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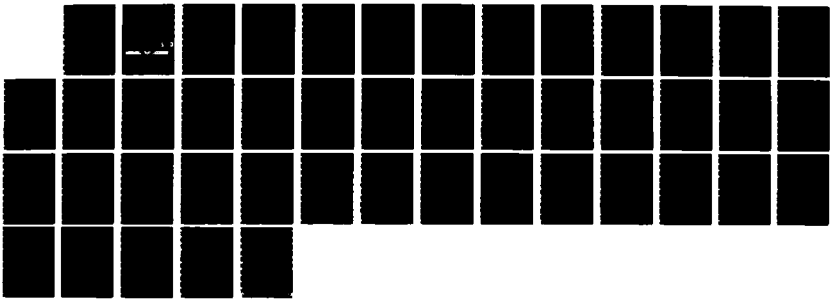

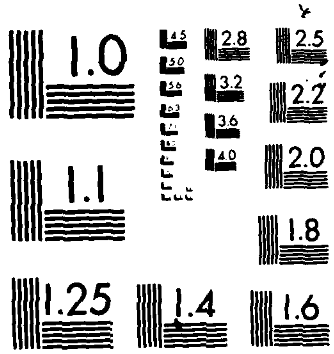

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REPORT NO. T9/86

BOTSBALL (WGT) PERFORMANCE CHARACTERISTICS AND THEIR IMPACT ON THE IMPLEMENTATION OF EXISTING MILITARY HOT WEATHER DOCTRINE

U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts

APRIL 1986

UNITED STATES ARMY
MEDICAL RESEARCH & DEVELOPMENT COMMAND

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Effective implementation of existing military hot weather doctrine requires accurate measurement of environmental heat stress. The WBGT (Wet Bulb-Globe Temperature) Index is the standard measure of heat stress used to assess the risk of heat injury and to select, from the doctrine, appropriate guidance for work/rest cycles and water consumption rates. The WGT (Wet Globe Temperature) Kit, Botsball (NSN 6665-01-103-8547) was introduced as a simple alternative to the WBGT. Based on its reported close correlation with the WBGT, the Botsball has been used as a measurement device for implementing hot weather

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doctrine.

This study was conducted to document the performance characteristics of the Botsball relative to the WBGT Index and to evaluate the options for heat stress measurement in the context of current hot weather doctrine and available instrumentation. Data were obtained from wind tunnel tests under simulated solar load of 800 Watts.m^{-2}, windspeed (W) 2.5 to 30 mph, dry bulb (DB) 80 to 125 F, and relative humidity (RH) 10 to 90%. Conditions were limited to the region between 75 and 105°F on WBGT Index scale and resulted in 75 different test environments. Results confirm earlier reports of inordinately low Botsball readings under hot, dry, and windy conditions: AT 125°F DB, 10% RH, and 30 mph W, the Botsball read 11°F lower than the WBGT Index.
Various equations reported to allow conversion of Botsball readings to the WBGT Index were tested and found to have precision limits (2 Standard Deviations) of ± 5°F over the range of environments tested here. This level of precision was judged inadequate for safe implementation of existing WBGT based doctrine. Precision of conversion was improved to ± 1.6°F by making two additional measurements, natural wet bulb (WB) and DB, and incorporating them into the conversion equation: WBGT=Botsball+0.185(DB-WB) +0.68. Two compact WBGT instruments, recommended in TB MED 507 (1980), were tested and showed overall precision on the order of ± 1°F. These instruments, the electronic NAVSEA meter (NSN 6685-01-055-5298) and the mechanical WBGT Kit (NSN 6665-00-159-2218) appear to be the appropriate heat stress measurement devices for operational/ tactical environments.

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Technical Report T9/86

Botsball (WGT) Performance Characteristics and Their Impact on the Implementation of Existing Military Hot Weather Doctrine

April 1986

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PREFACE

The following report is intended to support current efforts to determine the suitability of the Wet Globe Temperature (WGT) Kit, Botsball, as an alternative to the WBGT for measuring heat stress in military training and operational environments.

It is our desire to present the findings of this study in a way that is easily related to existing military hot weather doctrine and to those devices currently available to the military for heat stress measurement. In as much as the WBGT Index provides the measurement basis for implementation of current doctrine, the scope of this report will be limited to evaluations of the Botsball against the WBGT Index. This report therefore does not address the continuing controversey over the performance of the WBGT Index itself as a linear correlate of heat induced physiological strain.

To present our results in a form that is familiar to those having field experience with military heat stress measurements and to be consistent with current doctrine specifications and instrument outputs, we have made a departure from standard scientific convention with respect to units of measure: the unit of temperature reported here will be the Fahrenheit degree (^{O}F) and for wind speed, miles per hour (mph).

Disclaimer Statement

The views, opinions, and findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

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ABSTRACT

Effective implementation of existing military hot weather doctrine requires accurate measurement of environmental heat stress. The WBGT (Wet Bulb-Globe Temperature) Index is the standard measure of heat stress used to assess the risk of heat injury and to select, from the doctrine, appropriate guidance for work/rest cycles and water consumption rates. The WGT (Wet Globe Temperature) Kit, Botsball (NSN 6665-01-103-8547) was introduced as a simple alternative to the WBGT. Based on its reported close correlation with the WBGT, the Botsball has been used as a measurement device for implementing hot weather doctrine.

This study was conducted to document the performance characteristics of the Botsball relative to the WBGT Index and to evaluate the options for heat stress measurement in the context of current hot weather doctrine and available instrumentation. Data were obtained from wind tunnel tests under simulated solar load of 800 Watts.m^{-2}, windspeed (W)2.5 to 30 mph, dry bulb (DB) 80 to 125 F, and relative humidity (RH) 10 to 90%. Conditions were limited to the region between 75 and 105^{O}F on WBGT Index scale and resulted in 75 different test environments. Results confirm earlier reports of inordinately low Botsball readings under hot, dry, and windy conditions: At 125^{O}F DB, 10% RH, and 30 mph W, the Botsball read 11^{O}F lower than the WBGT Index.

Various equations reported to allow conversion of Botsball readings to the WBGT index were tested and found to have precision limits (2 Standard Deviations) of $\pm$ 5^{O}F over the range of environments tested here. This level of precision was judged inadequate for safe implementation of existing WBGT based doctrine. Precision of conversion was improved to $\pm$ 1.6^{O}F by making two

additional measurements, natural wet bulb (WB) and DB, and incorporating them into the conversion equation: WBGT=Botsball+0.185(DB-WB)+0.68. Two compact WBGT instruments, recommended in TB MED 507 (1980), were tested and showed overall precision on the order of $\pm$ 1°F. These instruments, the electronic NAVSEA meter (NSN 6685-01-055-5298) and the mechanical WBGT Kit (NSN 6665-00-159-2218) appear to be the appropriate heat stress measurement devices for operational/tactical environments.

I. BACKGROUND AND MILITARY RELEVANCE

A. General Concepts:

The ability of the soldier to perform a given task in a hot environment is related directly to the prevailing heat stress level: the higher the heat stress level, the greater the risk of fatal or debilitating heat injury. It has become a fundamental concept that if the prevailing heat stress level can be accurately measured, then doctrine can be implemented to optimize soldier performance, i.e., minimize risk of heat injury and at the same time maximize mission performance. Efforts in this area have included the development of special uniforms for hot environments as well as specific guidelines for water consumption rates and work rest cycles based directly on prevailing heat stress levels (1,2). Explicit in this approach is the requirement for an Index of environmental heat stress that provides a reliable and consistent correlation with the induced physiological strain. The heat stress index currently used by the military is the WBGT Index (Wet Bulb Globe Temperature). The WBGT Index is computed from 3 seperate environmental measurements as follows:

WBGT = 0.7 x WET BULB TEMP + 0.2 x BLACK GLOBE TEMP + 0.1 x DRY BULB TEMP

This Index provides the rational basis for the graded array of countermeasures that constitute current hot weather doctrine.

B. WBGT Instruments and TB MED 507:

The apparatus for the measurement of the WBGT Index, as described in TB MED 507, has been employed at military training facilities for many years. It consists of a support framework approximately 5 ft high and 5 ft long from which the three sensor components, shaded dry bulb, naturally convected wet bulb, and 6 in Vernon black globe are suspended. Although this equipment provides reliable WBGT measurements, its use in many field situations is limited by two factors: 1) The equipment is cumbersome and more suited to fixed-site measurements than high mobility tactical situations 2) The components for the standard WBGT apparatus are not available through the Federal Supply System and thus require local acquisition or fabrication.

As noted in TB MED 507, two compact alternatives to the full size WBGT apparatus have been developed and are listed in the Federal Supply system. One of these is a hand-held mechanical WBGT kit (NSN 6665-00-159-2218) developed by the Army. The other, also hand held, is an electronic WBGT meter (NSN 6685-01-055-5298) developed by the Navy. Both of these devices afford reasonably accurate measurements of the local WBGT Index for highly mobile forces in tactical/training situations.

C. The Botsball and DA Cir 40-82-3:

A third device for the measurement of heat stress is the WGT (Wet Globe Thermometer) or Botsball (NSN 6665-01-103-8547) (3). This instrument is rugged, light weignt, relatively inexpensive, and easy to use. It requires only a single temperature reading from a dial thermometer. Although the single Wet Globe component of the Botsball is clearly different from the three component WBGT Index in terms of the physics involved, introduction of the Botsball as a device for the implementation of hot weather doctrine was predicated on its reported (4,5) close correlation with the WBGT Index. Based on those studies, it was suggested that the WBGT could be closely approximated by adding 2^{O} F to the Botsball reading; i.e. the Botsball would always read approximately 2^{O} F lower than the prevailing WBGT Index. On the basis of this apparently consistent relationship with the standard WBGT Index, interim guidelines for military use of the Botsball were established and appeared in DA Cir. 40-82-3 (Issued: 1 July, 1982, Expired: 1 July, 1984).

D. The Botsball Problem:

In early July 1983, reports of Botsball readings significantly lower than the WBGT Index were received from two different locations: Ft. Bliss, Texas and the Sinai, Egypt. Both locations were experiencing extremely low humidity, high wind velocity, and high ambient tempratures. In response to these reports we initiated a preliminary test in our tropic wind tunnel facility. At the 20% humidity level we found that the Botsball was reading as much as $6^{O}F$ lower than the WBGT Index. During our participation in Operation Bright Star 83, we were able to confirm, under field conditions, Botsball readings 5.2 to $5.5^{O}F$ lower than the WBGT Index (Wadi Seidna, Sudan and Berbera, Somalia).

