 through 21-Feb-1998.

3. The third data collection period started on 6-Mar-1998 and lasted through 2-Apr-1998. V02 operated incorrectly through this period until it was repaired on 2-Apr-1998. Data analysis for this period will not include V02.

4. The fourth data collection period started on 3-Apr-1998 and terminated on 8-May-1998. All sensors were operational until 9-May-1998 when V02 stopped operating correctly.

5. The fifth data collection period started on 9-May-1998 and terminated on 26-May-1998. V02 was operating incorrectly for this period and will be removed from the analysis. On 27-May-1998 Pole 02 blew down in a 15-meters/second crosswind.

6. The sixth data collection period started on 27-May-1998 and terminated at 2000 on 18-Jun-1998 when C17 died. For this period, since the crosswind C02 is missing for the tracking algorithm, only the data from Poles 03 to 18 will be processed.

7. The seventh data collection period started on 23-Jun-1998 and ended 31-Jul-1998. All sensors were operating correctly. The failed sensors were repaired at 2300 on 22-Jun-1998. Since C17 was out of service for only 4 days, which significantly reduces the utility of the data, the data with C17 missing will not be processed.

8. The eighth data collection period started on 1-Aug-1998 and terminated on 8-Sep-1998. On 9-Sep-1998, V08 developed a weak signal that affected its wake vortex response. C12 developed a starting threshold of about 1 meter/s on 14-Aug-1998; the threshold dropped to a more normal level on 23-Aug-1998. Since the response to vortex crosswinds appeared to be unaffected by this drop in sensitivity, the normal analysis will be used for this period.

9. The ninth data collection period started on 9-Sep-1998 and terminated on 3-Oct-1998 at 1245 when C09 failed. V08 was weak during this time period. V15 was weak (perhaps one third of normal response) on 15-Sep-1998. Since the vertical wind is not critical to vortex tracking and causes problems with the least-square fits only if it is far from correct, the short-duration problem with V15 will be ignored and only V08 will be eliminated from processing for this period.

10. The tenth data collection period started on 5-Nov-1998 with all anemometers except V08 functioning and terminated on 17-Nov-1998 at 1800 when C16 failed.

11. The eleventh data collection period started on 2-Dec-1998 with all sensors functioning and terminated on 20-Dec-1998 with many data collection problems.

12. The twelfth data collection period started on 15-Jan-1999 with all sensors functioning and lasted through 21-Feb-1999. V13 died on 18-Jan-1999 at 1900 and will be considered out for the entire period. V18 was weak for (28-30)-Jan-1999, but showed some vortex response and will be included in the analysis for the whole period. C04 and C15 showed high starting thresholds on some days but responded to wake vortices.

13. The thirteenth data collection period started on 22-Feb-1999 when V18 failed (V13 also still not operating), and continued through 2-Mar-1999.

14. The fourteenth data collection period started on 3-Mar-1999 when V15 failed (V13 and V18 also not operating), and ended on 11-Mar-1999 when all sensors were restored.

15. The fifteenth data collection period started on 12-Mar-1999 and terminated on 30-Mar-1999 after which, aircraft data became unavailable.

3. DATA PROCESSING

Figure 1 illustrates the activities involved in data processing. The real-time programs WVN and META generate the WM (complete data file), RM (run file) and DM (1-minute means and standard deviations) files. The WM files are reprocessed to give rerun RM files. The rerun RM files are processed for aircraft and wind data (AC_ALL). The DM files are processed (JFKMET) into ON daily binary performance files, which are combined (COMBIN) into test period files and then processed (MAKEPRN) to extract selected parameters in comma-separated format.

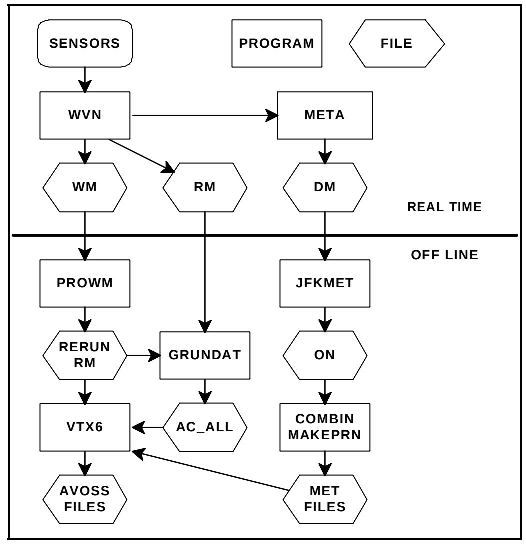

Figure 1. Data Processing Flow Chart

The AC_ALL and MET files are then imported into the relational database program PARADOX. AC_ALL is matched with the FAA aircraft arrival data and MET is processed to obtain averaged turbulence data. The database parameters are then combined with the rerun RM files to generate AVOSS (via VTX6) and other output data output data files.

The following sections describe these processes and the output file formats in detail.

3.1 WAKE VORTEX ALGORITHMS

3.1.1 Version Summaries

The four versions of the processing algorithms are summarized in the following sections.

3.1.1.1 Version 1

Version 1 used low, fixed thresholds on vortex-induced crosswind for starting and stopping vortex tracks and hence was not usable under high turbulence conditions.

3.1.1.2 Version 2

Version 2 was developed to analyze the JFK-1 (November 1996) test data and was the first version to use tracking thresholds that varied with the crosswind turbulence value. A 15-minute average of crosswind turbulence was used.

3.1.1.3 Version 3

Version 3 was developed for real-time processing at the AVOSS-1 test (September-October 1997 at DFW airport). It featured automatic turbulence processing and 10-second smoothing of the wake vortex data to reduce fluctuations in the vortex results. This algorithm was used for real-time processing of the DFW data from September 1997 through June 1998.

3.1.1.4 Version 4

Version 4 was developed for off-line processing of DFW data. The main change from version 3 was designed to avoid tracking vortices from previous arrivals. The vortex was first detected at the time when it generated the greatest induced crosswind. It was then tracked to earlier times until it was lost and then tracked to later times until it was again lost. Logic was also added to ensure that the vortex location where it was detected was consistent with its assumed initial location and the current ambient crosswind. This version is used for this report and was installed at DFW for real-time processing in July 1998.

3.1.2 Input Data

The ground-based anemometer system measures the vertical and cross wind components with an array of anemometer poles laid out on a baseline perpendicular to the aircraft flight path. Pole spacing is 50 ft. Pole height is assumed to be 28 ft, the mean height of the vertical and horizontal anemometers which were separated by about 1 ft. Two-second averages of the anemometer measurements were stored for analysis.

3.1.3 Traditional Algorithm

3.1.3.1 Vortex Location, Ambient Crosswind

The traditional algorithm assigns the vortex positions to the position of the anemometers measuring the maximum and minimum cross wind. As an extension to the traditional algorithm, the median wind may give a reasonable estimate of the ambient crosswind even in the presence of wake vortices.

Input:

Cross wind c_i at pole lateral positions x(i), i = 1, n (n = number of poles)

Calculate:

Maximum cross wind c_{max} at pole i_{max}, Minimum cross wind c_{min} at pole i_{min}

Median cross wind c_{med}

Output:

Max Vortex: position $x_{max} = x(i_{max})$, crosswind c_{max}

Min Vortex: position $x_{min} = x(i_{min})$, cross wind c_{min}

Median cross wind c_{med}

Saving the maximum and minimum crosswinds is also an extension of the traditional algorithm. Since this algorithm is critically dependent on the proper performance of *all* crosswind anemometers, only continuous sequences of valid anemometers can be processed correctly.

