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Anemometer Array and Meteorological Data: May 1998 SOCRATES Test

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ABSTRACT

SOCRATES sensor technology uses laser beams to simulate an array of microphones. One possible application of this technology is to detect and track aircraft wake vortices by means of the sound emitted. In May 1988, a feasibility test was conducted at the approach to Runway 31R at JFK International Airport. Vortex lateral position was measured using a 700-foot array of horizontal and vertical single-axis anemometers mounted on 28-foot poles. Meteorological sensors provided information about the state of the atmosphere. This report (with an accompanying CD-ROM) presents the aircraft arrival, wake vortex, and meteorological data from this test, including descriptions of processing algorithms and database formats.

PREFACE

One of the long-term goals of the United States Wake Vortex Program has been to develop real-time, all-weather systems for the measurement of wake vortices. Ground-based anemometers qualify as real-time, all-weather vortex sensors and, when installed in an array, are effective in providing information as to the lateral position of vortices that have descended into ground effect. In addition, based on algorithms developed in 1994, estimates of height and circulation can be derived. The reliability of the anemometer array in tracking wake vortices has led to its use as ground truth in the evaluation of other potential sensors for wake vortex detection. This report makes use of the Version 4 processing algorithms for tracking vortices and extracting height and circulation values from such measurements under all turbulence conditions. Analyses of landings at Kennedy International Airport are presented in support of the SOCRATES sensor evaluation test program.

The Federal Aviation Administration (FAA) SOCRATES Program Manager, George 'Cliff' Hay has asked the Volpe National Transportation Systems Center (Volpe Center) to make its wake vortex data available in electronic form to support wake vortex research. This report documents the anemometer array data, associated meteorological data, and other data, obtained during the SOCRATES test program, that is provided in a CD-ROM that accompanies this report.

The authors would like to acknowledge the support of Leo Jacobs who helped install and maintain the Kennedy Test Site and David Hazen who managed and validated the data files coming from the site. Both are employees of the System Resources Corporation.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
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 yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F	=	y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

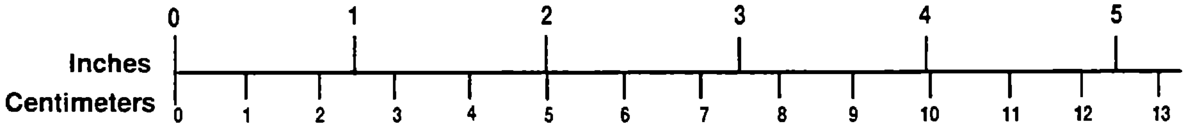
VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C	=	x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



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

Updated 6/17/98

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1. INTRODUCTION

1.1 WIND-LINE BACKGROUND

In 1994, the John A. Volpe National Transportation Systems Center (Volpe Center) installed a ground-wind wake vortex tracking system[1] at New York's Kennedy Airport at the same Runway 31R approach region used for testing[2] in the 1970s. The installation consists[3] of an array of two-axis anemometers (vertical wind and crosswind). The headwind is also measured at the ends of the array to provide complete ambient wind[4] data. The data collection system operates automatically. Aircraft arrivals are detected automatically with noise monitors; each arrival generated data files containing data until the next arrival or 180 seconds later, whichever came first. The wake vortex processing algorithms[5] have been developed to a point where the array provides reliable information on vortex lateral position under all turbulence conditions and some information on vortex height and strength.

1.2 SOCRATES BACKGROUND

In support of the Federal Aviation Administration, the Volpe National Transportation Systems Center (Volpe Center) is conducting an evaluation of a laser based system concept called SOCRATES to determine its possible application in detecting potentially hazardous meteorological and wake turbulence phenomena. SOCRATES technology uses a laser beam to detect sound in the atmosphere. SOCRATES technology is based upon the modulation of the phase of a reflected laser beam due to the induced change of the index of refraction of the propagating medium by an acoustic signal.

1.3 TEST OBJECTIVES

The objectives of the test were to define the nature of wake vortex acoustic signals and evaluate the capability of the SOCRATES technology to detect those acoustic signals. The SOCRATES test was conducted at the Wake Vortex Test Site at Kennedy Airport from May 13, 1998 through May 22, 1998.

1.4 SCOPE OF THIS REPORT

This report presents the data obtained by the Volpe Center using the ground-wind line to provide wake vortex lateral position ground truth and the data obtained using supplementary instrumentation.

1.5 DATA PROCESSING HISTORY

A preliminary analysis of the wind-line data was based on the run files recorded in real time and used the available processing programs and configuration files. A number of problems noted in the preliminary analysis have been corrected in this report:

1. Some of the B-747 runs were terminated early, apparently because a false new arrival was triggered by thrust reverser noise. This problem was addressed by reprocessing the complete wind-line data files using a minimum time between arrivals of 45 seconds (rather than the 20 seconds used in the real-time program).

2. Although one of the vertical anemometers was not functional during the test, existing processing software included its measurement in the least-square fit. The processing software was updated to permit nonfunctioning anemometers to be excluded from the analysis.
3. The vortex tracks behaved oddly near the end of the anemometer array. This problem was traced to incorrect signs for two vertical anemometers. The signs were corrected.

Note that problems with vertical anemometers require sophisticated analysis for detection. Under normal conditions, the vertical wind component is close to zero; consequently, it is difficult to detect an unresponsive anemometer and even harder to verify the correct sign.

Prior analyses of anemometer array data terminated with the arrival of the next aircraft. The analysis of this report extends past the next arrival.

In addition to these improvements in the wind-line processing software, new software had to be developed to analyze the sonic anemometer data.

2. DATA COLLECTION

2.1 ANEMOMETER ARRAY

The coordinate system of the data collection system is oriented to the runway direction. Lateral positions are taken with respect to the extended runway centerline (positive to the right as viewed by an approaching aircraft). Longitudinal positions are taken with respect to the location of the middle marker (positive toward the runway). Wind directions are similarly defined. A head wind is positive if it is blowing from the runway toward the middle marker. A crosswind is positive when blowing to the right as viewed from an approaching aircraft. Positive vertical wind is up.

Table 1 lists the anemometer poles of the array and the number of axes measured using R. M. Young single-axis propeller anemometers (current Model No. 27106R), which measures a single wind component. The poles with two axes measured crosswind and vertical wind components. The three-axis poles also included the headwind component. The wind components were averaged for two seconds and then recorded.

Table 1. Anemometer Pole Locations

Pole	Distance (ft) from Runway Centerline	Distance (ft) from Middle Marker	Height(ft)	Number Axes
01	-350	400	28	3
02	-300	400	28	2
03	-250	400	28	2
04	-200	400	28	2
05	-150	400	28	2
06	-100	400	28	2
07	-50	400	28	2
08	0	400	28	2
09	50	400	28	2
10	100	400	28	2
11	150	400	28	2
12	200	400	28	2
13	250	400	28	2
14	300	400	28	2
15	350	400	28	3
16	0	450	28	2
17	50	450	28	2
18	0	200	28	2
19	50	200	28	2
20	100	415	14	2
21	100	420	7	2
22	100	425	3.5	1
23	100	430	1.75	1
24	350	350	28	Spd/Dir

The anemometer measurements are labeled Cnn, Vnn or Hnn, where nn refers to the pole number and C, V or H refer to crosswind, vertical wind or headwind, respectively. The names of the corresponding standard deviation parameters are obtained by prefixing a "T" for turbulence, e.g., TVnn.

The aircraft detector consisted of a horn-type loudspeaker aimed 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 horn was mounted on the runway side of the plywood box housing the field data acquisition modules, which was located near Pole 9. In this location, the aircraft noise was somewhat blocked from the horn until the aircraft was directly overhead and thus should provide a sharply rising noise signature for landing aircraft. The signal from the horn loudspeaker was amplified and rectified to produce the noise signal that was digitized.

2.2 METEOROLOGICAL SENSORS

The wind and temperature sensors were recorded as one-minute averages.

2.2.1 Wind

In addition to the wind component sensors, a conventional propeller/vane sensor was mounted on Pole 24 of Table 1 (parameter names WSPD/WDIR).

2.2.2 Temperature

Four temperature sensors were mounted at heights of 6.75, 13.5, 20.25 and 27 feet on Pole 24. The corresponding parameter names are TMP1, TMP2, TMP3, and TMP4.

2.2.3 Sonic Anemometer

The Metek sonic anemometer was located at a height of approximately four feet at the three sites listed in Table 2. Table 3 lists the data and time when the location was changed.

Table 2. Sonic Anemometer Locations

Location	Distance from Runway Centerline	Distance from Middle Marker
1	104 ft	65
2	127	325
3	338	297

Table 3. Sonic Anemometer Location Changes

Location	Date	Time
3	5/13/98	12:00
1	5/16/98	15:33
2	5/19/98	21:45

2.3 DATA ACQUISITION

The primary data acquisition system (DAS) is hosted in an industrial PC and was derived from an available weather 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 sensors were digitized using Campbell Scientific dataloggers, which averaged the data and transmitted it to the DAS via serial links. A binary format was used for the two-second averages to minimize bandwidth and storage requirements.

The following four sections describe the various files recorded by the DAS.

2.3.1 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 one-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 large amount of two-second averaged data, the complete WM file for one day contains more than 4 Mbytes. The file size can be reduced by eliminating periods with no aircraft arrivals. Two options were specified for the amount of data saved in the WM file: (a) all data, or (b) the minute before and four minutes after each aircraft arrival.

The WM files can be reprocessed with different parameters (e.g., aircraft noise threshold or minimum time between arrivals) to generate a new set of run files (Section 2.3.3).

2.3.2 Meteorological Data Storage

A secondary data acquisition program receives each one-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 two-second binary data into one-minute means and standard deviations, which are stored as ASCII. The meteorological file is named DMmmDdd.Yyy and stores all one-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.

2.3.3 Wake Vortex Run

The real-time wake vortex run files were named 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. The start of run is defined by the two-second average of aircraft noise reaching a peak (i.e., noted by a decrease in the next two-second average) that is above a detection threshold. The recorded arrival time is that of the reduced noise level; consequently, the acoustic arrival time is actually a few seconds after the aircraft has passed the wind line. The start of the next run is suppressed for 20 seconds to prevent multiple triggers on the same aircraft (more likely on a 13L departure than a 31R arrival because of the higher altitude). The run file records two-second data blocks from ten seconds before the arrival until the next arrival or until 180 seconds has elapsed since the start of run.

The run file name has recently been changed to RMyymmdd.nnn, which keeps track of the year. The reprocessed run files used in the analysis of this report have this naming format.

2.3.4 Real-Time Analysis

The data collection program also outputs three files to the network fileserver that can be used for real-time analysis.

2.4 KNOWN SENSOR FAILURES

1. Vertical anemometer V04 was inoperative during the entire test period.

2. Vertical anemometers V08 and V11 had relative high starting thresholds during the test period, but appeared to respond to wake vortices.

3. AIRCRAFT INFORMATION

3.1 MODE-S SQUITTER

The Mode-S squitter is part of the Traffic Collision Avoidance system (TCAS) system and is therefore installed on passenger aircraft, but usually not on freight aircraft. The squitter message is broadcast once per second and includes a code uniquely identifying the aircraft and the aircraft altitude. Since sequences of aircraft codes are assigned to different countries, the country of the aircraft can be identified. For United States aircraft, the squitter processor was programmed with the US aircraft registry and, hence, the aircraft manufacturer and model are known for US aircraft.

The squitter data were correlated with the wind-line arrival data using the real-time run files. The following steps were carried out:

1. The lowest height was selected for each arrival. The squitter time (assigned by the processing computer) was corrected to approximate the wind-line arrival time by adjusting the time to 200-foot aircraft altitude, assuming a descent rate of 10 feet/second.

