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EVALUATION OF THE PULSED ACOUSTIC DOPPLER WIND SHEAR SENSING SYSTEM AT DULLES INTERNATIONAL AIRPORT

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by

Peter V. Versage
Augusto M. Ferrara

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ROBERT L. FAITH
Director, National Aviation Facilities
Experimental Center
Federal Aviation Administration
Department of Transportation

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PURPOSE.

This effort was directed toward the test and evaluation of the dual sensor system to determine if the system could accurately and continuously sense wind speed and wind direction at 30 meters (100 feet) intervals between a range of 30 and 510 meters (100 and 1,500 feet) above ground level (AGL).

BACKGROUND.

The threat presented by low-level wind shear to aircraft during takeoff and landing operations has been emphasized by a number of wind shear-related incidents and accidents that have occurred in the past several years. Aircraft making landing approaches have descended dangerously below their intended glide path resulting in contact with approach lights, hard, short landings, or ground contact short of runway threshold.

The National Transportation Safety Board (NTSB) has established that strong wind shear has been a prime contributory factor in certain aircraft accidents.

The Federal Aviation Administration (FAA) established several concurrent projects to help provide a solution for the wind shear hazard. One of these projects utilizes a dual sensor wind shear sensing system consisting of a pulsed acoustic doppler wind shear sensing system (PADWSS). The PADWSS was developed by the Wave Propagation Lab (WPL) under the sponsorship of the FAA. A pulsed doppler radar wind shear sensing system (PDRWSS), which was an established system, complements the acoustic system when precipitation occurs.

SYSTEM DESCRIPTION.

The system is installed, operating, and is currently collecting data at Dulles International Airport. Figure 1 depicts a perspective view of the dual sensor location with respect to the Dulles terminal and runway areas. The system is installed approximately 1 mile southwest of the west end of runway 12/30 and approximately 3 miles west of runway 1/19. Meteorological records at Dulles indicate that weather fronts consistently approach the airport from