E. The Present Study:

The present study was initiated to obtain a data set that could be employed to systematically document the Botsball performance, and evaluate the options for heat stress measurement in the context of current hot weather doctrine and available instrumentation.

II. OBJECTIVES AND APPROACH

A. Objectives:

The primary objectives of this study were to: 1) Document the performance of the Botsball against the standard WBGT over a range of environmental conditions relevent to potential military field operations 2) Evaluate the reliability of various equations that have been proposed for approximating the WBGT Index from the Botsball (WGT) reading. 3) Evaluate the precision of alternative field portable instrumentation for the measurment of the WBGT Index.

B. Approach

A major focus of the test design was to include test points representing extreme real world values for those parameters associated with low Botsball readings: low relative humidity and high wind speed. With that emphasis, the approach was to obtain simultaneous measurements of the standard WBGT, the Botsball (WGT), and other heat stress instruments at discreet points over a broad range of comprehensively defined heat stress environments.

Environmental test points were selected to provide data set combinations which would result in WBGT values spanning the region between 75 and 105°F, at a constant simulated solar load approximating mid-day (sun more the 45° above the horizon), clear sky conditions. Each of 15 different combinations of dry bulb temperature and relative humidity were studied at 2.5, 5, 10, 20, and 30 mph. This resulted in 75 discreet environments with the following values for individual test parameters:

Parameter	Nominal Test Points	Actual Range
Dry Bulb (°F)	80, 95, 100, and 125	80.7 - 127.4
Wind Speed (mph)	2.5, 5, 10, 20, and 30	2.3 - 35
Relative Humidity (%)	10, 15, 20, 30, 50, 70, and 90	9.2 - 99.2
Natural Wet Bulb (°F)	---	61.3 - 95.8
Dew Point (°F)	---	41.6 - 92.1
Black Globe (°F)	---	89.1 - 158.0
Simulated Solar Radiation (Watts·m^{-2})	constant @ approx. 800	

III. METHODS

A. Instruments Tested

1. Standard WBGT apparatus (Ref. TB MED 507)

2. Stortz WBGT Kit (NSN 6665-00-159-2218, Ref. TB MED 507)

3. Reuter-Stokes NAVSEA meter (NSN 6685-01-055-5298, Ref. TB MED 507)

4. Botsball WGT Kit (NSN 6665-01-103-8547, Ref. DA Cir 40-82-3)

5. Reuter-Stokes Wibget, model 211D

6. Reuter-Stokes mini-Wibget, model RSS-213

The black globe and naturally convected wet bulb components of the standard WBGT apparatus were instrumented with thermister probes and their temperatures read using electronic digital thermometers (Cole-Parmer, Model 8110-20).

B. Tropic Wind Tunnel Facility:

The Tropic Wind Tunnel Facility, US Army Natick Research and Development Command, Natick, Massachusetts was used for these tests. During test sessions, conditions within the tunnel were monitored and recorded at 2 minute intervals using a computer controlled automatic data acquisition system. The following parameters were obtained from this system:

1. Wind Speed (cup anemometer, Climet, Inc.)

2. Shaded Dry Bulb Temperature (Platinum RTD thermometer)

3. Dew-Point Temperature (dew-point hygrometer, General Eastern Inc.)

4. Relative Humidity (computed from dew-point and dry bulb temperatures)

Solar radiation was simulated, and held constant for all tests by an array of heat lamps suspended approximately 6 ft above the test instruments. The radiant flux produced by these lamps was determined to be approximately 800 $watts.m^{-2}$ at the level of the test instruments using a cosine corrected pyranometer (LiCor Inc.).

C. Procedures:

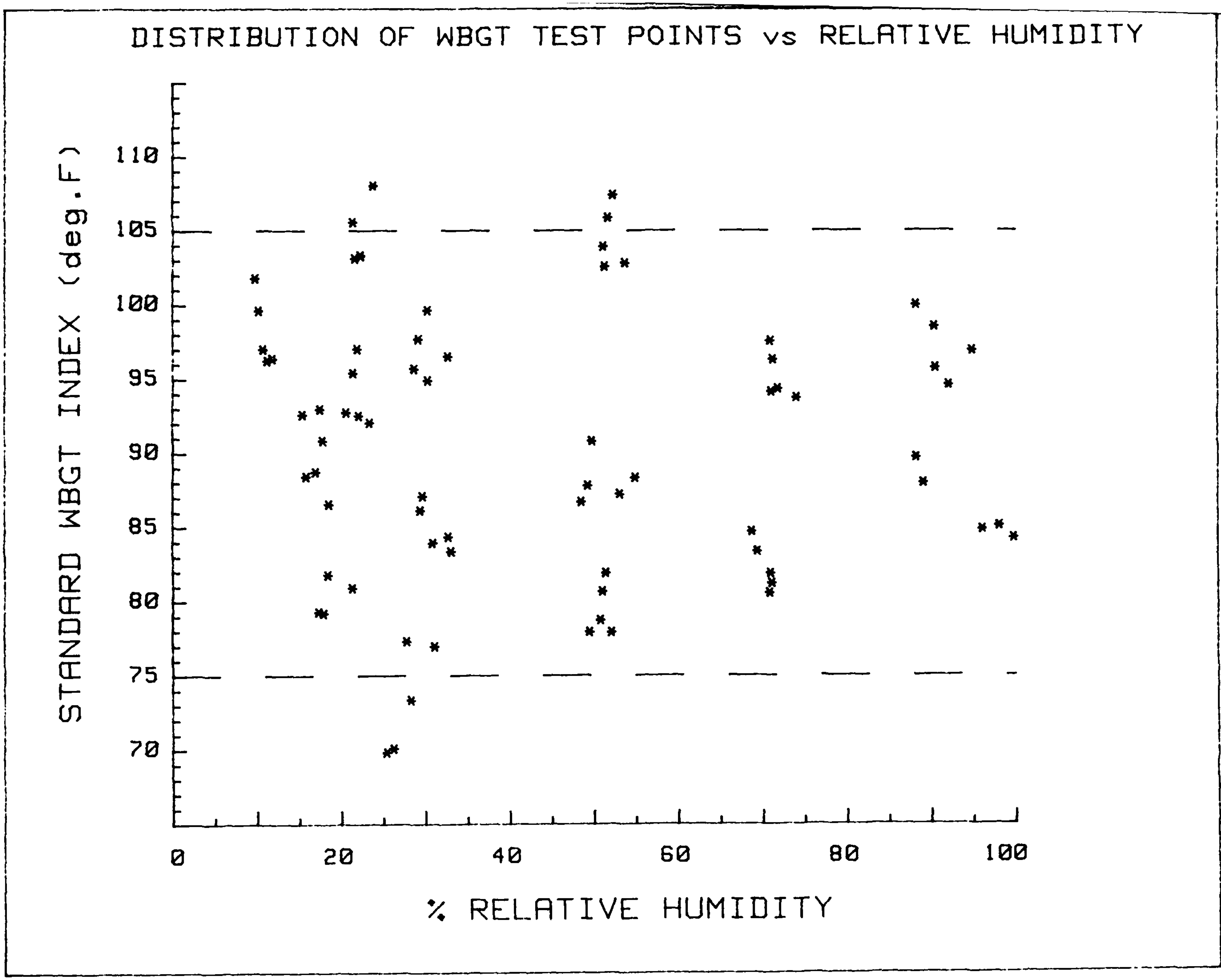

Figure 1. Distribution of the WBGT Index values for the 75 test environments with respect to relative humidity.

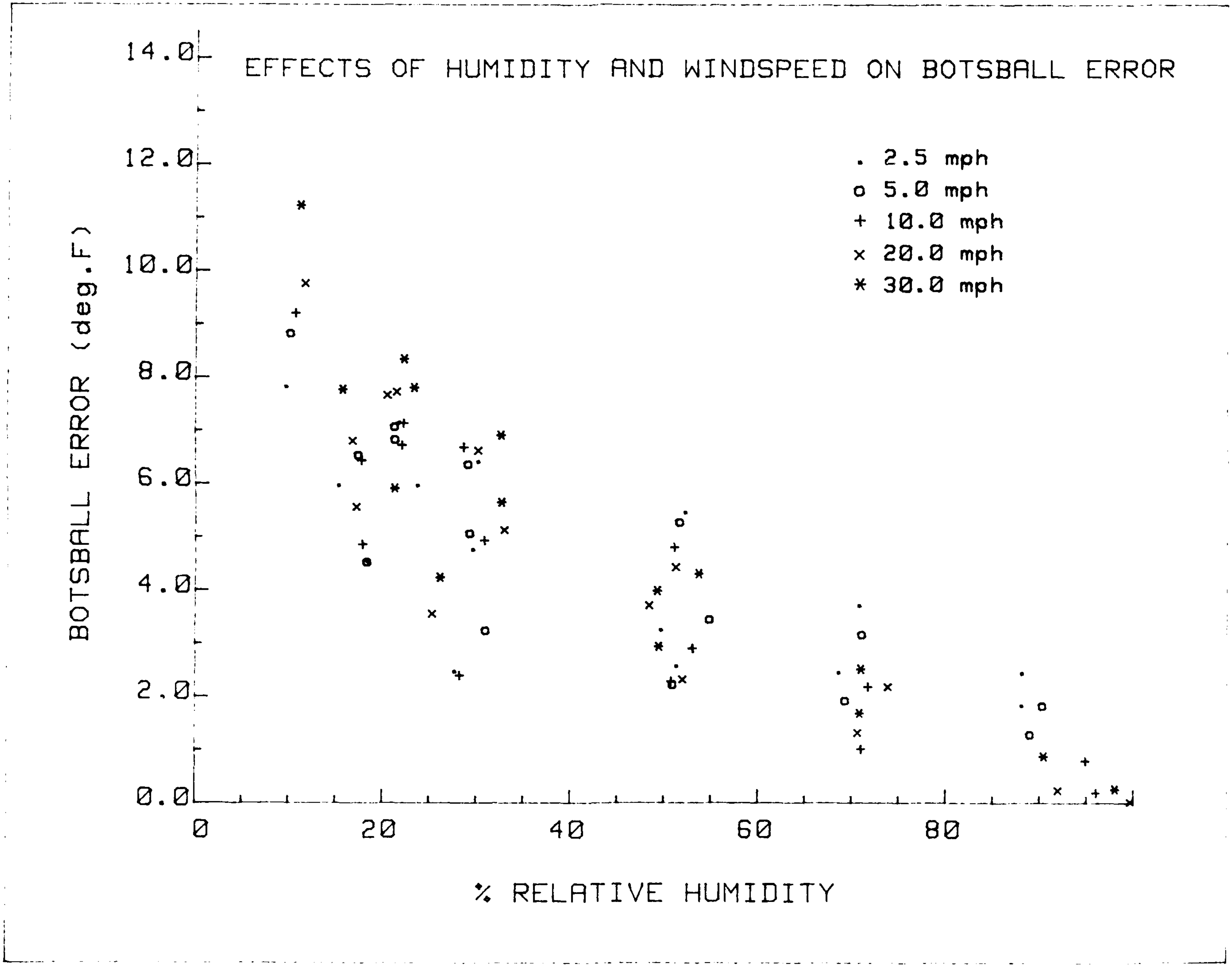

Figure 2. Effect of relative humidity on Botsball "error".