2. Heights greater than 500 feet were rejected (probably takeoffs oN other runways).

3. Groups of squitter arrivals were defined based on gaps of more than 30 minutes in the arrival stream and a maximum number of 40 arrivals per group.

4. Groups of more than 20 arrivals were matched to wind-line arrival times by adding time offsets of -60 to +80 seconds and looking for the maximum number of matches within ±5 seconds. Table 4 shows the results of this matching process (groups with one arrival have been deleted). Clock differences varies by about ± one minute.

5. The time offsets were interpolated between groups and used to match all the runs, using a tolerance of ±20 seconds.

Table 4. Group Matching of Mode-S and Wind-Line Arrival Times

Group	Count	Correction (sec)	Count5
1	2	-36	
2	24	-36	2
3	7	-37	
4	40	-38	30
5	3	-42	
6	32	-46	23
7	11	-40	
8	40	-34	23
9	31	-38	22
11	2	-30	
13	40	-24	24
14	21	-24	18
17	40	-22	28
18	32	-24	29
19	40	10	34
20	41	6	38
21	41	6	33
22	41	6	38
23	41	6	37
24	41	4	40
25	25	2	19
26	40	16	35
27	41	16	34
28	41	16	35
29	41	16	36
30	41	14	35
31	41	12	34
32	21	48	12
33	40	30	29
34	17	30	
35	3	35	
38	40	54	24
39	38	66	34
43	40	72	24
44	39	66	27
46	3	60	
48	31	52	28
49	40	-24	34
50	41	-26	31
51	41	-34	28
52	41	-34	32
53	19	-34	
54	40	-52	34
55	41	-52	36
56	41	-50	36
57	25	-50	21
58	40	-22	32
59	5	-22	
61	7	-22	
63	27	-22	22
64	40	-32	38
65	41	-32	35
66	12	-32	

Since the Mode-S data were not available for all runs, it was ultimately less useful than the Collection & Analysis of Terminal Records (CATER) data discussed in the next section. Nevertheless, it provided the exact aircraft model and is therefore included in the databases (Section 5.1.2.2). The Mode-S data also allowed the CATER data to be unscrambled when the reported landing times were incorrect.

3.2 CATER DATA

The CATER data is the official record of operations for the Port Authority of New York and New Jersey. The starting data set was filtered to include only arrivals on Runway 31R from 5/13/98 through 5/22/98. The following steps were taken to analyze the CATER data:

1. Add four hours to convert times to GMT, correcting the date when necessary.
2. Eliminate aircraft types of H or HELI, which were helicopters.
3. Manually match the CATER list of arrivals with the wind-line run list and the Mode-S list.

Most of the time the CATER list matched perfectly with the real-time wind-line run list with two minor exceptions: Sometimes the wind-line did not trigger for small aircraft (e.g., JSTA). Sometimes the wind-line triggered again shortly after an arrival because of thrust reverser detection or some other false alarm.

Sometimes the CATER data showed bunches of incorrect arrival times. In most cases, the Mode-S data gave enough additional information to permit unscrambling the arrivals.

3.3 SELECTED DATA SET

Table 5 shows when the SOCRATES system was operational. These time limits were used (a) to limit the amount of CATER data to be manually validated and (b) to select wind-line files for analysis. The jet transport aircraft arrivals were selected based on the CATER data and are listed in Table 6. This list is the usable data set for analysis from the May 1998 JFK test. Typically the wind line did not detect wake vortices from the smaller aircraft. Table 6 lists arrival time and run duration data based on the acoustic detection of arrivals. Included are the reprocessed run file name and maximum vortex age recorded (minimum of time until next arrival or 180 seconds).

Table 5. SOCRATES Operational Times

DATE	START TIME	STOP TIME
19980513	140600	143200
19980513	233700	240000
19980514	000000	003900
19980514	103800	132000
19980515	101400	140500
19980516	101200	133000
19980518	102000	234000
19980519	102500	194000
19980519	215000	240000
19980520	000000	005000
19980520	104000	141000
19980521	103000	121000
19980521	184700	220500
19980522	115700	123000

Table 6. 461 Jet Transport Aircraft Arrivals During SOCRATES Operational Times

File Name	Max Age (sec)	DATE	TIME (GMT)	CATER Type	Mode-S Model
i:rm980513.071	180	19980513	140931	B767	767-223
i:rm980513.072	132	19980513	141911	B74B	N/A
i:rm980513.074	110	19980513	142225	B727	727-2J4
i:rm980513.075	158	19980513	142415	B74A	747-269B
i:rm980513.076	106	19980513	142653	MD80	MD 83
i:rm980513.077	116	19980513	142839	A300	A300B4-605R
i:rm980514.027	126	19980514	104129	DC9	
i:rm980514.028	180	19980514	104335	DC8	DC-8-62
i:rm980514.029	154	19980514	104833	B74B	N/A
i:rm980514.030	122	19980514	105107	B727	
i:rm980514.032	132	19980514	105549	B757	757-2Q8
i:rm980514.038	180	19980514	111320	B767	767-322
i:rm980514.041	180	19980514	112426	B727	
i:rm980514.042	124	19980514	112748	B74A	
i:rm980514.045	98	19980514	113258	DC10	DC-10-10
i:rm980514.046	180	19980514	113436	MD11	N/A
i:rm980514.047	144	19980514	113736	A310	N/A
i:rm980514.052	46	19980514	115036	DC8	
i:rm980514.053	82	19980514	120312	B727	727-247
i:rm980514.054	180	19980514	120434	B767	767-322
i:rm980514.055	52	19980514	120812	B757	
i:rm980514.056	180	19980514	121558	DC9	DC-9-31
i:rm980514.059	180	19980514	123146	CONC	N/A
i:rm980514.062	108	19980514	125311	B767	N/A
i:rm980514.064	144	19980514	130603	CONC	N/A
i:rm980514.065	114	19980514	130827	EA32	N/A
i:rm980515.037	168	19980515	101711	B767	767-223
i:rm980515.038	180	19980515	101959	B727	
i:rm980515.039	180	19980515	102405	DC9	
i:rm980515.040	180	19980515	103429	B767	767-322
i:rm980515.041	50	19980515	103832	DC8	DC-8-62
i:rm980515.045	180	19980515	105342	DC10	DC-10-10
i:rm980515.046	140	19980515	105810	B74B	N/A
i:rm980515.047	50	19980515	110030	B757	757-2Q8
i:rm980515.051	156	19980515	110736	B727	
i:rm980515.056	136	19980515	111804	B74A	N/A
i:rm980515.060	44	19980515	112529	B727	
i:rm980515.066	180	19980515	113521	B767	N/A
i:rm980515.070	180	19980515	114945	DC8	
i:rm980515.072	106	19980515	115605	A310	N/A
i:rm980515.074	180	19980515	115952	MD11	N/A
i:rm980515.075	164	19980515	120500	B757	757-223
i:rm980515.078	106	19980515	121212	B727	
i:rm980515.080	96	19980515	121624	DC9	DC-9-31
i:rm980515.083	180	19980515	122406	B767	N/A
i:rm980515.084	180	19980515	123446	CONC	N/A
i:rm980515.087	180	19980515	125023	B74A	
i:rm980515.089	180	19980515	130305	B777	777-222
i:rm980515.094	100	19980515	132912	CONC	N/A
i:rm980515.096	180	19980515	134422	B727	727-290
i:rm980515.097	180	19980515	134756	A300	A300B4-605R
i:rm980516.061	180	19980516	101351	B767	767-223
i:rm980516.062	80	19980516	101845	B767	767-322
i:rm980516.063	180	19980516	102005	B767	
i:rm980516.066	180	19980516	102723	B767	767-322
i:rm980516.067	180	19980516	103629	DC8	

i:rm980516.068	118	19980516	104145	DC9	
i:rm980516.073	180	19980516	105234	DC10	DC-10-10
i:rm980516.074	178	19980516	105706	DC8	
i:rm980516.076	104	19980516	110538	EA32	A320-231
i:rm980516.078	158	19980516	110900	B74A	747-132
i:rm980516.081	156	19980516	111524	DC8	DC-8-62
i:rm980516.082	110	19980516	111800	B727	
i:rm980516.083	148	19980516	111950	B74B	N/A
i:rm980516.092	132	19980516	113611	MD11	N/A
i:rm980516.093	106	19980516	113822	B727	
i:rm980516.095	180	19980516	114127	B727	
i:rm980516.096	162	19980516	114557	DC8	
i:rm980516.101	132	19980516	120337	MD11	N/A
i:rm980516.104	80	19980516	120804	B737	727-231
i:rm980516.105	148	19980516	120923	DC10	N/A
i:rm980516.106	116	19980516	121151	B757	757-223
i:rm980516.108	142	19980516	122302	B747	747-212B
i:rm980516.113	180	19980516	124204	B757	757-2Q8
i:rm980516.114	180	19980516	124646	DC8	
i:rm980516.116	180	19980516	125202	CONC	N/A
i:rm980516.118	180	19980516	125812	B767	N/A
i:rm980516.120	180	19980516	130547	B757	757-28A
i:rm980516.121	180	19980516	131137	CONC	N/A
i:rm980518.044	126	19980518	102151	B767	767-231
i:rm980518.045	180	19980518	102357	B767	767-323
i:rm980518.046	180	19980518	102813	B74B	747-422
i:rm980518.048	152	19980518	104320	DC10	DC-10-10
i:rm980518.050	50	19980518	105456	B757	757-2Q8
i:rm980518.054	130	19980518	110637	B74B	N/A
i:rm980518.058	44	19980518	111734	A310	N/A
i:rm980518.070	180	19980518	114141	MD11	N/A
i:rm980518.077	152	19980518	120226	B767	N/A
i:rm980518.084	128	19980518	121922	B767	N/A
i:rm980518.086	118	19980518	122424	B757	757-223
i:rm980518.087	134	19980518	122622	EA32	A320-231
i:rm980518.088	126	19980518	122836	B74A	747-212B
i:rm980518.090	140	19980518	123210	MD11	N/A
i:rm980518.091	124	19980518	123431	DC9	DC-9-32
i:rm980518.093	180	19980518	123911	CONC	N/A
i:rm980518.095	180	19980518	125337	MD11	N/A
i:rm980518.096	180	19980518	130133	B74A	N/A
i:rm980518.100	180	19980518	134252	B727	N/A
i:rm980518.101	180	19980518	134604	A300	A300B4-605R
i:rm980518.105	136	19980518	141823	B74B	N/A
i:rm980518.106	100	19980518	142039	B767	767-223
i:rm980518.108	180	19980518	142329	MD80	DC-9-82(MD-82)
i:rm980518.111	180	19980518	143459	MD80	DC-9-82(MD-82)
i:rm980518.112	78	19980518	144337	B74B	N/A
i:rm980518.113	112	19980518	144456	B74A	747-136
i:rm980518.114	166	19980518	144648	B74A	N/A
i:rm980518.115	180	19980518	144934	CONC	N/A
i:rm980518.117	108	19980518	145900	DC9	DC-9-31
i:rm980518.118	180	19980518	150048	B767	767-322
i:rm980518.121	102	19980518	152003	B757	757-2Q8
i:rm980518.126	112	19980518	152845	B74B	N/A
i:rm980518.130	114	19980518	154729	B74A	
i:rm980518.132	146	19980518	155227	B74A	N/A
i:rm980518.134	118	19980518	160700	A300	A300B4-605R

