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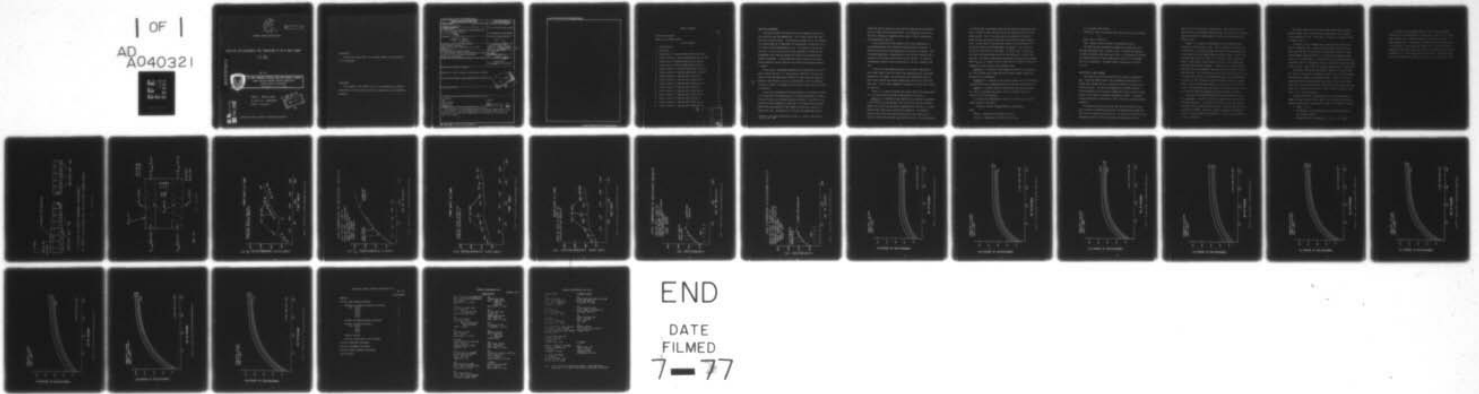
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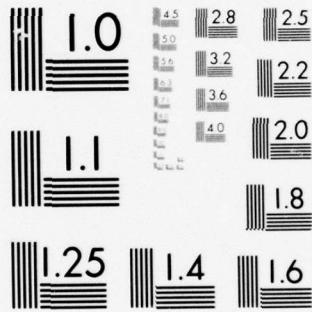
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TECHNICAL REPORT ARLCB-TR-77027

ANALYTICAL AND EXPERIMENTAL TUBE TEMPERATURES IN THE 8" XM201 CANNON

R. G. Gast
P. M. Vottis

ADA 040321

May 1977



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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BENET WEAPONS LABORATORY
WATERVLIET, N. Y. 12189

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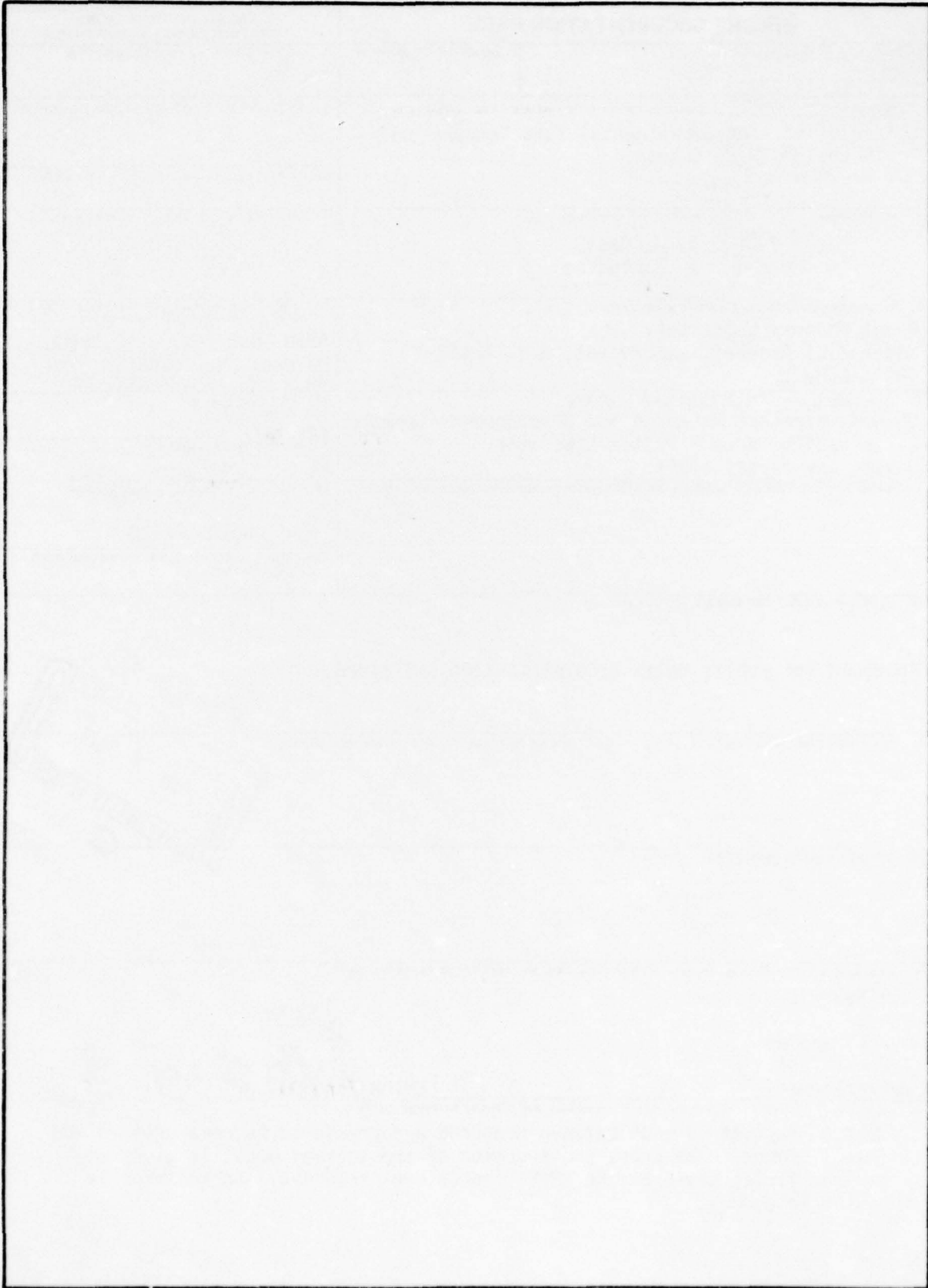
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ANALYTICAL BACKGROUND

