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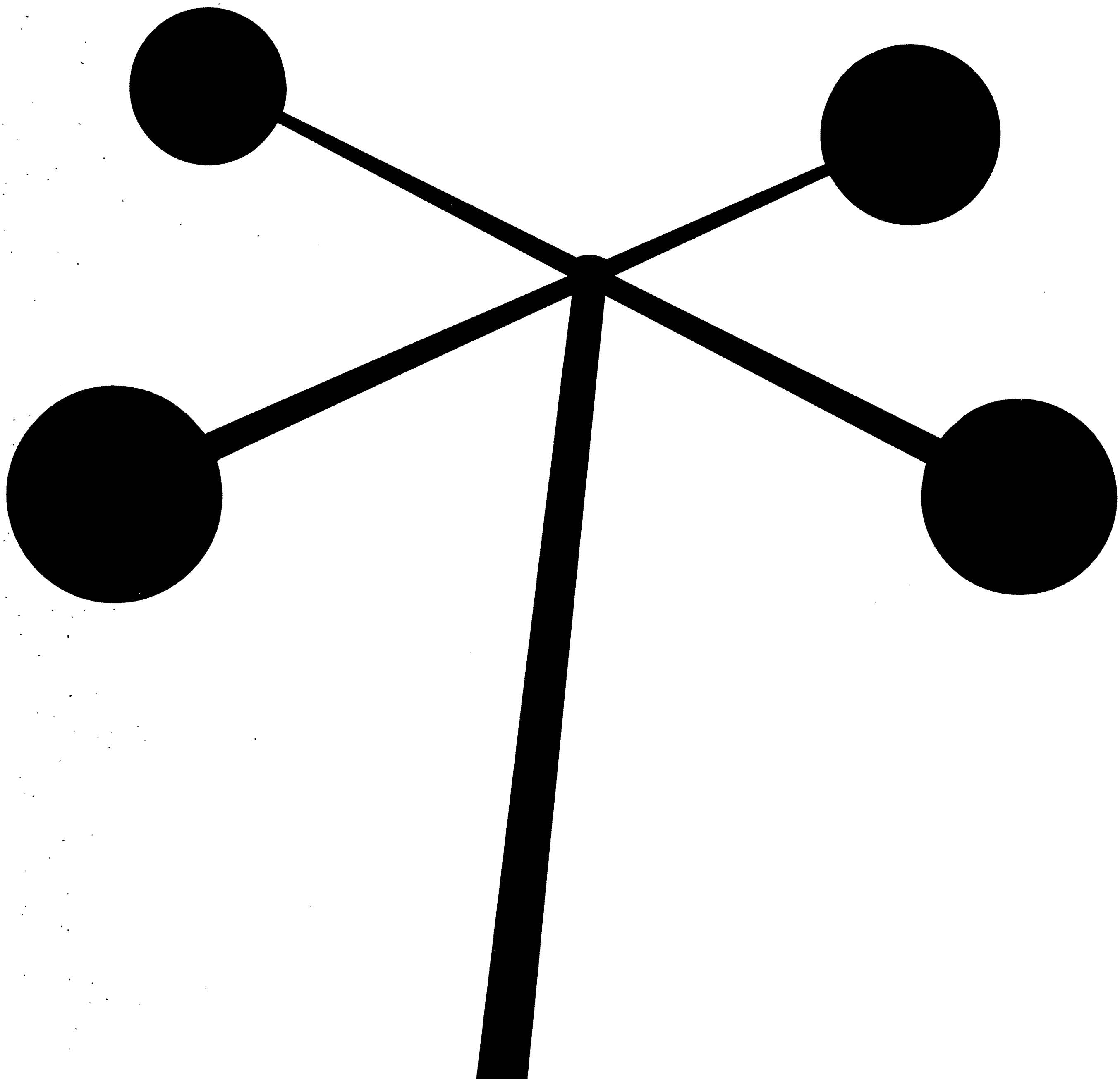

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ANEMOMETER PERFORMANCE AT FIRE-WEATHER STATIONS

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Wind speed measurements are critical when computing wildland fire-danger rating and predicting fire-behavior. A sensitivity analysis of the Rothermel (1972) rate-of-spread model showed that in a category of 11 variables, wind speed ranked first (Sanderlin and Sunderson 1975). For grass fuel models, an 18 percent wind speed error over the range 6 to 13 m/s results in a 40 percent error in predicted rate of spread (Kessell *et al.* 1977).

Unfortunately, fire-weather forecasters and fire-behavior specialists have no way of determining the accuracy of wind speed observations at fire-weather stations. A survey in the Northeastern United States indicated that field maintenance of anemometers ranged from fair to good, but that testing of the instruments was virtually nonexistent (Frost and Haines 1982). Because wind speed measurements significantly affect fire-behavior predictions and fire-danger ratings, we developed a portable instrument to test field anemometers (Haines *et al.* 1980). Since then we have checked the performance of anemometers at fire-weather stations throughout the Northeastern United States. This is a report of our findings.

