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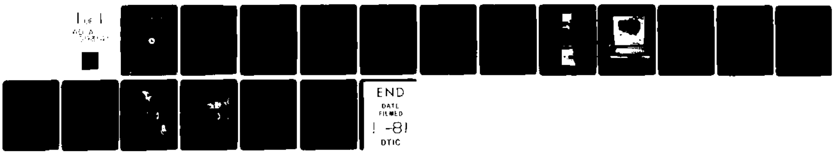

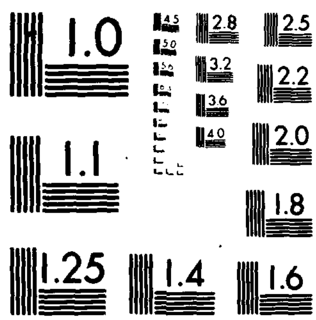

MICROCOPY RESOLUTION TEST CHART

Report No. FAA-RD-80-118
FAA-CT-80-48

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AD A093141

EVALUATION OF AN ANEMOMETER CALIBRATOR FOR THE LOW-LEVEL WIND SHEAR ALERT SYSTEM

Peter V. Versage

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DEPARTMENT OF TRANSPORTATION · UNITED STATES OF AMERICA

FINAL REPORT

OCTOBER 1980

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16. Abstract

This effort was directed toward the evaluation of a Belfort calibration test stand which has been designed and manufactured for calibrating the Belfort type N wind vector transmitters being used at operational airports for the Low-Level Wind Shear Alert System (LLWAS).

This activity was accomplished under FAA Technical Center Document No. 15-414 and identified as Sustaining Engineering Project No. 154-452-820, Task No. 2.

Results indicate that the calibration test stand allows accurate calibration of the wind vector transmitter (anemometer), but some improvement in design is recommended before quantity procurement is considered.

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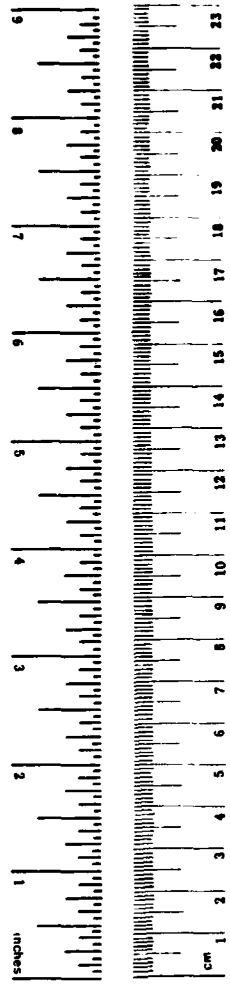
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

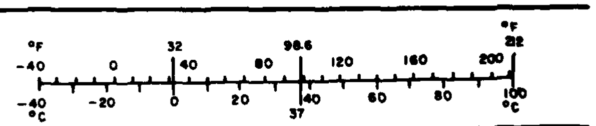
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

PURPOSE.

This effort evaluated the Belfort calibration test stand (Belfort Drawings 16838 and 16979, Instruction Book 17144) to determine if this device could accurately provide for the calibration of the Belfort type N wind vector transmitter and to assess the operational characteristics of this equipment.

BACKGROUND.

Presently, the Belfort wind vector transmitter is being used as the primary sensing device for the Low-Level Wind Shear Alert System (LLWAS) which is being used at many operational airports.

The transmitter (sensor) senses both wind speed and wind direction and converts these two measurements into direct current (d.c.) voltages. One voltage is proportional to the sine of the wind angle with respect to magnetic north, and the other voltage is proportional to the cosine of the same angle. These voltages are referred to as the U and V components of the wind, respectively.

The sensing device is an aerodynamically configured assembly that pivotally responds to wind directional changes and includes an impeller that drives a d.c. generator whose voltage output is directed through slip rings to a potentiometer transducer (sine-cosine pot). The sensor requires no external power for operation.

Anemometer-type sensors are initially validated in a manufacturer's wind tunnel tests where calibrated airflow is translated to sensor output voltage versus impeller shaft revolutions per minute (rpm). Due to the lack of user wind tunnel facilities, it is generally accepted practice for the user to couple a known rpm input device to the anemometer impeller shaft and observe the output voltage(s) to be within a specified tolerance; however, such devices are not on hand or readily available for certification testing. It is anticipated that a valid need will develop for some type of calibration test stand at operational facilities.