3.1.3.2 Vortex Tracking

Start Track: The algorithm should start only when the vortex crosswind can be distinguished from the ambient turbulence. The vortex trajectory starts when the difference between the vortex crosswind and the median crosswind is greater than a limiting value c_{lim}, e.g., $|c_{max} - c_{med}| > c_{lim}$. Ultimately, the choice for c_{lim} should be based on the ambient crosswind turbulence. If the crosswind turbulence is measured in the ten seconds prior to aircraft arrival, this approach has problems with the residual effect of the vortices from the previous landing as well as the very short averaging time. The simpler approach (Version 1) of using a fixed value for c_{lim} (e.g., 2 meters/second) is more reliable, but creates problems in turbulent conditions. See Section 3.1.3.3 for the Version 4 vortex tracking thresholds.

End Track: The simplest stopping algorithm stops the tracking when the difference between the median wind and the vortex wind is below a certain value, perhaps 1 meter/s. A value below the starting limit will follow a vortex longer once it has been detected. This algorithm is blind to normal vortex behavior and needs to be augmented (see section 3.1.3.3) with an algorithm that determines when the vortex goes off the end of the array. Such an algorithm will prevent misidentifying the secondary vortices of the other vortex.

Off End of Array: The end-of-array algorithm has limitations for vortices that change their direction of motion but otherwise appears to give reasonable results. It allows the vortex location to be assigned to the end of the array for 1.5 times the time it spent at the next to last location:

1. See if vortex is in next to last position, count the number of data samples *n* until its location changes.
2. End the track 1.5**n* samples later.

Position Jump - The traditional method of ending a vortex track was to see when the vortex location jumps to a distant location, such as more than two poles away (as used in the current analysis).

3.1.3.3 Version 4 DFW Implementation

The DFW data processing algorithms incorporated a number of improvements:

1. The wind data were averaged for 10 seconds before being processed. This averaging produced much more stable results.

2. The vortex detection thresholds were adjusted for the ambient turbulence level. Each minute the crosswind standard deviation was taken as the minimum value from the two ends of the array. This turbulence value was averaged for 5, 10, 15 and 20 minutes. The 10-minute value was found to be stable enough for reliable use.

3. The track-start threshold was taken as the greater of 1.25 meters/second or 5.0 times the crosswind turbulence.

4. The track-end threshold was taken as the greater of 1.0 meters/second or 3.5 times the crosswind turbulence value. The starting and stopping thresholds were derived from an analysis of how the algorithms performed for about 100 selected AVOSS-1 runs. The goal was to track as many vortices as possible with only a few false alarms. The resulting thresholds were significantly lower

lower than those used in Version 3, which seldom tracked vortices under turbulent conditions.

5. Instead of starting the tracking at the beginning of the run, the tracking was started at the time in the range of from 20 to 60 seconds when each vortex had the greatest induced crosswind. If the induced-crosswind is above the track-start threshold, then the vortex is tracked toward earlier times until it drops below the track-end threshold or jumps more than two poles in location. The vortex is then tracked from that point toward longer times until it reaches the edge of the array, drops below the end-track threshold, or jumps more than two poles. This algorithm is implemented differently for off-line processing (e.g., program VTX6) and real-time processing (e.g., program VTX5 and RTPROC). The off-line algorithm applies the tracking algorithm after all the data for a run have been received. The real-time algorithm first processes the available data 60 seconds after the arrival; it then completes the tracking to later times as the data are received and terminates the processing when no vortices remain.

6. The tracking of the vortex from the point of maximum induced crosswind is subject to a validity test based on comparing the expected vortex transport speed under the influence of the median crosswind with the actual vortex transport speed. The expected transport speed is equal to the median crosswind ±0.5 meters/second (- for min vortex, + for max vortex). The actual transport speed assumes that the initial vortex location (age 0) is ±20 meters (- for min vortex, + for max vortex) and uses the location and age of the maximum induced crosswind as the final vortex location. The two calculated values must agree to within 2 meters/second +0.2 times the absolute value of the median crosswind.

3.1.4 Image Vortex Model

The image vortex model accounts for the fact that the vertical wind must be zero at the ground. This boundary condition can be assured if the vortex flow field is computed from the real vortex above the ground (circulation = Γ, lateral position = X, height = Z > 0) and an image vortex (circulation = $-\Gamma$, lateral position = X, height = -Z) located below the ground. Figure 2 shows the geometry of this calculation. A positive circulation rotates in the counterclockwise direction. Define G = $\Gamma/2\pi$; then the vortex tangential velocity = G/(vortex radius) as long as the point of interest lies outside the vortex core. G is positive for the max vortex and negative for the min vortex. Derive the wind components at position (x,z) from the real vortex (see left plot in Figure 2):

Distance from real vortex center = r = $\text{sqrt}[(z-Z)^2+(x-X)^2]$; Tangential velocity = G/r

z component = $(G/r)\,(x-X)/r = G(x-X)/r^2$ [x-X is positive in Figure 2, z component is positive]

x component = $-(G/r)\,(z-Z)/r = -G(z-Z)/r^2$ [z-Z is negative in Figure 2, x component is positive]

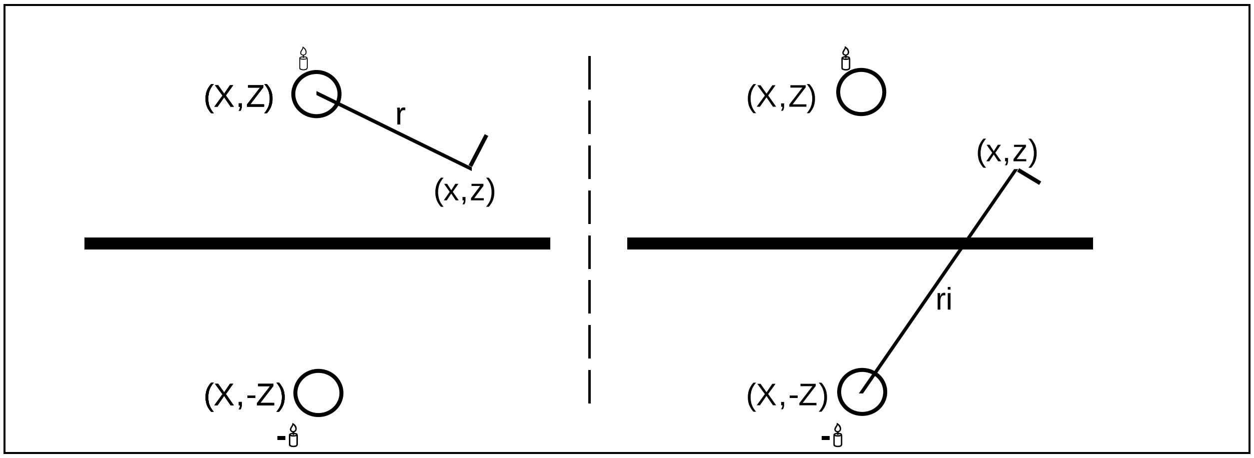

Figure 2. Velocity Contributions from Real Vortex (left) and Image Vortex (right)

The corresponding results for the image vortex (see right plot in Figure 2) are:

Distance from image vortex center = ri = sqrt$[(z+Z)^2+(x-X)^2]$; Tangential velocity = G/ri

z component = (-G/ri) (x-X)/ri = $-G(x-X)/ri^2$ [x-X is positive in Figure 2, z component is negative]

x component = (G/ri) (z+Z)/ri = $G(z+Z)/ri^2$ [z+Z is positive in Figure 2, x component is positive]

Combining the velocity components from real and image vortices gives the vortex velocity at lateral position x and height z:

Vertical component: $W(x,z,X,Z,G) = G(x-X)\{1/[(z-Z)^2+(x-X)^2]-1/[(z+Z)^2+(x-X)^2]\}$

Cross component: $U(x,z,X,Z.G) = G\{(z+Z)/[(z+Z)^2+(x-X)^2]-(z-Z)/[(z-Z)^2+(x-X)^2]\}$

For multiple vortices, the wind components from each are simply added. The mean ambient cross wind is added to the vortex cross winds. The mean ambient vertical wind is zero.

