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An Automated Method for Low Level Wind Shear Alert System (LLWAS) Data Quality Analysis

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16. Abstract

The Low Level Windshear Alert System (LLWAS) is an anemometer-based surface network used for detection of hazardous wind shear and acquisition of operational wind information in the airport terminal area. The quality of wind data provided by the LLWAS anemometers is important for the proper performance of the LLWAS wind shear detection algorithms. This report describes the development of an automated method for anemometer data quality analysis (DQA). This method identifies potential data quality problems through comparison of wind data from each sensor within a network to the mean wind speed and direction of the entire network. The design approach and implementation are described, and results from testing using data from the demonstration Phase III LLWAS network in Orlando, FL are reported. Potential improvements to the automated DQA algorithm are presented based on experience gained during analysis of the Orlando data. These recommended improvements are provided to assist future development and refinement of the DQA methodology to be performed by the FAA Technical Center.

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ABSTRACT

The Low Level Windshear Alert System (LLWAS) is an anemometer–based surface network used for detection of hazardous wind shear and acquisition of operational wind information in the airport terminal area. The quality of wind data provided by the LLWAS anemometers is important for the proper performance of the LLWAS wind shear detection algorithms. This report describes the development of an automated method for anemometer data quality analysis (DQA). This method identifies potential data quality problems through comparison of wind data from each sensor within a network to the mean wind speed and direction of the entire network. The design approach and implementation are described, and results from testing using data from the demonstration Phase III LLWAS network in Orlando, FL are reported. Potential improvements to the automated DQA algorithm are presented based on experience gained during analysis of the Orlando data. These recommended improvements are provided to assist future development and refinement of the DQA methodology to be performed by the FAA Technical Center.

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1. INTRODUCTION

The Low Level Windshear Alert System (LLWAS) is currently the primary mechanism for detection of hazardous wind shear and acquisition of operational wind information in the terminal area at more than 100 U.S. airports [Goff and Gramzow, 1989; Wilson and Gramzow, 1991]. The system relies on wind measurements taken at approximately 10–second intervals from a network of anemometers covering the airport area. LLWAS algorithms use these measurements to estimate local divergence (or convergence) of wind that is evidence of potentially hazardous wind shear. This system has undergone a series of upgrades; the current system (Phase II LLWAS) employs a network of six sensors spaced 4 to 6 km apart. Plans are in progress for deployment of a more sophisticated version of the wind shear detection algorithm (Phase III) at approximately 10 to 12 airports. This upgrade will include a more dense network of sensors, typically consisting of 12 to 20 anemometers spaced approximately 2.5 km apart.

The quality of wind data provided by the LLWAS anemometers is important for the proper performance of the LLWAS wind shear detection algorithms. Filters in the algorithms provide protection against occasional spurious wind measurements. However, systematic bias or error in the wind measurements can cause degraded wind shear detection performance either by causing missed wind shear detections or by causing false alerts. In addition, for reasons of economy, LLWAS sensor networks are designed to provide minimal redundant coverage for wind shear detection. Thus, high data quality from each sensor in the network is required for proper system performance.

Degradation in sensor performance resulting in unacceptable data quality is both difficult and costly to detect through manual analysis since many of the potential problems are subtle or intermittent. Because of the importance of data quality and the large number of deployed sensors, the FAA is interested in an automated method for data quality monitoring. The current on–line capability allows detection of obvious hardware or communications failures but is unable to identify more subtle problems or a gradual degradation in performance. MIT Lincoln Laboratory has been working to develop an automated LLWAS Data Quality Analysis (DQA) method that will identify these types of sensor problems in a timely manner so as to avoid degraded LLWAS wind shear detection performance. Primary development and testing of a viable methodology was performed using anemometer data collected as part of Lincoln Laboratory's Terminal Doppler Weather Radar (TDWR) (Turnbull et al., 1989) testbed in Orlando, FL during 1991 and 1992 and using data collected during 1993 as part of the Phase III LLWAS Operational Test & Evaluation in Orlando.

The objective is an algorithm that automatically runs in real time as part of the LLWAS system. An intermediate step may be to process data off line using the automated methodology at a central facility. The FAA requested from Lincoln Laboratory a document detailing the functional requirements of an automated analysis system so that it could be included as part of the system requirements for a future LLWAS procurement. Results and experience from the off–line DQA testing done from 1991 through 1993 were used to develop these system functional requirements.

This report documents the development of the DQA methodology to date and recommends improvements for future development and implementation. It includes the rationale for selecting a design approach, an overview of the design, and some of the details regarding implementation of the algorithm. It also includes a description of algorithm performance and lessons learned during off–line testing using anemometer data from the Orlando testbed. Experiences from this testing indicated several key improvements to the algorithm that would make it a more reliable automated data analysis method. These improvements are described and were taken into consideration during development of the DQA functional requirements document for the FAA (See Appendix A). The description of algorithm processing and experimental results presented here also represent a reasonable baseline for any future development of a formal algorithm specification.

2. DEVELOPING AN ANALYSIS APPROACH

2.1 Scientific and Engineering Considerations

The purpose of making wind measurements at an LLWAS sensor is to obtain a reliable estimate of the wind velocity in the region near the sensor, which represents the wind 10 m above a fairly smooth surface. The 10 m height is a standard established by the FAA for winds representative of the airport area (Wieringa, 1980). For purposes of this discussion, we need to consider measurement of the local wind under two separate general conditions: steady–state ambient wind flow resulting from larger–scale geostrophic forcing and mesoscale winds in the presence of local low level wind shear. Characteristic of the former condition is a vertical wind profile in which the wind speed increases gradually with height for several hundred meters due to the frictional effect near the earth's surface. Under the latter conditions, this profile is disrupted by the local dynamics of the wind shear event. During such an event, wind energy is transported near the ground by strong downdrafts such that the vertical wind profile typically shows the strongest winds near the ground (i.e., in the lowest 100–200 meters above ground level).

We wish to detect errors in wind measurements by monitoring the wind measurements during the steady–state wind conditions, during which time the network of LLWAS sensors represents an over–sampling of the wind field in the airport area. The degree to which a sensor measurement fails to be regionally representative is viewed as one contribution to measurement error. The sources of these errors fall into one of two broad categories:

a. Inadequate sensor siting or

b. Equipment malfunction (mechanical or electrical).

Both inadequate sensor siting and equipment malfunctions can result in wind measurement error distributions that are biased in speed or direction and that have excessive variance.

We have chosen a method of analysis that involves the comparison of the winds at each sensor with the winds measured over the entire network. The patterns of differences in these winds is the basis for the LLWAS wind shear detection algorithm. When wind shear is not present and when the wind speed exceeds 3 m/s, there is significant uniformity in the observed wind field. At these times there is a significant correlation of the surface winds observed at proximate locations. The error variance increases with distance until local topographic effects decorrelate the winds. For example, locations separated up to 3 km exhibit a variability of about seven percent [Wieringa, 1980]. Our analysis shows that over the time of a few days, there is enough consistency of the winds over the 14–16 sensor LLWAS networks at Denver and Orlando so that these comparisons can provide the basis for a reliable analysis of sensor performance. The same may not be true for larger networks where it may be necessary to partition the network into a few clusters of sensors and to apply the analysis separately to each cluster.

2.1.1 Inadequate Sensor Siting

Proper sensor siting depends on a variety of factors that are described in detail in [Simiu and Scanlan, 1986] and FAA Order 6560.21A [FAA, 1989]. The problem is that the sensor can correctly measure the winds at its location, but that these winds have been so modified by local effects that they reflect a sub–scale phenomena and are not representative of the nearby winds. There are three primary effects that can negatively influence that measurement of regionally representative winds at a sensor position: surface roughness, sheltering, and channeling.

Wind speed is reduced near a rough surface due to friction and turbulence. For steady–state wind conditions, a simple mathematical model of this speed reduction near the surface incorporates two parameters, the roughness exponent α and the effective surface height d. The roughness exponent depends on the surface roughness and the stability of the boundary layer. Over a uniform tree canopy, the effective surface height is below but near the tree tops rather than at ground level. During a wind shift or wind shear event, the vertical dynamics of the situation control the vertical structure. Surface effects may be minimal at this time and are difficult to analyze theoretically or by modeling. A steady–state wind, after a brief period of time, typically 1 to 2 minutes, will establish a vertical wind speed profile which varies from nearly zero at the effective surface to its free flow speed at a few hundred meters, and whose increase with height above the effective surface is reasonably described by

$$u(z) = u(r) \left[(z-d) / (r-d) \right]^{\alpha} \qquad \text{(Eq. 2–1)}$$

where z is the height above the surface, r is the reference height and u(r) is the wind speed at the reference height. For a neutral boundary layer, α varies in value from 0.10 over flat terrain to 0.25 over nonuniform forests and irregularly developed urban areas. Values up to 0.6 have been observed in stable boundary layers. An important observation is that any error from this effect is proportional to the wind speed.

The vertical wind speed profile at a sensor position may vary, depending on the direction of the wind. A typical situation at an airport is that the area near the runways is cleared and the area outside the airport may be forested or developed. The result is that both the effective surface height and the up–wind roughness exponent may depend on the wind direction [Wieringa, 1980]. In most situations, this effect will result in the sensor winds having a slight high bias from some directions and a slight low bias from others. If the discrepancy is too great, the only solution is to relocate the sensor site [FAA, 1989]. Since the maximum LLWAS pole height is 50 m, the high bias is usually only a few percent, although biases up to 15 percent are possible. Over a tall forest, the effective surface may be 25 m above the ground and it is difficult to avoid a low bias of 20 percent or more. In cases where installation restrictions require that an exceptional bias be accepted, then the sensor performance evaluation algorithm should make use of this information to avoid issuing unwarranted trouble alerts.

One may be tempted to use this knowledge to tune the data from each sensor to eliminate the bias [Wieringa, 1976]. This approach may have value for operational wind information (i.e., during steady–state wind conditions), but caution is advised in the case of wind measurements for wind shear algorithms. The vertical wind structure may take a couple of minutes to re–establish after the completion of a wind shift or wind shear event, and the compensation would be erroneous at these times, precisely the time when accurate winds are desired. Making such compensations has the potential both to reduce detections and to induce false alerts. This is not a situation where current scientific understanding can readily provide guidance. Therefore, it would be unwise to make such corrections when the winds are to be used for wind shear computations.

Sheltering and channelling refer to the respective alteration of wind speed and direction as the winds flow around obstacles. At positions close to the obstacle, both severe sheltering and channelling are possible. An anemometer should either be placed sufficiently high above the obstacle or at a location sufficiently far away to avoid this situation [FAA, 1989]. At greater distances, channelling is not likely, but some modest speed reduction is still a possibility. In this case, the reduction is by a nearly fixed percentage of wind speed. The LLWAS Siting Order provides guidelines for locating sensors so that they are not subject to channelling and they incur no more than 20 percent low speed bias due to surface roughness and sheltering.

2.1.2 Equipment Malfunction

Any attempt to infer the nature of an equipment failure, from symptoms exposed by data quality analysis, must involve some consideration of the design of the sensing system. We have applied these techniques to data from the LLWAS installations by Loral Data Systems at the Orlando and Denver airports. These systems use prop and vane anemometers. We have also evaluated data from the MIT Lincoln Laboratory mesonet, which uses cup and vane anemometers. This equipment is similar to the Climatronics LLWAS II installations. While there are some differences in the data that results from these two systems, the dominant factor is that both systems measure speed and direction directly. Therefore, to understand the nature of an equipment failure, it is necessary to apply tests that separately analyze speed error and direction error. Other anemometer designs involve measuring two or more directional components of the horizontal wind and mathematically computing speed and direction. For these sensors, the addition of specific analysis of the errors in the measured components may be useful for detecting certain sensor failures.

2.2 Design Overview

The LLWAS Data Quality Analysis (DQA) algorithm and software was designed to work in conjunction with the LLWAS Wind Shear/Microburst (WSMB) detection algorithms. As such, it is able to take advantage of the LLWAS data acquisition function, network configuration parameters, algorithm control parameters, and wind shear alert information. The relationship between LLWAS and DQA processing is illustrated in Figure 2–1.

Since most sensor problems produce characteristic effects in the wind speed and/or direction measurements, the general approach of the DQA is to continually compare the wind speed and direction from each sensor within the network to some standard wind speed and direction. The standard for comparison was chosen as the mean values of wind speed and direction of all sensors within the network, in the absence of wind shear. The assumption here is that the network mean wind is a fair representation of the the true local wind, and a consistent departure from the mean by an individual sensor (when no wind shear is present) is indicative of a sensor problem. In addition, the characteristics of the departure are often an indicator of the nature of the problem.

In order to choose a method for comparing individual sensor measurements to the mean wind, we consider the expected effects of a malfunctioning sensor on the measurement characteristics. Most speed sensing problems, such as bearing drag and sheltering, reduce speed measurements proportionately rather than by some discrete increment. For this reason, we choose to examine speed

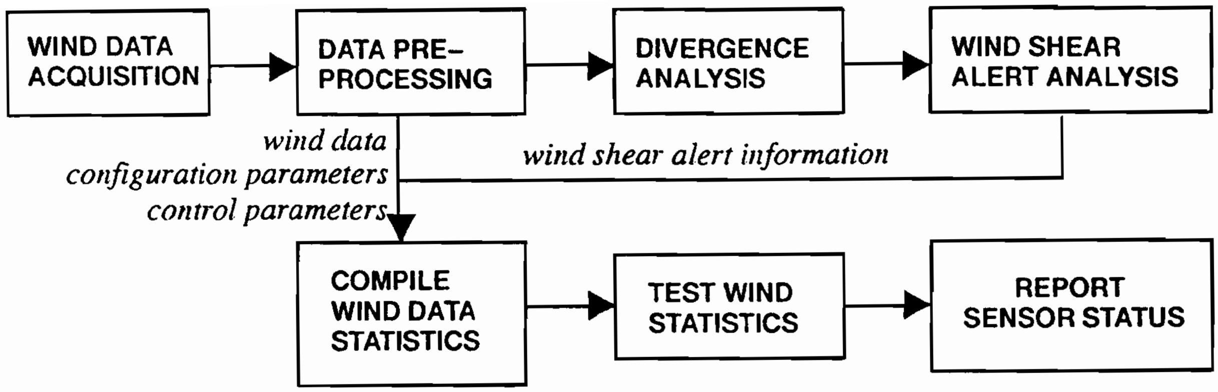

Figure 2–1. Functional relationship between LLWAS wind shear detection processing (top row) and data quality analysis (DQA) processing (bottom row).

measurements as the ratio of an individual sensor's value to the value of the network mean speed. In contrast to speed errors, wind direction problems are best characterized by a discrete difference (including sign) of the direction measurement from the network mean direction.

The basic algorithm processing is as follows: for each poll of LLWAS data (approximately once every ten seconds), the ratio of wind speed at each sensor and the network mean wind speed is computed; similarly, the difference between each sensor's wind direction and the network mean direction is computed. Using these ratios and differences, a statistical data base is continually updated that reflects these speed and direction characteristics for each station. For wind speed ratio, data are maintained separately for various ranges of mean wind direction since speed sensing problems may be directionally dependent, e.g., due to sheltering from a nearby obstruction. Once data from a sufficient number of polls have been accumulated, they are used to create percentage frequency distributions that indicate the characteristics of the speed–ratio and direction–difference profiles of the wind data from each sensor. These distributions are then compared to thresholds derived from "expected" distributions of speed ratio and direction difference, based on very large samples of data from all of the sensors within the network. A significant deviation from the expected distribution indicates a potential problem with that sensor. Table 2–1 illustrates the relationship between typical data abnormalities and the likely associated sensor problem.

TABLE 2-1
List of Potential Symptoms Indicated by Wind Speed and Direction Statistics and the Corresponding Problems with Which They Are Likely Associated

SYMPTOM	PROBLEM
all speed ratios near zero	catastrophic electro–mechanical failure
low speed bias, directionally dependent	sheltering
low speed bias, directionally independent	frictional drag on speed sensor, siting problem (low sensor height)
high speeds bias	siting problem (wind channeling or sensor height)
direction offset	misorientation, loose direction mounting, sticky direction bearings
flat distribution of direction differences, without direction offset	loose direction mounting, sticky direction bearings

3. DQA ALGORITHM IMPLEMENTATION

This section document provides a more specific description of the functional concepts and design implementation associated with the DQA algorithm. Descriptions are broken down into four general areas:

a. Data preparation / preprocessing

b. Accumulating wind speed and direction counts

c. Preparing accumulated data for testing

d. Performing tests

These descriptions reflect design implementation employed during 1992 testing using data from the Orlando testbed. A discussion of improvements to this version is presented later on in this report.

3.1 Data Preparation / Preprocessing

3.1.1 Input Winds

In order to monitor sensor performance, we choose to process and analyze the raw winds (i.e., wind values as measured by the LLWAS sensors) rather than a representation of the wind resulting from any data preparation or pre–processing performed by the LLWAS algorithm. Within the DQA processing, the u,v wind components of the raw wind from each sensor are converted to a wind speed (m/s) and wind direction (degrees from which the wind is blowing, measured clockwise from magnetic north).