The calibration test stand evaluated in this report is the original unit fabricated by the sensor manufacturer after a Federal Aviation Administration (FAA) request for assistance.

In addition, sustaining engineering efforts had recommended installation of an additional sensor site data box at the user locations as part of a spare parts inventory. Installed in a bench test mode (figure 1) this additional data box could be used in conjunction with the Belfort calibration test stand for simultaneously viewing sensor output U and V voltages directly on the LLWAS diagnostic cathode ray tube (CRT) display terminal. The need for an additional and inadequate one-channel meter was, thus, obviated.

Further advantage can be realized from using the calibration test stand in bench test mode for checking suspect printed-wire card assemblies and for validating system software for correct wind shear thresholds, etc.

A concurrent recommendation was made to modify the existing LLWAS operational software to include a keyboard capability for calling up the test bench data box as a seventh station without disrupting the LLWAS operating system. Figure 2 shows a suggested CRT diagnostic display where columns 1 through 7 remain unchanged from present operations, and columns 8 and 9 are added. Format descriptions are listed in appendix A.

EQUIPMENT DESCRIPTION.

The calibration test stand provides accurate shaft rotation from 180 to 1,800 rpms in 10 steps permitting the testing

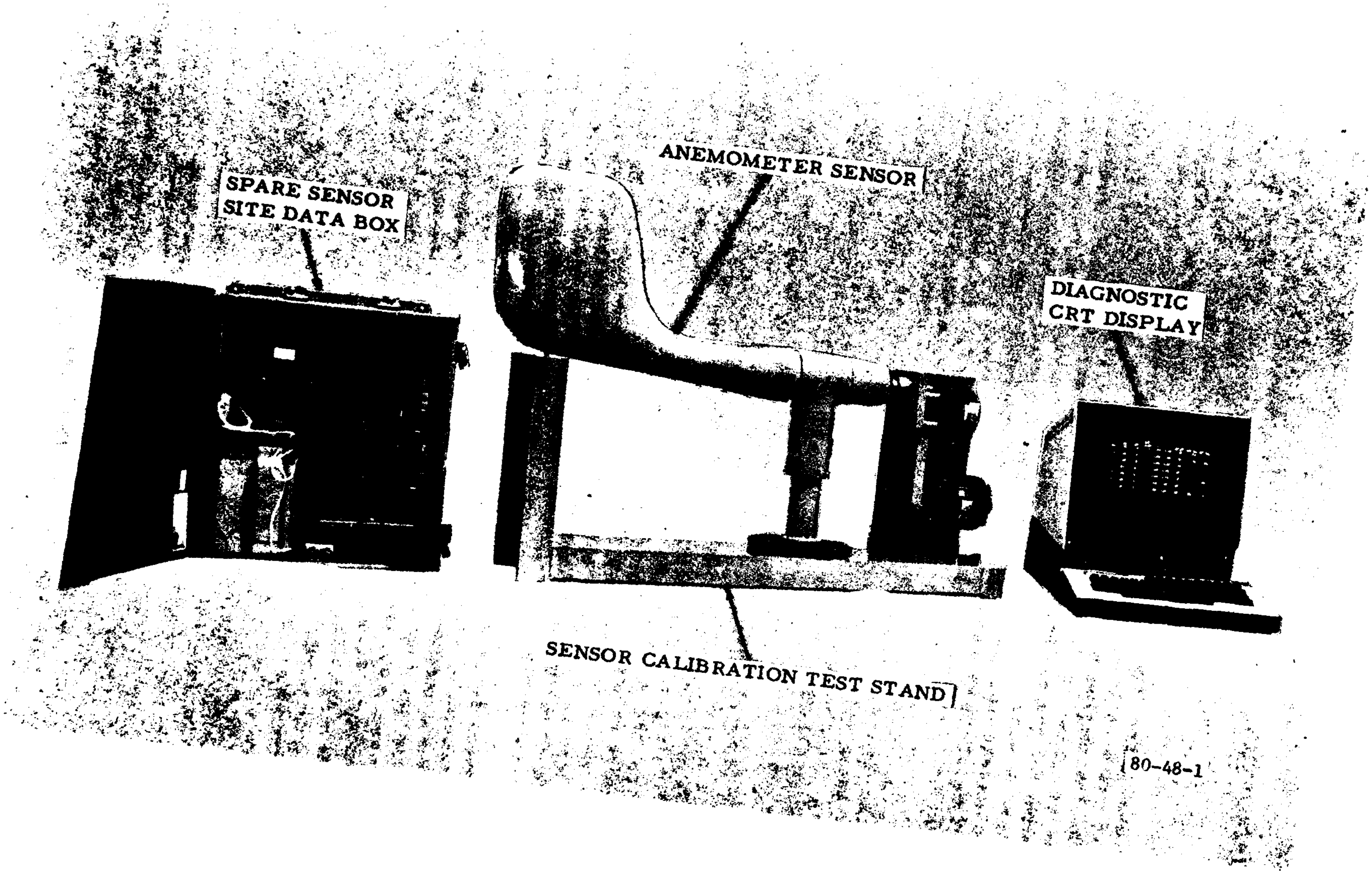

FIGURE 1. LLWAS BENCH TEST CONFIGURATION

FIGURE 2. LLWAS DIAGNOSTIC CRT DISPLAY TERMINAL AND SUGGESTED FORMAT REVISIONS

of the wind vector transmitter. A synchronous motor rotating at 1,800 rpm provides an accuracy of 0.1 percent; a 10-speed gear box provides speed reduction in 10 steps from 1:1 (1,800 rpm) to 1:10 (180 rpm). The selected rpm shaft rotation is transmitted from the speed gear box to a coupling which drives the sensor hub upon which the sensor impeller is normally mounted. The hub is shafted to the d.c. generator. An electrical connector in the base of the sensor provides the voltage output to an external stand connector through test stand cable mounting.

In addition, the calibration test stand provides the capability for measuring the ability of the sensor to accurately measure wind direction. The base of the sensor is mounted on an azimuth plate and keyed so that the 0° reference on the azimuth plate corresponds with the 0 (voltage) positioning of the sensor's sine-cosine potentiometer. While providing a fixed rpm input to the generator shaft, the evaluator can rotate the azimuth plate to any arbitrarily selected angle setting, measure the d.c. sine-cosine voltage outputs for that setting, and compare these recorded values to predetermined voltages established by the sensor manufacturer.