i:rm980518.138	180	19980518	163100	B767	N/A
i:rm980518.141	126	19980518	163826	B73A	737-222
i:rm980518.142	180	19980518	164033	MD11	N/A
i:rm980518.143	164	19980518	164513	B757	
i:rm980518.144	102	19980518	164757	B767	N/A
i:rm980518.149	178	19980518	170843	B74A	N/A
i:rm980518.151	158	19980518	171445	B757	757-2Q8
i:rm980518.152	100	19980518	171724	MD80	DC-9-82(MD-82)
i:rm980518.153	162	19980518	171903	B767	767-231
i:rm980518.156	156	19980518	173252	B727	727-223
i:rm980518.157	148	19980518	173528	B767	767-323
i:rm980518.158	180	19980518	173756	A300	A300B4-605R
i:rm980518.160	96	19980518	174254	B74A	
i:rm980518.161	180	19980518	174430	DC10	N/A
i:rm980518.162	108	19980518	175148	B767	767-231
i:rm980518.163	142	19980518	175336	MD80	MD 83
i:rm980518.164	56	19980518	175559	B767	N/A
i:rm980518.166	112	19980518	175939	B74A	747-222B
i:rm980518.168	102	19980518	180316	A330	N/A
i:rm980518.169	180	19980518	180458	B767	767-231
i:rm980518.171	98	19980518	181205	B757	757-222
i:rm980518.172	180	19980518	181343	B767	767-231
i:rm980518.173	180	19980518	181823	B767	767-323
i:rm980518.175	180	19980518	182345	A310	N/A
i:rm980518.178	140	19980518	183839	B767	767-332
i:rm980518.181	180	19980518	184744	MD80	DC-9-82(MD-82)
i:rm980518.182	120	19980518	185416	B767	767-222
i:rm980518.183	168	19980518	185616	B767	N/A
i:rm980518.184	140	19980518	185904	B727	727-231
i:rm980518.185	122	19980518	190124	A340	N/A
i:rm980518.187	132	19980518	190458	DC10	JETSTREAM 4101
i:rm980518.189	180	19980518	191406	MD80	DC-9-51
i:rm980518.190	152	19980518	191725	DC9	N/A
i:rm980518.191	98	19980518	191956	B74B	N/A
i:rm980518.192	104	19980518	192135	MD11	JETSTREAM 4101
i:rm980518.194	132	19980518	192443	B767	N/A
i:rm980518.196	138	19980518	192807	B74B	N/A
i:rm980518.199	138	19980518	193405	B74F	N/A
i:rm980518.200	180	19980518	193623	B74A	N/A
i:rm980518.202	180	19980518	194423	B727	727-227
i:rm980518.203	120	19980518	194841	DC10	DC-10-10
i:rm980518.204	152	19980518	195041	B757	757-222
i:rm980518.206	108	19980518	195552	B767	767-223
i:rm980518.208	148	19980518	195931	B74A	N/A
i:rm980518.209	162	19980518	200200	B74B	747-422
i:rm980518.210	96	19980518	200442	B757	757-223
i:rm980518.211	122	19980518	200624	B767	N/A
i:rm980518.212	106	19980518	200826	B74B	N/A
i:rm980518.213	112	19980518	201012	B74B	N/A
i:rm980518.215	180	19980518	201344	B767	767-222
i:rm980518.216	94	19980518	201732	B767	767-231
i:rm980518.217	116	19980518	201906	B767	767-322
i:rm980518.218	112	19980518	202102	MD88	767-222
i:rm980518.219	120	19980518	202254	B727	MD-88
i:rm980518.222	142	19980518	202845	MD88	MD-88
i:rm980518.224	180	19980518	203302	B757	757-232
i:rm980518.225	124	19980518	203602	B757	757-2Q8
i:rm980518.227	174	19980518	204127	B757	757-232

i:rm980518.228	130	19980518	204421	B757	757-2Q8
i:rm980518.229	164	19980518	204631	EA32	A320-232
i:rm980518.231	150	19980518	205119	B74A	N/A
i:rm980518.232	86	19980518	205349	B767	767-223
i:rm980518.233	132	19980518	205515	B767	767-3P6
i:rm980518.234	116	19980518	205727	B767	767-323
i:rm980518.235	108	19980518	205923	B767	767-205
i:rm980518.236	114	19980518	210111	A300	A300B4-605R
i:rm980518.243	90	19980518	211216	B767	767-323
i:rm980518.245	144	19980518	211520	B767	N/A
i:rm980518.246	94	19980518	211744	B757	757-2Q8
i:rm980518.248	98	19980518	212046	B757	757-223
i:rm980518.249	132	19980518	212224	B767	N/A
i:rm980518.250	82	19980518	212436	MD80	DC-9-82(MD-82)
i:rm980518.251	124	19980518	212558	A300	A300B4-605R
i:rm980518.252	144	19980518	212802	B74A	N/A
i:rm980518.253	100	19980518	213026	A300	A300B4-605R
i:rm980518.255	136	19980518	213306	MD11	N/A
i:rm980518.256	94	19980518	213522	B757	757-232
i:rm980518.257	84	19980518	213656	B727	727-231
i:rm980518.258	172	19980518	213820	B777	N/A
i:rm980518.260	124	19980518	214244	B767	767-332
i:rm980518.261	90	19980518	214448	B767	767-332
i:rm980518.262	166	19980518	214618	CONC	N/A
i:rm980518.263	88	19980518	214905	MD80	DC-9-82(MD-82)
i:rm980518.264	100	19980518	215032	MD80	DC-9-82(MD-82)
i:rm980518.267	110	19980518	215525	MD88	MD-88
i:rm980518.268	132	19980518	215715	L101	L-1011-385-1-15
i:rm980518.269	122	19980518	215926	B757	N/A
i:rm980518.271	98	19980518	220251	MD80	DC-9-83(MD-83)
i:rm980518.272	110	19980518	220429	A300	A300B4-605R
i:rm980518.273	122	19980518	220619	B767	767-332
i:rm980518.274	120	19980518	220821	B767	767-223
i:rm980518.276	158	19980518	221143	B767	N/A
i:rm980518.277	100	19980518	221421	B767	767-3P6
i:rm980518.279	100	19980518	221725	B74A	N/A
i:rm980518.280	134	19980518	221905	B767	767-332
i:rm980518.281	92	19980518	222119	B767	767-332
i:rm980518.285	180	19980518	222907	MD80	DC-9-82(MD-82)
i:rm980518.286	148	19980518	223258	DC9	DC-9-51
i:rm980518.287	108	19980518	223525	B767	N/A
i:rm980518.288	108	19980518	223714	B727	727-264
i:rm980518.294	154	19980518	224856	A310	A310-325
i:rm980518.295	180	19980518	225130	A300	A300B4-605R
i:rm980518.297	100	19980518	225814	B757	757-223
i:rm980518.300	180	19980518	230542	MD80	DC-9-82(MD-82)
i:rm980518.301	154	19980518	231012	B757	757-2Q8
i:rm980518.302	106	19980518	231246	B757	757-223
i:rm980518.304	168	19980518	231733	B74B	N/A
i:rm980518.305	112	19980518	232020	MD80	MD 83
i:rm980518.306	106	19980518	232212	A340	N/A
i:rm980518.307	116	19980518	232359	B74B	N/A
i:rm980518.310	114	19980518	232833	B74A	N/A
i:rm980518.311	124	19980518	233027	B767	767-222
i:rm980518.315	156	19980518	233655	B777	777-222
i:rm980519.086	152	19980519	102531	B767	767-223
i:rm980519.087	138	19980519	102804	B767	767-322
i:rm980519.088	44	19980519	103021	B727	

i:rm980519.090	130	19980519	103401	DC10	N/A
i:rm980519.091	124	19980519	103612	DC9	
i:rm980519.092	106	19980519	103816	B74A	N/A
i:rm980519.093	44	19980519	104002	B727	
i:rm980519.095	134	19980519	104144	B74A	
i:rm980519.096	136	19980519	104357	DC8	DC-8-62
i:rm980519.097	158	19980519	104614	B757	757-231
i:rm980519.098	132	19980519	104852	DC10	DC-10-10
i:rm980519.101	46	19980519	105826	B727	
i:rm980519.108	180	19980519	111645	B74B	N/A
i:rm980519.112	180	19980519	113149	MD11	N/A
i:rm980519.114	132	19980519	113735	B757	757-223
i:rm980519.117	180	19980519	114701	DC8	
i:rm980519.120	180	19980519	115605	DC8	
i:rm980519.122	120	19980519	120714	B767	N/A
i:rm980519.123	146	19980519	120914	B727	
i:rm980519.124	60	19980519	121140	DC9	DC-9-32
i:rm980519.127	178	19980519	121710	B757	757-223
i:rm980519.129	96	19980519	122522	B767	N/A
i:rm980519.131	102	19980519	122806	MD11	N/A
i:rm980519.136	180	19980519	124345	CONC	N/A
i:rm980519.137	180	19980519	124739	EA32	A320-231
i:rm980519.142	180	19980519	130605	CONC	N/A
i:rm980519.146	180	19980519	133804	A300	A300B4-605R
i:rm980519.147	108	19980519	140126	B767	767-223
i:rm980519.150	180	19980519	141511	B74B	N/A
i:rm980519.152	138	19980519	142105	MD80	DC-9-82(MD-82)
i:rm980519.155	146	19980519	142923	B74B	N/A
i:rm980519.158	172	19980519	143659	B74A	N/A
i:rm980519.159	180	19980519	143952	MD80	DC-9-82(MD-82)
i:rm980519.160	122	19980519	144316	B73A	737-2B7
i:rm980519.161	180	19980519	144518	B727	N/A
i:rm980519.162	118	19980519	144954	B74A	N/A
i:rm980519.163	180	19980519	145152	B767	767-322
i:rm980519.164	110	19980519	145624	B74B	N/A
i:rm980519.172	180	19980519	152829	B74B	N/A
i:rm980519.175	108	19980519	154245	B757	757-2Q8
i:rm980519.177	138	19980519	154657	A300	A300B4-605R
i:rm980519.178	180	19980519	154915	B74A	N/A
i:rm980519.179	148	19980519	160950	DC9	DC-9-31
i:rm980519.185	180	19980519	163012	B767	N/A
i:rm980519.187	180	19980519	164429	B74A	N/A
i:rm980519.188	180	19980519	164841	B73A	N/A
i:rm980519.189	104	19980519	165723	B757	757-2Q8
i:rm980519.191	118	19980519	170159	B757	757-2Q8
i:rm980519.192	180	19980519	170357	B767	N/A
i:rm980519.193	156	19980519	170803	B767	767-231
i:rm980519.194	162	19980519	171039	B74B	N/A
i:rm980519.195	180	19980519	171322	MD80	DC-9-82(MD-82)
i:rm980519.196	180	19980519	171705	B74A	N/A
i:rm980519.198	180	19980519	172244	B767	767-323
i:rm980519.199	120	19980519	173140	B727	
i:rm980519.200	124	19980519	173340	B757	757-223
i:rm980519.201	180	19980519	173544	B777	N/A
i:rm980519.202	106	19980519	173846	B767	767-231
i:rm980519.203	128	19980519	174032	A330	N/A
i:rm980519.205	180	19980519	174354	B767	767-205
i:rm980519.206	180	19980519	175110	A300	A300B4-605R