3.1.5 Least-Square Fit to Vortex Pair

The least-square fit is carried out by:

1. Estimating the initial vortex positions (X,Z) and circulations (Γ) for the vortices (one or two) being tracked and estimating the ambient cross wind C.
2. Calculating the vertical w(i) and horizontal u(i) winds at each anemometer location (x(i),z(i)) using the estimated vortex and ambient wind parameters:

$$w(i) = W(x(i),z(i),X_{max},Z_{max},G_{max}) + W(x(i),z(i),X_{min},Z_{min},G_{min})$$

$$u(i) = C + U(x(i),z(i),X_{max},Z_{max},G_{max}) + U(x(i),z(i),X_{min},Z_{min},G_{min}$$

3. Calculating the sum of the squares of the differences between the estimated (w(i), u(i)) and measured (v_i, c_i) vertical and cross wind components:

$$Sum = \Sigma\ (i=1,N)\ [(w(i)-v_i)^2 + (u(i)-c_i)^2].$$

4. Varying the initial estimates until the sum of the squares is minimized.

The least-square method works best if the parameters have more or less independent effects on the difference between the measured and calculated values. The vortex height and circulation do not meet this criterion since the maximum vortex wind is proportional to the ratio of circulation to height. Therefore, this ratio is taken as one of the parameters to fit. The specific parameter used is $vm = \Gamma/2\pi z$, which is approximately the maximum vortex cross wind. The height z is used as the other parameter; given vm, it then specifies the spatial width of the vortex cross wind profile.

The initial values are taken from the traditional tracking algorithm:

$X = x_{min}$ or x_{max},	Initial increment = 8 meters
Z = 30 meters	Initial increment = *0.2
$vm = c_{min}-c_{lim}$ or $c_{max}-c_{lim}$	Initial increment = *0.2
Cross wind = c_{med}	Initial increment = 0.7 m/s

Two approaches are used to vary the parameters, a constant increment or a fractional increment. The type and initial size of the increment are listed above. After the minimum sum of squares is found for the initial increments, the size of the increment is reduced by a factor of two and the process is repeated. After the third increment reduction, the best fit parameters are accepted as the fit. The parameters are varied in turn up or down by one increment. If a lower sum of squares is achieved, then the new value of the parameter is kept. The parameters are passed through many times until no parameter is changed. If too many passes through the parameters (30) are taken before the minimum is achieved, the fitting process is abandoned as unsuccessful.

Depending upon the mode, the routine uses the measured wind values to return the sum of the squares of the errors, or returns the calculated wind values.

Including invalid anemometers in the least-square fit can lead to erroneous results. In the summer of 1998, provisions were made in the software to exclude invalid anemometers from the fit. Since valid tracking requires all crosswind anemometers to be functional, this provision is used only when vertical anemometers are not functioning.

3.1.6 Least-Square Fit Including Secondary Vortices

When a vortex is located far enough from the end of the anemometer array, it is possible for the anemometer array to detect opposite-sign secondary vortices (caused by the interaction of the primary vortices with the boundary layer); they can be added to the fitting process, thereby allowing up to four vortices. The secondary vortices are assumed to be:

1. Located outside the primary vortices (initial lateral position taken as 25 m outside the primary vortex),
2. Weaker than the primary vortex [initial vm value of -0.4*(primary vortex vm)] and
3. At a nominal height of 30 meters.

As yet, no criteria for rejecting secondary vortices have been determined. However, it is clear that when the secondary vortex lies on top of the primary vortex, it simply subtracts from the circulation of the primary vortex.

3.1.7 Classical Vortex Trajectory Model

The image model described above does not consider the dynamics of vortex motion. It can be integrated to give classical motion where vortices created at spacing b' descend toward the ground at speed G/b' and then separate and propagate laterally at height b'/2. This model does not account for the interaction of the vortices with the boundary layer, but should give an approximate estimate for the early life of the vortices with the assumption of no circulation decay.

3.2 VORTEX PARAMETERS

The fitted vortex parameters are generated and output by a program called OUTFIT. The output file is called VTX.TXT and is in comma-separated format. The filename is used to identify the run. The vortex is identified by a number (0 for min vortex, 1 for max vortex). The vortex age and vortex induced crosswind are included. The fitted parameters of lateral position, height and circulation are included. If a least-square fit to the vortex could not be made, the record was not saved. Each output record was coded with a one-character code to specify why it was saved. The following sections describe the codes and suggest possible uses for the records.

3.2.1 Times - T

The records were saved for integral multiples of 10 seconds, starting at 20 seconds. These records might be used, for example, to select vortices that were stalled near the runway centerline at age 60 or 80 seconds.

3.2.2 Last Point - L

The last point indicates the vortex lifetime within the array and places an upper limit on the times for the other codes.

3.2.3 Maximum Velocity Point - M

The maximum velocity typically occurs when each vortex is closest to the ground and hence is most readily measured by the ground-based anemometers.

3.2.4 Paired Maxiumum Velocity Points - B,A

For some purposes it is useful to have equal-age data when both vortices are low. The B code selects the time of the maximum sum of the crosswinds for the two vortices. The A code goes back in time from the B code to the point where the sum of the two crosswinds is less than 80 percent of the maximum value.

The B and A code data can be used to integrate the vortex image motions back to age zero (as in Section 3.1.7) using the dynamic image model. The initial parameters given will be the mean lateral motion (assuming the aircraft was on the runway centerline), the vortex spacing, and the vortex height. The vortex separation and circulation values can be combined to estimate the aircraft mass.

3.2.5 Vortex Crosswind Limits - 3,4,6,8

For decay studies it may be useful to define vortex lifetimes that are relatively unaffected by atmospheric turbulence. Such lifetimes would permit the influence of turbulence on lifetime to be studied. As a first cut toward such lifetimes, the last time was recorded where the vortex crosswind remained above four threshold values, 4.0, 3.0, 2.0, and 1.5 meters/second. These lifetimes are indicated by a code value equal to twice the threshold value (8, 6, 4, and 3, respectively). Vortex-induced crosswind values are calculated before the vortex tracking algorithms are applied. Consequently, the record will be missing if the vortex track is terminated by going off the end of the array before the crosswind drops below the threshold.

3.2.6 All Times - t

The program OUTFIT saves only selected data points for two reasons:

1. To reduce the size of the data file, and
2. To facilitate subsequent data analysis.

For some purposes, however, it is useful to have all the valid data points. The program OUTALL generates an output file called VTXALL.TXT which contains all the valid data points. The code character is “t.”

3.2.7 AVOSS V1.8 Format

The NASA AVOSS format is designed to provide a common file format for a variety of wake vortex sensors. Perhaps the easiest way of describing the AVOSS windline format is to examine a sample file (see Table 4). Note that a value of 9999 means no data and that lines beginning with ‘#’ are considered comments by standard AVOSS processing algorithms.

