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AVOSS Windline at Dallas/Ft. Worth Airport

Volume 1

Installation and Operation

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13. ABSTRACT (Maximum 200 words)
A 259-meter windline, with horizontal and vertical single-axis anemometers mounted on 9-meter poles, was installed at the Dallas/Ft. Worth Airport under the approach to Runway 17C, as part of NASA's Aircraft VOrtex Spacing System (AVOSS) development program. Real-time processing algorithms provided wake vortex tracking information. Additional weather sensors, including additional anemometers, temperature and dewpoint, weather sensor and a sodar wind profiler were deployed at various times of windline operation. Wake and meteorological data were provided in real time to AVOSS. This report, Volume 1 of a two-volume report, describes the installation, the data processing algorithms, and the data files supplied to AVOSS.

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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, 1997, and 1998.

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 1 of a two-volume report, documents the windline installation and operation. In particular, it describes the data files provided to AVOSS.

The authors would like to acknowledge the support of Kevin Clark, Joe Ruggerio, Lynne Osovski, Brian Berkwitz, and Phil McCarty who supported the 1997 windline installation effort and development of the data acquisition and real-time processing software; and David Hazen, who managed and validated the data files coming from the site from 1997 through 1999.

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

Inches	0			1			2			3		4			5	
Centimeters	0	1	2		3	4	5	6	7		8	9	10	11	12	13

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

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

1.1 WINDLINE HISTORY

In 1994, the Volpe National Transportation Systems Center (Volpe Center) installed a ground-wind wake vortex tracking system[1] (windline) at New York's Kennedy Airport (JFK) 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 to provide ambient wind information. The data collection system operated automatically. Aircraft arrivals were detected automatically with noise monitors with each arrival generating a data file. The data files were terminated by the next arrival or after 180 seconds, whichever came first. A single report[5] documented data collection, processing algorithms and databases from the 1994 JFK deployment. The JFK report served as a model for subsequent database reports.

Another windline was installed[6] at the Memphis, Tennessee, airport after the termination of the 1994 JFK deployment; it operated from August 1995 to December 1995. The JFK site was reactivated 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.

A windline (see Figure 1) was installed at the Dallas/Ft. Worth (DFW) International Airport to support the NASA Langley Research Center's Aircraft VOrtex Spacing System (AVOSS) Program. DFW airport was selected as the AVOSS test bed and the windline was installed in September 1997 as part of the first test (AVOSS-1) at the site. The unique features of the DFW windline deployment were that it was completely automatic and processed the data in real-time, both of which features were needed to meet the requirements of AVOSS.

Figure 1. MD-80 Approaching Runway 17C over Windline.
Windline Electronics Trailer Is Located at Right.

1.2 AVOSS ROLES FOR WAKE SENSORS

Wake vortex sensors play two roles in AVOSS:

1. Provide data for developing algorithms for predicting wake behavior, and
2. Provide real-time feedback to detect anomalous wake behavior.

A windline can detect and track only those vortices that are generated near the ground or descend to the ground. The vortex detection sensitivity depends also upon the crosswind turbulence level. In addition, a windline can make only rough estimates of wake vortex height or circulation. Consequently, a windline is not a good sensor for studying vortex decay, since the loss of signal may be caused by vortex decay or by a vortex rising out of the windline's sensing range. Nevertheless, the windline is currently the only wake sensor that has achieved routine, automatic, unattended operation and hence can perform both wake sensor roles in AVOSS.

1.3 SCOPE OF REPORT

The windline measured the wakes of 76,000 arrivals from September 1997 through March 1999. These measurements were analyzed and are provided on CD-ROM as part of Volume 2 of this final report. Volume 2 describes the data set, the processing methods, and the database format. The AVOSS data format was version 1.7. The aircraft types were obtained from the Federal Aviation Administration (FAA) as part of the AVOSS data collection system. Since aircraft type information was not available to the windline installation in real time, the aircraft types were added later by matching the windline and FAA-determined arrival times.

The large number of arrivals already analyzed provides an extensive database for any further studies that can make use of the data generated from within the DFW windline coverage area (983meters from runway threshold, lateral coverage of –107 meters to +152 meters). Consequently, no additional arrivals have been analyzed. While the coverage area is adequate for single-runway wake transport studies, the coverage area is marginal[7] for parallel-runway studies.

In contrast to Volume 2 that addresses the DFW Windline measurements, this report describes the windline installation and the processing algorithms from a system point of view. Because the processing algorithm development is described in detail in Volume 2, only an outline will be presented here. One of the goals of this report is to provide information that can define the potential role of windlines in future wake turbulence systems and research.

Section 2 describes the data collection and Section 3 the data processing. Section 4 presents conclusions. Appendix A documents the data files provided in real time to AVOSS. Appendix B describes the AVOSS file formats.

2. DATA COLLECTION

2.1 SENSOR LAYOUT

The windline was installed on a baseline perpendicular to the extended runway centerline, 983 meters from the threshold of Runway 17C. As shown in Figure 2, the available real estate permitted coverage of only –107 meters in the negative direction (to the east or to the left as viewed from a landing aircraft). The wiring to the last two anemometers had to pass under the airport perimeter road. Section A-1 lists the exact pole locations.

Figure 2. Negative End of Windline, Looking toward Direction of Arriving Aircraft

More room was available in the positive direction, to the west; as a result the windline covered +152 meters. The positive end of the windline is shown in Figure 3.

Figure 3. Positive End of Windline

The windline used 18 fiberglass poles 9 meters high, to mount the anemometers. The poles were mounted in a fixture (Figure 4) that permitted the alignment to be

Figure 4. Pole Mount

Figure 5. Center of Windline

maintained when the pole was tilted down for maintenance. Every pole included crosswind and vertical wind measurement anemometers. The two end poles and the pole on the extended runway centerline also included headwind anemometers (see Figures 2, 3, and 5).

2.1.1 Aircraft Detectors

The aircraft detectors measured the aircraft noise on the extended centerline of Runway 17C (see Figure 5). The loudspeakers used as microphones were pointed toward the runway, as shown in Figure 6. The noise signals were amplified, rectified, and averaged for a fraction of a second.

One aircraft detector was processed with the windline data (2-second average) and was used to detect an arrival by looking for a noise peak above a defined noise threshold. Since identifying the peak requires a drop in signal, the time of the detection is 2 seconds after the peak occurs. The time assigned to the arrival includes this 2-second delay, but the wake processing corrects the wake age to the time of the peak noise. The other detector was used to grab a video frame containing the aircraft from a video camera viewing the windline from inside the electronics

Figure 6. Aircraft Detectors

Figure 7. Additional Meteorological Sensors at Positive End of Windline

the electronics trailer.

2.1.2 Meteorological Sensors

Meteorological measurements are an important component of AVOSS. The goal of the meteorological sensors is to permit the prediction of wake behavior. To complement the other AVOSS meteorological sensors, some additional meteorological sensors (beyond the basic windline capabilities) were installed in the vicinity of the windline electronics trailer, as shown in Figure 7. Not all the sensors were installed for all test periods.

2.1.2.1 MiniSodar

The minisodar (Aerovironment Model 4000) is shown more clearly at the left of Figure 3. It has a maximum range capability of 200 meters and a minimum range of 15 meters. It provides a vertical profile of the vertical and horizontal wind components with a range resolution of 5 meters.

2.1.2.2 Present Weather Sensor

The HSS present weather sensor (on top of left pole in Figure 8) measures the visibility by forward scattering, detects precipitation particles, and distinguishes rain from snow by comparing forward scattering with back scattering.

Figure 8. Meteorological Sensors: Present Weather (left), Wind/Temperature/Relative Humidity (middle), Ceiling (right)

2.1.2.3 Wind Speed/Direction

The Young propeller/vane (on top of right pole in Figure 8) 8) measures the wind speed and direction.

2.1.2.4 Temperature/Dewpoint

The temperature and relative humidity sensors are enclosed inside a radiation shield mounted in the middle of the right pole in Figure 8.

2.1.2.5 Ceilometer

The Vaisala laser ceilometer is housed in the white box at the right of Figure 8. It detects clouds by back scatter and has a maximum range of 3,800 meters.

2.2 COMPUTER NETWORK

The windline data system is based on a Novell local area network, consisting of a single fileserver (Netware v3.12 operating system), and a number of computers (PC type) connected by a single ethernet 10Base-T physical network. The data collection computers store data on the fileserver where it can be processed in real time by a multitasking computer or a separate data processing computer. The network configuration has varied over a 4-year test period (1997-2000), depending upon the sensors deployed. Some changes were also made to improve system reliability.

2.2.1 Fileserver

The fileserver clock is synchronized to GPS time. The synchronization of the data collection computers is assured by reading time directly from the fileserver rather than from the local computer clock. The fileserver clock time has a resolution of 1 second. Finer time resolution can be achieved by reading the time more frequently than once per second and looking for changes in the reported second. For example, the data collection program reads the time twice per second and hence resolves time to 0.5 seconds.

2.2.2 Main Data Collection Computer

The main data collection computer accepts data via eight RS232 serial ports. The main computer accepts windline data and data from any meteorological sensors having no more than a few serial messages per minute.

The main data collection software runs under DOS because it provides more immediate interrupt service than more advanced operating systems. The interrupt service routine examines every character received and hence can handle virtually any message format.

The main data collection program carries out the following basic functions:

1. Reads configuration file that defines the processing parameters and the characteristics of the messages on each serial port.
2. Looks for and processes messages from each serial port every 0.5 seconds.
3. Saves current 1-minute data block in file “Current.dat” on fileserver.
4. Saves daily data file containing 1-minute data blocks.