i:rm980519.207	120	19980519	175542	B767	767-231
i:rm980519.208	84	19980519	175743	A300	A300B4-605R
i:rm980519.209	118	19980519	175907	MD80	DC-9-82(MD-82)
i:rm980519.210	44	19980519	180105	B767	767-323
i:rm980519.213	112	19980519	180537	B767	767-300
i:rm980519.214	100	19980519	180729	A340	N/A
i:rm980519.216	180	19980519	181231	B777	N/A
i:rm980519.220	172	19980519	183053	B74A	N/A
i:rm980519.221	80	19980519	183345	B757	757-222
i:rm980519.222	96	19980519	183505	A330	N/A
i:rm980519.227	180	19980519	184418	B727	727-231
i:rm980519.228	108	19980519	185038	B74B	N/A
i:rm980519.229	116	19980519	185226	DC10	DC-10-10
i:rm980519.230	130	19980519	185422	MD80	MD 83
i:rm980519.233	180	19980519	190612	MD11	N/A
i:rm980519.235	106	19980519	191122	B767	767-222
i:rm980519.236	130	19980519	191309	MD80	DC-9-82(MD-82)
i:rm980519.237	180	19980519	191518	B727	
i:rm980519.239	180	19980519	192517	DC9	DC-9-51
i:rm980519.241	120	19980519	192929	MD80	N/A
i:rm980519.242	180	19980519	193129	A300	A300B4-605R
i:rm980519.243	100	19980519	193549	B74A	747-251B
i:rm980519.244	110	19980519	193729	MD80	DC-9-82(MD-82)
i:rm980519.245	90	19980519	193919	B74A	747-243B
i:rm980519.306	108	19980519	215106	MD80	DC-9-82(MD-82)
i:rm980519.307	126	19980519	215254	B767	767-3P6
i:rm980519.309	52	19980519	215626	B767	767-223
i:rm980519.311	106	19980519	215852	MD80	DC-9-83(MD-83)
i:rm980519.312	102	19980519	220039	B757	N/A
i:rm980519.313	110	19980519	220220	MD11	N/A
i:rm980519.314	88	19980519	220411	B767	767-3P6
i:rm980519.315	104	19980519	220539	B767	
i:rm980519.317	136	19980519	220825	A340	N/A
i:rm980519.319	112	19980519	221233	B767	767-332
i:rm980519.321	114	19980519	221635	B767	767-332
i:rm980519.322	134	19980519	221829	DC9	DC-9-51
i:rm980519.327	98	19980519	223747	B727	727-227
i:rm980519.330	180	19980519	224918	A300	A300B4-605R
i:rm980519.331	180	19980519	225254	B74A	N/A
i:rm980519.332	114	19980519	225910	B757	757-223
i:rm980519.333	128	19980519	230104	A310	A310-325
i:rm980519.336	180	19980519	230643	B757	757-223
i:rm980519.338	136	19980519	231146	A340	N/A
i:rm980519.342	110	19980519	231929	A320	N/A
i:rm980519.343	168	19980519	232118	B757	757-231
i:rm980519.344	104	19980519	232407	B74B	N/A
i:rm980519.346	180	19980519	233003	B767	767-222
i:rm980519.349	114	19980519	233709	B777	777-222
i:rm980519.352	98	19980519	234359	B767	767-322
i:rm980519.354	120	19980519	234749	EA32	A320-231
i:rm980519.357	180	19980519	235455	EA32	
i:rm980519.358	54	19980519	235806	B74B	
i:rm980520.001	180	19980520	000252	B727	N/A
i:rm980520.003	104	19980520	001139	B757	757-223
i:rm980520.004	146	19980520	001323	B767	767-323
i:rm980520.006	148	19980520	001721	A340	N/A
i:rm980520.008	104	19980520	002115	B777	N/A
i:rm980520.010	84	19980520	002405	B757	757-223

i:rm980520.011	180	19980520	002529	B74A	N/A
i:rm980520.012	134	19980520	002847	MD80	DC-9-83(MD-83)
i:rm980520.013	156	19980520	003100	B767	N/A
i:rm980520.014	100	19980520	003337	B767	767-231
i:rm980520.016	106	19980520	003637	DC10	N/A
i:rm980520.017	106	19980520	003823	A300	A300B4-605R
i:rm980520.037	106	19980520	104204	DC8	DC-8-62
i:rm980520.039	86	19980520	104544	B757	757-2Q8
i:rm980520.041	180	19980520	104851	B727	
i:rm980520.042	180	19980520	105445	B767	767-322
i:rm980520.043	98	19980520	105919	DC10	DC-10-10
i:rm980520.046	122	19980520	110417	B74B	N/A
i:rm980520.048	122	19980520	110859	B74A	N/A
i:rm980520.050	104	19980520	111219	A310	N/A
i:rm980520.053	128	19980520	111711	B727	
i:rm980520.057	88	19980520	112733	B74A	N/A
i:rm980520.065	114	19980520	114954	B767	N/A
i:rm980520.068	96	19980520	115458	DC8	
i:rm980520.072	92	19980520	120718	B727	
i:rm980520.073	122	19980520	120850	B767	N/A
i:rm980520.075	144	19980520	121325	DC9	DC-9-31
i:rm980520.076	96	19980520	121548	B757	757-223
i:rm980520.081	180	19980520	123821	CONC	N/A
i:rm980520.083	154	19980520	124641	B747	
i:rm980520.088	116	19980520	130458	CONC	N/A
i:rm980520.094	180	19980520	134125	B727	N/A
i:rm980520.096	180	19980520	135007	B727	
i:rm980520.098	180	19980520	140301	B767	767-223
i:rm980521.084	180	19980521	103500	EA32	A320-231
i:rm980521.085	108	19980521	103959	B767	767-223
i:rm980521.089	114	19980521	104602	EA32	N/A
i:rm980521.093	180	19980521	110057	B74B	
i:rm980521.094	102	19980521	110603	EA31	N/A
i:rm980521.095	180	19980521	110745	B74B	
i:rm980521.096	152	19980521	111548	B74A	
i:rm980521.098	54	19980521	111904	B727	
i:rm980521.100	98	19980521	112313	MD11	N/A
i:rm980521.101	100	19980521	112451	B74A	N/A
i:rm980521.102	120	19980521	112630	DC8	
i:rm980521.103	132	19980521	112831	DC10	
i:rm980521.104	136	19980521	113043	A300	A300B4-605R
i:rm980521.112	152	19980521	115639	B767	N/A
i:rm980521.113	98	19980521	115911	B757	757-2Q8
i:rm980521.114	154	19980521	120050	MD11	N/A
i:rm980521.117	180	19980521	120648	B727	
i:rm980521.217	180	19980521	184718	B74A	
i:rm980521.219	122	19980521	185428	DC8	
i:rm980521.220	136	19980521	185630	B767	
i:rm980521.221	180	19980521	185846	B767	
i:rm980521.222	140	19980521	190240	A330	
i:rm980521.223	44	19980521	190500	MD80	
i:rm980521.225	180	19980521	191040	B767	
i:rm980521.226	154	19980521	191538	A310	
i:rm980521.230	180	19980521	192431	MD80	
i:rm980521.231	120	19980521	192850	B767	
i:rm980521.232	128	19980521	193051	B74A	
i:rm980521.233	140	19980521	193259	B767	
i:rm980521.234	122	19980521	193519	B74A	

i:rm980521.235	78	19980521	193721	B727	
i:rm980521.236	144	19980521	193839	B74S	
i:rm980521.237	120	19980521	194103	DC9	
i:rm980521.238	122	19980521	194303	B74A	
i:rm980521.239	144	19980521	194505	A300	
i:rm980521.240	108	19980521	194729	B757	
i:rm980521.241	94	19980521	194917	B767	
i:rm980521.242	144	19980521	195051	MD11	
i:rm980521.243	120	19980521	195315	B767	
i:rm980521.244	104	19980521	195515	B767	
i:rm980521.245	130	19980521	195659	B727	
i:rm980521.246	132	19980521	195910	B767	
i:rm980521.247	144	19980521	200121	B74A	
i:rm980521.248	108	19980521	200346	MD88	
i:rm980521.249	98	19980521	200533	B767	
i:rm980521.250	86	19980521	200712	B767	
i:rm980521.252	130	19980521	201006	B767	
i:rm980521.253	142	19980521	201216	A310	
i:rm980521.256	126	19980521	201746	MD88	
i:rm980521.257	126	19980521	201952	B74B	
i:rm980521.260	138	19980521	202530	B74B	
i:rm980521.261	146	19980521	202748	B767	
i:rm980521.262	136	19980521	203014	B74A	
i:rm980521.263	100	19980521	203230	B757	
i:rm980521.264	92	19980521	203410	B767	
i:rm980521.265	142	19980521	203542	B74A	
i:rm980521.266	144	19980521	203804	B767	
i:rm980521.267	118	19980521	204028	B767	
i:rm980521.268	116	19980521	204227	MD80	
i:rm980521.270	124	19980521	204546	B767	
i:rm980521.271	108	19980521	204750	B74A	
i:rm980521.273	106	19980521	205115	B727	
i:rm980521.274	150	19980521	205301	B767	
i:rm980521.275	174	19980521	205531	B757	
i:rm980521.278	180	19980521	210315	EA32	
i:rm980521.279	142	19980521	211305	A300	
i:rm980521.280	132	19980521	211527	MD11	
i:rm980521.282	124	19980521	211916	B767	
i:rm980521.283	108	19980521	212120	MD80	
i:rm980521.284	70	19980521	212307	B757	
i:rm980521.286	96	19980521	212618	B757	
i:rm980521.287	104	19980521	212754	B767	
i:rm980521.288	132	19980521	212937	B747	
i:rm980521.289	132	19980521	213150	B767	
i:rm980521.290	146	19980521	213402	B767	
i:rm980521.291	154	19980521	213628	CONC	
i:rm980521.292	98	19980521	213902	B767	
i:rm980521.293	118	19980521	214040	B777	
i:rm980521.295	90	19980521	214416	MD80	MD 83
i:rm980521.297	116	19980521	214724	MD80	
i:rm980521.300	152	19980521	215232	B767	
i:rm980521.304	100	19980521	220124	B767	
i:rm980521.305	140	19980521	220304	A300	
i:rm980522.141	86	19980522	115919	B767	
i:rm980522.142	132	19980522	120045	DC8	
i:rm980522.144	100	19980522	120439	A310	
i:rm980522.148	130	19980522	121247	MD11	
i:rm980522.149	180	19980522	121457	B767	

i:rm980522.150	136	19980522	122411	B74B
i:rm980522.152	84	19980522	122803	B757
i:rm980522.153	94	19980522	122928	B757

3.4 LASER RANGE FINDER

The laser range finder was mounted:

1. On the extended runway centerline,
2. At the position of the main anemometer array, 400 feet from the middle marker,
3. About five feet above the ground, and
4. Pointing vertically.

The laser range finder measures the range to a hard target at 2000 Hz with a resolution of better than 0.1 m. Range data are time tagged and stored in hourly data files. Only data points with valid range measurements were saved.

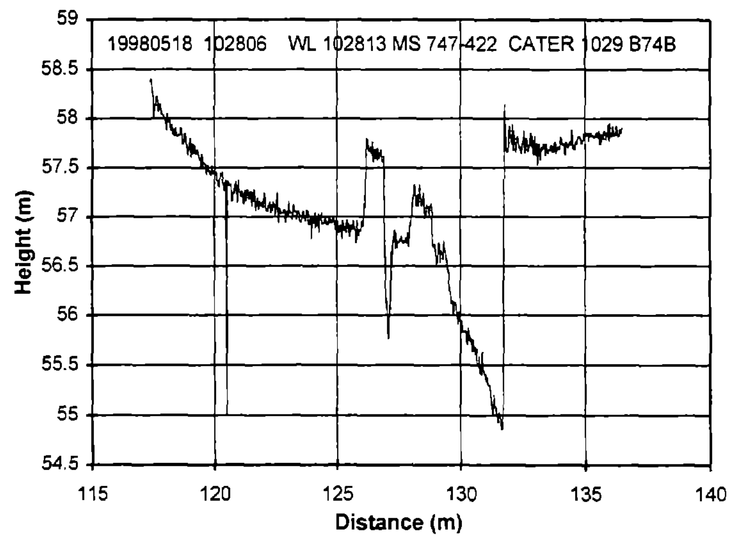


Figure 1. Sample Range Finder Data for B-747 Arrival

Figure 1 shows the range data from a B-747 arrival. The sample number is converted to distance along the aircraft assuming a ground speed of 200 ft/s. Measurements in Figure 1 first show the wing with flap extended (distance 117 to 132 m) and the then jump up to the elevator (distance 132-137 m). Deployment of the flap uncovered two holes in the wing (distances of 136 and 138 m) which permitted the top of the wing to be measured.