METHODS

Approximately 250 forestry stations in the 21-State, Northeastern Region make fire-weather observations. The USDA Forest Service North Central Forest Experiment Station, the National Forest System, and Northeastern Area State and Private Forestry cooperate in a station inspection and a National Fire-Danger Rating System implementation program. As part of this program, a meteorological technician visits most of these stations on a 2-year rotating basis. The data for this paper were collected between January 1979 and January 1982 during these inspection visits and include detailed reports of 142 anemometers.

The following are the types of anemometers most often used at fire-weather stations in the Northeast:

Model[1]	Percent of use
M. C. Stewart aluminum-cup	55
Forester 9 x 145	25
Small Airways Model	16
Natural Power Model A75-104	4

We purchased three M. C. Stewart, two Forester 9 ×145, and one each of the other two anemometers (fig. 1), and calibrated them in wind tunnels.[2] The wind tunnel response of all three M. C. Stewart anemometers was essentially the same, therefore, we will show the error and calibration curves for just one of these units (figs. 2 and 3)[3] . The two Forester 9 ×145 units displayed differences in initial wind tunnel tests, therefore, we had them retested. The air flow accelerated near this anemometer due to its large size relative to the cross-sectional areas of the wind tunnels. Calculations showed that the tunnel speed in the vicinity of this anemometer was 1.04 times the speed measured by a pitot static tube, consequently, the reported data were corrected using this ratio.

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[1]*Mention of trade names does not constitute endorsement of the product by the USDA Forest Service.*

[2]*Anemometers were calibrated by: Hassan M. Nagib, Armour College of Engineering, Illinois Institute of Technology, Chicago, IL; Robert C. Nelson, Department of Aerospace and Mechnical Engineering, University of Notre Dame, Notre Dame, IN.*

[3]*Operational results are given in miles per hour and meters per second. Metric units satisfy requirements specified in the International Systems of Units; but fire-weather observers report their observations in miles per hour.*

