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NWC TP 4834
Part 3

Evolution of the NWC Thermal Standard

Part 3. Application and Evaluation of the Thermal Standard in the Field

by
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Brigham Young University
and
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Naval Weapons Center

MAY 1977

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FOREWORD

The work described in this report was conducted from June 1971 through June 1976. The program was accomplished by Brigham Young University under Contract No. N00123-71-1706 and N6-530-76-C-0091. The Naval Weapons Center (NWC), China Lake, California, was the sponsoring activity and the work was supported by the Naval Air Systems Command under AirTask A3303300/008B/6F31332300.

Mr. H. C. Schafer of NWC was the technical coordinator. This report is released for information at the working level. Because of the continuing nature of the study, it is subject to refinement or revision. The report was reviewed for technical accuracy by Wallis Parmenter and Kenneth Katsumoto.

Released by
C. J. DI POL, *Head*
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30 June 1976

Under authority of
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(U) *Evolution of the NWC Thermal Standard. Part 3. Application and Evaluation of the Thermal Standard in the Field*, by Dr. Richard D. Ulrich, Brigham Young University, and Howard Schafer, NWC. China Lake, Calif., Naval Weapons Center, May 1977, 66 pp. (NWC TP 4834, Part 3, publication UNCLASSIFIED.)

(U) Part 1 of the report series described the theoretical concepts of a thermal standard, and Part 2 the comparison of predicted and experimental data. The objective of Part 3 was to use the thermal standard to determine field thermal response for ordnance stored unsheltered. The study was conducted from 1971-1976.

(U) The thermal standard has proven to be a valuable tool as a means to (1) predict hourly surface temperatures of adjacent ordnance, replacing the need to instrument a large variety of ordnance, (2) predict cumulative probability-temperature curves for various items, and (3) generate a "typical day" and, using only 10% of the daily maximum and minimum temperatures, predict the annual cumulative probability-temperature curve accurately for various ordnance items. This will allow for the relatively simple reduction of a large volume of data.

(U) Future uses, e.g., environmental work, for the concept of the thermal standard are suggested.

CONTENTS

ACKNOWLEDGEMENT

This report is the result of a combined effort by H. C. Schafer (Code 45330) at the Naval Weapons Center and Dr. R. D. Ulrich, Professor of Mechanical Engineering at Brigham Young University (BYU). Also, Frank Markarian, Branch Head of NWC Code 4061, and Tom Cooper, Professor of Mechanical Engineering at Naval Post Graduate School, have made major contributions. Tim Maher and Alan Parkinson, students at BYU, have also contributed. Billy Martin instrumented the ordnance and reduced the data for the diurnal comparisons.

INTRODUCTION

The Thermal Standard has been under development for several years. The preliminary aspects and exposure correlations have been published in the two previous parts to this report (Refs. 1 and 2). The other two parts of this report are summarized as follows.

SUMMARY OF PART 1

The "thermal standard" was conceived to be a simple, inexpensive device which could be placed at any location of the world to determine unsheltered exposure response temperatures of naval ordnance. The thermal standard was to be "representative" of a large variety of expensive ordnance items which might be dump stored.

Analysis showed that many ordnance type items could be represented by a thin metallic shell filled with a low thermal conductivity material. It was also shown that for diameters between 2.5 and 24 inches the resulting temperature was relatively insensitive to diameter. Thus, the thermal standard recommended was a 6-inch-diameter, stainless steel spherical shell filled with RTV-511. There were five thermocouples, four attached to the steel surface and one at the center. The thermal standard was to be exposed to the same circumstances as the dump stored ordnance items and the thermal responses were to be compared.

SUMMARY OF PART 2

A few devices as described in Part 1 were fabricated and placed in dump storage areas world wide. After temperature response data from these thermal standards were collected for about 300 days at two separate storage dumps, a comparison of the predicted temperature response of the thermal standard from meteorological data was done with experimental values actually derived from the devices. This was done for the maximum temperature attained during each day. The comparison indicated that the thermal standard was amenable to analysis by theory and it appeared to be "typical" of dump stored naval ordnance. That is, the temperatures attained by the thermal standard were typical of those attained by a previously instrumented and similarly exposed variety of naval ordnance.

Based on these results, it was concluded that further development and evaluation should proceed on the thermal standard as a method of prediction of dump storage response temperatures in naval ordnance.

PART 3 OBJECTIVE

The objective of this part of the report is to present the work done to evaluate the comparison of ordnance thermal response to that of the thermal standard in the field, to demonstrate its wide range of applicability, and to make recommendations concerning its future use.

This report first presents the results of a series of hourly temperature predictions for some field instrumented naval ordnance and then compares the prediction with the experimental results. This is followed by a discussion of the cumulative-probability versus temperature method of data presentation and several cumulative-probability temperature predicted curves are compared with reduced experimental data. Then some possible future applications of the thermal standard are presented. The basic report is concluded by a parametric study based on an analytical model developed to predict the diurnal temperature variation of a missile surface.

THERMAL STANDARDS IN THE FIELD

About twenty thermal standards have been built of which 13 have been placed in possible typical dump storage locations around the world. These locations were selected to include some of the extreme environments of the world. They were placed in:

1) Hot, arid desert regions:
    - China Lake, Calif. (2)
    - Death Valley, Calif. (1)
2) Tropic regions:
    - Panama Canal Zone (1)
    - Thailand (1)
    - Subic Bay, Phillipine Islands (1)
    - Queensland, Australia (2)
3) Cold and polar regions:
    - Alaska (both coast and interior)
    - Ft. Richardson, Anchorage (1)
    - Ft. Greely, Delta Junction (1)
    - Resolute Bay, Canada (1)
    - Canadian Forces Base, Alert Canada (1)

Two to seven years of continuously recorded data have been taken in the tropics, desert and arctic. Adjacent to most of the thermal standards were well instrumented ordnance items. These included rocket motors and missiles, rockets in containers, small-arms ammunition, bombs, gun projectiles, and fuses. Also, local air temperature was monitored, and in most locations, normal meteorological information, including solar radiation, relative humidity and wind speed was available through the world network of meteorological reporting stations.

HOURLY TEMPERATURE PREDICTION-COMPARISON

A major series of measurements was made during the summer of 1974 at China Lake at the NWC Salt Wells dump storage measurement site. Temperatures were measured on Shrike and Sidewinder missiles in and out of their shipping containers. In addition, local meteorological conditions, such as ambient air temperature, solar radiation, wind speed, and relative humidity, were monitored for use as input data for analytical predictions.

Three separate predictive techniques were evaluated. These were (1) analytical solutions which approximated the input conditions through the use of sine and step functions, (2) estimations of the thermal response of the ordnance of interest from the temperature history of a thermal standard (Ref. (1)), and (3) numerical computer solutions. Predictions were made by Professor T. E. Cooper of the Naval Post-Graduate School, Monterey (analytical solution), Professor R. D. Ulrich of Brigham Young University (computer and thermal standard solutions), and C. F. Markarian of the NWC Aerothermodynamics Branch, Code 4061 Naval Weapons Center (computer solution).

The objectives of these measurements and analytical predictions relative to this report were twofold. One, evaluate the thermal standard as a tool for diurnal temperature predictions at specific locations on a variety of ordnance items. Two, compare the thermal standard predictive ability with the pure analysts' ability, using meteorological data, to predict the same diurnal temperature variations.

This was another of the critical field evaluations of the thermal standard. If analytical techniques used by heat transfer experts can predict, for example, the thermal response of the top thermocouples on a Shrike rocket motor as well as the thermal standard, then the thermal standard might not be needed for that future purpose. Thus, this series of experiments was designed and the analytical experts were commissioned to predict, using their best knowledge inputs, the temperature response of several thermocouples at specific locations. The experts were given the hourly meteorological data for the several days needed, but they did not know the experimental results until after they had submitted their predictions. In order to make the thermal standard predictions only the thermal standard temperature records as well as the ambient air temperature records were specified.

For all of the predictive techniques it was necessary to assume values for the absorptivity (of solar energy) of the ordnance or shipping container surfaces. In addition, the analytical techniques utilized additional assumptions which were based on prior art. The more sensitive assumptions were sky temperature, material properties, radial heat flow (1-D) only, sometimes no internal temperature gradients, etc. Each assumption induces error in the solution and so "exact" answers were not anticipated. Also, previous measurements on "identical" ordnance items instrumented with identical thermocouples did not yield identical thermal responses. The measured temperature response differed by as much as 6-7°F for similarly located thermocouples on two different ordnance items at the same time of day. Hence, two temperatures which are within about 5°F of each other are considered to be essentially the same value. Thus, predictions within 8-10°F of the measured values are considered to be very good. Of course it would be expected that a few errors would be randomly higher or lower but not consistently higher or lower, lest one would suspect to find a reason for the error.

ORDNANCE TEMEPRATURE MEASUREMENTS

Temperature measurements for comparison with predictions were obtained on an AGM-45A-3 Shrike missile and an AIM 9H-2 Sidewinder missile. Both missiles had operational guidance and control sections and simulated warheads and rocket motors. Desert sand was used as a simulant for the rocket motor grain. A plastic simulated the explosive in the warhead section of the Sidewinder. Both missiles were extensively instrumented with copper-constantan thermocouples. The missiles were exposed in an all-up configuration, although wings and fins were not installed.

Measurements were taken on the missiles both in and out of their standard shipping containers. The Shrike containers consisted of a MK 399 Mod 0, light-navy-gray, steel, single-store, shipping container and a three-missile shipping container with a white plastic top and gray aluminum bottom. The Sidewinder shipping container was white plastic and accommodated four missiles. During the sequence with multi-store containers dummy missiles were used in addition to the instrumented missile in order to fill the container as it would be in a storage situation. The containers were also instrumented with thermocouples.

In addition to the ordnance temperature, various meteorological conditions, such as, ambient air temperature, wind speed and direction, and relative humidity, were monitored at the measurement site. Solar radiation as measured by a pyrheliometer was obtained from the Range Instrumentation Support Division. Data were recorded continuously throughout the summer of 1974. The dates selected for analysis and the corresponding missile configurations are listed below:

Date	Test Configuration
12 Jun 1974	Shrike out of container
28 Jun 1974	Shrike in single store container
29 Aug 1974	Sidewinder out of container
11 Sep 1974	Shrike and Sidewinder in multi-store containers

The details of the locations of all the thermocouples for all the measurements are given in Reference 4.

Prior to the measurements described above, temperature measurements were taken on three identical Mk 33 Mod 0 gray containers. The purpose of these measurements was to investigate the effect of the ground surface on the container temperature. The three containers were placed within twenty feet of each other on surfaces of asphalt, concrete, and sand. The complete circumferential temperature distribution was measured simultaneously on each container. The results showed no noticeable difference in the temperature around the container for the various surfaces tested. This could be explained by the higher reflected solar wave-length radiation from the sand and concrete compensating for the higher long wave radiation emitted by the asphalt surface. The differences in the surfaces may be more pronounced on a white container which would not absorb as much of the reflected solar radiation but would absorb the emitted long wave radiation. All Shrike and Sidewinder measurements were obtained with the test items placed on sand.

The details of the analyses are presented in Reference 4.

RESULTS AND DISCUSSION

The first results are for the all-up Shrike rocket motor, and are shown in Figures 1, 2, 3, and 4 for the top, bottom, east and west, respectively. The maximum and minimum temperatures and the times they occurred are shown in Table 1 for the comparisons. The comparison of the three analytical methods indicates that the thermal standard was significantly more accurate overall in predicting the maximum values of ordnance response temperatures. It over predicted the minimum temperature on the top of the round because the thermal standard was bare metal, while the Shrike was painted. The paint has a very high emittance to the night sky while the bare metal emits very little at sky temperature wave lengths. The bottom and sides of the thermal standard were much better predictors of the minimum temperature for the missile

Differences of 5°F or less probably have no significance. That is, on a given day they may be high or low by a few degrees and that is as close as can be expected for prediction under any field circumstances. The low prediction of both Markarian and Cooper is probably attributable to the use of Brunt's equation for temperature. Apparently, there were particles in the sky at high altitudes which nullify Brunt's equation and make the effective sky temperature 30-40°F higher than Brunt's equation would predict. The reason for this suggestion is that the results of both approaches were uniformly low in the night as well as the daytime. The Ulrich analytical prediction did not use Brunt's

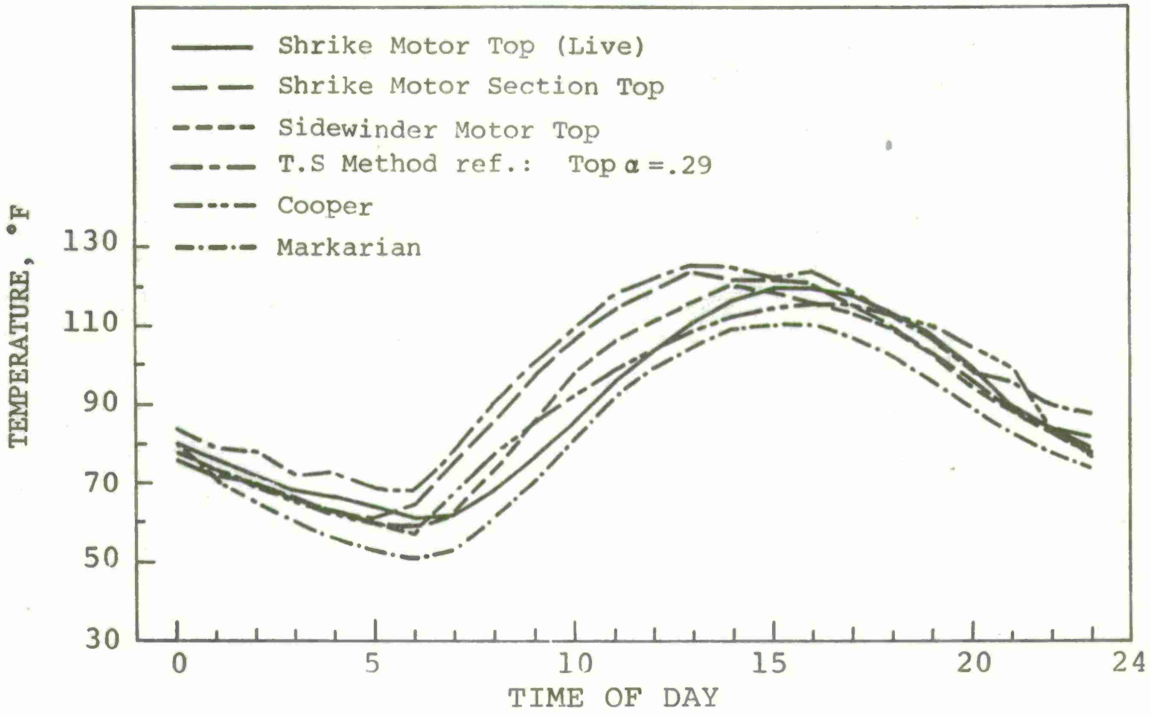

Figure 1. Comparison of Analytical Solutions with Shrike Top Experimental Temperatures (12 June 1974)

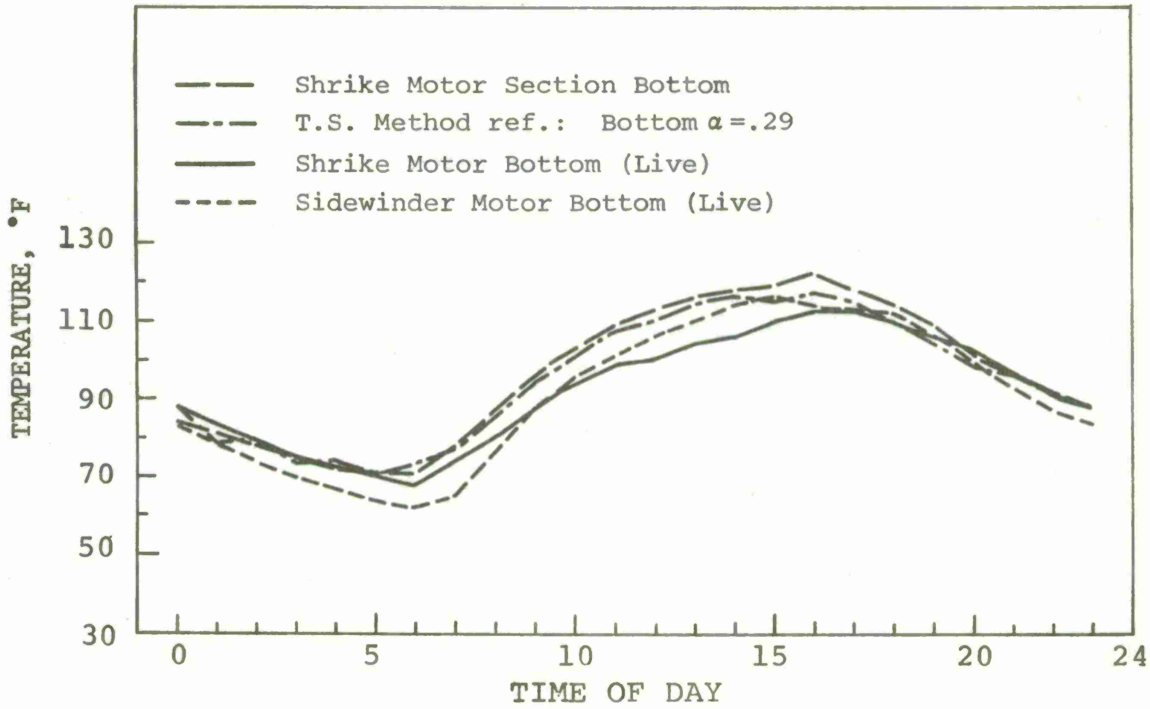

Figure 2. Comparison Using Thermal Standard Method-Shrike Bottom (12 June 1974)

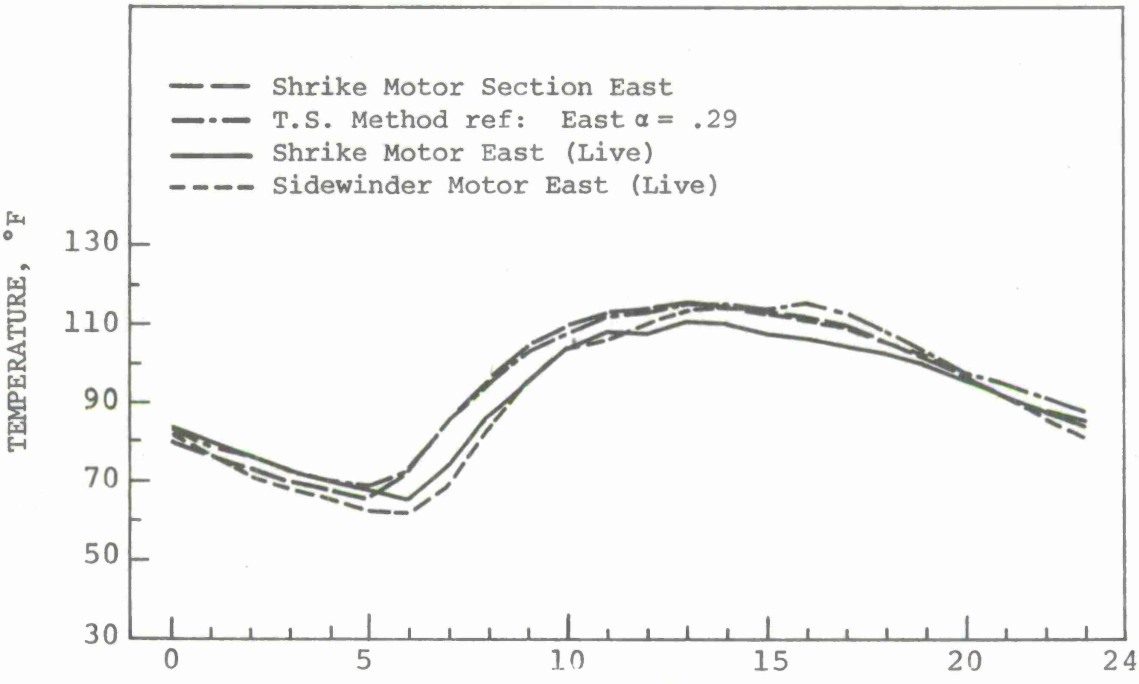

Figure 3. Comparison Using Thermal Standard Method - Shrike East (12 June 1974)

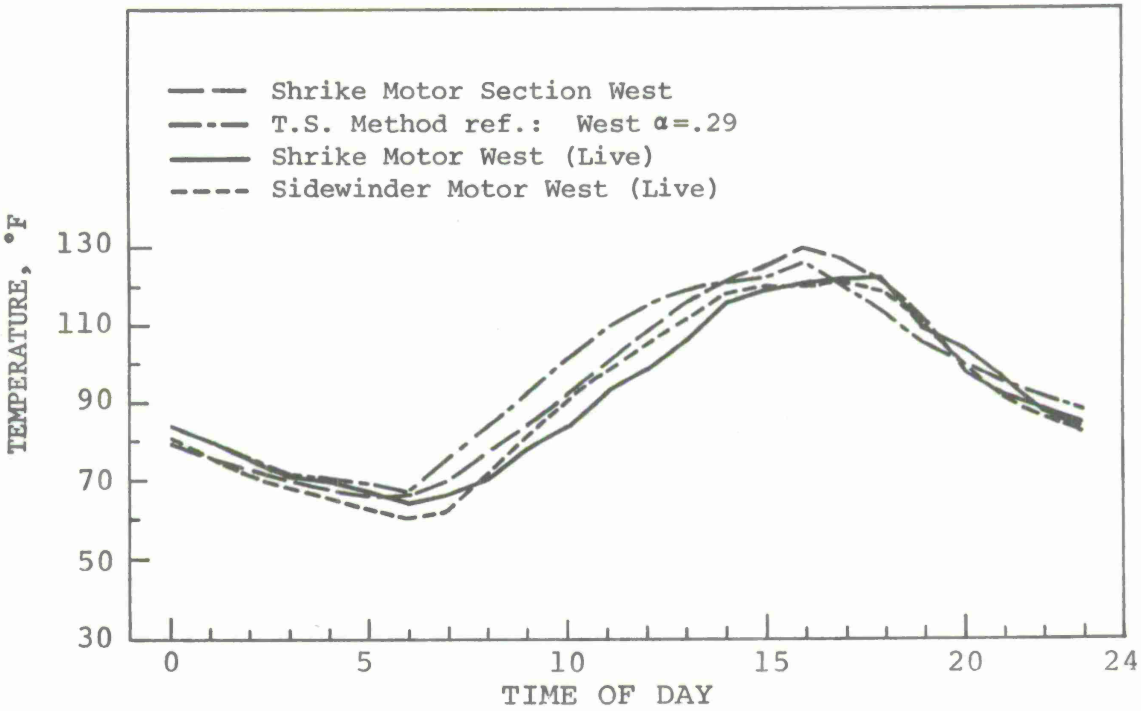

Figure 4. Comparison Using Thermal standard Method - Shrike West (12 June 1974)

TABLE 1. Maximum and Minimum Temperature Comparisons.

	Top		Bottom		East		West	
	Max	Min	Max	Min	Max	Min	Max	Min
	Shrike (June 12, 1974)							
EXPERIMENTAL	123-1300	61-0500	122-1600	71-0500	116-1300	65-500	130-1600	66-0500
Thermal Standard	125-1300	68-0600	117-1600	71-0500	116-1600	69-500	126-1600	67-0600
Markarian	110-1500	51-0600						
Cooper	115-1700	57-0600						
Ulrich	122-1400	60-0600	116-1700	72-0600	107-1200	65-0500	118-1600	64-0600
	Shrike Container (June 28, 1974)							
EXPERIMENTAL	161-1400	54-0500	123-1800	65-0500	150-1100	56-0500	157-1400	56-0500
Thermal Standard	156-1400	61-0500	127-1400	62-0500	133-1100	62-0500	151-1500	62-0500
Markarian	148-1400	38-0600						
Cooper	125-1500	54-0300						
	All Up Sidewinder (August 29, 1974)							
EXPERIMENTAL	107-1500	56-0600	108-1500	62-0700	105-1500	60-0600	110-1600	59-0700
Thermal Standard	111-1400	59-0600	105-1400	60-0600	104-1300	59-0600	111-1500	58-0600
Cooper	104-1600	58-0700						
	Multi Store Container (September 11, 1974)							
EXPERIMENTAL	102-1500	61-0700	107-1600	69-0700	NO DATA		110-1600	63-0700
Thermal Standard	111-1500	66-0700	109-1500	66-0700			118-1500	67-0700

equation but used $T_{sky} = T_{air} - 20$, while Brunt's equation gave the approximate values $T_{sky} = T_{air} - 60$. A discussion of Brunt's equation and sky temperature is in Reference 3.

The information used in the thermal standard method was the thermal standard temperature responses and meteorological air temperatures. These two parameters, along with the assumed absorptivity ratio, are sufficient to predict any other surface temperature profile. The theoretical calculation methods used air temperature, humidity, wind velocity, solar radiation and the assumed absorptivities (both short and long wave length). This seems to give an advantage to the thermal standard method since it alone integrates all the thermal forcing functions into its own surface temperature. It has inherently the capacity to store energy and conduct heat toward the center and back to the surface, making it truly a thermal integrator.

The method for prediction using the thermal standard was relatively simple compared to any of the analytical techniques. The temperature for any time, e.g. T_{13}, was

$$T_{13} = (T_{air})_{13} + (T_{TS} - T_{air})_{13} \frac{\alpha}{\alpha_{TS}} \qquad (1)$$

This was repeated for each hour of the day and the results plotted for comparison.

This method used less information (data) than the analytical methods but, on the otherhand, it does have the advantage of being a "spy in camp", whereas the analytical methods used information from instruments (wind, solar radiation, humidity) which can be viewed as surrounding the camp.

Referring again to Table 1 and Figures 5-8, the thermal standard prediction method was near the top maximum temperature for the Shrike Container (June 28, 1976). All the predictions were low: the thermal standard was low because of an α assumed too low; and Markarkan was low because of the use of Brunt's equation and an α too low. Cooper was only predicting an average temperature and this prediction was also low, 125°F predicted to 142°F experimental, again the assumed α was probably too low. Both Markarian and Cooper used an α_{solar} of 0.6 and α_{long} of 0.9. The thermal standard method used an α of 0.8. A real problem in this type of analytical or predictive work is a lack of knowledge of absorptive and radiation properties in general for particular items. There is a need for a low cost instrument which will measure these properties to the order of plus or minus 5-10%.