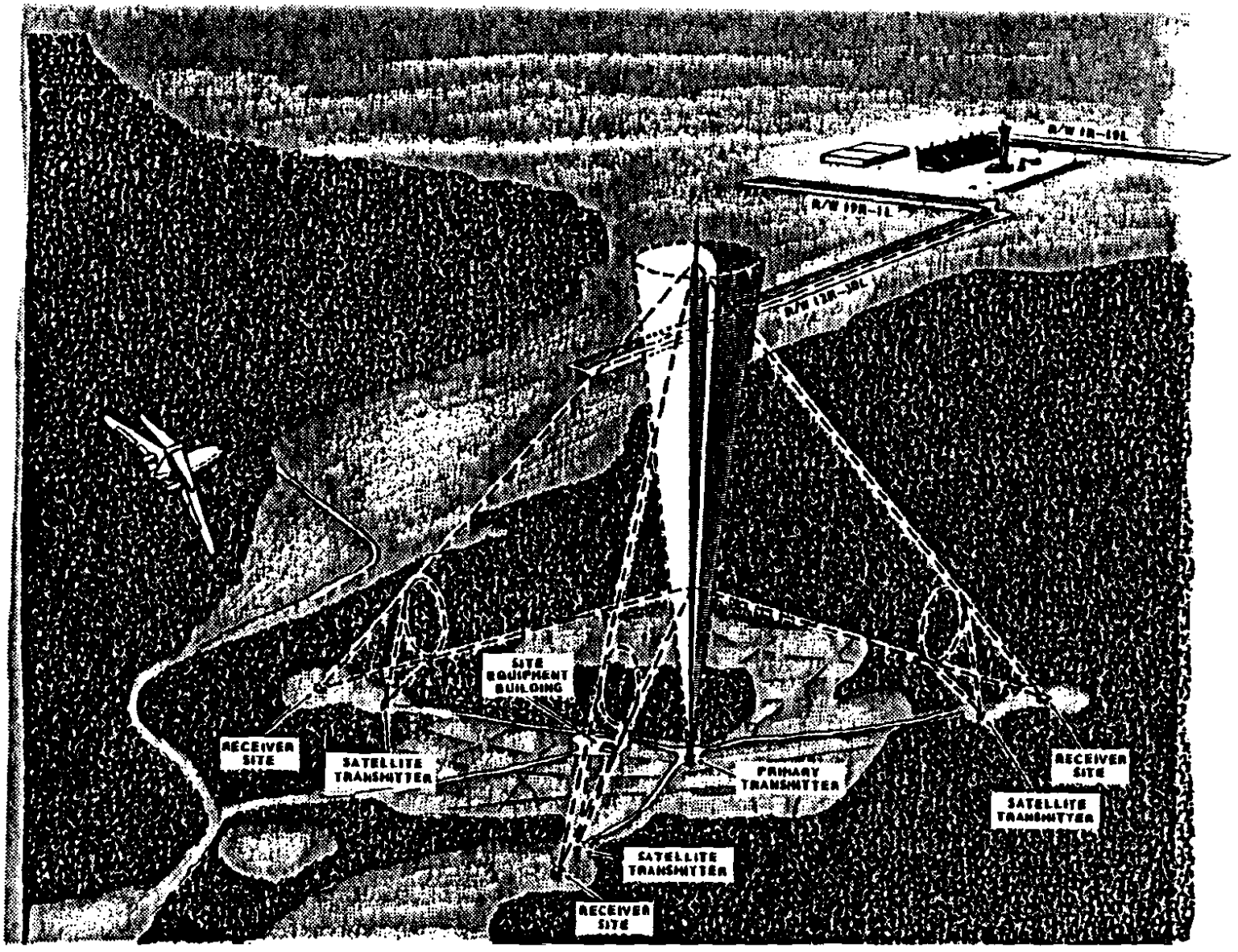

FIGURE 1. SITING CONFIGURATION - DULLES ACOUSTICAL/DOPPLER RADAR EQUIPMENT

the west. Since frontal passages are a cause of synoptic-scale wind shears, it was desirable to locate the system at a point where it would detect such shears before they reached the airport approaches. Another important aspect of the site selection was the desire to minimize background noise. Noise surveys indicated that the site selected had a relatively low-background noise level. Analysis of air traffic patterns also indicated that jet aircraft in the proximity of the site was light.

The system was designed to distinguish wind conditions between heights of 30 to 510 meters (100 to 1,500 feet) above ground level (AGL). The sensor system provides vertical wind shear data associated with synoptic frontal changes and temperature inversions. The system was not designed to sense low-level horizontal wind shear that is normally associated with gust fronts that precede thunderstorm arrival.

The sounder system, shown schematically in figure 2, consists of an acoustic transmitter which is an off-axis parabolic horn antenna with a 12-driver array of manifold transducers. The transmitter emits a 1,250 Hz acoustic tone burst directed vertically upward. Three parabolic dishes placed in separate bunkers, approximately 300 meters (1,000 feet) from the main transmitter on 120° radii, receive the reflected signal after it passes through the acoustically transparent cover of the bunker. The incoming signal is reflected by the parabolic surface and is collected by receive transducers. The receive antenna is electronically steered to seven positions along vertical axes. A smaller satellite transmitter is positioned approximately 50 meters (165 feet) in front of each of the receiver sites. The smaller satellites pulse simultaneously with each primary pulse. The main transmitter provides measurement from 150 to 510 meters (400 to 1,500 feet) height and the satellite transmitters provide wind measurements from 30 to 150 meters (100 to 400 feet).

A NOVA Eclipse minicomputer, computer interface, A/D converter, data storage and display are located in a building adjacent to the main transmitter location.

The primary transmitter projects a pulse vertically upward into the atmosphere every 18 seconds. As the upward traveling pulse