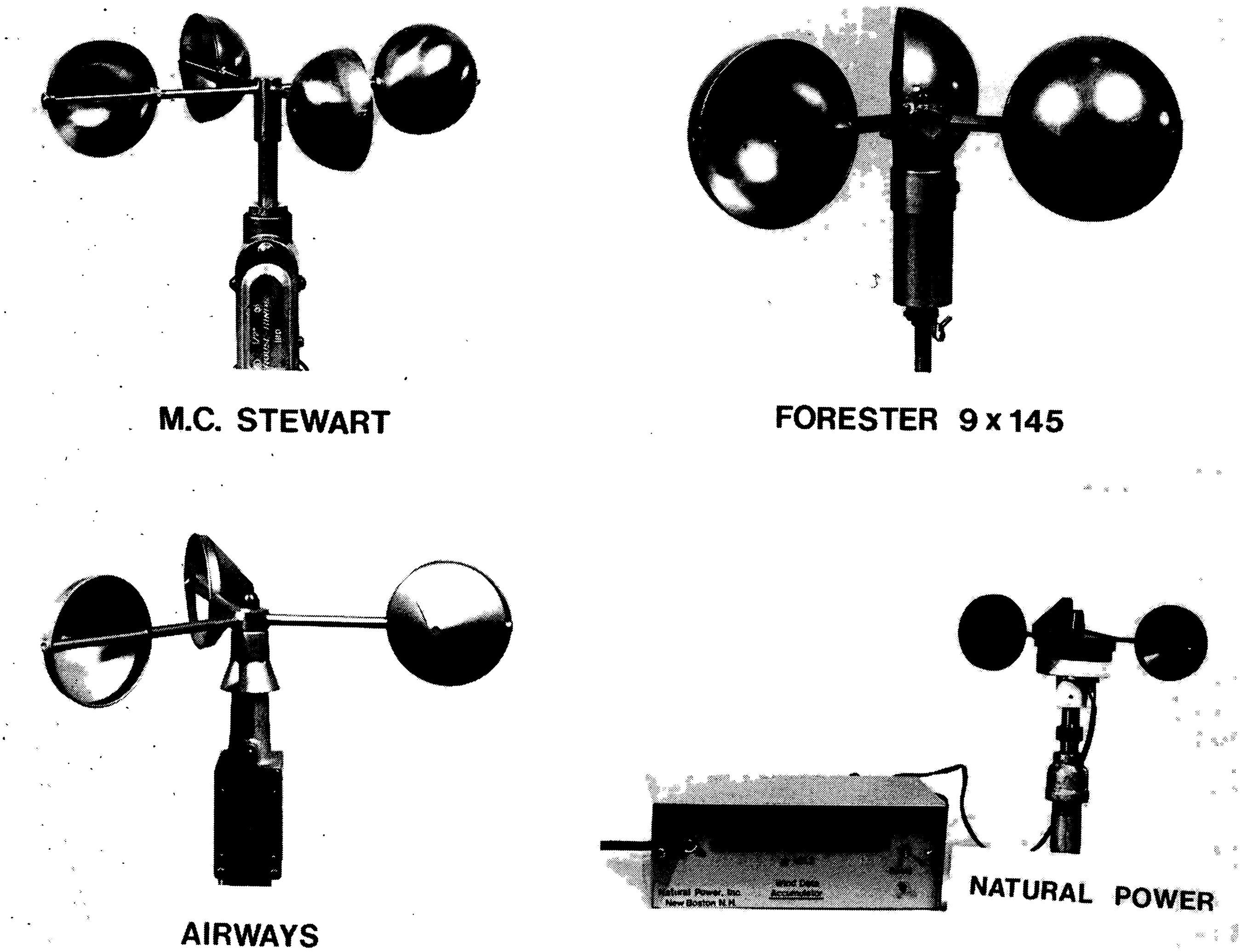

Figure 1.—*The four types of evaluated anemometers.*

The Airways and Natural Power anemometers displayed a negative error response over the entire range of tested velocities. The M. C. Stewart was negative below 15 m/s while the Forester 9 ×145 was positive over the tested range (fig. 2). As one might expect, the greatest change in the error curves occurred at low wind speeds. At higher velocities, the change in error was relatively uniform in most cases.

Before going to field stations, extensive tests were conducted to determine how accurately our portable equipment measured the wind speeds of the calibrated M. C. Stewart and Forester 9 ×145 anemometers (fig. 4). When testing the M. C. Stewart with this equipment, over a range of wind speeds from 2.2 to 9.0 m/s, maximum error was ±0.13 m/s at 9.0 m/s; ±0.09 at 4.5 and 7.0 m/s; and ±0.04 at 2.2 m/s. With the Forester 9 ×145 anemometer, the maximum error was ±0.04 m/s over the full range of considered wind speed. Therefore, we were confident that our equipment operated within the accuracy range required to check the performance of field anemometers.

RESULTS

We tested the M. C. Stewart and Airways anemometers at 2.2 m/s (5 mph) increments to 9.0 m/s (20 mph). Because of the large size of the Forester 9 ×145 relative to our equipment, we were unable to test its performance over the same range; its highest tested speed was 6.3 m/s (14 mph). The Natural Power anemometers were installed a short time before the study began, and all those tested conformed to the calibration standard (fig. 3). The deviations from ideal shown for the three anemometer types include both the wind-tunnel calibration error and the error identified during the field tests of individual anemometers. The calibration error is included because we found that the observers were not applying manufacturer specified corrections to their reported observations. Therefore, both error sources are incorporated in documented records.

Deviations from ideal wind speeds for the M. C. Stewart anemometers were most commonly -0.4 m/s