SUPPORT TEST EQUIPMENT.

Evaluation No. 1:

Voltage outputs versus angle settings at 900 rpm.

Fluke 8000A Digital Multimeter

Serial No.: 97666

Calibration Date: 6/19/79

Next Calibration: 6/80

Evaluation No. 2:

Observed versus rpm settings for NO LOAD/LOAD.

Tektronix DC505 Universal

Counter/Timer

Serial No.: 89637

Calibration Date: 5/23/79

Next Calibration: 5/80

DISCUSSION

TEST PROCEDURE.

Two separate sensors (serial numbers 135 and 77-188) were used during each of two data evaluations. The two data evaluations performed were:

1. Voltage Outputs versus Angle Settings.

The speed reducer was positioned for a 1:5 ratio which provided a constant 900 rpm.

The sensor base was mounted, both electrically and mechanically, on the center of the (connector) azimuth plate. The tail assembly was cradled in a V-shaped bracket, and a mating coupling, which is directly driven by the speed reducer, was extended to concentrically fit over the hub of the sensor on which an impeller is normally mounted. The coupling was locked in position. Power was applied to the stand resulting in d.c. output voltages at an external connector. Each run consisted of cycling the azimuth plate through 15° incremental settings from 0° to 360° and then reversing through the incremental settings. Observed voltages were recorded for each incremental setting.

This evaluation compared angle settings with angles calculated with voltage values.

2. RPM Measured versus RPM Setting for NO LOAD and LOAD Conditions.

NO LOAD — This evaluation was performed without a sensor mounted on the azimuth plate. The test stand was cycled through 10 gear settings from 0 to 1800 rpm and then reversed. Measured rpm values were recorded for each gear setting. Four runs were conducted.

LOAD — The sensor was mounted on the azimuth plate, and the same process used under NO LOAD conditions was followed. Four runs were conducted.

This evaluation determined if the rpm measured for each gear setting was affected by a LOAD versus NO LOAD condition.

METHOD OF ANALYSIS.

FOR VOLTAGE OUTPUTS VERSUS ANGLE SETTINGS AT 900 RPM. Table 1 has been established by Belfort and identifies the output volts for sine and cosine for each appropriate angle setting at a generator shaft speed of 900 rpm.

The angular deviation for each incremental angular setting was calculated. The mean and standard deviation of the differences were then calculated (See evaluation results.).