1. The top line is the header for the data records at the end of the file.

2. The second line identifies the runway.

3. The third and fourth lines give the parameter names and values for significant windline parameters. The first two, respectively, specify whether the port and starboard vortices were detected (0 = no, 1 = yes) inside the safety corridor (See Table 5 later). These parameters help interpret the measured residence times. If the vortex was detected only outside the corridor, then its residence time may be larger than the actual residence time. The next two parameters specify, respectively, which side (P = port, S = starboard) of the corridor the port and starboard vortices exit. This information may be useful for detailed evaluation of residence time algorithms. The next two parameters give the threshold vortex-induced crosswind values (meters/second) for starting and stopping vortex tracking, respectively. The final parameter defines whether the vortex tracking was terminated abnormally (0 = no, 1 = yes), for example by the next aircraft arrival or the end of the data file.

This parameter specifies whether file contains the complete windline dataset for the arrival.

4. The fifth and sixth lines give meteorological data for the arrival. The first two parameters give the headwind and crosswind (meters/ second) averaged over the first 60 seconds of the run. The second two parameters give the last available 1-minute-average (computed at the end of each minute) headwind and crosswind before the arrival. The last three parameters are 10-minute averages of turbulence available at the aircraft arrival time. The first and third are the standard deviations of the crosswind and headwind, taken from the upwind end of the array. The second is the standard deviation of the crosswind, using the minimum value for the two ends of the array. This value was also used to derive the thresholds for starting and stopping tracking.

Table 4. Sample AVOSS 1.8 File: VN981106.127

```
#age,y_port,deltaYP,z_port,deltaZP,circ_p,y_stb,deltaYS,z_stb,deltaZS,
circ_s
#DFW Runway 17C
#detected_p,detected_s,exit_p,exit_s,victhresh_start,victhresh_stop,
artificial_termination
#0, 0,    S,    S, 1.25, 1.00, 0
#run_hwind,run_xwind,hwind,xwind,xturb,xminturb,vertturb
#0.15,1.89,0.45,1.80,0.24,0.23,0.15,
wl1,983, 0, 0, 981106, 140525
MD80, 140525, 9999
983
34, 9999, 9999, 9999, 46, 9999, 9999, 9999,
34, 9999, 9999, 9999, 46, 9999, 9999, 9999,
9999, 9999, 9999, 9999, 9999, 9999, 9999, 9999, 9999, 9999, 9999, 9999
22
 32,  61.0,  9999,  12.8,  9999,   -22,  9999,  9999,  9999,  9999,  9999
 34,  61.0,  9999,  12.8,  9999,   -25,  9999,  9999,  9999,  9999,  9999
 36,  61.0,  9999,  12.0,  9999,   -23,  9999,  9999,  9999,  9999,  9999
 38,  62.0,  9999,  13.1,  9999,   -32,  9999,  9999,  9999,  9999,  9999
 40,  63.0,  9999,  15.6,  9999,   -48,  9999,  9999,  9999,  9999,  9999
 42,  66.0,  9999,  20.0,  9999,   -68,  9999,  9999,  9999,  9999,  9999
 44,  85.0,  9999,  27.7,  9999,  -149, 115.9,  9999,  26.4,  9999,   150
 46,  85.4,  9999,  20.5,  9999,  -100, 117.2,  9999,  13.5,  9999,    74
 48,  90.4,  9999,  25.2,  9999,  -147, 117.2,  9999,  19.4,  9999,   123
 50,  92.4,  9999,  26.3,  9999,  -143, 127.2,  9999,  23.4,  9999,   119
 52,  96.7,  9999,  23.4,  9999,  -107, 134.2,  9999,  13.4,  9999,    63
 54, 108.7,  9999,  32.7,  9999,  -179, 134.2,  9999,  14.8,  9999,    81
 56, 108.7,  9999,  16.6,  9999,  -101,  9999,  9999,  9999,  9999,  9999
 58, 113.9,  9999,  18.1,  9999,  -112,  9999,  9999,  9999,  9999,  9999
 60, 115.9,  9999,  19.2,  9999,  -119,  9999,  9999,  9999,  9999,  9999
 62, 121.9,  9999,  21.2,  9999,  -139,  9999,  9999,  9999,  9999,  9999
 64, 125.9,  9999,  22.1,  9999,  -165,  9999,  9999,  9999,  9999,  9999
 66, 135.2,  9999,  28.4,  9999,  -177,  9999,  9999,  9999,  9999,  9999
 68, 138.2,  9999,  34.1,  9999,  -226,  9999,  9999,  9999,  9999,  9999
 70, 141.4,  9999,  29.2,  9999,  -208,  9999,  9999,  9999,  9999,  9999
 72, 155.4,  9999,  42.1,  9999,  -334,  9999,  9999,  9999,  9999,  9999
 74, 160.4,  9999,  54.4,  9999,  -439,  9999,  9999,  9999,  9999,  9999
```

5. The seventh line gives the windline number (Line 1 is under the approach to Runway 17C) , the distance (983 meters) from runway threshold, the lateral and vertical positions of the sensor, and the date and time of the arrival.

6. The eighth line gives aircraft type using standard FAA 4-character names and the UTC arrival times, sensor (014907) and radar-based.

7. The ninth line gives the longitudinal position of the measurement.

8. The tenth through twelfth lines give various exit times (horizontal transport time, vertical transport time, combined transport time and demise time) within three defined safety corridors. Table 5 defines the first two [the third is now undefined]. The values of Ylim are the same for the two

Table 5. Safety Corridor at Windline

	Option 1	Option 2
Ylim	±47.5 m	±47.5 m
Zlim	6.3 m	46.3 m

options. The values of Zlim are quite different, however. For Option 1 (tenth line) the limiting value is so low that virtually no vortex will ever descend below the limit. On the other hand, the windline will rarely detect a vortex unless it is lower than Zlim for Option 2 (eleventh line). Since windline circulation measurements are too uncertain to reliably define vortex demise (at 90 meters^2/s), the demise parameter is not appropriate. Therefore, only the horizontal transport time makes sense for the windline. The exit time (time for two detections outside the ± 47.5-meter corridor) is 34 and 46 seconds for the port and starboard vortices, respectively.

8. The thirteenth line gives the number of following data lines.

9. In the data lines, the vortex parameters are lateral position, height and circulation, along with accuracy estimates of each. Since no accuracy estimates have yet been developed for the windline, these parameters are not included.

3.2.8 AVOSS V1.8 Log Files

The program that generates the AVOSS 1.8 files, also generates log files that summarize the processing. Table 6 shows the file that is generated for each day. It identifies the location as DFW and includes the daily windline run number (fourth field). The number of records and port and starboard residence times are then listed. The rest of the line lists the special windline parameters and the meteorological parameters listed at the top of the AVOSS 1.8 file. The complete log file listed in Table 7 omits the location and combines the date and run value into the format used in the run file name. The complete file contains all the runs processed for a period and is the most convenient place to start further analysis of the residence time results.