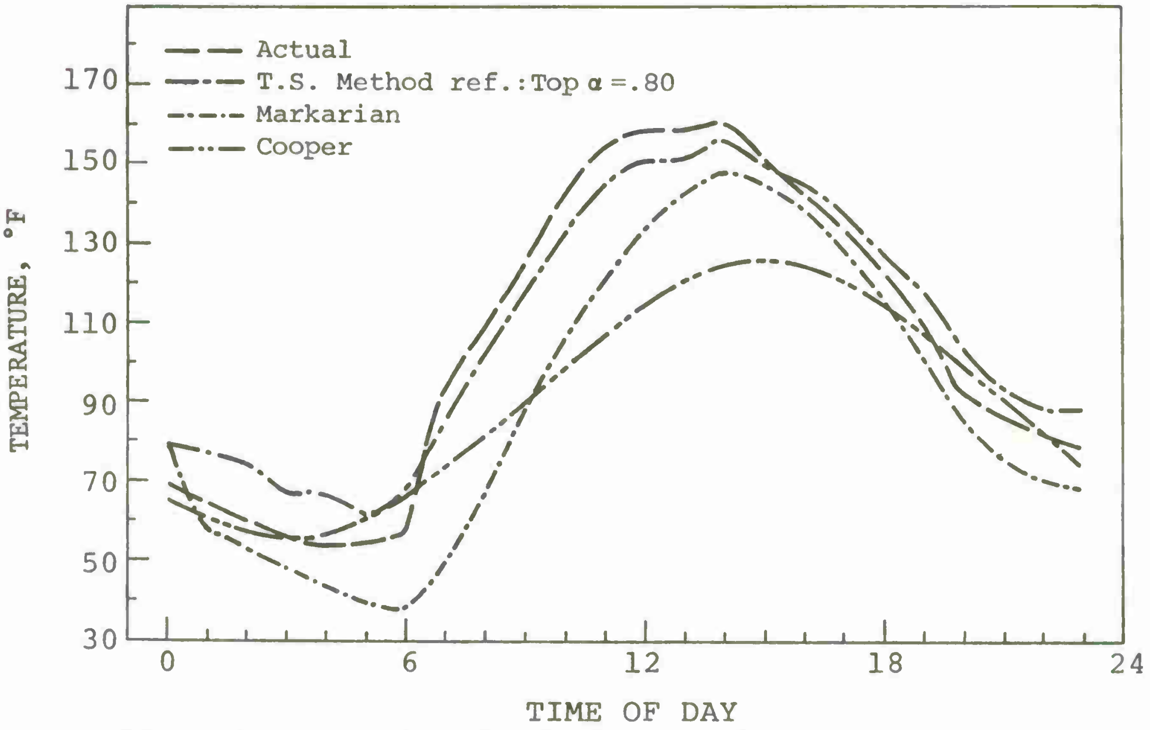

Figure 5. Comparison for Shrike Container Top (28 June 1974)

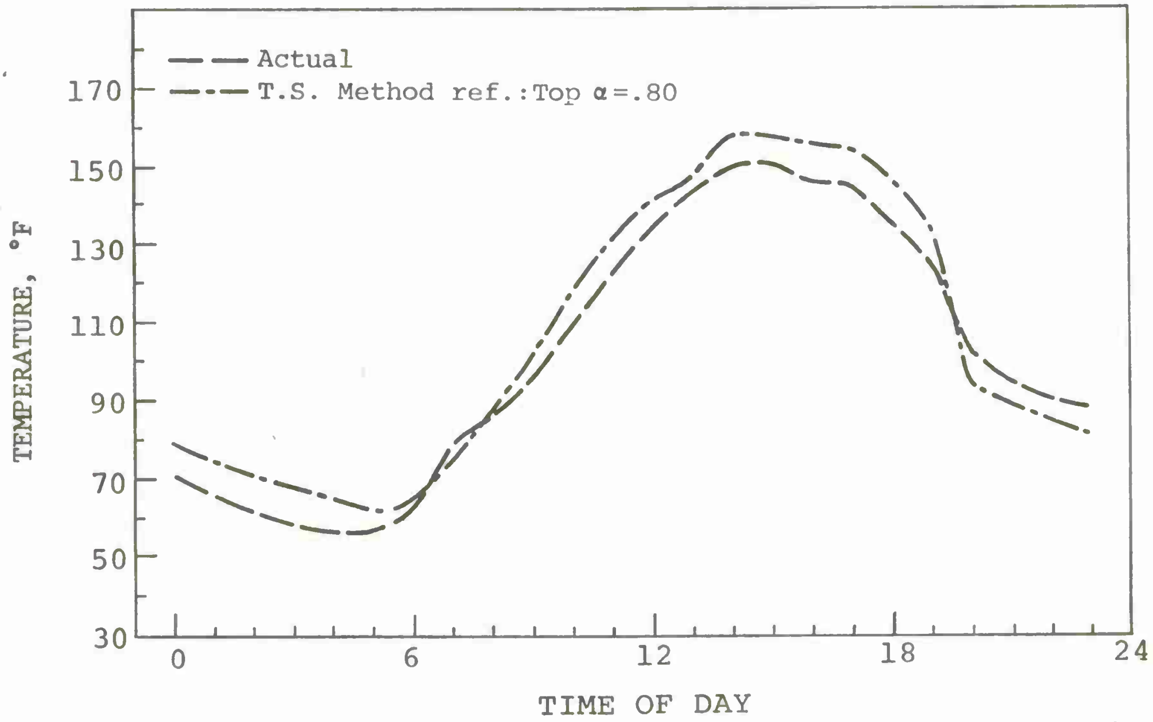

Figure 6. Comparison for Shrike Container West (28 June 1974)

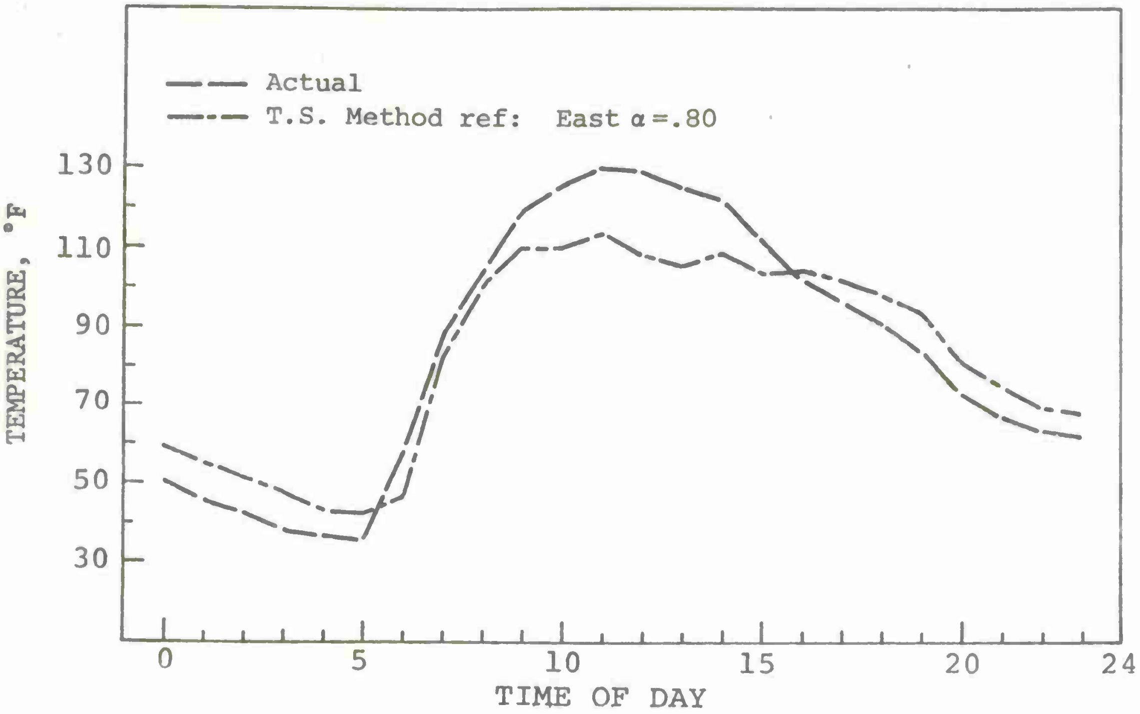

Figure 7. Comparison for Shrike Container East (28 June 1974)

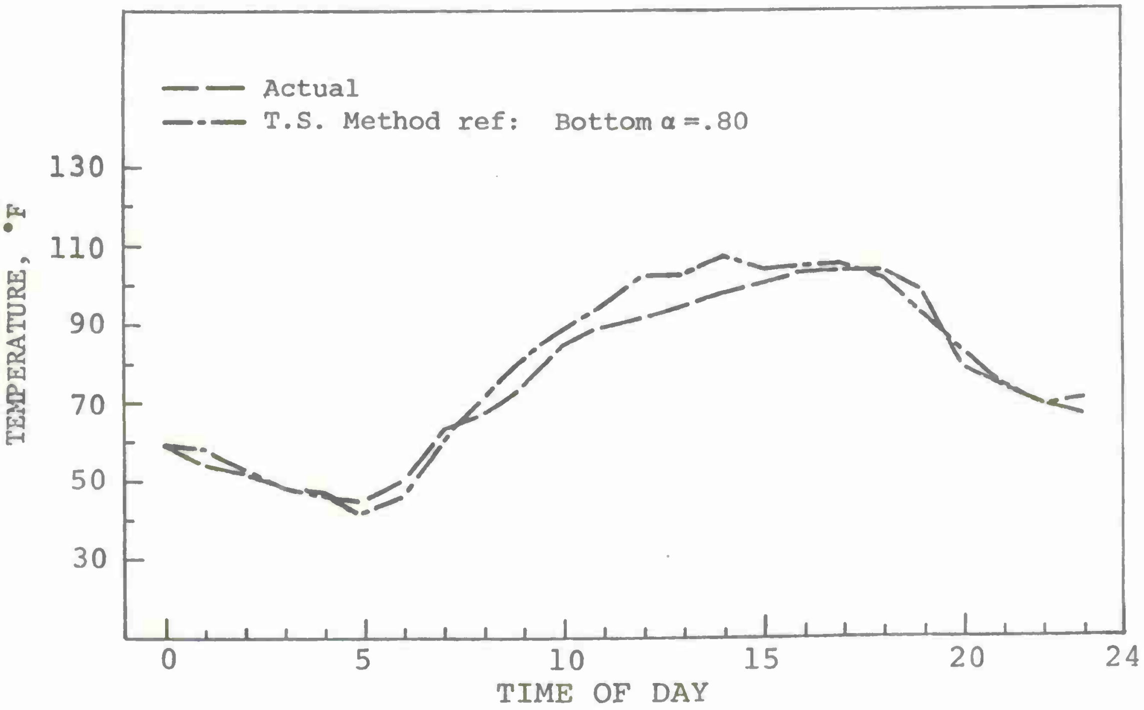

Figure 8. Comparison for Shrike Container Bottom (28 June 1974)

The thermal standard prediction for the all-up Sidewinder (August 29, 1974) (see Figures 9 through 12) had a maximum error of 4°F for all four positions and for maximum and minimum temperatures. This was considered to be an excellent comparison.

The predictions for the Multi-Store Container as shown in Figures 13 through 15 were all 2-9°F high. The reason for this is not known. It was anticipated that if any errors were present they would be on the low side. This is because the low flat object should have a lower cooling heat transfer coefficient than the thermal standard.

The average error of all 30 thermal standard predictions in Table 1 is less than 1°F ($\sigma = 5$). There seems to be no general trend of errors in the sign (+ or -) of the error. Based on predictions, in comparison to the other methods, the thermal standard is an excellent tool for ordnance temperature prediction and should be exploited further.

The preceding discussion has related mainly to rocket motors and in particular to motor skins. This was because the thermal standard was designed with rocket motors and warheads in mind. The following comparisons deal with other sections of the missile system including the internal parts of the motor, guidance and computer sections, both skins and internal parts.

Figures 16 through 24 show these various comparisons. Where internal temperatures were predicted, the center thermocouple in the thermal standard was used in place of the surface thermocouples for surface prediction. Otherwise the prediction equation was the same as equation (1). Here again, these figures show very excellent agreement between the thermal standard prediction and the measured values. Some of the internal locations were also predicted analytically as shown in Figures 19, 20 and 21. The trends of the predicted curves are similar to the measured, but the peak temperatures are generally lower. This is probably due to the same problem observed in surface temperature prediction, i.e. the use of Brunt's equation for sky temperature calculations gave low predictions. It would be difficult to get good internal temperature predictions since the internal temperature calculations depend on surface temperature calculations.

The Shrike container predictions were made using an assumed absorptivity for the container of 0.8. Figure 25 shows the effect of using 0.75 and 0.85 as compared to 0.8 as well as the actual curve. This shows a predicted maximum temperature rise of about 3°F for each 0.05 increase in the assumed absorptivity. It is impossible to know, in general, the actual value of absorptivity of a surface, which depends on the specific paint originally used, oxidation or aging of the paint, corrosion, erosion and other factors.

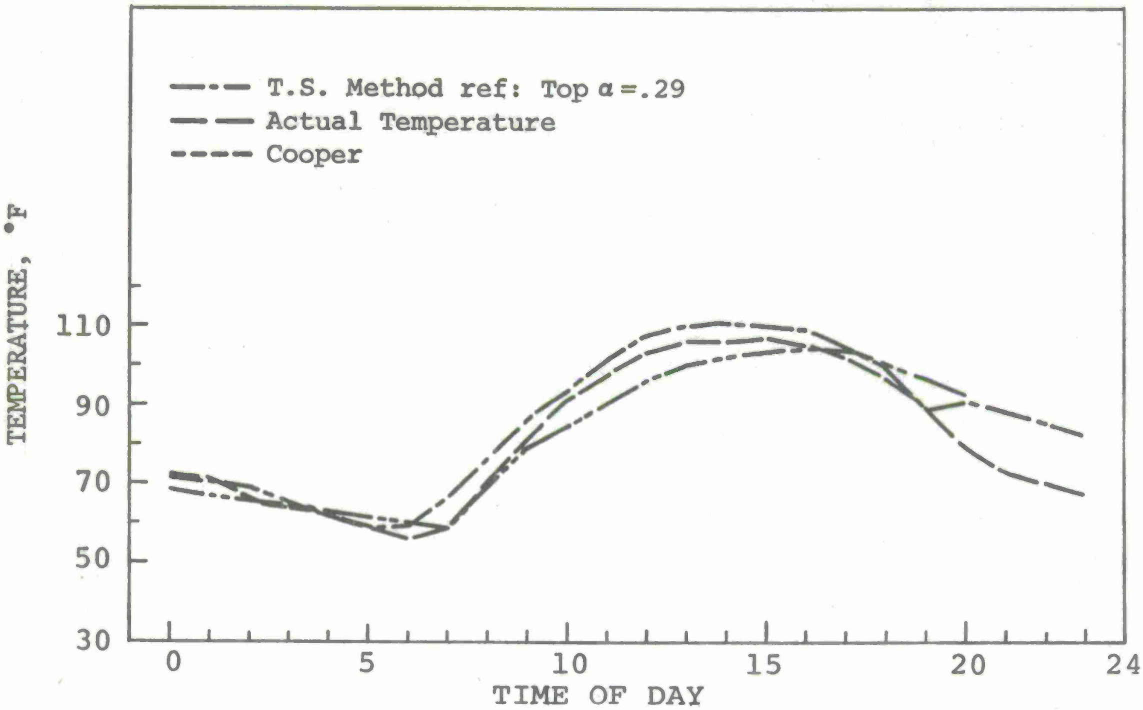

Figure 9. Comparison for Sidewinder Motor Top (29 August 1974)

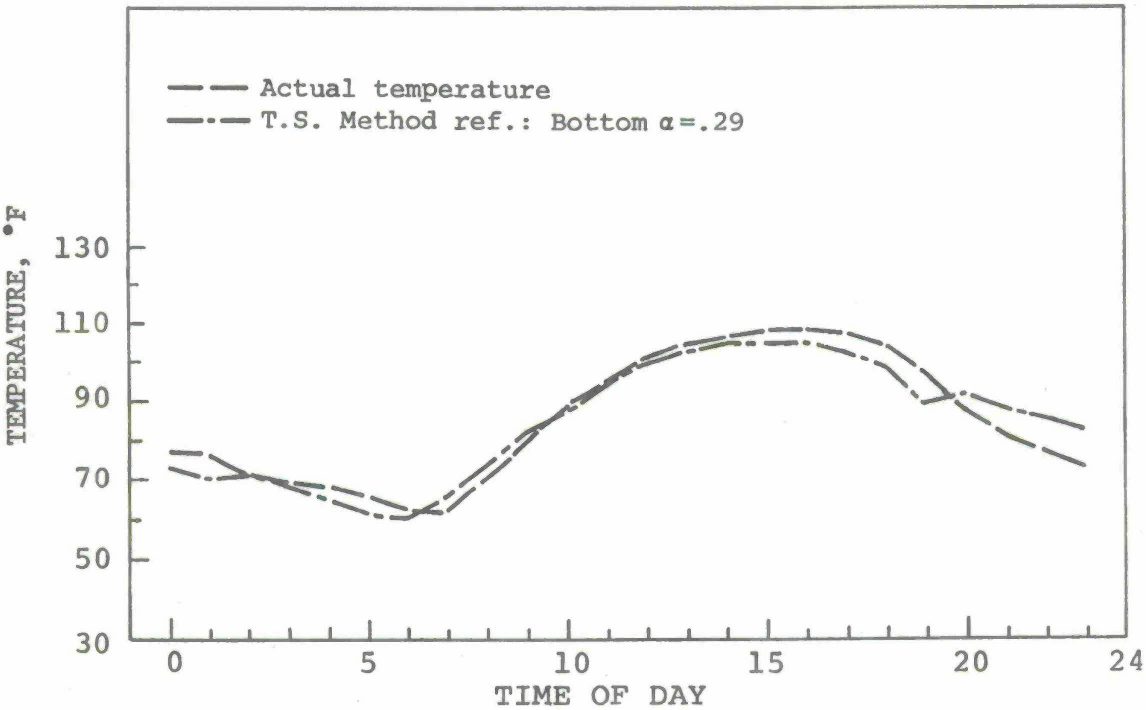

Figure 10. Comparison for Sidewinder Motor Bottom (29 August 1974)

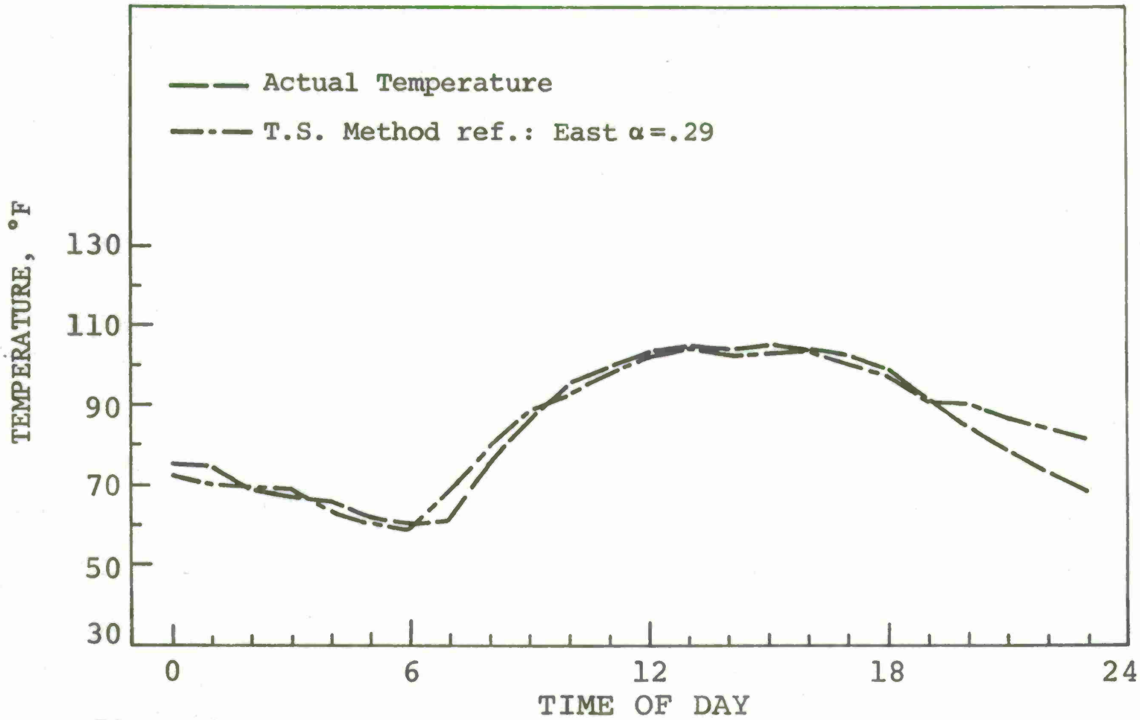

Figure 11. Comparison for Sidewinder Motor East (29 August 1974)

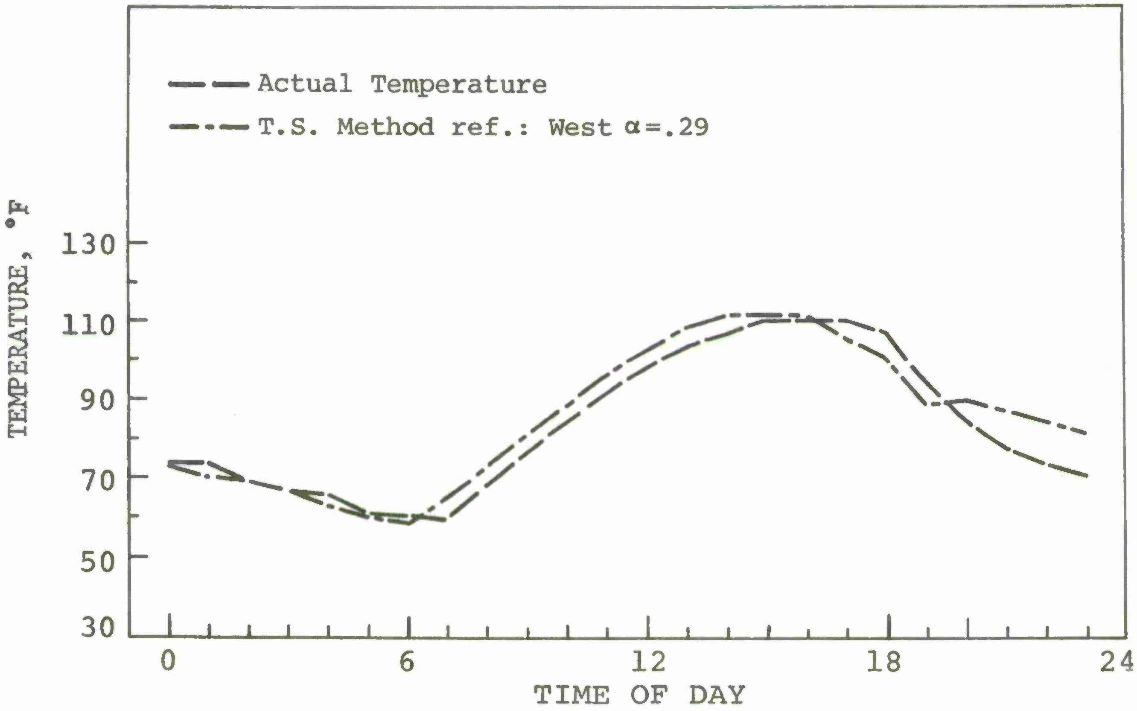

Figure 12. Comparison for Sidewinder Motor West (29 August 1974)

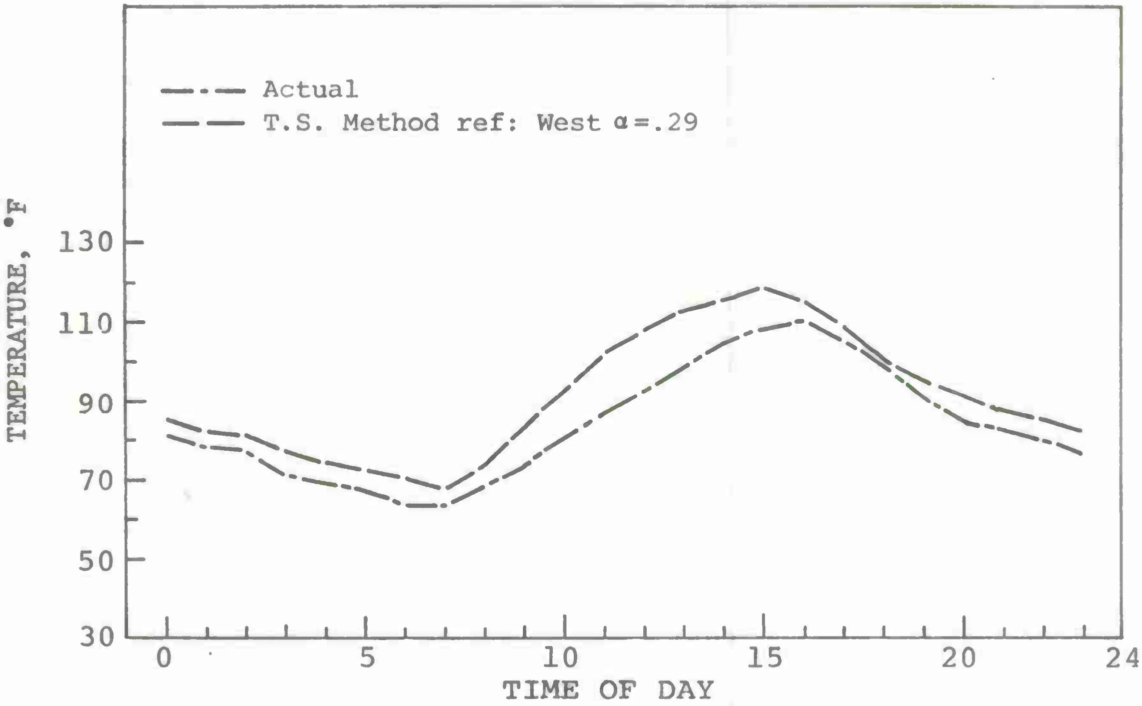

Figure 13. Comparison for Shrike Container West Side (11 Sept. 1974)