FOR RPM MEASURED VERSUS RPM SETTINGS FOR NO LOAD AND LOAD CONDITIONS.

The rpm value for each gear setting was calculated.

Example: for the 1:8 ratio,

0.8 x 1,800 rpm (synchronous motor speed) = 1,440 rpm

RPM Calculated	RPM Measured
1,440	1,440.02

The differences between the calculated and measured rpm values for each gear setting were established. The mean and standard deviations of the differences were then calculated (See evaluation results.).

The following equations were used to calculate the mean ($\bar{x}$), the standard deviation (σ), and the range ($\bar{x} \pm 2\sigma$) in which 95 percent of data points fall, assuming normal distribution.

$$\text{Mean Difference} = \bar{x} = \sum_{i=1}^{n} \frac{x_i}{n}$$

$$\text{Standard Deviation} = \sigma = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \bar{x})^2}{n-1}}$$

$$\text{Range} = \bar{x} \pm 2\sigma$$

EVALUATION RESULTS.

FOR VOLTAGE OUTPUTS VERSUS ANGLE SETTINGS AT 900 RPM. Table 2 represents a statistical summary for four runs using serial number 135 sensor, two runs using serial number 77-188 sensor, and combined results of the six runs.

The first set of four runs provided a consistent positive bias. The second set of two runs provided a consistent negative bias. It is inferred that the sensors, and not the calibration test stand, were responsible for the different biases. The available manufacturer's error established for the sensor is ±3°.

Using the range equation, $\bar{x} \pm 2\sigma$, and the values for $\bar{x}$ and σ for combined runs we obtain:

$$0.71 + 2(0.26) = 1.23$$

$$0.71 - 2(0.26) = 0.19$$

The range 0.19 to 1.23 represents the degree difference in angle settings that 95 percent of the data points covered,

TABLE 1. POTENTIOMETER OUTPUTS*

Wind Angle (Degrees)	Sine (U) Output Volts (D.C.)	Cosine (V) Output Volts (D.C.)
0(N)**	0.00	2.59
15	0.67	2.50
30	1.30	2.25
45	1.83	1.83
60	2.25	1.30
75	2.50	0.67
90	2.59	0.00
105	2.50	-0.67
120	2.25	-1.30
135	1.83	-1.83
150	1.30	-2.25
165	0.67	-2.50
180	0.00	-2.59
195	-0.67	-2.50
210	-1.30	-2.25
225	-1.83	-1.83
240	-2.25	-1.30
255	-2.50	-0.67
270	-2.59	0.00
285	-2.50	0.67
300	-2.25	1.30
315	-1.83	1.83
330	-1.30	2.25
345	-0.67	2.50

* Generator shaft speed = 900 rpm = 5.18 Vdc potentiometer input.

**(N) Designates north. Each of four runs provided sine and cosine output volts for each 15° incremental angle setting as identified in the angle (degrees) column. These voltage values for the four runs were averaged for each angle setting and used to calculate the angle obtained (from voltage readings) for comparison with the azimuth plate setting.

Example: For 30° Azimuth Plate Setting

Run No.	U-Volts	V-Volts
Run 1	1.37	2.23
Run 2	1.38	2.22
Run 3	1.37	2.24
Run 4	1.37	2.18
Sum	5.49	8.87

Average $\bar{u} = 1.3725$ $\bar{v} = 2.2175$

$$\tan^{-1}\frac{\bar{u}}{\bar{v}} = 31.755^\circ$$

This provides a deviation of 1.755° from the established 30° angle.

TABLE 2. DIFFERENCE IN ANGLE SETTINGS (DEGREES)

Runs	Mean ($\bar{x}$)	Standard Deviation (σ)
4 Runs	+1.16	0.35
2 Runs	-0.01	0.61
Combined Runs (4 + 2)	+0.71	0.26

NOTE: + indicates value greater than azimuth plate
- indicates value smaller than azimuth plate

assuming normal distribution. This range is acceptable. The manufacturer's sensor tolerance is ±3°.

<u>FOR RPM MEASURED VERSUS RPM GEAR SETTINGS FOR NO LOAD AND LOAD CONDITIONS</u>. The following mean and standard deviations of the differences between the gear settings and measured rpm values were calculated. (See table 3.)