All instruments were calibrated and placed in the throat of the tunnel at a height of 4 ft above the floor. When tunnel conditions achieved the desired setpoints and the test instruments were providing stable readings, data were manually recorded at 2 to 3 minute intervals over a test period of 4 to 9 minutes. Subsequently, the average of the readings for each test or monitoring instrument over that period was computed and used as the value for that environment.

IV. RESULTS

A. The Data Set:

Figure 1 is a scatter plot of the standard WBGT and Botsball readings versus relative humidity for the 75 different combinations of windspeed dry-bulb and relative humidity (RH) . This figure demonstrates that reasonably comprehensive coverage of the WBGT Index region between 75 and 105 ^{O}F was achieved over a broad range of relative humidities.

B. The Effect of Relative Humidity on Botsball Deviation from the WBGT:

Figure 2 illustrates the fundamental problem with previous attempts to directly correlate the Botsball (WGT) reading with the WBGT Index. The x-axis is relative humidity and the y-axis is the difference or "error" between the Botsball reading and the WBGT Index (WBGT-Botsball). Although DA Cir 40-82-3 assumes a constant 2 deg.F "error", our data indicate that the magnitude of the error is not constant and varies, in fact, from near zero at the highest humidities to as much as 11^{O}F at the lowest (~10% RH). Furthermore, at the 10% RH level we were able to resolve a significant effect of windspeed: The Botsball error was 8^{O}F at 2.5 mph and 11^{O}F at 30 mph.

C. Equations to Convert the Botsball reading to the WBGT Index:

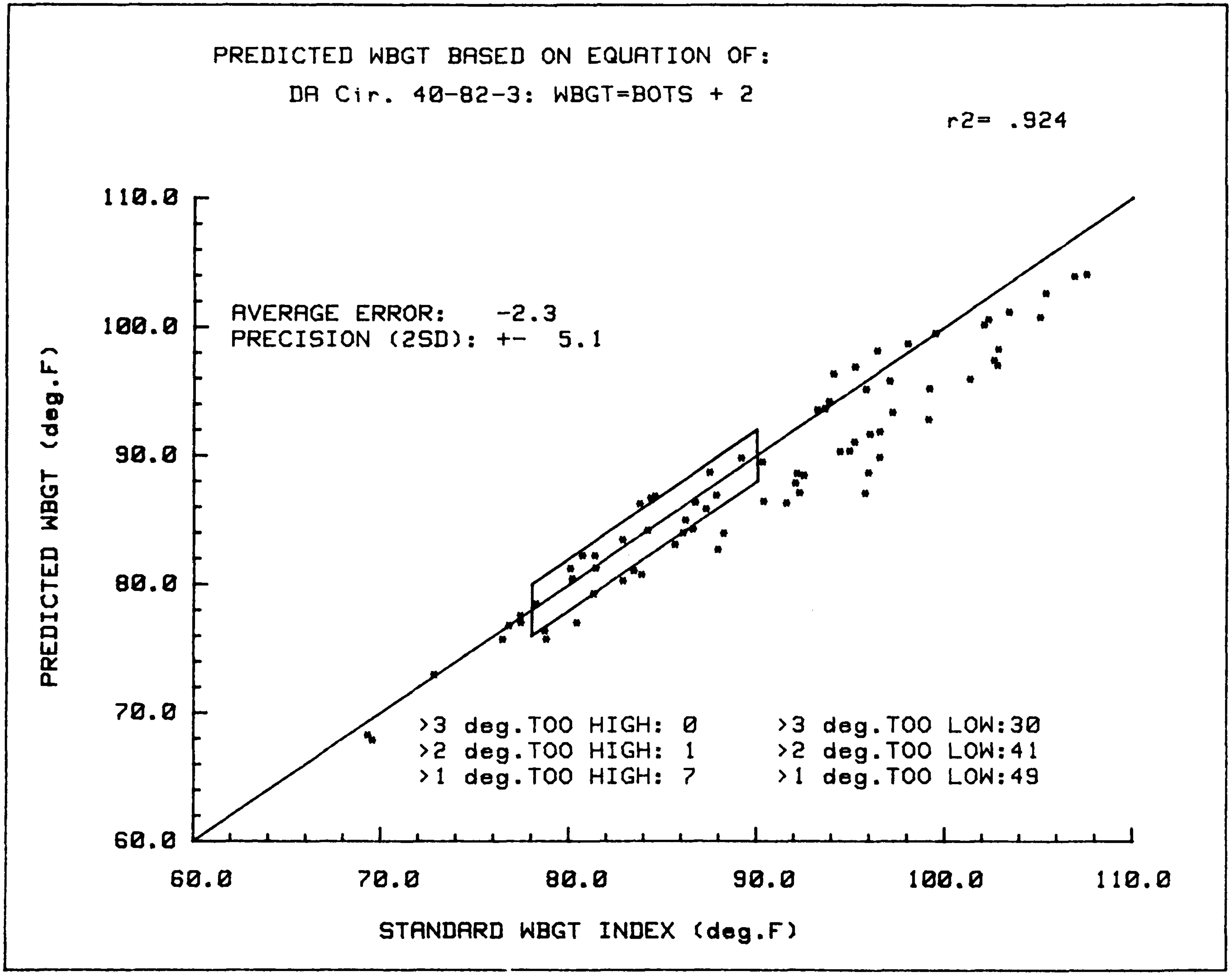

Figure 3. Effect of applying DA Cir 40-82-3 recommended 2°F to our Botsball data for the 75 environments.

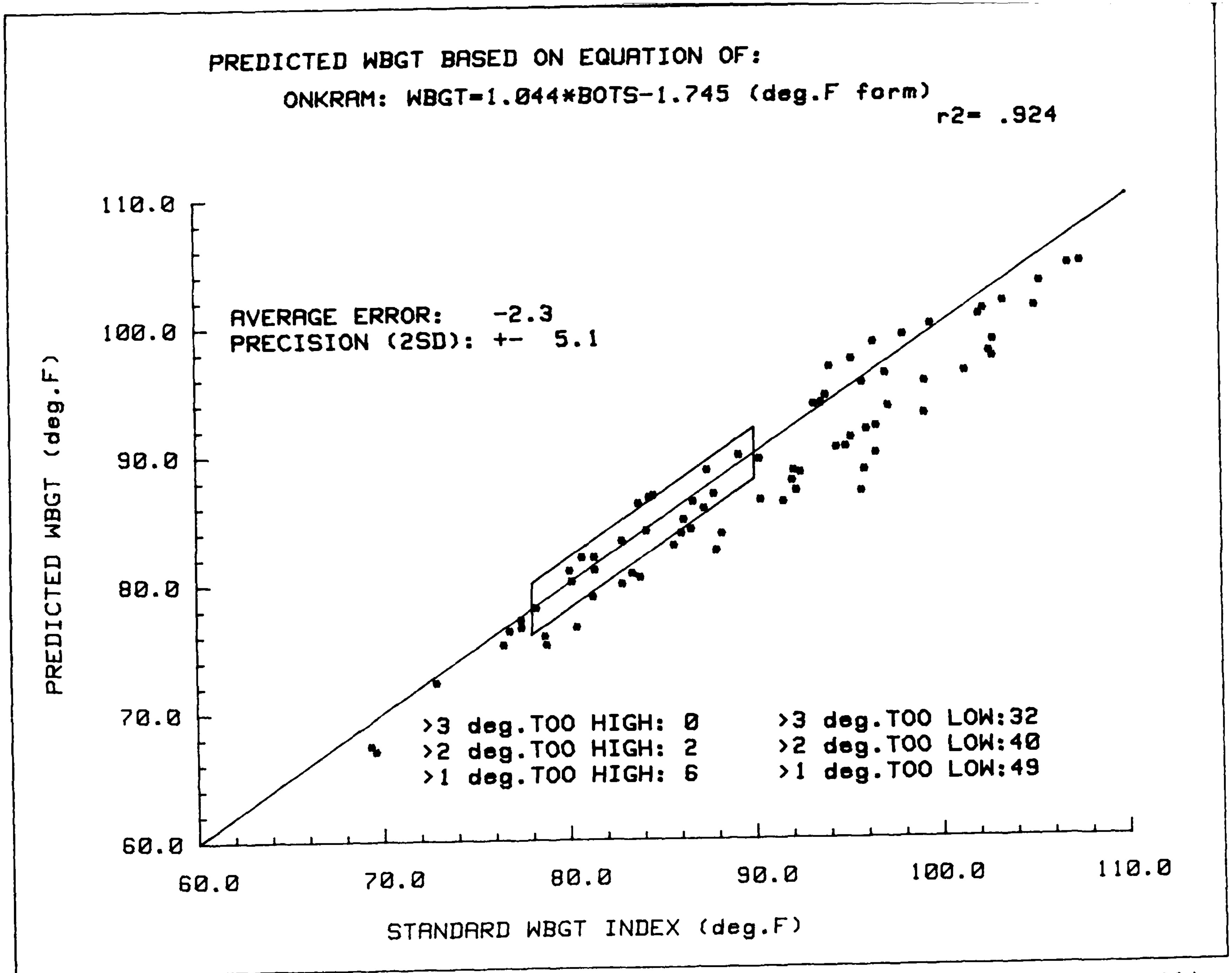

Figure 4. Effect of applying equation of Onkram et al. to our Botsball data for the 75 environments. (This equation converted from their published °C form.)