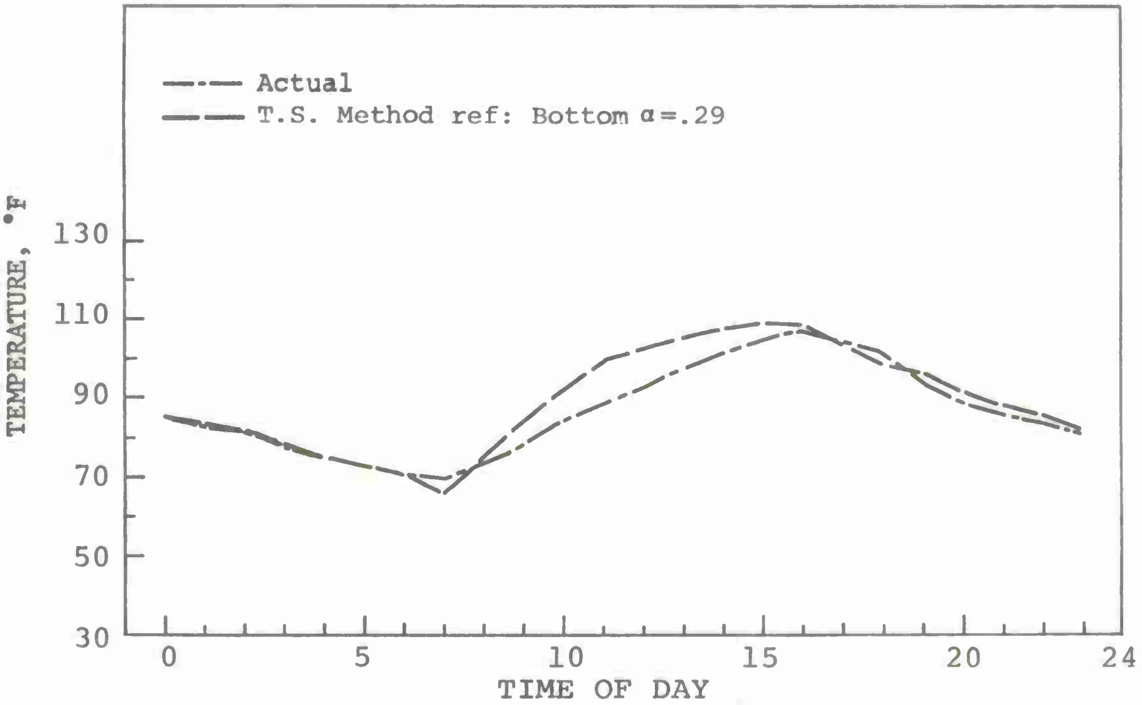

Figure 14. Comparison for Shrike Container Bottom (11 Sept. 1974)

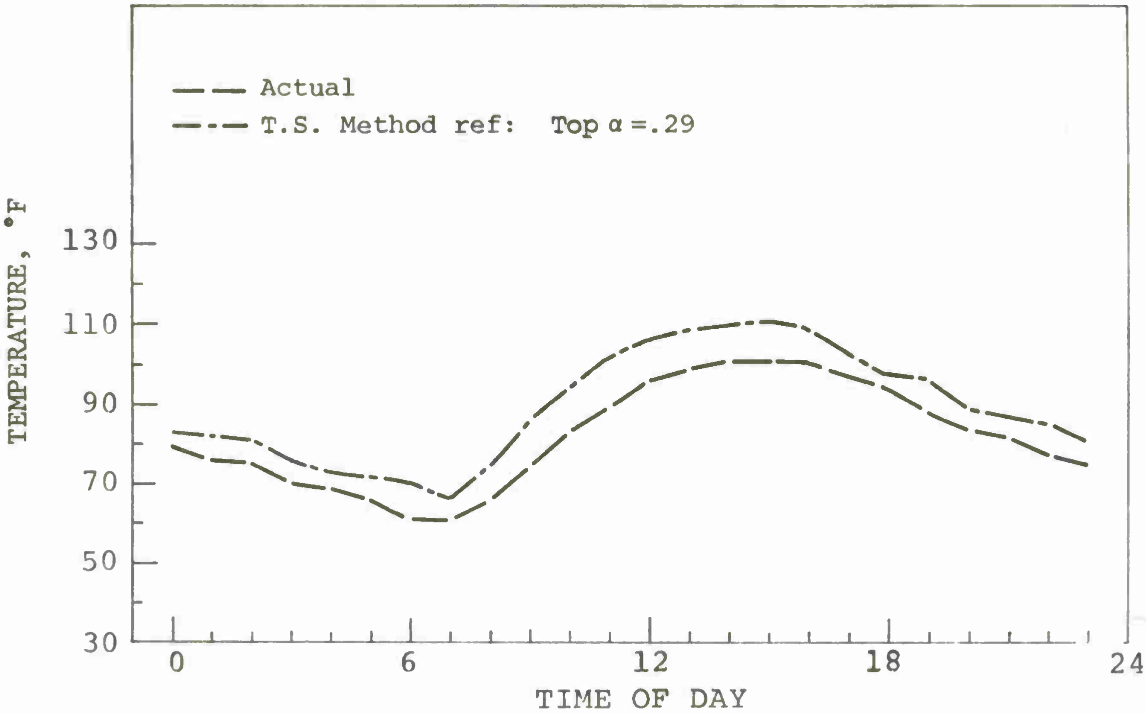

Figure 15. Comparison for Shrike Container Top (11 Sept. 1974)

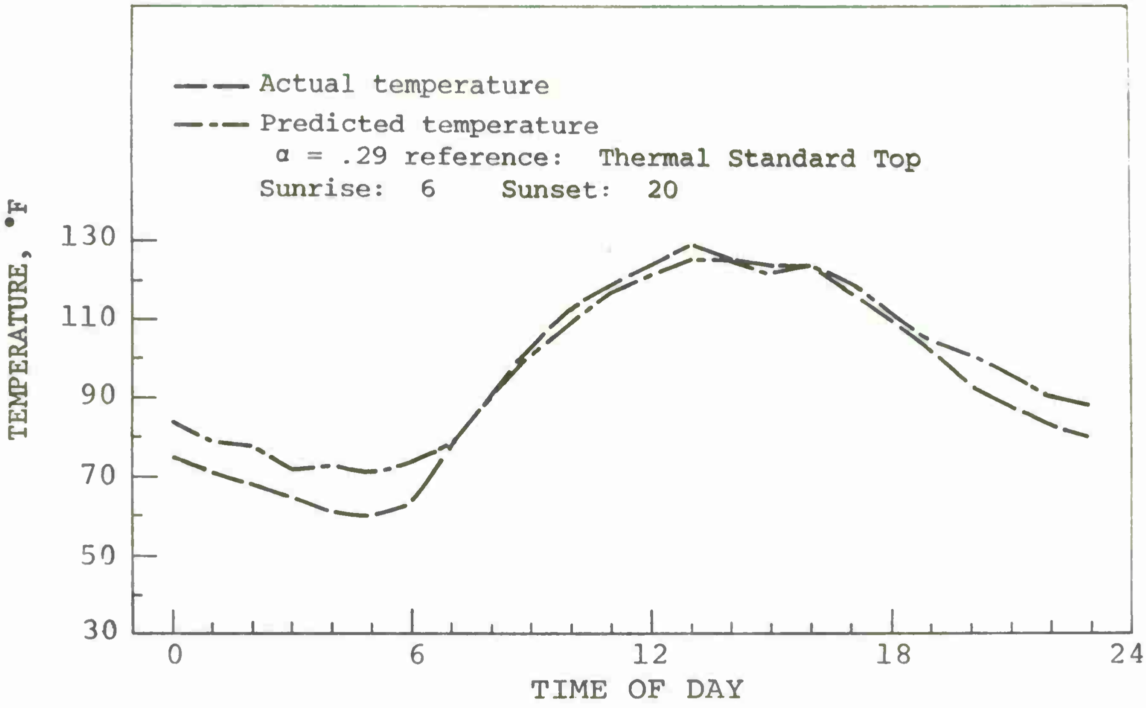

Figure 16: Comparison for Shrike Control Section Top Skin (12 June 1974)

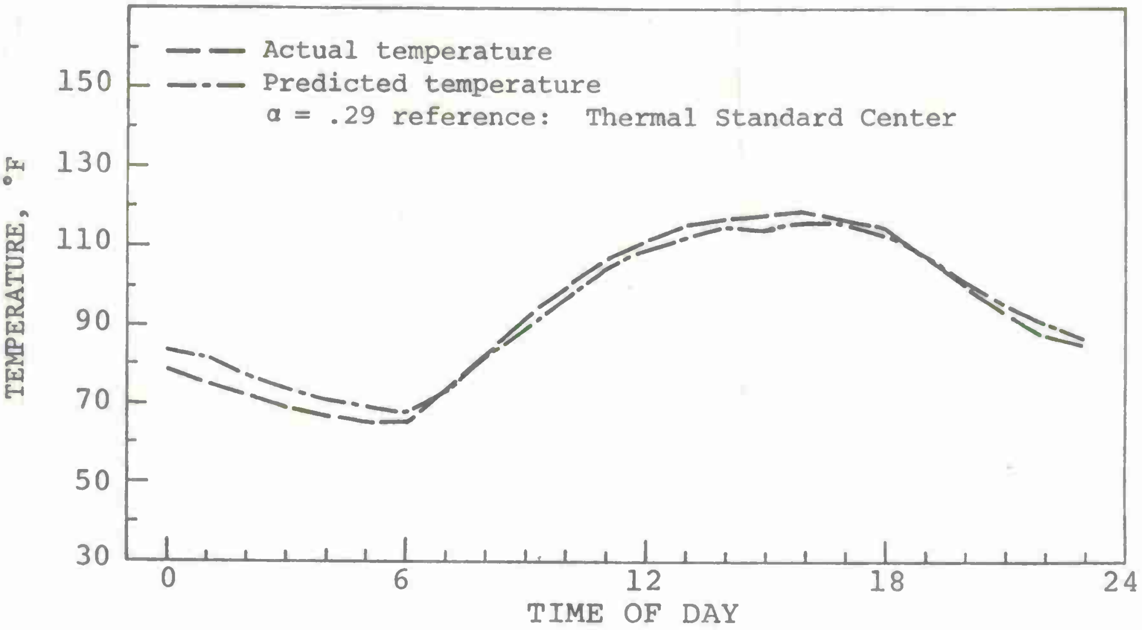

Figure 17. Comparison for Shrike Computer Section Top Skin (12 June 1974)

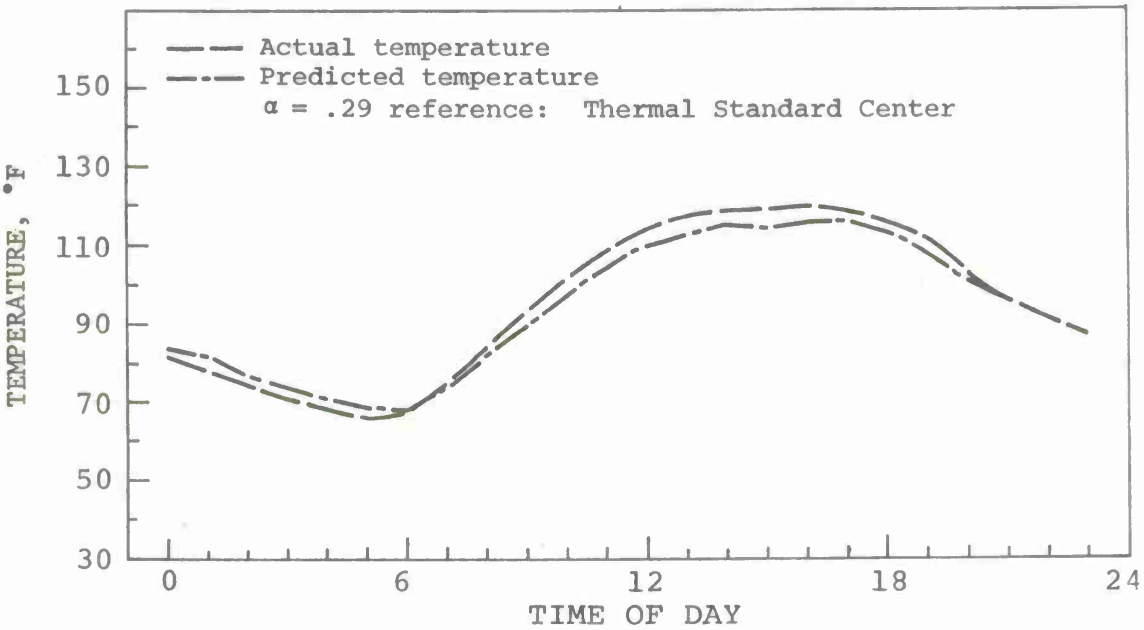

Figure 18. Comparison for Shrike Control Section Center Steel Bulkhead (12 June 1974)

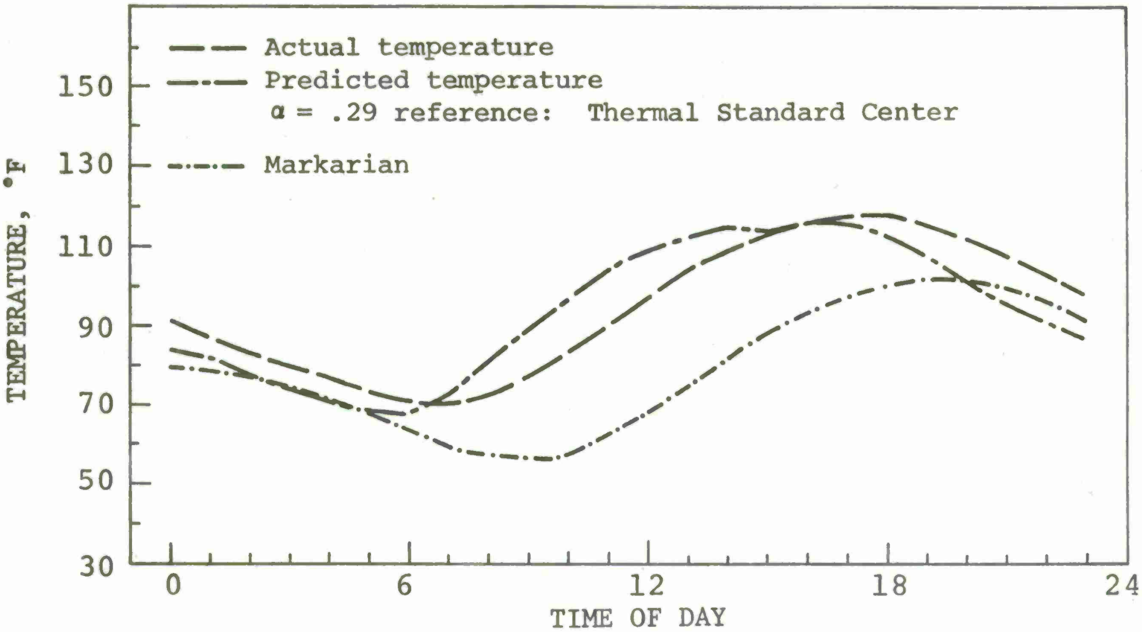

Figure 19. Comparison for Center of Shrike Motor Section (12 June 1974)

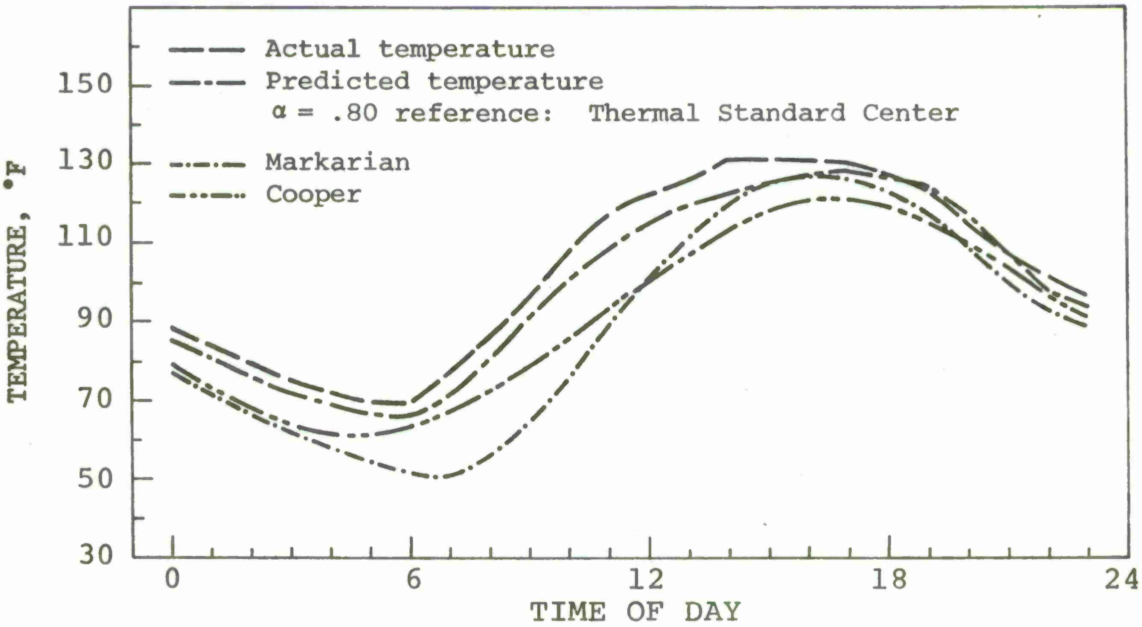

Figure 20. Comparison for Shrike Motor Top in MK 399 Container (28 June 1974)

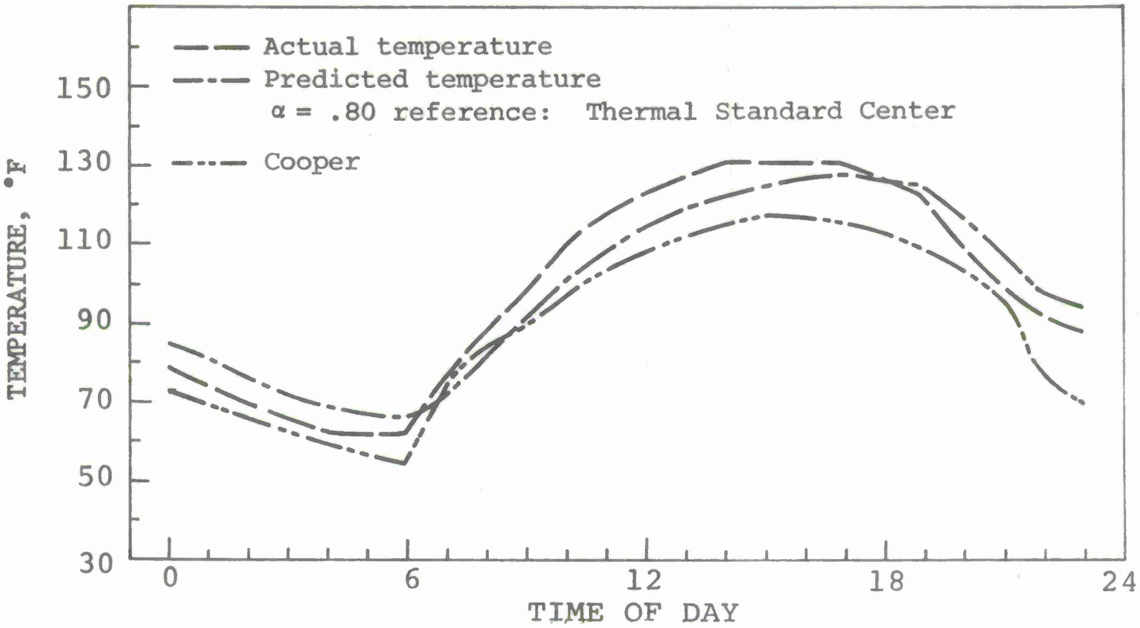

Figure 21. Comparison for Shrike Guidance Section Top MK 399 Container (28 June 1974)

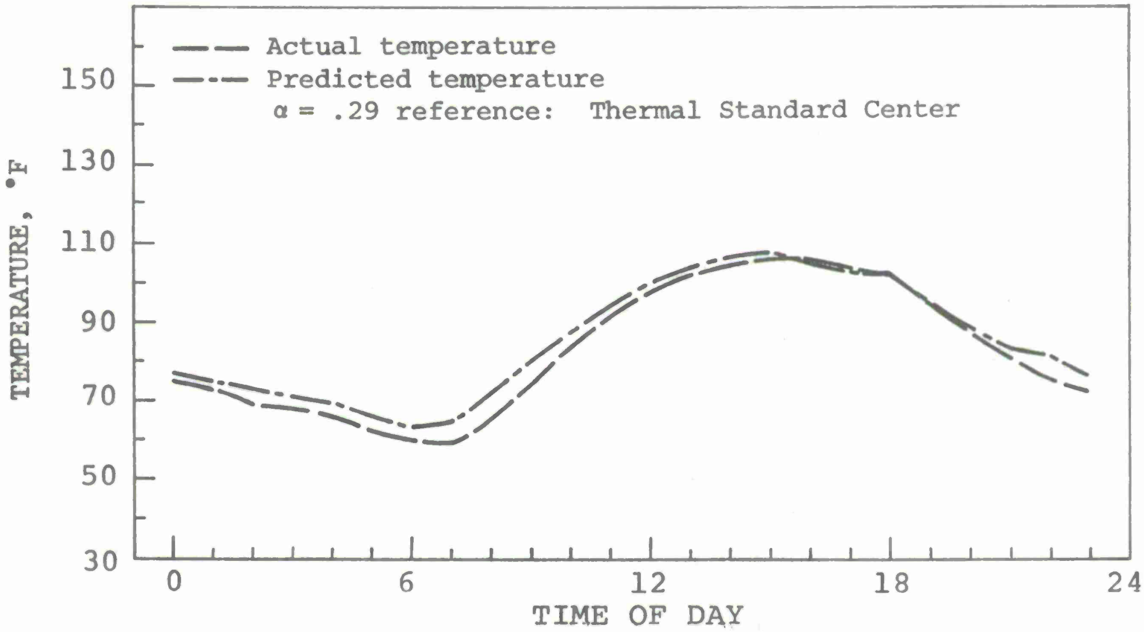

Figure 22. Comparison for Sidewinder Motor Section Center

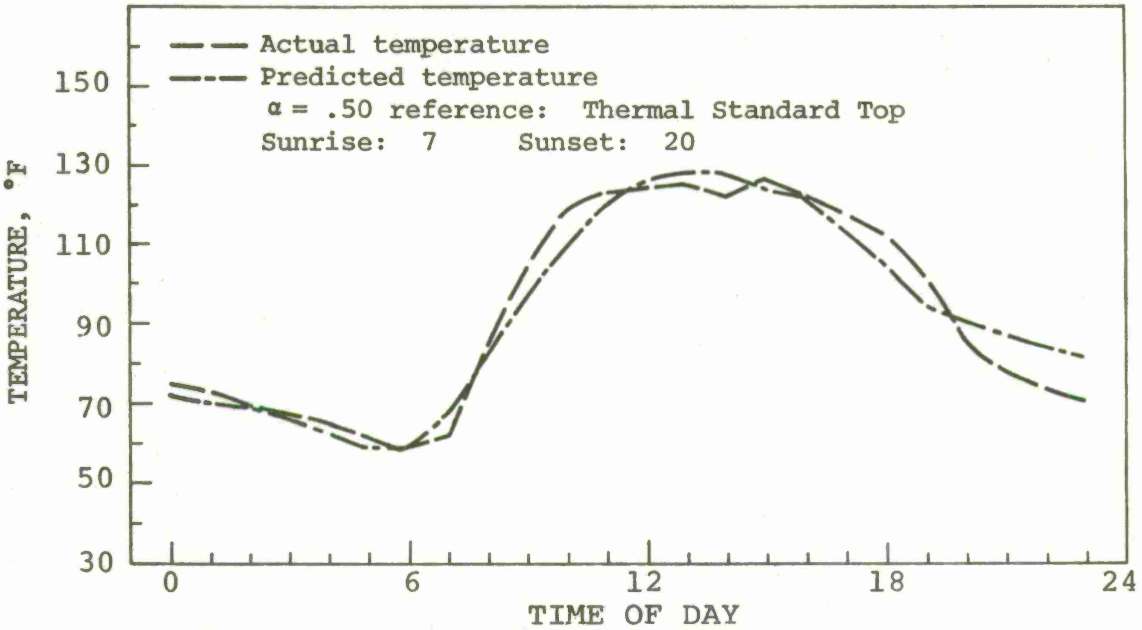

Figure 23. Comparison for Sidewinder Control Section Top Skin (29 August 1974)

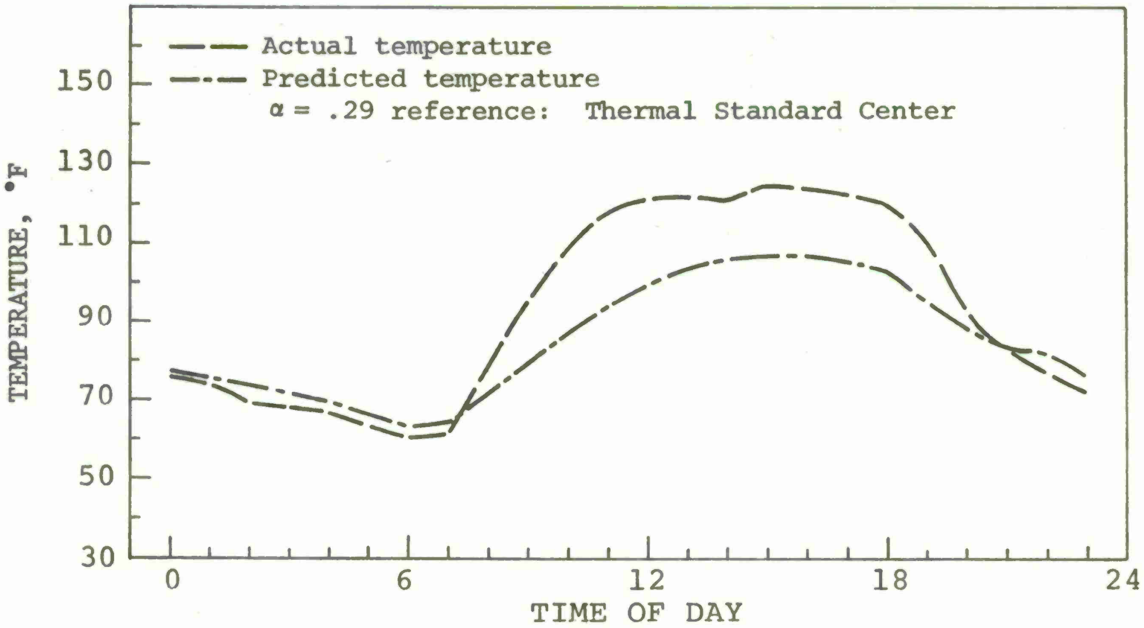

Figure 24. Comparison for Sidewinder Control Section Plastic Surface of Module (29 August 1974)

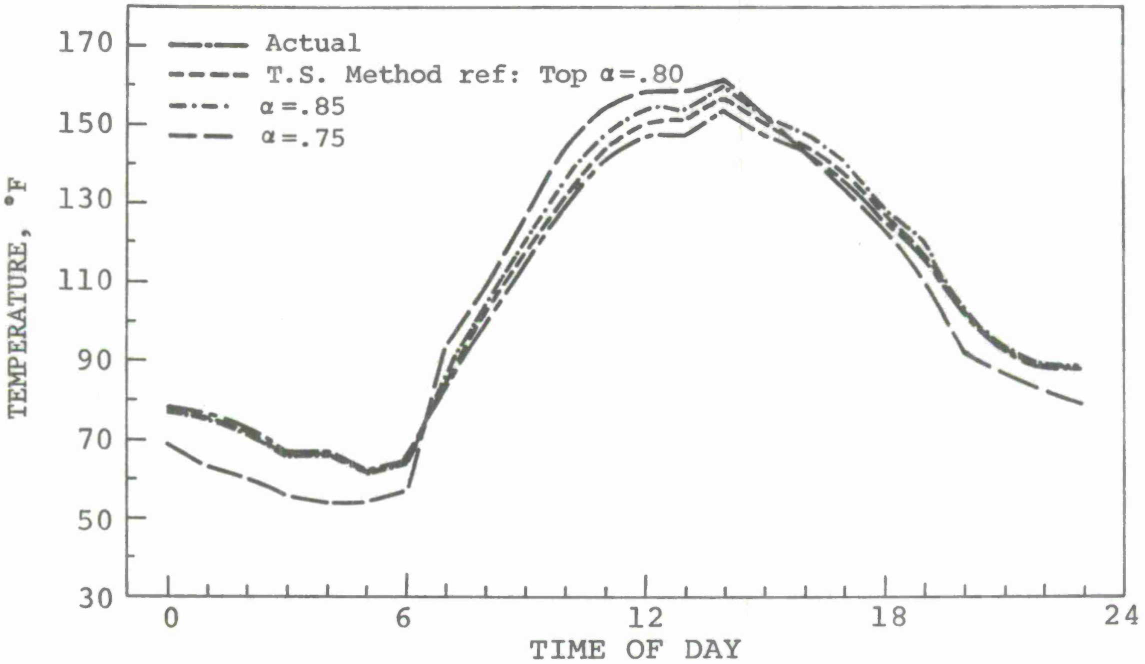

Figure 25. Comparison for All-up Shrike Container Top

CUMULATIVE PROBABILITY TEMPERATURE DATA

One method by which the enormous number of hourly data points have been presented is to plot the cumulative total of the hours that the thermal response was a certain temperature value or less. This has been done for all five thermocouples on a thermal standard and for the meteorological air temperature at several dump storage measurement sites for one or more years. Typical results are shown in Figure 26, for the Panama Canal Zone. Some of the general features which are discussed relative to Figure 26 apply to all the warm climate thermal standard exposures. An object placed in a dump storage situation is generally warmer during the day than the free air because it receives its heat directly from the sun, while the air, being semi-transparent, receives most of its heat by convection from the earth. The thermal response of the west side of an exposed item is either equal to or greater than that of the east side. However, the top of an exposed item generally will be slightly hotter than the west side with the peaks occuring at about the same time. The center of an object never attains the extreme high temperatures of the surface because it is protected from the extreme exposure by the outside. Generally, for most of the night (about half of the total time) all the temperatures are about the same. In the cold arctic regions where there is little solar energy, all the temperatures are about the same. This is especially true for the temperatures below the 0.5 cumulative probability point.