The main data collection program also carries out special real-time processing for windline data:

1. Saves last minute's data in rotating buffer.
2. Saves last 2-second data block in file "Local.dat" on fileserver.
3. Detects aircraft arrivals as a noise peak above the detection threshold. Multiple detections from the same arrival are suppressed by disabling detection for 20 or 25 seconds after a detection. Unfortunately, takeoffs from the opposite end of the runway are also detected. In principle, arrivals and departures can be distinguished by the noise signature (broader for departure since the aircraft altitude is higher). However, since no reliable method of rejecting takeoff detections has been developed, the windline data will include departures as well as arrivals. The vortex detection threshold will normally give no vortex data for takeoffs. In any case, the correlation of windline arrival data with other sources of arrival data will validate the true arrivals.
4. Sends arrival message over the network.
5. When an arrival is detected, a run file is created and tagged with the date and arrival number for the day. The run file is then filled with 2-second data blocks starting with 10 seconds before the arrival and lasting until the next arrival or 180 seconds after arrival, whichever comes first.
6. In parallel with the run file, the file Currrun.dat on the fileserver is filled with data from the current run. The current data location in the file is coded so that a real-time processing program can access new data as it arrives and knows when a new arrival has occurred.

The files Local.dat and Currrun.dat are kept open continuously with shared reading enabled. New data blocks are added as they become available. The real-time processing program can then read the new data.

2.2.3 Dedicated Data Collection Computers

Dedicated data collection computers are used for data sources that are inappropriate for the main data collection computer. For example, the sodar has a dedicated network computer that runs a program that controls the sodar's own data processing computer. The sodar's current output is saved in a file "Recent.dat" on the fileserver.

2.2.4 Data Processing Computer(s)

A number of data processing functions are required to operate the windline as a real-time wake vortex sensor. The following sections will describe these functions.

Originally, these processes were carried out on the main data collection computer, using the Desqview environment to provide multitasking capabilities. Since Desqview was found to be incompatible with the most convenient remote access method (Wanderlink, see Section 2.2.4.2), an alternative configuration was installed in the summer of 1999. The main data collection program is run on a DOS computer and the other processes are run on a Windows NT computer.

2.2.4.1 Meteorological Processing

The meteorological processing program processes 1-minute data blocks (e.g., from Current.dat) and carries out the following functions:

1. Calculates mean and standard deviations of windline measurements.
2. Saves daily files with 1-minute blocks containing meteorological sensor messages and windline means and standard deviations. Data plots from these files (see Section A.3) are used for maintenance checks of sensor performance. In particular, malfunctioning windline anemometers are identified and replaced.
3. Writes fileserver file "Met.dat" which contains data from the additional meteorological sensors.
4. Writes fileserver file "Wind.dat" which contains mean wind data from the windline.
5. Assesses the crosswind turbulence level. To avoid wake contamination, the crosswind turbulence level is taken as the minimum crosswind standard deviation from the two ends of the windline. This value is averaged for 5, 10, 15 and 20 minutes and saved in the file "Cwturb.dat" on the fileserver and ultimately in the header of the run file. The 10-minute average was found to be steady enough to give a reasonable turbulence value and is used to set the crosswind tracking threshold in the real-time windline processing program. The turbulence values are also logged in a daily file of turbulence values; the log file can be used to assess the proper performance of the turbulence calculation and hence the wake tracking thresholds.

2.2.4.2 Windline Processing

The windline processing program processes the data in Currrun.dat using the turbulence level in Cwrturb.dat to set the tracking threshold. The windline program carries out the following functions:

1. Detects and tracks wake vortices.
2. Determines vortex lateral position, height and circulation using a least-square fit to the crosswind and vertical wind profiles.
3. Assesses residence times within the AVOSS corridor.
4. Writes summary data file with information about every arrival.
5. Writes processed data files in AVOSS format. If vortices are detected, writes fileserver file "Vortex.dat."

2.2.4.3 Arrival Logging

The network arrival messages from all sources (main data collection program, Mode-S processor, laser range finder processor) are logged in a daily log file.

2.2.5 *Remote Access*

2.2.5.1 AVOSS

Since security is vital for AVOSS, the windline connection to AVOSS consists of a one-way serial link using a synchronous modem. The AVOSS interface program looks on the fileserver for new files: met.dat, wind.dat, recent.dat, and vortex.dat. Appendix B describes the format of these files. When new files are found, they are sent over the serial link to AVOSS.

2.2.5.2 Remote Maintenance

The unique feature of the windline wake sensor is its automatic operation. Automatic operation requires remote dial-up access to ensure that the entire system is operating correctly. Two methods of remote access are available:

1. Remote control (e.g., pcAnywhere) where the remote user takes control of a network computer. The remote keyboard and mouse inputs are transmitted to the network computer and the screen display is sent back to the remote computer. This method is excellent for intensive data processing since the data do not have to be sent over the phone line, but it is poor for rapid display update since a rapidly changing display generates a large amount of data traffic.
2. Remote node (e.g., Fastlink) where the remote computer becomes a node on the network. This mode is ideal for generating complex displays based on a small amount of data (e.g., the windline real-time files local.dat or currrun.dat) but bad for processing large data files.

Since only three phone lines were available at the windline site, it was not convenient to use remote access software that provided only one of the two methods. Fortunately, a program called Wanderlink (by Funk Software) provides both types of access using a single modem and phone line attached to a Novell fileserver. A Wanderlink connection permits a remote user to log into the network to access network files and to use a program called Proxy (master) to take control of any network computer also running Proxy (host). Recent versions of Proxy can also make a direct modem connection (like pcAnywhere) to a network computer. Such a connection could be used, for example, to reset Wanderlink on the fileserver if it becomes inoperative.

Novell fileservers are generally stable enough to keep running indefinitely if they are plugged into an uninterruptible power supply (UPS). Since DOS and Windows computers are much less reliable, they are connected to a reboot device which can be set to trigger on a specific number of rings on a phone line. Gracefully rebooting a Windows computer requires a special program to be running and connected to the reboot device via a serial port.

2.2.6 *Video*

Two video cameras were installed in the windline trailer to provide a remote of arriving aircraft. One pointed up the flight path while the other viewed the windline location. The Visualo Security system was used to send the video pictures over a telephone dial-up link. The remote viewer can select which camera to display.

2.3 ANALOG DATA ACQUISITION

The analog sensors were digitized by five Campbell Scientific data acquisition systems (CSDAS #n, n=1-5). Each then reported to one of the serial data ports of the main data collection computer. Table 1 summarizes the analog sensors recorded.

2.3.1 *Windline Data*

CSDAS #1-3 can each digitize 16 single-ended channels and are used to measure the propeller anemometer and aircraft noise signals. They are programmed to:

1. Report in low-resolution binary format (2 bytes per channel), which is very efficient for storing data,
2. Sample the sensors at 10 Hz, and
3. Report 2-second averages every 2 seconds.

.

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

Since the three CSDAS may not be synchronized, the data acquisition system prefixes the second the message is detected (to hundredths of a second) in standard Campbell low resolution format. Current data processing programs ignore the time tags and simply process the data after all three messages have been received, and assume that all three messages represent simultaneous measurements. Future processing programs could: (a) group the messages according to the time tags to give minimum time spread or (b) correct the analysis for the exact times of the messages.

2.3.2 *Meteorological Sensors*

CSDAS #4-5 report in ASCII format and record temperature/humidity and wind speed/direction, respectively.

3. DATA PROCESSING ALGORITHMS

The windline data processing steps were outlined in Section 2.2.4, which explained the computers used for the processing. This chapter will present a more detailed description of the processing. The description, however, will still be functional rather than mathematical. The database report in Volume 2 presents a mathematical description of the wake processing algorithms and discusses their development history. Only the final algorithms will be presented here.

3.1 AMBIENT WIND AND TURBULENCE LEVEL

Most windline meteorological algorithms are based on 1-minute mean and standard deviation values of the anemometers on the two ends of the windline; these values are calculated from the 30 independent 2-second averages for each minute. Estimates of the crosswind turbulence level are needed to set the crosswind vortex tracking thresholds. Estimates of the ambient wind are needed for predicting wake vortex lateral transport. These estimates must avoid the influence of wake vortices if they are to represent the true ambient wind conditions.

3.1.1 Crosswind Turbulence

Because the influence of the wake is to increase the apparent turbulence level, the simplest method for eliminating wake effects is to take the lowest 1-minute standard deviation of the crosswind at the two ends of the windline. This algorithm fails only if both ends are affected by wakes, which is unlikely. To reduce the large minute-to-minute fluctuations (factor of two) in crosswind standard deviation, the resulting turbulence values are averaged for 5, 10, 15 and 20 minutes. The 10-minute average reduces the fluctuations to a reasonable level (see Section A.3).

3.1.2 Ambient Crosswind

The wake vortex processing (Section 3.2) estimates the ambient crosswind from each 2-second data block using a radically different algorithm (see next section) to eliminate the influence of the wake. The median crosswind across the windline is calculated. As long as the two wake vortices each affect less than half the windline, then the median value will reflect the ambient crosswind.

3.1.3 Upwind Measurement

The upwind end of the windline should be free of wake unless the crosswind is so small that the upwind wake vortex can travel to the end of the windline. The upwind end is selected by averaging the crosswind measurements on the ends. Then, the wind means and standard deviations (all three wind components) are taken from the upwind end. This algorithm has not been used for real-time processing, but only for off-line processing.

3.2 WAKE VORTEX TRACKING ALGORITHM

The tracking algorithm is based on the 18 crosswind measurements across the windline.

3.2.1 *Preprocessing*

The 2-second anemometer measurements are first processed with a 10-second running average. Next, the maximum, median and minimum crosswind-across-the-windline are found.

3.2.2 *Initial Tracking*

The initial tracking algorithm is based on the maximum vortex-induced crosswind (MVICW), which is taken as the difference (positive) between the: (a) maximum and median crosswind (corresponds to starboard wake vortex) and (b) median and minimum crosswind (corresponds to port wake vortex). The locations of the anemometers showing the maximum and minimum crosswind are the first estimates for the two wake locations.