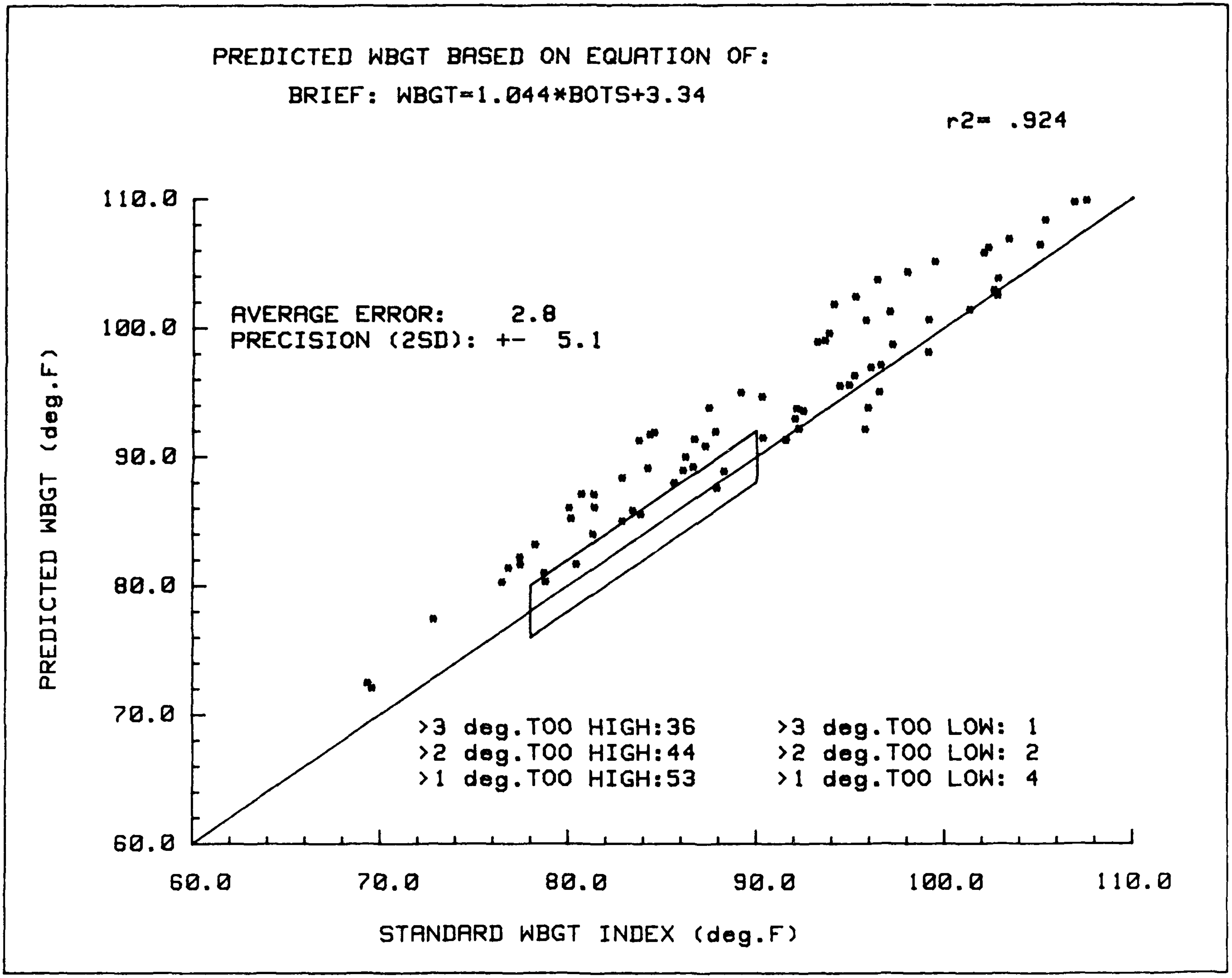

Figure 5. Effect of applying the equation of Brief & Confer to our Botsball data for the 75 environments.

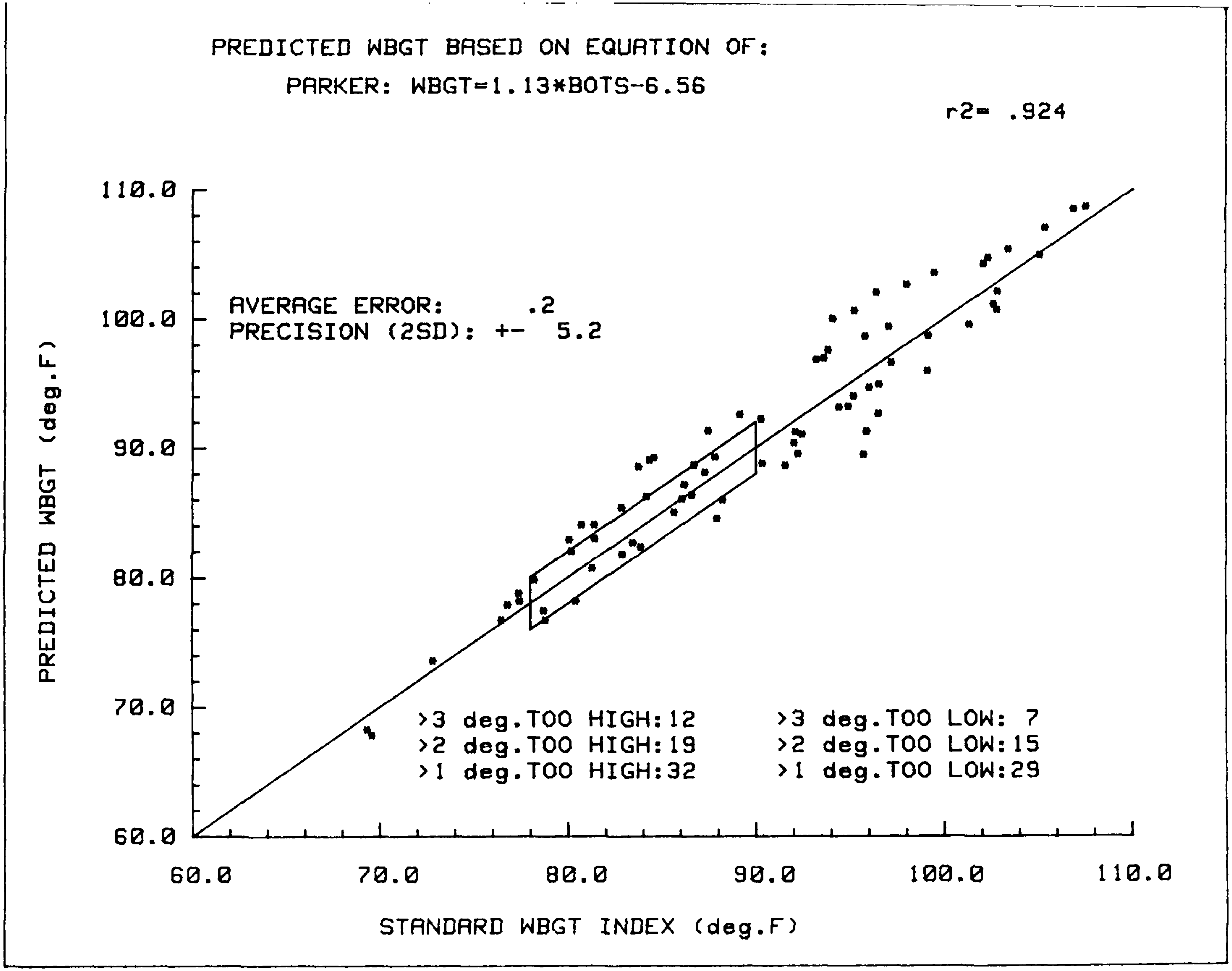

Figure 6. Effect of applying the equation of Parker & Pierce to our Botsball data for the 75 environments. (Their equation for outdoor, non-industrial environments).

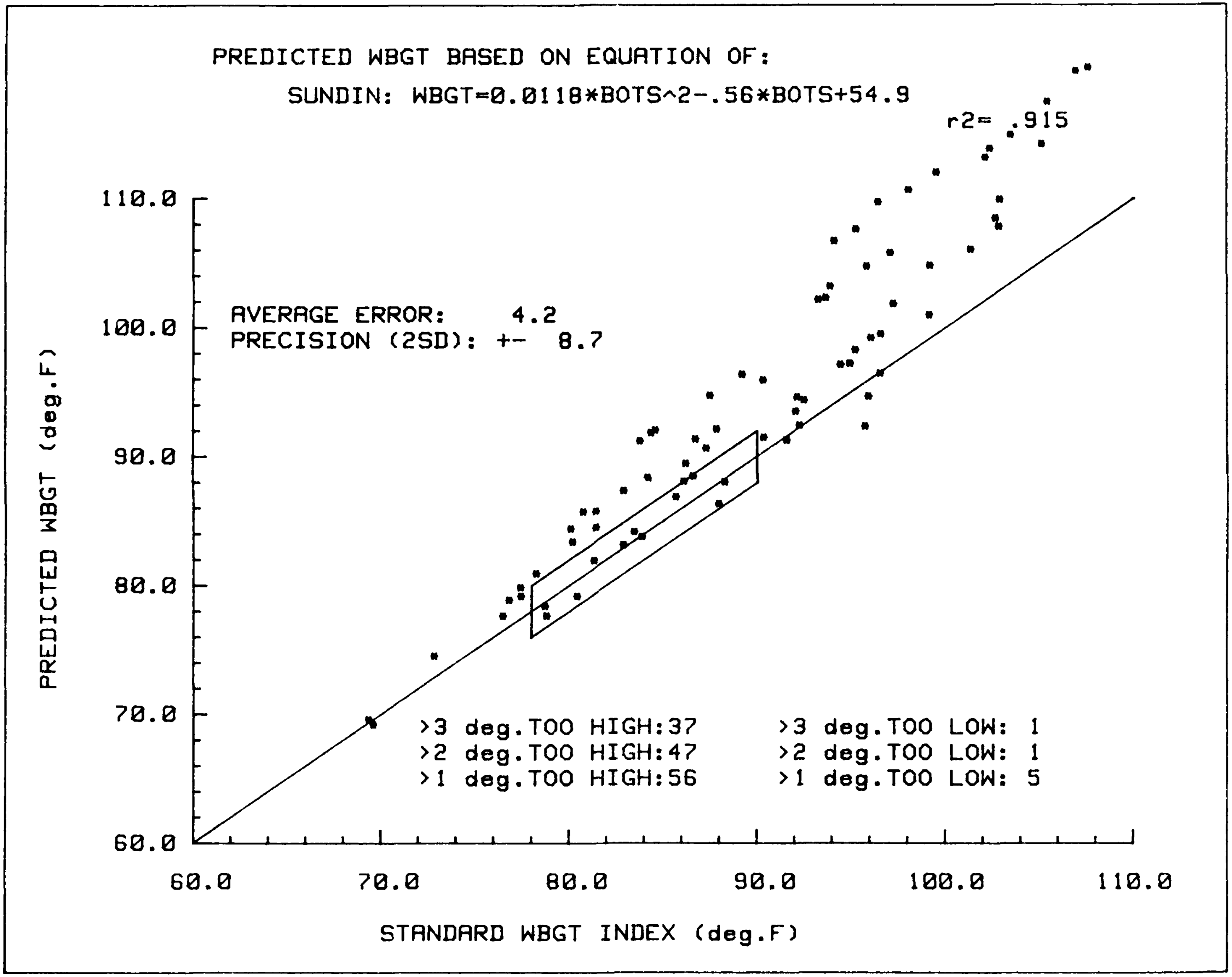

Figure 7. Effect of applying equation of Sundin et al. to our Botsball data for the 75 environments.