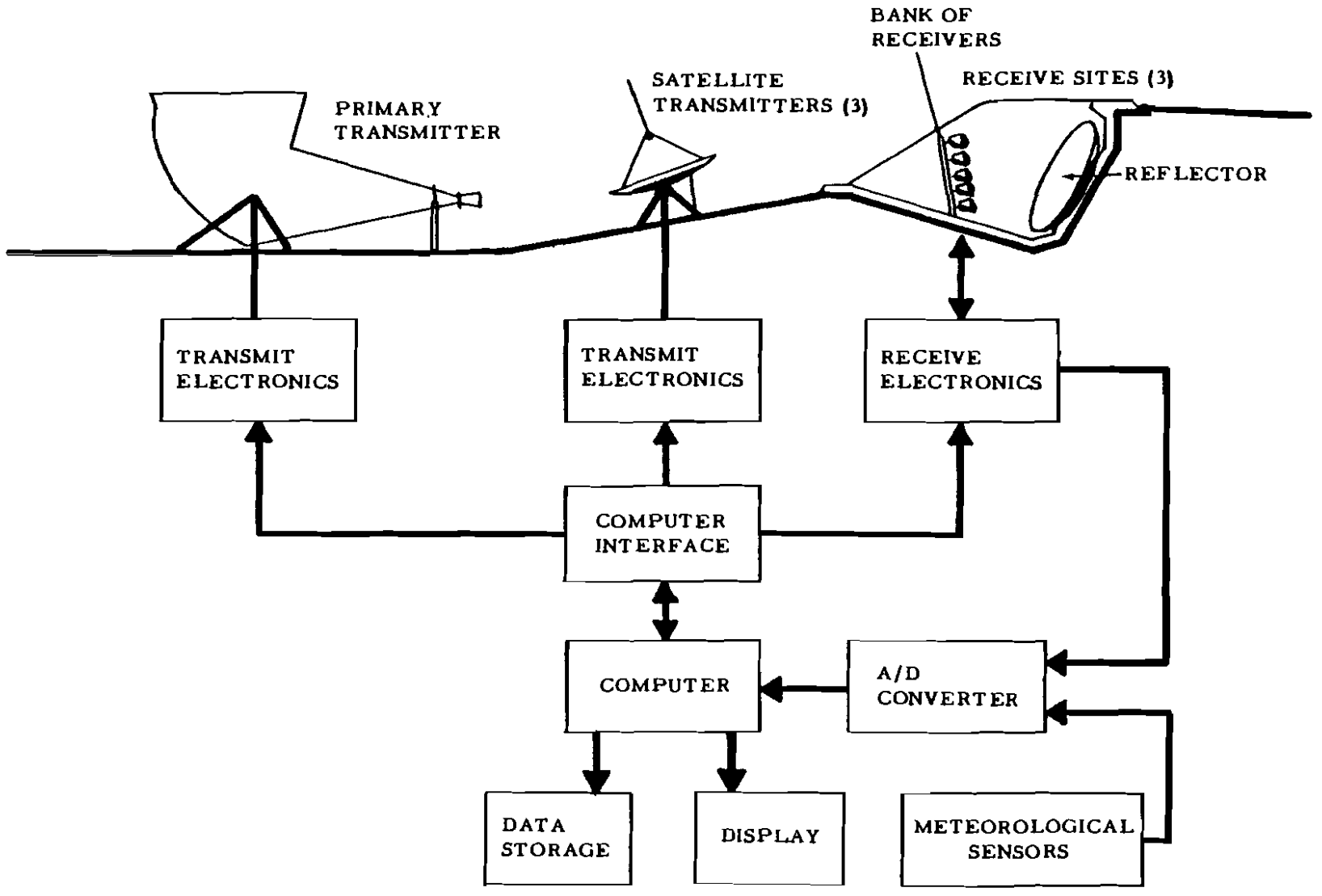

FIGURE 2. BLOCK DIAGRAM - DULLES ACOUSTICAL RADAR EQUIPMENT

passes through the lower atmosphere, a small scattering of sound energy is scattered out of the 9° (inverted cone) beam by wind effect. Some of this scattered energy is collected by the electronically steered seven-beam receiving antenna. The reflected energy from a specific altitude arrives at the receiver after the time required for the sound pulse to traverse the beam, reach altitude, and travel to the receiver. Pulses from the various altitudes are distinguished by the lag time between transmit and receive points. After receipt of signals at the receivers, they are preamplified and conducted by cable to the main processing location adjacent to the transmitter. Further analog processing, such as bandwidth filtering, is followed by digitization and input to the NOVA Eclipse.

The sound scattered by wind energy imparts a frequency change to the soundwave called a doppler shift. A digital hardware fast Fourier transform is used to extract the doppler frequency shift. Additional calculations are used to subtract noise, determine signal-to-noise ratio and evaluate the wind profile, which are displayed on a local graphic terminal and archived on magnetic tape. The shifted frequency of the received signal provides a measure of wind velocity and wind direction which is vectorially determined.

Data from two receivers is required for wind measurement. To determine which receivers are to be used, the noise level of each receiver is measured for each transmitted pulse. Based upon the noise measurements, a pair of receivers is selected by the computer for wind speed calculations.

The transmitter outputs a pulse every 18 seconds, which is close to the maximum update rate of the system. However, to minimize the rapid fluctuations in the measurements (noise), the current implementation averages 20 measurements (a 6-minute period). The information so derived is formatted and transmitted for display. The high sensitivity of the receiver which is necessary for proper operation, also represents a limitation on system capability. High-level ambient noise and overflying by aircraft affect or destroy the required signal to noise characteristics. Intermittent noise due to an aircraft passage is handled by rejection filters in the software.

The sound of heavily falling rain also affects or destroys the signal to noise characteristics of the system; therefore, the pulsed doppler radar is automatically activated during periods of precipitation.

The computer, in addition to determining doppler frequency shift, controlling pulse repetition rate, beam steering for receivers, and performing data manipulation, is programmed to compare the reliability of the acoustic system with the radar system and use the most reliable data. When precipitation is no longer present, the radar system shuts down automatically.

TEST OBJECTIVES.

The test activity was planned in two stages. If the results of Stage 1 proved acceptable, then Stage 2 was to be initiated. The stages are identified as:

Stage 1: Which involved continuously recording the wind speed and direction measured by the PADWSS and comparing that data for corresponding time periods with data accumulated by the following systems:

1. A NAFEC-instrumented aircraft.

2. A boundary layer profiler (BLP) which is a tethered, instrumented balloon.

3. A PDRWSS.

If the results of these data comparisons proved accurate and the PADWSS did, in fact, sample wind conditions that truly represented the wind speed and wind direction for the spatial volume of the air terminal, and if an interim assessment of the system's operability and reliability proved acceptable, then Stage 2 would be initiated.

Stage 2: Was to design, develop, and evaluate a digital display. The display and associated software were to provide wind shear intelligence when predesignated vectorial differences attributable to wind speed and/or wind directional changes, for preselected height ranges, were exceeded. An audio alarm and a flashing display was to depict, for the user, the height range in which the most hazardous wind shear condition existed.

With vested acceptance, it was planned to install the display in the Dulles control tower and have wind shear information relayed to potentially affected aircrews by ground controllers.

This second stage was never implemented.

BRIEF DESCRIPTION OF OTHER SYSTEMS USED FOR COMPARISONS.

NAFEC-Instrumented Aircraft: The aircraft utilizes special transducers, an Inertial Navigation System (INS), and a true airspeed computer to measure meteorological and navigational parameters. Data was recorded on magnetic tape for 5-second averages.

All aircraft runs were performed under VFR with a minimum wind speed of 5 meters per second.

Two types of aircraft runs were performed. They are described as:

1. Flat Runs: When the aircraft flew directly into the wind at a preselected height above the ground from 300 to 1,500 feet, passing directly over the acoustic sounder. The aircraft was essentially sampling the 3- to 7-mile slab of air that the sounder had previously sampled.