3.1.2 Counting Polls and Accumulating Data

The DQA algorithm operates by periodically performing threshold tests on accumulated statistical data. The frequency with which the various tests are performed is keyed to the number of total polls of LLWAS data processed. Upon initialization, a running count of the total number of polls processed is maintained. This overall poll count is used to determine the frequency with which to perform various tests for updating the status of each sensor. During 1992 testing, this frequency was set to perform testing on each 24–hour period of data.

3.1.3 No Wind Shear Requirement

An underlying assumption to the approach presented here is that the wind speed and direction from a properly functioning sensor will not deviate substantially from the network mean wind, as we have described the anemometer network as an oversampling of a nearly uniform wind field. The exception to this would be instances where there is a shear in the horizontal wind field within the sensor network. Under this circumstance, one would expect one or more sensors to deviate significantly from the network mean wind. Consequently, the use of data for compiling sensor statistics relative to the mean wind could incorrectly imply a sensor problem. In order to avoid this scenario, compiling of statistical data for all sensors is suspended during the presence of wind shear over the network.

It should be noted that the impact of this effect was found to be small during testing. Essentially, it is significant in instances when the only "windy" portion of the overall data sample occurs during periods of wind shear. For an on–line system, however, it is recommended that this approach be implemented in order to minimize false indications of a sensor failure that would require an unnecessary response from maintenance personnel.

3.2 Comparison with Mean Wind Speed and Direction

3.2.1 Computation of Standard Wind

The basic scheme of the algorithm is to continually compare the wind from each sensor with some estimate of some "standard" wind speed and direction in order to detect a significant departure as evidence of a sensor malfunction. This standard wind is defined as the mean wind speed and direction of all the active sensors within the network. The use of the network mean wind as the standard implies that it is a fair representation of the "true" wind, i.e., most of the sensors have been properly sited and a majority of the network sensors are generally assumed to be in good working order.

The standard wind speed is computed each poll using the raw data from each sensor. The u,v components from each station are converted to a mean wind speed and direction. Then a simple arithmetic mean of the wind speed is computed. The mean direction in degrees is computed from the mean u,v values.

3.2.2 Determination of Mean Wind Direction Bin

Since deficiencies associated with wind speed sensing may be directionally dependent, e.g., sheltering by a nearby obstruction, it is necessary to determine wind speed characteristics separately for differing wind directions. This is done by using the mean wind direction as a directional standard. Wind speed statistics are then compiled separately for various "bins" of mean wind direction. This is done by identifying ranges of mean wind direction that define a wind direction bin. For data processed during 1992 and 1993, the direction bins were defined to have a width of 30 degrees. For example, the first direction bin was centered on 30 degrees and included winds from 15 degrees to 45 degrees; the second bin was centered on 60 degrees and included winds from 45 degrees to 75 degrees, etc. Thus, for each new poll of LLWAS data, speed statistics for each sensor are updated specifically for the bin corresponding to the current mean wind direction bins. An additional bin including wind from any direction is also updated each poll.

3.2.3 Compiling Speed Ratio Statistics

For each poll of data (approximately once every 10 seconds), the ratio of the wind speed at each sensor with the mean wind speed is computed. In order to ensure a reliable representation (i.e., uncontaminated by the effects of a light and variable wind), ratios are only computed for polls of data for which the mean wind speed is at least a minimum speed (3 m/s).

The speed ratio for each sensor is then used to update the corresponding speed–ratio bin count for the appropriate mean wind direction bin, i.e., the direction bin corresponding to the mean wind direction during the current poll. The speed ratio bins, analogous to the mean wind direction bins, represent a range of speed ratio values. For instance, the "middle" speed ratio bin includes counts of the number of data polls for which an individual sensor had a speed ratio whose value was between 0.90 and 1.10. Thus, after processing a large number of data polls, the result was a matrix of counters that indicated the frequency distribution of counts in each speed ratio bin, sorted by mean direction bin:

	Mean Wind Direction Bin					
Speed Ratio Bin	015–045	045–075	075–105	105–135	135–165	165–195...
0.00 to 0.50	X	X	X	X	X	X
0.50 to 0.70	X	X	X	X	X	X
0.70 to 0.90	X	X	X	X	X	X
0.90 to 1.10	X	X	*Speed Ratio Counters*		*X*	*X*
1.10 to 1.30	X	X	X	X	X	X
1.30 to 1.50	X	X	X	X	X	X
1.50 to 2.00	X	X	X	X	X	X
2.00 +	X	X	X	X	X	X

3.2.4 Compiling Direction Difference Statistics

For each poll that the network mean wind speed is at least a minimum speed (3 m/s), wind direction differences are computed for each sensor whose wind speed is also at least the minimum speed. (The minimum speed requirement is used to disregard large direction fluctuations that commonly occur during light wind conditions.) Wind direction differences are computed as the difference between the sensor wind direction and the mean wind direction. Direction difference is represented in degrees, with a negative value indicating a direction displacement oriented counter–clockwise from the network mean wind direction.

Analogous to speed ratio, direction difference bins (with each bin representing some range of direction differences) are used to update wind direction counts for each station. Unlike speed ratio, however, it is not necessary to maintain direction difference counts for each network mean directional bin. For each computed direction difference, the counter corresponding to the proper direction difference bin is updated separately for each sensor. The direction difference bins are defined to have a width of 10 degrees, e.g., –95 to –85, –85 to –75, . . ., –5 to +5, +5 to +15, . . ., +75 to +85, +85 to +95. An additional "Extreme High" bin is maintained to count all direction differences of greater than 95 degrees, irrespective of sign.

3.3 Performing Tests

Threshold tests using the statistical wind data are performed periodically at an interval determined by the total number of polls elapsed following algorithm initialization. Prior to performing threshold tests, the statistical counts compiled for speed ratios and direction differences are converted to a format that allows testing for deviations from expected values. For wind speed, this includes (for each sensor) a percentage distribution of wind speed ratio for each mean wind direction bin, a distribution for all wind directions combined, an average wind speed ratio representing each distribution, and the number of valid counts used to generate each distribution. An example of speed ratio statistics used for testing is shown in Figure 3–1.

STATION #5

SPEED RATIO BIN	MEAN DIRECTION BIN CENTER VALUE (DEGREES)												
RANGE	030	060	090	120	150	180	210	240	270	300	330	360	ALL
0.00–0.50	0	2	1	2	2	2	0	0	0	0	0	0	2
0.50–0.70	2	13	3	2	8	9	0	0	0	0	0	0	8
0.70–0.90	25	44	20	20	30	16	0	0	0	0	0	0	29
0.90–1.10	43	35	49	25	22	27	0	0	0	0	0	0	37
1.10–1.30	11	6	21	33	21	29	0	0	0	0	0	0	17
1.30–1.50	7	0	5	17	14	15	0	0	0	0	0	0	6
1.50–2.00	8	0	2	2	3	3	0	0	0	0	0	0	2
2.00+	4	0	0	0	0	0	0	0	0	0	0	0	0
AVG RATIO	0.00	1.16	1.11	1.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97
COUNTS	182	1672	1219	192	125	978	0	0	0	0	0	0	4369

Figure 3–1. Example of statistical data available from a single sensor, used for wind speed threshold testing. Included are station number, table of percentage frequency distributions of speed ratio sorted by mean wind direction bin, average speed ratio for each wind direction, and number of valid counts comprising the distribution for each wind direction bin.

Statistics for wind direction tests include a percentage distribution of wind direction difference, average wind direction difference, and the number of valid counts for each distribution. An example of direction difference statistics used for testing is shown in Figure 3–2.

Once the counters are converted to percentage frequencies and average values, the objective is to test for a significant deviation from expected values or distribution profiles. The only discrete guideline provided in FAA standards is that the wind speed not deviate by more than 20 percent from the "true" wind speed, where the true speed is defined as that measured by a properly functioning sensor situated 10 meters above ground level and totally unsheltered by any local obstructions such as buildings, trees, topography, etc.[FAA, 1989] Although this is a necessary criterion for testing, it is not considered sufficient since it provides no standard for the distribution of speed measurements and does not address direction measurements at all.

In order to identify instances where a sensor showed a significant deviation from an expected profile of speed ratio or direction difference, some expected profiles were established. This was initially done by examining a very large sample of data (hundreds of thousands of data polls) available from the prototype Phase III LLWAS network deployed at Stapleton International Airport in Denver. Once sufficient data was available for processing, similar profiles were examined for Orlando, and a reasonable binning approach was established. (The bins for speed ratio and direction difference are adjustable, but the values chosen for implementation are shown here.) An example of the large–sample percentage frequency distributions of speed ratio and direction difference for Orlando are shown in Figure 3–3 and 3–4, respectively.

#	DIR DIF BIN RANGE(deg)	LLWAS STATION NUMBER 1	2	3	4	5	6	7	8	9	10	11	12
1	-95 to -85	0	0	1	0	0	0	0	0	1	0	2	0
...													
5	-55 to -45	0	0	1	0	0	0	0	0	2	0	6	0
6	-45 to -35	0	1	2	0	0	2	0	0	5	0	19	0
7	-35 to -25	2	3	9	2	3	5	2	3	11	2	39	0
8	-25 to -15	5	6	11	5	15	13	16	17	13	4	26	2
9	-15 to - 5	20	19	21	17	34	25	30	30	15	18	5	18
10	- 5 to + 5	41	41	28	47	31	22	23	30	13	32	2	40
11	+ 5 to +15	26	26	22	26	13	12	10	12	10	20	1	32
12	+15 to +25	5	5	0	3	4	9	6	7	9	5	0	7
13	+25 to +35	1	0	0	0	0	6	3	2	8	2	0	0
14	+35 to +45	0	0	0	0	0	3	1	0	6	0	0	0
15	+45 to +55	0	0	0	0	0	1	0	0	3	0	0	0
16	+55 to +65	0	0	0	0	0	0	0	0	3	0	0	0
...													
20	<-95, >+95	0	0	0	0	0	0	0	0	1	17	0	0
AVG DIFFERENCE		-0.1	-0.8	-6.0	0.3	-5.0	-1.5	4.7	-4.4	-0.5	1.4	-24.1	2.4
COUNTS		1992	1984	1911	1977	2403	1904	2012	1513	1935	1984	1970	1915

Figure 3-2. Example of statistical data available for wind direction threshold testing. Included are number of total elapsed polls following initialization, table of percentage frequency distributions of direction difference for each station, average direction difference for each station, and number of valid counts comprising each distribution, and number of polls of data indicating a FLAG value for each station.

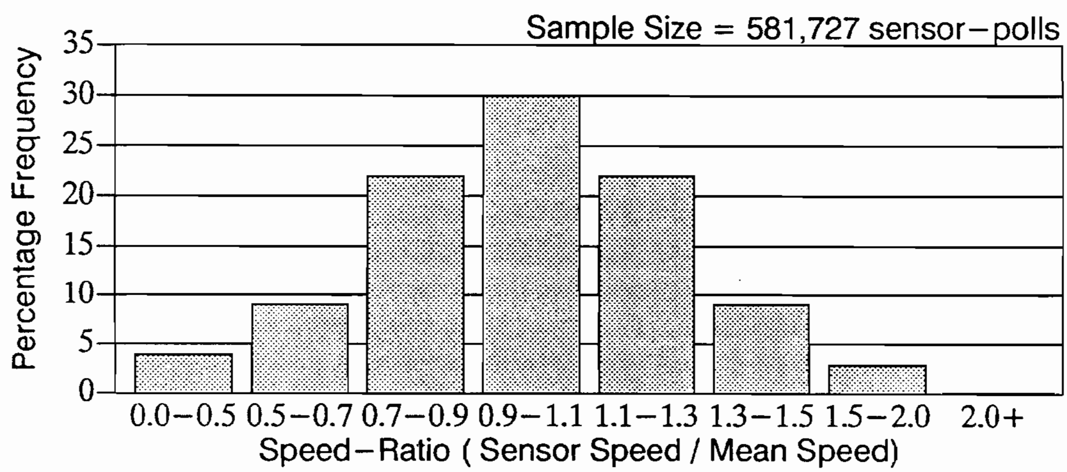

Figure 3-3. Percentage frequency distribution of wind speed ratio for a large sample of data polls from the LLWAS anemometer network in Orlando, FL.

These profiles were used empirically to establish reasonable parameter values against which the speed and direction profiles would be tested for deviations. The parameters were selected conservatively such that a large deviation was required to indicate a sensor fault. The following paragraphs

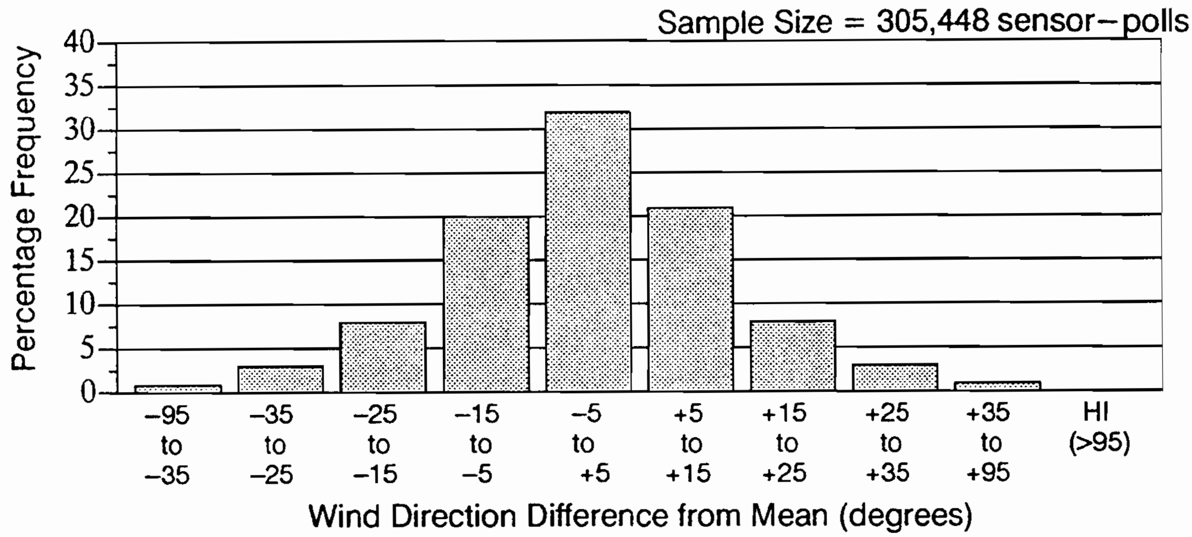

Figure 3–4. Percentage frequency distribution of wind direction difference from mean for a large sample of data polls from the LLWAS anemometer network in Orlando, FL.

describe the rationale for establishing the threshold tests to monitor speed and direction data quality using these parameters and the accepted FAA guidelines.

3.3.1 Speed Tests

Speed tests consist of examination of a sensor's average speed ratio for wind from all directions, its distribution of speed ratios, and its variability of speed ratio value with mean wind direction. Figure 3–5 shows the conceptual logic employed in diagnosing a wind speed data quality problem. The following paragraphs describe the specific implementation of the various speed threshold tests.

3.3.1.1 Severe or catastrophic malfunction

Severe malfunctions that are either electrical or mechanical in nature often result in extreme values of wind speed, often manifested as reporting of a constant near–zero value. As a test for this type of problem, wind speed distributions are examined for an unexpectedly high proportion of speed ratios occurring in the extreme low and/or speed ratio bins. From the large data sample, the expected occurrence of wind speed ratios less than 0.50 or greater than 1.50 was approximately four percent and three percent, respectively. For our catastrophic speed test using a 24–hour period of data (which would be expected to exhibit a larger variance due to its smaller sample size), a speed sensing problem is indicated if the percentage frequency of either of these extreme speed bins exceeds 25 percent. For this type of severe error, a message of "extreme low" or "extreme high" speed bias is generated.