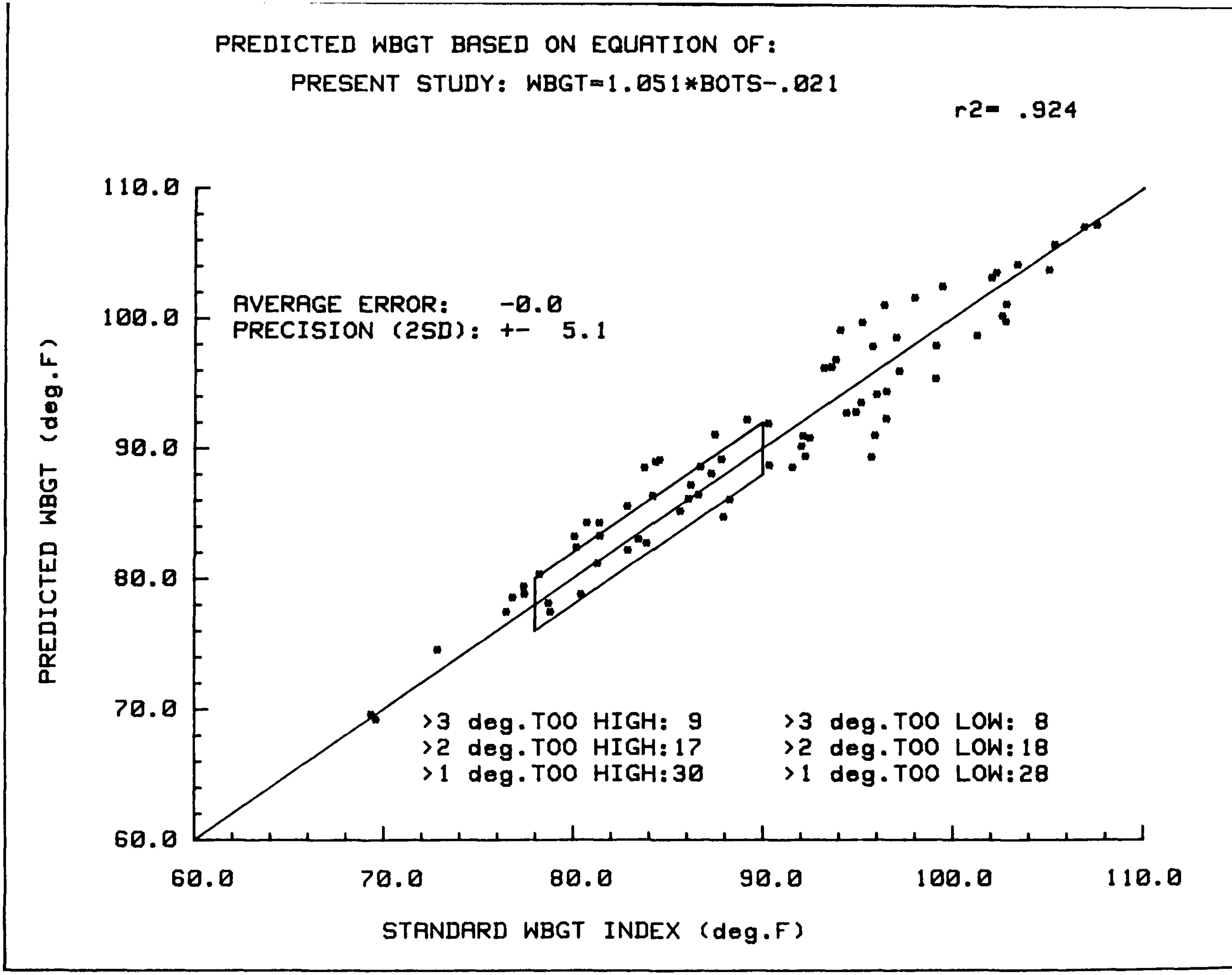

Figure 8. Effect of applying our own linear regression equation back to our Botsball data for the 75 environments.

A number of investigators have proposed equations for the conversion of Botsball readings to the WBGT index (5,6,7,8) and some of these have been reviewed previously (9). We applied the conversion equations of several authors, the 2 deg F. offset recommended in DA Cir. 40-82-3, as well as our own regression equation, to our Botsball data for the 75 environments and plotted the results against the standard WBGT Index we actually measured.

The results are shown in figures 3 through 8. The diagonal line is the line of identity and points falling exactly on the line represent perfect agreement with the standard WBGT Index. The paralellogram shape is for reference only and delineates the important doctrinal region between WBGT=78 and 90°F, and $\pm$ 2°F from the line of identity. It is clear from these figures that while some of these equations work reasonably well in terms of average error, there is substantial variation around the line of identity and precision ($\pm$ 2SD) is on the order of $\pm$ 5°F. This amount of variation from the standard WBGT Index could translate into inconsistent and potentially dangerous application of doctrine.

D. A Possible Solution for the Botsball Problem:

Based on the results noted above it appears very unlikely that any computation of the WBGT Index from the Botsball reading alone could provide acceptable levels of accuracy over the full range of militarily relevant heat stress environments. It seems clear that the environment must be further defined by, at least, an additional humidity measure and perhaps even wind speed. As a preliminary step in that direction, we examined the relationship between the Botsball "error" and the difference between the dry bulb and wet bulb temperatures (DB-WB). Regression analysis of the Botsball "error" (WBGT-Botsball) versus the difference between the dry bulb and wet bulb (DB-WB)

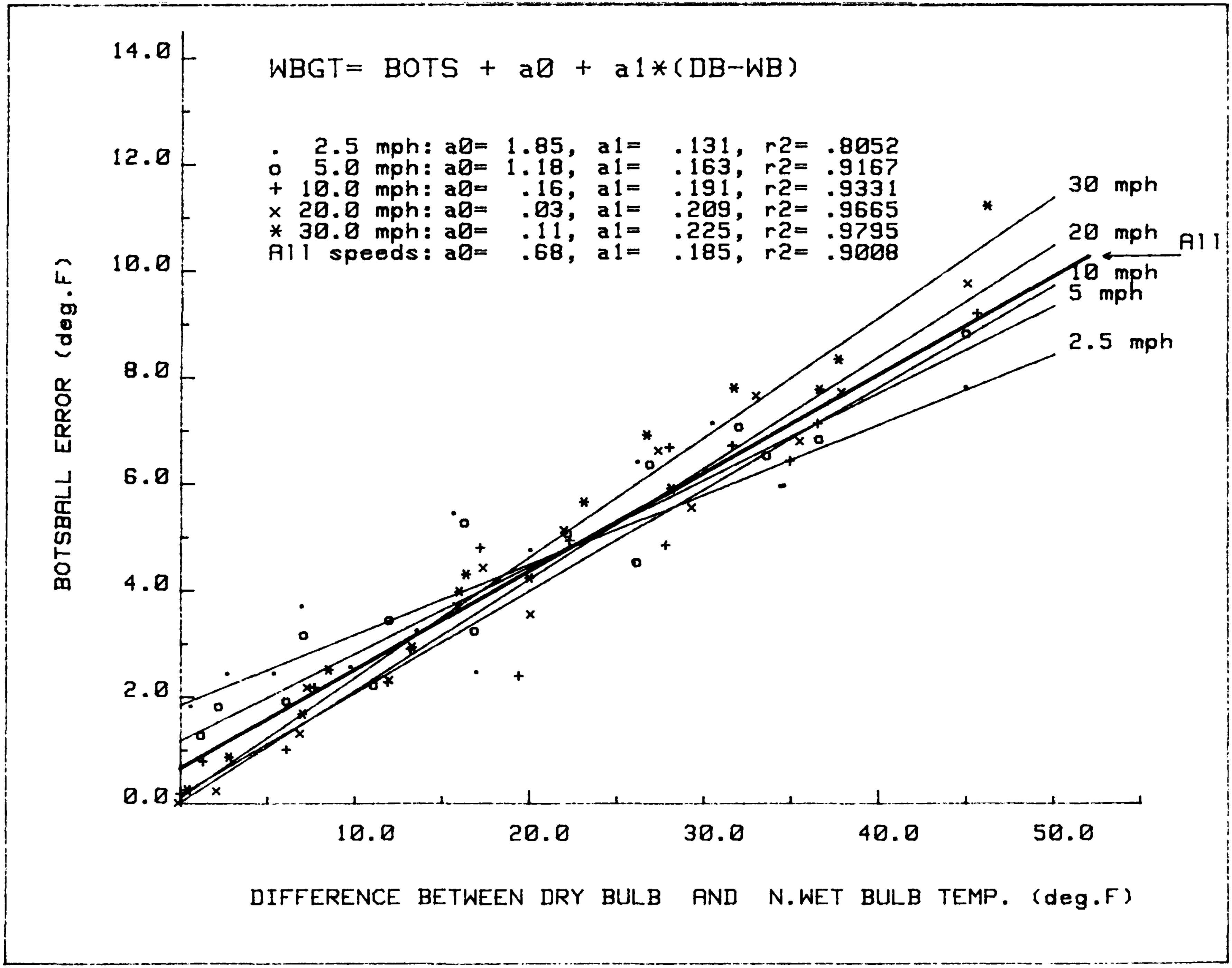

Figure 9. Linear regression analysis of Botsball "error" versus the difference between prevailing dry bulb and natural wet bulb (DB-WB) for each wind speed and for all wind speeds combined.