The manufacturer's established accuracy for the wind vector transmitter is ±0.1 percent full scale (1,800 rpm). The largest differences noted in data occurred in the 900 to 1,200 rpm range with 0.35 to 0.24 rpm differences recorded. Using the largest value of difference, 0.35, and dividing by the speed setting of 900 rpm results in a variation of 0.04 percent, considerably better than the manufacturer's specified accuracy.

Utilizing the range equation, $\bar{x} \pm 2\sigma$, and the $\bar{x}$ and σ values of the combined LOAD and NO LOAD,

$$0.099 + 2(0.011) = 0.121$$

$$0.099 - 2(0.011) = 0.077.$$

The range 0.077 to 0.121 represents the rpm difference within which 95 percent of the data points fall, assuming normal distribution, considerably better than the manufacturer's specification tolerance for the synchronous speed of 1,800 rpm (+1.8 to -1.8 rpm).

TABLE 3. RPM DIFFERENCES

Condition	Mean ($\bar{x}$)	Standard Deviation (σ)
NO LOAD (80 Data Points)	0.119	0.099
LOAD (80 Data Points)	0.078	0.012
Combined LOAD and NO LOAD	0.099	0.011

OPERATIONAL EVALUATION AND DESIGN RECOMMENDATIONS.

Problem 1: As seen in figure 3, the coupling (item A) is locked to the speed reducer drive shaft with two allen set screws. The operation instructions call for positioning this coupling over the hub of the anemometer and locking the allen set screws. The anemometer is then supported at two points: at the coupling (item A) and the tail support (item B). The flange-to-azimuth plate (item C) mating is a sloppy fit. This two-point horizontal support provides considerable vibration, and the only means of reducing it is to shim under the flange with approximately 0.090- to 0.100-inch wedge material in line with the longitudinal axis of the sensor. As the azimuth plate is rotated, vibration once more develops as the location of the wedge material approaches the transverse axis of the sensor. This problem requires repositioning the wedge in line with the longitudinal axis in order to continue with diminished vibration.

Recommendation 1: To eliminate the two-point horizontal suspension, use a flexible type of soft material coupling at point A (hose configuration) and allow flange of sensor to firmly sit on azimuth plate. With reduced vibration, it would be feasible to reduce the structural size of the frame and reduce cost.

Problem 2: The tail support at point B in figure 3 is vertically adjustable and provides a metal-to-plastic contact. The sensor surfaces (plastic) are scratched in that area of contact, and the present configuration of the V-notched support plate interferes with the installation of the sensor because it projects above the structural channel.

Recommendation 2: Coat the metal surface of the V-notched plate with a hard plastic finish and reconfigure the V-notched plate so it can be dropped below the upper surface of the channel during sensor installation. Wing nuts and captive screws would simplify adjustments.

Problem 3: An additional connector for the type L anemometer is installed on the stand (figure 4).

Recommendation 3: This additional connector is not required for LLWAS sensors. Eliminate for cost reduction.

Problem 4: The overall cost for operational procurement is high.

Recommendation 4: Consideration should be given to the selection of components that would provide three points of calibration rather than 10 points, which are excessive.

Problem 5: Sustaining engineering has advised the use of the additional sensor data box at user locations in conjuction with the calibration test stand. Installed in the bench test mode (figure 1) it would support maintenance evaluation. It is necessary to observe the sensor output U and V voltages simultaneously at the test stand and the CRT display for comparison. The present electrical configuration does not accommodate this condition.

Recommendation 5: Retain the type N connector outlet as furnished. Delete the presently supplied signal cable. Each user location shall furnish its own cable because of the varying dimensional test equipment layouts. Incorporate into the test stand assembly female banana plug outlets for measuring the same U and V voltages which are supplied to the pins of the type N connector.