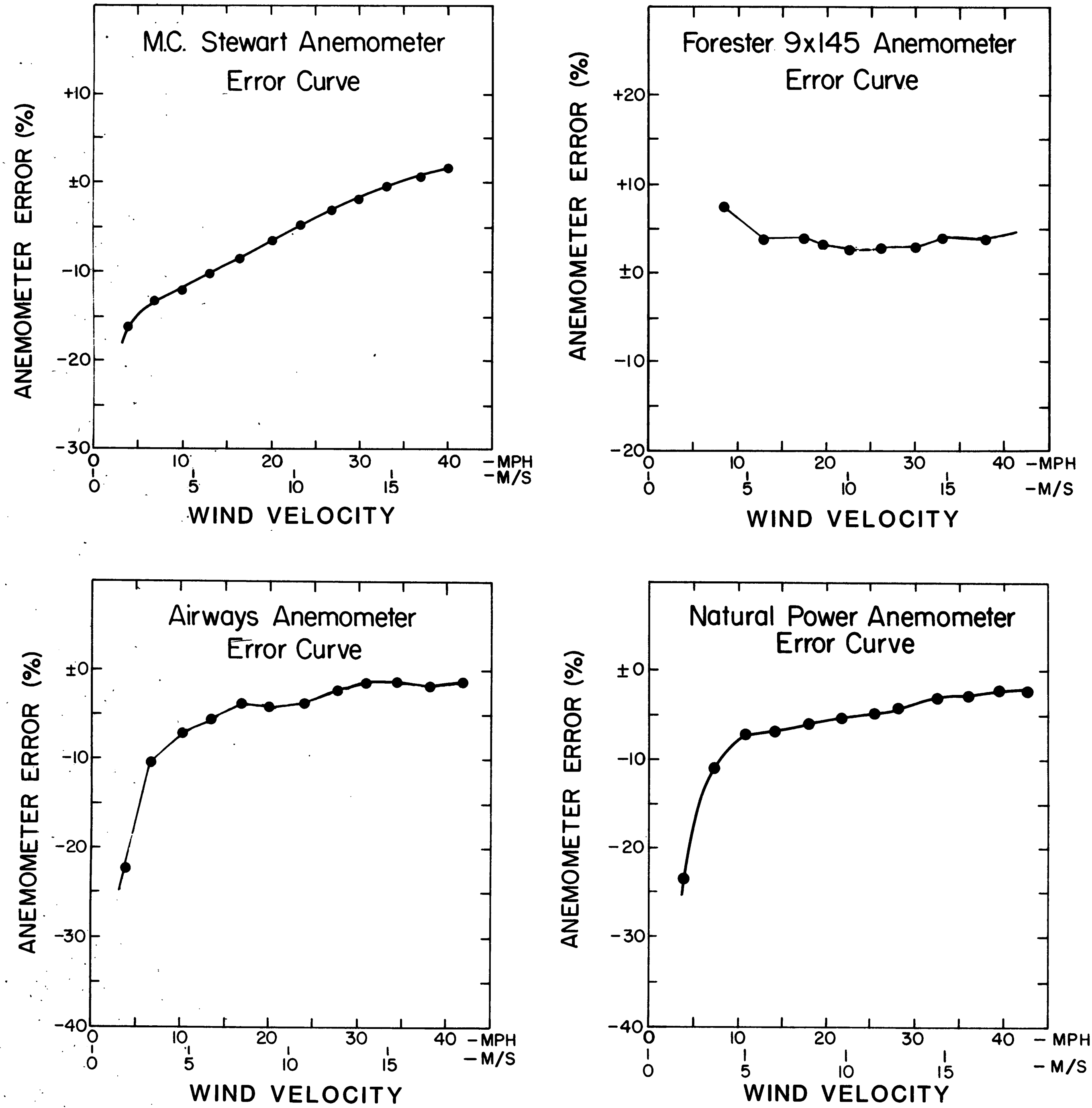

Figure 2.—*Error curves from wind tunnel calibrations for each anemometer type.*

(-1 mph) (42 to 63 percent of M. C. Stewart test results were in this category) (fig. 5). At wind speeds of 4.5, 7.0, and 9.0 m/s, 28 to 32 percent of the deviations were -0.9 m/s (-2 mph). The widest range of deviations occurred at the lowest tested wind speed, 2.2 m/s (5 mph). Here deviations ranged from 0.4 to -2.2 m/s (1 to -5 mph); the latter value resulted because some anemometer cups did not turn at low wind speeds.

Deviations from ideal for the Airways anemometer were concentrated at -0.4 m/s (-1 mph) over the full range of tested wind speeds (fig. 6). This anemometer was the most consistent of those tested.

Forester 9 ×145 tests were conducted at 2.2, 4.5, and 6.3 m/s (fig. 7). Most (89 percent) of the tested anemometers did not deviate from ideal at lower wind speeds; at the highest tested wind speed these anemometers showed a 0.4 m/s (1 mph) deviation from ideal.