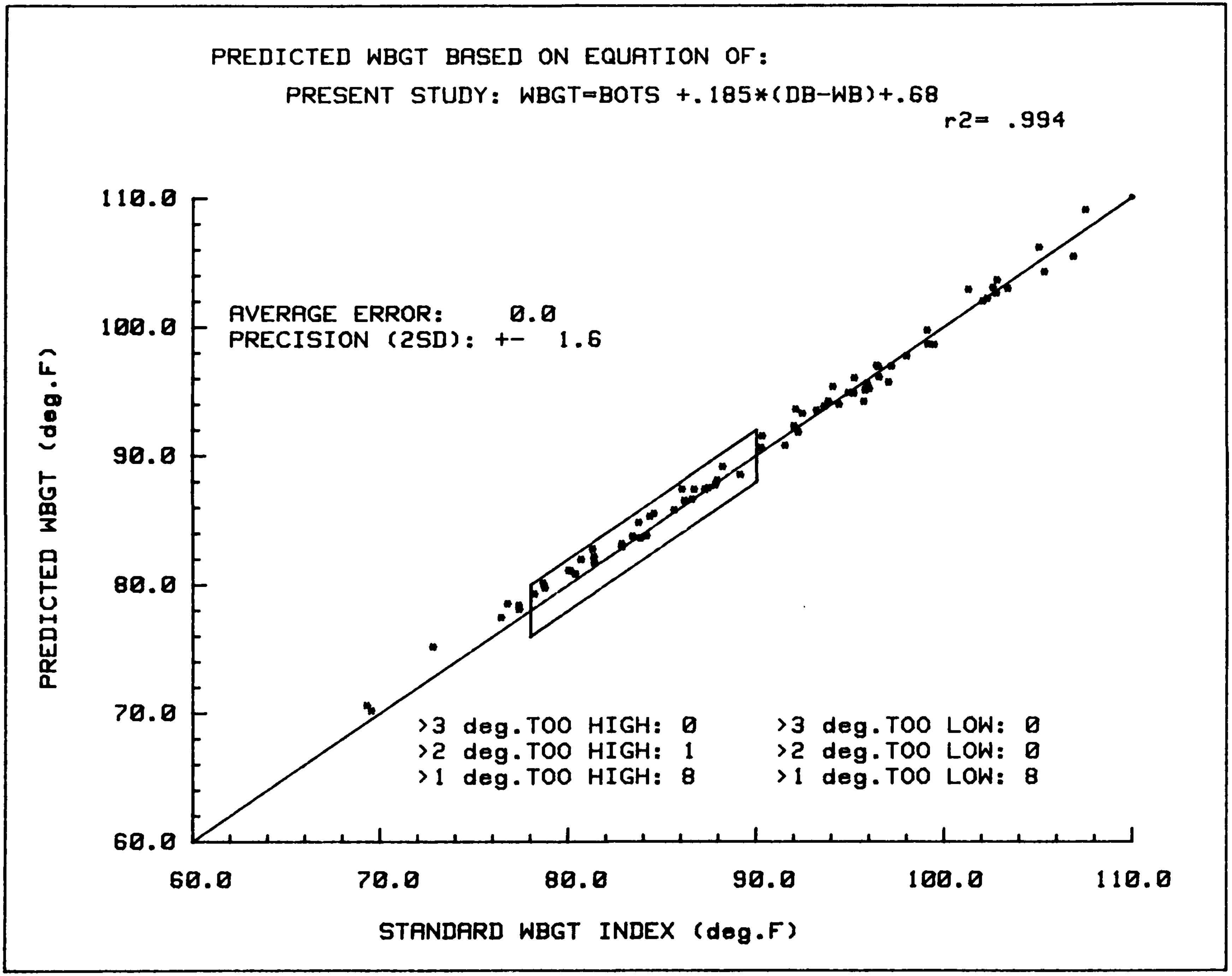

Figure 10. Effect of applying the DB-WB correction equation to our data for the 75 environments.

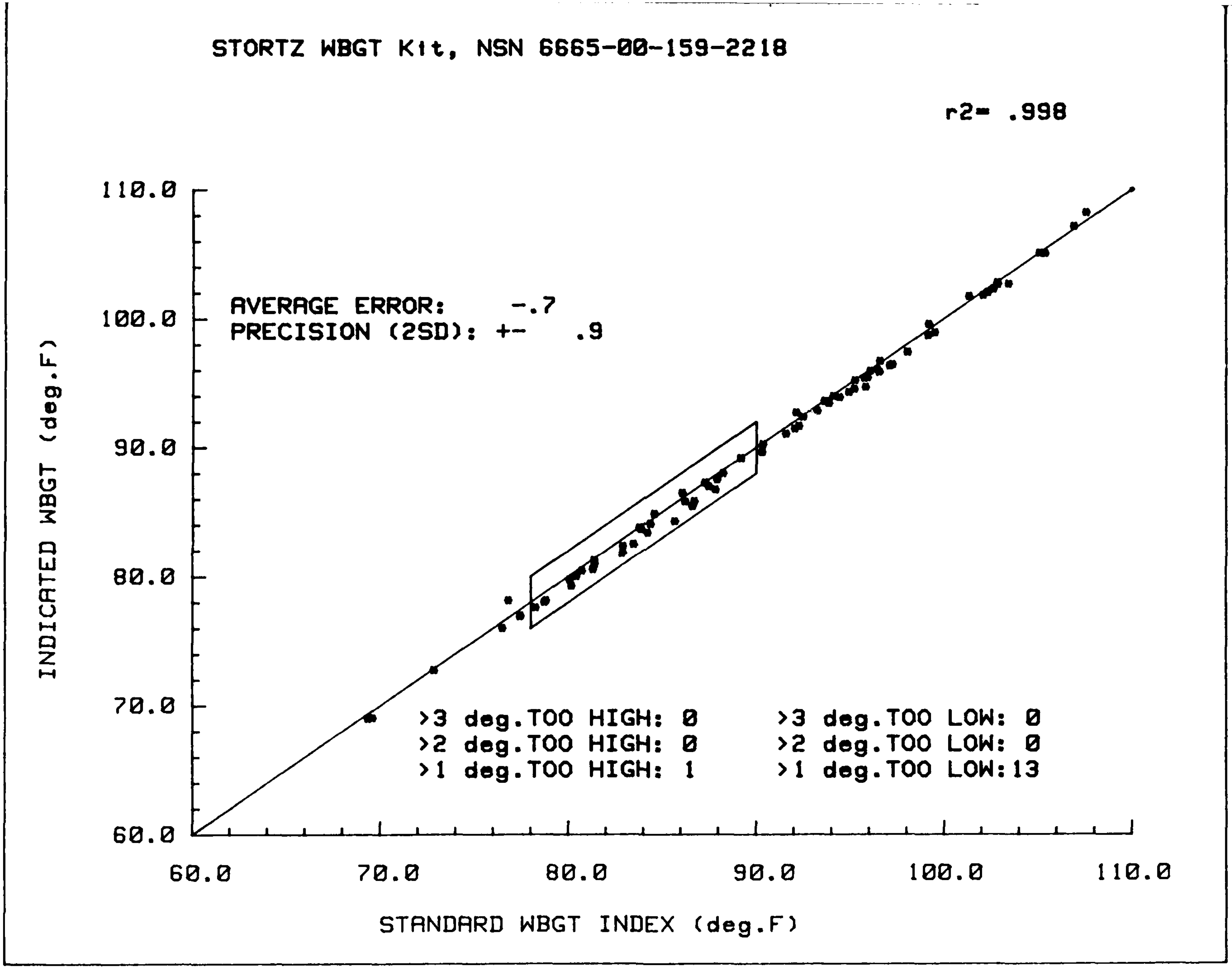

Figure 11. Performance of the Stortz WBGT kit, (NSN 6665-00-159-2218).