While this cumulative probability format does not give the daily temperature profiles of an object, it does give a method of estimating annual extremes and distributions and delineates the range of temperatures which exists any desired percentage of the time. The Cumulative Probability Temperature format will be useful in making economic trade-off studies for designing weapons which are to operate in both hot and cold or "world-wide" environments. It must be realized that no weapon is really designed for any given day. It must be designed to function accurately for a wide range of daily thermal situations. Since this connotes a statistical sample of daily situations on a "world-wide" scale, then the probability of occurrence must be addressed. The designer, being an engineer, is only interested in those environmental situations that can be expected to happen within the same probability risk for which the weapon is being designed. For example, if the weapon is being designed for a reliability of 95% (or less), then probable chance of occurrence temperature response values of one in a billion are neither appropriate, nor wanted, even though they can be projected to be possible.

Therefore, the cumulative probable chance-of-occurrence of temperature data gives the designer a variety of "extremes" and a statistical context in which they are appropriate. This approach is in the spirit and context of DoD Directive 5000.1.

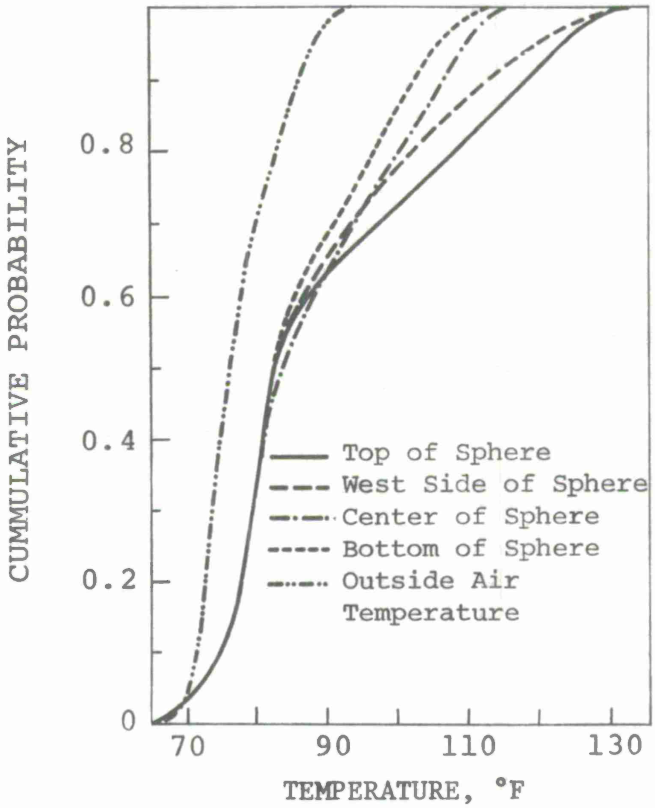

Figure 26. Thermal Standard Panama Canal Zone, 1971-72

Another valuable application of the cumulative probability plot is the composite plot which shows a band which includes many individual curves for a given location. Figures 27, 28, 29, and 30 are composite plots for China Lake; Innisfail, Australia; Ft. Richardson, Alaska; and Death Valley, respectively. The one for China Lake (Figure 27), for example, includes the following:

1. All five thermal standard temperatures for five years
2. Ten CP-T curves for a Sparrow missile
3. Five CP-T curves for a Sparrow motor in its shipping container
4. Six CP-T curves for a loaded 2.75" rocket container
5. Two CP-T curves for small arms in a container

A similar variety of Cumulative Probability Temperature curves are contained in the other three composite displays. The composite plot is not only valuable because of the many different ordnance temperature curves it contains, but because it indicates the types of dump storage items of which the thermal standard may be typical. It is almost amazing that a temperature band 15-20°F wide can include such a vast array of data from such a variety of dump storage ordnance items.

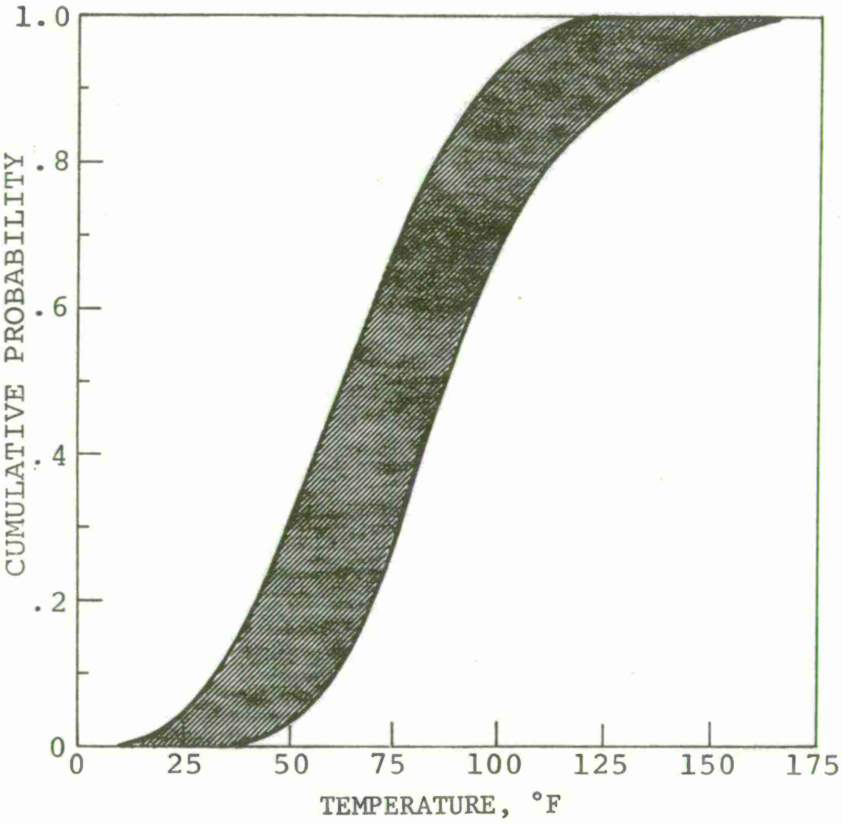

Figure 27. Thermal Standard Composite for China Lake

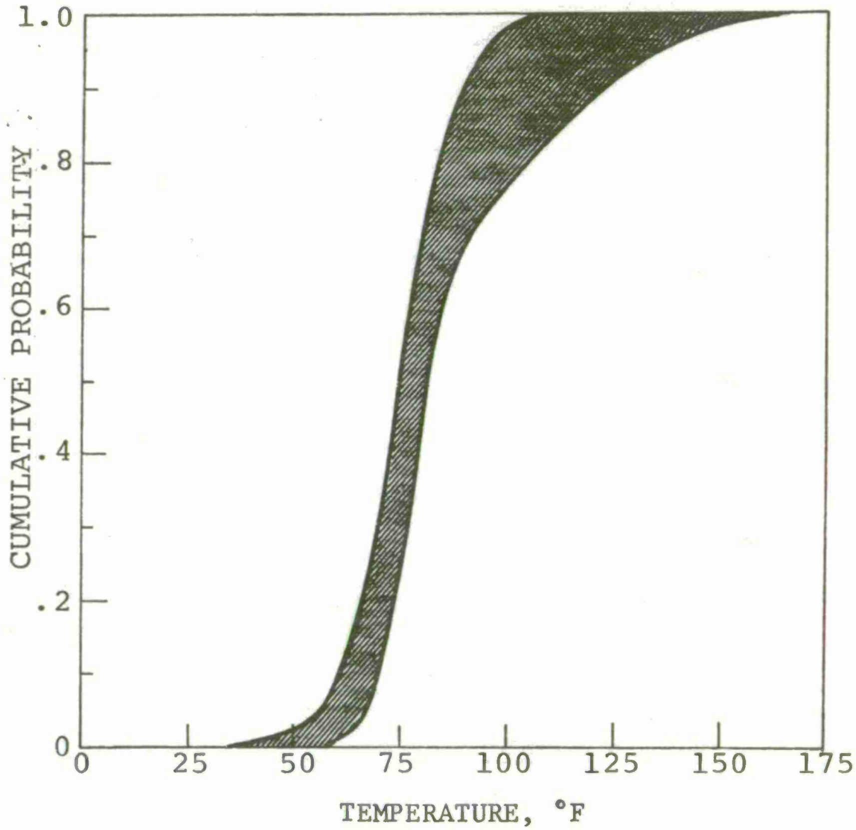

Figure 28. Thermal Standard Composite for Innisvail

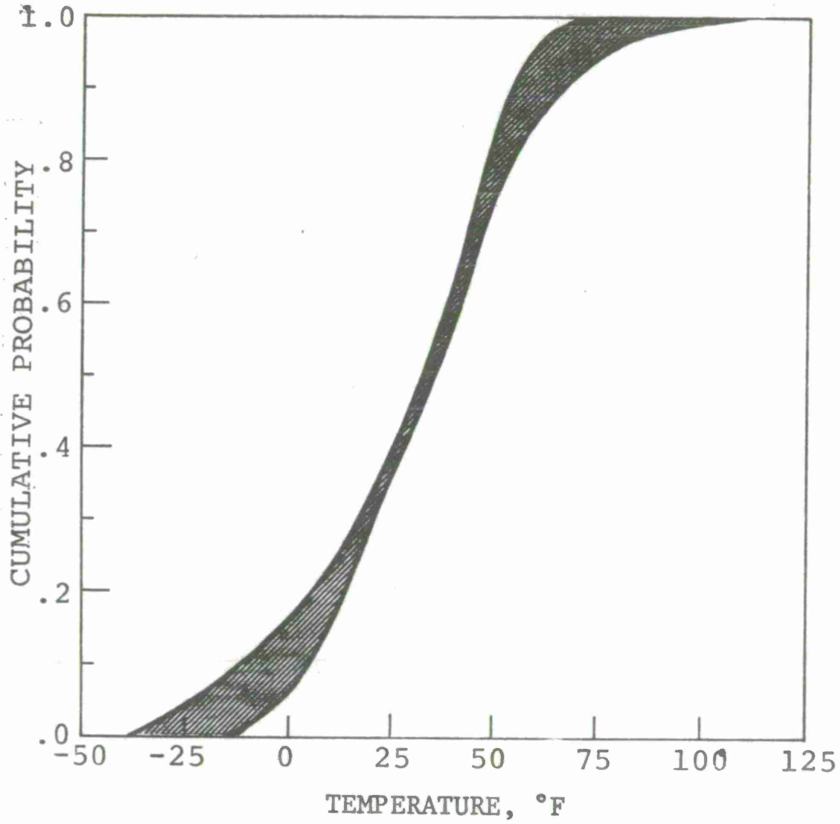

Figure 29. Composite for
Fort Richardson, Alaska

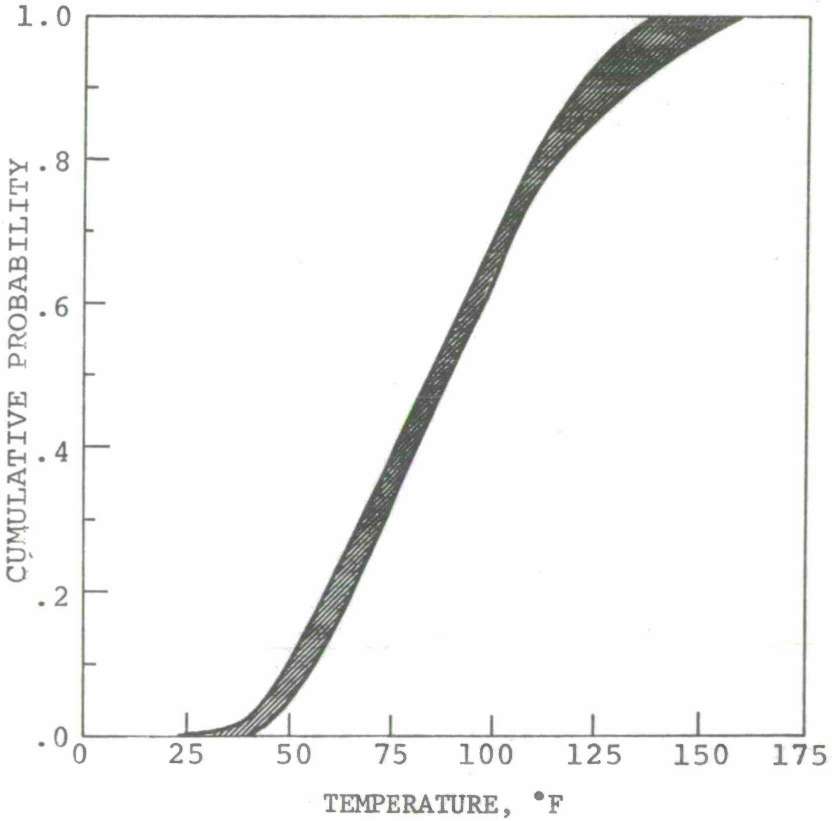

Figure 30. Composite for
Death Valley, California

STATISTICAL CUMULATIVE PROBABILITY STUDIES

A series of statistical comparisons were made using the hourly temperatures from the China Lake 36" high thermal standard top thermocouple (1974) as a baseline. The objective was to see how small an amount of data could be used and still compare favorably with the 8,760 hours per year cumulative probability temperature curve. First, different fractions of hourly data were chosen and cumulative probability temperature graphs were drawn and compared with the baseline. Second, daily data were chosen and compared. Figure 31 shows a typical comparison, this one for every tenth hour. Table 2 shows the results of the various graphs drawn including the maximum difference between the baseline and the generated graph.

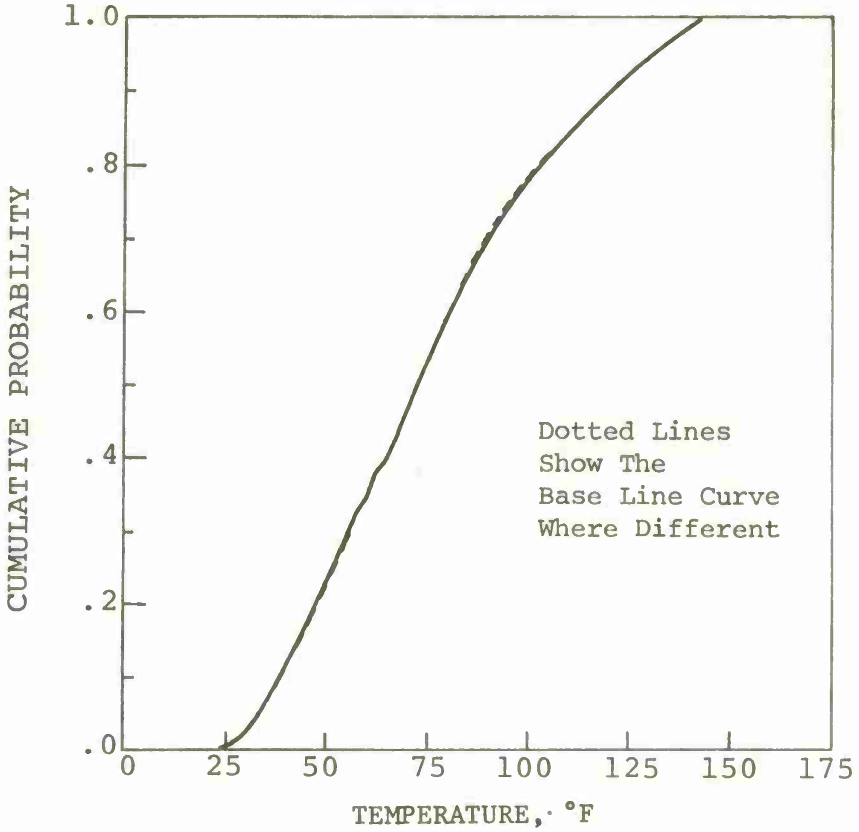

Figure 31. Top Thermocouple, Thermal Standard 1974

TABLE 2. Comparison of Graph Data.

Data Graphed	% Data Used	% Maximum Error
Every other hour	50%	.25
Every 3rd hour	33%	.85
Every 5th hour	20%	.85
Every 5th hour randomly selected	20%	1.1
Every 7th hour	14%	1.0
Every 10th hour	10%	1.0
Every 10th hour randomly selected	10%	3.8
Every 15th hour randomly selected	7%	4.2
Every 20th hour	5%	1.7
Every 20th hour randomly selected	5%	3.1
Every 30th hour	3%	2.8
Every 50th hour	2%	4.2
100 random points plus year max and min	1%	5.0
Every other day	50%	.25
Every 3rd day	33%	.85
Every 4th day	25%	.85
Every 5th day	20%	1.4
Every 5th day randomly selected	20%	2.0
Every 9th day	12%	3.6
Every 10th day	10%	1.7
Every 10th day randomly selected	10%	1.9
Every 20th day	5%	3.6
Every 20th day randomly selected	5%	4.7
Every 40th day	2%	5.6

Every 3rd day means that all 24 hourly temperatures were used in generating the cumulative curve for every third day beginning with January 3, 1974.

The results show that using data in hour groups rather than daily groups produced less error. The results also show that the data can be reduced 90% without producing an error greater than 3%. It can also be concluded that selecting exactly every nth hour (or day) biased the results. In every case in which the data were selected randomly the maximum error was greater than when the data had been selected on an exact basis.

It was postulated that for most days the thermal standard has essentially the same general temperature-time pattern and that the only variation from day to day is the maximum and minimum values of temperature. Hence, approximations of the Cumulative Probability Temperature curve were attempted using only the daily maximum and minimum. The accuracy of this method was unsatisfactory. A better approximation using the sine function was attained by changing the ratio of points generated above the mean temperature to points generated below the mean from 6 above and 6 below to 5 above and 8 below. This ratio of 5/8, or .625, was close to the ratio of the actual data, .628. The maximum error of this approximation was 3.1%.

However, a better approximation to the base line curve was formed by computing the average ratio of a specific hour of a "standard day" minus the minimum temperature for the day to the difference of the maximum and minimum temperatures. These hourly ratios were computed in two different ways. In the first case, the ratios for each day were calculated and then the ratio was averaged over the entire year to find the typical temperature curve. The curve thus generated did not, however, include a maximum of one and a minimum of zero. In the second case, the temperatures for each separate hour of the day for all the days were first averaged over the year and then these averages used to calculate the ratios for the typical temperature curve. This method did provide a maximum of one and a minimum of zero.

The second method proved to be the most accurate of the two. The maximum error was less than 2.2%. This method was called the "Typical Day" method. Figure 32 shows the graph of "Typical Day" (TD) temperature ratios as a function of time of day for both the top and center thermocouples from China Lake and the top thermocouple from Australia. Table 3 also gives the values of the TD ratios for any time of day. The TD ratio for any hour is given by

$$(\text{TD ratio})_i = \frac{(\Sigma Ti) - (\Sigma T)\text{min}}{(\Sigma T)_{\text{max}} - (\Sigma T)_{\text{min}}}$$

where the i is the ith hour, Σ is the sum over the ith hour for 365 days, $(\Sigma T)_{\text{min}}$ and $(\Sigma T)_{\text{max}}$ are the minimum and maximum ith hour sums.

TABLE 3. TD Ratios Used.

PERIOD	CHINA LAKE CENTER T.S.	CHINA LAKE TOP T.S.	AUSTRALIA TOP T.S.
1	.2264	.1433	.040
2	.1842	.1170	.023
3	.1434	.0879	.015
4	.1060	.0657	.050
5	.0683	.0378	.000
6	.0303	.0144	.025
7	.0000	.0000	.160
8	.0007	.0693	.340
9	.0978	.2561	.580
10	.2731	.4871	.815
11	.4760	.7019	.930
12	.6523	.8625	.990
13	.7959	.9560	1.000
14	.9007	1.0000	.890
15	.9677	.9920	.758
16	.9999	.9382	.635
17	1.0000	.8481	.475
18	.9578	.7158	.295
19	.8662	.5715	.205
20	.7282	.4205	.150
21	.5690	.3096	.110
22	.4411	.2488	.085
23	.3507	.2058	.065
24	.2863	.1733	.050

Figures 33 through 51 are graphs showing the comparisons mentioned in Table 4. A discussion of the curves follows. The successful prediction of ordnance temperature curves by the TD ratios means that the diurnal temperatures are different. Of course clouds, rain and other factors are present during the year but these effects are averaged out. Since all the days are "similar" only a representative sample of days are necessary to generate the cumulative probability curve for the year. The comparisons made in Figures 33 through 51 were designed to show that limitations exist for each set of TD ratios. It was expected that the TD ratios from the China Lake Thermal Standard top thermocouple could be used to accurately predict the top skins of various ordnance items. This appears to be the case. However, those TD ratios did not predict as well the Sparrow motor inside a container (Figure 36).

TABLE 4. Typical Day 10% Max-Min Comparisons.

Fig. No.	Ordnance Item-Location	Typical Day Used	Max Error %
33	All up Sparrow-Motor Top Skin	China Lake-Top	2
34	Sparrow Container - Top	" " "	3.5
35	20 mm ammo - Inside Top Round	" " "	3
36	Sparrow Motor Skin - Top in Container	" " "	4.5
37	Ambient Air - Ster. Shelter	" " "	4
38	Ambient Air - Ster. Shelter	China Lake-Center	3
39	20 mm ammo - Center	" " "	2
40	20 mm ammo - Top Row Center	" " "	1.5
41	Zuni Motor in Cont.-East, Top	" " "	3.5
42	Sparrow Mtr. Skin in Cont.	" " "	2.5
43	Thermal Std.-Center	" " "	2
44	Sparrow Cont.-Center	" " "	8
45	MAGAZETTE - Air	" " "	2.5
46	Thermal Std. - Top	Australian-Top	2
47	7.62 NATO ammo - Top Row	" "	2
48	2.75 Out of Cont. - Top	" "	3
49	Sparrow in Cont. - Top	" "	7
50	Sparrow Motor - Top	" "	6
51	ASROC Motor - Top	" "	6

APPLICATIONS OF THE TYPICAL DAY METHOD

Cumulative distribution curves were also made for the thermal standard temperatures generated using the typical day ratios and maximum and minimum temperature data for every 10th, 20th and 40th days, and also for random 10th, 20th and 40th days. The error using every 10th day (for example) was less than 3.5 percent.

Based on the success of the typical day method using only 10% of the daily maximum and minimum temperatures, it was decided to examine a variety of ordnance items whose thermal responses could be predicted in this manner. Table 4 shows which ordnance items were used and the TD ratio source used in generating the prediction curves. The baseline data had been taken earlier for other purposes and are shown here as if the data were taken afterwards.