3.2.3 *MVICW Thresholds*

Table 2. MVICW Tracking Thresholds

Alternate Threshold Parameter	Start Track	Stop Track
Minimum	1.25 m/s	1.0 m/s
Crosswind Turbulence Factor	5.0	3.5

Vortex tracking starts when the MVICW values are above the threshold for starting the track. Tracking terminates when MVICW drops below drops below the threshold for stopping tracking. Table 2 lists the two alternative methods for selecting the thresholds. The first is a minimum threshold that is used for low turbulence levels. The minimum value serves to prevent excessively long tracking of the distorted crosswind profile left after the wake has substantially decayed. The second is a larger value that is used for high-turbulence levels. The thresholds are calculated by multiplying the current 10-minute crosswind turbulence value by the factors listed. The high-turbulence thresholds were selected to maximize the detection and tracking of real vortices while minimizing false tracks from atmospheric turbulence. A windline is most likely to track a turbulent eddy as a vortex when the ambient wind is blowing directly down the windline.

The use of variable tracking thresholds for analyzing windline data gives the maximum amount of valid wake data, but may be misleading for addressing operational questions because much weaker wakes can be detected under low turbulence conditions. Because such weak wakes are unlikely to pose operational risk, selecting a fixed higher threshold might give a better indication of the operational impact of the wakes being tracked. In principle, a wake that is lost in the ambient turbulence cannot pose an encounter risk unless the turbulence level itself is high enough to pose a risk. For a windline, this argument raises two questions:

1. A windline measures the vortex-induced flow at the ground, which is not the location of maximum encounter risk. The argument for defining the wake hazard in terms of the turbulence level would be more convincing for a sensor (e.g., sodar or lidar) that measures the complete wake flow field, not just the flow at the ground. A correction factor for windline data could be developed by making comparisons[Note 1] with simultaneous sodar or lidar measurements.
2. Comparing wake and ambient turbulence levels in a plane, such as sensed by a sodar or lidar, may still underestimate the potential influence of the wake on an encountering aircraft because the wake is coherent for some distance along the flight path while the turbulence has roughly the same coherence distance along the flight path as transverse to the flight path.

[1] The JFK-1 test (November 1996) compared windline and lidar tracking data, but not flow field data.

3.2.4 Track Validation

The DFW AVOSS installation required that a wake vortex sensor provide a tracking file shortly after it finished tracking the wake from each arrival. This requirement is easier than providing an up-to-date real-time track because the wake vortices can be detected more certainly when their windline signals are maximized rather than early in their lifetime when their windline signals might be marginal or might be mixed up with signals from the previous arrival.

3.2.4.1 Vortex Detection

The vortex track validation algorithm first looks for the maximum MVICW value over the wake age range of 20 to 60 seconds, when wake vortices are normally detected. If the maximum MVICW value is below the start-track threshold, then the vortex is considered invalid.

If the maximum MVICW is above the start-track threshold, then the location of the maximum MVICW value is tested for reasonableness. The lateral transport speed of the vortex is calculated using an assumed initial location of ±20 meters (- for port vortex, + for starboard vortex) from the extended runway centerline. The transport speed must agree with the median crosswind at the time to within 2 meters/second + 0.2 times the absolute value of the median crosswind.

3.2.4.2 Track Termination

Once the vortex detection is validated, the vortex first is tracked to earlier times until the track is lost and then it is tracked to later times until the track is again lost. The track is lost when one of the following occurs:

1. MVICW drops below the stop-track threshold,
2. MVICW location jumps by more than 2 poles, or
3. Vortex passes the end of the windline.

The windline-end algorithm assumes that the vortex travels smoothly past the end of the windline. The effective transport speed is estimated by the number of times the vortex is detected at the next-to-last anemometer. The vortex is allowed to be detected at the last anemometer 1.5 times as long as it was detected at the next-to-last anemometer. This algorithm allows the vortex lateral position to be extrapolated beyond the last anemometer by approximately one pole spacing.

3.3 WAKE VORTEX FITTING ALGORITHM

After the crosswind measurements have been used to track the vortices to the nearest anemometer pole, a least-square fit is used to calculate vortex parameters that minimize the sum of the squared differences between calculated and measured values of both crosswind and vertical wind. A least-square fit requires: (a) a model for calculating the wind field of the wake vortices from the wake parameters and (b) estimates for the initial values of the parameters.

3.3.1.1 Wake Parameters

The first wake parameter is the ambient crosswind, which is assumed to be independent of height above the ground. The natural vortex parameters are the lateral position, height and circulation.

However, variations in the height and circulation have similar effects on MVICW, which is approximately proportional to the ratio of circulation to height when the two wake vortices have separated in ground effect. When two parameters of a least-square fit vary together in such a way, then it is difficult to get the convergence to the optimal parameter values. Consequently, the parameters of the fit were changed from height and circulation to the circulation/height and height. After the fit is complete, the fitted parameters are converted back to height and circulation.

Therefore, the number of fitted parameters is equal to 1 + 3 times the number of valid wake vortices.

3.3.1.2 Initial Parameter Values

The initial values for a least-square fit must be close to the optimum parameters if the fit is to converge. The vortex tracking results are used to select the initial values:

1. The median crosswind is taken as the initial ambient crosswind.
2. The location of the MVICW anemometer is taken as the initial vortex lateral position.
3. The MVICW value is used to estimate the initial circulation/height value.
4. The initial height is set at the fixed value of 30 meters because it has the least effect on the fit. The height has subtle effects on the shape of the crosswind profile and somewhat greater effect on the vertical wind profile.

3.3.1.3 Initial Increment Size

The initial increment sizes for the wake parameters are taken as relatively large values so that only a few steps are needed to reach the optimum value. The initial crosswind increment is taken as 0.7meters/secondecond. The initial lateral position increment is taken as 8 meters. The initial increments for circulation/height and height are taken as 0.2 times the initial value.

3.3.1.4 Wake Model

The simplest model for the interaction of an aircraft wake with the ground makes use of image vortices. The vertical wind at the ground is guaranteed to be zero if the ground is replaced by image vortices. For each vortex with lateral position y, height h and circulation Γ, the image vortex has lateral position y, height $-h$ and circulation $-\Gamma$. The other normal boundary condition of zero horizontal wind at the ground is *not* satisfied by the image model, but requires a boundary layer model. The wake flow field is calculated from the image model by calculating the contribution of all vortices, real and image, to the vertical and crosswind components. The ambient crosswind is added to the wake flow field.

3.3.1.5 Least-Square Calculation

The basic process of the least-square fit is to vary each parameter in turn up and down by one increment, looking for a lower value of the sum of the squares of the differences between calculated and measured wind components. The basic process is repeated until no parameter changes are made. Then the size of the increment is divided by two and the basic process is repeated again until no changes are made. The fit is completed after three increment reductions. The fitting process is terminated as “not converging” if parameter changes continue after 30 passes through the basic process.

3.4 AVOSS PARAMETERS

The AVOSS file format (see Section B.1) contains parameters beyond the vortex parameters provided by the least-square fit. This section discusses these parameters.

3.4.1 Safety Corridor

The AVOSS system is designed to predict how long after aircraft passage a safety corridor protecting the approach path will be clear of wake vortices, whether by vortex decay (i.e., circulation value below 90 m^2/s) or vortex transport outside the corridor, either laterally or vertically. Because windline circulation values are not particularly accurate, the decay criterion is not applied to windline data, even though the circulation values are included in the output file format.

Table 3. Safety Corridor at Wind Line

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

Table 3 lists the corridor limits at the windline location (y = lateral position, z = height above ground) for two corridor options; the z limit is the bottom of the corridor. Again, because windline height values are inaccurate, the height limits are not applied to windline data. However, windline measurements have quite different implications for the two options. If a vortex is detected, it is likely below the 46.3-meter limit of Option 2. On the other hand, virtually all vortices detected will have heights above the 6.3-meter limit of Option 1. Thus, the lateral transport time is the only AVOSS safety corridor parameter derived from windline data.

3.4.2 Lateral Transport Time

The lateral transport time algorithm starts with the first and last vortex detection locations. If the first location is inside the corridor and the last is outside the corridor, then a valid lateral transport time is possible. Two vortex detections outside the corridor are required to define the transport time. The vortex track is followed to shorter times until the vortex lateral position is inside the corridor. The transport time is taken as the time of the second detection outside the corridor.

It would be possible to define an upper limit to the lateral transport time even if the vortex were never detected inside the corridor. However, the lateral transport times are used to validate the AVOSS vortex lateral transport model and using an upper limit would not give an unbiased validation.

3.4.3 Parameter Error Estimates

The AVOSS file format includes fields for error estimates for all vortex parameters. To date, the windline analysis has not attempted to generate such error estimates. However, such estimates would assist in interpreting the validity of windline height and circulation data.

Windline parameter errors result primarily from three effects:

1. The 10-second average distorts the wind profiles, especially the vertical wind, when the vortex is moving rapidly. This source of error can be reduced by lowering the averaging time.

2. The turbulence inside the wake introduces measurement noise. Measurements with high-speed anemometers have shown[8] that vortices interacting with the ground are highly turbulent.

3. The image model does not accurately represent the interaction of a wake with the ground. In particular, boundary layer effects are ignored. Frequently, the wake vortices detach the boundary layer from the ground to form secondary vortices. Secondary vortices have been included in the least-square fit to the windline measurements, but no criteria for when to include them have yet been developed.

Most systematic error analyses are designed to deal with random errors, not systematic errors. Since systematic errors play an important role in the windline least-square fit, standard methods for estimating parameter errors are questionable.

However, conducting an error analysis of the least-square fit is complicated by the interaction of the height and circulation, as discussed in Section 3.3.1.1. Height and circulation can vary together by much greater amounts for a given overall square error sum than they can vary individually. The AVOSS error limits for each parameter should reflect this greater common error rather than the individual error.