3.3.1.2 Speed Bias (frictional drag, improper sensor height, sheltering)

These tests examine the wind statistics for a low or high bias in the wind speed estimate. An average deviation of 20 percent or more (adaptable parameter) from the standard wind speed is con-

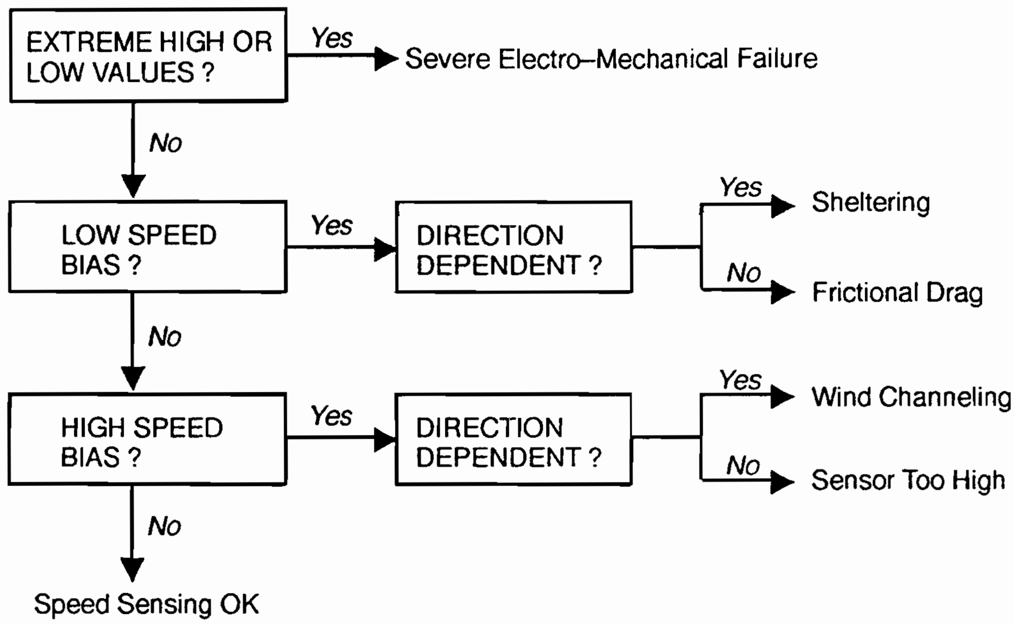

Figure 3–5. Conceptual logic applied to testing for and diagnosing speed sensing problems.

sidered an unacceptable bias. Potential causes of wind speed biases include undue friction in the sensor bearings, a sensor that is sited either too low or too high, or physical obstructions that shelter the sensor.

The overall average speed ratio of wind from all directions (0 to 360 degrees) is examined for a low or high speed bias. If it is less than a 0.80 (representing a 20 percent low departure from standard), then a low speed bias is indicated. If it is greater than 1.20 (representing a 20 percent high departure), then a high speed bias is indicated. If a low bias indication persists for several days, the speed distributions of the individual direction bins are then examined using a larger data sample (10–30 days) to determine whether the speed bias shows some directional dependence. The long duration for accumulating data for this test is required so that sufficient samples are available for winds from all directions. The speed ratio distribution for each wind direction is then tested separately, and a message is reported to indicate if the speed bias showed any dependency on wind direction. If the unacceptably low bias is apparent for only a subset of all wind directions, then the problem is considered to be directionally dependent and attributed to sheltering by nearby obstructions. If the low bias shows no directional dependence, the problem is attributed to either frictional drag on the sensor or an insufficient pole height.

3.3.2 Direction Tests

Direction tests consist of examination of a sensor's average direction difference from the mean and the frequency distribution of direction differences. Figure 3–6 shows the logic employed in diagnosing a direction sensing problem. The following paragraphs provide and explanation of the various direction threshold tests.

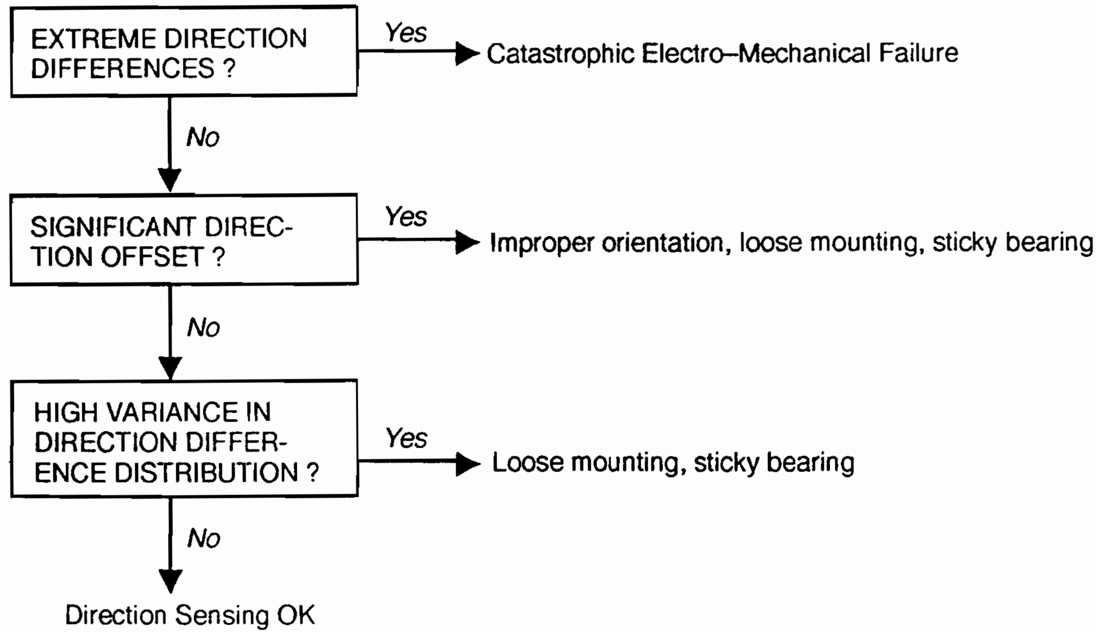

Figure 3–6. Conceptual logic applied to testing for and diagnosing direction sensing problems.

3.3.2.1 Severe or Catastrophic Malfunction

As with wind speed, severe malfunctions that are either electrical or mechanical in nature often result in extreme departure in wind direction values from the mean direction. From the large sample of data, extreme direction differences (greater than 95 degrees) occurred with a frequency of less than one percent. For the daily test for catastrophic direction problems, an error is indicated if this extreme condition occurs with a frequency of greater than five percent.

3.3.2.2 Directional Offset (improper orientation, loose mounting, sticky bearing)

This test checks for an offset in the wind direction sensor from the true wind direction. A direction offset is usually associated with a direction sensor that is not properly oriented (i.e., incorrect ground reference), one whose mounting is loose, or with a "stickiness" in the direction bearings that cause a jerkiness or lag in movement of the wind direction vane. For each sensor, the average direction difference is compared against a parameter indicating the maximum allowable difference. Any persistent daily difference greater than 15 degrees is considered unacceptable.

3.3.2.3 Flat Distribution (loose mounting, sticky bearing)

If a sensor is experiencing a loose mounting or a sticky bearing, over time the average difference from the true direction may not stray far from zero, as errors of different sign (i.e., clockwise or counterclockwise) may tend to offset one another. However, the problem would still be evident as a broadened distribution (higher variance) in the wind direction frequency profile. Thus, even for acceptably small average direction differences, the difference profile was tested for variance.

To test for variance, the percentage frequency of direction difference counts of less than 15 degrees and less than 35 degrees are examined. From the large data sample, one would expect that the direction difference to be less than 15 degrees approximately 80 percent of the time, and less than 35 degrees approximately 90 percent of the time. For the threshold test on these standards, a distribution is considered to have an unacceptably broad distribution if less than 45 percent of the counts have a direction difference of plus/minus 15 degrees, or if less than 80 percent of the counts have a direction difference of plus/minus 35 degrees.

3.4 Reporting Sensor Status

Using the logic and threshold tests described for wind speed and direction, a summary page that indicates the status of each sensor is automatically generated for each day of data. For each sensor, the status summary page indicates the number of valid counts for compiling speed ratio data, the general speed sensing status (good, bad, or unknown), the average speed ratio, a text comment regarding any bad speed status message, the direction dependency of any bad speed problem, the general direction sensing status, and the average direction difference. A sample summary page is shown in Figure 3–7. In addition, a summary of the speed and direction profile characteristics for each sensor is also generated in order to further investigate any deficiency indicated on the summary page.

STA	SPEED SENSOR INFORMATION					DIRECTION INFORMATION	
	COUNTS	STATUS	RATIO	COMMENT	DIR DEP	STATUS	DIFFERENCE
1	4337	Good	1.12			Good	-0.1
2	4332	Good	0.97			Good	-0.8
3	4339	Bad	0.77	Low bias	No	Good	4.2
4	4337	Good	1.03			Good	-2.0
5	0	Bad	0.00	Missing data		Bad	0.0
6	4331	Good	0.89			Good	-3.8
7	4338	Good	1.07			Bad	22.8
8	4330	Good	1.03			Good	-5.1
9	4337	Bad	0.92	Low speed	Yes	Good	-3.7
10	4332	Good	0.92			Good	4.4
11	4331	Good	1.01			Bad	-1.3
12	4330	Bad	0.22	Extreme low spds	No	Good	2.7

Figure 3–7. Sample summary indicating sensor status.

4. TESTING THE DQA APPROACH

During 1991–1993, MIT Lincoln Laboratory conducted an operational demonstration of the Terminal Doppler Weather Radar (TDWR) system at Orlando International Airport. There were two anemometer networks deployed in association with these demonstration and testing efforts. The first was the 14–station Phase III Network Expansion LLWAS system owned and operated by the FAA. This system was capable of operating both as a stand–alone wind shear detection system for MCO, and as a component of the TDWR/LLWAS integration system that was being demonstrated. As part of the Phase III LLWAS upgrade at MCO, the anemometers were mounted on tall towers ranging from 120 to 150 feet in height to minimize sheltering effects in the airport terminal area. The second anemometer network was the 15–sensor mesonet (mesoscale network) operated by Lincoln Laboratory. Data from this network was collected off line in support of the TDWR/LLWAS testing effort. These sensors were raised on portable aluminum towers and were situated approximately 90 feet above ground level to lessen the sheltering effects in the heavily–wooded central Florida environment. An illustration of both anemometer networks in relationship to the runways at MCO is shown in Figure 4–1.

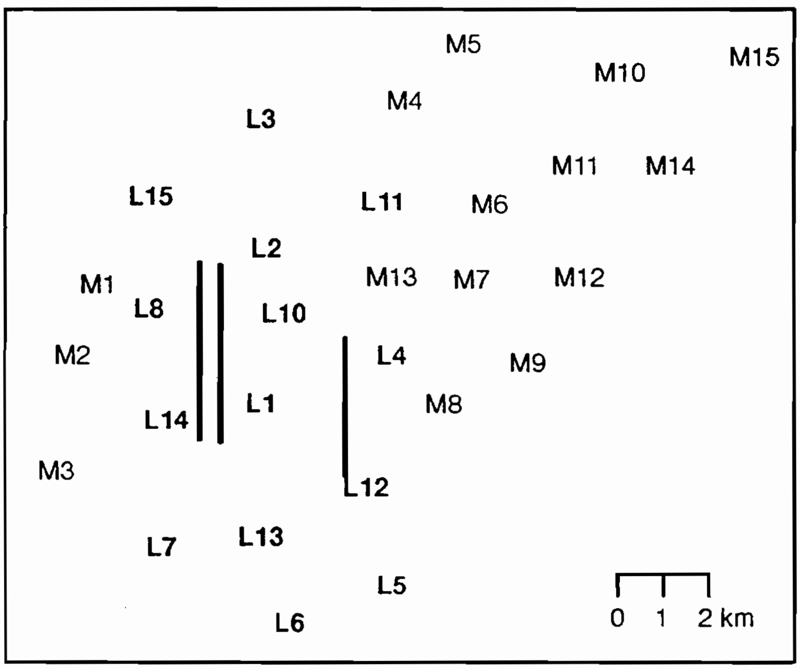

Figure 4–1. Location of FAA and MIT Lincoln Laboratory anemometer networks during 1992 at MCO. L1 through L15 (bold face type) indicate locations of 14 FAA LLWAS sensors (Station L9 not sited). M1 through M15 indicate locations of 15 Lincoln Laboratory mesonet sensors.

Although some feasibility testing of the DQA was done during 1991, most of the analysis of the automated methodology reported here was performed using data collected during 1992 and 1993. During 1992, anemometer data were collected from mid–April through mid–September. At the end of each day (0000 UTC), the data from both networks were processed off line by the DQA software, and the output summaries were examined. Periodically, a data sample comprising several (usually 2–5) days of data was processed to more closely examine instances of marginal sensor performance or to better determine speed sensing dependency on wind direction. A summary log of the speed and direction status of each sensor was maintained throughout the five–month period. When data quality problems were clearly evident, the appropriate maintenance personnel (FAA or Lincoln Laboratory, depending on the network) were notified. At the end of the data collection period, several very large samples of data (ranging from 10 to 30 days each) were processed to further examine sensor performance and assess the effectiveness of the DQA method.

Following the 1992 data collection season, the Phase III configuration of LLWAS was downgraded to a Phase II six-sensor configuration, while the Lincoln Laboratory mesonet was removed (for deployment at another site). However, during 1993 the FAA restored off–line data collection of the 14–sensor Phase III LLWAS configuration as part of a system performance evaluation for the Phase III LLWAS contractor. DQA processing was also performed on much of this data.

The following paragraphs discuss observations of DQA performance, focusing on the 1992 and 1993 data sets. This discussion includes some general observations as well as examples of individual sensor performance in detecting both severe and non–severe data quality problems.

4.1 General Observations

The DQA was initially run using data from a merged file of synchronized data from all 29 anemometers, i.e., using LLWAS and Lincoln mesonet sensors combined. The first few data quality checks in April of 1992 indicated a distinct speed sensing difference between the two networks. The automated daily status summary typically indicated nearly half of the sensors as having a speed sensing problem; many of the LLWAS sensors were showing unacceptably high speed biases, while the Lincoln sensors had low biases. Examining several days of data, the average speed ratio of the LLWAS sensors was 1.07; that of the Lincoln sensors was 0.88. It was concluded that this characteristic difference of approximately 15 percent was primarily attributable to the different pole heights of the two networks. The LLWAS anemometers, located 120 to 150 feet above the ground, in general were safely above obstructions in the terminal area (with some exceptions). The Lincoln sensors, although raised 90 feet above ground level, were at a lower effective height relative to the tree canopies that are plentiful in central Florida. In one sense, this result served as justification for the FAA decision to raise the LLWAS sensors on the tall poles (incurring additional site expense), as the LLWAS sensors were viewed as providing a better measurement of the operational winds. To avoid the effect of the differing speed sensing characteristics of the two networks, the DQA software was run separately each day for each network.

With the DQA being run separately for LLWAS and Lincoln sensors, it was found to be very successful in indicating severe sensor malfunctions such as grossly underestimated wind speeds or largely erroneous wind directions. There were several instances of these severe failures, particularly in the Lincoln mesonet, due to a variety of problems such as faulty cables, low power supplies, lightning strikes, misoriented ground reference for direction sensing, etc. These extreme problems primarily occurred toward the beginning of the data collection period when the Lincoln network was being stabilized. More subtle data quality problems were a greater challenge, as expected, but the DQA gave reliable indications of when a potential problem existed. Most of the difficulty in providing a timely indication of the more subtle problems arose from the limitations of using single–day data samples. The two primary limitations were: 1) many days included a small sample size because of light wind conditions (i.e., mean wind speed of less than 3 m/s) not uncommon in central Florida, and 2) even for days with large samples, the mean wind direction is usually limited to a modest range (typically 30–60 degrees), so it is virtually impossible to make judgement on the direction dependency of speed–sensing performance. In spite of the limitations of working with single–day samples, analysis of large samples covering several days were quite reliable and consistent in assessing speed–sensing performance.

After analyzing both large and small samples from both the 1992 and 1993 data sets, it was clear that the most effective implementation of the DQA would be to vary the sample size and thresholds for various tests. It is clear that some problems are evident in a very small data sample (an hour or so), some require a very large sample (several days, or even weeks), while others require a sample size somewhere in between. In addition, some tests could be done using more than one sample size, applying less stringent thresholds to the smaller sample. Details for this type of implementation are given in Section 5. These recommendations were included in development of the DQA functional requirements provided to the FAA.

4.2 Examples of Irregular Sensor Performance

The following paragraphs cite some specific examples from the 1992 and 1993 data sets that illustrate the performance of the automated DQA.

4.2.1 Catastrophic Speed Sensing Failure

As mentioned, there were several instances where an anemometer experienced a severe problem, usually evidenced by extremely low wind speed values. Oftentimes these problems result in reporting of a continuous zero or near–zero wind speed, which is evident in a very small data sample. Problems of these types are characterized by a discrete change in sensing performance rather than a gradual degradation.

An example of a catastrophic speed sensing failure identified by the automated DQA occurred on 1 May 1992. The average speed ratio for that day was reported at 0.09 (see Figure 4–2). In addition to a low value of the average speed ratio, an indication of the critical nature of the failure was provided by the 90 percent frequency value in the "extreme low" speed ratio bin, i.e., a speed ratio of less than 0.50 was occurring 90 percent of the time, far greater than the 25 percent threshold. The sensor site was examined, and the problem was isolated to a faulty cable to the speed sensor. The cable was replaced on 2 May; the output statistics from 3 May (Figure 4–2) showed no data quality problems. Extreme speed sensing problems of this nature were apparent in small sample sizes, and the DQA methodology was very effective in providing a timely indication of failure.