The time tags could not be used to identify gaps in the data. For example, in Figure 1 there was no time gap at 132m where the data jumped from the wing to the elevator (although wing-tail gaps were seen in some runs). On the other hand, the downward spike at distance 121 m was added to mark a time gap of just under one second. Such gaps were common and were apparently an artifact of the data recording software.

The detailed range profile depends upon the lateral displacement of the arriving aircraft. Some runs show the entire fuselage. Some show the landing gear. Trying to interpret the profiles in terms of a specific part of the aircraft (e.g., the wing) would be very complex. Consequently the decision was made to define the aircraft height as the simple average all the heights for a run and the "laser" arrival time as the average of all the time tags for the range points. Note that the range data have not been corrected for the five-foot height of the range finder.

The " laser" arrival times were matched with wind-line acoustic arrival times with a tolerance of –14 to +29 seconds. Of the 1463 laser runs, 1218 matched the acoustic arrival times. Figure 2 shows the distribution of time differences. One would expect the acoustic times to be somewhat later than the laser times because the acoustic horn was mounted on the runway side of a large plywood box and the acoustic time is delayed two seconds from the noise peak. The distribution in Figure 2 is broader than would be expected from such considerations and probably reflects some loss of time synchronization between the wind line and range finder data collection computers. The laser height data are included in the AC_ALL database of Section 5.1.1.1, but not in the SOCRATES run data of Section 5.1.2.

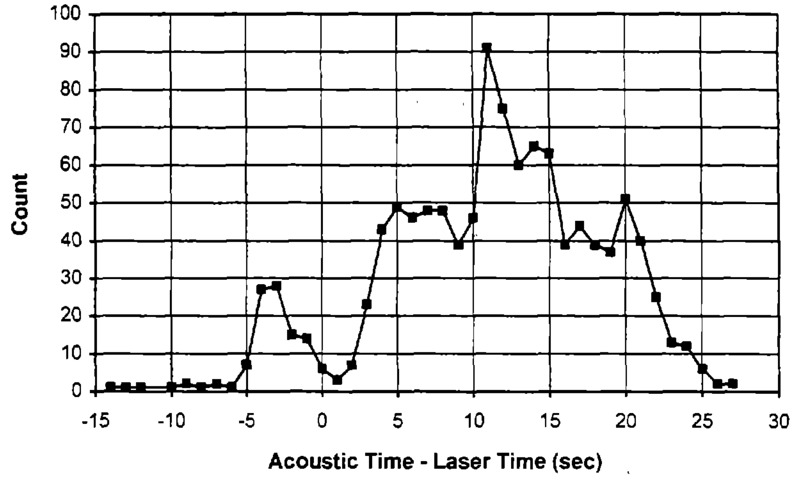


Figure 2. Distribution of Time Differences between Acoustic and Laser Arrival Times

4. DATA PROCESSING

4.1 ANEMOMETER ARRAY

4.1.1 Vortex Processing Algorithms

Two versions of the processing algorithms[5] were used in the analysis of this report:

Version 1 of the processing algorithms was used in References 3 and 4 and was summarized in Reference 4. Version 1 used fixed starting and stopping algorithms and hence was not usable under high turbulence conditions.

Version 4 was developed for off-line processing of DFW data. The data are averaged for ten seconds to reduce noise and the tracking thresholds were set to match the current level of crosswind turbulence. Version 4 was also 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 undetectable and then tracked to later times until it was lost. Logic was also added to assure that the vortex location where it was detected was consistent with its assumed initial location and the current ambient crosswind.

The Version 4 processing used 10-minute averages of the crosswind turbulence, obtained from the meteorological processing described in Section 4.2. The turbulence parameters were inserted into the header of the run file so that they were always available for processing. Similarly, the aircraft types were inserted into the run-file header so that they could be included in the printouts from the data processing.

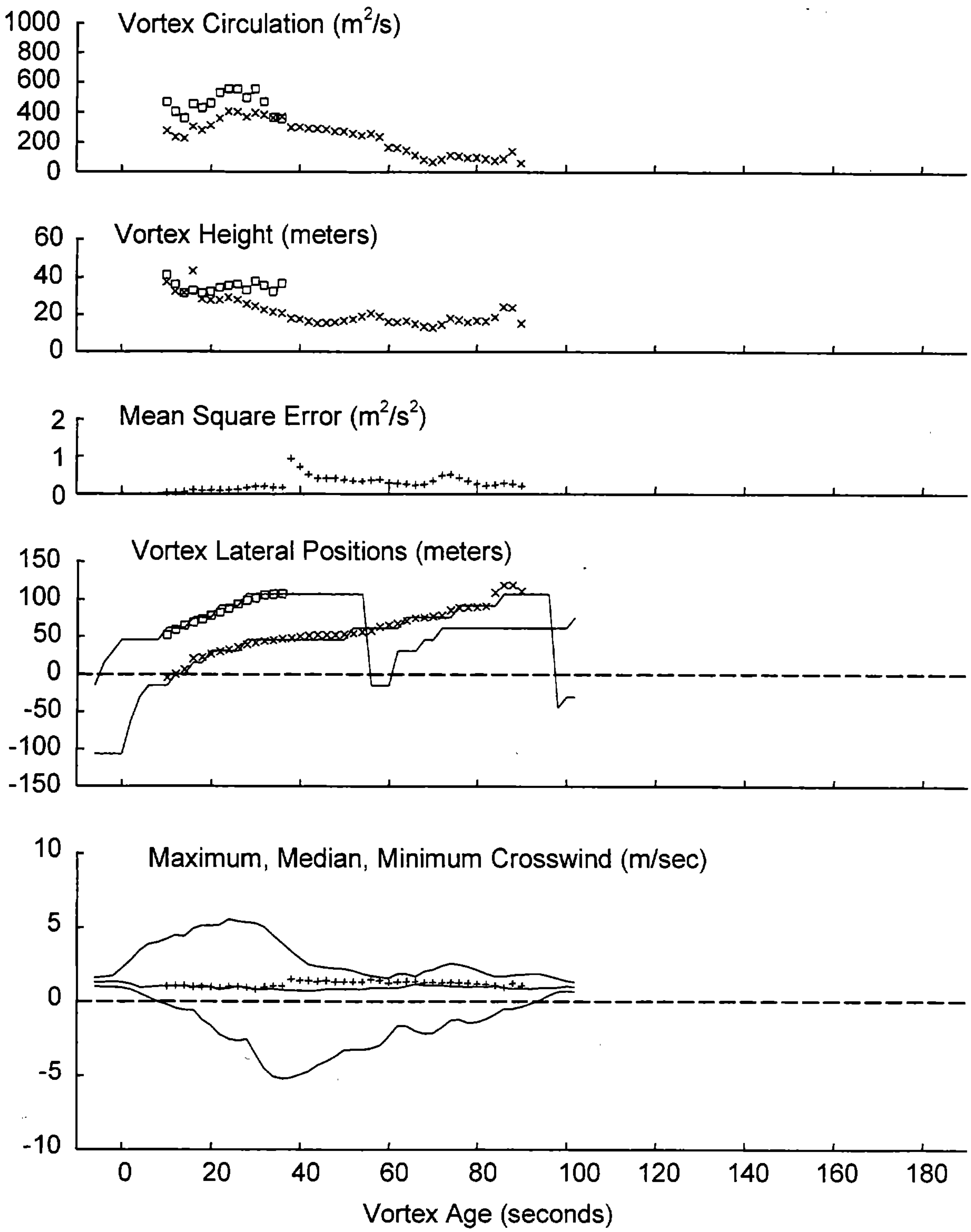
4.1.2 Data Output

Whenever the vortex tracking algorithms detected a vortex, a least-square fit was made to the measured wind data to give the ambient crosswind and the following vortex parameters:

1. Vortex-induced crosswind,
2. Lateral position
3. Height, and
4. Circulation.

The wind data give a robust indication for lateral position. The height and circulation are less certain, since the same maximum induced crosswind can be generated by a weak, low vortex or a strong, high vortex.

Figure 3 shows the standard printed output from the processing algorithms. This format presents all the data in a compact form on a single page and can be generated quickly from the run files.



JFK 31R Wind Line Data for File: i:rm980519.092
980519 103816 turb: 0.28 start/end cw 1.40 1.00 B74A

Figure 3. Printed Output from Processing Algorithm

Figures 4 through 7 show the data presented in a different format, where every parameter is plotted in a separate plot. These plots are generated using a spreadsheet (see Section 5.1.2.6). This approach takes considerable manual effort to plot each run.