CONCLUSIONS

1. The calibration test stand is an accurate device for calibrating the Belfort type N wind transmitter.

2. The physical operating characteristics of the device are not acceptable.

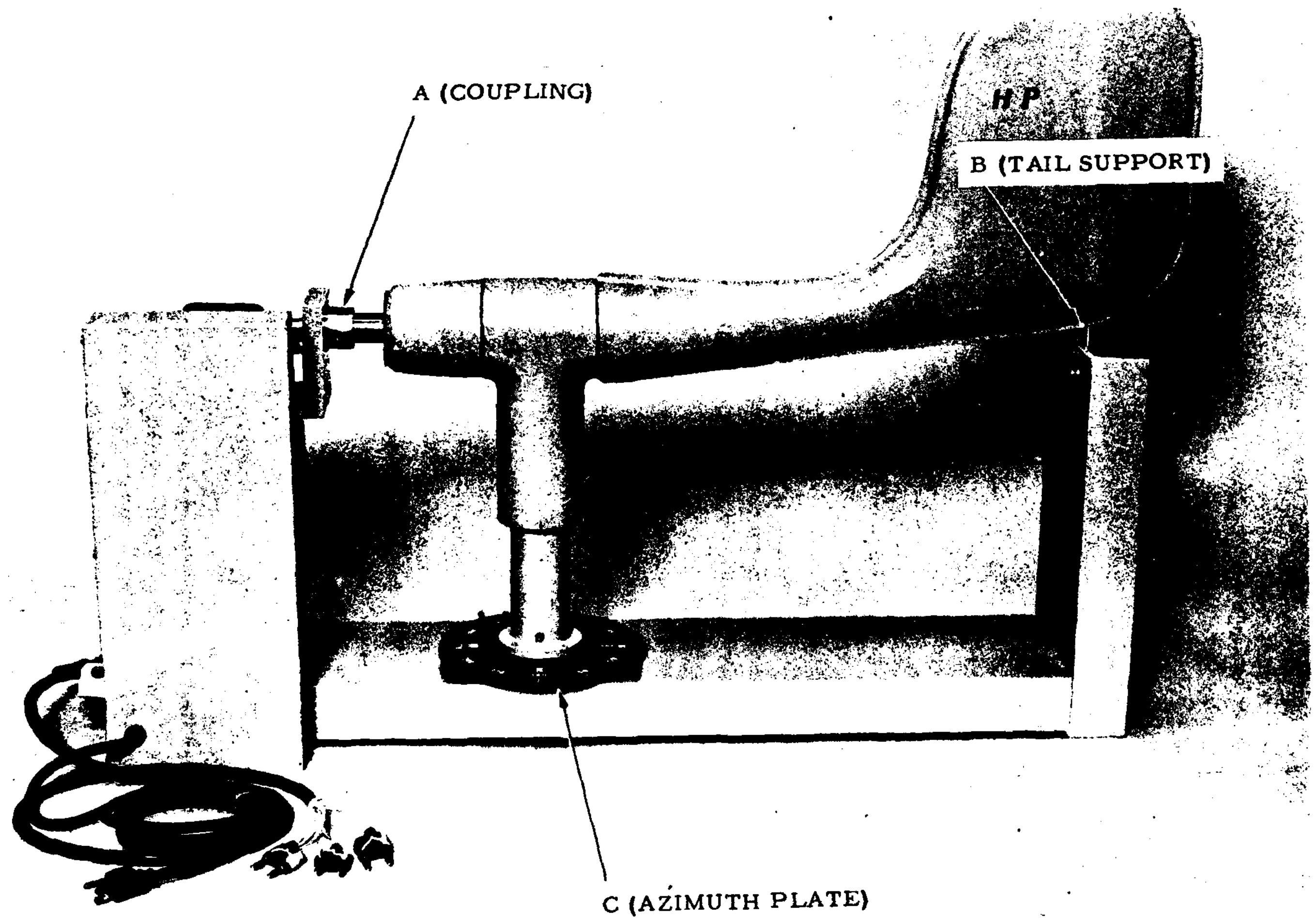

FIGURE 3. CALIBRATION TEST STAND (REAR VIEW)