4.2.2 Speed Biases and Direction Dependency

In contrast to the extreme speed–sensing failures, there were several instances in which an anemometer indicated a speed ratio that was just outside the acceptable 0.80 to 1.20 range for only a one– or two–day period, and yet was satisfactory most of the time. Once again, this was more evident in the Lincoln sensor network. From these single–day indications, it was unclear whether the overall performance of the sensor should be considered acceptable. It was assumed that the short–term indication of inferior performance was due to two possible effects: 1) the problem was direction–dependent and the wind was blowing from a more sheltered direction on those days, or 2) the overall performance of the sensor was marginal and the intermittent failure indications were a conse-

1 MAY 1993

STATION #3

SPEED RATIO BIN RANGE	030	060	090	120	150	180	210	240	270	300	330	360	ALL
0.00–0.50	61	71	0	0	0	0	0	0	0	100	100	100	90
0.50–0.70	12	9	0	0	0	0	0	0	0	0	0	0	3
0.70–0.90	14	10	0	0	0	0	0	0	0	0	0	0	3
0.90–1.10	7	6	0	0	0	0	0	0	0	0	0	0	2
1.10–1.30	5	2	0	0	0	0	0	0	0	0	0	0	1
1.30–1.50	1	1	0	0	0	0	0	0	0	0	0	0	0
1.50–2.00	1	0	0	0	0	0	0	0	0	0	0	0	0
2.00+	4	0	0	0	0	0	0	0	0	0	0	0	0
AVG RATIO	0.35	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09
COUNTS	457	281	0	0	0	0	0	0	1	825	800	309	2673

MEAN DIRECTION BIN CENTER VALUE (DEGREES)

3 MAY 1993

STATION #3

SPEED RATIO BIN RANGE	030	060	090	120	150	180	210	240	270	300	330	360	ALL
0.00–0.50	0	0	0	0	0	0	0	1	3	11	15	0	6
0.50–0.70	0	0	0	0	0	0	0	6	9	18	17	0	11
0.70–0.90	0	0	0	0	0	0	0	15	18	24	24	0	20
0.90–1.10	0	0	0	0	0	0	0	23	25	21	21	0	23
1.10–1.30	0	0	0	0	0	0	0	25	22	15	15	0	20
1.30–1.50	0	0	0	0	0	0	0	17	15	8	7	0	13
1.50–2.00	0	0	0	0	0	0	0	13	7	3	2	0	7
2.00+	0	0	0	0	0	0	0	0	0	0	0	0	0
AVG RATIO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.15	1.06	0.90	0.86	0.00	1.02
COUNTS	0	0	0	0	0	0	0	610	1594	754	369	0	3330

MEAN DIRECTION BIN CENTER VALUE (DEGREES)

Figure 4–2. Speed sensing statistical data for Station M3, for 1 May and 3 May 1993. Included are station number, table of percentage frequency distributions of speed ratio sorted by mean wind direction bin, average speed ratio for each wind direction, and number of valid counts comprising the distribution for each wind direction bin.

quence of the day–to–day variability of the wind field over the network, i.e., on some days the wind is more turbulent or gusty, thus causing a larger standard deviation of wind values across the network for any given data poll. In light of these instances, it became clear that future versions of the algorithm should include threshold testing on different time–tiers (i.e., short– and long–term tests) as will be described in Section 5. The next few paragraphs show examples of how direction dependency affects the testing for speed biases.

4.2.2.1 Example of Low Speed Bias with Direction Dependence

An example of a sensor with a low speed bias that exhibited direction dependence was observed with Station M4 of the Lincoln mesonet. Figure 4–3 shows a plot of the daily speed ratio during 12–21 June. The plot also shows the predominant mean wind direction for each day. Over this 10–day period, the average speed ratio was 0.90, safely within the acceptable 20 percent criterion. However, on 16 June, the daily speed ratio was 0.78, which is considered unacceptably low. Since this was the only day of the 10–day sample during which the wind blew from 120 degrees, the implication is that the sensor experienced an unacceptably high amount of sheltering from that direction. Although this is apparent in the 10–day sample, the sample is still limited in the range of directions covered; furthermore, the sample sizes from many of directions that *are* covered are sparse. As a matter of fact, there were only 611 valid polls of data from the 120 degree mean direction bin on the 16th, which does not qualify as a sufficient sample for an individual direction. (720 polls is considered a sample size minimum; there were 1175 valid polls from *any* direction on that day, which yielded the 0.78 daily speed ratio value. The speed ratio using *only* the 611 polls from 120 degrees was 0.71.)

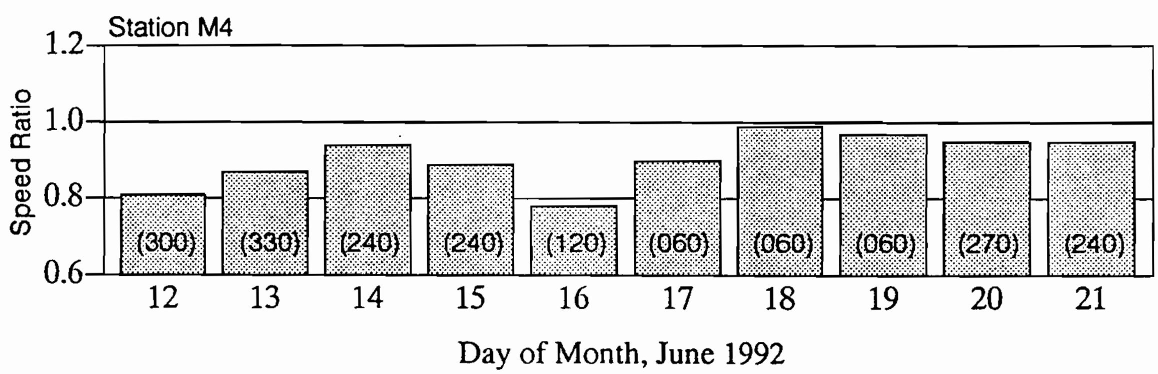

Figure 4–3. Overall daily speed ratio for Station M4 during 12–21 June 1992. Numbers in parentheses indicate predominant wind direction (in degrees) on each day.

It was clear that reliable conclusions regarding directional dependency of speed sensing performance require a much larger sample. In order to better understand this dependency and its variability from station–to–station, several very large samples of data were DQA processed at the end of the data collection period. The results of these large sample statistics are shown in Figures 4–4 and 4–5. The graphs in Figure 4–4 were compiled using data from 13 of the Lincoln mesonet sensors between the period 21 May to 17 June 1992 (the other two Lincoln anemometers were inoperable during this period), representing a sample of more than 25,000 valid polls, and includes a sufficient sample of data for all mean wind direction bins. The figure shows the speed ratio for each mean direction bin as well as the average speed ratio for all directions combined. (This overall value represents a weighted average since some direction bins contain more samples than others.) A similar representation for the 14 FAA LLWAS sensor is shown in Figure 4–5. This sample was taken during 6–22 June (except for Station L5, which was missing much data during this particular period) and includes approximately 40,000 polls of valid data.

These distributions give a better perspective of single–day indications of speed sensing deficiencies. For example, if we re–examine Station M4, the overall speed ratio is 0.90 (same as that

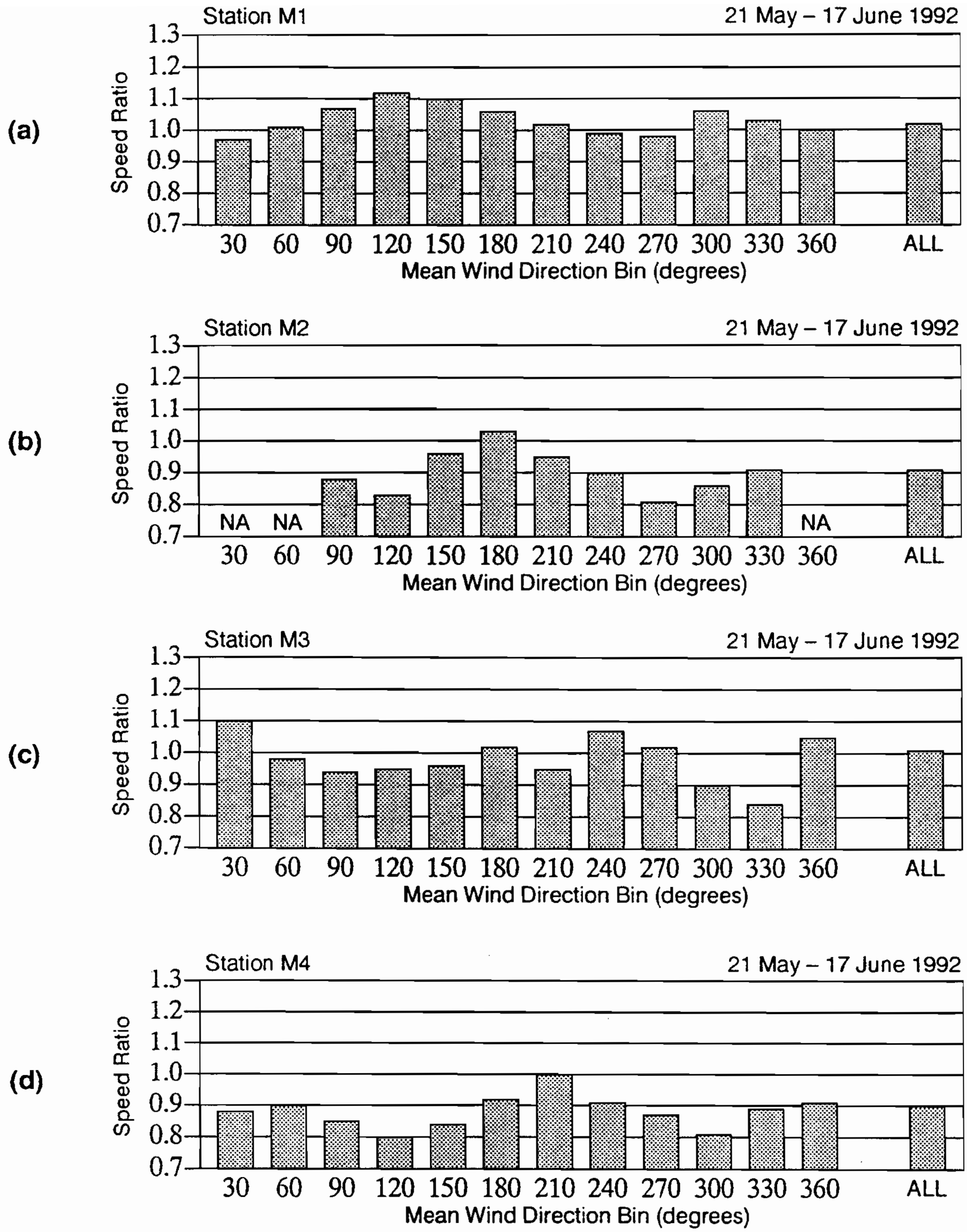

Figure 4–4. Graphs showing long–term average speed ratios for 13 Lincoln Laboratory mesonet anemometer stations. Each graph shows the speed ratio corresponding to each of the 12 mean wind direction bins, plus the overall speed ratio for all directions.

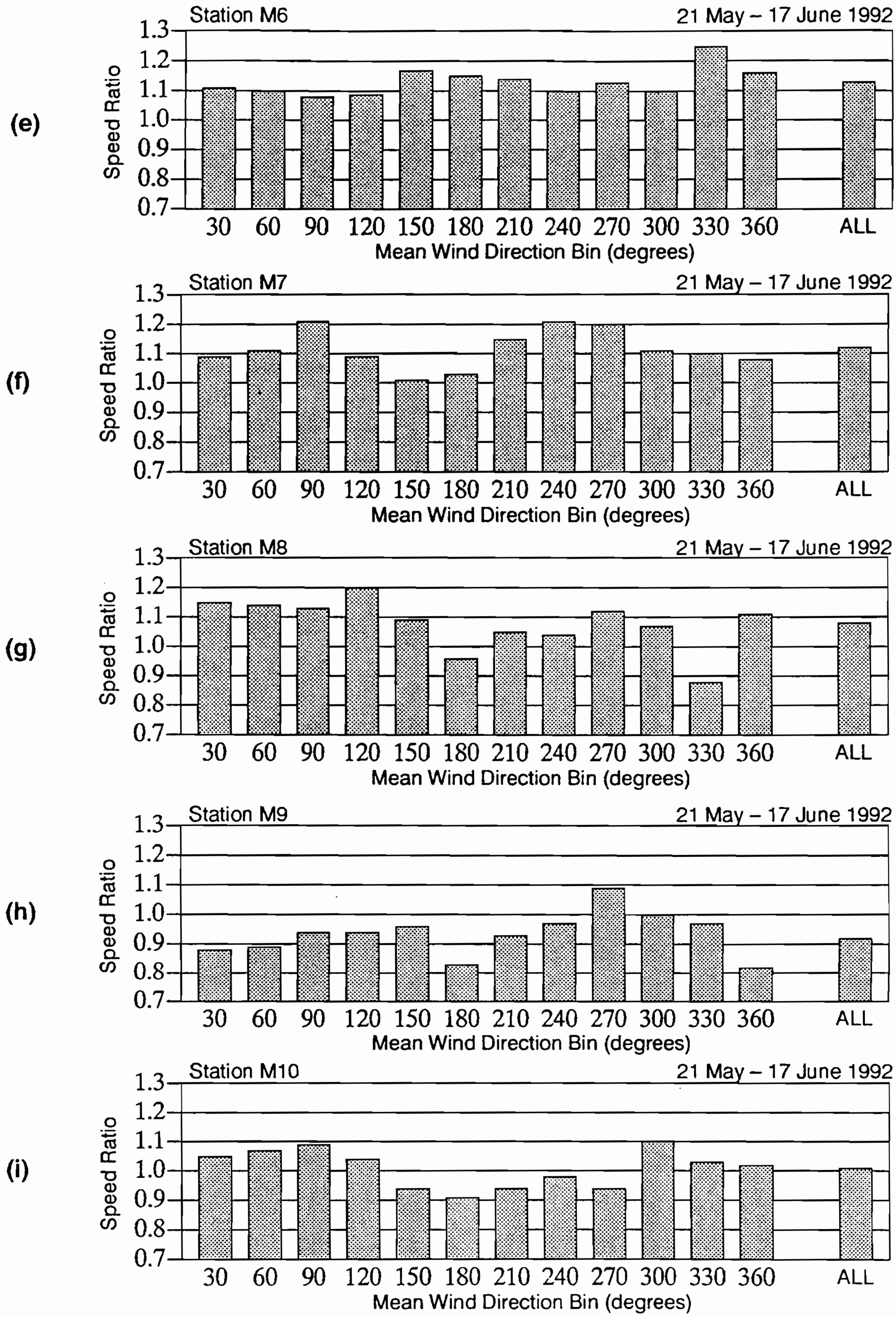

Figure 4–4 (Continued).

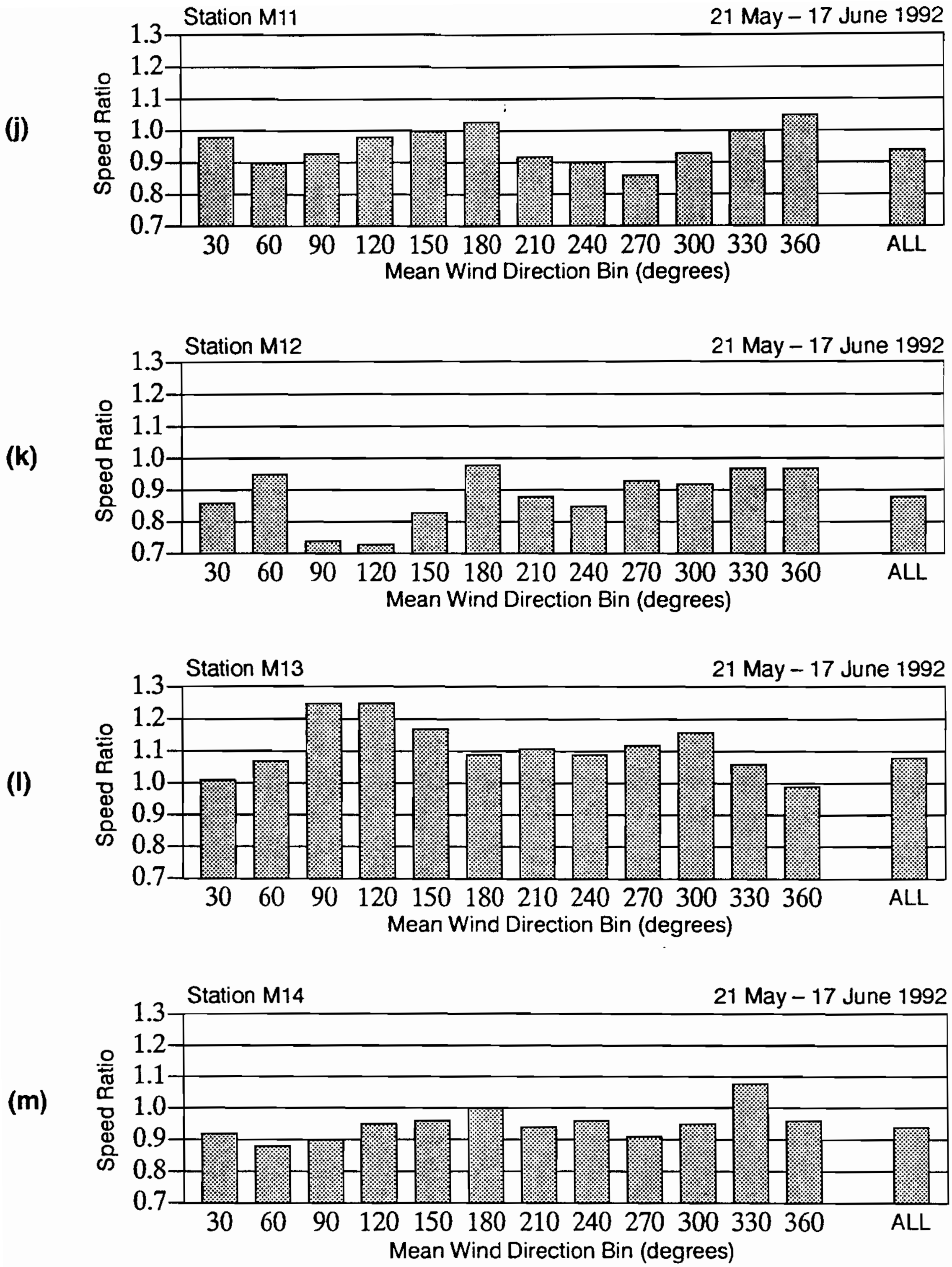

Figure 4–4 (Continued).