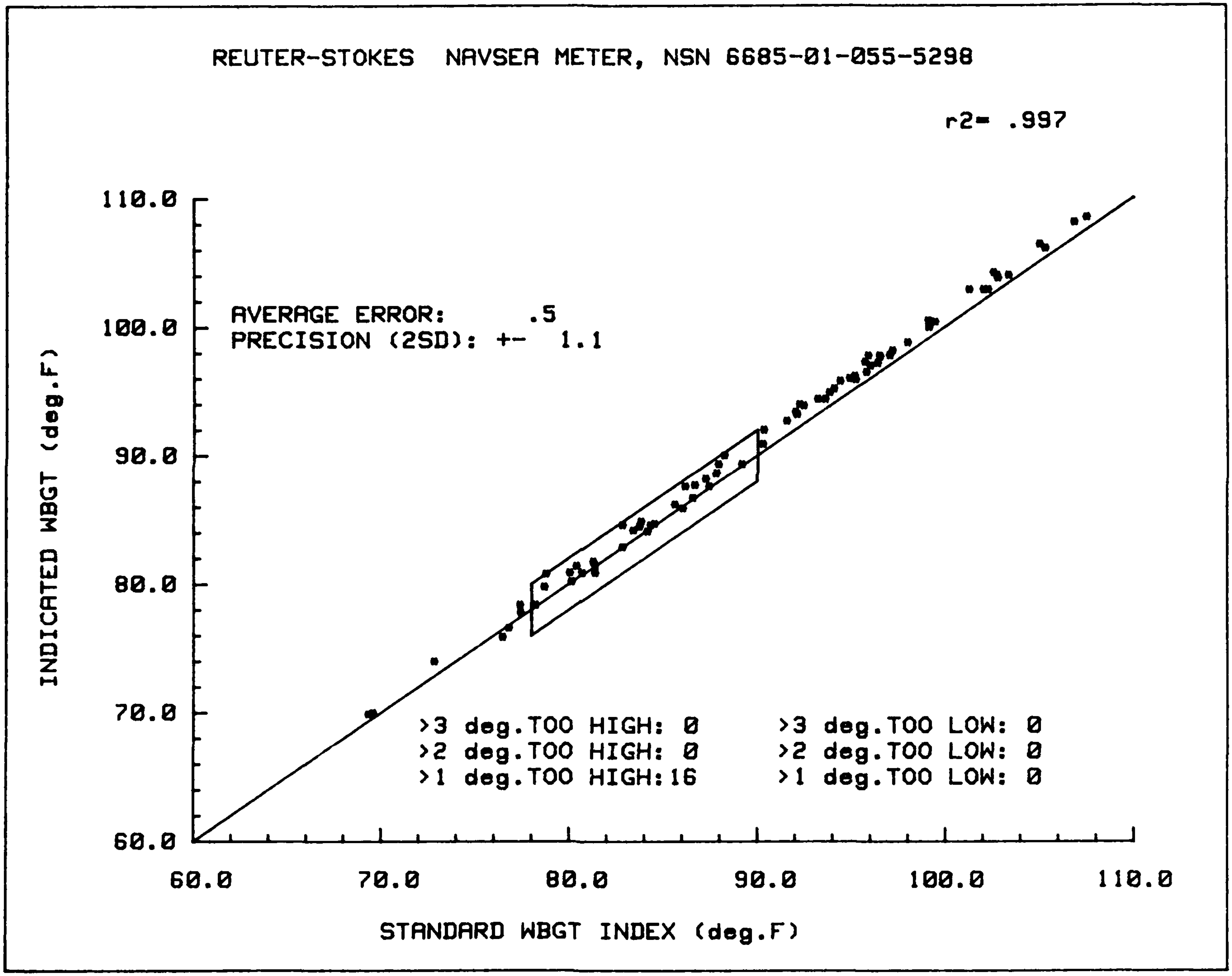

Figure 12. Performance of the Reuter-Stokes NAVSEA meter. (NSN 6685-01-055-5298).

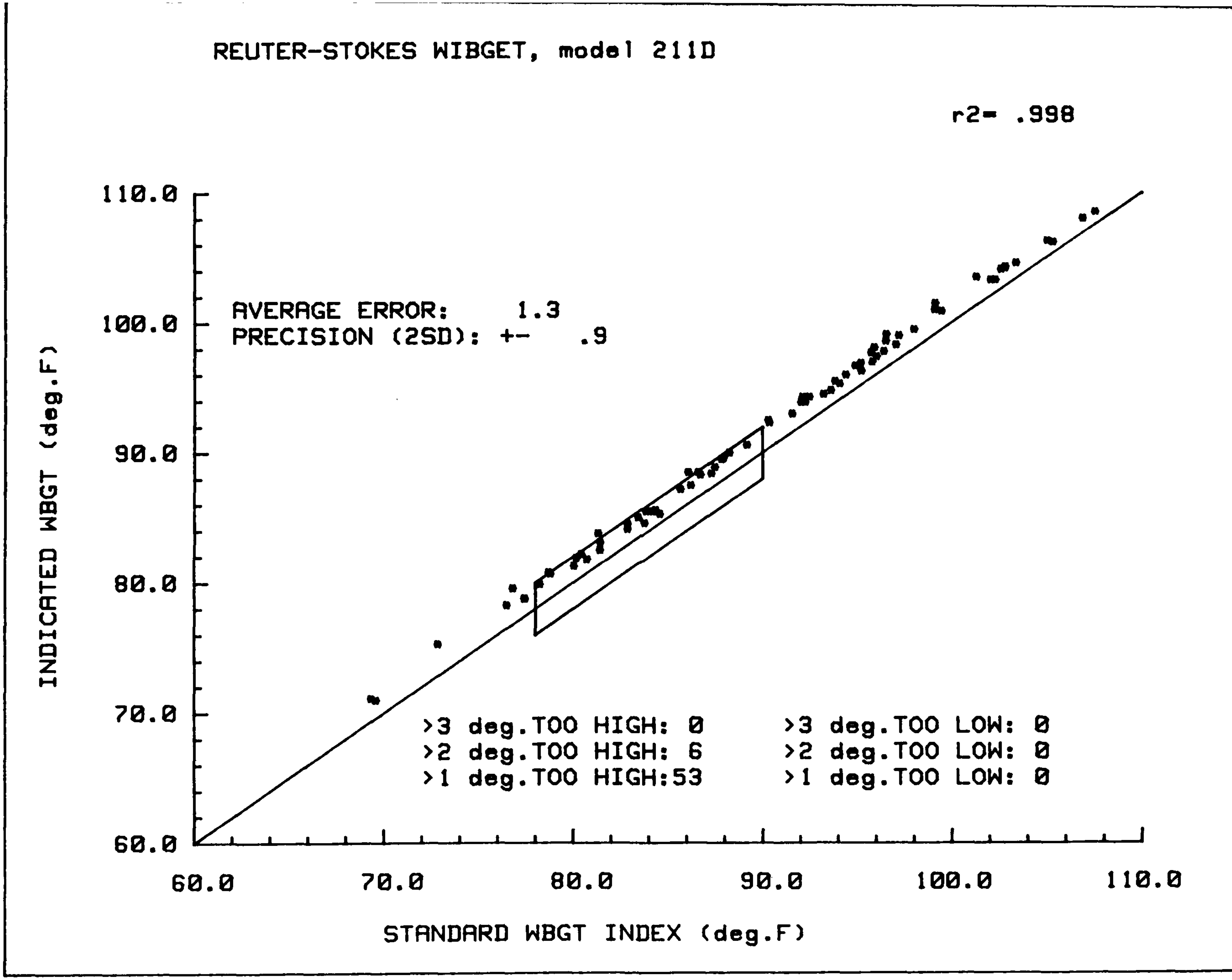

Figure 13. Performance of the Reuter-Stokes Wibget, Model 211D.

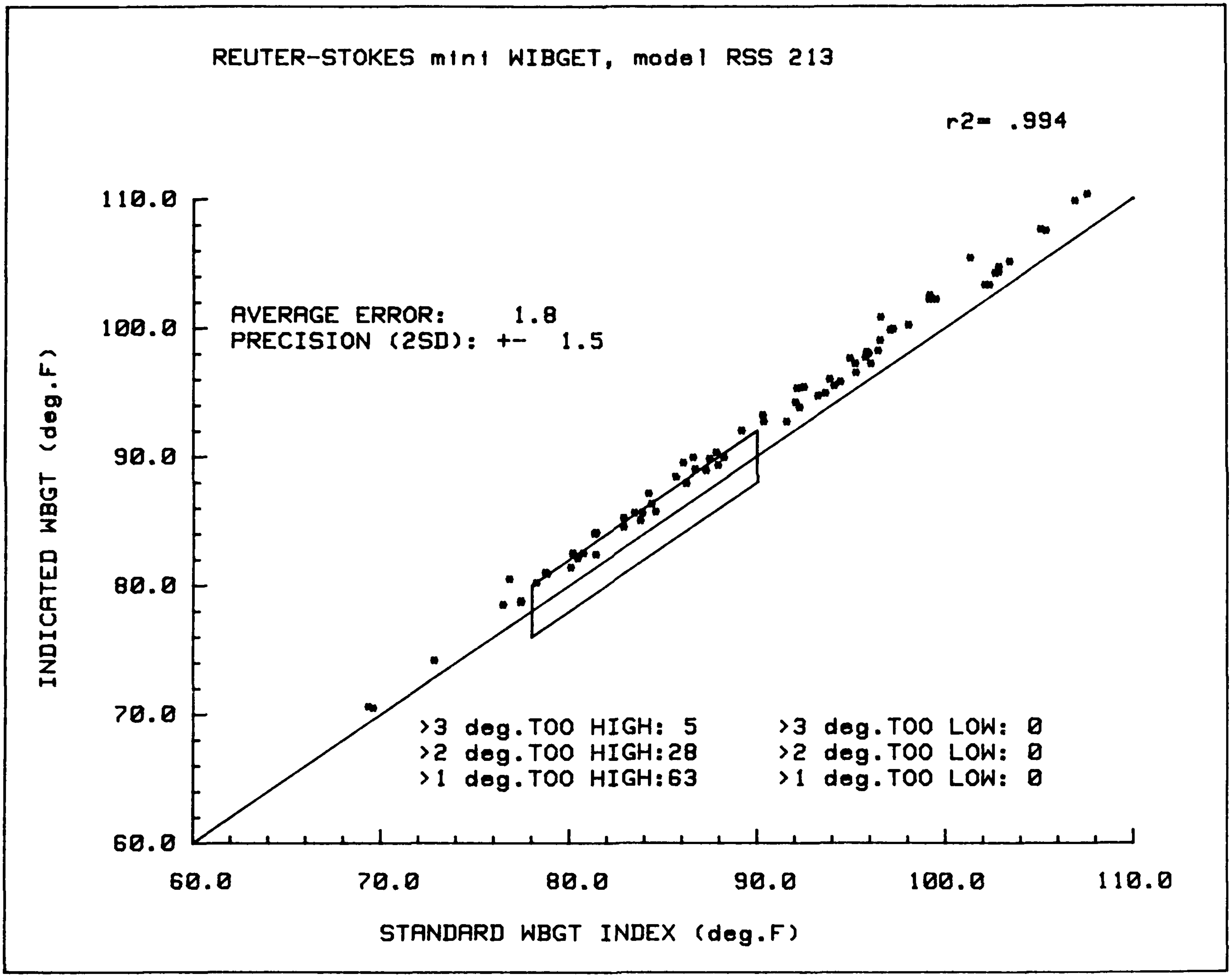

Figure 14. Performance of the Reuter-Stokes mini Wibget, model RSS 213.

TABLE 1. Precision of Heat Stress Measurement Alternatives to the Standard WBGT Apparatus.

a. Conversion Equations for the Botsball.

	SOURCE	EQUATION	AVERAGE ERROR ($\bar{D}$ Statistic) °F	PRECISION (2 S.D.) °F
1.	DA Cir 40-82-3 (2)	WBGT=Bots+2	-2.3	±5.1
2.	Onkram *et al.* (4,5)*	WBGT=1.044xBots-1.745	-2.3	±5.1
3.	Brief & Confer (6)	WBGT=1.044xBots+3.34	+2.8	±5.1
4.	Parker & Pierce (8)	WBGT=1.13xBots-6.56	+0.2	±5.2
5.	Sundin *et al.*(7)	$WBGT=0.118xBots^2-0.56xBots+54.9$	+4.2	±8.7
6.	Present Study	WBGT=1.051xBots-0.021	0.0	±5.1
With Dry Bulb-Wet Bulb (DB-WB) measurements:				
7.	Present Study	WBGT=Bots+0.185x(DB-WB)+0.68	0.0	±1.6

b. Alternative instruments.