2. Glideslope Approaches: This occurred when the aircraft approached, on glideslope, the various runways at Dulles; sometimes sampling the same airmass before or after the acoustic sampling, dependent upon the prevailing wind direction.

Boundary Layer Profiles (BLP): The BLP is a kytoon (tethered balloon) with a suspended instrumentation package that senses altitude, wind speed, wind direction, wet bulb temperature, and dry bulb temperature whose values were telemetered to a receiver on the ground and recorded on a strip chart recorder. The data was later digitized for comparison with the acoustic data for specific time elements.

Pulsed Doppler Radar Wind Shear Sensing System (PDRWSS): The PDRWSS is located immediately adjacent to the PADWSS in the computer building.

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A precipitation sensor, mounted on the roof, automatically activates the radar when the appropriate moisture content, in the atmosphere, is experienced.

The radar provides wind information by measuring the radial velocity of the wind at 100-foot increments, in the height range from 300 to 1,500 feet, in the north, east, south, and west azimuths and combines the sensed measurements into values of wind speed and direction. Data is recorded on magnetic tape, shared with the acoustic system at the same sample and average rates.

SUMMARIZATION AND EVALUATION.

Acoustic Versus Aircraft: Summary, Table 1A, depicts the total number of aircraft runs and data points.

Summary, Table 1B, depicts the results for statistical computations for wind speed. The mean difference in speed for flat runs, in meters/second is -0.67 for flat runs with a standard deviation of 2.63 meters/second. This difference was attributed to a slight error in aircraft instrumentation which was subsequently corrected.

The mean difference in speed, for glideslope approaches, in meters/second is -0.15, a more acceptable value, but with a standard deviation of 2.65 meters/second. The magnitude of these standard deviation values can be attributed to the averaging of aircraft data for 5-second intervals, whereas the acoustic system is averaged over a 6-minute period. Since averaging the data over a long period of time smooths the effect of turbulence, much of the scatter measured may be attributed to the difference in sampling techniques. To demonstrate this point, the aircraft data from run 14 of September 13, 1977, was averaged by hand over a 2-minute period (versus 6 minutes for the acoustic sounder) and the standard deviation of the wind speed fell to less than 1.1 meter/second. Data is not available from the aircraft tapes for the periods prior to each run, therefore, a long-term running average could not be performed for all the comparisons.

Summary, Table 1C, depicts the results for statistical computations for wind direction.

TABLE 1A

AIRCRAFT RUNS AND DATA POINTS

Type Run	Number of Runs	Number of Data Points
Flat Runs	22	1,000
Glideslope Runs	24	950
TOTAL	46	1,950

Table 1A is a summary of aircraft runs made to accumulate data for comparison with the PADWSS.

TABLE 1B

ACOUSTIC SYSTEM VERSUS AIRCRAFT - WIND SPEED

Type Run	Mean Differences In Speed (m/sec)	Standard Deviations In Speed (m/sec)
Flat Runs	-0.67	2.63
Glideslope Runs	-0.15	2.65

Table 1B is a summary of the statistical computations for wind speed. A negative sign for the mean values indicates that the aircraft-sensed wind speeds, on average, were greater than the acoustic system-sensed wind speeds.

TABLE 1C

ACOUSTIC SYSTEM VERSUS AIRCRAFT - WIND DIRECTION

Type Run	Mean Differences In Direction	Corrected Mean Difference in Direction	Standard Deviation In Direction
		(°)	(°)
Flat Runs	-7.2	-0.7	10.4
Glideslope Runs	-7.4	-0.9	20.9

Table 1C is a summary of statistical computations for wind direction. The corrected mean differences reflect compensation for true north used by aircraft instrumentation versus magnetic north used for the acoustic systems. A negative sign indicates that the aircraft-sensed directions, on average, were greater than the acoustic system-sensed directions.

The mean difference in direction between the acoustic sounder and the aircraft was -7.2° for the flat runs and -7.4° for glideslope. Much of this difference is a consequence of the acoustic system using true north and the aircraft using magnetic north. If the difference between true and magnetic north is accounted for (6.5°), the mean differences are less than 1°. The standard deviations of 10.4° for flat runs and 20.9° for glideslope approaches are fairly large and can be attributed to the aircraft averaging over 5 seconds versus 6 minutes for the acoustic system. The standard deviation for glideslope runs was approximately twice as large as flat runs (21° versus 10°), however, this can be attributed to crosswinds encountered on glideslope approaches and the error in direction is a function of the difference between the aircraft heading and the wind direction. (Note that flat runs were headed directly into the prevailing wind.)

Acoustic Versus BLP: Summary, Table 2A, depicts the total hours of comparison time, 26.7, for acoustic versus BLP and the total number of BLP data points.

Summary, Table 2B, depicts the statistical computations for wind speed and wind direction.

The results of the BLP comparisons were similar in pattern to the aircraft comparisons; that is, the mean difference for wind speed was less than 0.1 meter/second and the adjusted direction, after compensation for true and magnetic norths, was 4.6°. The standard deviation for wind speed was 1.2 meters/second and 23.3° for direction. Some of the deviation in direction was probably attributable to the instrumentation package being subjected to swaying, oscillation, and flutter (vibration) when the wind speed approached 10 meters/second (20 knots); in addition, the BLP data was instantaneous with no averaging.