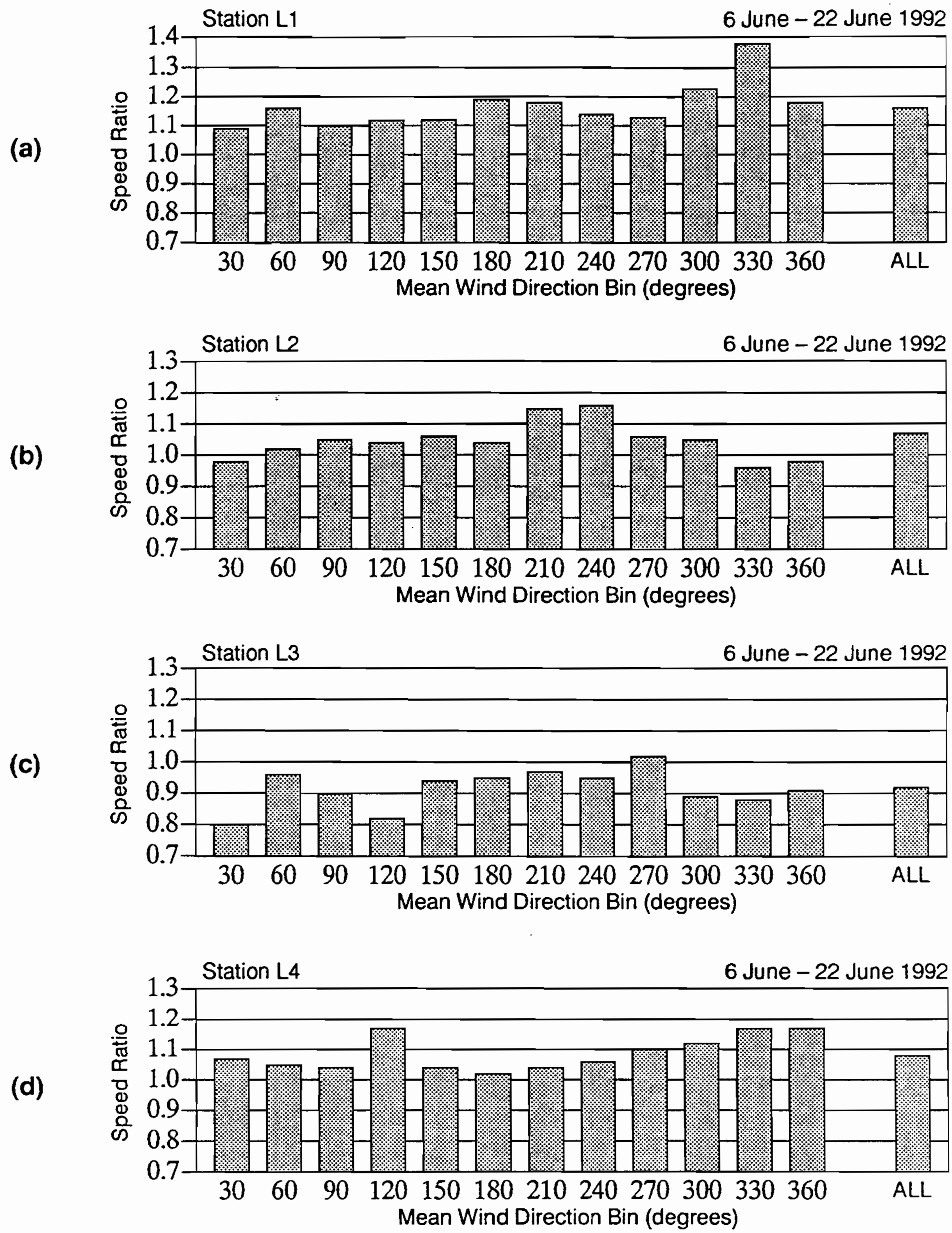

Figure 4–5. Graphs showing long–term average speed ratios for 14 FAA LLWAS anemometer stations. Each graph shows the speed ratio corresponding to each of the 12 mean wind direction bins, plus the overall speed ratio for all directions.

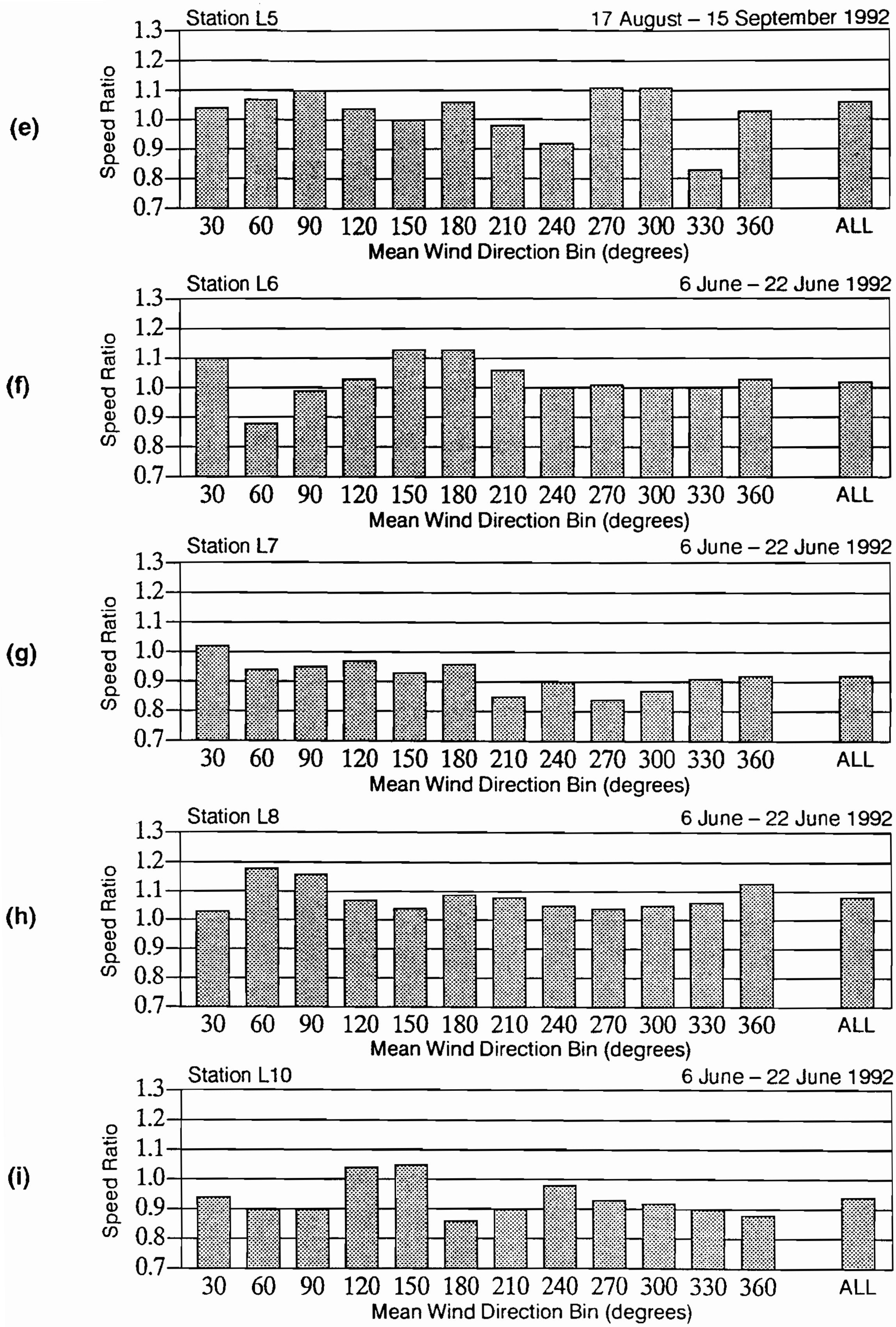

Figure 4–5 (Continued).

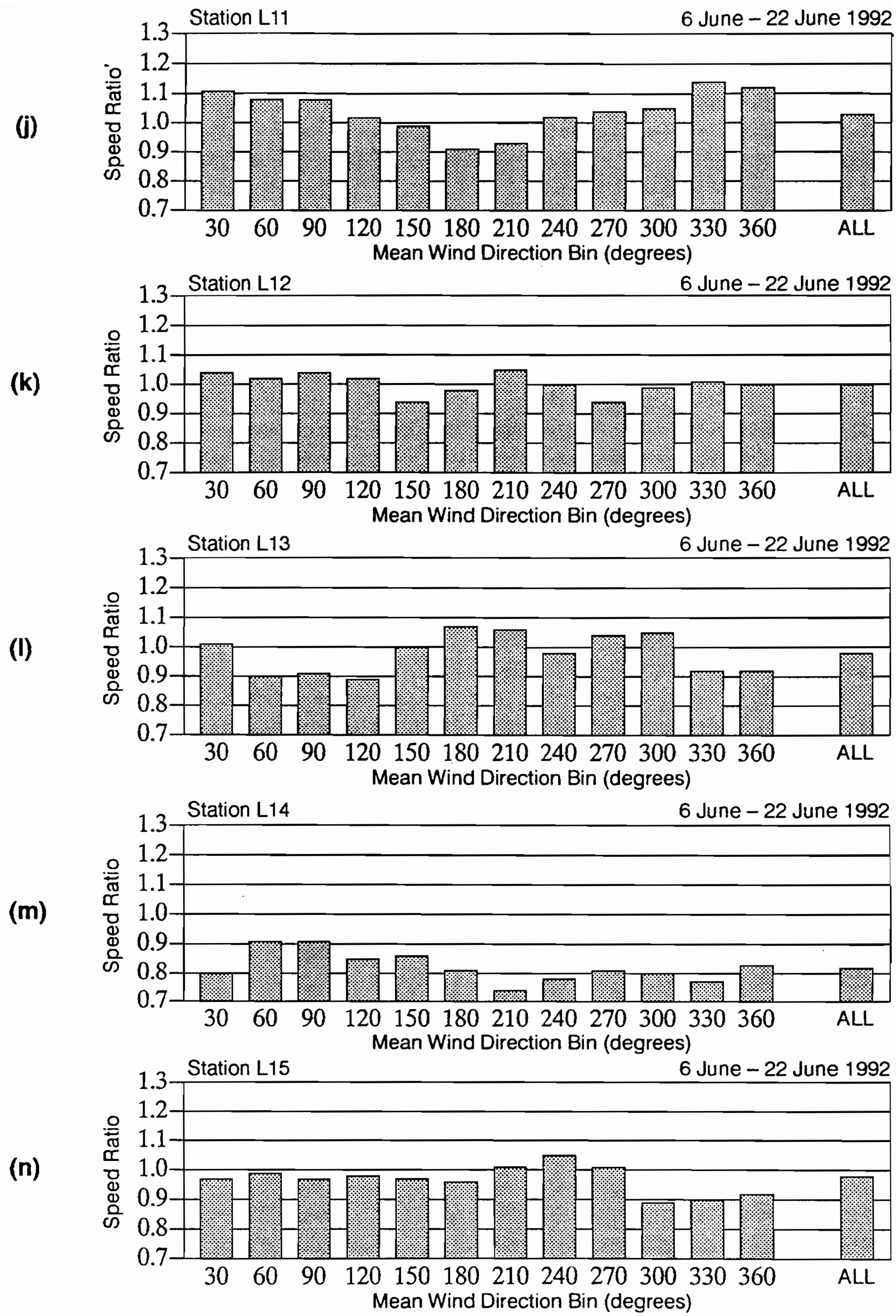

Figure 4–5 (Continued).

of the smaller 10–day sample), with the lowest speed ratio of 0.80 occurring for the 120 degree mean wind direction bin. This is consistent with our observation of the low speed ratio of 0.78 on the 16th, when the predominant wind was from 120 degrees. The next question, however, is whether this sensor's performance should be considered acceptable (for the moment disregarding the fact that the entire Lincoln mesonet is considered to have a low speed problem due to insufficient tower height). The larger sample indicates that the performance is acceptable, albeit marginal from a couple of directions (0.80 speed ratio from 120 degrees, 0.81 from 330), while the single–day sample implies a sensor deficiency. For implementation as an on–line monitoring system, it was concluded that the best approach would be to apply a less stringent threshold to the single–day sample and apply the stricter threshold to a larger sample. Thus, a deviation from the mean would be required to be more "convincing" in the one–day sample in order to justify action to be taken by maintenance personnel.

4.2.2.2 An example of direction dependence speed bias for an LLWAS sensor

Only two of the FAA LLWAS sensors indicated potential speed sensor problems worthy of note. The first involved Station L10, which is of special significance as it represented the Centerfield sensor of the network, which is the wind value that is provided routinely to pilots. It also illustrates the importance of directional dependence of speed performance monitoring by the DQA. For the first part of the summer, Station L10 showed no indication of a potential sensor problem. This is consistent with the large sample distribution shown in Fig 4–5i. The average speed ratio over all directions was 0.94; the value of speed ratio over the twelve different direction bins ranged from 0.86 for a southerly wind (180 degrees) to 1.05 for a southeasterly wind. There is also a fair amount of sheltering from directions ranging from north–northwest clockwise around to east, with speed ratios near 0.90. A channelling effect is apparent for winds from the southeast, with ratios greater than 1.00 for winds in the 120 and 150 degree direction bins. This distribution with direction is consistent with the local obstructions in the area near Sensor L10. There are airport terminal buildings to the south of the anemometer and some sheltering by trees to the west, north, and east. The buildings seem responsible for the sheltering from the south, with a potential channeling effect for winds from the southwest and southeast.

During the latter portion of the data collection period, there were frequent days for which the DQA indicated a low speed bias for Station L10, with daily speed ratios reaching as low as 0.72. A second large sample of over 80,000 polls was processed using data collected from 17 August to 15 September. Figure 4–6 shows distribution of speed ratios over the twelve direction bins for this period as compared to that of the previous large sample (6–22 June). This second sample shows the overall speed ratio to be 0.85. The directional dependence of the speeds shows tendencies similar to that of the first sample, but more exaggerated in amplitude. For instance, the sheltering from the north around to the east appears much more severe, with speed ratios ranging from 0.75 to 0.82. In addition, the channeling from the southeast and southwest is also exaggerated, with values as high as 1.10. Although these exaggerations are not clearly understood, the significant reduction in overall speed ratios (i.e., from all directions) from 0.94 to 0.85 is primarily due to the persistent northeast wind that predominated during the latter data collection sample, thus weighting the overall average with winds from the more sheltered directions. If we compare the speed ratios for the two samples using equal weighting to each wind direction (irrespective of the number of polls from each direction), the speed ratio difference of the two samples is insignificant (0.93 versus 0.92). This does not, however, account for the difference in speed sensing performance within individual direction bins

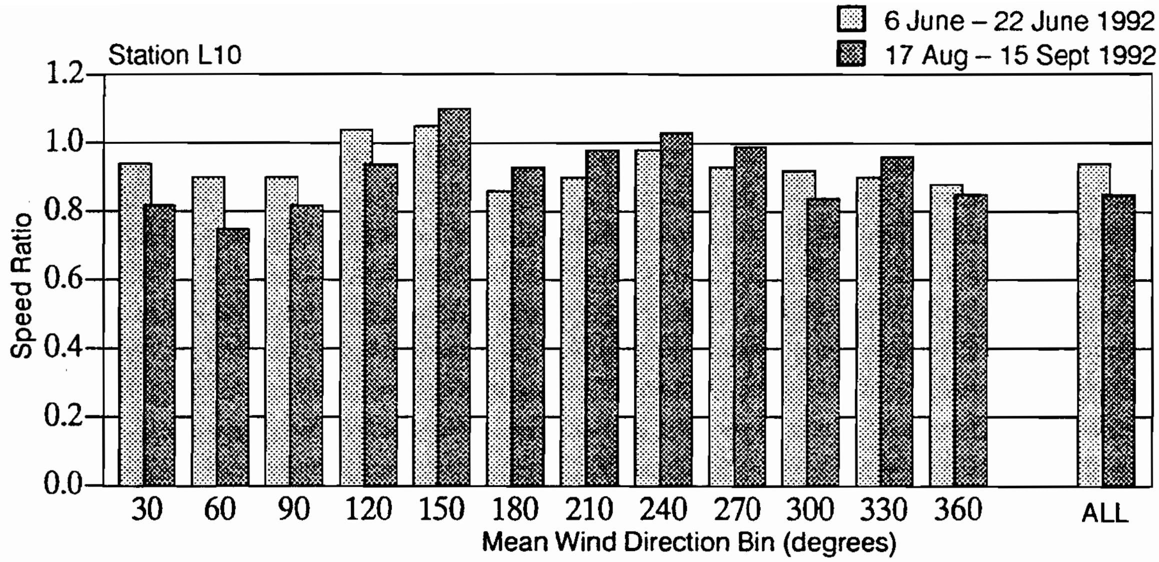

Figure 4–6. Average speed ratio corresponding to each mean wind direction bin, for two separate samples of data.

using the two samples, e.g., why was the sheltering from the northeast more severe in the later sample? (It is possible that in addition to sheltering, the sensor also experienced a gradual degradation from some other source, such as a speed bearing problem.) Due to the limited availability of land in the central portion of the runway area, there are virtually no options in finding a superior site, and obstruction height restrictions in the immediate runway area preclude raising the sensor further, so no further corrective action was taken during 1992.