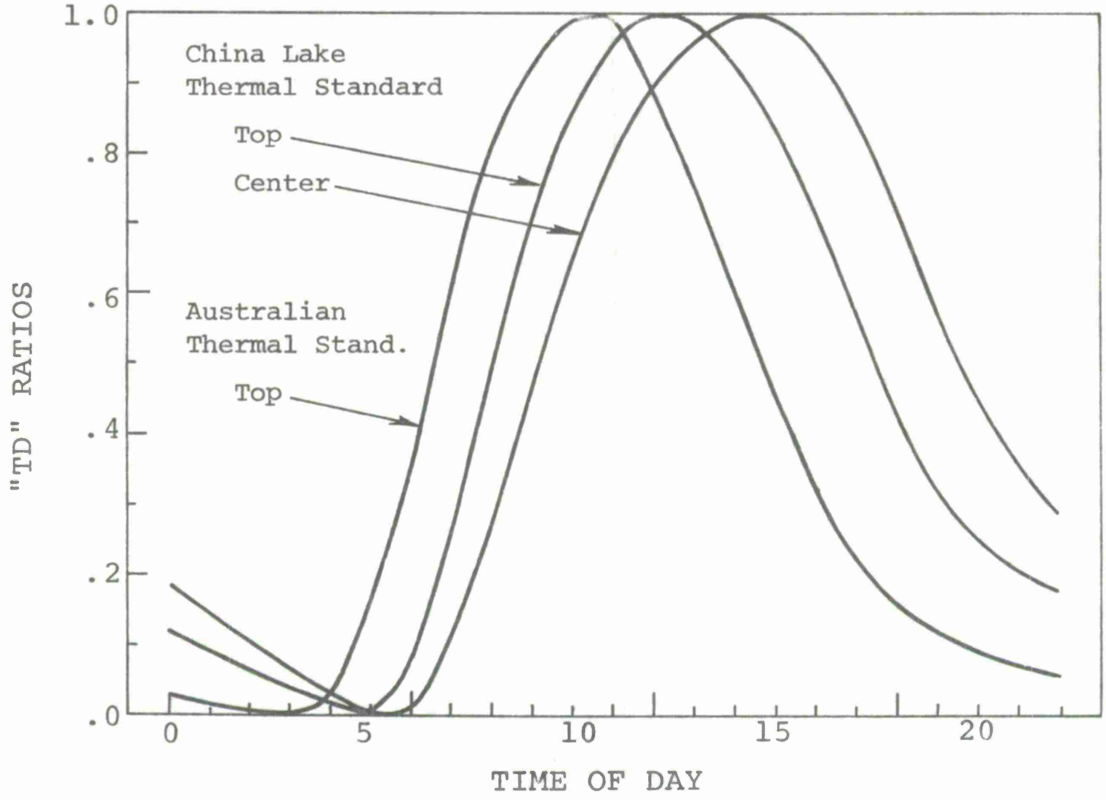

Figure 32. Typical Day Ratios for China Lake and Australia

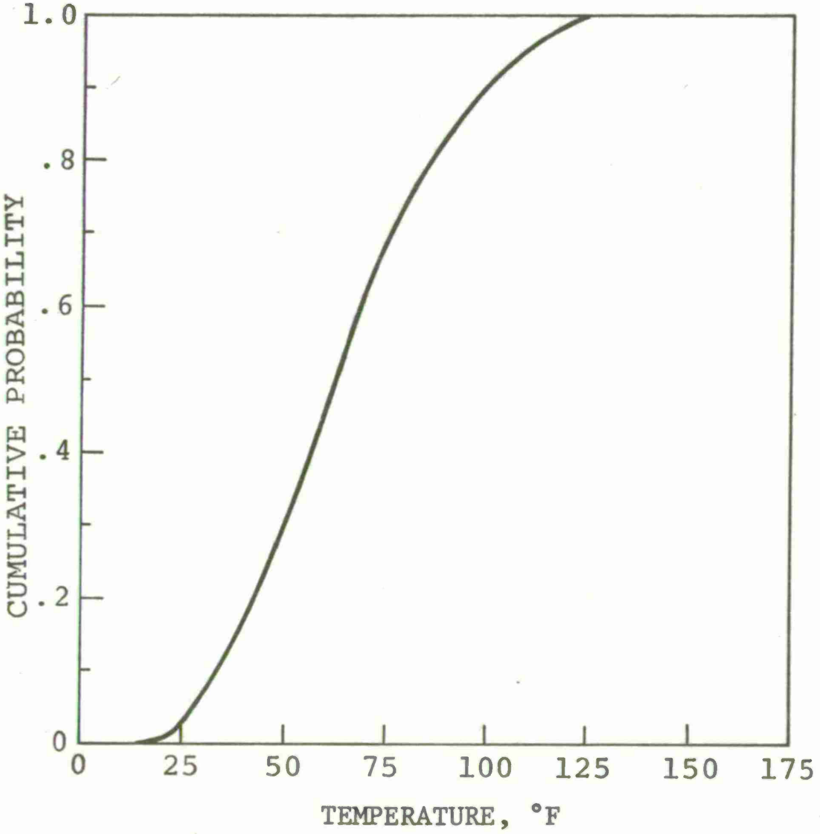

Figure 33. TD Ratio Prediction for
All-Up Sparrow
China Lake

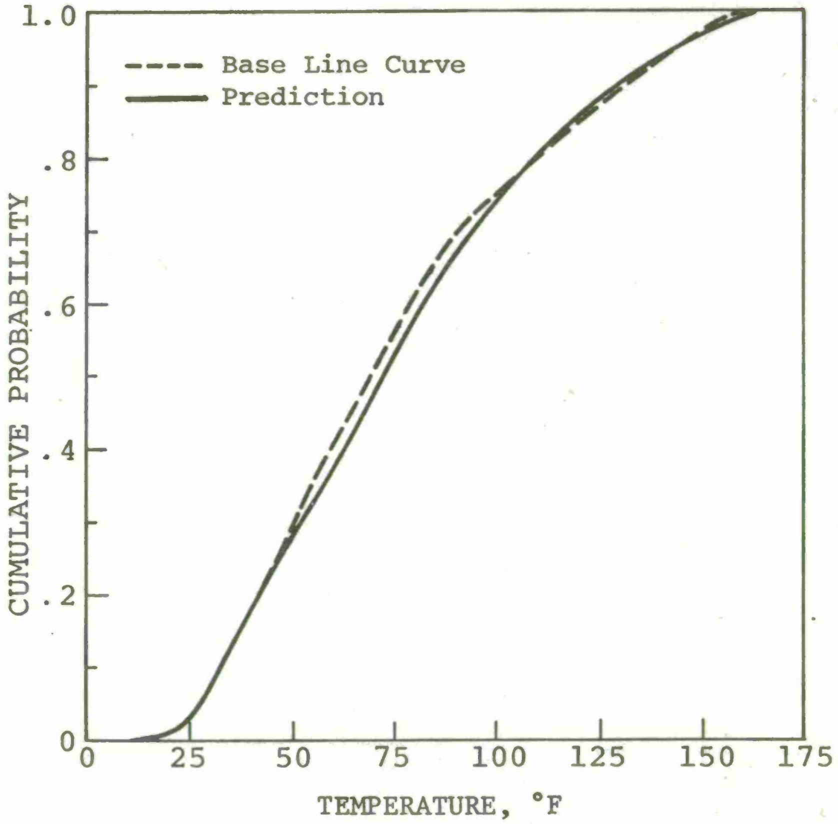

Figure 34. T.S. Top TD Ratio Prediction
of Sparrow Container
China Lake

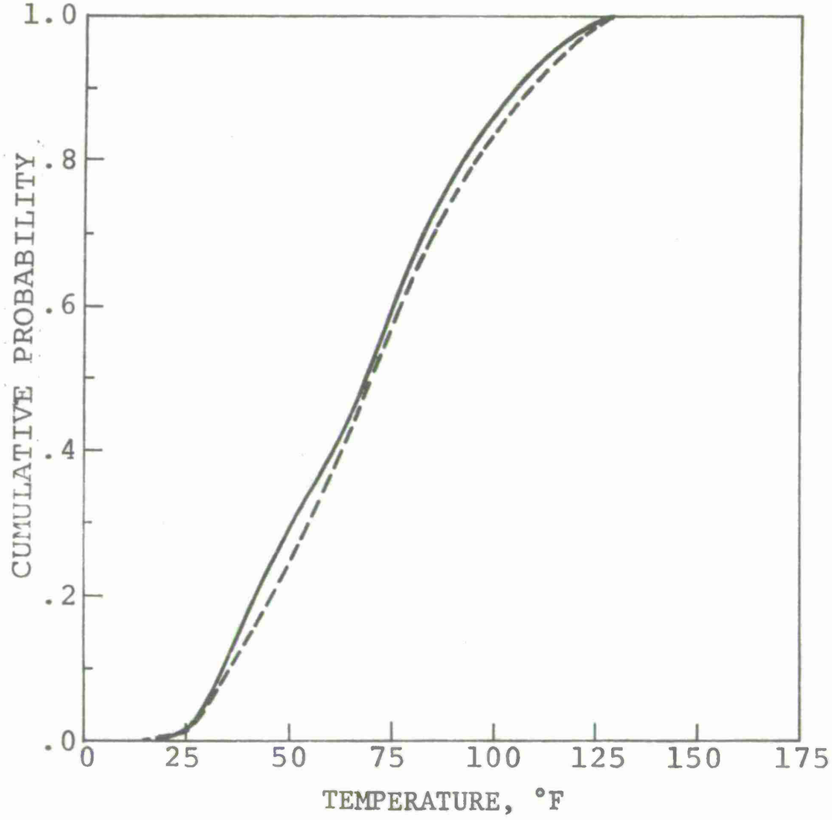

Figure 35. T.S. Top TD Ratio Prediction of 20 mm Ammo Can China Lake

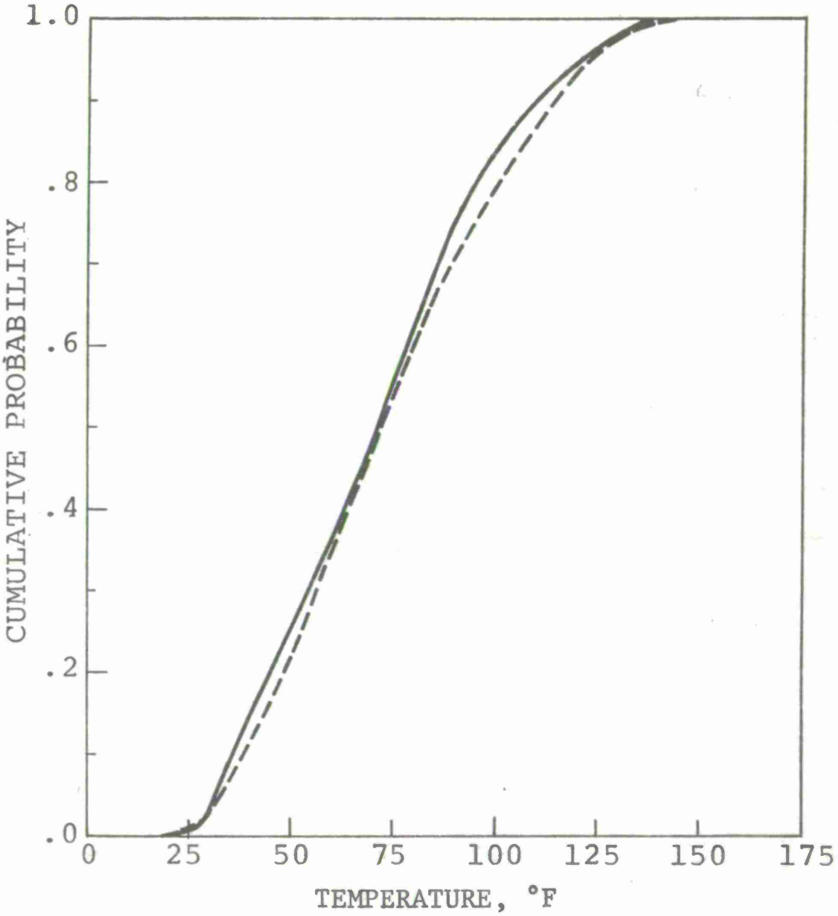

Figure 36. T.S. Top TD Ratio Prediction of Sparrow Motor in Container China Lake

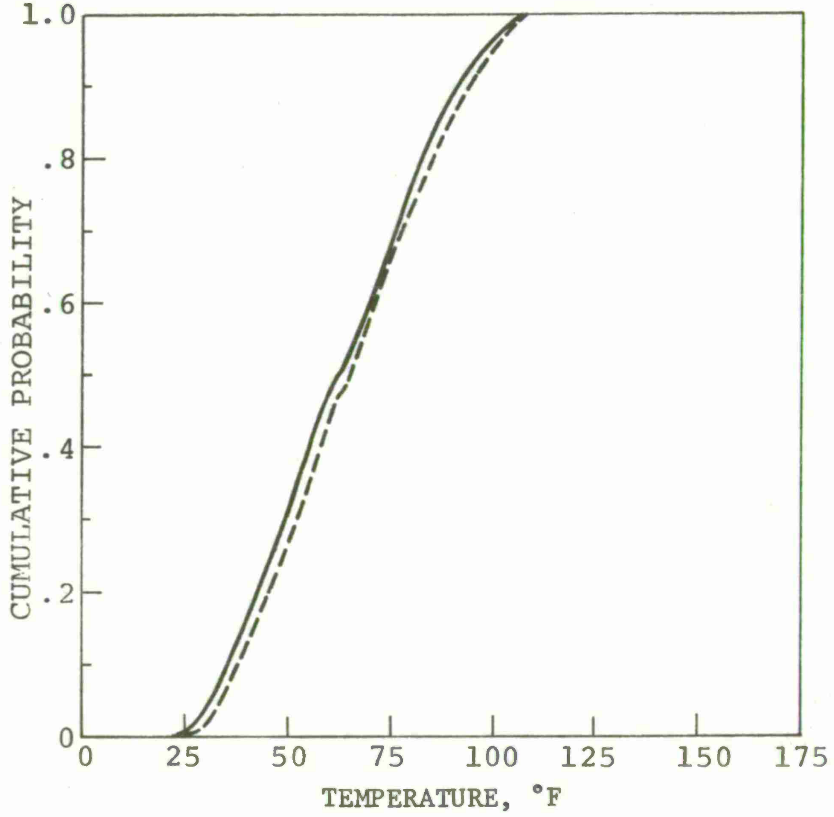

Figure 37. T.S. Top TD Ratio Prediction
of Ambient Air
China Lake

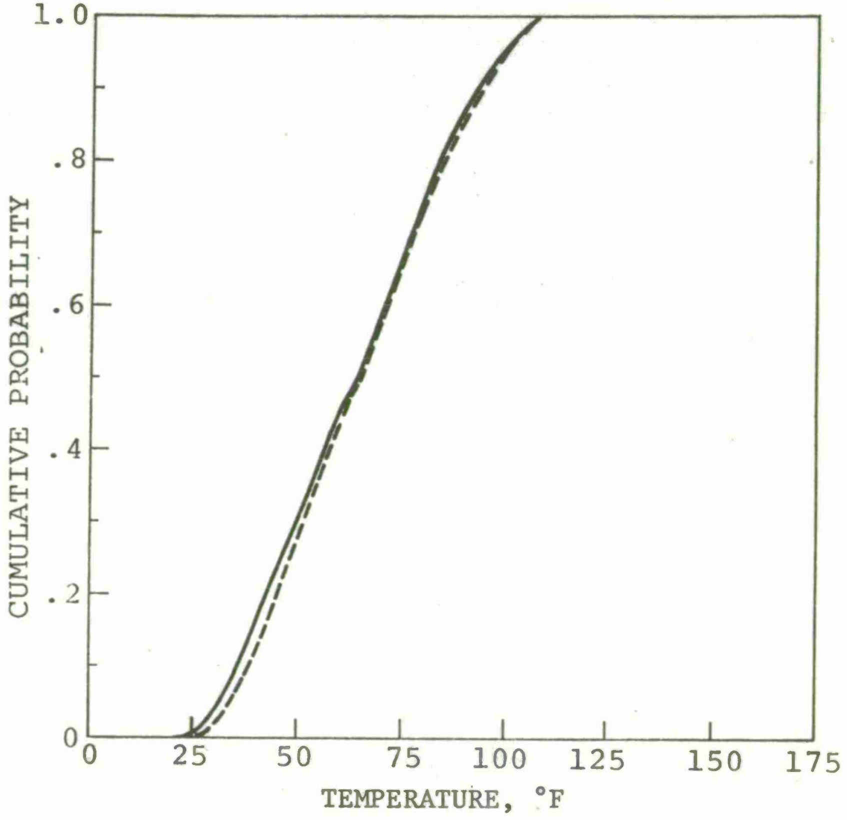

Figure 38. T.S. Center TD Ratio Prediction
of Ambient Air
China Lake

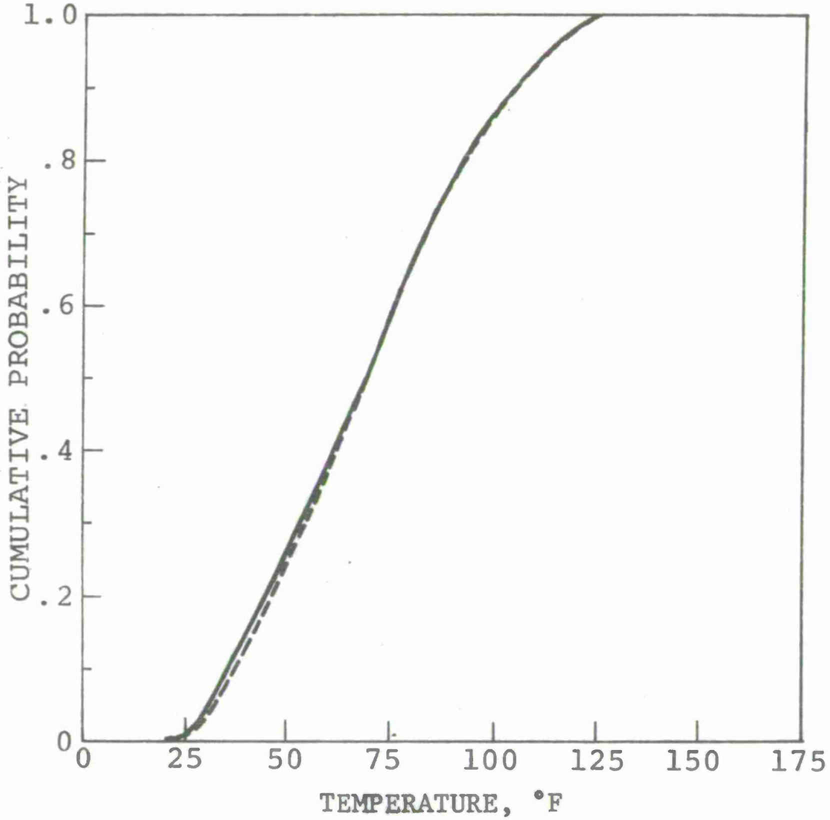

Figure 39. T.S. Center TD Ratio Prediction
of 20 mm Ammo in Container
Middle Row Center
China Lake

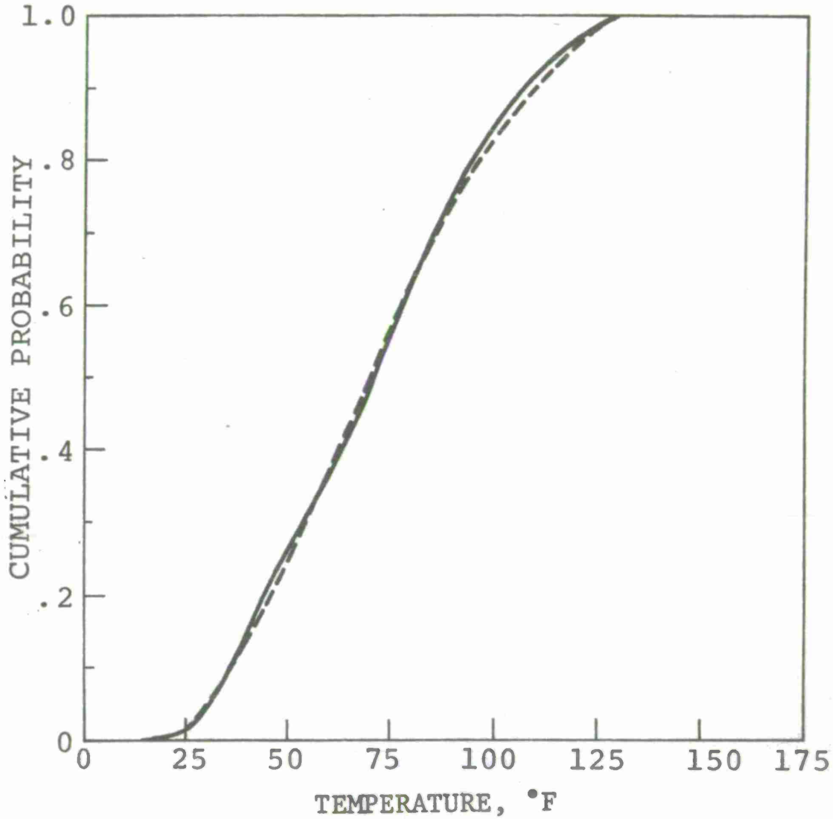

Figure 40. T.S. Center TD Ratio Prediction
of 20 mm Ammo in Container
Top Row Center
China Lake

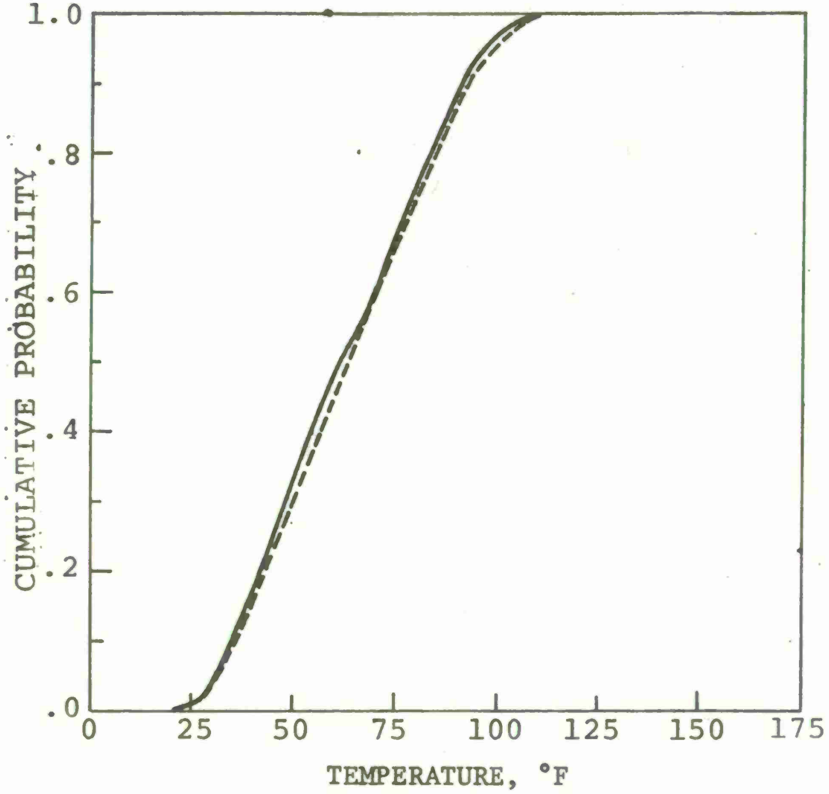

Figure 41. T.S. Center TD Ratio Prediction of Grain in All-Up Zuni Motor East Side - China Lake

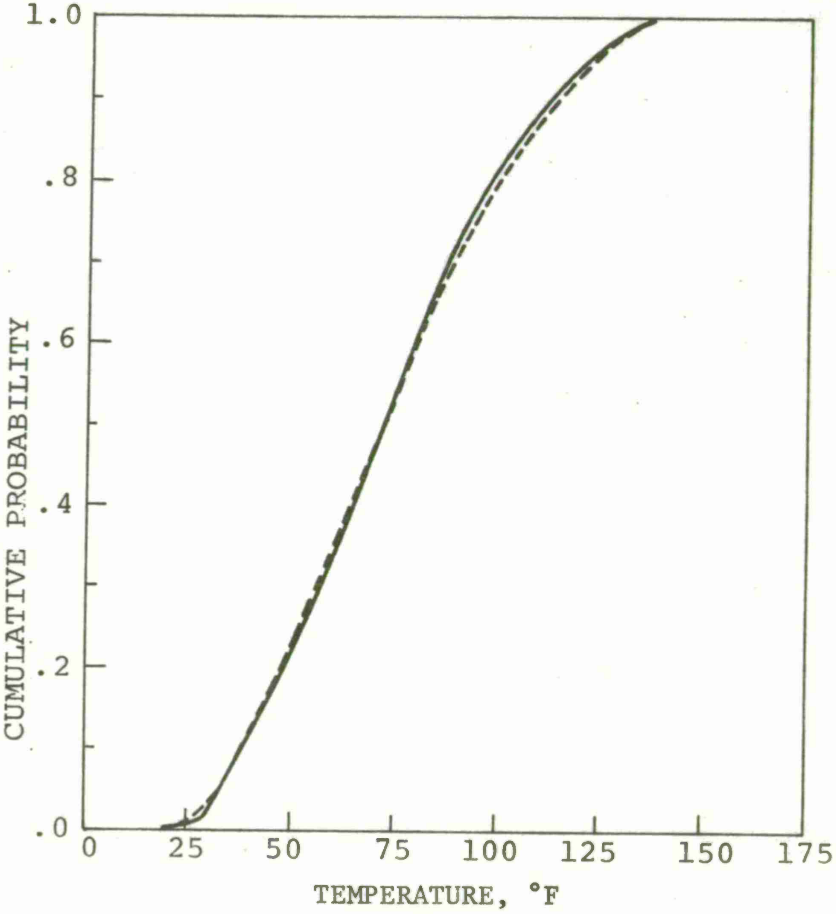

Figure 42. T.S. Center TD Ratio Prediction of Sparrow Motor in Container China Lake