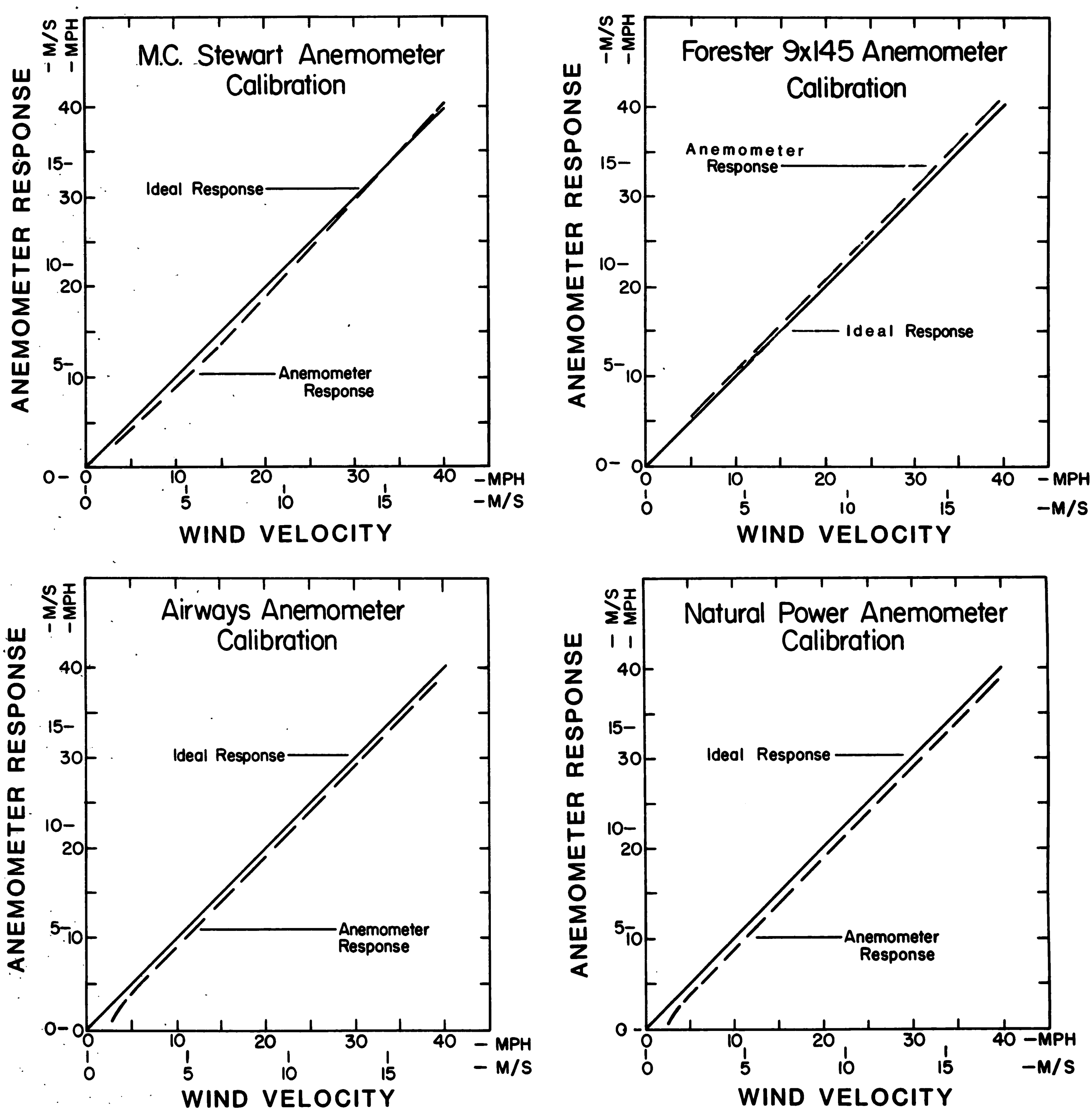

Figure 3.—*Wind tunnel calibration curves for each anemometer type.*

Of the tested units, 29 (20 percent) failed to respond with measurements within 10 percent of the wind tunnel calibrated anemometers at one or more test wind speeds. These units were either replaced or repaired. There was no significant failure difference among the three anemometer types; all failed roughly in proportion to the number surveyed. An examination of the failure rate as a function of time showed no discernible trend, but this may be a problem of a number of factors including sample size. It is readily apparent why field anemometer readings may deviate from the standard. Poor maintenance, for example, may result in excessive wear and cause increased friction on moving parts. Damaged parts, including bent or loose cups as well as bent spindles, may also result in changes in recorded wind speeds.

To the best of our knowledge, this is the first study to summarize information from a large number of field anemometers, some in use for many years. One-third of the Stewart anemometers were less than 4 years of age, while 45 percent were in service from 4

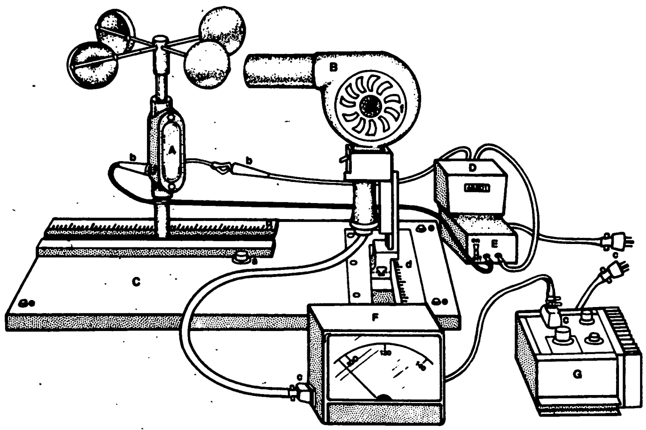

Figure 4.—*The anemometer tester includes: (A) anemometer to be tested, (B) industrial blower, (C) 12" ×21" solid testing board, (D) 12 volt DC counter, (E) 12 volt regulated DC power supply, (F) line voltage monitor, (G) variable voltage controller, (a) bubble level, (b) connections to counter, (c) electrical plugs, (d) tracks with metal measures, (e) level adjustment screws, and (f) blower manifold. Track mountings for the blower and the test anemometer permit both horizontal and vertical movement. The operator can generate a range of wind speeds by varying the distance between the blower and the anemometer and/or changing the air intake which is controlled by the blower manifold.*

to 9 years, and 22 percent for 10 or more years. The oldest unit was in use for more than 25 years. The Airways model has not been manufactured in the last 10 years, therefore, all units are at least that age. The Natural Power units were in place for no more than 2 years. The ages of the Forester anemometers were uniformly scattered from 1 to 9 years with only four units more than 10 years old. As with the failure survey, we did not see a well-defined trend in performance decline with years of service, but the effects of age are partially masked by a number of factors. Some anemometers are used throughout the year, while others are used only during the fire season; some are well maintained and properly lubricated, while others are not. Also, age assessments were estimates in a number of cases.