4.2.2.3 An example showing deficiency in the direction dependence test

The other LLWAS sensor exhibiting questionable performance during 1992 was Station L14. The DQA algorithm identified this sensor as having a direction dependent speed bias. Although it was correct in identifying a speed bias, closer examination indicated that the bias was not directionally dependent. This example has led to proposal of an improved method of determining direction dependence, as described in the following paragraphs.

Referring back to Figure 4–5m, the overall long–term speed ratio from all directions for Station L14 is 0.82, which is marginally acceptable. The figure shows that the sensor performance would be considered acceptable from some directions (greater than 0.80 ratio) but not for others (less than 0.80 ratio), and thus the low speed bias would be judged by the DQA algorithm as demonstrating a directional dependency. However, the range of speed ratios over the spectrum of direction bins is much smaller than that seen in the previous example (Station L10). This flatter distribution with direction would imply that there is *little* direction dependency and that the reason a subset of directions appear acceptable is because the overall speed ratio (0.82) is so close to the acceptable threshold. From this observation, it became apparent that the determination of directional dependency should be based on the range of speed ratio values over all of the direction bins. To establish a typical range of values with direction, we used the large samples and computed for each sensor the difference between the overall speed ratio (from all directions combined) and the speed ratio of the direction bin that differed farthest from the overall average ratio. The distribution of these difference values for the Lincoln and FAA sensors is shown in Figure 4–7. For the Lincoln mesonet, Stations M1, M4, and M10 show the least directional dependence, as the difference between the overall speed ratio and the "worst" direction ratio is 0.10. Station M8 shows the most directional dependence, with a difference of 0.20. The median difference value for the Lincoln mesonet was 0.14. Directional dependence of speed performance for the FAA LLWAS network was less evident, with a median difference value of 0.095. Only station L1 exhibited extreme directional dependence, with a difference value of 0.22. Referring back to its speed ratio distribution (Figure 4–5a), Station L1 showed an overall high speed bias of 13 percent; its most sheltered direction was from 030 degrees, for which its speed ratio was 1.09. In contrast, the speed ratio from 330 degrees was a dramatic 1.38, the largest deviation from average for any station or direction for either network. It is presumed that this is an effect of wind channeling around the terminal building located to the north. (This is the same building that is responsible for the wind channeling effect on Station L10 for a wind with southerly component.) In any event, it seems appropriate that these difference values should be used to determine directional dependence. For instance, the standard deviation of difference values over the LLWAS network is 0.038, so an empirically–derived threshold for a direction–dependence test might be the mean difference (0.095 in this example) plus one standard deviation. In this example, this approach would yield a threshold of approximately 0.13, so Stations L1, L5, and L6 would be considered to have a speed–sensing performance that varies significantly with direction.

4.2.2.4 The importance of inter–station dependency in assessing directional dependence

One final issue regarding directional dependence of speed sensing has to do with inter–station dependency. Looking back a Station L1 and its large high bias from the 330 degree direction bin, it is clear that an effect of this station would be to raise the network mean wind speed, thus giving the appearance of increased sheltering at all other stations. In order for the DQA to be effective in this regard, the network must be sufficiently large so that the contribution from a single station does not overwhelm the network mean speed value and create artificial speed ratios at the remaining sensors. In this example, Station L1 has a speed ratio value for 330 degrees that is 0.22 greater than

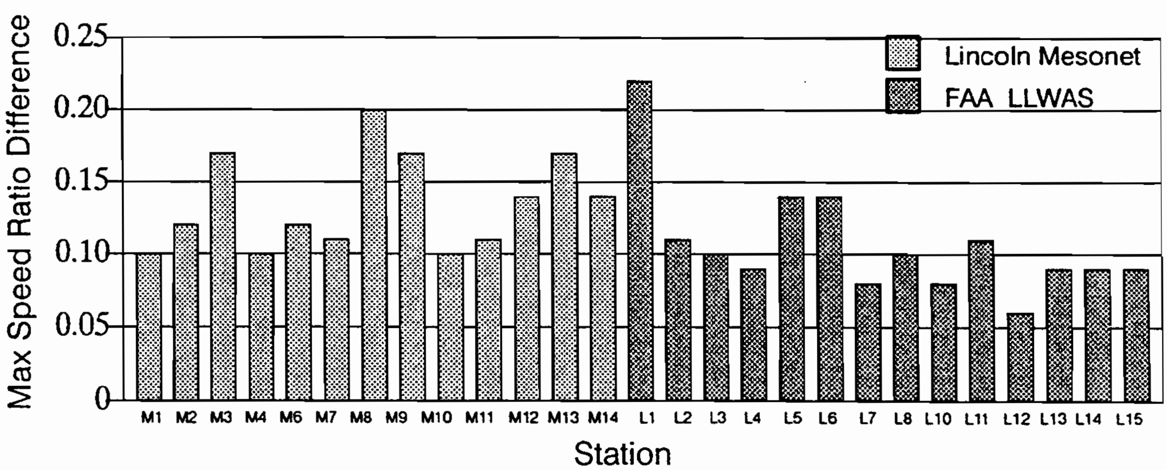

Figure 4–7. Maximum speed ratio difference defined for each sensor as the maximum difference in speed ratio between the overall average speed ratio (all directions) and the average speed ratio corresponding to each of the 12 mean wind direction bins.

its overall average. If this were the only non–meteorological effect contributing to an increase in the network mean speed, its impact would be an artificial increase in speed ratio of nearly 0.02 for the other stations for winds from 330 degrees. If this were a six–sensor network, the impact would be a speed ratio decrease of 0.04 for the remaining five sensors. Although not catastrophic to the methodology, it lends support to an approach of varying the stringency of the speed ratio thresholds to account for this inter–station dependency. Perhaps less strict speed ratio thresholds should be employed by smaller networks (like the six–sensor Phase II system) than those used for the larger (12–20 sensor) Phase III networks. The tradeoff would be a decrease in false indications of a bad sensor, at the expense of a lower (or less timely) detection rate of faulty sensors. (Of course, for the largest networks, e.g., greater than 20 sensors, the larger areal extent introduces additional variance in wind speeds within the network due to greater horizontal displacement, as described earlier.) We must also consider that, in contrast to the simple example involving Station L1, the combined effects of local sheltering and obstructions of all the sensors within a network is far more complex. Figure 4–8 shows a scatter diagram of wind speed ratios of all 14 LLWAS anemometers for each of the 12 direction bins and provides some sense of directional dependence and the sensitivity of inter–station dependence of speed ratio values. Based on the distribution of speed ratio values, the speed sensing performance of the network as a whole can be seen to more "well–behaved" for some wind directions compared to others. This behavior has an impact on the effectiveness of the DQA methodology. For example, for the 030 degree direction bin, the 0.80 speed ratio (Station L3) is a clear outlier from the rest of the network, while the 0.77 value from 330 degrees (Station L13) is at least partly exagger-

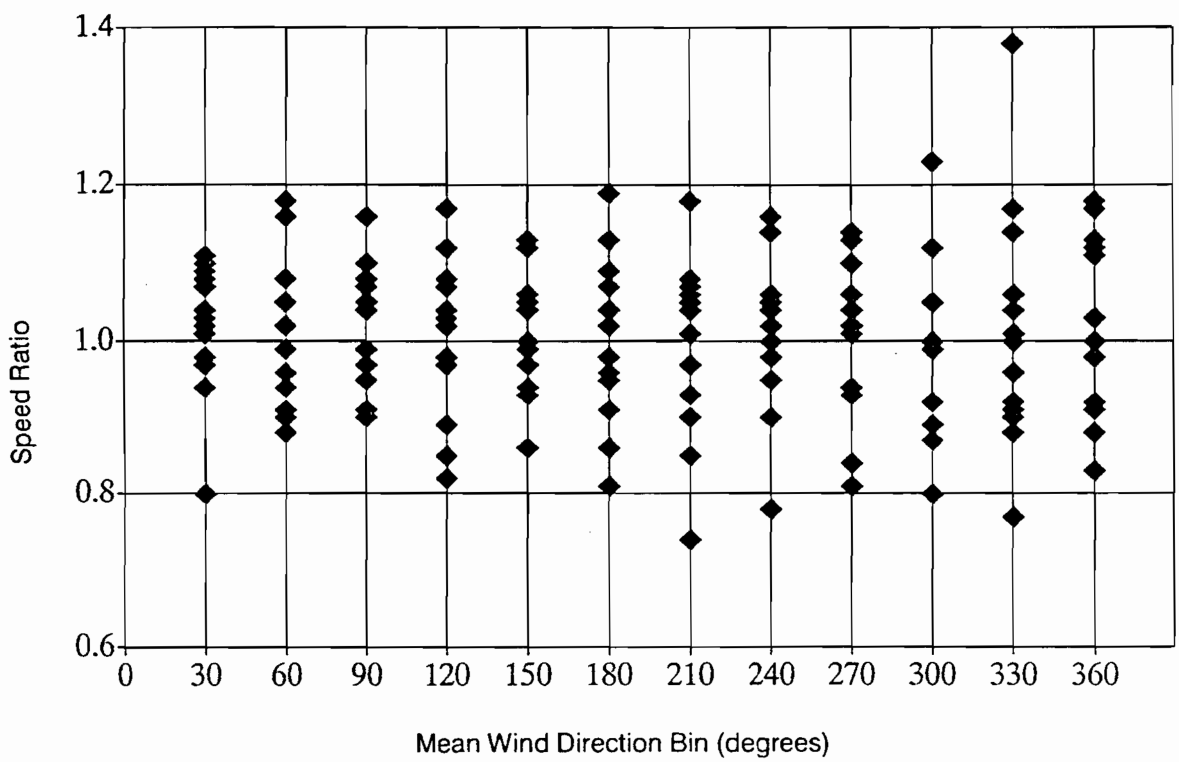

Figure 4–8. Scatter diagram showing distribution of speed ratio values of all 14 FAA LLWAS sensors for each of the 12 mean wind direction bins.

ated by the extreme high speed bias (1.38 ratio) of Station L1. This example lends additional support for choosing less stringent thresholds, particularly for the small sample tests.

4.2.3 Examples of Direction-Independent Non-catastrophic Speed Failures

Two excellent examples of detection of degraded speed-sensing performance that were independent of wind direction were encountered in the 1993 data sample. The first is a straightforward example of low speed readings from Station L7 (see Figure 4-9). The speed at this station was consistently half that of the rest of network, with no apparent dependence on wind direction. FAA personnel investigated the sensor and determined that it had been struck by lightning, verifying sub-standard performance. The other example during 1993 involved Station L2. Speed sensing performance was considered marginal during early June, with speed values approximately 80 percent of the network mean value (Figure 4-10). A sample taken later in the summer indicated that performance had degraded significantly, with typical speed ratio value of approximately 0.65. Once again, FAA personnel investigated and verified the problem, isolating the cause as excessive friction in the speed sensor bearings, a condition that was slowly deteriorating with time.

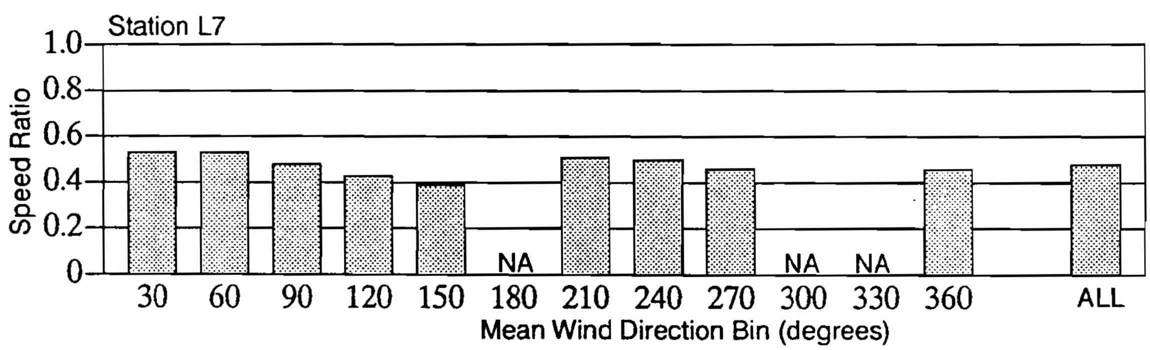

Figure 4-9. Speed ratios for Station L7. Values represent a composite of several samples taken during 1993.

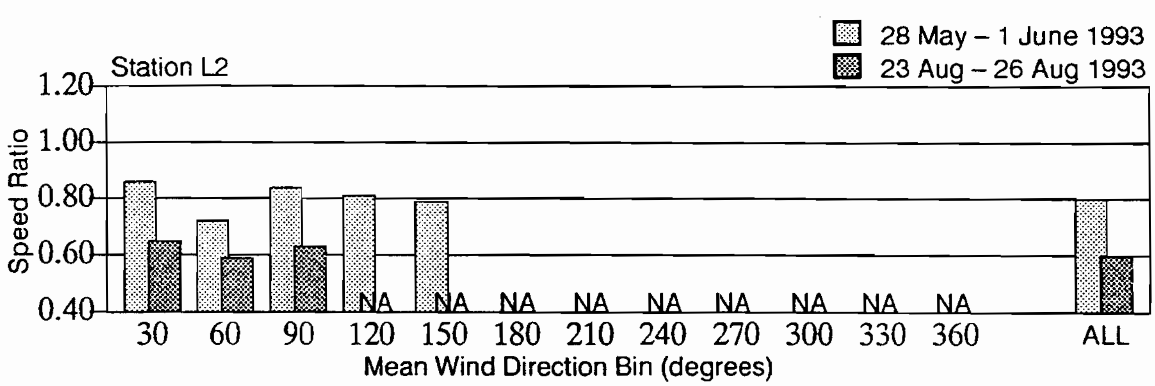

Figure 4-10. Speed ratios for Station L2, showing values corresponding to two separate samples taken during 1993.

4.2.4 Direction Sensing Failures

There were several instances of individual sensors showing evidence of some problems in sensing wind direction. Once again, most of the problems were with the Lincoln mesonet, while the FAA LLWAS sensors were superior in performance. Unfortunately, many of the direction–sensing problems were not diagnosed and were simply corrected by equipment replacement. One good example involving station M2, however, was diagnosed in early June. The daily direction displacement from the mean for Station M2 ranged from 10 to 60 degrees. A plot of the percentage frequency distribution versus direction difference bin for Station M2 on 2 June 1992 is shown in Figure 4–11. The figure also shows the corresponding distribution for all stations in the network combined. On this day, the average direction difference from mean was 27 degrees, well above the acceptable threshold of 15 degrees for a one–day sample. Equally important is the flatter distribution compared to that of the entire network combined. This sensor was found to have a loose direction mounting that was allowing slippage in the wind vane as it turned. The significance of the statistical distribution is noteworthy for this type of failure since it is conceivable that a wind vane could exhibit slippage that results in a near–zero average direction difference from mean, as errors of different sign tend to cancel one another. This same effect may also be evident for a sensor with a sticky direction bearing that causes a lag in response to wind direction changes. These examples identify the need to examine the distribution of direction differences in addition to the average value. The implementation of a new variance test for this purpose is discussed in the next section.