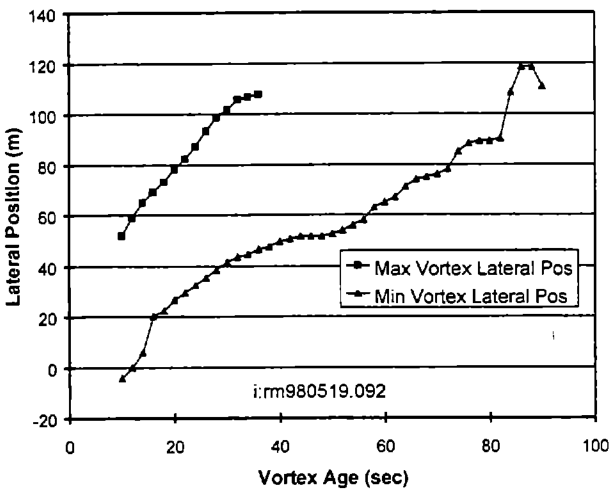


Figure 4. Lateral Position vs. Age

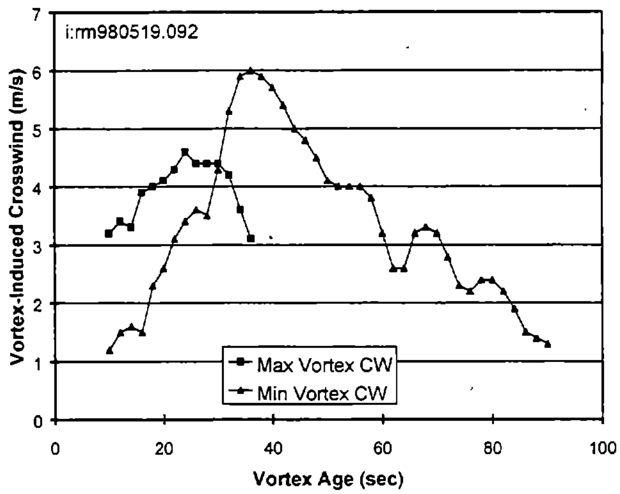


Figure 5. Vortex-Induced Crosswind vs. Age

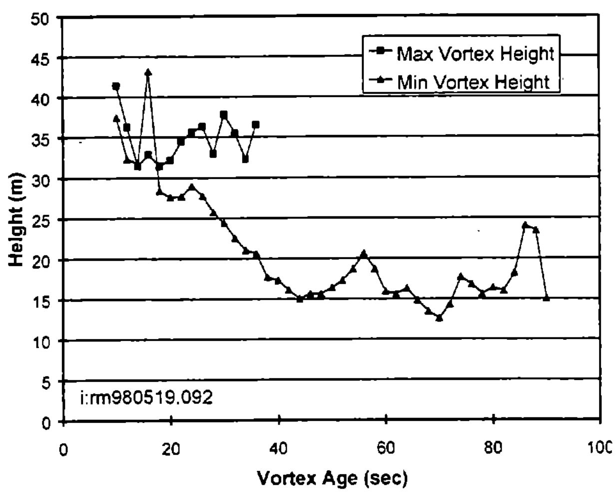


Figure 6. Height vs. Age

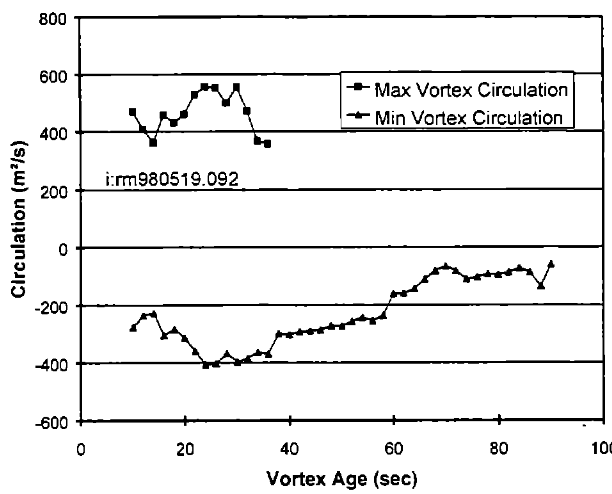


Figure 7. Circulation vs. Age

4.1.3 Vertical Array

The Volpe anemometer array includes a vertical array near Pole 10 (+30 m lateral position), as shown at the bottom of Table 1 (Poles 20-23). The vertical array has three vertical anemometers and five cross anemometers. The height of each pole is half that of the previous pole. Figure 8 shows the vertical array data for the same run shown in Figure 3. The time axis has been stretched to show more detail. The wind plots can be identified by small vertical ticks:

1. The 28-foot plot has large up ticks.
2. The 14-foot plot has small up ticks.
3. The 7-foot plot has no ticks.

4. The 3.5-foot plot has small down ticks.
5. The 1.75-foot plot has large down ticks.

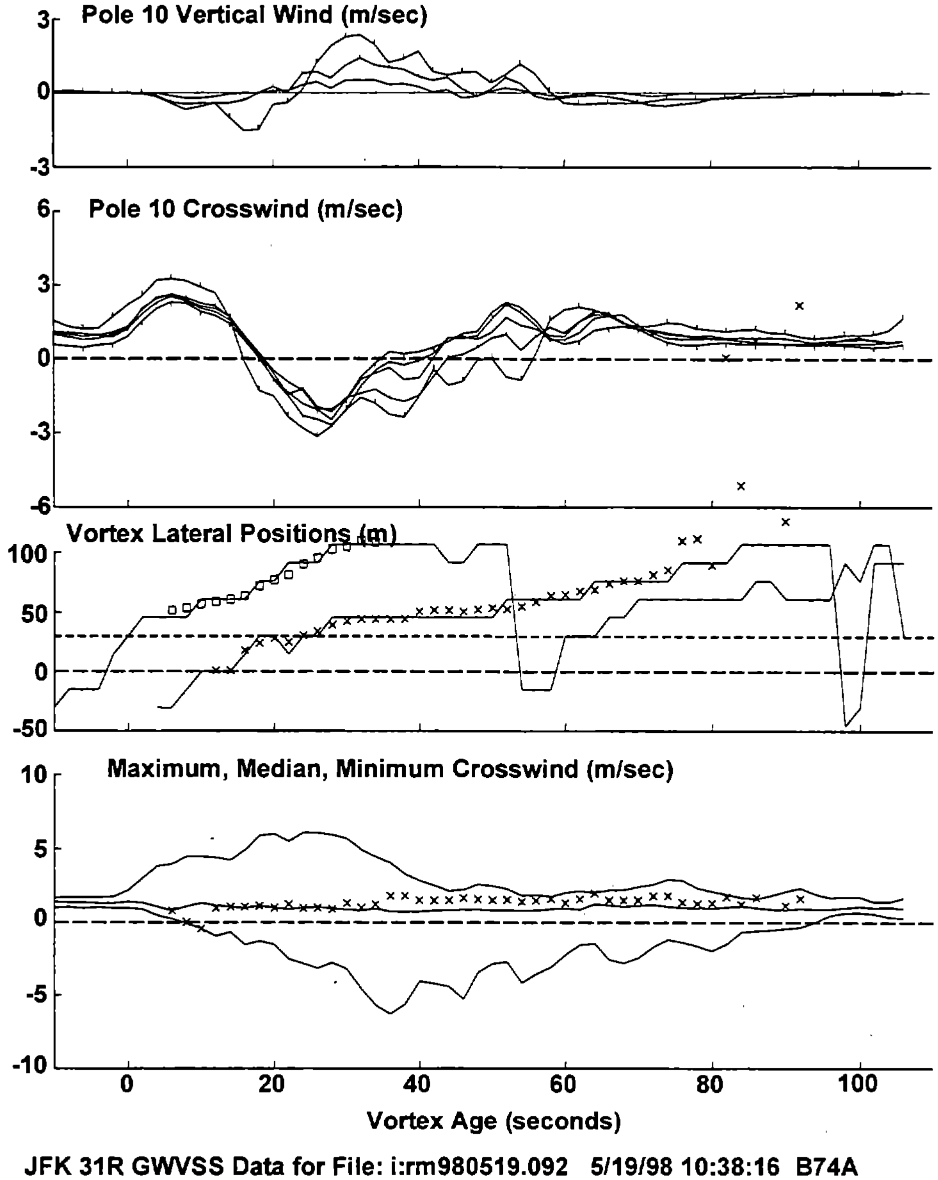


Figure 8. Vertical Profile at Pole 10 (+30 m)

The bottom two plots of Figure 8 show the basic tracking information from the wind line and are the same plots as the bottom two plots of Figure 3. The data are more jagged in Figure 8 since the wind data in Figure 3 were smoothed by a running 10-point average before being processed.

The crosswind and vertical wind profiles in Figure 8 can be understood by the motion of the two wake vortices:

1. The maximum-crosswind vortex (lateral position plotted as boxes) is over the +30 m location (dotted line) just after aircraft arrival. It induced a positive crosswind at Pole 10.

2. The minimum-crosswind vortex (lateral position plotted as x) reaches the +30 m location at vortex age 24 seconds. It induced a negative crosswind at Pole 10, which is greatest when the vortex is directly over Pole 10.

3. The vertical wind is negative between the two vortices and becomes positive when the minimum-crosswind vortex passes the location of Pole 10. The vertical wind magnitude increases with distance from the ground.

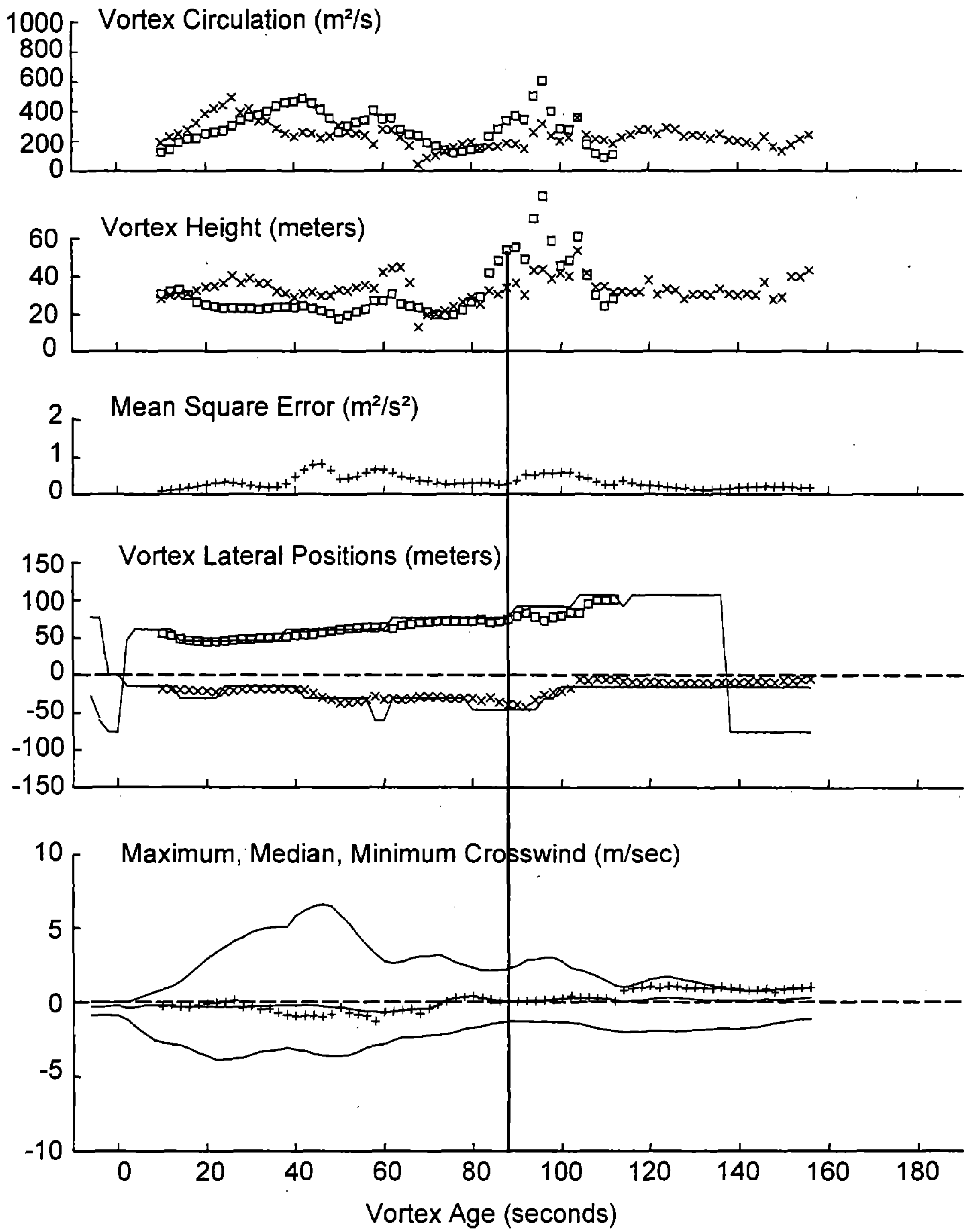
4. The crosswind magnitude varies relatively little with height (the 28-foot value is a bit larger, but the lower measurements are closely clustered) until after the minimum-crosswind vortex passes the measurement location. After passage, the behavior is more complex; three lowest anemometers read significantly higher crosswinds until about age 56 seconds. This difference is presumably due to the secondary vortex generated by the interaction of the primary vortex with the ground; the height of the secondary vortex appears to be about 10 feet.

The vertical uniformity of the crosswind near the ground under a wake vortex is a consequence of the boundary condition of zero vertical wind at the ground. A mathematical way of satisfying this boundary condition for a vortex at height h is to position an image vortex of opposite circulation below the ground at height $-h$. The pair of vortex plus image is just like the originally generated vortex pair, but rotated 90 degrees. The downwash between the vortices becomes the crosswind measured by the vertical array. The image model leads to a vortex–induced crosswind that is uniform near the ground. Since the actual crosswind must also approach zero at the ground, there is a thin boundary layer below the vortex core where the transition to zero crosswind is made. The data in Figure 8 suggest that the boundary layer thickness is less than 0.5 m. Note that the grass near the vertical array was cut short for the SOCRATES test.