An error analysis should probably look only at anemometers located near the wake vortex being analyzed. A systematic error analysis could examine the vortex parameter changes that would increase the sum of the square errors by, for example, 10 percent. Such an analysis would lead to a two-dimensional contour of vortex parameters around the best-fit parameters in the three-dimensional space of lateral position, height and circulation. If crosswind or the parameters of the other vortex were added to the analysis, the error contour would become very complex.

4. CONCLUSIONS

This chapter will summarize the lessons learned from the DFW Windline installation. The improvements suggested here would have increased initial costs without improving the initial benefit of the system. They would be cost effective only for a longer-term installation or for expanded data utility.

4.1 PERFORMANCE

The DFW Windline demonstrated that routine, automatic, unattended operation is possible for a wake sensor. The windline performed its role of monitoring the area below the flight path within moderate distances from the extended centerline of Runway 17C. However, the limited lateral coverage (-107meters to + 152 meters) coupled with aircraft heights that were well out of ground effect (roughly 65 meters above ground level) meant that, in strong crosswinds, some wakes were never detected. Wider lateral coverage would have reduced this problem.

4.2 MAINTENANCE

The DFW Windline was maintained via remote computer access and by site visits from Volpe Center personnel. The DFW Windline was operated for 3 years, which was long enough to provide guidance on maintenance issues for future windline installations. When practical, maintenance improvements were made during the 3-year period. The following conclusions can be drawn from the DFW test experience:

1. The predominant maintenance problem was nearby lightning strikes that regularly disabled the system with varying levels of damage, in spite of the fiberoptic links to the Campbell Scientific data acquisition modules. The lightning frequency at DFW is known to be high (e.g., roughly four times greater than at JFK airport). Future windline installations in lightning-rich locations should make maximum use of lightning protection technologies. Since the original windline installation was for the short AVOSS-1 test, only a moderate amount of lightning protection was provided. Of course, predicting the ultimate duration of a test configuration can be difficult.
2. Anemometer failure at DFW appeared to be related to subtle, delayed lightning-induced damage to the DC generators, as well as to bearing wear. Yearly replacement of all anemometers with refurbished units would probably have been cost effective for reducing the number of site visits.
3. Another strategy for reducing site visits is to secure the services of someone local who could (a) check out the system after a failure to guide site-visit preparations and (b) take care of minor maintenance problems.
4. The final remote access configuration provided adequate, redundant access.

APPENDIX A - WINDLINE DETAILS

A.1 WINDLINE POLE LOCATIONS

Table A-1 lists the anemometer pole locations in English units of measurement.

Table A-1. Anemometer Pole Locations (with respect to extended runway centerline)

Pole	Lateral Position (m)	Axes
1	-107	3
2	-91	2
3	-72	2
4	-61	2
5	-46	2
6	-31	2
7	-16	2
8	0	3
9	16	2
10	31	2
11	46	2
12	61	2
13	72	2
14	91	2
15	107	2
16	122	2
17	137	2
18	152	3

A.2 PARAMETER NAMES

The anemometer parameters 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.

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 the Monin-Obukhof similarity theory[9], 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.

A.3 DAILY PARAMETER PLOTS

Figures A-1 through A-5 show the daily parameter plots (actually just first 16 hours) for September 28, 1999. The hours are UTC, which is 5 hours later than local time for this date.

Figure A-1 shows the three headwind anemometers and the rest of the anemometers from the ends of the windline. The turbulence levels are much greater for Pole 18 than for the other poles for hours 0 to 3 and hours 12 to 14. For these hours, a positive crosswind was blowing the aircraft wakes over Pole 18.

Figure A-2 shows the crosswind across the windline. Apart from bumps caused by wakes, all anemometers give the same time variation in the crosswind. Therefore, all are performing correctly. A malfunctioning crosswind anemometer can be detected easily because it does not track with the other anemometers.

Figure A-3 shows the vertical wind across the windline. Because the mean vertical wind is zero, consistent nonzero vertical winds (e.g., V01 for hours 0 to 6) are caused by slight misalignments such that some of the horizontal wind is detected. A malfunctioning vertical anemometer can be detected because it has consistently smaller turbulence levels than the other vertical anemometers.

Figure A-4 shows the crosswind turbulence across the windline. The turbulence spikes (e.g., hour 0 for Poles 12 to 18) show where the wake vortices are travelling.

Figure A-5 shows the vertical wind turbulence across the windline. Since the ambient vertical wind turbulence is smaller than that for the crosswind turbulence, the effects of the aircraft wakes are even more evident than in Figure A-4.