	INSTRUMENT		
1.	Stortz WBGT Kit, NSN 6665-00-159-2218	-0.7	±0.9
2.	Reuter-Stokes NAVSEA, meter NSN 6685-01-055-5298	+0.5	±1.1
3.	Reuter-Stokes Wibget, model 211D	+1.3	±0.9
4.	Reuter-Stokes mini Wibget, model RSS 213	+1.8	±1.5

*°F form of their °C equation: WBGT= 1.044 x Bots-0.187

yielded reasonably linear relationships and good correlations at each wind speed. Results are shown in Figure 9. Using the more generally applicable regression constants for all wind speeds combined, we derived the equation:

$$WBGT = \text{Botsball reading} + 0.185 \times (DB-WB) + 0.68$$

The result of applying this equation to our Botsball data from the 75 environments is depicted in Figure 10. Precision ($\pm$2SD) of the conversion of the Botsball reading to the WBGT Index was improved from $\pm$ 5.1°F to $\pm$ 1.6°F with the inclusion of the DB-WB computation.

E. Alternative Instrumentation:

Figures 11 through 14 illustrate the performance of four other WBGT measuring instruments which are available through the Federal Supply system or commercial sources. The Reuter-Stokes NAVSEA meter and the Stortz WBGT Kit (both Federal Supply items, and both listed in TB MED 507) provided very good accuracy ($\pm$1°F) with respect to the standard WBGT apparatus.

The other two electronic devices from Reuter-Stokes, Ltd., the model RSS 211D Wibget and the RSS 213 mini-Wibget, provided good precision but tended to read generally 1 or 2°F higher than the standard WBGT.

F. Summary of Results:

Average error and precision estimates for the tested equations and instruments are summarized in table 1.

V. DISCUSSION

A. Precision Requirements for Implementing Doctrine:

The effective implementation of existing military hot weather doctrine requires fairly accurate measurement of the WBGT Index. Figure 15 is a graphic synopsis of hot weather guidelines from TB MED 507 and DA Cir 40-82-3. Scales at the left are for the WBGT Index and the Botsball (The Botsball scale

WBGT Index AND HOT WEATHER DOCTRINE

WBGT (WGT*)	color code	DA Cir.40-82-3 BOTSBALL (WGT) GUIDELINES	TB MED 507 WBGT TRAINING GUIDELINES
95 (93) – 90 (88)	black	2.0 qt/hr 20/40 WORK/REST (CONDITIONAL)	SUSPEND PHYSICAL TRAINING AND STRENUOUS EXERCISE FOR ALL PERSONNEL
90 (88)	red	1.5 TO 2.0qt/hr 30/30 WORK/REST	NO HEAVY EX. FOR TROOPS WITH <12wks HOT W. TRAINING
– 85 (83)	yellow	1.0 TO 1.5qt/hr 45/15 WORK/REST	NO HEAVY EX. FOR UNACCL. TROOPS, NO CLASSES IN SUN. CONTINUE MOD.TRNG.3rd.week
85 (83)	green	0.5 TO 1.0qt/hr 50/10 WORK/REST	USE DISCRETION IN PLANNING HEAVY EXERCISE FOR UNACCL. PERSONNEL
80 (78) – 75 (73)		0.5qt/hr 50/10 WORK/REST	CAUTION: EXTREMELY INTENSE PHYSICAL EXERTION MAY CAUSE HEAT INJURY

* BASED ON: WBGT = WGT+2 (SERIOUSLY UNDERESTIMATES WBGT IN DRY CONDITIONS)

Figure 15. Graphic synopsis of military hot weather guidelines from TB MED 507 (1980) and DA Cir 40-82-3.

in the Figure assumes the constant 2 ^{O}F offset of the Botsball which has now been shown to be unreliable). Current hot weather doctrine (TB MED 507) as well as proposed guidelines (DA Cir 40-82-3) provide specific guidance for a wide range of physiologically manageable heat stress environments. However, it will be noted from figure 15 that dramatic changes in physiological limitations and requirements occur over a range of only 12^{O}F on the WBGT Index scale (78 to 90^{O}F). Within this 12 degree zone are 4 bands, ranging from 2 to 4^{O}F in width, for which specific guidance has been established. From this perspective, it is apparent that the selection of WBGT methodology suitable for implementing existing doctrine must be based upon a consideration of the accuracy required to achieve effective resolution of the prevailing heat stress level. Clearly, any instrument or computation that showed a range in variability of $\pm$ 5^{O}F from the prevailing WBGT Index would have limited value for determining appropriate water consumption rates or work/rest cycles. Moreover, an instrument that reads 5^{O}F lower than the prevailing WBGT Index poses the risk of causing heat injury when the guidelines are strictly applied (e.g. a WBGT of 90^{O}F is read as 85^{O}F.)

B. Previous Work on the Botsball vs the WBGT:

Most of the previous work intended to provide a practical mathematical scheme for the conversion of a Botsball (WGT) reading to the WBGT Index has had an empirical basis: regression analysis of sets of simultaneously acquired Botsball and WBGT data (5,6,7,8,9). The present study is no exception in this regard. Nevertheless, there are limitations inherent in this approach which are probably responsible for the generally poor performance of these equations noted in our results. The high coefficients of determination (r^2) reported with individual published equations, reflect the sensivity of regression analysis to the composition of the data set employed. Differences in the values of the constants (4,5,6,8) and even the form of the equation (7) may be attributable to data sets having widely different composition with respect to ranges in environmental parameters other than the Botsball and WBGT values, most notably humidity and wind speed. Since the only input into these equations is the Botsball reading, an assumption has been made regarding the adequacy of this single variable to define an acceptable mathematical relationship with the WBGT Index. Although the need for an expedient and practical conversion capability underlies the motivation for this assumption, the lack of precision of these conversion equations strongly suggests that additional environmental variables should be taken into account.

More rigorous evaluations of the performance characteristics of the Botsball and the WBGT based on sound theoretical considerations of the physical responses of these devices, were reported recently by Gonzalez et al (10). Their work predicted substantial divergence between the Botsball and WBGT readings at high ambient temperatures, and low humidity: at 122°F dry bulb, 20% relative humidty, and ~ 600 Watts m^{-2} solar radiation, their predicted Botsball reading was 84.0 when the WBGT Index was 96.1 deg F. This predicted 12°F error is similar to the 11°F error we measured under roughly comparable wind tunnel conditions in the present study.

The dry bulb-wet bulb (DB-WB) correction to the Botsball reading, noted in the Results section, appears to provide a generally acceptable level of accuracy. Although this enhancement could be implemented in field situations using a small sling psychrometer, it would require these two additional measurements and a calculation, thus negating two significant advantages of the Botsball: Simplicity and ease of use. If three measurements (Botsball, WB, and DB) are required for the Botsball to provide an accurate assessment of the prevailing WBGT index, it may be more desirable to make direct WBGT measurements using an acceptable mechanical or electronic device.

VI. CONCLUSIONS:

1. There is a continued requirement for accurate, portable heat stress measurement devices to support implementation of existing military hot weather doctrine and guidelines.

2. Considering the broad range of potential military heat stress environments, the expedient of adding 2 deg.F to the Botsball reading to obtain the WBGT Index (proposed as interim guidance, DA Cir. 40-82-3) does not provide adequate precision for the implementation of existing hot weather doctrine.

3. There is no reliable way to convert a Botsball reading to the WBGT Index without obtaining additional environmental measures.

4. It may be possible to achieve adequate precision using the Botsball if separate wet bulb and dry bulb measurements are made and the following correction is applied:

WBGT = Botsball + 0.185 (DB-WB) + 0.68

5. The hand-held WBGT instruments, listed in TB MED 507 (1980), performed, in the present study, with sufficient accuracy and precision to support safe implementation of existing hot weather doctrine.

VII. RECOMMENDATION:

1. Issue guidance, through all appropriate channels, restricting use of the Botsball to jungle environments only.

REFERENCES:

1. TB MED 507 (NAVMED P-5052-5, AFP 160-1), Occupational and Environmental Health; Prevention, Treatment and Control of Heat Injury. Headquarters, Departments of the Army, Navy and Air Force, (1980).

2. DA Cir. 40-82-3, Prevention of Heat injury, Headquarters, Department of the Army, (Interim changes: Issued July 1982, Expired July 1984).

3. Botsford, J.H., A Wet Globe Thermometer for Environmental Heat Measurement. American Industrial Hygiene Association Journal, 32:1-10. (1971).

4. Onkram, B., L.A. Stroschein, and R.f. Goldman. A comparison of Four Instruments for Measuring WBGT Index Correlations of Botsball with WBGT. USARIEM Technical Report No. T 4/78, U.S. Army Medical Research and Development Command. (1978).

5. Onkram, B., L.A Stroschein, and R.F. Goldman. Three Instruments for Assessment of WBGT and a Comparison with WGT (Botsball). American Industrial Hygiene Association Journal, 41:634-641, (1980).

6. Brief, R.S. and R.G. Confer. Comparison of Heat Stress Indices. American Industrial Hygiene Association Journal, 32:11-16, (1971).

7. Sundin, D., F. Dukes-Dobos, R. Jensen and C. Humphreys. Comparison of the ACGIH TLV for Heat Stress With Other Heat Stress Indices. Paper presented at American Industrial Hygiene Conference, San Francisco, (1972).

8. Parker, R.D.R. and F.D. Pierce. Comparison of Heat Stress Measuring Techniques in a Steel Mill. American Industrial Hygiene Association Journal, 45:405-415, (1984).

9. Beshir, M.Y. A Comprehensive Comparison Between WBGT and Botsball. American Industrial Hygiene Association Journal, 42:81-87, (1981).

10. Gonzalez, R.R., G.N. Sexton, and K.B. Pandolf. Biophysical Evaluation of the Wet Globe Temperature Index (Botsball) at High Air Movements and Constant Dew Point Temperature. Paper presented at the Fourteenth Commonwealth Defence Conference on Operational Clothing and Combat Equipment, Australia, (1985).

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