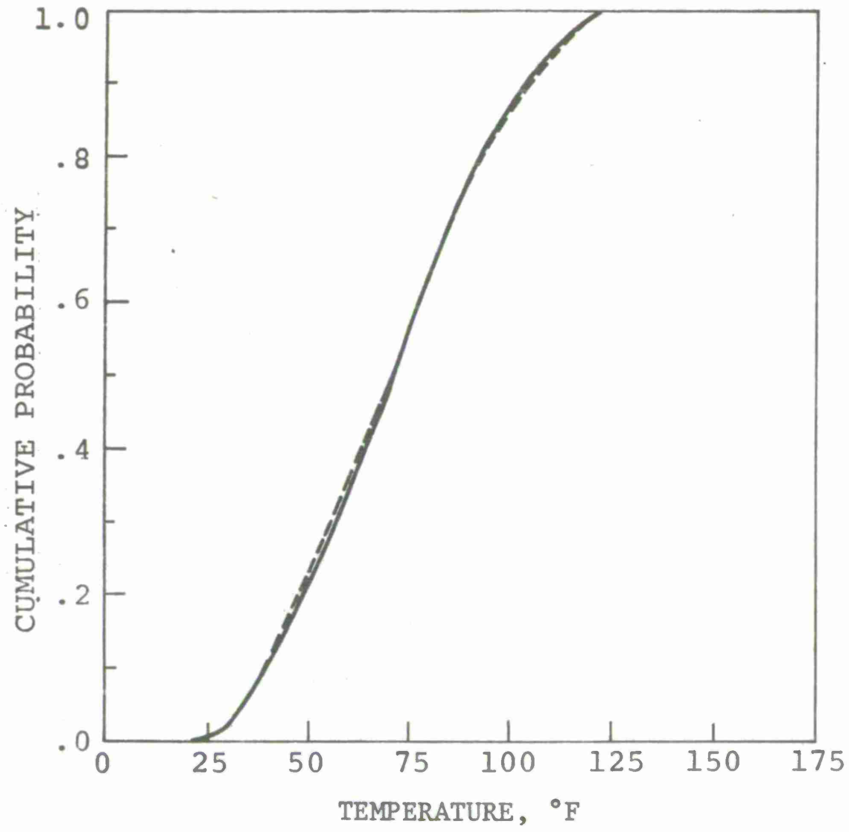

Figure 43. T.S. Center TD Ratio Prediction of Thermal Standard Center China Lake

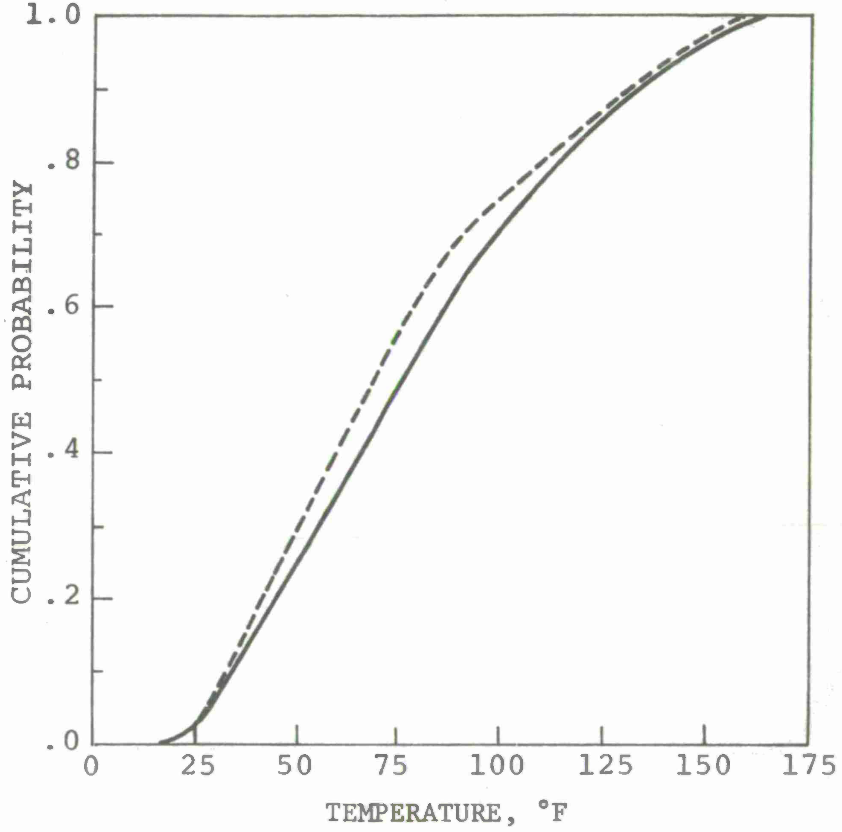

Figure 44. T.S. Center TD Ratio Prediction of Sparrow Container China Lake

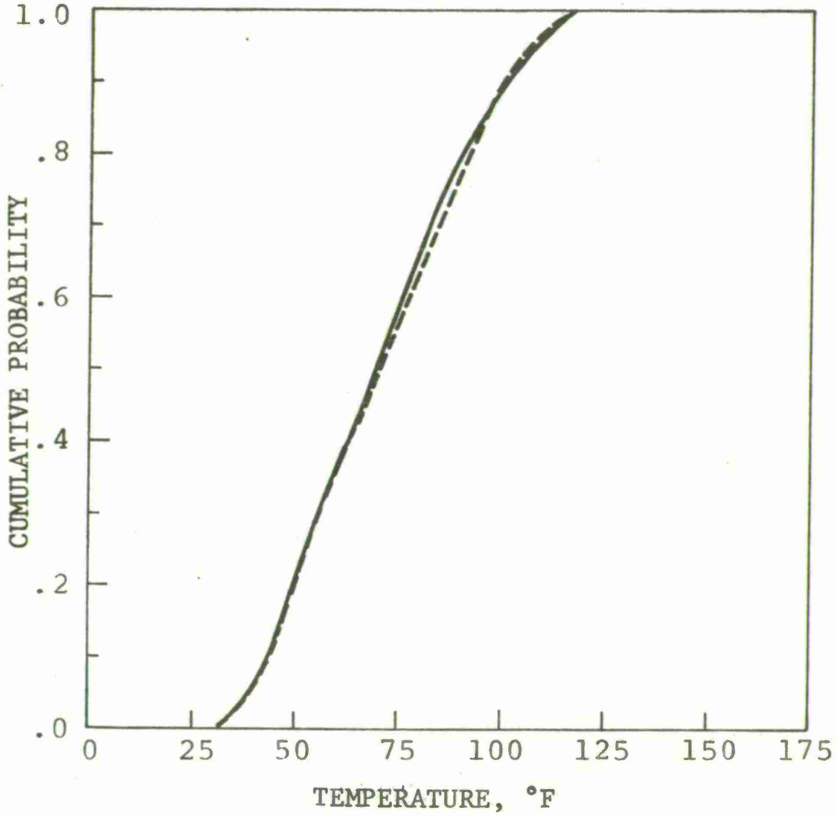

Figure 45. T.S. Center TD Ratio Prediction of Inside Air of Magazette China Lake

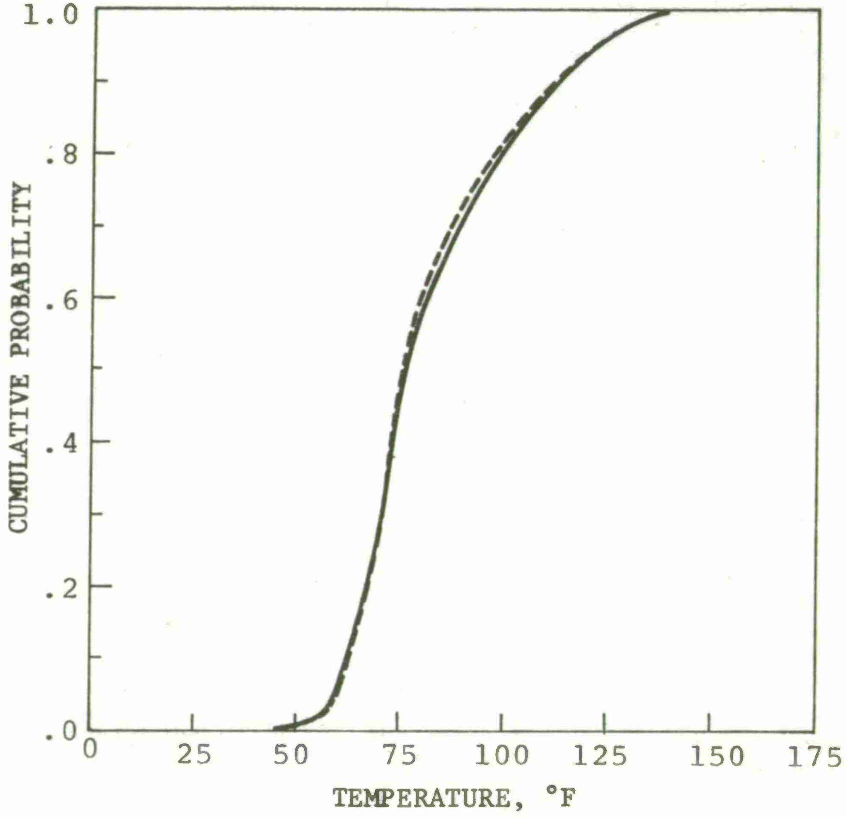

Figure 46. T.S. Top TD Ratio Prediction of Thermal Standard Top Australia

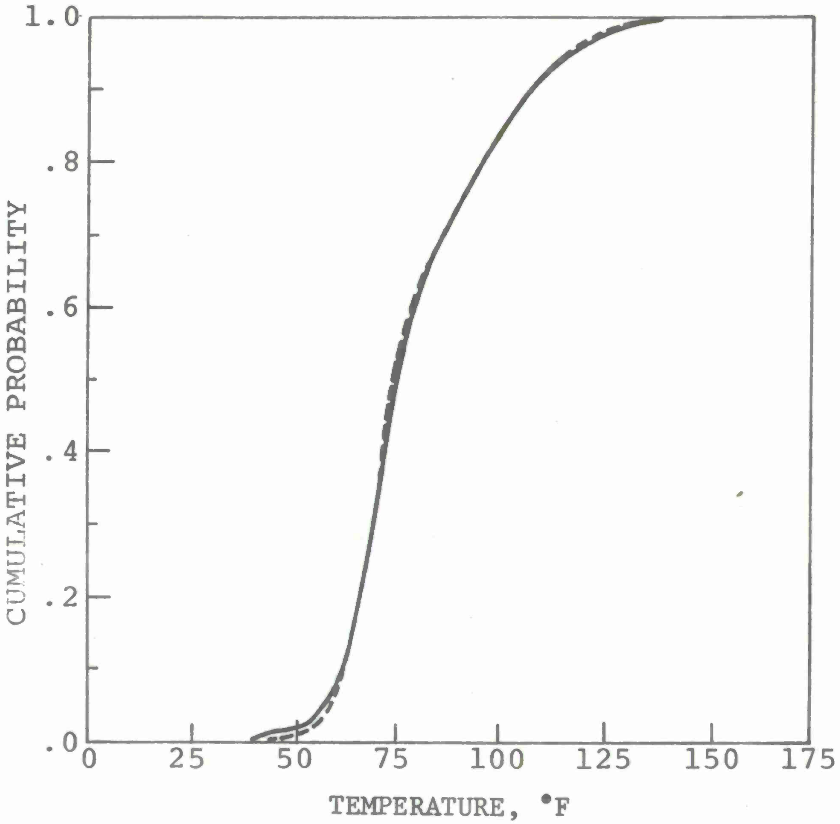

Figure 47. T.S. Top TD Ratio Prediction
of 7.62 NATO Cartridge Top Row
Australia

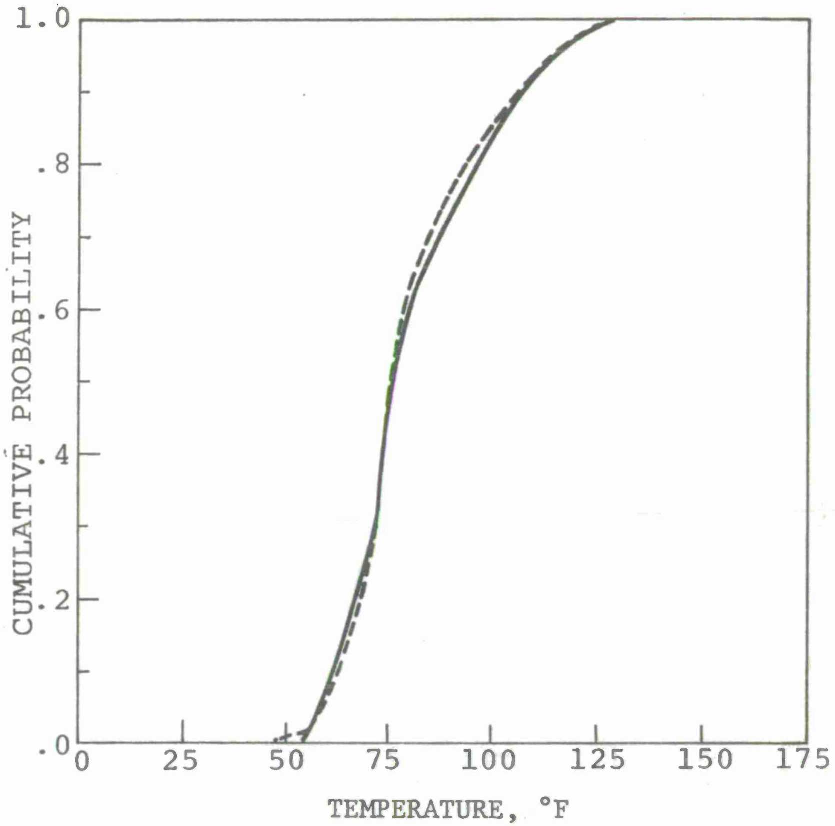

Figure 48. T.S. Top TD Ratio Prediction
of 2.75 Motor Wall Out of Container
Australia

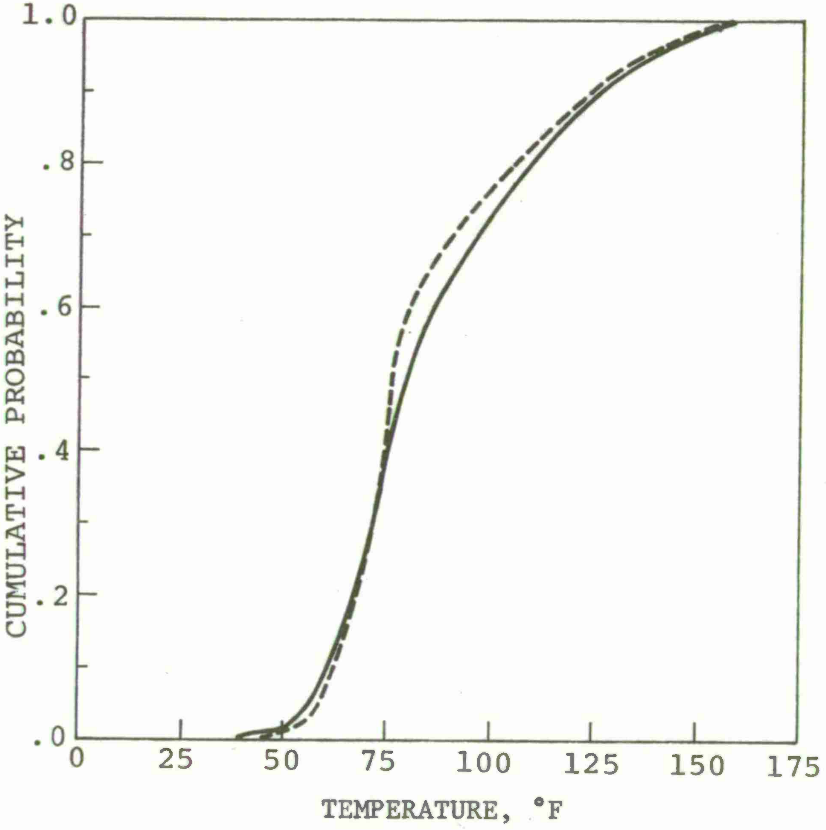

Figure 49. T.S. Top Ratio Prediction of Sparrow in Container Skin Australia

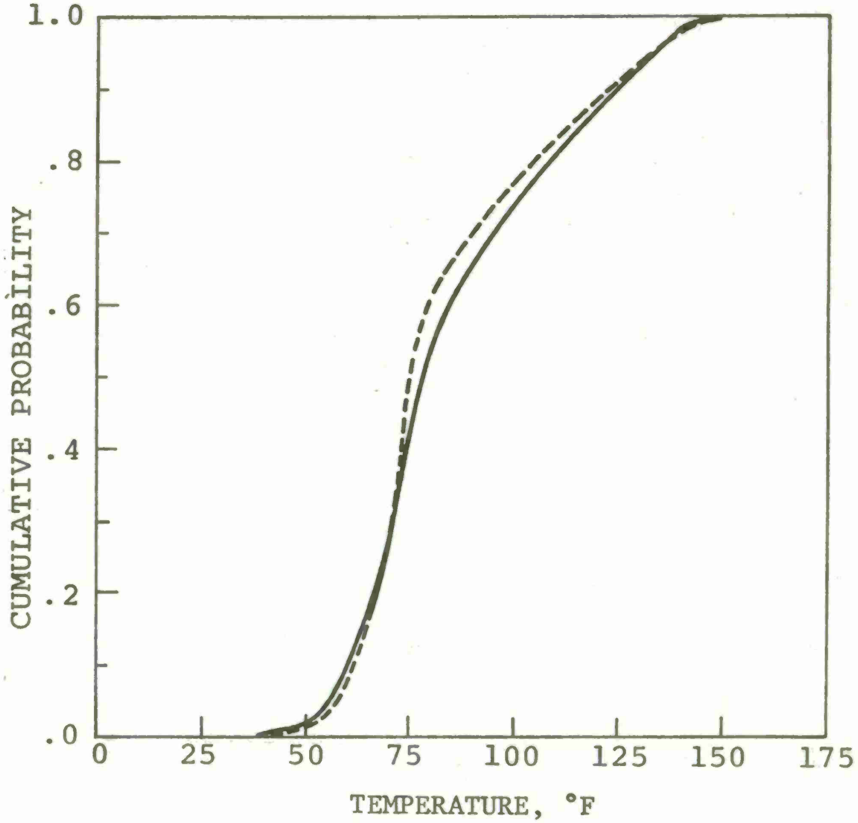

Figure 50. T.S. Top TD Ratio Prediction of Sparrow Out of Container Motor Wall Australia

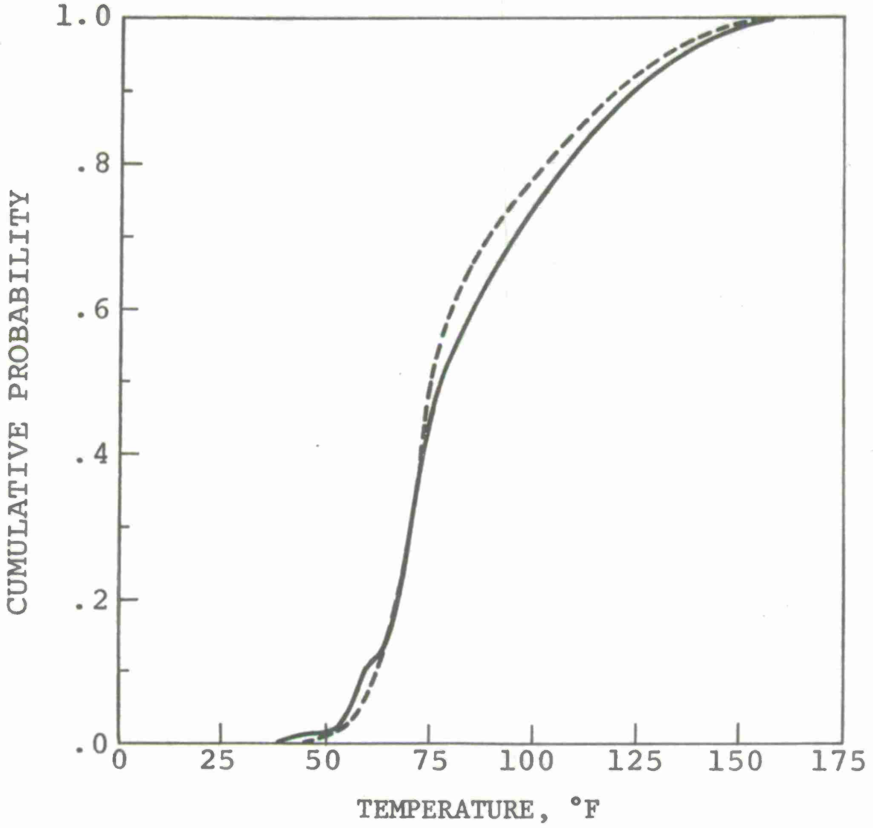

Figure 51. T.S. Top TD Ratio Prediction of ASROC Out of Container Motor Skin Australia

As a matter of interest an attempt was made to predict the cumulative probability curve for the ambient air. It was surprisingly successful.

Following this line of reasoning, it was suspected that the TD ratios developed from the center thermocouple would better predict the cumulative probability curve for any internal thermocouple. This proved to be so (Figure 43). Even the ambient air temperature was better predicted this way. As an internal extreme the Cumulative Probability Temperature curve for a magazette was tried and again was surprisingly successful. This gives reason to believe that other internal storage locations Cumulative Probability Temperature curves could also be accurately predicted by the center thermocouple. The use of the center thermal standard TD ratios to predict a container skin Cumulative Probability Temperature curve was not too successful (see Figure 44), but this was expected.

An attempt was made to use the China Lake thermal standard top thermocouple to predict the Cumulative Probability Tempertature curve for a container in Australia. This was so unsuccessful that it was necessary to generate the TD ratios from the top thermocouple in the Australian thermal standard. These were used to predict some Australian dump stored ordnance Cumulative Probability Temperature curves and the results were not as good as those for China Lake (see Figures 44 through 51). However, there is some question as to the validity of the baseline curves for all the Australian Cumulative Probability Temperature curves. Thus, no negative conclusions concerning the Cumulative Probability Temperature predictions may be drawn because of these poor comparisons.

These results in general indicate that the thermal standard, using the TD ratios, is an excellent means for predicting yearly Cumulative Probability Temperature curves from only 72 data points taken from a yearly record.

NORMAL DISTRIBUTION COMPARISON

China Lake Data

The cumulative distribution curve for the thermal standard top and center thermocouples was compared to a normal distribution having the same mean (μ) and standard deviation (σ). The objective of the comparison was to see if the curves were close enough to the normal to justify using normal distribution confidence intervals to predict the maximum error caused by using only part of the data to draw the baseline curve. The graphs are shown in Figures 52 and 53. In both cases the graphs show the data to be close to a normal distribution except at the extremes, where the actual data is not as severe. The longer tails of the normal distribution are more clearly seen in the observed frequency profile, shown in Figures 54 and 55. The greater