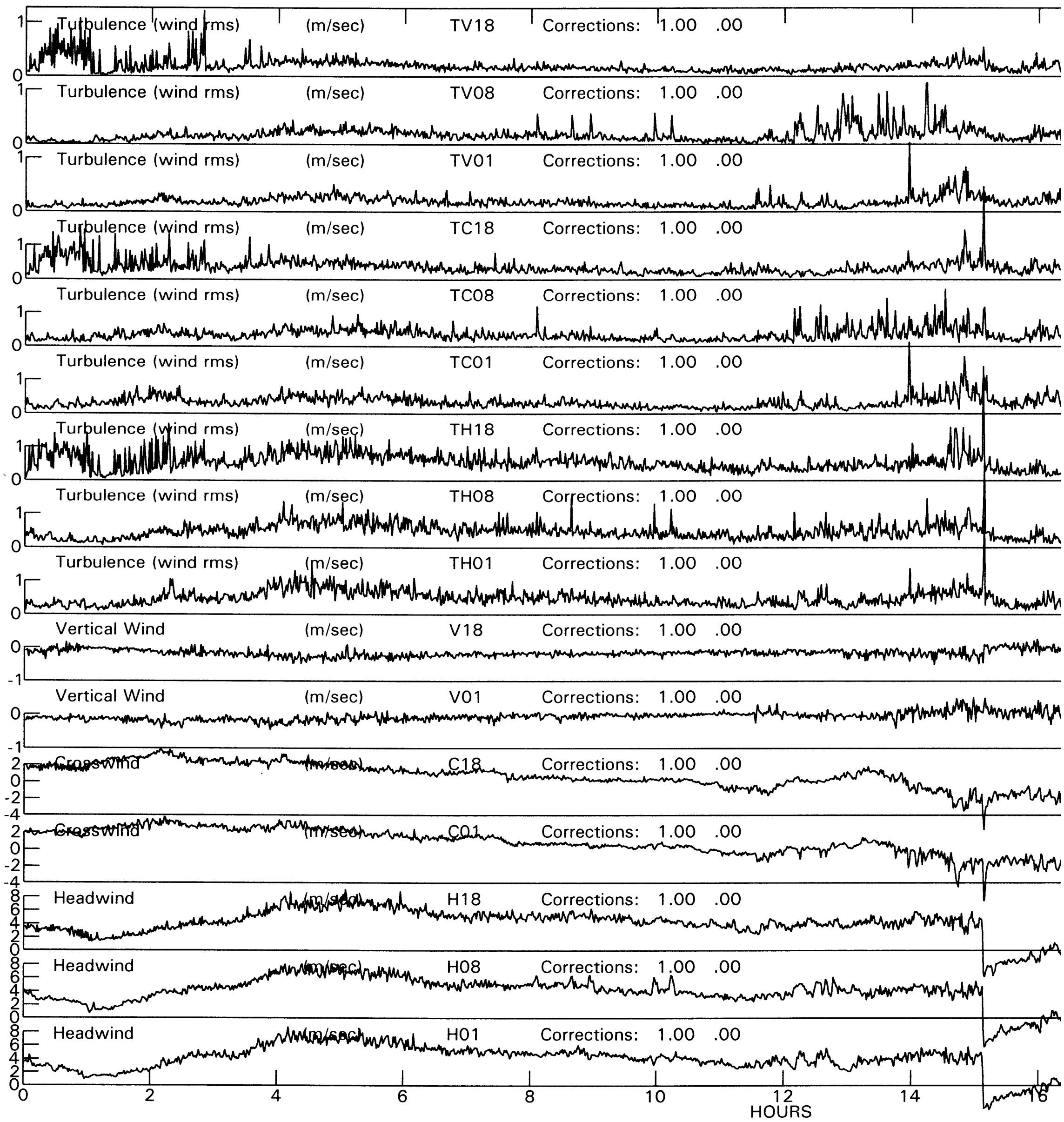

Figure A-1. Wind and Turbulence Summary

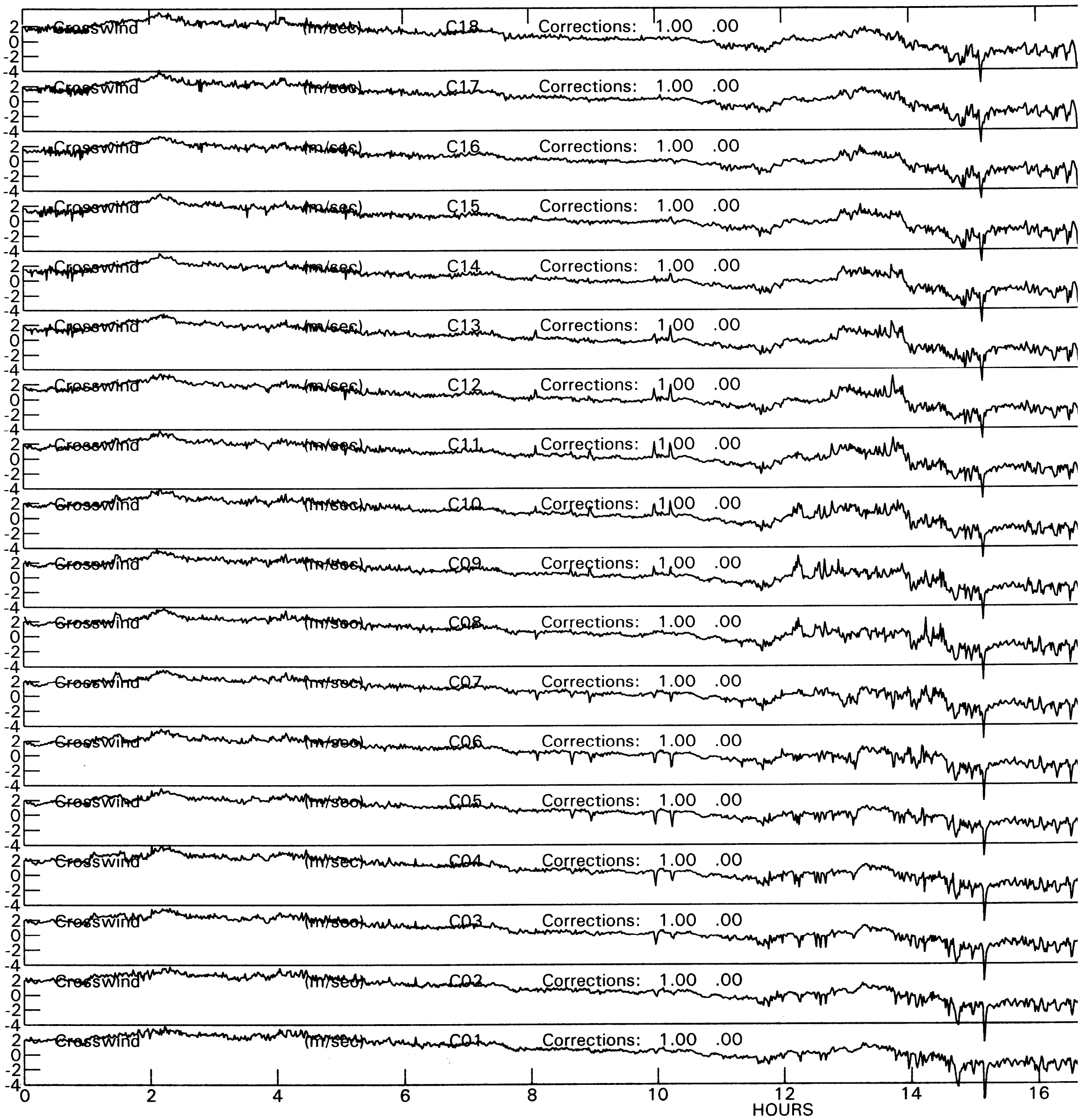

Figure A-2. Crosswind across Windline

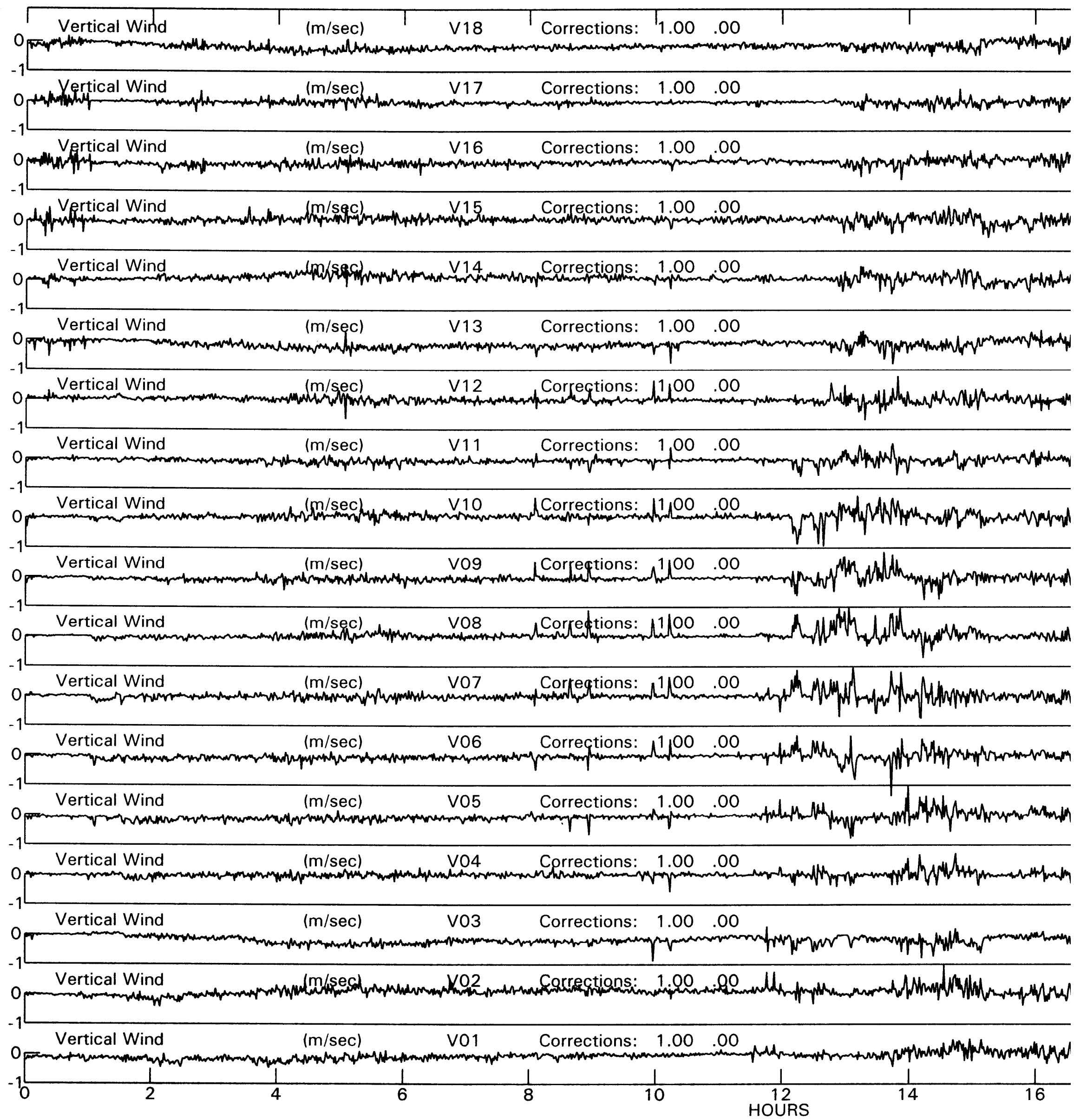

Figure A-3. Vertical Wind across Windline

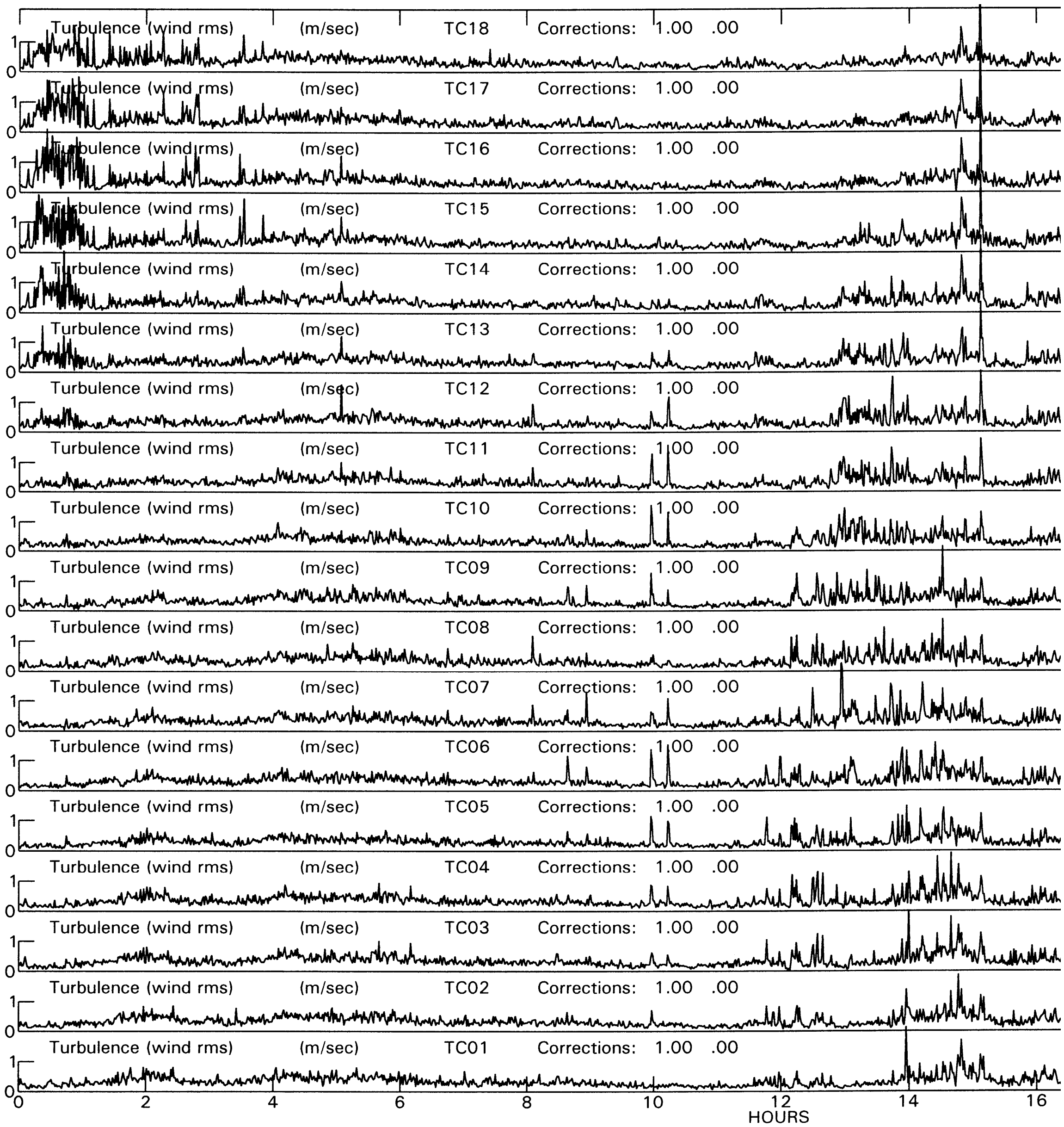

Figure A-4. Crosswind Turbulence across Windline

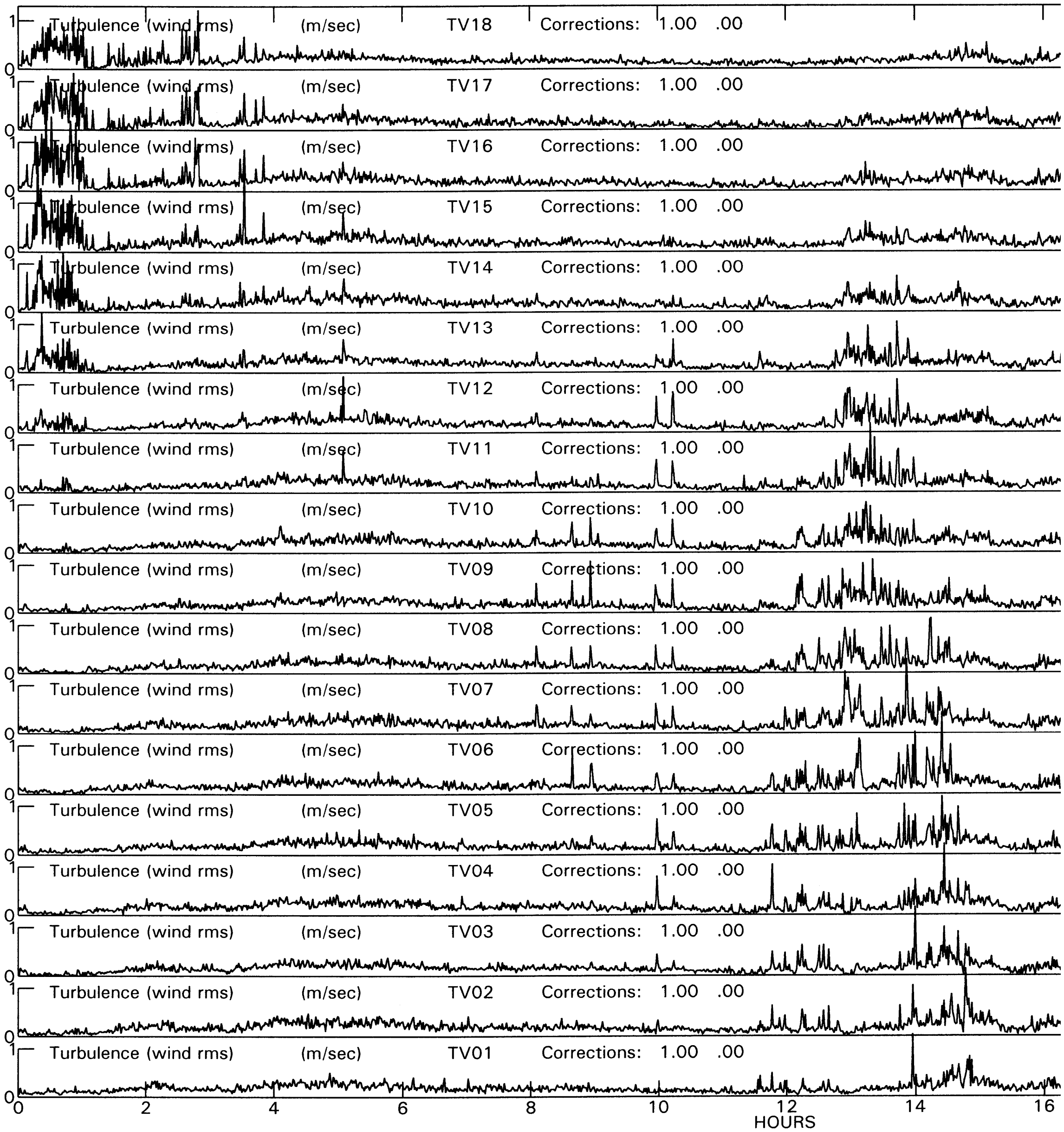

Figure A-5. Vertical Wind Turbulence across Windline

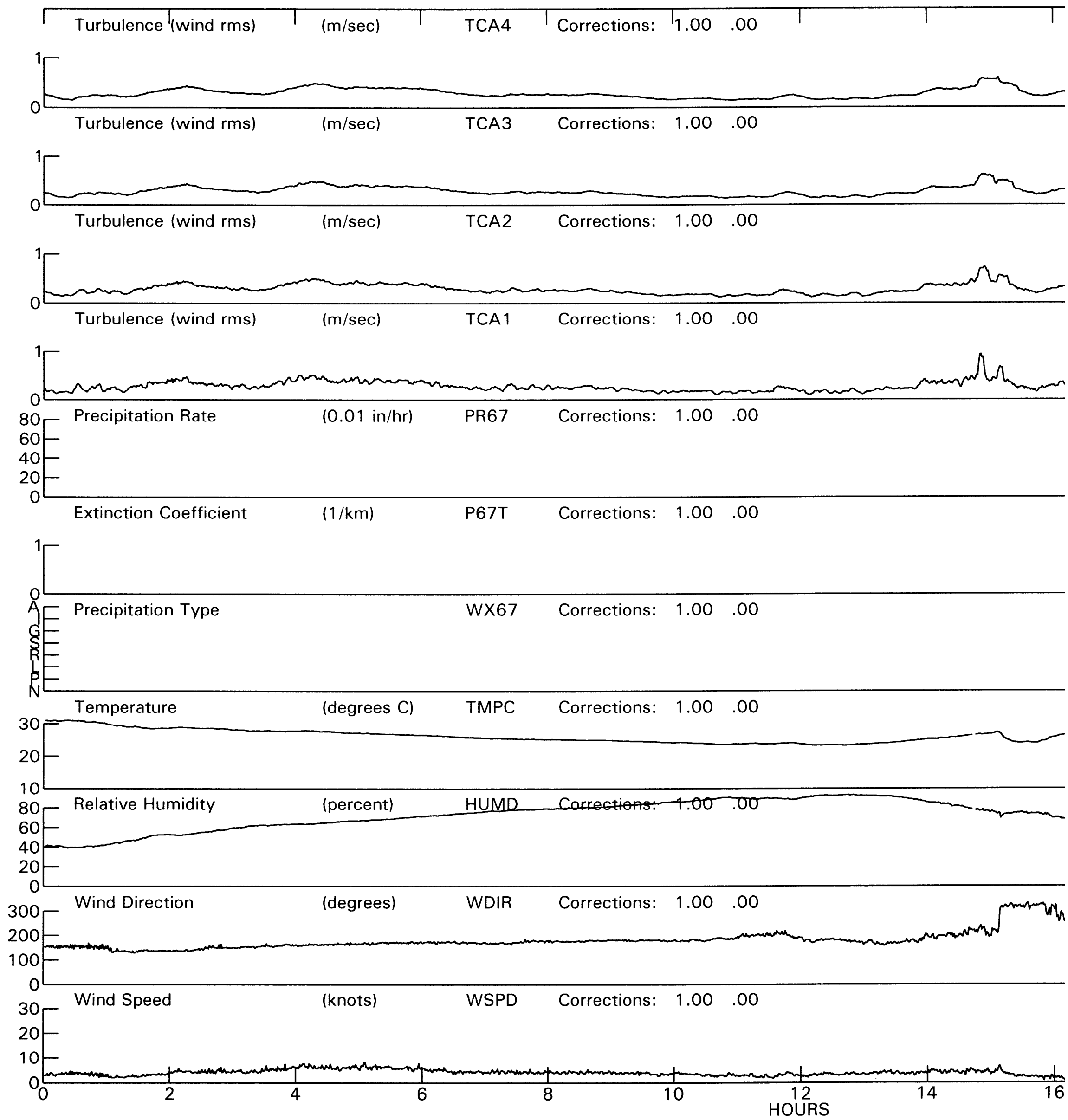

Figure A-6. Other Meteorological Parameters

Figure A-6 plots other meteorological parameters. The top four plots (TCA1, TCA2, TCA3, and TCA4) show the crosswind turbulence (minimum 1-minute value from the ends of the windline, Poles 1 and 18) averaged for 5, 10, 15, and 20 minutes, respectively. The longer averaging times produce smoother turbulence level plots. The 10-minute average (TCA2) selected for calculating the windline detection threshold eliminates rapid fluctuations while giving reasonably responsive estimates for the crosswind turbulence level. The current weather data on precipitation type and rate and extinction coefficient are missing for this day. The temperature and humidity plots show the temperature dropping at night, with a resulting increase in relative humidity. The wind speed and direction plots tell the same story as the component plots in Figure A-2. The most notable event is the abrupt direction change at 1500.