Given the deviations from ideal wind speeds generated by the two error terms, what is the impact on the calculated values of wildfire spread rates? Spread rate is usually defined in the context of a fuel model. Fuel model E (a part of the National Fire-Danger Rating System; Deeming *et al.* 1977) is a representative model for common fuels in the Northeastern United States. If we assume dead fine fuels and a relative humidity of 25 percent, then at a wind speed of 4.5 m/s (10 mph) negative deviations from the ideal of only 0.4 to 0.9 m/s (1 to 2 mph) will underpredict model E spread rates by 13 to 25 percent. At 9.0 m/s (20 mph) these same negative deviations from ideal will underpredict spread rates by 7 to 14 percent. Obviously these error terms are most important at lower wind speeds.

CONCLUSIONS AND RECOMMENDATIONS

Given that the field anemometer is continuously exposed to the worst of weather conditions, these instruments performed well year after year. None of the types tested proved unsatisfactory for use at fire-weather stations.

The Airways model has not been manufactured for some years; but given its proven durability, we expect that those units now in service will continue to perform for many years.

The M. C. Stewart wears somewhat faster than the other models, but is inexpensive and totally satisfactory for use at fire-weather stations. We note one word of caution with this anemometer; the contact points tend to wear quickly. This problem is solved by spending an additional few dollars and ordering the unit with a magnet-reed switch.

The Forester 9 ×145 model is more expensive than the other types tested, but the data indicate that it is sturdy and performs well in the field.

The Natural Power model appears somewhat fragile, and as yet it has not been subjected to the long-term rigors of the other three types. However, some units now have been in use at Northeastern field locations more than 4 years and as of this writing are performing satisfactorily.

Our inspections and survey disclosed that observers are not using calibration curves to correct wind speed observations. To assist in remedying this problem, we include the corrections obtained when calibrating our units (table 1).

This study was concerned with two error sources in anemometer performance. MacCready (1966) has documented other possibilities. Major wind-velocity reporting errors can also occur if the anemometer is not exposed properly (Fischer and Hardy 1972, Albini and Baughman 1979). And, even if all sources of anemometer and exposure error are properly addressed, one important factor remains: the ratio of forest to airport wind speeds ranges from 0.4 to 0.7, with a typical value of 0.5 (Simard 1969, Silversides 1978). Fire-weather forecasters located at airports must adjust their wind forecasts for this difference.