Note that the image model is not dynamically stable when there is a boundary layer at the ground. The strong crosswind below the vortex leads to detachment of the boundary layer at the edge of the vortex. This process generates the secondary vortex that shows up in the crosswind profile of Figure 8 after 32 seconds.

4.1.4 Double Arrival Plot

Since the vortices do not always completely decay before the next aircraft arrives, the reprocessing program was modified to save two arrivals in a single run file. Such run files permit the vortex behavior to be studied after the arrival of the next aircraft. For example, Figure 9 shows the standard plot format (Figure 3) for a B-747 arrival followed by a small aircraft arrival 88 seconds later. The second arrival is marked with a vertical line.



JFK 31R Wind Line Data for File: i:rt980520.057
980520 112733 turb: 0.10 start/end cw 1.25 1.00 B74A

Figure 9. Sample Double Arrival Data Plot

4.2 METEOROLOGICAL PARAMETERS

The meteorological parameters of temperature, wind and turbulence are available from the normal data files recorded by the Volpe data acquisition system. All three can be derived from the DM file, described in Section 2.3.2. Wind values can also be obtained from the run files described in Section 2.3.3.

4.2.1 DM File

The first step in processing the DM files is to convert them into binary performance files (see Section 5.2.1). Selected data from the performance files is converted to ASCII format (Section 5.2.1.3) and entered into a database (Section 5.1.3). The one-minute standard deviation of the two-second wind component values is used as an estimate of turbulence. Average turbulence values are calculated using a Paradox script for 5-, 10-, 15- and 20-minute averaging times and using (1) the upwind algorithm for crosswind and vertical wind turbulence values, and (2) the minimum crosswind turbulence algorithm for crosswind turbulence. The aircraft arrival times are used to select the appropriate meteorological data to associate with the aircraft arrivals. The four crosswind turbulence values from algorithm (2) are put into the header of the run files and used for processing the run files.

4.2.2 Run File

The run-file wind data for vortex age 0 to 58 seconds are averaged to give wind values that should correlate well with vortex motion. The one-minute averaging time is much too short to give stable turbulence parameters.

4.2.3 Wind

The head and crosswind components for each arrival are contained in the database ACMET (Section 5.1.1.2). Both the DM (last one minute average before the arrival) and run file (average first minute of the run) are included. Twenty-four-hour wind plots of any desired wind parameters can be generated using PSIGB (Section 5.2.1.2).

4.2.4 Temperature

The temperature profile data are best viewed using the spread sheets described in Section 5.2.1.4. Figure 10 shows the day with the greatest vertical variation during the nocturnal inversion. The heights of the four sensors (TMP1 - TMP4) were 6.75, 13.5, 20.75 and 27 feet, respectively. The temperature profiles were typically as expected, with the lowest sensor typically recording the highest temperature during the afternoon and the lowest temperature after midnight (0400 GMT).

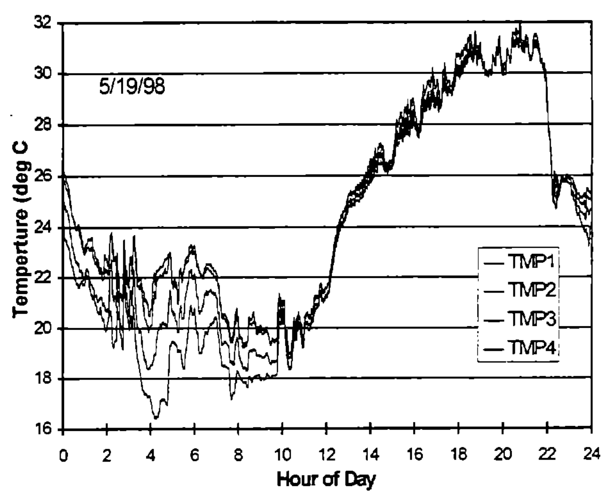


Figure 10. Temperature Profile vs. Time of Day (GMT) for 5/19/98

However, the amount of inversion varied considerable from night to night.

Comparisons of absolute temperature sensors are usually problematic and this test was no exception. Variable offsets had to be added to two of the sensors to give reasonable results. Table 7 lists the offsets by date. On many days reasonable temperatures resulted when all sensors were made to overlap for the first hour (GMT).

Table 7. Temperature Offset (deg C) vs. Date

Date	TMP1	TMP3
5/13	-0.2	-0.7
5/14	-0.2	-0.5
5/15	-0.2	-0.9
5/16	-0.4	-0.8
5/18	-0.9	-0.8
5/19	-1.0	0.0
5/20	-1.0	0.0
5/21	-0.7	0.0
5/22	0.0	0.0

4.2.5 Turbulence

A variety of turbulence parameters are available in the ACMET file of Section 5.2.1.4. The CTAn and VTAn (n=1,4 for averaging times of 5, 10, 15 and 20 minutes) are the standard deviations of the crosswind and vertical wind components, respectively, from the upwind side of the array. The Mctan (n=1,4) values are derived using the end of the array with the lowest crosswind standard deviation and are therefore smaller than or equal to the CTAn values.

4.3 SONIC ANEMOMETER

The Metek sonic anemometer was located at different sites for different SOCRATES beam configurations (see Section 2.2.3). Since it served two functions:

1. To determine the ambient turbulence conditions near the SOCRATES beam, and
2. To assess the effect of the wake vortices on the SOCRATES beam,

the data will be presented in two forms, one meteorological and the other related to the aircraft arrivals.

4.3.1 Meteorological Parameter Plots

Figure 11 shows a sample plot of sonic anemometer data. The temperature and three wind components, along with their standard deviations are shown. Unfortunately, the temperature standard deviation data show many glitches of about 0.5 °C. Aircraft arrivals can be seen clearly in several places:

1. Positive spikes in temperature.
2. Positive spikes in headwind (caused by headwind shear).
3. Mostly negative spikes in crosswind.
4. Spikes of both signs in vertical wind.
5. Spikes in standard deviation for all wind components.

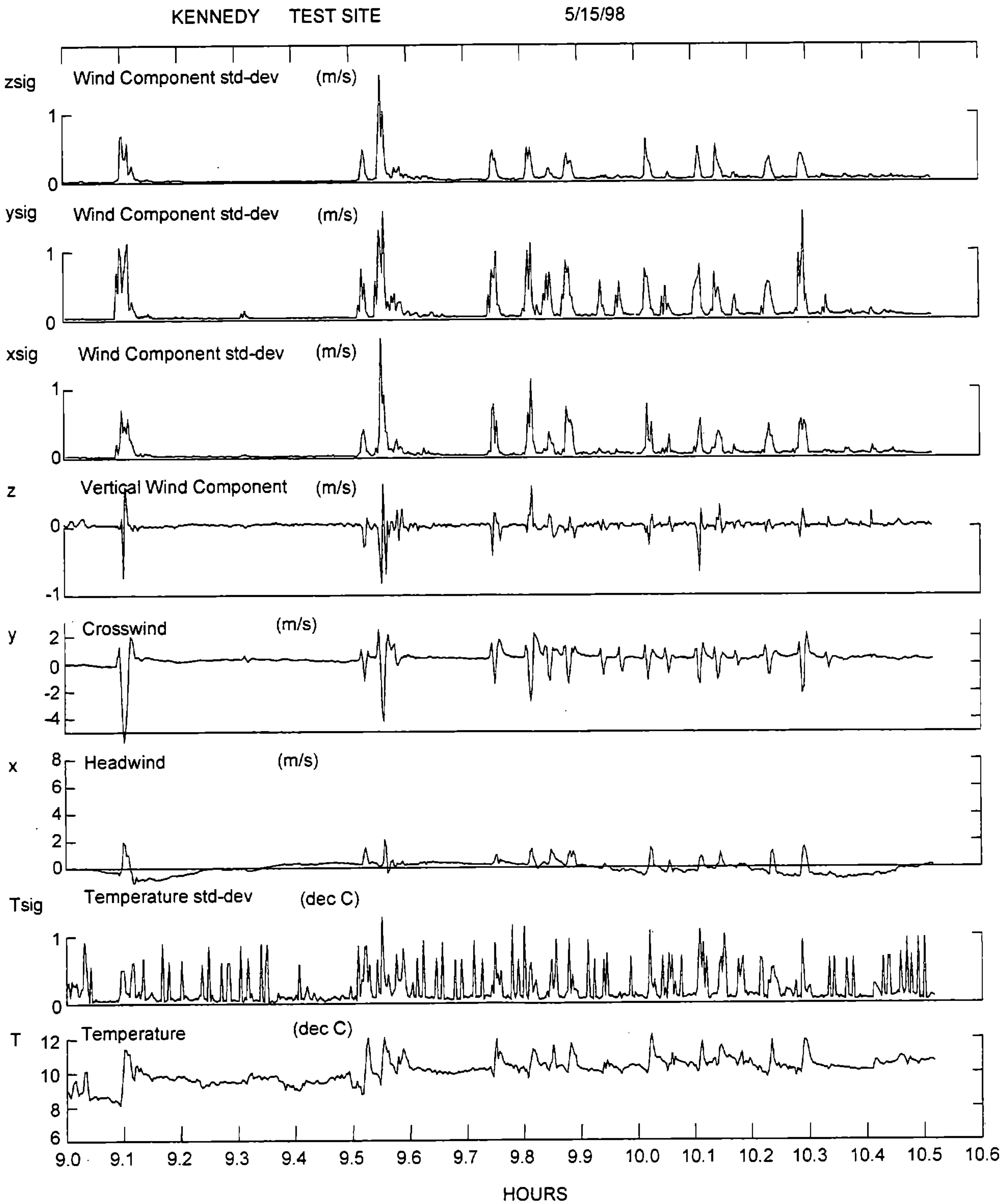


Figure 11. Sample One-Hour Plot of Sonic Anemometer Data for 5/15/98

4.3.2 Vortex Related Plots

The Metek sonic anemometer measurements were extracted for each arrival and stored in a file with name similar to the wind-line run file name: MKyymmdd.nnn. Figure 12 shows a sample B-747 run. A number of features can be noted in Figure 12:

1. The ten-second average used for the Metek data leads to less time resolution than the two-second average for the wind-line data.

2. Two lines are plotted for each Metek parameter: the mean value ± the standard deviation.

3. The arrival of the aircraft is accompanied by changes in the mean and standard deviation of the all four Metek parameters. Note that the Metek temperature is plotted relative to the first temperature value so that higher resolution can be provided.

4. Some of the standard deviation increases appear to be related to changes in the parameter over the ten-second average period rather than high frequency turbulence.

5. The changes in the Metek values occur somewhat earlier than the arrival time given by the wind-line. This difference represents errors in time synchronization between the Metek and primary data acquisition systems. In general, the Metek vortex arrival times are earlier than the wind-line times, with a maximum difference of 20 seconds.

6. The behavior of the Metek data suggest nocturnal inversion conditions (see Figure 10). The temperature and headwind increase as the vortex oval descends toward the ground, bringing a sample of the atmosphere from the 50-meter height of the aircraft path.

7. The crosswind appears to be responding to the negative crosswind induced by the min-vortex (lateral position plotted as x).

8. The temperature standard deviation associated with the aircraft arrival appears to be real rather than a glitch (such as noted between 140 and 160 seconds). A similar increase in temperature standard deviation is also noted for the following arrival (110 seconds) which terminated the wind-line data. Figure 12 also suggests that the aircraft arrivals are associated with increased temperature standard deviations that are different from the glitches.