Table 6. Sample AVOSS Format Daily Log File

```
DFW 17C, 981106, 140525, 127, MD80,  22,   34,   46, 0, 0,    S,    S,   1.25,   1.00, 0, 0.15, 1.89, 0.45, 1.80, 0.24, 0.23, 0.15
DFW 17C, 981106, 140645, 128, B752,  22,   36, 9999, 1, 0,    S,    S,   1.25,   1.00, 1, 0.24, 2.58, 0.85, 2.03, 0.24, 0.24, 0.15
DFW 17C, 981106, 140801, 129, MD80,   6,   48,   40, 0, 0,    S,    S,   1.40,   1.00, 0, 0.23, 2.32, 0.88, 2.38, 0.28, 0.28, 0.16
DFW 17C, 981106, 140919, 130, MD80,  19,   32,   22, 0, 0,    S,    S,   1.50,   1.05, 0, 0.25, 2.33, 0.86, 2.34, 0.30, 0.30, 0.16
DFW 17C, 981106, 141058, 131, MD80,   0, 9999, 9999, 0, 0, 9999, 9999,   1.50,   1.05, 0, 0.13, 2.44, 0.65, 2.42, 0.30, 0.30, 0.17
DFW 17C, 981106, 141225, 132, MD80,  19,   52,   34, 0, 0,    S,    S,   1.60,   1.12, 0, 0.21, 1.79, 0.79, 2.35, 0.32, 0.32, 0.17
DFW 17C, 981106, 141357, 133, F100,  18,   34, 9999, 1, 0,    S, 9999,   1.50,   1.05, 0, 0.18, 1.93, 0.71, 1.92, 0.30, 0.30, 0.15
```

Table 7. Sample AVOSS Format Complete Log File

```
981106.127, 140525, MD80,  22,   34,   46, 0, 0,    S,    S,   1.25,   1.00, 0, 0.15, 1.89, 0.45, 1.80, 0.24, 0.23, 0.15, 4, 2, 160, 74, 134,
981106.128, 140645, B752,  22,   36, 9999, 1, 0,    S,    S,   1.25,   1.00, 1, 0.24, 2.58, 0.85, 2.03, 0.24, 0.24, 0.15, 1, 2, 153, 70, 130,
981106.129, 140801, MD80,   6,   48,   40, 0, 0,    S,    S,   1.40,   1.00, 0, 0.23, 2.32, 0.88, 2.38, 0.28, 0.28, 0.16, 3, 2, 85, 48, 142,
981106.130, 140919, MD80,  19,   32,   22, 0, 0,    S,    S,   1.50,   1.05, 0, 0.25, 2.33, 0.86, 2.34, 0.30, 0.30, 0.16, 2, 2, 131, 56, 152,
981106.131, 141058, MD80,   0, 9999, 9999, 0, 0, 9999, 9999,   1.50,   1.05, 0, 0.13, 2.44, 0.65, 2.42, 0.30, 0.30, 0.17, 0, 0, 9999, 9999, 9999, 9999
981106.132, 141225, MD80,  19,   52,   34, 0, 0,    S,    S,   1.60,   1.12, 0, 0.21, 1.79, 0.79, 2.35, 0.32, 0.32, 0.17, 2, 2, 161, 68, 152,
981106.133, 141357, F100,  18,   34, 9999, 1, 0,    S, 9999,   1.50,   1.05, 0, 0.18, 1.93, 0.71, 1.92, 0.30, 0.30, 0.15, 2, 0, 112, 62,9999,9999
```

Six additional parameters are added for the complete data file in Table 7. The first two specify how the port and starboard vortex tracks were terminated:

0 Never detected

1 Track not terminated (because of abnormal termination)

2 Induced crosswind dropped below threshold

3 Location jumped more than two poles

4 Vortex transported off end of array

The next two parameters show, for the port vortex, the maximum distance (meters) from the extended runway centerline where the vortex was detected (absolute value) and the time (sec) for the maximum distance. The final two parameters are the same parameters for the starboard vortex.

3.3 METEOROLOGICAL PARAMETERS

3.3.1 From Run File

The program GRUNDAT processes the parameters listed in a file SAVE.DAT to characterize the meteorological conditions of the run. The program processes up to 30 data points (first minute of run) to determine the mean and standard deviation of the parameter. The outputs of GRUNDAT are saved in a file named AC_ALL.TXT which has comma-separated variable format. The normal contents of SAVE.DAT are the three wind components at the middle and each end of the anemometer array (H01, C01, V01, H08, C08, V08, H18, C18 and V18).

For the purpose of assessing the validity of the ground-based anemometer measurements, the crosswind standard deviations, TC01 and TC18, are probably most relevant, since variations in crosswind directly affect the vortex tracking algorithm. Since the wake vortices may reach the end of the array and affect the TC values, a way of estimating the ambient crosswind variance is to take the minimum value (MinTC) of TC01 and TC15. This algorithm is applied as a Paradox script after the AC_ALL.TXT file is imported into a Paradox database.

The turbulence parameters from the run files have too short an averaging time and therefore typically have variations of a factor or two from run to run. The values of the head and crosswind from the run file are more useful and are included in the RUNDATA database. These are the actual values for the first 60 seconds of the run and should correlate well with vortex transport. The mean crosswind from the two ends of the array are calculated (C01 & C18), and the head and crosswind values are taken from the upwind end.

3.3.2 DM File

The data from the DM files are entered into a database. Average turbulence values are calculated using a Paradox script for 5-, 10-, 15-, and 20-minute averaging times using the upwind algorithm for crosswind and vertical wind turbulence values and the minimum crosswind turbulence algorithm for crosswind turbulence. The four minimum-crosswind turbulence values are put into the header of the run files and used for processing the run files.

4. DATABASES

This chapter describes the databases provided on CD ROM.

4.1 TEST PERIODS

Table 8 lists the defined test periods (see Section 2.3 for details), the processing used and the number of cases obtained in various parts of the analysis:

1. The number of windline (WL) runs are restricted to files (usually more than 90 percent) with a maximum vortex age of at least 60 seconds. This limitation removes (a) reprocessing errors that can result in a few runs lasting less than the normal minimum of 20 seconds, (b) false arrivals generated by other noise sources, and (c) actual aircraft spacings of less than 60 seconds. Note that departures may still be included. In any case, the resulting cases should give (a) consistent vortex detections (the detection algorithm looks over the time period of 20 to 60 seconds after arrival) and (b) valid one-minute winds averaged for the beginning of the run.
2. The FAA aircraft arrival records were provided to the AVOSS program. The number of arrivals are listed for each test period.
3. The windline arrivals and FAA arrivals were correlated by time (see Appendix A); the number of matches is listed in the WL-AC column.
4. Finally, the matched arrivals with valid 10-minute turbulence data are listed in the WL-AC-Met column.

Table 8. Defined Test Periods with Number of Cases

Period	Start	End	Process	WL Runs	Aircraft	WL-AC	WL-AC-Met
1	17-Sep-97	9-Oct-97	Normal	7,024	6,993	5,293	4,977
2	5-Feb-98	21-Feb-98	Normal	5,139	4,466	3,035	3,034
3	6-Mar-98	2-Apr-98	-V02	9,742	4,145	3,940	3,930
4	3-Apr-98	8-May-98	Normal	11,466	6,697	6,392	6,385
5	9-May-98	26-May-98	-V02	6,611	5,569	5,345	5,331
6	27-May-98	18-Jun-98	-P02	8,733	7,779	7,433	7,424
7	23-Jun-98	31-Jul-98	Normal	14,526	15,458	13,448	13,438
8	1-Aug-98	8-Sep-98	Normal	14,720	11,550	11,036	10,946
9	9-Sep-98	3-Oct-98	-V08	7,605	3,612	2,850	2,843
10	5-Nov-98	7-Nov-98	-V08	819	452	444	444
11	2-Dec-98	19-Dec-98	Normal	5,759	3,086	2,965	2,951
12	15-Jan-99	21-Feb-99	-V13	12,199	8,359	7,746	7,731
13	22-Feb-99	2-Mar-99	-V13,V18	2,997	2,370	2,273	2,273
14	3-Mar-99	11-Mar-99	-V13,V15,V18	2,672	1,496	1,442	1,442
15	12-Mar-99	30-Mar-99	Normal	6,070	3,058	2,970	2,966
Total				116,082	85,090	76,612	76,115

4.2 AIRCRAFT TYPES

Table 9 lists the number of runs by aircraft type for all 15 test periods. FAA types with less than 10 runs total have been eliminated to keep the list manageable. Note that some of the FAA type names are equivalent, e.g., EA30 and A300, because of changes in naming. Also, some names (e.g., B722, B727 and B72Q) reflect the aircraft model as well as the type.