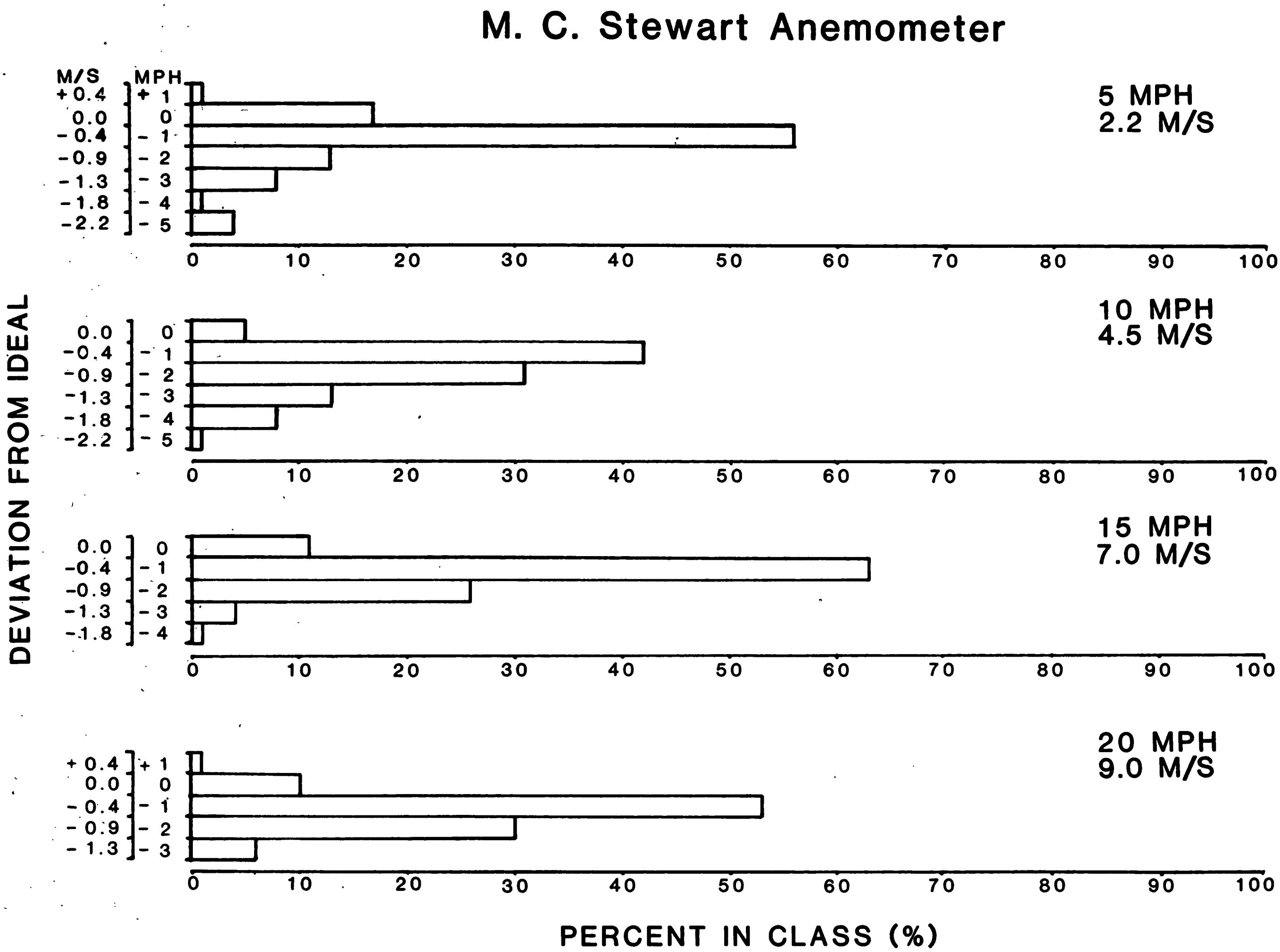

Figure 5.—*Deviations of the M. C. Stewart anemometer from ideal at four wind speeds. Data are grouped within a 0.4 m/s (1 mph) range. The groups include two error sources, the wind tunnel calibration difference and the error difference between the individual field units and the calibrated anemometers. Seventy-eight instruments were tested.*

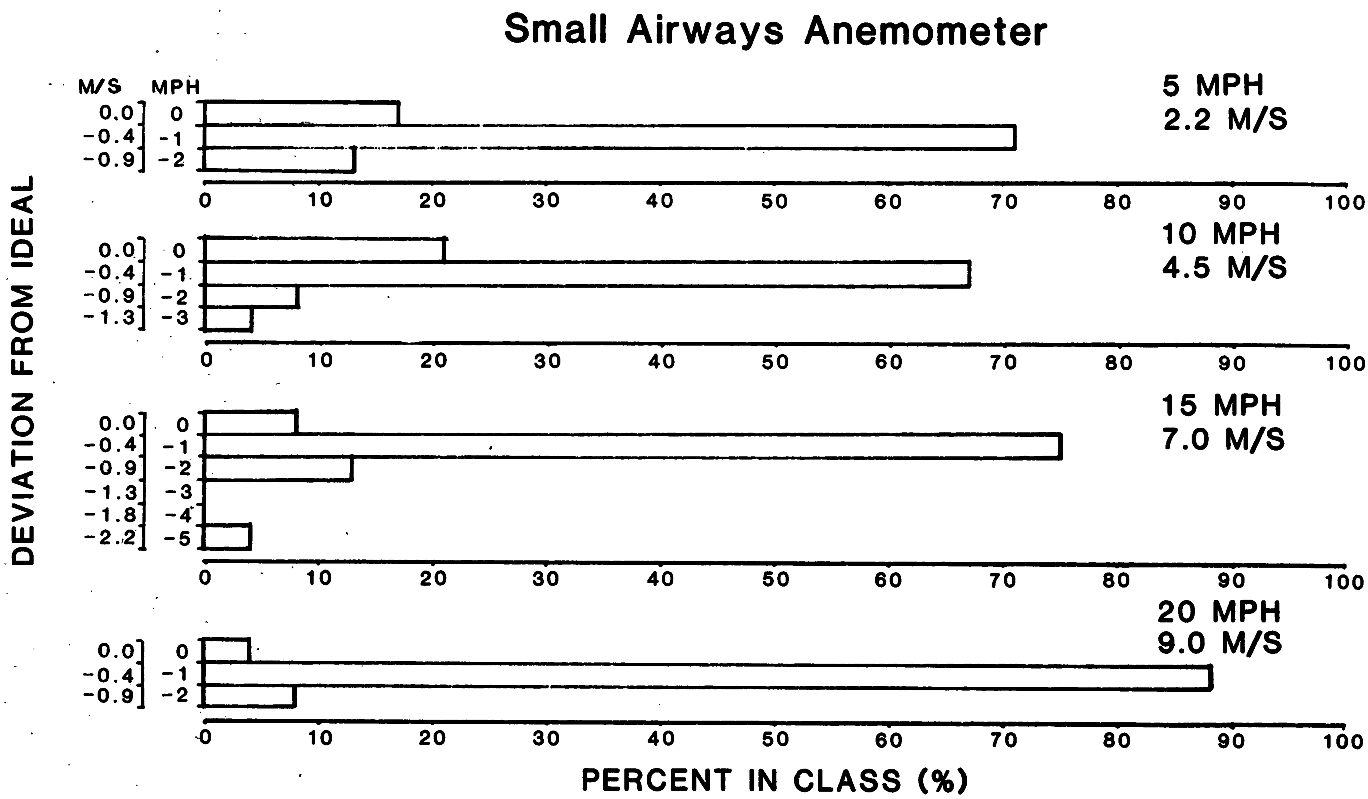

Figure 6.—*Deviations of the Small Airways anemometer from ideal at four wind speeds. Twenty-four instruments were tested.*