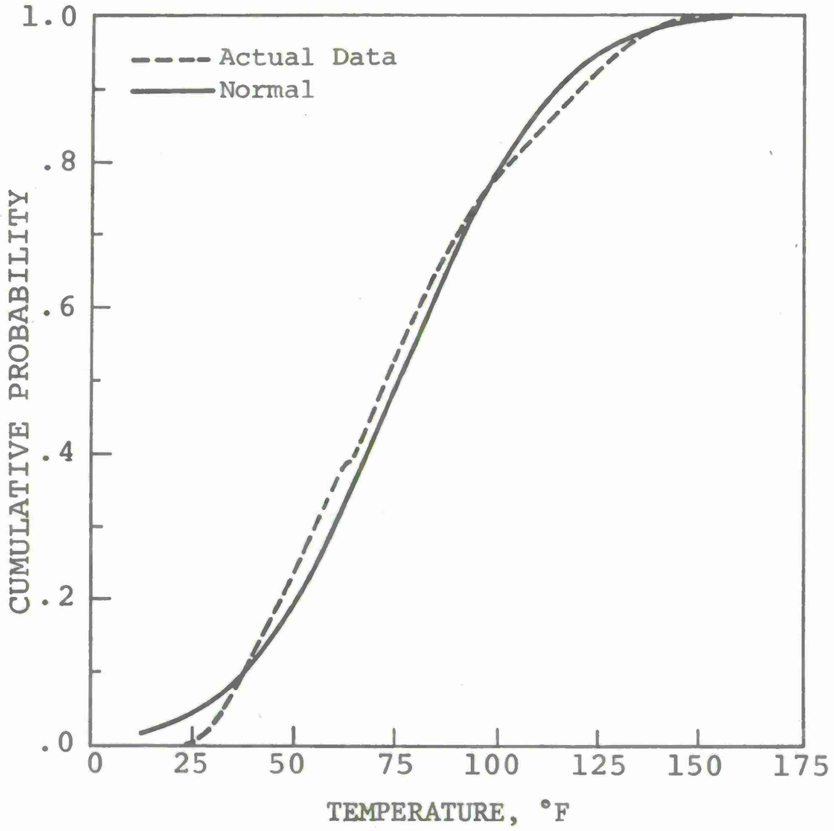

Figure 52. Normal Curve and Baseline of T.S. Top - China Lake

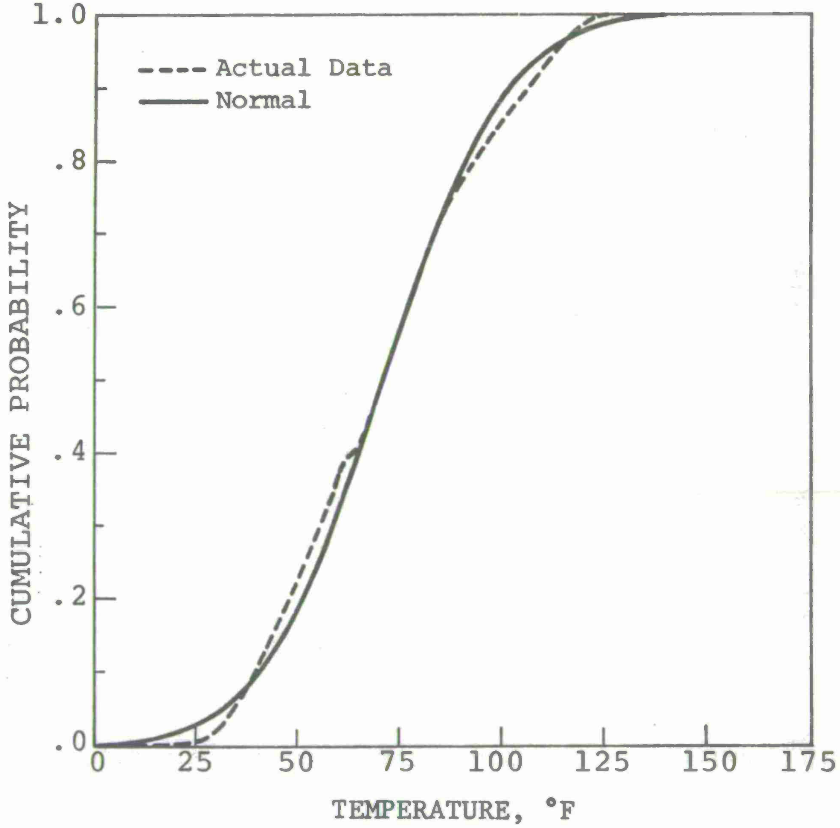

Figure 53. Normal Curve of Baseline of T.S. Center - China Lake

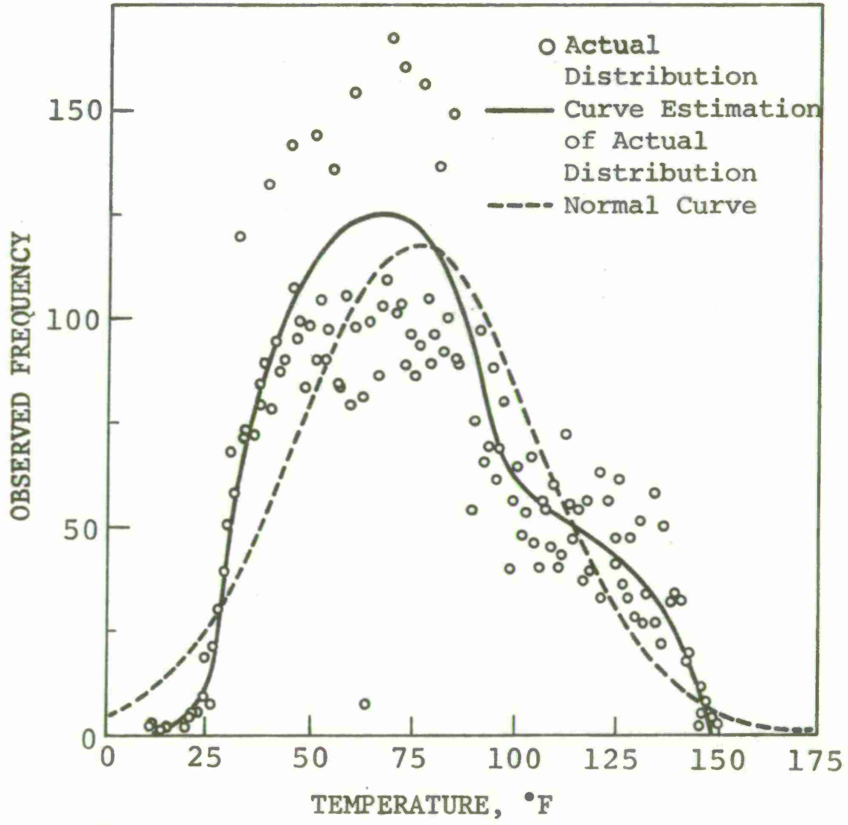

Figure 54. Observed Frequency Profile of Normal and T.S. Top China Lake

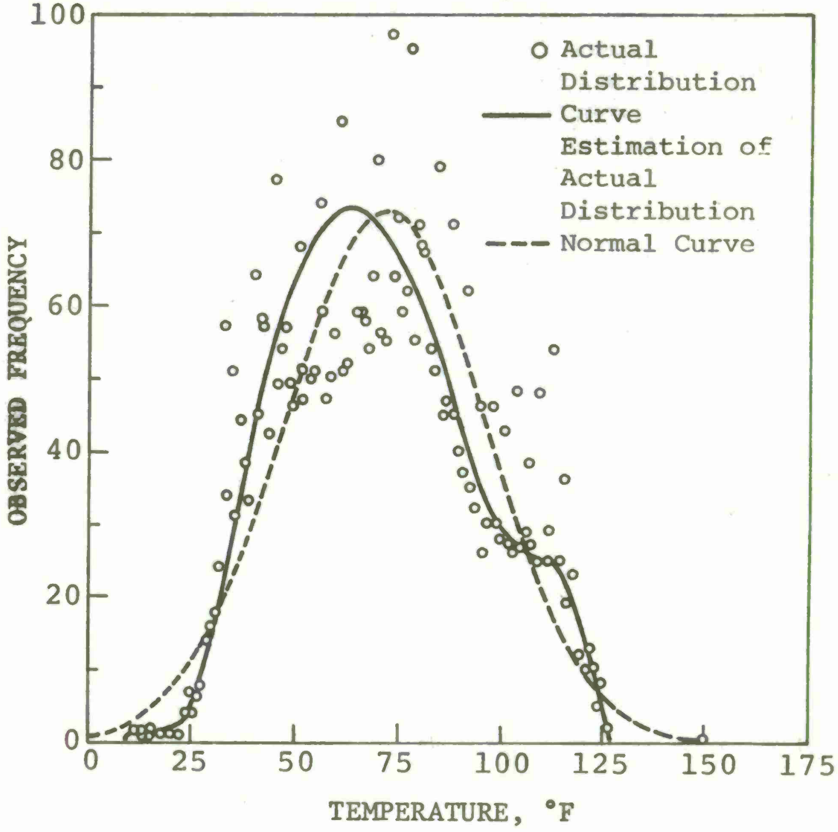

Figure 55. Observed Frequency Profile of Normal and T.S. Center China Lake

severity of the normal curve indicates that the normal confidence intervals would be conservative estimates for the actual data, i.e. the actual data bandwidths of error are smaller than those of the normal curve.

The hypothesis that this is true was tested by graphing 50 randomly selected samples of 5% of the total data (438 points per sample), and comparing the maximum error between the samples and the baseline to a normal confidence interval. All 50 of the samples were no more than 6.7% away from the baseline. This corresponds to the bandwidth expected for a 96% confidence interval. The probability that all 50 samples would lie within 96% confidence interval if normally distributed is approximately 13%. This is low enough to conclude that the temperature data are probably more conservatively distributed than the normal distribution. At any rate, it is safe to use normal confidence intervals to predict the bandwidths of error caused by data reduction.

Australian Data

A comparison of the normal and Australian thermal standard top is shown in Figure 56. The data deviate more from the normal than the China Lake data, the most significant deviation being at the top extreme where the actual data are more severe than the normal. A better profile of the data is given in Figure 57, which shows that the data resemble a Chi Square distribution, having a high peak and a long tail. The greater severity in the tail means that the bandwidth of error might be greater than the normal; however this could be offset by the compactness of the data in the center region, as revealed in the high peak. To check this a comparison similar to the one described above was done. The bandwidth was a maximum 6.7% away from the base line. This corresponds to an 85% confidence interval. (The interval is smaller than in the China Lake case because only 304 pts per sample were used.) The probability that all 50 samples would be inside an 85% interval, if normally distributed, is only .006. This at the 0.01 level of significance (highly significant) it can be concluded that the normal confidence intervals provide conservative estimates for the Australian data also.

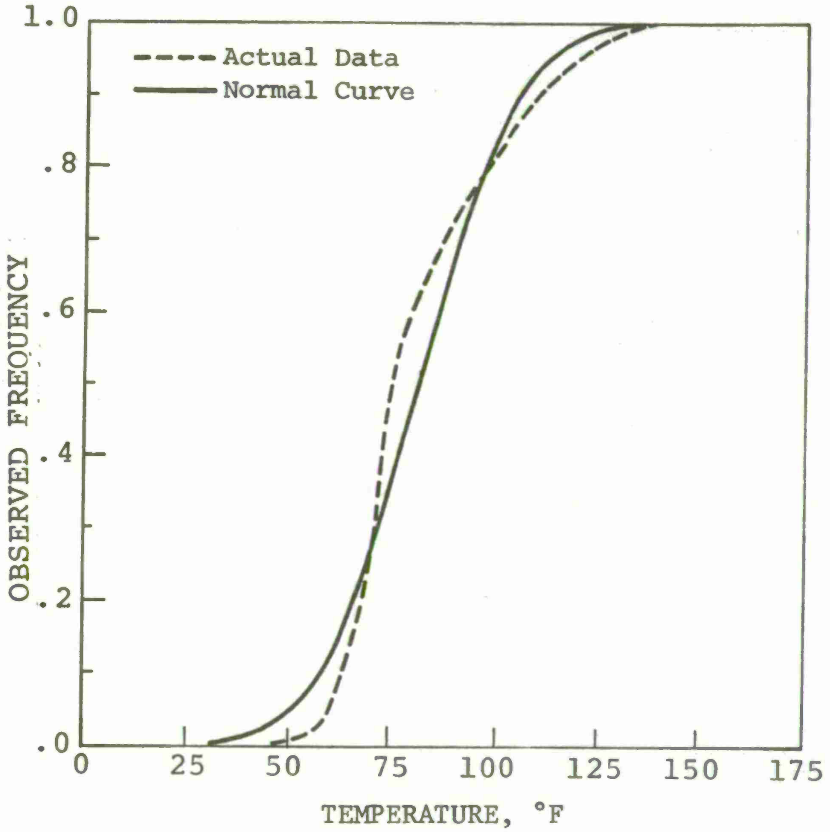

Figure 56. Normal Curve and Baseline of T.S. Top - Australia

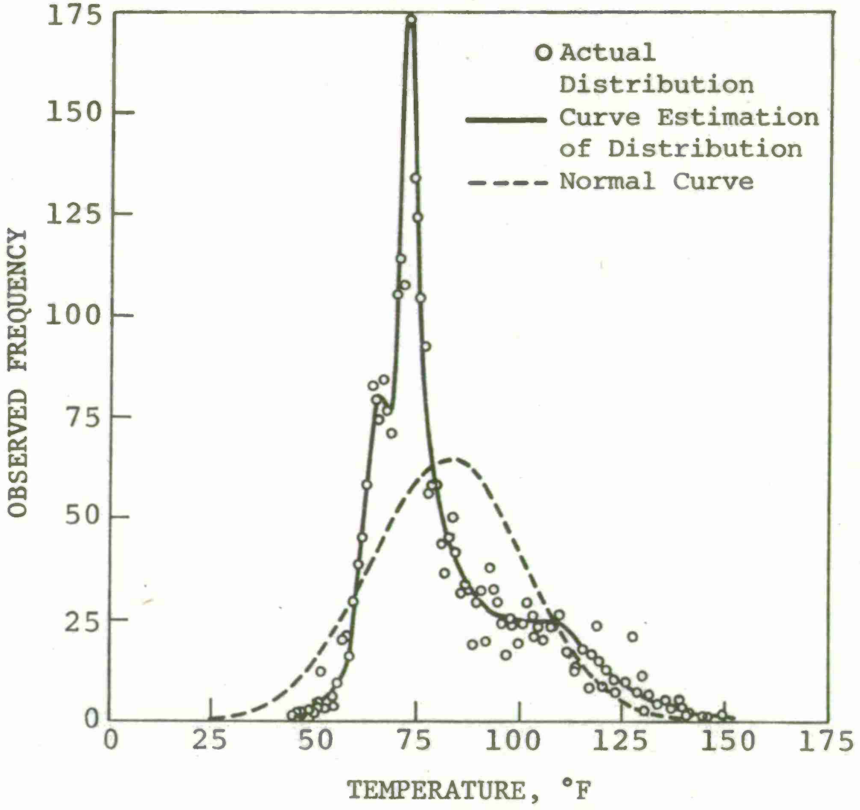

Figure 57. Observed Frequency Profile of T.S. Top and Normal - Australia

POSSIBLE FUTURE THERMAL STANDARD USES

The thermal standard is a neophyte as a tool in thermal environment instrumentation. However, its value has been demonstrated in a few areas as described in this report. Additional future applications are discussed below.

1. A large number of thermal standards should be placed in various places of the world where any possible future ordnance storage locations may be conceived. This will provide design information for future generations of naval weapons. So far, only a few extreme locations have been sampled. The new locations should include each continent and a variety of climates which are common to that continent. Some emphasis should be given also to isolated strategic locations.

The results will probably fall into a relatively few general patterns and then the map of the earth can be marked according to these patterns. Possibly, this can be done in conjunction with existing weather stations. These thermal standards would not need monitoring indefinitely, but only for a few years in each location. This would be sufficient to give the desired engineering design information.

2. The thermal standard concept may be useful in predicting temperature responses of items larger than typical naval ordnance, such as airplanes, ships, antennae, or even buildings.

3. The thermal standard could be used as a control device in environmental test chambers. That is, if the thermal standard is forced through a particular time-temperature curve as derived in the field, other adjacent ordnance may be expected to go through a simulated field experience. This is only true if the chamber is primarily a radiation oven and secondarily a convection oven. Also it is necessary that the radiation control be such that sun movement can be simulated. Most currently used environmental chambers do not have this capability.

PARAMETRIC STUDIES

In conjunction with one of the analytical models (Ulrich) developed for evaluating the thermal standard, a series of parametric studies were performed demonstrating several quantitative effects on dump store temperatures. The studies were all for the top location on a horizontal motor. The baseline values for each parameter not being investigated were held constant. All such values are in the Basic language computer program in Appendix A.

1. The effect of relative humidity (using Brunt's equation) shows a significant variation in daily temperatures (see Figure 58). This is because of the radiative energy interchange with the sky (long wavelength).

2. With the total solar wave length of radiation held constant, the fraction coming directly from the sun was varied from 1 to 0 and indicated no significant effect on top temperature (see Figure 59).

3. The baseline wind velocities were varied by a fraction of 1/2 to 10 and there was little effect on the calculated temperatures (see Figure 60).

4. The daytime temperature variation caused by different surface absorptivities is very significant. The white (very bright) paint would yield a maximum only a few degrees above air temperature while the dull black paint would be 70-80°F above ambient air temperature (see Figure 61). Of course, there is no significant difference in Figure 62.

5. Variation of diameter among missile, bombs, etc., in the navy range of use was not significant, including the diameter effect on mass (see Figure 63). However, when the mass was chosen independently from diameter the effect was significant and is shown in Figure 64. This is the same effect as making large changes in material density.

6. A similar set of studies was made for dark gray ($\alpha = .85$) painted stores as was with white painted ones. The sky temperature effect was similar. The wind velocity had more effect because there was more potential, since there was a large temperature difference between the missile and the ambient air. The mass and diameter effects were larger also. These effects are shown in Figures 65 through 69.

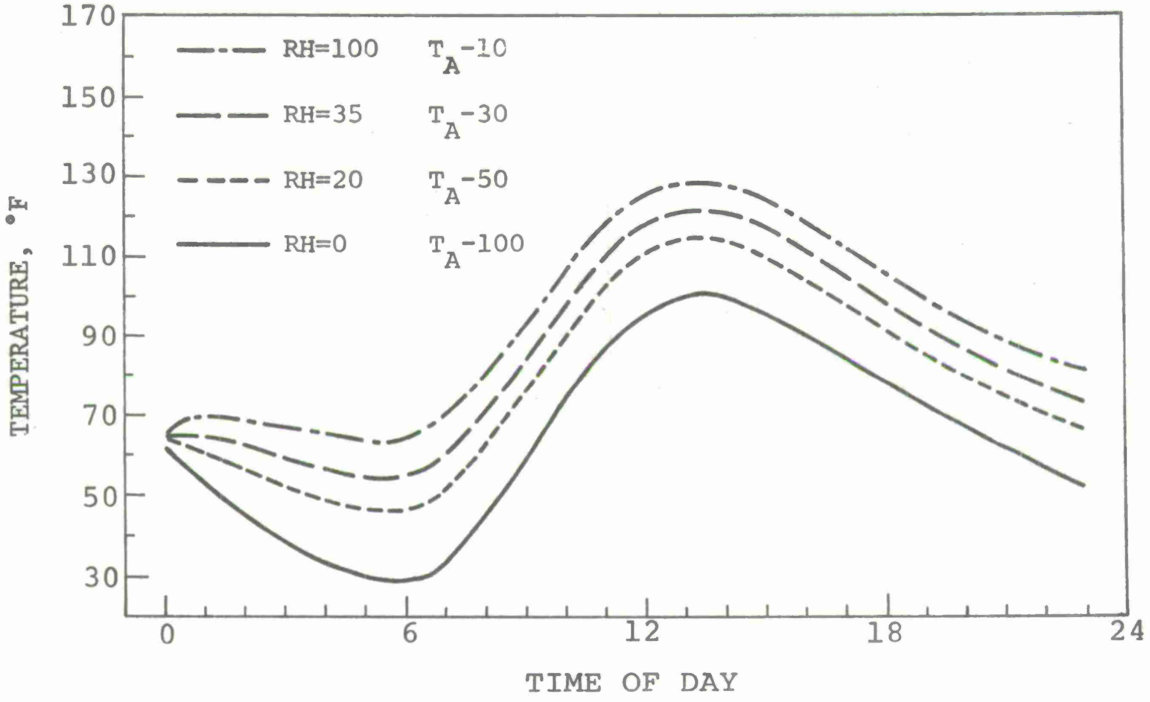

Figure 58. The Effect of Sky Temperature (or Relative Humidity) on Baseline

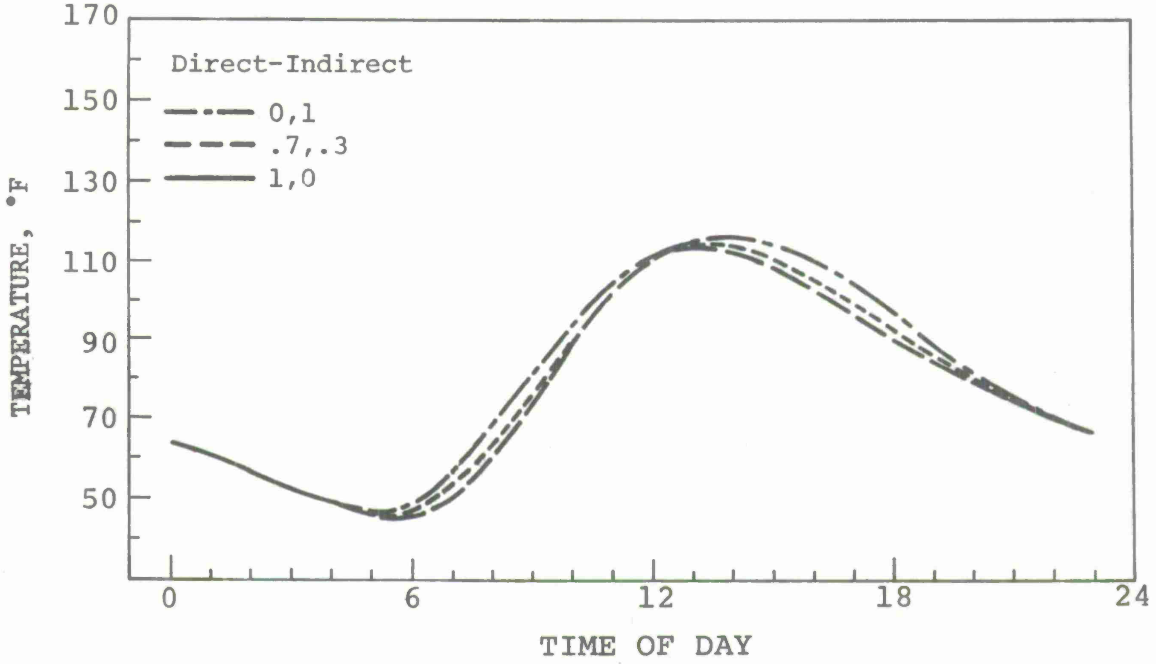

Figure 59. The Effect of Direct (Versus Indirect) Solar Radiation on Baseline Missile Top Temperature