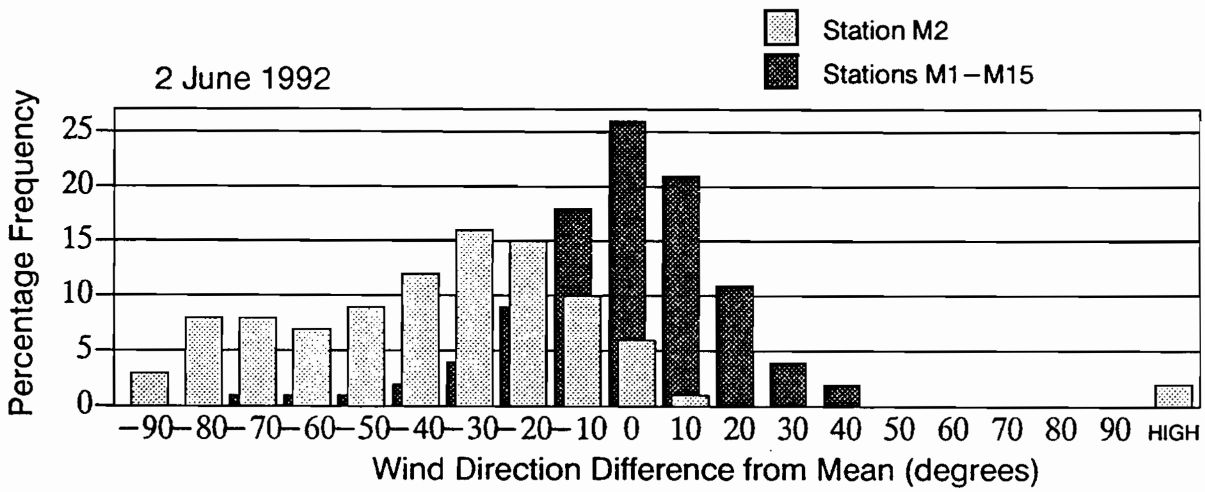

Figure 4–11. Percentage frequency distribution of wind direction differences for Station M2 compared to distribution using all sensors within the mesonet.

5. IMPROVEMENT TO DQA DESIGN

5.1 General

The automated DQA was successful during 1992 in providing a timely (day by day) assessment of anemometer data quality and demonstrated feasibility for automated on–line performance monitoring. When used in conjunction with human review to eliminate overwarning, the method resulted in many identifications of faulty sensors, with no clear evidence of a false alert (though some of the alerts of faulty sensors or inadequate data quality were inconclusive). However, improvement to the DQA design is necessary to eliminate the step of manual intervention in eliminating false alerts of a sensor failure. This section presents several proposed improvements leading toward greater effectiveness both as an off–line analysis tool and for on–line performance monitoring. These recommended improvements are provided as guidelines for further development and refinement of the DQA methodology to be performed at the FAA Technical Center.

Experience indicates the greatest potential improvement to the DQA methodology would be to change the implementation of sampling frequency (and sample sizes) and test thresholds. The DQA algorithm was run once per day during 1992 testing, using a single set of thresholds. Since some malfunctions become apparent in a data sample smaller than one day and others require samples much larger than a single day, the accumulated statistical data base should be varied according to test type. In addition, some tests should be performed for more than one size data sample, using thresholds that vary with sample size. Selecting less stringent thresholds for smaller samples and more stringent thresholds for larger samples would help to eliminate most of the potential false alarming due to expected fluctuations resulting from the daily variation in the meteorological environment. The following paragraphs discuss suggested alterations to the DQA methodology. The improved implementation presented here was used as the baseline in developing the system functional requirements delivered to the FAA.

5.2 Accumulating Data Samples of Varying Size

The accumulation of statistical data for wind speed ratios and wind direction differences should be partitioned into small, medium, and large samples. Regulation of data accumulation and testing frequency should be keyed to a running count of "valid" data polls, i.e., data polls for which the network mean wind speed is above the minimum speed threshold. (Keep in mind that many one–day samples of data consisted of very few "valid" data polls due to light winds). This running count is then used to regulate the accumulation of data in short–, medium–, and long–term counters. Counts for speed ratio and direction difference are initially recorded in short–term counters; after a sufficient number of polls have accumulated, the counts from the short–term counters are added to the medium–term counter. Short–term threshold tests are then performed, after which the short–term counters are re–initialized. The same approach is then used for passing medium–term counters into the long term counters. The overall count of valid polls (polls for which the standard wind speed is above the minimum) thus regulates passing of data from one set of counters to the next, as well as frequency of performance of short–, medium, and long–term threshold tests.

It is envisioned that small–sample tests will require about a half–hour's worth of valid polls (~200), the medium sample tests will require several hours of valid polls (~2000), and the large sample tests will require at least several days of valid polls (~50,000). Since only a fraction of the total polls are of sufficient speed to be considered valid, the actual time to compile this number of valid polls may be considerably longer, e.g., the accumulation of 50,000 valid polls may require weeks of data. In order to improve timeliness for warnings, a sliding window for data analysis and testing should also be considered.

5.3 Sample Size and Thresholds for Specific Malfunction Tests

This section describes suggested data sample sizes and thresholds to be used for each of the various wind speed and direction tests. The thresholds cited here are estimates and may need to be refined (either empirically or theoretically, or both) to ensure proper statistical significance.

Figure 5–1 is a summary of the testing logic and thresholds that represent an improvement of the DQA design using multiple sample sizes and test thresholds. This logic is described in the following paragraphs.

5.3.1 Severe Wind Speed Sensor Malfunction

This test should be done frequently, using the small data sample. The average speed ratio is examined for a very large (>50 percent) deviation from unity. The result is a frequently performed test (several times per day) for a severe failure.

SMALL SAMPLE TESTS (200 VALID DATA POLLS)

IF SPD_RATIO < 0.50, —> Severe electro–mechanical failure of speed sensor
IF |DIR_DIFF| > 30 DEGREES, —> Severe electro–mechanical failure of direction sensor

MEDIUM SAMPLE TESTS (2000 POLLS)

IF SPD_RATIO < 0.70, —> Frictional drag or sensor too low
IF SPD_RATIO > 1.30, —> Sensor height too high
IF DIR_DIFF > 20 deg AND VARIANCE IS LOW —> Direction sensor misoriented
IF DIR_DIFF > 20 deg AND VARIANCE IS HIGH —> Loose mounting or sticky direction bearing
IF DIR_DIFF < 20 deg AND VARIANCE IS HIGH —> Loose mounting or sticky direction bearing

LARGE SAMPLE (50,000 POLLS)

IF |SPD_RATIO(overall) – SPD_RATIO(worst direction)| > 0.15 —> Directional dependence
IF SPD_RATIO(any direction) < 0.80 AND DIRECTION DEPENDENCE —> Sheltering
IF SPD_RATIO < 0.80 AND NO DIRECTION DEPENDENCE —> Frictional drag or sensor too low
IF SPD_RATIO(overall) > 1.20 AND DIRECTION DEPENDENCE —> Wind channeling
IF SPD_RATIO > 1.20 AND NO DIRECTION DEPENDENCE —> Sensor too high
IF DIR_DIFF > 10 deg AND VARIANCE IS HIGH —> Direction sensor misoriented
IF DIR_DIFF > 10 deg AND VARIANCE IS LOW —> Improper electrical grounding
IF DIR_DIFF < 10 deg AND VARIANCE IS HIGH —> Loose mounting or sticky direction bearing

Figure 5–1. Summary of logic associated with use of multiple sample sizes and test thresholds for malfunctioning testing, as proposed for improved DQA design. Actual values of sample sizes and thresholds are estimates.

5.3.2 Speed Bias from Frictional Drag or Improper Sensor Height

FAA Technical Order 6560.21A establishes the criteria that the sheltering at a sensor shall not exceed 20 percent. Based on this criteria, we have adopted the rule that the average speed ratio for a sensor shall not be less than 0.80 or exceed 1.20. This standard, however, assumes a stable estimate of speed ratio for a station. Due to expected day–to–day variability in wind speed ratio estimation, sensors with an acceptable stable (long–term) value of speed ratio may experience some days with an marginally unacceptable average value of speed ratio. This was observed many times during 1992 testing, particularly with the less reliable Lincoln mesonet sensors.

To avoid false alerting of unacceptable speed bias based on a single day sample of data, the best approach appears to be to test for speed bias using both the medium (several hours) and large (several days) samples. For the medium–size sample, the approach is to apply a less stringent standard (say a 30 percent deviation from the standard speed) so that a failed test would imply with reasonably high confidence that a more stable estimate (larger sample) would, in fact, yield a value that is not within the +/– 20 percent acceptable range. This same test would also be done using the large sample data, applying the more stringent 20 percent threshold. The benefit of testing on the medium–sized sample in addition to the large sample is that it allows for a more timely indication of some sensor malfunctions, while still providing some safeguarding against frequent false alarming.

5.3.3 Sheltering from Local Obstruction

The test for directionally dependent sheltering requires a large data sample, so that a reasonable sample of data is available for winds from a wide range of wind directions. During 1992 testing, a 10–day sample of data was analyzed periodically for this purpose. Wind speed ratio distributions were tested separately for each wind direction bin. The logic applied was that if the average wind speed ratio was less than 0.80 (more than 20 percent low) for only a subset of directions, the wind speed problem was interpreted as being directionally dependent.

Although this approach of testing wind speed characteristics separately for different wind directions had some merit, a refinement to the logic is necessary. For instance, if a sensor was showing speeds that were 21 percent low from one direction and 19 percent low from all other directions, that would be interpreted as a sheltering problem. A better approach would be to compare the speed ratio for each direction to the overall speed ratio. Using this logic, a station would be considered sheltered if it was at least 20 percent low for a subset of directions *and* its "worst" direction was significantly lower than the average speed ratio from all directions combined. In the previous example, the data would not suggest sheltering, since the unacceptable wind speed from the single direction wasn't much worse than the "acceptable" speeds from the other directions. A directionally dependent speed bias of 15 percent seems a reasonable value for this purpose, as supported by the empirical example described in 4.2.2. In other words, sheltering would be indicated if a station exhibited at least 20 percent low speed bias for only a subset of directions, *and* the speed ratio corresponding to the worst direction was at least 15 percent lower than the overall (i.e., from all directions) speed ratio.

5.3.4 Severe Direction Sensor Malfunction

As with the test for severe speed sensor malfunction, this test would be done frequently, using the small data sample. The average direction difference would be examined for large (>30 degrees) deviation from unity.

5.3.5 Directional Offset and High Variance of Direction Difference Values (Improper Orientation, Loose Mounting, High Frictional Drag)

As with the tests for speed bias, tests for directional offset should be done on both the medium and large data samples, varying the threshold with sample size. A long–term (i.e., using the large data sample) stable estimate of more than 10 degrees wind direction difference from the standard wind direction would be considered unacceptable. A less stringent threshold of 20 degrees difference would be used for the medium–sized sample.

In addition to testing for directional offset, a test of the distribution of direction difference values is also necessary. This was done during 1992 by examining the cumulative frequencies within certain direction difference bins. In retrospect, it seems more appropriate to compute a mathematical variance of direction difference values and develop an acceptable variance threshold. Directional offset with an acceptable variance would imply an orientation problem, while an offset with an unacceptably high variance would imply a loose mounting or sticky bearings. Even without directional offset, these two latter problems could potentially exist with no directional offset if the variance was unacceptably high.

6. CONCLUSIONS AND RECOMMENDATIONS

During 1991, manual analysis of wind statistics demonstrated the feasibility of using characteristic departures from network mean speed and direction to identify and isolate potential LLWAS sensor malfunctions. A series of logical tests was developed to automate the statistical analysis procedure. Automated data quality analysis software was run off line each day for several months during 1992 using data from both the 14–station enhanced LLWAS network and the 15–station Lincoln mesonet at Orlando, FL; additional LLWAS data was examined during 1993. It was found that the analysis automation was effective in timely identification of severe sensor malfunctions. The method also showed effectiveness in identifying more subtle data quality deficiencies when a sufficiently large data sample was available for analysis. However, assessment of sensor performance from a single day's data was more difficult when data quality appeared marginal, and further manual analysis of the statistical wind data over a larger sampling period was necessary to avoid false indications of a sensor problem. As a result, it became evident that implementation of an on–line system would best be applied using a more conservative alerting approach in order to minimize unnecessary response of maintenance personnel for false alerts. Consistent with this philosophy and based on experience gained during testing, improvements to the DQA method have been suggested. The most fundamental improvement is to implement the method using test thresholds that vary with sample size. The variation in sample size allows timeliness for detection of problems that are evident in a small sample of data as well as providing sufficiently large samples for identifying more subtle problems. Variation of test thresholds with sample size is a reflection of the different level of confidence afforded by different sample sizes, which is of particular importance when the quality of data appears marginal.

The recommendation presented here is that the FAA begin by developing an off–line automated DQA methodology as outlined in this report and perform regular data quality analysis at a central facility for anemometers from remote network sites. Once acceptable thresholds are determined for individual sites and the DQA approach is refined, this methodology should be implemented as an on–line performance monitoring system, with sensor failure messages reported directly to the LLWAS Remote Maintenance Monitoring System display so that more timely corrective action may be taken by on–site personnel.

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APPENDIX

Automated LLWAS Data Quality Analysis
Functional Requirements Document

19 February 1993

1. GENERAL

1.1 Scope

This document establishes the functional requirements for development of an automated Data Quality Analysis (DQA) method for detection of malfunctioning Low Level Windshear Alert System (LLWAS) sensors. The DQA is intended to operate in real time in conjunction with the LLWAS Wind Shear/ Microburst (WSMB) detection algorithms.

1.2 Introduction

The Phase II LLWAS is currently the primary mechanism for detection of hazardous wind shear in the terminal area at more than 100 airports throughout the United States. In addition to wind shear information, it also provides surface observations for the airport centerfield wind and runway threshold winds. It employs a network of six anemometers surrounding the airport terminal area. Over the next several years, a more sophisticated and reliable system (Phase III) will be installed at more than half of the existing sites. The improved system will typically require 12 to 24 sensors per site. By the end of the decade there will be well over 1000 LLWAS senors at airports throughout the country.

The quality of wind data is important for the proper functioning of LLWAS. Filters in the LLWAS algorithms provide protection against occasional spurious wind measurements. However, systematic bias in the wind measurements, which is difficult to detect by manual data inspection, can cause degraded wind shear detection performance either by causing missed detections or by causing false alerts. In addition, LLWAS sensor networks are designed to provide minimal redundant coverage for wind shear detection. Thus, high data quality from *each* sensor in the network is required for proper system performance. In the absence of wind shear, however, there is redundancy in the wind shear measurement by the sensors within the network; this redundancy can be used as a basis for identification of sensors that are not functioning properly. This document describes the requirements of an automated method for detection of degraded sensor performance based on the statistical comparison of the data from each sensor with that from the full network when wind shear is not present over the network.

1.3 Reference Documents

This document references FAA document "Network Expansion (Phase III) Algorithm Specification, Version 1990.02." The LLWAS Algorithm Specification supercedes any conflict with this functional requirements document.

2. DQA DESCRIPTION

2.1 Relationship with LLWAS

The DQA is intended to operate on–line in parallel with the LLWAS Phase III Network Expansion algorithm. As such, it uses the LLWAS data stream for wind data acquisition and may access LLWAS algorithm parameters from the Airport Configuration File (ACF) as well as input/output variable values from LLWAS function modules (Figure 2–1).

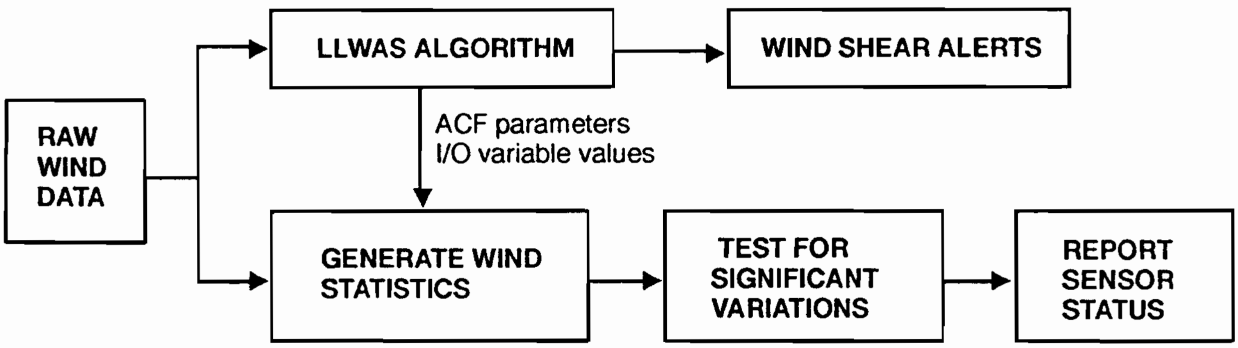

Figure A2–1. Relationship between processing of wind data by LLWAS Algorithm (top row) and automated sensor Data Quality Analysis (bottom row).

2.2 Algorithm Description

The basic approach of the DQA is to detect a systematic departure in the wind data from a single sensor with that from some standard wind, where the standard wind is defined as the mean wind derived from all of the sensors within the local network For each poll of LLWAS data, the ratio of wind speed at each sensor and the standard wind speed is computed. The difference between each sensor's wind direction and the standard direction is also computed. Using these speed–ratios and direction–differences, a statistical data base is compiled for each station. For wind speed–ratio, statistics are maintained separately for various ranges of standard wind direction, since speed sensing problems may be directionally dependent, e.g., due to sheltering from a nearby obstruction. For each station, the statistical information includes the mean and sample standard deviation of speed–ratio and direction difference values.