APPENDIX B - FILE FORMATS

B.1 AVOSS V2.1 Format

Table B-1. Sample AVOSS 2.1 File: VN000723.009

```
#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,artifici
al_termination
#1, 1,    P, 9999, 1.25, 1.00, 1
#run_hwind,run_xwind,hwind,xwind,xturb,xminturb,vertturb
#9999,9999,9999,9999,9999,0.10,9999
wl1,983, 0, 0, 000723, 002116
9999, 002116, 9999
983
52, 9999, 9999, 9999, 9999, 9999, 9999, 9999
52, 9999, 9999, 9999, 9999, 9999, 9999, 9999
9999, 9999, 9999, 1, 9999, 9999, 9999, 9999
41
 20,  9999,  9999,  9999,  9999,  9999,  24.2,  9999,  38.9,  9999,   120
 22,  9999,  9999,  9999,  9999,  9999,  24.2,  9999,  34.6,  9999,   122
 24, -38.7,  9999,  35.9,  9999,  -155,  20.2,  9999,  34.7,  9999,   179
 26, -38.7,  9999,  35.0,  9999,  -165,  17.2,  9999,  36.0,  9999,   193
 28, -39.7,  9999,  32.4,  9999,  -161,  22.2,  9999,  33.0,  9999,   192
 30, -38.7,  9999,  35.6,  9999,  -200,  18.2,  9999,  33.1,  9999,   228
 32, -37.7,  9999,  34.0,  9999,  -218,  17.2,  9999,  34.0,  9999,   256
 34, -35.7,  9999,  35.6,  9999,  -266,  15.2,  9999,  36.0,  9999,   308
 36, -35.7,  9999,  32.2,  9999,  -262,  15.2,  9999,  36.0,  9999,   311
 38, -37.7,  9999,  29.2,  9999,  -244,  16.2,  9999,  36.0,  9999,   291
 40, -38.7,  9999,  28.5,  9999,  -249,  17.2,  9999,  34.7,  9999,   286
 42, -39.7,  9999,  28.5,  9999,  -267,  17.2,  9999,  32.4,  9999,   302
 44, -41.7,  9999,  27.1,  9999,  -258,  19.2,  9999,  31.5,  9999,   299
 46, -43.7,  9999,  26.5,  9999,  -268,  20.5,  9999,  31.4,  9999,   312
 48, -46.7,  9999,  24.0,  9999,  -250,  21.5,  9999,  29.3,  9999,   299
 50, -49.7,  9999,  29.0,  9999,  -313,  22.5,  9999,  30.0,  9999,   326
 52, -49.7,  9999,  29.3,  9999,  -325,  23.5,  9999,  31.5,  9999,   348
 54, -52.7,  9999,  28.4,  9999,  -324,  25.5,  9999,  30.7,  9999,   337
 56, -54.7,  9999,  29.1,  9999,  -324,  26.5,  9999,  29.3,  9999,   324
 58, -57.0,  9999,  29.9,  9999,  -337,  27.5,  9999,  28.5,  9999,   327
 60, -60.0,  9999,  30.9,  9999,  -345,  28.5,  9999,  27.6,  9999,   320
 62, -60.6,  9999,  28.6,  9999,  -264,  29.5,  9999,  33.0,  9999,   437
 64, -62.6,  9999,  29.1,  9999,  -266,  30.5,  9999,  32.4,  9999,   435
 66, -66.6,  9999,  43.2,  9999,  -464,  30.5,  9999,  30.0,  9999,   369
 68, -67.6,  9999,  41.0,  9999,  -429,  30.5,  9999,  30.0,  9999,   353
 70, -70.6,  9999,  37.8,  9999,  -389,  35.5,  9999,  27.0,  9999,   310
 72, -73.6,  9999,  39.6,  9999,  -393,  36.5,  9999,  27.0,  9999,   302
 74, -77.6,  9999,  38.7,  9999,  -390,  36.5,  9999,  28.5,  9999,   285
 76, -81.4,  9999,  37.4,  9999,  -296,  37.7,  9999,  32.5,  9999,   397
 78, -84.4,  9999,  38.7,  9999,  -387,  37.7,  9999,  28.5,  9999,   273
 80, -86.4,  9999,  38.9,  9999,  -396,  37.7,  9999,  29.7,  9999,   270
 82, -91.4,  9999,  39.6,  9999,  -409,  37.7,  9999,  30.0,  9999,   265
 84, -95.4,  9999,  36.3,  9999,  -367,  38.7,  9999,  29.5,  9999,   261
 86, -95.4,  9999,  34.2,  9999,  -340,  40.7,  9999,  26.0,  9999,   212
 88,-100.4,  9999,  35.1,  9999,  -336,  40.7,  9999,  26.3,  9999,   207
 90,-104.7,  9999,  29.2,  9999,  -226,  39.7,  9999,  32.4,  9999,   292
 92,-119.4,  9999,  43.2,  9999,  -475,  41.7,  9999,  26.4,  9999,   189
 94,-135.4,  9999,  43.2,  9999,  -682,  42.7,  9999,  28.0,  9999,   194
 96,-134.4,  9999,  39.0,  9999,  -657,  43.7,  9999,  28.5,  9999,   185
 98,-126.4,  9999,  41.0,  9999,  -526,  44.7,  9999,  29.3,  9999,   182
100,-113.4,  9999,  39.6,  9999,  -391,  46.0,  9999,  29.5,  9999,   175
```

B.1.1 Wake File

The NASA AVOSS wake 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 B-1). Note that a value of 9999 means no data and that lines beginning with '#' are considered comments by standard AVOSS processing algorithms. All units are metric.

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 3). 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 transport time algorithms. The next two parameters give the threshold MVICW values (m/s) 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 the file contains the complete wind-line data set for the arrival.

4. The fifth and sixth lines give meteorological data for the arrival. The first two parameters give the headwind and crosswind (m/s) 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 is used to derive the thresholds for starting and stopping tracking and is the only parameter available in real-time files.

5. The seventh line gives the wind-line 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 (002116) and radar-based.

7. The ninth line gives the longitudinal position of the measurement in meters with respect to the runway threshold.

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. Only the transport time is calculated from windline data (see Section 3.4.1). The exit time (time for two detections outside the ± 47.5-meter corridor) is 52 seconds for the port vortex. The starboard vortex never exited the corridor; however, note that the run was terminated abnormally (see line four), most likely by the next arrival.

9. The unused corridor Option 3 in the twelfth line is used to flag other issues. The 1 in field four indicates that the windline data are properly timed relative to the aircraft arrival and are *not* to be corrected for any difference in windline and radar arrival times.

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

11. In the data lines, the vortex parameters are wake age in seconds, lateral position, height and circulation, along with accuracy estimates of each in meters-squared/second. Since no accuracy estimates have yet been developed for the wind line, these parameters are not included.

Table B-2. Sample AVOSS Format Daily Log File

Real-time:
DFW 17C, 000723, 000536, 003, 9999, 28, 9999, 56, 1, 1, 9999, S, 1.25, 1.00, 1, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
DFW 17C, 000723, 000656, 004, 9999, 32, 9999, 40, 1, 1, P, S, 1.25, 1.00, 0, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
DFW 17C, 000723, 001044, 005, 9999, 37, 76, 9999, 1, 1, P, 9999, 1.25, 1.00, 0, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
DFW 17C, 000723, 001308, 006, 9999, 0, 9999, 9999, 0, 0, 9999, 9999, 1.25, 1.00, 0, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
DFW 17C, 000723, 001548, 007, 9999, 44, 9999, 9999, 0, 1, P, 9999, 1.25, 1.00, 1, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
DFW 17C, 000723, 001740, 008, 9999, 21, 9999, 9999, 1, 1, 9999, 9999, 1.25, 1.00, 0, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
DFW 17C, 000723, 002116, 009, 9999, 41, 52, 9999, 1, 1, P, 9999, 1.25, 1.00, 1, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
DFW 17C, 000723, 002302, 010, 9999, 11, 9999, 9999, 0, 1, 9999, 9999, 1.25, 1.00, 0, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
DFW 17C, 000723, 002536, 011, 9999, 22, 24, 9999, 1, 1, P, 9999, 1.25, 1.00, 1, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
DFW 17C, 000723, 002644, 012, 9999, 24, 9999, 9999, 0, 1, P, 9999, 1.25, 1.00, 1, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00, 0.00
Off-line:
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

B.1.2 Log File

The program that generates the AVOSS 2.1 files also generates log files which summarize the processing. Table B-2 shows part of the file that is generated for each day. It identifies the location as DFW 17C and includes the daily windline run number (fourth field). The number of records and port and starboard transit times are then listed. The rest of the line lists the special wind-line parameters and the meteorological parameters listed at the top of the AVOSS 2.1 file (lines 4 and 6 of Table B-1). The upper portion of Table B-1 was generated in real-time at DFW on July 23, 2000. The bolded record is for the run listed in Table B-1. The lower portion was generated in the off-line analysis of data from November 6, 1998. The off-line analysis fills in all parameters, including aircraft type and meteorological parameters.

B.2 METEOROLOGICAL FILES

B.2.1 WIND.DAT

The following is a sample wind.dat file from 1824 hours on 7/24/00:

```
V01_wind, 9999, 000724, 182400, 32.92556, 97.03500, 17C, 184.90, 60
#lp, w_speed, w_dir, x_comp, y_comp, x_var, y_var
18
-107,   1.7,  95.1,  0.15,  1.68,  0.61,  0.46
 -91,  9999,  9999,  9999,  1.88,  9999,  0.43
 -72,  9999,  9999,  9999,  1.77,  9999,  0.48
 -61,  9999,  9999,  9999,  1.44,  9999,  0.37
 -46,  9999,  9999,  9999,  1.88,  9999,  0.32
 -30,  9999,  9999,  9999,  1.77,  9999,  0.46
 -15,  9999,  9999,  9999,  1.66,  9999,  0.46
   0,   1.6, 124.3,  0.90,  1.32,  0.41,  0.57
  15,  9999,  9999,  9999,  1.51,  9999,  0.70
  30,  9999,  9999,  9999,  1.62,  9999,  0.97
  46,  9999,  9999,  9999,  1.74,  9999,  0.83
  61,  9999,  9999,  9999,  1.87,  9999,  0.88
  76,  9999,  9999,  9999,  2.18,  9999,  0.73
  91,  9999,  9999,  9999,  2.23,  9999,  0.52
 107,  9999,  9999,  9999,  2.16,  9999,  0.80
 122,  9999,  9999,  9999,  2.49,  9999,  0.74
 137,  9999,  9999,  9999,  2.79,  9999,  0.65
 152,   3.1, 120.3,  1.55,  2.65,  0.46,  0.63
```