Table 9. Aircraft Types

Type	Count	Type	Count
A300	137	B772	22
A310	14	BE20	16
A320	71	BE35	18
A340	13	BE36	10
AT42	32	C208	14
AT72	1,735	D328	19
B721	30	DC10	470
B722	1,050	DC8	258
B727	5,521	DC86	49
B72Q	360	DC87	44
B732	183	DC8S	24
B733	91	DC9	1,688
B735	30	DC9Q	240
B737	649	E120	2,687
B73A	234	E145	367
B73B	151	EA30	25
B73C	13	EA34	11
B73Q	34	F100	4,032
B73S	37	FK10	1,780
B742	22	L101	409
B747	19	MD11	325
B74A	73	MD80	22,277
B74B	13	MD88	2674
B752	863	MD90	1,351
B757	3,619	SF34	5,737
B762	57	SW3	26
B763	293	9999	14,559
B767	1269		

4.3 AVOSS 1.8 FILES

The CD-ROM containing the AVOSS 1.8 files contains a subdirectory for each of the 15 test periods. Each subdirectory contains the complete and daily log files and zipped files containing the individual run files (VNyymmdd.rrr). The subdirectory ALL contains the complete log file (VL_LOG.TXT) for all test periods and a special file (CASELIST.TXT) with selected parameters for all cases:

1. Date
2. Time (UTC)
3. Port residence time (sec) in AVOSS corridor
4. Starboard residence time (sec) in AVOSS corridor
5. Port vortex indicator (0 = lost inside array, 1 = traveled outside array)
6. Starboard vortex indicator (0 = lost inside array, 1 = traveled outside array)
7. Maximum lateral distance (m) reached (observed) for either vortex
8. Time (sec) when vortex reached maximum distance
9. Mean headwind (meters/second) for first minute of run
10. Mean crosswind (meters/second) for first minute of run

4.4 DATABASES

Table 10 lists the fields for the run database which is called RUNDATA. Table 11 lists the format for the vortex databases. The database files were generated in Paradox for DOS, Version 4.5. These databases are linked by the file number. Enough fields are keyed (indicated by asterisk) to uniquely identify each record. The type of parameter is indicated as A for ASCII, S for 16-bit signed integer, $ for two-decimal resolution floating point, and N for floating point number.

The databases are provided only ASCII form (extension TXT), not in the equivalent Paradox form (extension DB).

Table 10 lists two different fields each for head and cross wind. The First (marked Run) comes from the run files and represents the mean value for the first 60 seconds of the run. The second comes from the DM files and is the 1-minute average for the minute before the arrival. The times in the DM file are for the end of the 1-minute averaging time. The selected DM file data is obtained by matching the year, month, day, hour, and minute of the arrival time. Therefore, the difference in the time period averaged for the two wind component values varies by 0 to 59 seconds, depending upon the arrival second. Both wind component values come from the upwind end of the array. Presumably the "Run" value should correlate better with the actual vortex transport, since it represents the first 60 seconds of the run.

Table 10. Fields for Run File RUNDATA

Field Name	Field Type
Year	S*
Month	S*
Day	S*
Hour	S*
Minute	S*
Second	S*
File Name	A13
Max Age	S
Noise Peak	$
Noise Sum	$
Type	A4
Head Run	$
Cross Run	$
Head	$
Cross	$
CTA2	$
Mcta2	$
VTA2	$

The three turbulence parameters in Table 10 (CTA2, Mcta2, and VTA2) require some additional discussion. All three represent 10-minute averages of the 1-minute standard deviation of the 2-second average propeller anemometer measurements. CTA2 and VTA2 use the average crosswind at the two ends to select the upwind end of the array to get the crosswind and vertical wind turbulence values, respectively. The Mcta2 value uses the minimum crosswind turbulence algorithm and was used to set the vortex track-start and track-end thresholds. The question of which turbulence value best represents the effect of atmospheric turbulence on vortex decay is open for discussion. The vertical turbulence value represents smaller eddies and is perhaps more appropriate for eddy-viscosity diffusion inside the vortex. The crosswind values include larger eddies and might be better for Crow instability.

Table 11. Fields for Vortex Files VTX, VTXALL

Name	Type	Units
File Name	A13*	ASCII
Code	A1*	ASCII
Vortex	S*	0 or 1
Age	S*	sec
Max Crosswind	N	m/s
Lateral Position	N	m
Height	N	m
Circulation	N	m^2/s

APPENDIX A - MERGING WINDLINE AND AIRCRAFT DATA

A.1 METHOD

The windline aircraft arrival times were compared to the arrival times recorded by the AVOSS testbed. When both were correctly synchronized to GPS time, the results looked like Figure A-1 where time matches were made over differences of ± 100 seconds. The correct matches occurred over ± 10 seconds, with very few matches out to ± 40 seconds. The matches then increase to plateaus at ±90 seconds, which is a typical spacing between arrivals.

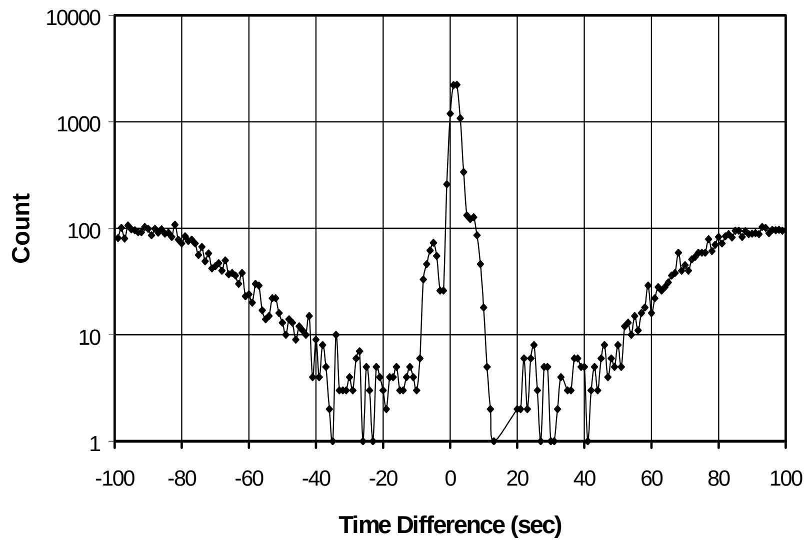

Figure A-1. Time Differences for 27-May-98 to 18-Jun-98

The procedure adopted was to identify the peak in the time correlation and then eliminate matches with differences significantly away from the peak (typically ± 10 seconds away, but somewhat farther when the AVOSS testbed computer was drifting in time. When the time of the AVOSS computer changed during a period, two peaks would be observed. In that case, care was taken to separate the two time periods so that only closely correlated arrival times are included in the analysis. The periods where the AVOSS recording computer clock was drifting were broken into smaller subperiods where the time difference was roughly constant. The matches were then selected for each subperiod and the final matches added together for the final database of matched data.

A.2 OBSERVED TIME DIFFERENCES

Figures A-2 through A-18 show the time differences for the subperiods analyzed. The data for the AVOSS-1 test showed good synchronization (Figure A-2). The correct synchronization was reestablished on 22-Apr-98 (see Figure A-10).