This evaluation was for calibration comparisons. The BLP was always flown in proximity to the sounder, therefore, it sensed wind speed and wind direction immediately above the ground location of the acoustic system.

Acoustic Versus Radar (PDRWSS): Summary, Table 3, depicts the approximate number of hours during which the reliability values,

TABLE 2A

ACOUSTIC SYSTEM VERSUS BOUNDARY LAYER PROFILER

Acoustic Versus BLP Comparison Time (hrs)	Number of BLP Data Points
26.7	6,150

Table 2A is a summary of acoustic versus BLP data collection. All data points represent both wind speed and wind direction.

TABLE 2B

ACOUSTIC SYSTEM VERSUS BLP

	Mean Difference	Standard Deviation
Wind Speed (m/sec)	-0.1	1.2
Wind Direction (°)	-4.6	23.3

Table 2B are the results of the acoustic versus BLP system comparison for both wind speed and direction. The direction is corrected for the difference between true and magnetic north. A minus sign for the mean difference indicates that the BLP values were greater than the acoustic values.

TABLE 3

ACOUSTIC SYSTEM VERSUS RADAR SYSTEM

Breakdown of Comparison	Hours of Comparison	Mean Difference In Speed (m/sec)	Mean Difference In Direction (°)	Standard Deviation In Speed (m/sec)	Standard Deviation In Direction (°)
November/ December 1977 (6-minute averages)	55	1.1	9.0	2.8	61.0
2-Minute Averages on Acoustic	110	0.7	1.6	2.2	29.6
6-Minute Averages on Acoustic	310	1.0	3.5	2.1	33.0
Total Acoustic Versus Radar	475	0.9	6.3	2.2	36.6

Table 3 is a summary of the statistical computations for wind speed and wind direction which are broken down according to observations noted while accumulating data or planned. Both systems referenced true north.

established by the system developer, were high enough to allow a meaningful comparison of the acoustic system (PADWSS) with respect to the radar system (PDRWSS).

When reviewing this acoustic versus PDRWSS data, it became apparent that the data should be categorized for more meaningful evaluation. The breakdown consists of:

November/December 1977 Data (6-Minute Averages) - This breakdown was established when it was noted that large standard deviations applied for that time period. Detailed consideration coupled with on-site experience led to the conclusion that the absence of leaves on the trees in combination with occasional snow cover adversely affected the acoustic system's signal-to-noise ratio. Without the green foliage which absorbs noise, the reverberations were at a higher level. Snow cover also contributed to this ground clutter by reflecting the transmitted pulses. Another factor that contributes significantly to ambient noise is dry leave movement in the bunker areas.

A review of the mean difference in wind speed of 1.1 meter/second and in the wind direction of 9° provides a neutral evaluative response, but the large standard deviations are cause for concern. Based on statistical computations, one could expect the direction output, for the acoustic system, to fall anywhere within plus or minus 122° (standard deviation = 61°) 95 percent of the time and the wind speed to fall within plus or minus 5.6 meters/second (standard deviation = 2.8^{o}) of the true wind speed 95 percent of the time for similarly described environmental conditions.

Two-Minute Averages - In order to increase the system's response to rapidly changing weather conditions (such as thunderstorms), it was decided to change the averaging time from 6 minutes to 2 minutes. The effects of this change were studied during a 2-month period, and it was determined that the averaging change made the system much more sensitive to noise and consequently, lowered the profile reliability. (Please refer to the assessment under the following title of Profile Reliability.)

Referring to summary, Table 3, it can be noted that the mean differences and standard deviations for the 2- and 6-minute

averages, as well as the total data, indicates negligible differences in value; however, the effect that the 2-minute average had on the profile reliability (refer to Profile Reliability section) ruled out any possibility of utilizing the shorter average for aircraft advisement.

Six-Minute Averages - The system normally operates on 6-minute averages. Summary, Table 3, depicts the mean differences and standard deviations for both wind speed and wind direction for the statistical comparisons.

This breakdown presents the most functional data as the system developer (WPL) has indicated that when the averaging time is lowered, the average spectra is increasingly susceptible to perturbation by noise from ground wind and jet aircraft. Our observations confirmed this information.

Total Acoustic Versus Radar - A total of 475 hours of comparative data for the acoustic versus radar was accumulated. This value is a result of the addition of data for November/December 1977, 2-minute averages, and 6-minute averages.

ASSIGNMENT OF SYSTEMS ERROR.

Part of NAFEC responsibility in the evaluation process was to appraise both the accuracy and repeatability of the acoustic system. There was no established standard to use for comparative purposes; that is, neither the radar, BLP, or the aircraft could be considered as a standard, therefore, the rationale for establishing acoustic system values is described under the following headings.

Wind Speed Rationale: The following rationale and computations were utilized.

Acoustic Versus Radar - An assumption was made that both the acoustic system and the radar system equally contributed to the standard deviation of the differences for that time period when 6-minute averages were being recorded (normal operation) since each system was sampling the same wind condition using a different technique.