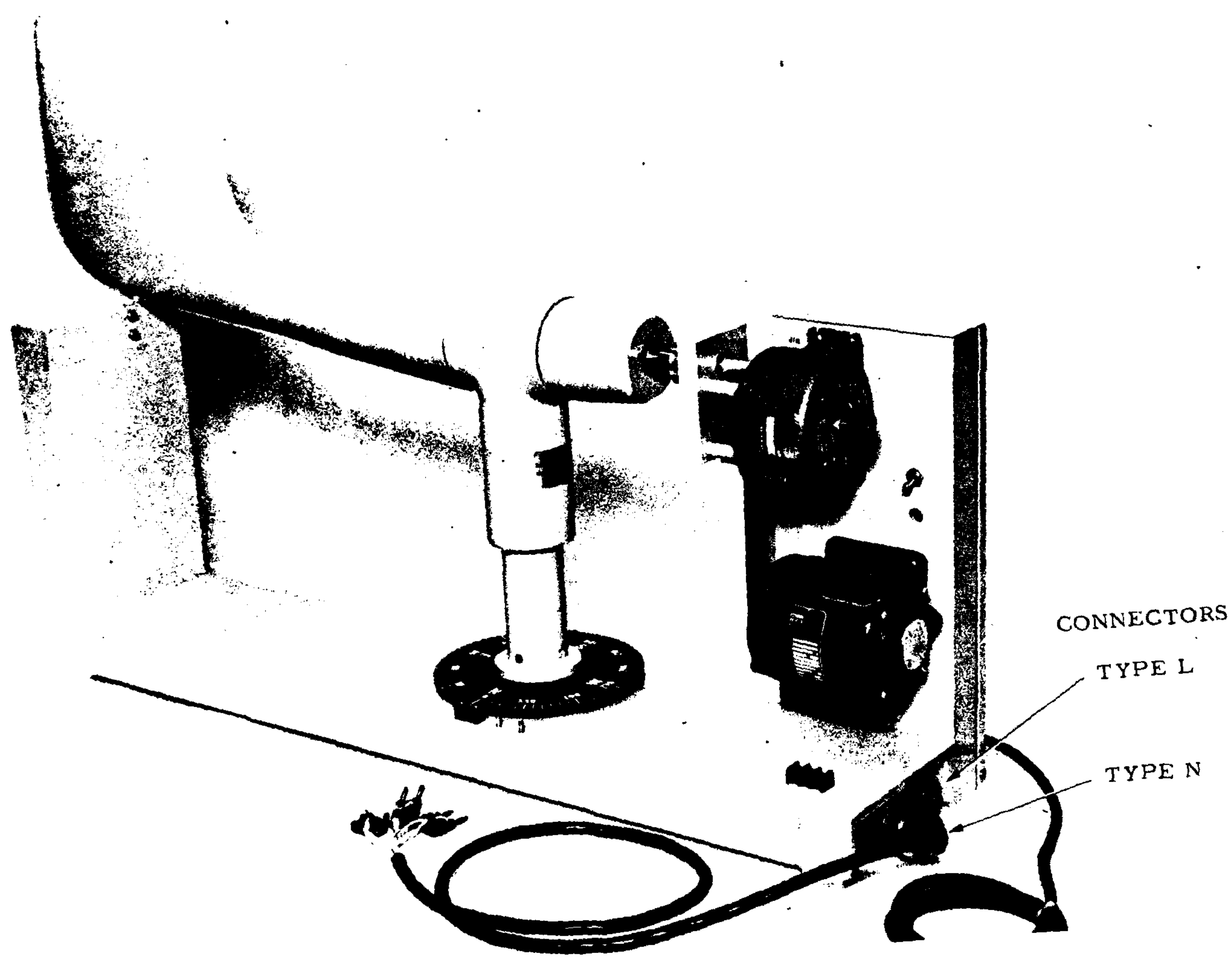

FIGURE 4. CALIBRATION TEST STAND (FRONT VIEW)

3. The unit cost is excessive for multiple procurement.

RECOMMENDATIONS

1. An immediate need exists to satisfy certification requirements at individual Airways Facilities Sector Field Offices (AFSFO's). Because of the aforementioned design deficiencies, only a minimum "as is" procurement is recommended for controlled use at the regional level.

2. The design recommendations identified in the previous section should be incorporated into a bid specification before quantity procurement activity is initiated for individual AFSFO use.

APPENDIX A

FORMAT IDENTIFICATION FOR AN IMPROVED LLWAS CRT DIAGNOSTIC DISPLAY

COLUMN 1 Remote site address. Note that the test bench station, designated as site address 7, is in use.

COLUMN 2 DIR; wind direction in degrees magnetic.

COLUMN 3 SPD; wind speed in knots.

COLUMN 4 GUST/ALARM; peak gust value in knots for the center field anemometer and wind shear alarm status (* = yes, blank = none) for sites 2 to 7.

COLUMN 5 U; sensor sine pot output voltage.

COLUMN 6 V; sensor cosine pot output voltage.

COLUMN 7 COM EFF; communication efficiency as a percentage of successful telemetry interrogations per past 100 attempts.

COLUMN 8 HARD FAIL; an accumulated total of successive telemetry interrogation failures which resulted in loss of data to the tower cab displays.

COLUMN 9 SOFT FAIL; an accumulated total of random telemetry interrogation failures not resulting in loss of data to the tower cab displays.