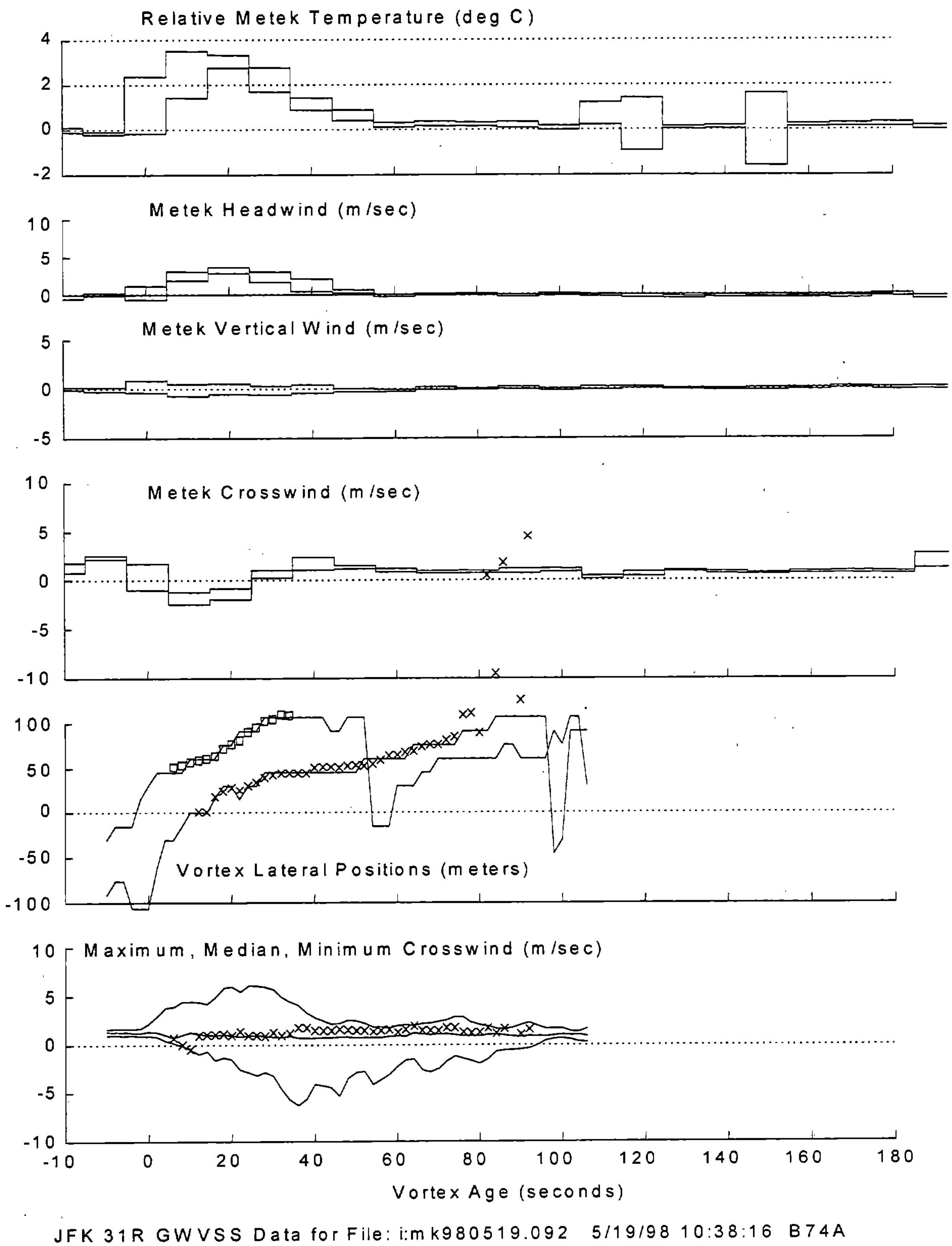


Figure 12. Sample Plot of Sonic Anemometer Data for B-747 Run

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5. CD-ROM INFORMATION

This chapter describes the databases on the CD-ROM "SOC_98A," dated 8/26/98. The structure of this section reflects the subdirectory structure of the CD-ROM.

5.1 DATABASE

The database files are provided in three formats:

1. Native PARADOX files (.db) which were used for the data analysis.
2. Text files (.txt) provide the data in ASCII format, but do not have any headers or field names. The field names for .txt files are contained in a related .txt file with "fmt" in the file name.
3. Lotus 1-2-3 files (.wk1) were exported from the PARADOX data files and retain the field names.

5.1.1 ALLRUNS

5.1.1.1 AC_ALL

This database contains information on all the aircraft arrivals during the periods of SOCRATES operations. The following types of information are included:

1. Arrival time - The arrival time corresponds to a vortex age of 2 seconds. This delay results from the requirement that the aircraft noise level must decrease to define the precise time of arrival.
2. Wind-line file name - The primary file name is that for the reprocessed data that prevented new arrival detections for 45 seconds. The real-time filenames are also included since they were used for the initial correlation with Mode-S and CATER data.
3. The parameters after the wind-line file name are derived from the run file. They include aircraft noise information and various wind averages for the first 60 seconds of the run. The "Head Run" and "Cross Run" parameters are taken from the upwind side of the array to avoid vortex contamination.
4. The CATER and Mode-S aircraft types are then listed.
5. Finally, the laser range finder data are listed (only here, but not in SOCRUNS).

5.1.1.2 ACMET

The ACMET database is derived from the AC_ALL and MAY (meteorological data from Section 5.2.1) databases by matching (query acmet.sc) the minute of the day and requiring that the 10-minute-average turbulence parameter (Mcta2) be valid (not negative), since it is used in the wind-line vortex processing.

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5.1.2 SOCRUNS

5.1.2.1 SOCDTTM

This database contains the SOCRATES operational times.

5.1.2.2 AC_SOC

This database contains AC_ALL data for arrivals during SOCRATES operation (Table 6).

5.1.2.3 BIG_SOC

This database contains AC_SOC data for jet transport aircraft.

5.1.2.4 VTXALL

Table 8 lists the format for the vortex database VTXALL, which contains all vortex detections for the SOCRATES jet transport runs. The file name links the data to the run database (BIG_SOC). The code is always 't' for this database. The vortex field is 0/1 for the minimum-crosswind/maximum-crosswind or port/starboard vortex, respectively. The max crosswind is the estimated vortex-induced crosswind at the anemometer array. The lateral position is with respect to the extended runway centerline. The height is above the ground.

Table 8. Fields for Vortex Files VTXALL

Name	Type	Units
File Name	A15*	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

5.1.2.5 VTX05DD

Since all the vortex data points in VTXALL are too many for use in a spreadsheet analysis, the data for each day was extracted into spreadsheet files (.wk1). As an example, the data for 5/19 was moved into an Excel spreadsheet (.xls) for plotting. This process requires two steps. First, the data are sorted by vortex number. Then, the vortex 0 data are moved four columns to the right. This procedure allows the plots to distinguish the two vortices with different symbols. The Excel spreadsheet uses the advanced filter capability to select a single run for plotting. The file vtx0519.xls actually contains all the runs for 5/19.

5.1.2.6 VX747_13

This database contains the vortex data for B-747 runs arriving before 1300 GMT when SOCRATES was operational. The Excel file was generated by the same procedure described in the last section and contains the plots presented in Section 4.1.2.

5.1.3 MET

This subdirectory contains complete databases for the normal meteorological data (MAY) and the Metek data (0513).

5.1.4 AC

This subdirectory contains databases of the raw Mode-S and CATER data. The database MS05 contains all the Mode-S data, while the database MS05_500 contains data with aircraft heights below 500 feet. The CATER data are in the SOCCATER database.

5.1.5 HEIGHT

The database RG contains all the laser range finder runs.

5.2 METDATA

5.2.1 NORMAL

5.2.1.1 Performance Files

The DM data files are converted into daily binary performance files named Onyymmdd.hhm, which can be processed by the standard programs described in the following sections.

5.2.1.2 PSIGB

This program generates 24-hour plots of up to 20 parameters. For example, all the parameters from 5/15/98 can be plotted by the command: PSIGB<IN1.

5.2.1.3 MAKEPRN

This program can generate comma-separated-variable files from performance files for a file of parameter names. These selected parameters can then be imported into database or spreadsheet programs.

5.2.1.4 ON9805DD.XLS

The wind and temperature parameters are listed in the file METS, which was used to generate the Excel spreadsheet files for each SOCRATES test day. The spreadsheet files were needed to generate overlay plots for the four temperature sensors at different heights. The PSIGB plots were not adequate for comparing the temperatures at different heights.

5.2.2 METEK

5.2.2.1 Performance Files

The Metek sonic anemometer data was recorded in one-hour data files, containing ten-second averaged data. The first step in the data processing was to convert the data into daily binary performance files, which can be used as input to standard processing programs described in the next two sections. The Metek performance files are named mmdd.OUT.

5.2.2.2 PSIGC/PSIGD

These programs can generate plots of up to 20 parameters against time of day, with a maximum of 1500 different times. PSIGC generates hourly tick marks, while PSIGD generates tenth hourly tick marks. Two hour plots of temperature and wind and their standard deviations can be generated for roughly half of the SOCRATES test periods by the command: PSIGC<INLIST.

5.2.2.3 MAKEPRN

This program can generate comma-separated-variable files from performance files for a file of parameter names. These selected parameters can then be imported into database or spreadsheet programs.

5.3 RUNDATA

5.3.1 RUNS

This subdirectory contains all the reprocessed wind-line run files (RMyymmdd.nnn) and also the corresponding Metek files (MKyymmdd.nnn). Since the databases and file lists refer to drive i, these files must be located in drive i: if they are to be accessed.

5.3.2 PROGRAMS

This subdirectory contains a number of files containing lists of run files, which can be used by the two programs. Some are labeled by CATER aircraft type. ALLAC contains all the files in ACMET. BIGSOC contains the SOCRATES jet transport files. B747_VAL contains the B-747 runs arriving before 1300 GMT. SOC_SEL contains runs selected for SOCRATES analysis.

5.3.2.1 PRNTVTX3

This program prints the Version 4 wind-line vortex analysis shown in Section 4.1.2. It requests the name of the list of files. The printer is assumed to be attached to LPT1 and capable of printing HPGL/2 graphics (HP LaserJet III or later).

5.3.2.2 OUTALL

This program generates the vortex tracking file VTXALL.TXT using the Version 4 analysis and explicitly requests the list of files. The sample output used the list in SOC_SEL.

5.3.2.3 GPNTMKFT

This program prints the vortex lateral position using the Version 1 algorithms and provides the concurrent data from the Metek sonic anemometer. It uses a file list by redirection, e.g., GPNTMKFT<SOC_SEL.

5.3.3 PROGRAM2

The programs in subdirectory PROGRAMS use only the 15 anemometers on the main anemometer baseline. The programs in this subdirectory use *all* the anemometers, in particular the vertical array.

The program GPNTVAFT prints the data (Figure 8) from the vertical array. This program uses redirection to plot a list of files: GPNTFIT<SOC_SEL.

5.3.4 RUNSTWO

This subdirectory contains the run files with two arrivals. The file names are RTyymmdd.nnn.

5.3.5 PROGSTWO

This subdirectory contains a version of PRNTVTX3 that will work with the two-arrival run files to generate the plot format of Figure 9. The file SOC_SEL contains the two-arrival run file names for selected SOCRATES runs.

5.3.6 HEIGHT

5.3.6.1 Raw Data Files

The raw hourly laser range finder files are named: mmddyyyy.Lhh.

5.3.6.2 Spreadsheets

Spreadsheets were generated for four hourly raw data files. Range plots are included.

5.4 DOCS

This section contains the August 1998 MS Word versions of this report and Reference 5.

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