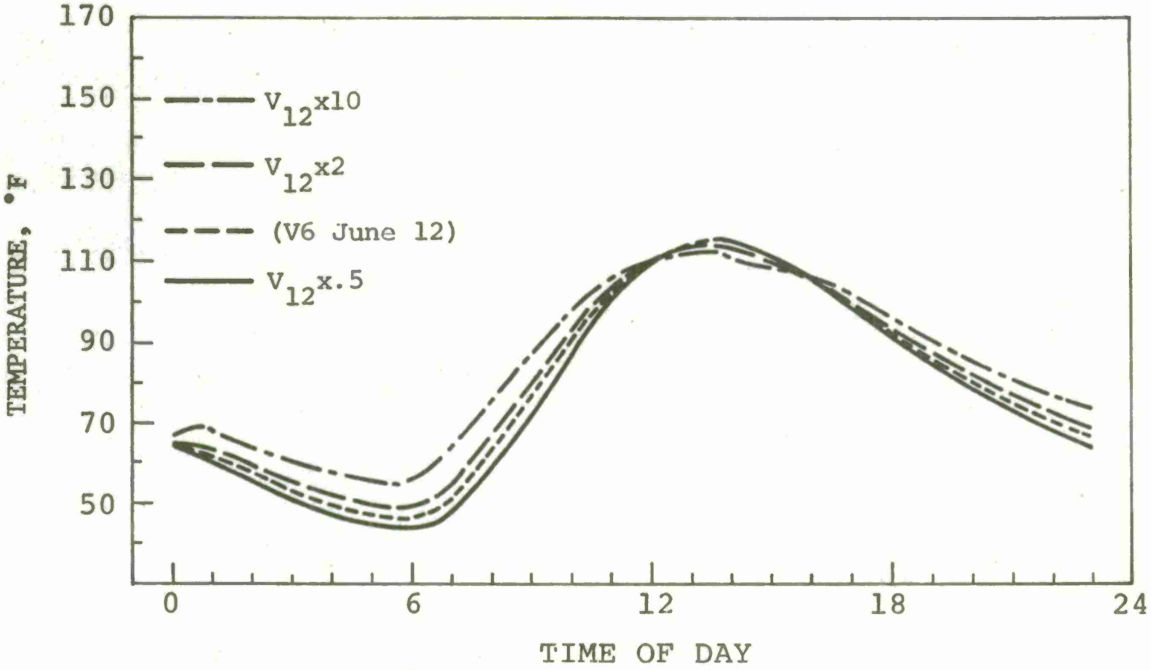

Figure 60. The Effect of Wind Speed on Baseline Missile Top Temperature

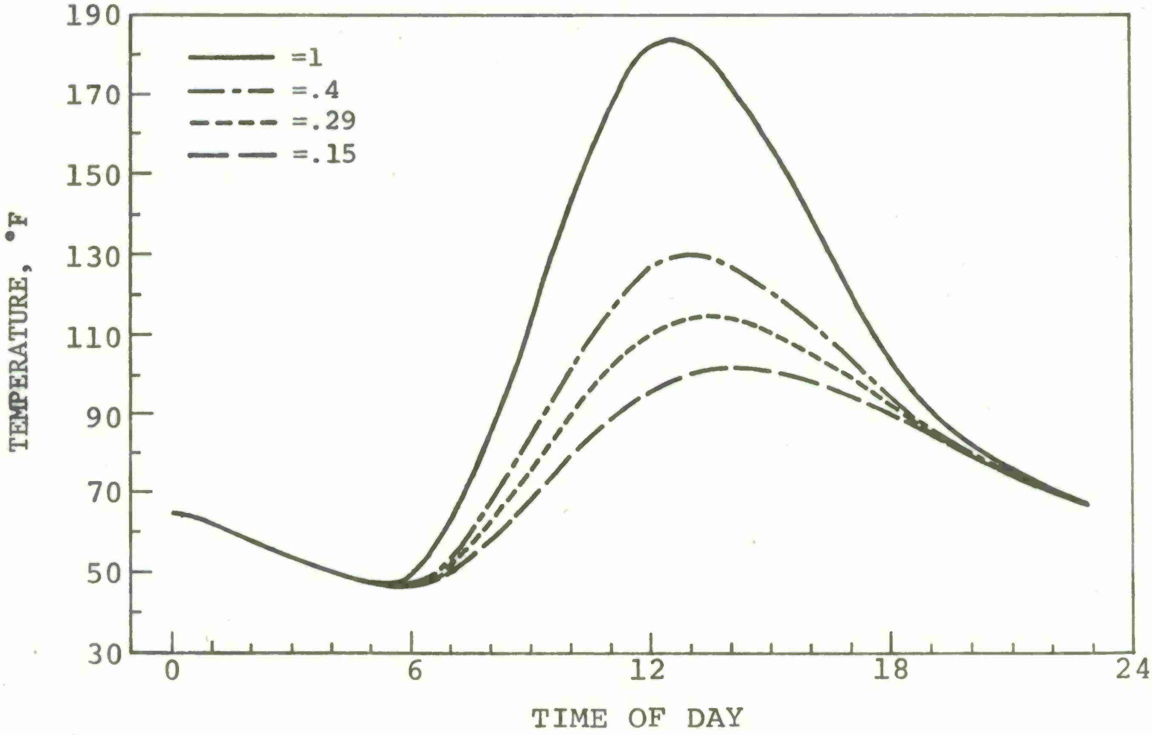

Figure 61. The Effect of Paint Color on Baseline Missile Top Temperature

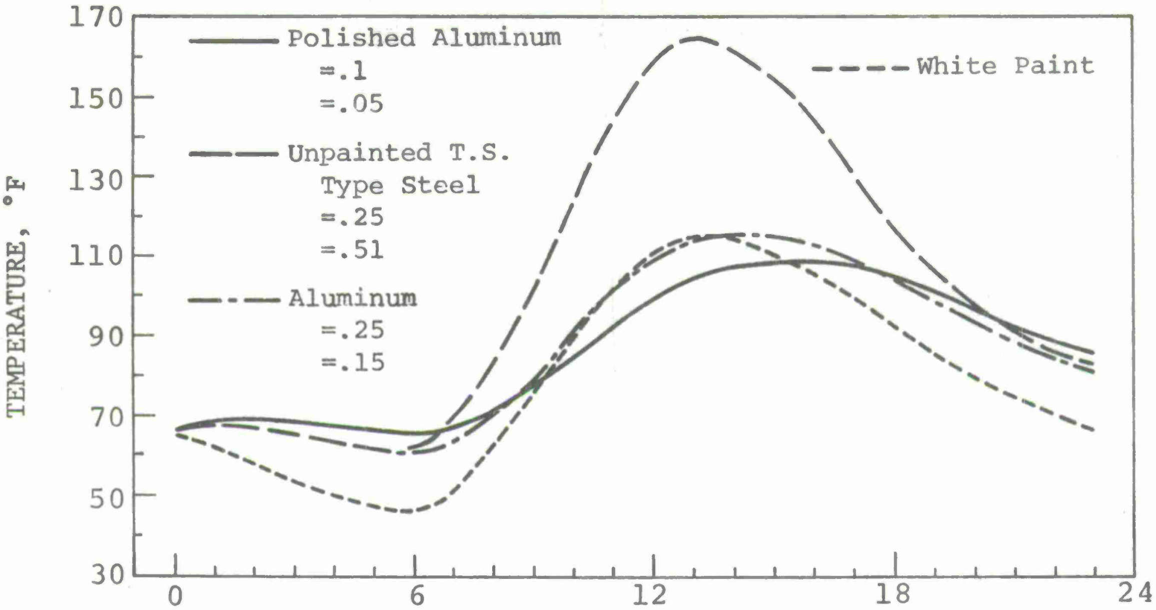

Figure 62. The Effect of Type of Surface on Baseline Missile Top Temperature

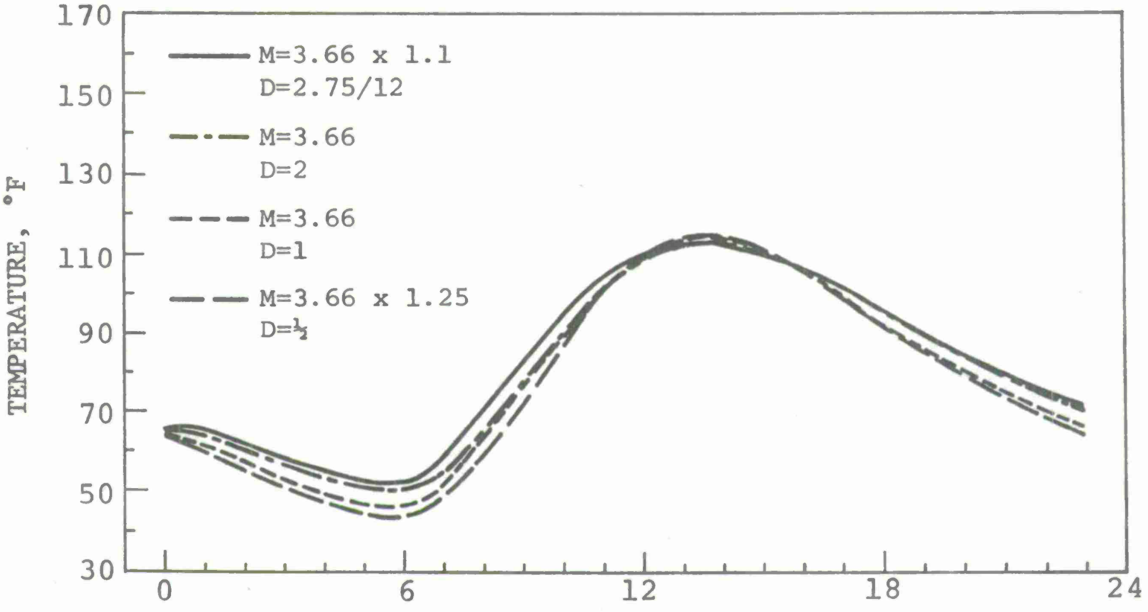

Figure 63. The Effect of Diameter on Baseline Missile Top Temperature

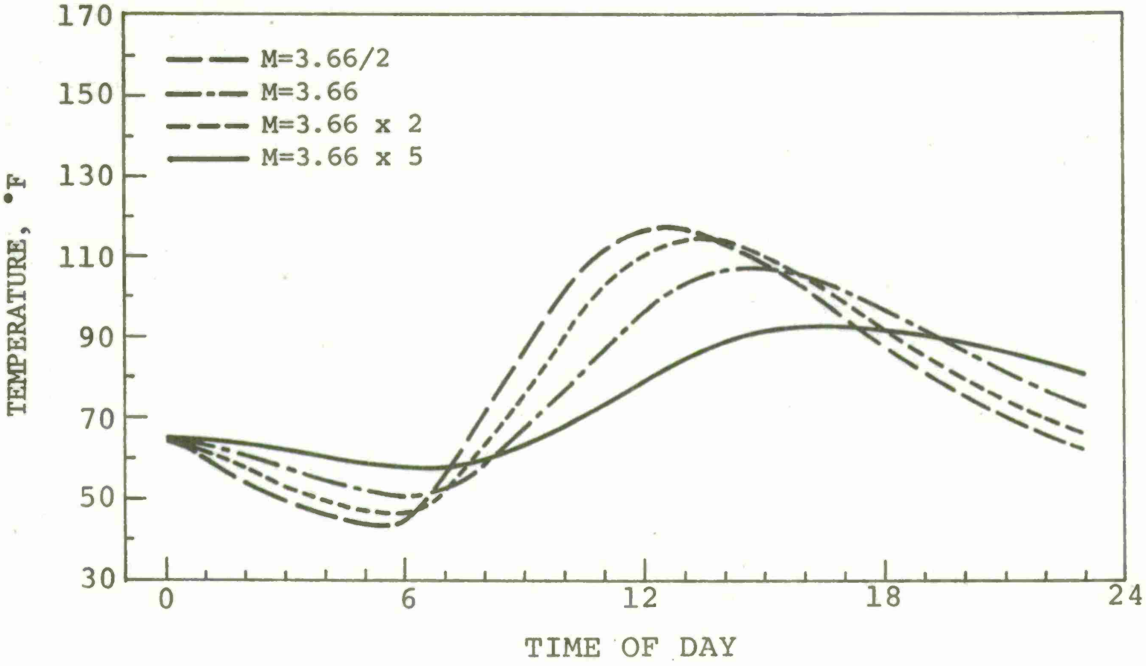

Figure 64. The Effect of Mass on Baseline Missile Top Temperature

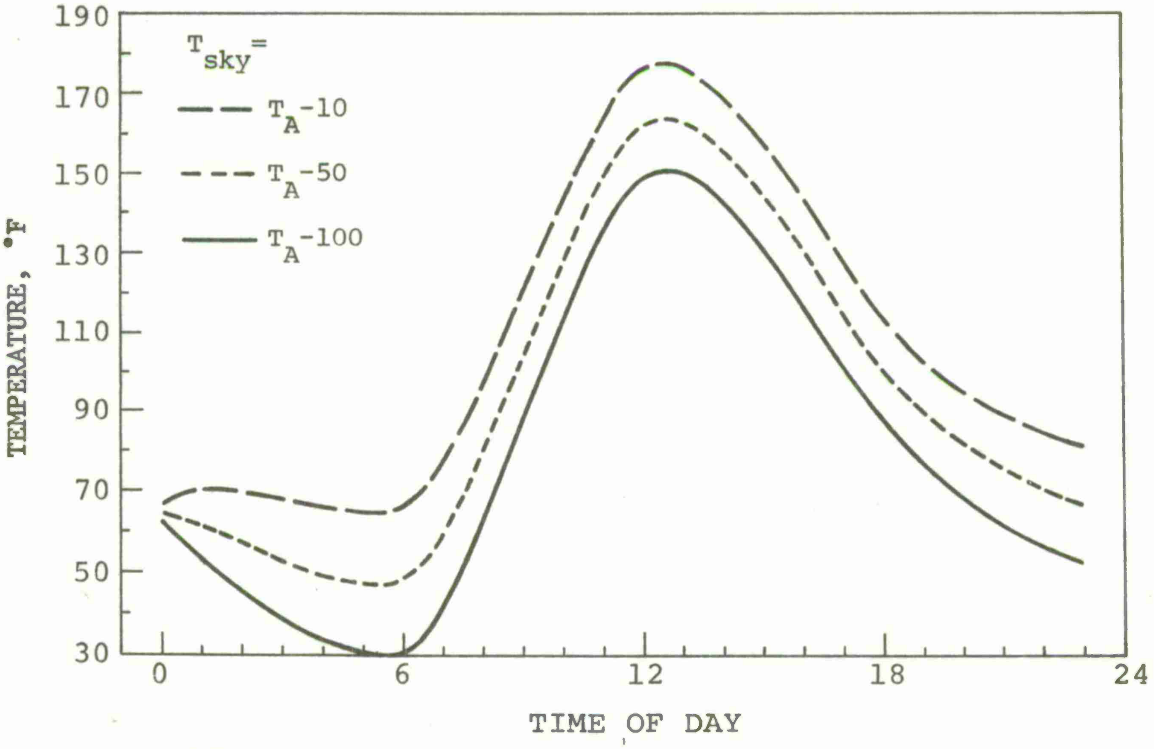

Figure 65. The Effect of Sky Temperature on a Gray (α = .8) Missile Top Temperature

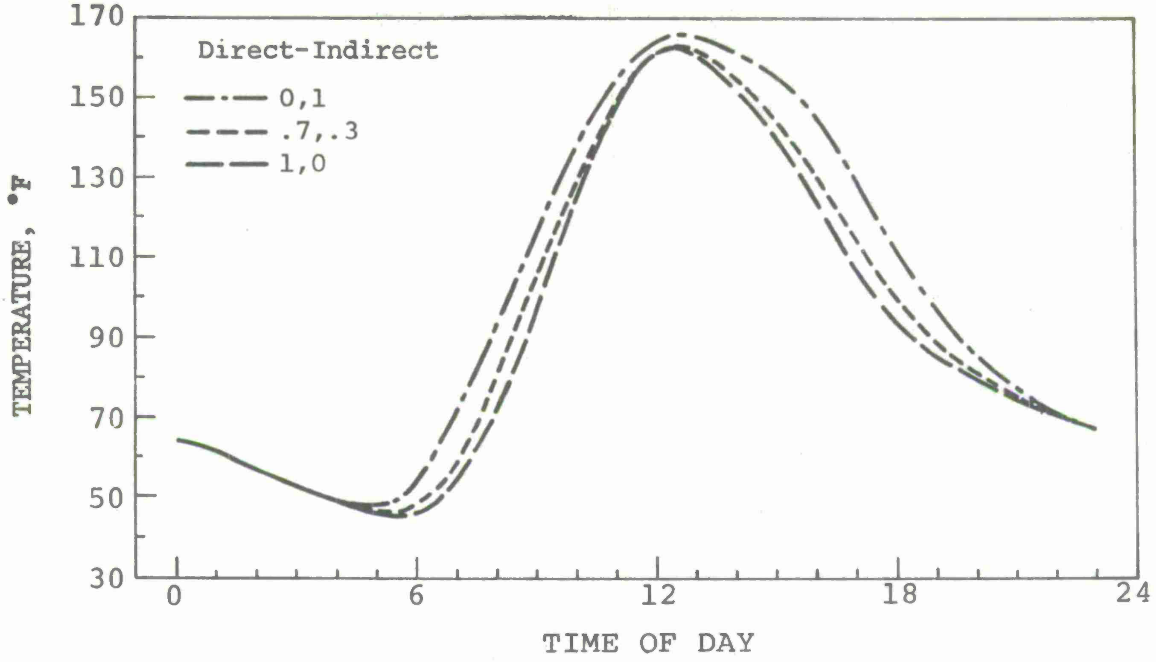

Figure 66. The Effect of Direct Versus Indirect Radiation on a Gray (α = .8) Missile Top Temperature

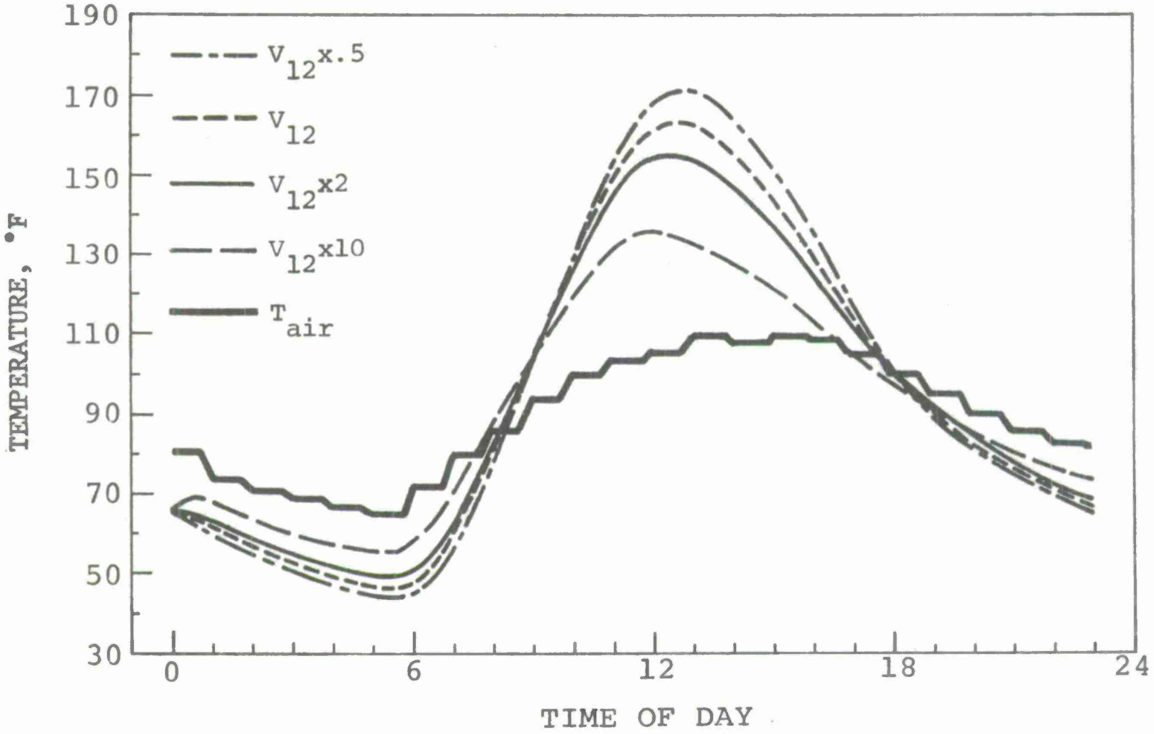

Figure 67. The Effect of Wind Speed on a Gray (α = .8) Missile Top Temperature

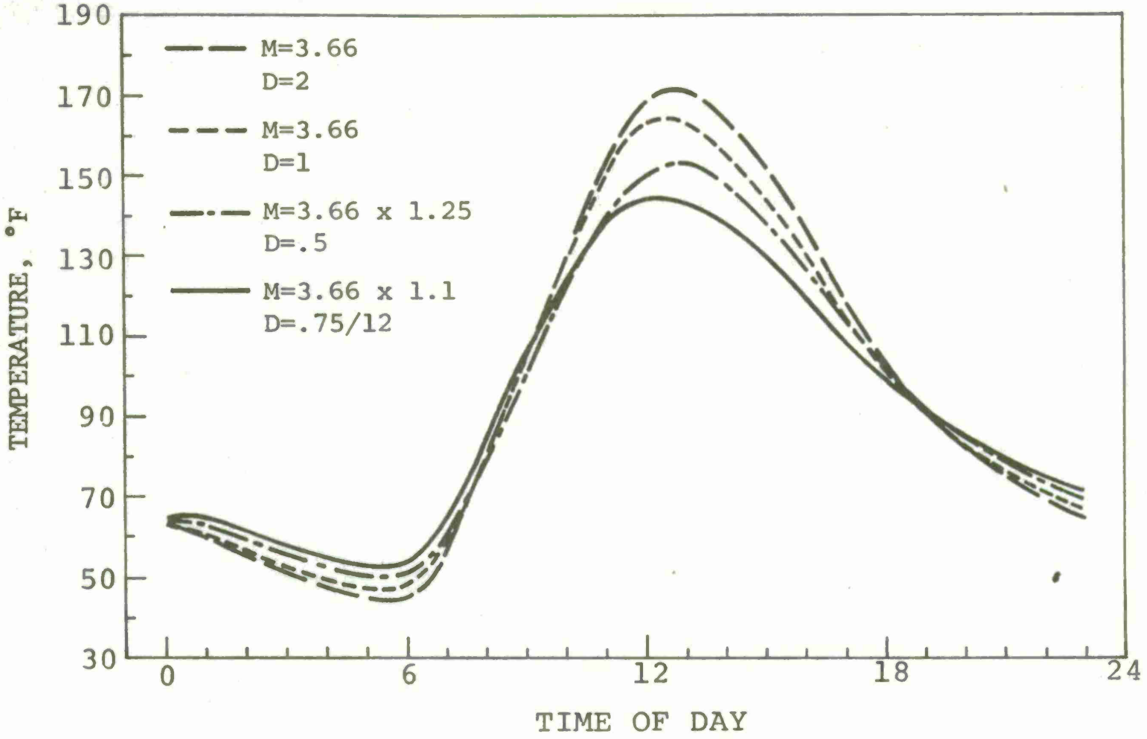

Figure 68. The Effect of Diameter on a Gray (α = .8) Missile Top Temperature

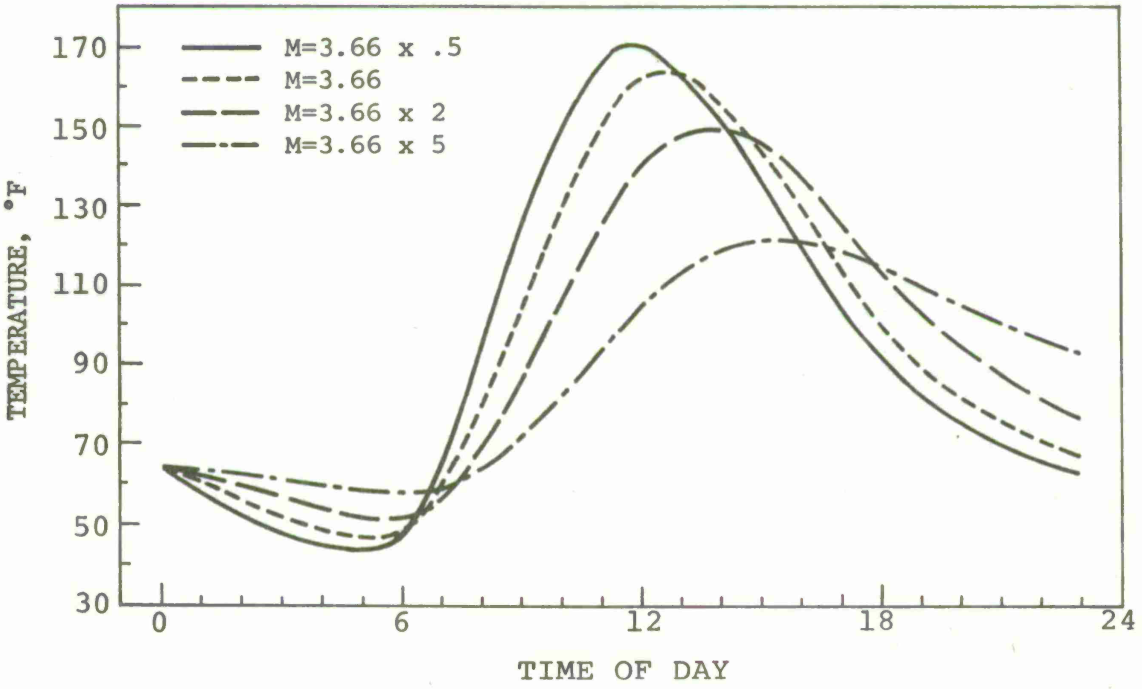

Figure 69. The Effect of Mass on a Gray (α = .8) Missile Top Temperature

CONCLUSIONS

1. The thermal standard method of predicting diurnal temperature variations for various locations on ordnance is simpler and more accurate than the analytical methods used by heat transfer experts.

2. The cumulative probability versus temperature is a good method to condense an enormous amount of data and it can be used by designers of future missile systems.

3. The typical day for the thermal standard plus only 72 data points (every tenth day maximum and minimum temperature) given as accurate estimate for the cumulative probability-temperature curves.

4. A dump-stored missile is insensitive to diameter but very sensitive to paint color. To keep the temperatures near air temperature, the missile should be painted white.

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APPENDIX A

The Basic Language Computer program used in the parametric studies. This was used on an HP 9830A computer.

```
20 SCALE 0,24,480,650
40 XAXIS 540,1,0,24
60 YAXIS 0,20,480,650                Definition of Symbols:
80 T = 525
85 D = 1                               D = Missile diameter
90 R1 = 0.25                          R1 = Time Stop
100 E = 0.9                            E = Emissivity to long wave length
                                           radiation
110 A1 - 0.29                         A1 = Absorptivity to solar wave
                                           length radiation
120 Z = 0.174 * 10 ↑(-8)               A = Stephan-Boltzman constant
140 M - 3.66                           M = Effective mass per unit area of
                                           missile
150 DIM A[4,25,25]
160 FOR I = 1 to 4
180 FOR J = 1 to 24
200 READ A[I,J]
220 NEXT J
240 NEXT I
260 DATA 0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23
280 DATA 0,0,0,0,0,67,4,22,37,2,51,63,2,72,79,78,2,70,8,62,6,49.8,35.4,
         19.8,7.2
300 DATA 0.4.0.0.0.0
320 DATA 81.74,71,69,67,65,72,80,86,94,100,104,106,110,108,110,109,105,
         100
340 DATA 95,90,86,83,82
360 DATA 2,2,1,1,1,1,1,2,2,3,3,3,4,5,4,3,5,5,4,4,4,4,2,2
380 FOR R = 0 to 24 STEP R1            R = Time of day
400 J = (INTR) + 1
410 P + (J-12)*P1/12                   P = Angle of the sun
420 Q = A[2,J]*3.6866
440 R2 = A[1,J]
460 T8 - A[3,J] + 460                 T8 = Air Temperature
480 V = A[4,J]                         V = Wind Speed
500 H = 0.76*(V/D)↑0.5                 H = Heat transfer coefficient
502 Q1 = 0.7*A1*Q*COS(P)              Q1 = Direct solar radiation absorbed
504 Q2 = 0.3*Q*A1                     Q2 = Reflected solar radiation
                                           absorbed
506 Q3 = H*[T-T8]                     Q3 = Convective heat lost from missile
508 Q4 = E*Z*(T↑4-(T8-50)↑4)          Q4 = Radiation to sky
520 T1 = (Q1+Q2-Q3-Q4)*R1/M           T1 = Temperature increment
540 T = T+T1
560 PLOT R,T
580 NEXT R
590 PEN
600 END
```

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  SD (1)
  YA (1)
  YF (1)
  YH (1)
  YM (1)
  YP (1)
  YX (1)
3 Assistant Secretary of Defense
  DIECO (1)
  Explosives Safety Board (1)
  E. F. von Marbod (1)
10 Director of Defense Research and Engineering
  AD(ET) G. R. Makepeace (1)
  OAD(ET) R. Thorkildsen (1)
  OAD(T) Col. B. Swett (2)
  DD(T&E) Lt. Gen. Lotz (1)
  AMRAD Committee (1)
  AD(CS) Greinke (1)
  Col. Strickland USA (1)
  Capt. J. Bres USN (1)
  Col. M. Weber USAF (1)
5 Defense Advanced Research Project Agency, Arlington
  Technical Director (1)
  Strategic Tech (1)
  Tactical Tech (1)
  Tech Assessments (1)
  Technical Library (1)
2 Defense Documentation Center
7 Joint Chiefs of Staff
  Chairmans Staff Group (1)
  Director J-3 (1)
  WWMCCS ADP (1)
  Standards Branch (1)
  Europe/Middle East/African Div (1)
  Director J-4 (1)
  Director J-5 (1)
3 Library of Congress
1 National Security Agency, Fort George G. Meade (Sgt. M. H. Schafer)
1 Aerojet-General Corporation, Azusa, CA (Technical Library)
1 Aerojet Liquid Rocket Co., Sacramento, CA (via AFPRO) (Technical Library)
1 Allegany Ballistics Laboratory, Cumberland, MD (Technical Library)

1 Applied Physics Laboratory, Johns Hopkins University, Laurel, MD (Technical Library)
1 ARINC Research Corporation, Santa Ana, CA
2 Bell Aerospace Textron, Buffalo, NY
  Technical Library (1)
  D. L. Kidd (1)
1 Booze Allen, Bethesda, MD
2 Chemical Propulsion Information Agency, Applied Physics Laboratory, Silver Spring, MD
  Sid Solomon (1)
  Technical Library (1)
1 Cushing Neveil Incorporated of California, Los Angeles, CA
1 Dayton T. Brown, Inc., Bohemia LI, NY (Technical Library)
1 General Dynamics, Pomona Division, Pomona, CA (Technical Library)
1 Governors State University, Park Forest, IL (Dr. T. Andrews)
1 Hercules, Inc., Bacchus Works, Magna, UT
2 Hughes Aircraft Company, Canoga Park, CA
  C. Clapp (1)
  Technical Library (1)
2 Institute for Defense Analyses, Arlington, VA
  Dr. R. C. Oliver (1)
  Technical Library (1)
2 Institute of Environmental Sciences, Mt. Prospect, IL
1 Lockheed-California Company, Burbank, CA
2 Lockheed-Georgia Company, Marietta, GA
  Technical Library (1)
  E. H. Parker (1)
1 McDonnell Douglas Astronautics, Huntington Beach, CA
2 McDonnell Douglas Corporation, Long Beach, CA
  Pabst (1)
  Technical Library (1)
1 McDonnell Douglas Corporation, Santa Monica, CA
3 McDonnell Douglas Corporation, St. Louis, MO
  Aircraft Division, Technical Library (1)
  Missile Division Technical Library (1)
  B. Dighton (1)
1 Marquardt Corporation, Van Nuys, CA
1 Martin Company, Denver, CO (Technical Library)
1 Martin-Marietta Corporation, Orlando, FL (Technical Library)
1 North American Rockwell Corporation, Columbus, OH (Technical Library)
2 Philco-Ford Corporation, Newport Beach, CA
  R. Elston (1)
  Technical Library (1)
2 Raytheon Company, Waltham, MA
  Missile Systems (1)
  Technical Library (1)

2 Rocketdyne, Canoga Park, CA
    A. Kohl (1)
    Technical Library (1)
1 Rocketdyne, McGregor, TX (Technical Library)
1 Rockwell International Corporation, Los Angeles, CA (Technical Library)
1 Rohm and Haas Company, Huntsville, AL
3 Sandia Corporation, Albuquerque, NM
    Section 1541, Jerry T. Foley (2)
    Section 1543, Mark B. Gens (1)
3 Sandia Corporation, Livermore, CA
    C. A. Scott (2)
    Technical Library (1)
1 Texas Instruments, Inc., Dallas, TX (Technical Library)
3 The Boeing Company, Seattle, WA
    S. Barber, MS 8609 (1)
    J. Stuart, MS 47-06 (1)
    Technical Library (1)
1 Thiokol Chemical Corporation, Bristol, PA
1 Thiokol Chemical Corporation, Wasatch Division, Brigham City, UT
1 United Technologies, Chemical Systems Division, Sunnyvale, CA
1 Value Engineering Company, Alexandria, VA (J. Toomey)
2 Vought, Incorporated, Systems Division, Dallas, TX
    R. N. Hancock, Unit 2-53483 (1)
    Technical Library (1)