A review of recorded data led to the conclusion that when the moisture content of the environment was adequate, as reflected

in the profile reliability of the radar system, the radar system was insensitive to changes in the level of magnitude of wind speed; therefore, the radar system error was consistent. Referring to Table 4A, the standard deviation for comparison of acoustic versus radar was 2.1 meters/second which results in an equal assignment of 1.5 meters/second to both the acoustic and radar systems for 6-minute average data.

Using a constant assignment of 1.5 meters/second for the radar system resulted in the following calculated standard deviation values for the acoustic system. They were:

1. Two-Minute Averages : 1.6 meters/second
2. November/December 1977: 2.4 meters/second
3. Total : 1.6 meters/second

Acoustic Versus Aircraft Instrumentation - The calculated standard deviation for wind speed for 6-minute averages for the acoustic system was subsequently used in the formula to determine the standard deviation for wind speed attributable to the aircraft's instrument system, which resulted in a standard deviation of 2 meters/second for the aircraft (reference to Summary, Table 4A). Some of the difference can be attributed to the short averaging time for the aircraft data.

Acoustic Versus BLP - The low-wind speed flight limitation required for BLP use, less than 10 meters/second, resulted in a comparative standard deviation for BLP versus acoustic of 1.2 meters/second (refer to Table 4A). For this comparison, it was assumed the acoustic and BLP system equally contributed to half of the deviation, therefore, the respective deviations are 0.85 meters/second. The reduced deviation at low-wind speed implies that as wind speed increases, so does the uncertainty associated with the acoustic systems measurement of wind speed.

Summary for Wind Speed Rationale - In summary for wind speed rationale, the engineering requirement identified an accuracy of ± 5 knots/second, assuming two standard deviations equates to 2.5 meters/second.

TABLE 4A

CALCULATED STANDARD DEVIATIONS FOR WIND SPEED - METERS/SECOND

Type of Comparison	Standard Deviation of Comparison	Calculated Standard Deviation			
		Acoustic System	Microwave Radar	Instrumented Aircraft	BLP
Radar versus acoustic with 6-minute average	2.1	1.5	1.5	NA	NA
Radar versus acoustic with 2-minute average	2.2	1.6	1.5	NA	NA
Radar versus acoustic November/December 1977	2.8	2.4	1.5	NA	NA
Total radar versus acoustic	2.2	1.6	1.5	NA	NA
Aircraft versus acoustic flat runs	2.6	1.6	NA	2.0	NA
Aircraft versus acoustic glideslopes	2.6	1.6	NA	2.0	NA
BLP versus acoustic	1.2	0.85	NA	NA	0.85

Table 4A calculated standard deviations for wind speed. All values are in meters/second. The values of the standard deviation were calculated and are tabulated above. Refer to the text under Wind Speed Rationale for a description of the assumptions made to compute this table. NA means not applicable for this type comparison.

Per Table 4A, the following is condensed:

	Engineering Requirement
Acoustic (compared with radar, 6-minute average) 1.5 meters/second	2.5 meters/second
Acoustic (compared with radar, 2-minute average) 1.6 meters/second	2.5 meters/second
Acoustic (compared with radar, November/December 1977) 2.4 meters/second	2.5 meters/second
Acoustic (compared with aircraft) 1.6 meters/second	2.5 meters/second
Acoustic (compared with BLP) 0.85 meter/second	2.5 meters/second

Results compare favorably if assumptions for assignment of error are reasonable.

Wind Direction Rationale: Similar rationale and computations were utilized in determining the standard deviations for the wind direction as used in the wind speed rationale.

Acoustic Versus Radar - It was assumed that the acoustic system and the radar system equally contributed to the comparative standard deviation of 33° for 6-minute average data (refer to Table 4B). Applying a formula for distribution of assigned contribution of error resulted in a standard deviation value of 23.3° for both the acoustic and radar systems.

Reference should be made to summary, Table 4B, which depicts 6-minute, 2-minute, and November/December 1977 wind direction values, and particular attention should be given to the standard deviation established for the November/December 1977 time period when the acoustic system was adversely affected by environmental conditions (bare trees and snow cover). The

TABLE 4B

CALCULATED STANDARD DEVIATIONS FOR WIND DIRECTION - DEGREES

Type of Comparison	Standard Deviation of Comparison	Calculated Standard Deviation			
		Acoustic System	Microwave Radar	Instrumented Aircraft	BLP
Radar versus acoustic with 6-minute average	33.0	23.3	23.3	NA	NA
Radar versus acoustic with 2-minute average	29.6	18.3	23.3	NA	NA
Radar versus acoustic November/December 1977	61.0	56.4	23.3	NA	NA
Overall radar versus acoustic	36.6	28.2	23.3	NA	NA
Acoustic versus aircraft flat runs	10.4	10.0	NA	3.0	NA
Acoustic versus aircraft glideslopes	20.9	10.0	NA	18.4	NA
Acoustic versus BLP	23.3	10.0	NA	NA	21.0

Table 4B calculated standard deviations for direction. All values are in degrees. NA means not applicable for this type of comparison. The values tabulated above were computed using the assumptions described in the text under Wind Direction Rationale.

acoustic system's standard deviation for that time period indicates a potential of error equivalent to approximately 113°, strong evidence that the system fails to function accurately in all environments.