The first line contains the following parameters:

1. File identifier (V01_wind)
2. Unknown
3. Date
4. Time (GMT)
5. Latitude (degrees) of windline center
6. Longitude (degrees) of windline center
7. Runway
8. Altitude (m) (MSL)
9. Averaging time (s)

The second line contains the parameter names for the final list of records:

1. Lateral Position (m)
2. Wind Speed (m/s)
3. Wind direction (degrees from true north??)
4. Headwind component (m/s)
5. Crosswind Component (m/s)

6. Headwind standard deviation (m/s)
7. Crosswind standard deviation (m/s)

Note that the headwind is available for only three locations

The third line contains the number of records (18), which follow in the next 18 lines

B.2.2 MET.DAT

The following is a sample met.dat file from 1824 hours on 7/24/00:

```
V01_met, 9999, 000724, 182400, 32.91932, 97.02759, 174.90, 60
1
# ht,pr,tp,ptp,vtp,vptp,dp,rh,ws,wd,ucomp,vcomp,wcomp
   0.0,  9999,  30.5,  9999,  9999,  9999,  9999,  38.4,   3.0, 112.5,  -2.8,  -1.1,  9999
```

The first line contains the following parameters:

1. File identifier (V01_met)
2. Unknown
3. Date
4. Time (GMT)
5. Latitude (degrees) of meteorological pole
6. Longitude (degrees) of meteorological pole
7. Runway
8. Altitude (m) (MSL)
9. Averaging time (s)

The second line contains the number of records (1), the third line the parameter names, and the fourth line the record. The parameters are:

1. Height of measurement
2. Pressure (millibars)
3. Temperature C
4. Potential temperature K
5. Virtual temperature C
6. Dewpoint C
7. Relative Humidity
8. Windspeed (m/s)
9. Wind direction, degrees from true north
10. East-west wind component (m/s)
11. North-south wind component (m/s)

12. Vertical wind component (m/s)

B.2.3 RECENT.DAT

The following is a sample recent.dat file from 0156 hours on 9/28/99, the last day of sodar operation.

```
S4_17C SAMPLE INTERVAL 09/28/99 01:55 TO 09/28/99 01:56 V4.13 60 5 17 15 7 64 4500 960 95 10 -120 0 359 718 700
3 COMPONENT 31HTS ZENITH 17-17 ARA 320 SEPANG 90
 HT  *    V  R  N *     U  R  N *    W     SDW    R  N   * MAG  DIR   R  N * IV  IU  IW * SDV   SDU   SNRV   SNRU   SNRW
 170  24.02 0   4  24.13 0   4                           34.05 185   0   4  73  72  36   1.83  2.23     6      6      2
 165  23.20 0   2  20.39 0   2                           30.89 181   0   2  67  71  36   1.75  1.04     6      6      2
 160                24.51 0   5                                             65  75  36         2.66     6      7      2
 155                24.99 0   4                                             66  72  36         1.14     6      6      2
 150  23.43 0   2  22.99 0   3                           32.83 184   0   2  64  67  35   0.07  1.42     6      6      2
 145  25.55 0   2  22.98 0   3                           34.36 182   0   2  60  64  34   1.04  2.99     6      6      2
 140  22.72 0   5  23.89 0   3                           32.97 186   0   3  63  62  32   1.52  1.28     6      6      2
 135  25.04 0   6  23.67 0   3                           34.46 183   0   3  64  58  31   2.21  1.07     6      5      2
 130  25.95 0   4                                                           61  58  31   3.14           6      6      2
 125                24.37 0   5                                             54  56  30         3.21     5      6      2
 120  25.12 0   2  21.44 0   4                           33.03 180   0   2  54  55  32   2.00  1.13     6      6      2
 115  22.71 0   6  25.23 0   4                           33.95 188   0   4  55  55  33   1.63  0.77     6      6      2
 110  22.60 0   3  23.26 0   4                           32.43 186   0   3  52  54  32   0.40  2.34     6      6      2
 105  23.58 0   2  23.63 0   3                           33.38 185   0   2  54  51  31   1.92  0.99     6      5      2
 100  23.22 0   4  24.05 0   2                           33.43 186   0   2  52  49  31   1.10  0.76     6      5      2
  95  22.56 0   4  25.47 0   3                           34.02 188   0   3  47  45  33   1.19  2.10     6      5      2
  90  23.61 0   6                                                           47  40  32   2.71           6      4      2
  85  22.82 0   2                                                           44  40  32   3.55           6      5      2
  80  22.60 0   3  25.83 0   2                           34.32 189   0   2  39  43  33   2.58  0.33     5      5      3
  75  23.63 0   5  23.54 0   2                           33.35 185   0   2  38  41  34   1.26  0.15     6      5      3
  70  16.90 4   2                                                           36  36  39   8.12           5      5      3
  65  17.33 4   4  -3.23 0   2  0.31  0.40   0   3  17.63 129   4   2  37  38  50   9.71  1.40     5      5      4
  60  15.97 4   2  -2.81 0   4  0.27  0.22   0   6  16.22 130   4   2  40  40  58   9.39  0.45     6      5      6
  55   9.46 0   8  -2.91 0   7  0.07  0.25   0   6   9.90 123   0   7  43  51  60   4.76  1.80     6      6      6
  50   6.77 0  10  -2.81 0  12  0.35  0.25   0  11   7.33 117   0  10  51  61  76   1.97  2.38     8      9      8
  45   7.16 0  14  -3.20 0  13  0.18  0.56   0  14   7.84 116   0  13  69  75  95   1.48  2.88    11     10      9
  40   7.05 0  16  -2.21 0  15  0.08  0.62   0  15   7.39 123   0  15  88  81 108   1.63  4.58    13     10     10
  35   6.94 0  17  -2.35 0  15  0.13  0.71   0  16   7.33 121   0  15  94 107 122   1.51  4.26    16     13     11
  30   6.16 0  16  -2.77 0  17  0.20  0.83   0  16   6.75 116   0  16  93 117 137   1.49  3.79    15     14     13
  25   6.13 0  17  -2.37 0  16  0.19  0.64   0  15   6.57 119   0  16  97 115 133   2.46  3.58    14     10     13
  20   4.90 0  16  -1.89 0  16  0.42  0.61   0  15   5.25 119   0  16 149 169 182   2.06  2.62    16     13     15
```

The header gives the operating parameters of the sodar and other information. The following parameters are included:

1. Station name: S4_17C
2. Sample Interval (one minute): 09/28/99 01:55 to 09/28/99 01:56
3. Software version number: v4.13
4. Seconds per averaging period: 60
5. Distance between averaged levels: 5 meters
6. Maximum number of transmit pulses: 17
7. Minimum amplitude for data acceptance: 15
8. Minimum Signal-to-Noise ratio for data acceptance: 7 db
9. FFT Size: 64 points
10. Operating frequency: 4500 Hz
11. Sample rate: 960 Hz
12. Percent of full power output: 95%
13. Running mean noise average number of pulses: 10

14. Adaptive amplitude threshold: -120
15. Background noise sample length: 0 ms
16. Z axis average background noise level: 359 mV
17. Y axis average background noise level: 718 mV
18. X axis average background noise level: 700 mV
19. Number of active antenna components: 3
20. Number of displayed range levels: 31
21. Zenith angle of horizontal beams: 17, -17 degrees
22. Antenna rotation angle: 320 degrees, clockwise from north
23. Horizontal beams separation angle: 90 degrees

The header is followed with a table of measurements. The following fields are included in each measurement (with sample values from the last record, which has all fields):

1. Height: 20 meters
2. V = North/south average wind component: 4.90 m/s
3. R = Reliability of V: 0
4. N = Number of accepted returns in V average: 16
5. U = East/west average wind component: -1.89 m/s
6. R = Reliability of U: 0
7. N = Number of accepted returns in U average: 16
8. W = Vertical wind component: 0.42 m/s
9. SDW = Standard deviation of W: 0.61 m/s
10. R = Reliability of W: 0
11. N = Number of accepted returns in W average: 15
12. MAG = Horizontal wind average magnitude: 5.25 m/s
13. DIR = Horizontal average wind direction: 119 degrees
14. R = Reliability of MAG & DIR: 0
15. N = Number of accepted returns in MAG & DIR average: 16
16. IV = V component signal return amplitude: 149
17. IU = U component signal return amplitude: 169
18. IW = W component signal return amplitude: 182
19. SDV = V standard deviation: 2.06 m/s
20. SDU = U standard deviation: 2.62 m/s

21. SNRV = V signal-to-noise ratio: 16 db
22. SNRU = U signal-to-noise ratio: 13 db
23. SNRW = W signal-to-noise ratio: 15 db

The minisodar was programmed to cover the range of 20 to 170 meters in 5-m range gates. However, only the lowest range gates show reasonable data (up to 50 meters at best).

The winds at the lowest range gates can be compared to the 9-meter values in Figure A-1, which show crosswind and headwind of about 3.0 meters/second and 2.5 meters/secondecond, respectively, for this time. The V component is approximately the headwind (6 meters/second) and the U component is approximately the negative crosswind (-2 meters/secondecond). These values are not in agreement with the values of Figure A-1 (headwind = 2 meters/second, crosswind = 2.5 meters/second/second. Although the sodar clock was normally also set to UTC, sometimes it was not synchronized. The sodar winds would agree better with the windline values at 0400: headwind = 6 meters/second, crosswind = 2 meters/secondecond. The time synchronization could be checked by making strip charts like Figure A-1 for the sodar data. For example, the abrupt change in headwind at 1500 would show the time offset between the sodar and windline clocks. Unfortunately, the software for making daily plots of sodar data was not available for this report.

Any clock synchronization problems did not affect the real-time AVOSS use of sodar data, since the sodar files were sent to the Business Center as soon as they were written.

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