Depending on sensor design, the basic sensor measurements may include one or more wind speeds (e.g., direct measurement of vector speed versus separate measurements of speed components). Speed statistics must be compiled separately for each type of speed measurement.

Using the statistical information, threshold tests are performed periodically to identify a significant departure from the standard wind. The frequency of testing depends on test type. In all, there are three levels of testing, whereby each level is characterized by the frequency with which the test is performed and the size of the data sample required for the test For example, tests to identify severe differences from the standard wind speed or direction are performed relatively frequently, using a small sample of data and lenient test thresholds. Tests to identify more subtle departures are performed using a large sample of data and more stringent thresholds. Data sample sizes will range from less than an hour for the small sample, several hours for the medium sample, and more than a week for the large sample. Table 2–1 indicates the characteristics of the wind data departures from the standard that are indicative of a sensor problem and the size of the corresponding data sample required to perform a legitimate test.

TABLE A2-1
Wind Data Characteristics Indicative of a Sensor Malfunction

Wind Data Characteristic	Sample required
Extreme high or low wind speeds	small
Speed bias	medium, large
Directional dependence of speed bias	large
Extreme direction offset	small
Extremely high variance of direction–difference values	small
Direction offset	medium, large
High variance of direction–difference values	medium, large

Determination of wind data characteristics from the small–, medium–, and large–sample tests can then be used individually and in conjunction with one another to isolate the characteristics of a sensor malfunction.

3. FUNCTIONAL REQUIREMENTS

This section defines the system functional requirements necessary for proper implementation of the DQA algorithm.

3.1 General

3.1.1 Parameters

The DQA software requires a number of adjustable parameters. DQA adjustable parameters **shall** be included within the LLWAS Airport Configuration File (ACF). The DQA **shall** be able to access all parameters from the local LLWAS ACF. A description of adaptable parameters required by the DQA is shown in Table 3–1.

3.1.2 LLWAS I/O Variables

The DQA **shall** be able to access all LLWAS I/O variable values, as listed for each module within the Network Expansion (Phase III) Algorithm Specification.

3.1.3 Algorithm Initialization

The DQA **shall** be initialized upon initialization or re–initialization of the LLWAS WSMB algorithm.

TABLE A3-1

Description of Adaptable Parameters Required by the DQA Algorithm. Each parameter is Described by a Paragraph Reference to This Document, its Units, the Value Type (fpd=floating point decimal, int=integer), its Default Value, and its Range of Possible Values.

Para	Parameter Description	Units	Type	Default	Range of Values
	DIRECTION BIN PARAMETERS				
3.2.3	Number of standard direction bins	none	int	36	1 to 72
3.2.3	Direction bin initial angle	deg	fpd	10.0*(n−1) [n=1 to 36]	0.0 to 360.0
3.2.3	Direction bin final angle	deg	fpd	10.0*n [n=1 to 36]	0.0 to 360.0
	VALID POLL THRESHOLDS				
3.2.4	Minimum speed threshold for valid poll	m/s	fpd	3.0	0.0 to 10.0
	PARAMETERS FOR TEST FREQUENCY AND SAMPLE SIZE				
3.4.1	Period elapsed between short−term tests	polls	int	200	100 to 1000
3.3.1	Small sample size	polls	int	200	100 to 1000
3.4.1	Period elapsed between medium−term tests	polls	int	2000	100 to 10,000
3.3.1	Medium sample size	polls	int	2000	500 to10,000
3.4.1	Period elapsed between long−term tests	polls	int	50,000	10,000 to 100,000
3.3.1	Large sample size	polls	int	50,000	10,000 to100,000
	THRESHOLDS FOR SHORT−TERM TESTS				
	Sufficient sensor sample	polls	int	150	100 to 1000
3.4.2.1	Low speed−ratio threshold	none	fpd	0.50	0.00 to 9.99
3.4.2.1	High speed−ratio threshold	none	fpd	2.00	0.00 to 9.99
3.4.2.2	Low direction−difference threshold	deg	fpd	−45	−99 to 0
3.4.2.2	High direction−difference threshold	deg	fpd	+45	0 to −99
	THRESHOLDS FOR MEDIUM−TERM TESTS				
	Sufficient sensor sample	polls	int	1000	500 to 10,000
3.4.2.1	Low speed−ratio threshold	none	fpd	0.75	0.00 to 9.99
3.4.2.1	High speed−ratio threshold	none	fpd	1.25	0.00 to 9.99
3.4.2.2	Low direction−difference threshold	deg	fpd	−30.0	−99.0 to 0.0
3.4.2.2	High direction−difference threshold	deg	fpd	+30.0	0.0 to −99.0
3.4.2.3	Direction−diff standard deviation threshold	deg	fpd	15.0	0.0 to 99.0
	THRESHOLDS FOR LONG−TERM TESTS				
	Sufficient sensor sample (per direction bin)	polls	int	1000	1000 to 10,000
3.4.2.1	Low speed threshold	none	fpd	0.80	0.00 to 9.99
3.4.2.1	High speed threshold	none	fpd	1.20	0.00 to 9.99
3.4.2.2	Low direction threshold	deg	fpd	−15.0	−99.0 to 0.0
3.4.2.2	High direction threshold	deg	fpd	+15.0	0.0 to −99.0
3.4.2.3	Direction−diff standard deviation threshold	deg	fpd	15.0	0.0 to 99.0
3.4.2.4	Speed−ratio difference from mean (direction dependency test)	none	fpd	0.10	0.0 to 9.9

3.1.4 Timing Requirements

All DQA processing **shall** be performed within TBD seconds following receipt of each poll of input data.

3.2 Data Preparation / Preprocessing

3.2.1 Input Winds

The DQA **shall** use as input the raw wind values acquired in real–time by LLWAS prior to any data preprocessing within the LLWAS algorithm. The design of the DQA will have some dependency on the basic sensor wind measurement, which is in turn dependent upon sensor design. As such, all speed data processing (speed ratio computations, statistical information processing, threshold testing) referenced throughout this document **shall** be performed on all basic sensor wind speed measurements. If the basic sensor measurement does not include a direct measurement of wind speed, then all speed data processing **shall** also be performed on the values of composite speed as derived from speed component measurements.

3.2.2 Determination of Standard Wind Speed and Direction

For each poll of LLWAS data, the DQA **shall** determine a standard wind speed and direction. The DQA **shall** derive the standard wind as the mean wind speed and direction of all sensors within the local network, using the mean wind component values (U_bar, V_bar) from the LLWAS NETWORK_MEAN function.

3.2.3 Standard Direction Bins

Since wind speed characteristics may be directionally dependent, the statistical information for wind speed must be derived separately for winds from various ranges of mean wind direction. Standard direction bins are defined as ranges of standard wind direction. The range of directions comprising each bin **shall** be adaptable, as described in Table 3–1.

3.2.4 Valid Polls

A valid poll for DQA processing purposes is defined as a poll of LLWAS data for which the standard wind speed is at least some adaptable speed threshold. The DQA **shall** monitor a count of valid polls of data received following DQA algorithm initialization or re–initialization. The count of valid polls **shall** be used to determine the frequency of performance of various threshold tests.

3.2.5 Computing Speed Ratios

For each valid poll of data, for each sensor with valid (not missing or flagged) data, the DQA **shall** compute the ratio of the sensor wind speed and the standard speed.

3.2.6 Computing Direction Differences

For each valid poll of data, for each sensor with valid (not missing or flagged) data whose wind speed is also above the adaptable speed threshold, the DQA **shall** compute the difference in degrees between the sensor wind direction and the standard wind direction.

3.2.7 Suspending Processing During Wind Shear

The DQA **shall** suspend processing of wind data (statistical data accumulation and processing) while evidence of wind shear exists in the airport vicinity. Evidence of wind shear is defined as occurrence of either of the following:

a. Existence of a non–NULL LLWAS alert message for any runway for the current data poll, or

b. Value greater than 1.00 for any of the following output variables from the LLWAS

DIVERGENCE_RATIO function, for the current poll:

Edge_dvrg_ratio(edge)	[edge= 1, NUM_EDGE]
Edge_cvrg_ratio(edge)	[edge= 1, NUM_EDGE]
Tri_dvrg_ratio(tri)	[tri= 1, NUM_TRI]
Tri_cvrg_ratio(tri)	[tri= 1, NUM_TRI]

3.3 Statistical Information

Statistical information describing the speed–ratio and direction–difference values computed for each sensor **shall** be automatically generated on a periodic basis. This statistical information **shall** be used for threshold testing at three different test levels, as described in 3.4.1.

3.3.1 Data Collection

The DQA **shall** collect samples of wind data for each sensor according to three classes. The three classes **shall** be categorized based on adaptable parameters which define sample size and sample update frequency, as described in Table 3–1.

3.3.2 Statistical Information Describing Speed–Ratio

The statistical information describing the speed–ratio values for each sensor **shall** include the following for each of the threes sample sizes:

1. Mean speed–ratio values. The mean speed–ratio **shall** be computed for both:

   a. each standard wind direction bin, i.e., a mean speed–ratio representative of the speed–ratio values that were computed when the standard wind was blowing from the range of directions defined by each bin, and

   b. speed–ratio values computed for winds from any direction, i.e., all direction bins combined.

2. Number of polls for which a speed–ratio value was computed, for each standard wind direction bin, and for all direction bins combined.

3. Sample standard deviation of speed–ratio values, computed separately for each standard wind direction bin, and for all speed–ratio values combined regardless of standard wind direction.

3.3.3 Statistical Information Describing Direction–Difference

The statistical information describing the direction–difference values for each sensor **shall** include the following for each of the three sample sizes:

a. Mean direction–difference value.

b. Number of polls for which a direction–difference value was computed.

c. Sample standard deviation of direction–difference values.

3.4 Performance of Threshold Tests

3.4.1 Test Levels

Threshold testing **shall** occur on three levels: short–, medium–, and long–term testing, where each of the three test levels is defined by the frequency of performance of testing (defined in terms of elapsed valid polls) and the size of the data sample used for testing (measured in valid polls). Frequency of performance and data sample size **shall** be adaptable parameters, as described in Table 3–1. The type of tests performed at each test level **shall** be as listed in Table 3–2.

TABLE A3-2
Types of Tests Performed at Each Test Level

	SHORT TERM	MEDIUM TERM	LONG TERM
SPEED BIAS	X	X	X
DIRECTION OFFSET	X	X	X
DIRECTION–DIFF VARIANCE		X	X
DIRECTION DEPENDENCE			X

3.4.2 Test Types

This section describes the threshold test types to be performed. Performance of each test **shall** provide an indication of the test result as summarized in Table 3–3. Indications resulting from specific tests are described in the following paragraphs.

3.4.2.1 Speed bias

Testing for wind speed bias **shall** be done for all three test levels. For each station with sufficient polls of valid data, the mean speed–ratio value for winds from any direction **shall** be compared with a low threshold value and a high threshold value. The number of sufficient valid polls and the threshold values for each test level **shall** be adaptable parameters as described in Table 3–1. If the mean speed–ratio value is less than the low threshold, an indication of *low speed* **shall** be given. If the mean speed_ratio value is greater than the high threshold, an indication of *high speed* **shall** be given. Otherwise, an indication of *good speed* **shall** be given. For the long–term test level using the large data sample, the mean–speed ratio for each of the standard direction bins with sufficient valid polls **shall** also be compared against the low and high threshold values. A separate speed indication, as described earlier in this paragraph, **shall** be given for each direction bin.

TABLE A3-3
Possible Indications Resulting from Small-, Medium-, and Large-Sample Threshold Tests

TEST TYPE	POSSIBLE INDICATIONS
SMALL SAMPLE TESTS	
SPEED–RATIO	LOW, HIGH, GOOD
DIRECTION–DIFFERENCE	LOW, HIGH, GOOD
MEDIUM SAMPLE TESTS	
SPEED–RATIO	LOW, HIGH, GOOD
DIRECTION–DIFFERENCE	LOW, HIGH, GOOD
DIRECTION–DIFFERENCE STANDARD DEVIATION	HIGH, GOOD
LARGE SAMPLE	
SPEED–RATIO	LOW, HIGH, GOOD
DIRECTION–DIFFERENCE	LOW, HIGH, GOOD
DIRECTION–DIFFERENCE STANDARD DEVIATION	HIGH, GOOD
DIRECTION–DEPENDENCE OF SPEED	YES, NO

3.4.2.2 Direction offset

Testing for wind direction offset **shall** be done for all three test levels. For each station with sufficient polls of valid data, the mean direction–difference value **shall** be compared with a low threshold value and a high threshold value. The number of sufficient valid polls and the threshold values for each test level **shall** be adaptable parameters as described in Table 3–1. If the mean direction–difference value is less than the low threshold, an indication of *low direction* **shall** be given. If the mean direction–difference value is greater than the high threshold, an indication *high direction* **shall** be given. Otherwise, an indication of *good direction* **shall** be given.

3.4.2.3 Large direction–difference standard deviation

Testing for an unacceptably high sample standard deviation of direction–difference values **shall** be done for the medium– and long–term test levels. For each station with sufficient polls of valid data, the sample standard deviation of direction–difference values **shall** be compared to a threshold value. The number of sufficient valid polls and the threshold value for each test level **shall** be adaptable parameters as described in Table 3–1. If the sample standard deviation is greater than the threshold, an indication of *high direction standard deviation* **shall** be given. Otherwise, an indication of *good direction standard deviation* **shall** be given.

3.4.2.4 Directional dependence of speed sensing performance

Testing for directional dependence of speed sensing performance **shall** be done for the long–term test level. The difference between the mean speed–ratio value corresponding to each of the standard direction bins with sufficient valid polls and the mean speed–ratio value for winds from any direction **shall** be computed. The number of sufficient polls per direction bin and the difference threshold **shall** be adaptable parameters as described in Table 3–1. An indication of *direction dependence* **shall** be given if the absolute value of any of these differences is greater than an adaptable threshold. Otherwise, an indication of *no direction dependence* **shall** be given.

3.5 Error Messages

The DQA **shall** use the indications from the threshold tests to provide an error message to the LLWAS maintenance function. The logic for error message generation **shall** be as shown in Table 3–4. The ASCII text associated with each message **shall** be adaptable.

TABLE A3-4

Logic Applied to Test Indications for Generation of Error Messages

TEST INDICATIONS	ERROR MESSAGE
A. SMALL SAMPLE TESTS	
1. Spd–Ratio = LOW	Low speed. Replace sensor
2. Spd–Ratio = HIGH	High speed. Replace sensor.
3. Dir–Difference = LOW	Check sensor orientation. Correct or replace sensor.
4. Dir–Difference = HIGH	Check sensor orientation. Correct or replace sensor.
B. MEDIUM SAMPLE TESTS	
1. Spd–Ratio = LOW, and Dir–Depend (from large–sample test) = NO	Low speed. Replace sensor.
2. Spd–Ratio = LOW, and Dir–Depend (from large–sample test) = YES	Sheltering. Notify FAA authority.
3. Spd–Ratio = HIGH, and Dir–Depend(from large–sample test) = NO	Improper sensor height. Notify FAA authority.
4. Spd–Ratio = HIGH, and Dir–Depend (from large–sample test) = YES	Improper sensor height. Notify FAA authority.
5. Dir–Difference = LOW, and Dir–Diff Standard Deviation = GOOD	Check sensor orientation. Correct or replace sensor.
6. Dir–Difference = HIGH, and Dir–Diff Standard Deviation = GOOD	Check sensor orientation. Correct or replace sensor.
7. Dir–Difference = LOW, and Dir–Diff Standard Deviation = HIGH	Check sensor orientation. Correct or replace sensor.
8. Dir–Difference = HIGH, and Dir–Diff Standard Deviation = HIGH	Check sensor orientation. Correct or replace sensor.
LARGE SAMPLE TESTS	
1. Spd–Ratio = LOW, and Direction Dependence = NO	Low speed. Replace sensor.
2. Spd–Ratio = LOW, and Direction Dependence = YES	Sheltering. Notify FAA authority.
3. Spd–Ratio = HIGH, and Direction Dependence = NO	Improper sensor height. Notify FAA authority.
4. Spd–Ratio = HIGH, and Direction Dependence = YES	Improper sensor height. Notify FAA authority.
5. Dir–Difference = LOW, and Dir–Diff Standard Deviation = GOOD	Check sensor orientation. Correct or replace sensor.
6. Dir–Difference = HIGH, and Dir–Diff Standard Deviation = GOOD	Check sensor orientation. Correct or replace sensor.
7. Dir–Difference = LOW, and Dir–Diff Standard Deviation = HIGH	Check sensor orientation. Correct or replace sensor.
8. Dir–Difference = HIGH, and Dir–Diff Standard Deviation = HIGH	Check sensor orientation. Correct or replace sensor.