Acoustic Versus Aircraft Instrumentation - Allowing for atmospheric conditions and other factors, a 10° standard deviation was assigned to the acoustic system (refer to Table 4B). Utilizing this assumed value for aircraft flat runs resulted in a standard deviation of 3.0° for the aircraft, a reasonable value when the aircraft heads directly into the wind and errors, in measuring direction, are minimized.

For the glideslope approaches, assigning the same 10° standard deviation to the acoustic system, the aircraft was subjected to crosswind influence and a standard deviation of 18.4° resulted.

Acoustic Versus BLP - Based on the standard deviation assigned to the acoustic system of 10°, when compared to the aircraft, and the similiarity in atmospheric conditions for flight days for aircraft and BLP, it was decided to assign 10° of standard deviation to the acoustic system for BLP comparisons.

By a deductive computation, this resulted in the assignment of 21° of standard deviation to the BLP from the comparative standard deviation of 23.3°. This assignment of 21° appears reasonable when one considers the swaying, oscillations, and flutter that the BLP experiences under varying wind conditions (refer to Table 4B).

Summary for Wind Direction Rationale - Meaningful comparisons are summarized for wind direction rationale; the engineering requirement identified an accuracy of $\pm 20°$ which equates to a standard deviation of 10°.

Per Table 4B, the following is condensed for standard deviations:

	Engineering Requirement
Acoustic (compared with radar)	
23.3° (6-minute average)	
56.4° (November/December 1977 conditions)	10.0°
Acoustic (compared with aircraft)	
10.0° (glideslopes)	10.0°
Acoustic (compared with BLP)	
10.0°	10.0°

The results are unfavorable for acoustic when compared to radar, particularly for the November/December 1977 described conditions. This degree of variation would have an adverse affect on display operation. Algorithms were to be developed that would allow the computer to sense vector differences, attributable to change in wind direction and/or wind velocity for values as low as 10 knots between preselected height ranges above ground level.

The large angular deviations would have caused many false alarms or may have allowed a hazardous condition to develop without sensing it because of the exceedingly large element of error.

PROFILE RELIABILITY STUDIES.

As previously indicated, a program was developed to determine the percentage of time when the acoustic systems profile reliability was equal to or exceeded a discrete value of 30, as identified by the system developer. The results of this analysis are tabulated in summary, Table 5A. A review of the table will indicate that when 6-minute averaging was used (normal operating average), data was available 92 percent of the time. This figure diminished to 85 percent when 2-minute averages were used and further diminished to 72 percent during the conditions previously described for November/December 1977.

With reference to Table 5B, it should be noted that a program was used to measure the profile reliability of the acoustic system whenever the ground wind speed exceeded 5 meters/second (10 knots). The profile reliability diminished substantially for all

TABLE 5A

PROFILE RELIABILITY ANALYSIS

Condition Influencing Acoustic Operation	Number of Data Points	Number of Points With Good Reliability	Percent Data Available
Ambient Conditions November/ December 1977	94,486	67,930	71.9
2-Minute Averages of Acoustic Data	189,098	160,833	85.1
6-Minute Averages of Acoustic Data	469,620	429,910	91.5
Overall Acoustic Operation	753,204	658,673	87.4

Table 5A overall profile reliability study results. Time elements for each breakdown for this analysis were as identified in Table 3.

TABLE 5B

PROFILE RELIABILITY ANALYSIS WITH GROUND WIND SPEED IN EXCESS OF 5 METERS/SECOND

Condition Influencing Acoustic Operation	Number of Data Points	Number of Points With Good Reliability	Percent Data Available
Ambient Conditions November/ December 1977	7,830	4,367	55.8
2-Minute Averages on Acoustic Data	10,980	8,298	75.6
6-Minute Averages on Acoustic Data	28,658	22,933	80.0
Overall Acoustic Operation	47,466	33,598	75.0

Table 5B profile reliability analysis when the ground wind speed exceeded 5 meters/second. Time elements for each breakdown for this analysis were as identified in Table 3.

categories. For 6-minute averaging, the reliability changed from 91.5 to 80.0. For 2-minute averages, the reliability changed from 85.1 to 75.6. For the November/December 1977 period, it changed from 71.9 to 55.8.

When the ground wind speed exceeded 10 meters/second (20 knots), the programmed analysis indicated the profile reliability almost invariably failed to exceed the established minimum value of 30, which for practical applications made the data useless. On-site observations substantiated this condition. The data analysis indicated that this condition existed for approximately 2 (two) out of 5,933 hours of total up time.

Additional evaluation indicated that the upper gates failed to meet the minimum profile reliability test regularly when the winds at the 30-meter (100 foot) level exceeded 8 meters/second (16 knots) and when the winds at that same level exceeded 11 meters/second (21 knots), the wind profiles were discontinuous and the wind information for every 30-meter (100 foot) height was not sensed. These conditions were also evidenced through on-site observation of the cathode ray tube display.

In summary, this analysis and observations further substantiate the uselessness of the system for ground traffic controller use.

DOWNTIME SUMMARY.

Refer to summary, Table 6, which has been assembled on the basis of information extracted from a daily log.