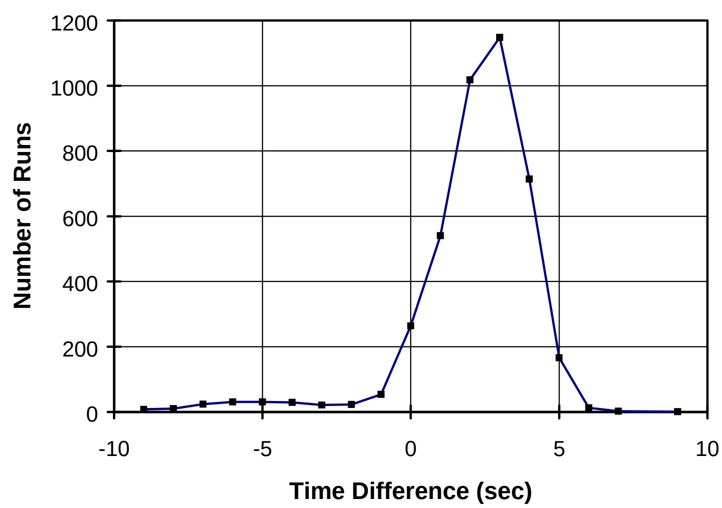

Figure A-2. Anemometer Array Arrival Time Minus the Aircraft Arrival Time for AVOSS-1 Test

For Figures A-3 through A-6, the time differences slowly drifted from -60 seconds to -90 seconds. The spread f or short period (Figure A-5) is almost as narrow as the AVOSS-1 data in Figure A-1. The difference jumps to +46 seconds on 31 Mar 1998 and then drifts to perhaps +61 seconds on 21 Apr 1998.