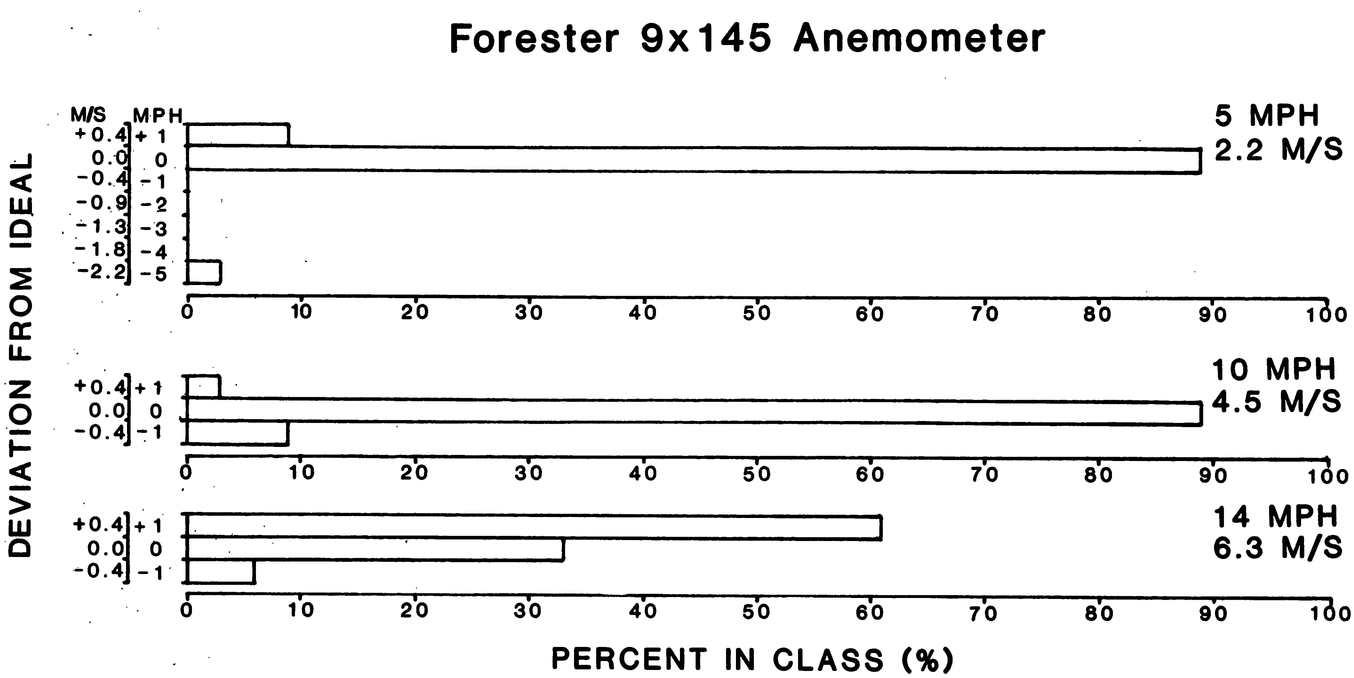

Figure 7.—*Deviations of the Forester 9 ×145 anemometer from ideal at four wind speeds. Thirty-five instruments were tested.*

Table 1.—*Wind tunnel specified corrections to be applied to individual observations to obtain ideal wind speed*

(In mph)

Ideal wind speed (mph)	Anemometer			
	Airways	Forester 9 x 145	M. C. Stewart	Natural power
5	+1.0	-0.5	+1.0	+1.0
10	+0.5	-0.5	+1.0	+1.0
15	+0.5	-0.5	+1.5	+1.0
20	+1.0	-0.5	+1.5	+1.0
25	+1.0	-0.5	+1.0	+1.0
30	+0.5	-1.0	+0.5	+1.0
35	+0.5	-1.5	±0.0	+1.0
40	+0.5	-2.0	±0.0	+1.0

Otherwise, airport forecasts will over predict wind speeds and resultant wildfire spread rates in the forest environment.

ACKNOWLEDGMENTS

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A survey of 142 fire-weather stations in the Northeastern United States showed that, although maintenance was generally satisfactory, calibration or testing of anemometers was virtually nonexistent. We tested these anemometers using portable equipment that we designed and found the deviations from true wind speed.

KEY WORDS: Wildfire behavior, fire-danger rating.