One column identifies the cause of downtime by event and in some cases, the events are further defined with subevents. An adjunct column identified the hours attributable to events and subevents, where applicable, and the remaining column identifies the downtime percentage of total hours. Most of the events and subevents are self-explanatory; however, some of them require amplification or clarification such as:

Item 4 - Hardware Problem, FFT: This item was a Fast Fourier transform board. The item was returned to the contractor in California for two independent failures. No spare board was

TABLE 6

DOWNTIME SUMMARY

TOTAL HOURS OF OPERATION: (2/15/77 TO 4/15/78) 10,176

Item	Cause of Downtime	Downtime		% of Total	
1	Tape Changes:				
	Normal	33.5		0.3	
	Aircraft Runs	9.5	43.0	0.1	0.4
2	System Maintenance:				
	Replace Parts	37.0		0.4	
	Pointing Angles	14.0		0.1	
	Electronic Checks	10.5	61.5	0.1	0.6
3	Computer Maintenance:				
	Repairman on Site	40.0		0.4	
	Wait for Parts	215.0	255.0	2.1	2.5
4	Hardware Problem-FFT:				
	Wait for D. G.	116.0		1.4	
	D. G. Repairman on Site	106.5		1.0	
	NAFEC/WPL Working on FFT	92.5		0.9	
	Wait for Parts D. G.	240.0		2.4	
	Wait for FFT	2,688.0		26.4	
	On Line/No Tape	110.0	3,353.0	1.1	33.0
5	"Quick" Look	34.2	34.2	0.3	0.3
6	Install CRT at National Weather Service	13.5	13.5	0.1	0.1
7	Software Changes	39.0	39.0	0.4	0.4
8	Power Outages:				
	Lightning	88.8		0.9	
	Other - Wind and Ice	76.0	164.8	0.7	1.6
9	Miscellaneous Computer Crashes	60.4	60.4	0.7	0.7
10	Miscellaneous	218.7	218.7	2.1	2.1
	TOTAL DOWNTIME		4,243.1		41.7

provided. Each time that the FFT failed, it had to be recycled at least twice per failure to and from the contractor for correction. Obviously, the final assembly test the manufacturer had developed was not adequate. Almost 2,800 hours can be attributed to this failure alone.

Item 5 - "Quick" Look: A routine used for extracting recorded information from magnetic tapes on site. It involves utilization of the system computer.

Item 7 - Software Changes: This item occurred as a result of modifications incorporated per the recommendation of the system developer.

Downtime Comments and Calculations: Both items 5 and 7 would not occur under pure operational conditions. Item 8 should be curtailed or effectively reduced because an uninterruptible power supply, installed in November 1977, provides backup battery power for one-half hour if utility power is interrupted. This will reduce the frequent computer crashes that occurred because of momentary power interruptions.

If adequate spares were provisioned and most of the unneeded events were eliminated, the downtime could substantially be reduced to approximately 727 hours in 10,000 hours or 7.25 percent of total operating time. This estimate is based on limited on-site experience and makes no allowance for system degradation.

A mean time between failures (MTBF) of 178 hours and a mean time to repair (MTTR) of 115 hours were calculated from daily (hourly) logs maintained on site. MTBF equates to about one failure every 7 1/2 days and MTTR equates to about 5 days to repair the system once a failure occurred.

These values can be reduced by provisioning a spare FFT board. If one had been available, the repair could have been implemented in approximately 20 hours. If, in addition, an uninterruptable power supply had been installed prior to the start of evaluation, the MTBF would have been approximately 250 hours. Major redesign would be required to improve upon these values.

A major portion of the failure associated with items 3, 4, and 8 could be attributed to storm activity or power interruptions or failure.

CONCLUSIONS.

A review of the standard deviation tables will reveal that the acoustic system failed, by a wide margin, to meet the standard deviation (repeatability) values for direction, calculated per the engineering requirements.[1]

More importantly, the amount of time that the system validly outputs data is affected by environmental conditions and ground wind speeds as described for the November/December 1977 time period when trees were bare, snow covered the ground, and ground wind speeds exceeded 5 meters/second and valid data output dropped to 56 percent of the time.

The availability of data was even more adversely affected when the output dropped to 0.0 percent for ground wind speeds in excess of 10 meters/second.

Additional analysis revealed that when the wind speed at the 30-meter (100 foot) level exceeded 8 meters/second (16 knots), the upper gates higher above ground level would fail to meet the established profile reliability criteria.

These aforementioned environmental conditions could occur at times when hazardous wind shear conditions exist.

In conclusion, the system cannot be utilized on an operational basis to provide accurate, timely wind shear information to potentially affected aircrews.

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[1]The engineering requirement (FAA ER 450-130B) identified a repeatability of ± 5 knots, $\pm 20^{\circ}$ which transcribes to an acceptable two standard deviation of 2.5 meters/second and 10° for all weather conditions.

RECOMMENDATIONS.

It is recommended that:

1. No additional consideration be provided for utilizing the system on an operational basis.

2. That the system be utilized for correlation activities only.

3. If no correlation activity is imminent, then a plan should be developed for the dismantle and removal of system equipment from the Dulles International Airport test site.

Mr. Peter V. Versage is the NAFEC Project Manager and may be contacted at (609) 641-8200, extension 2678, for further information regarding work involved.

APPENDIX A

NA-78-54-LR

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