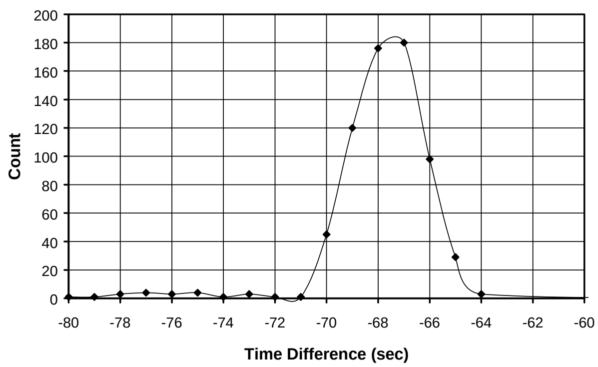

Figure A-3. Time Differences for 5-Feb-98 to 10-Feb-98

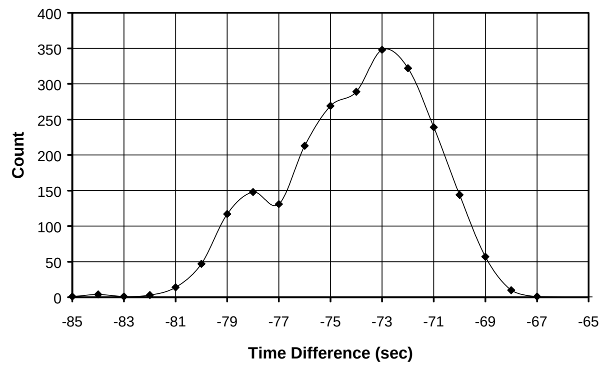

Figure A-4. Time Differences for 11-Feb-98 to 21-Feb-98

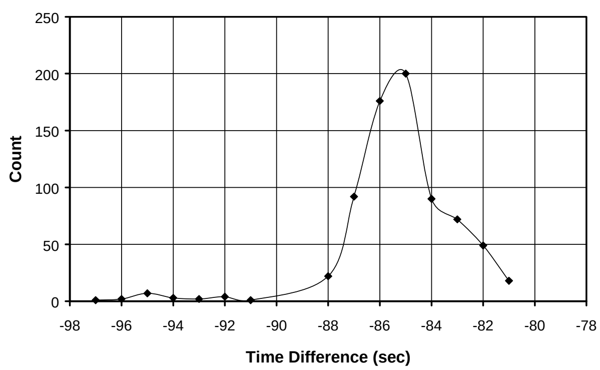

Figure A-5. Time Differences for 6-Mar-98 to 14-Mar-98

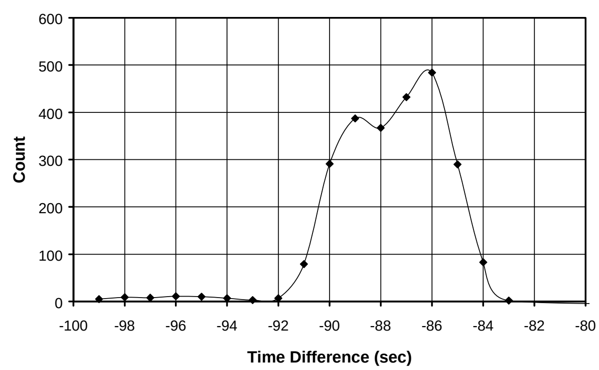

Figure A-6. Time Differences for 15-Mar-98 to 24-Mar-98

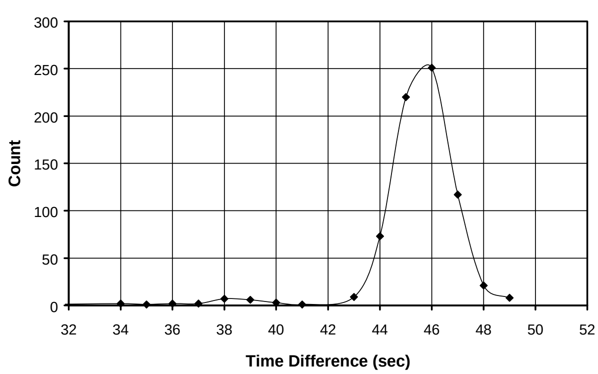

Figure A-7. Time Differences for 1-Apr-98 to 2-Apr-98

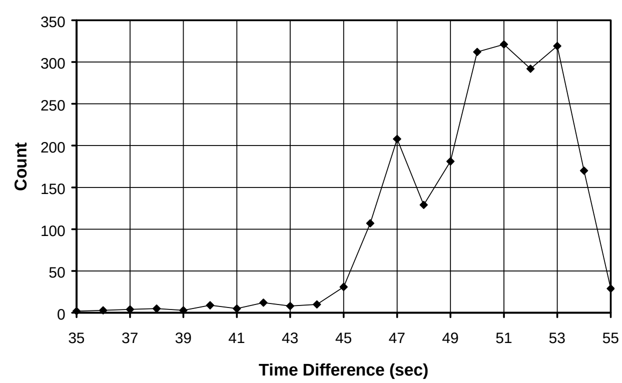

Figure A-8. Time Differences for 3-Apr-98 to 14-Apr-98

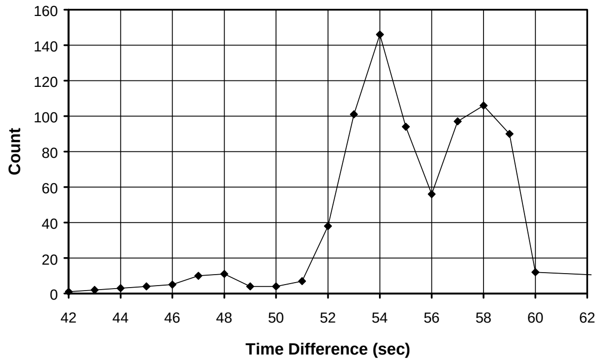

Figure A-9. Time Differences for 15-Apr-98 to 21-Apr-98

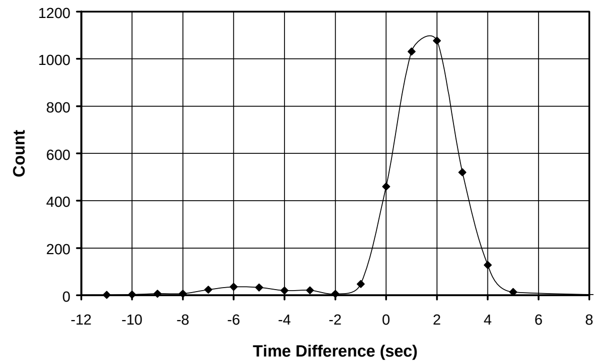

Figure A-10. Time Differences for 22-Apr-98 to 8-May-98

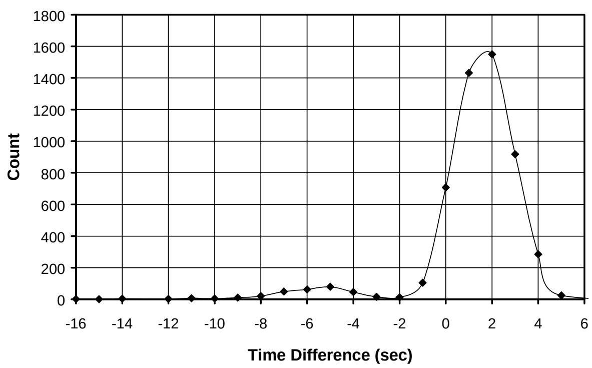

Figure A-11. Time Differences for 9-May-98 to 26-May-98

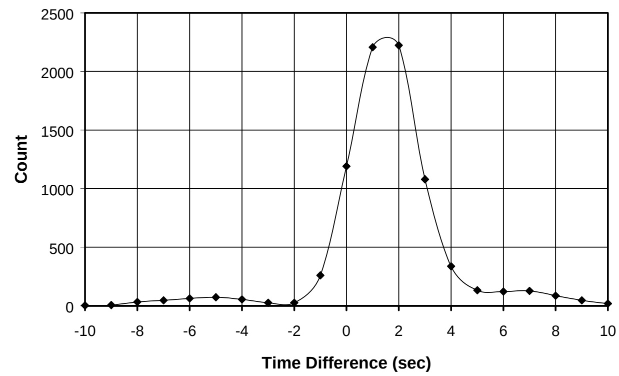

Figure A-12. Time Differences for 27-May-98 to 18-Jun-98

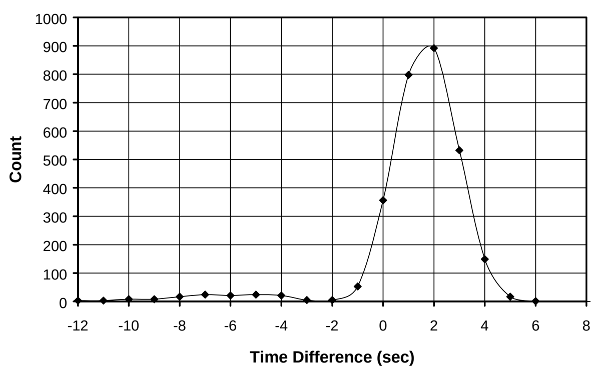

Figure A-13. Time Differences for Dec-98

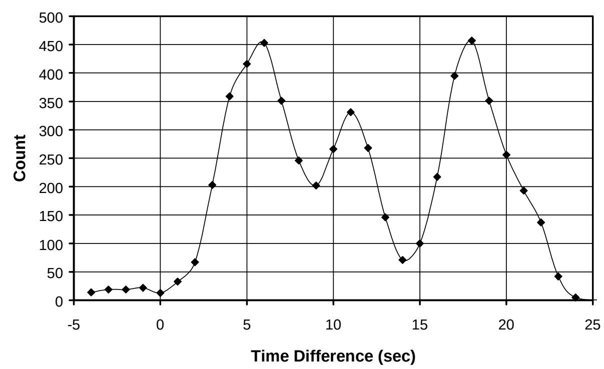

Figure A-14. Time Differences for 15-Jan-99 to 8-Feb-99

The two clocks were synchronized for the rest of 1998, as can be seen by comparing Figures A-12 and A-13. In 1999, the AVOSS clock again drifted with respect to the windline clock, as seen in Figures A-14 through A-18.

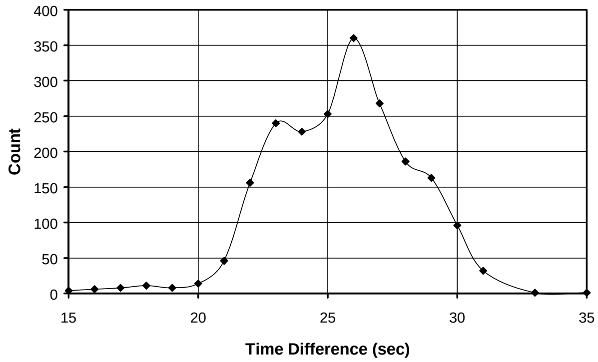

Figure A-15. Time Differences for 9-Feb-99 to 21-Feb-99

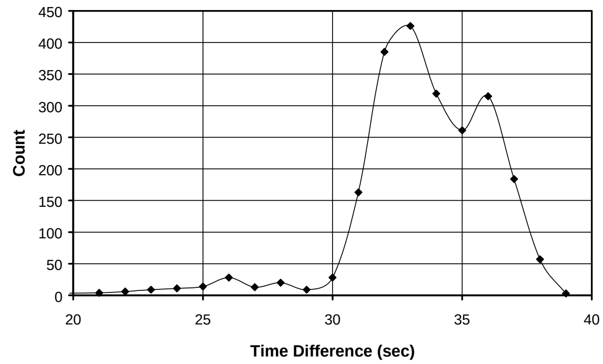

Figure A-16. Time Differences for 22-Feb-99 to 2-Mar-99

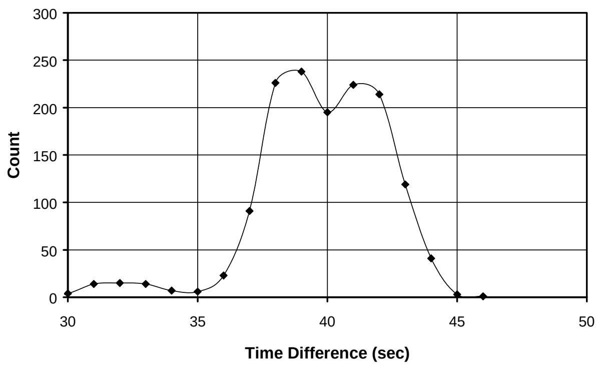

Figure A-17. Time Differences for 3-Mar-99 to 11-Mar-99

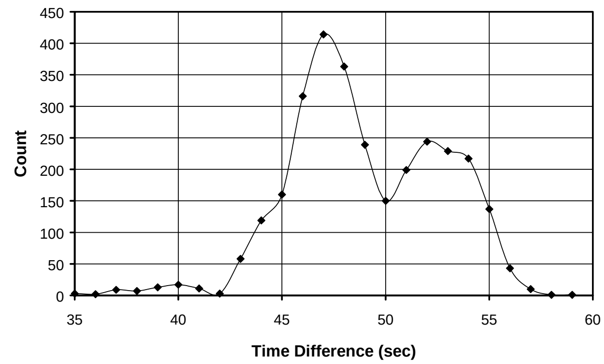

Figure A-18. Time Differences for 12-Mar-99 to 30-Mar-99

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