Available at Watervliet Arsenal are various computer programs used for calculating gun tube temperatures. All of these codings have their basic uses and restrictions. The particular program used in this analysis is entitled ITEMP and is applicable for closed breech systems which fire at a rate of three rounds/minute or less. The program is divided into two parts. In the first part, a ballistic computation is made and the hydrodynamic flow situation analyzed for purposes of determining heat transfer parameters. In the second part these parameters are used as driving functions and the tube wall heat balance and conduction problem is solved.

7 The gun tube is represented geometrically by subdividing it into 15 axial sections (see Fig 1). Each section is defined by its axial distance (X) from the breech face, and both its inner and outer diameters. Geometric representation is set up by the analyst. With the exception of section 3 (which is centered at the origin), all other section locations are arbitrary.

In part one, the method of Hicks and Thornhill as presented by Corner¹ is followed with minor modification to find the boundary layer thickness, the skin friction, and the heat transfer coefficient. The effect of non-uniformity and non-steadiness of the flow is included and heat transfer coefficients are produced for the midpoint of each axial section as a function of time. Monitored also is the gas core temperature and the

¹"Theory of the Interior Ballistics of Guns", J. Corner, John Wiley & Sons, NY, NY, 1950

cumulative time of exposure of each section through the entire ballistic cycle, including the post-ejection phase. The average heat transfer coefficient, average gas temperature, and exposure time for each section are transmitted to part two.

In the second part of the program, a bulk section temperature is calculated based upon the various heat flows through each section. A uniform distribution of heat energy within the section is assumed. This calculated temperature is approximately at the section's mid-wall and is assigned to the section's axial center of mass location. In actuality, a temperature gradient exists from the bore to the outer surface of the tube.

At actual gun tube temperature levels of 325-350°F experienced in the 8" M201 cannon firing at a rate of one round/two minutes, calculated temperatures are roughly 2-3% below actual bore temperatures and 2-3% above actual outside tube surface temperatures just prior to firing the next round. At this time, a temperature gradient of 15-20°F exists through the tube wall.

Figure 2 is a sketch of the Nth tube section when firing round number (k). The various heat flows (\dot{Q}) are represented at time $t=t_k$.

$\dot{Q}_{in}(N, t_k)$ is a function of the propellant gas properties (calculated in the first part of the program), bore surface area and the difference between the gas and the tube section temperature at time $t=t_k$. It is the effective heat input rate to section N for round (k). An auxiliary analytic solution has been used to determine the total heat input to section N during the relatively short ballistic pulse. This heat quantity

is divided by the time between rounds and the resulting average heat flow rate is allowed to enter section N slowly and uniformly during the time between rounds. This is for consistency and commonality of solution format with the other heat fluxes which are non-pulsed, slowly varying flows. By the time of firing the next round, all the required heat is in the section and the uniform temperature is computed. Thus arises the firing rate restriction for this model. At faster rates in a real gun, the radial distribution departs too far from uniformity. The wall temperature is set equal to the section average, and the controlling variable $[T_{\text{gas}} - T(N, t_{k+1})]$ is formed for use in the auxiliary analytic solution for computation of heat input on the succeeding round.

$\dot{Q}_{\text{out}}(N, t_k)$ is a function of the velocity and density of the ambient air, outer surface area of tube, and the difference between section temperature and air temperature.

$\dot{Q}_{\text{long}}(N, t_k)$ is a function of the thermal conductivity of tube material, intersectional area, and temperature difference between adjacent sections.

$\dot{Q}_{\text{sun}}(N)$ is a constant source of radiant heat from the sun and sky. Its value is calculated based upon a clear sky condition and a sun location of 60° from horizontal.

To calculate the temperature of section N at time $t = t_{k+1}$, the following equation is evaluated:

$$T(N, t_{k+1}) = T(N, t_k) + [Dt \cdot \text{NET } \dot{Q}(N, t_k)] / [M(N) \cdot C(N)]$$

where:

$T(N, t_k)$ = temperature of section N at time t_k

$T(N, t_{k+1})$ = temperature of section N at time t_{k+1}

Δt = iteration time interval

NET $\dot{Q}(N, t_k) = \sum$ of various heat flows occurring during time interval t_k

$M(N)$ = mass of section N

$C(N)$ = specific heat of section N at temperature $T(N, t_k)$

The model has been calibrated by comparing its predictions with measured temperatures from a variety of guns. The model was adjusted to predict centrally within the mass of data. An adjustment was effected by increasing the heat transfer coefficient since this is the weakest part of the computation. The model predicts temperature rise within 5 to 10%.

APPLICATION TO XM201 PROGRAM

The program has been used successfully for matching experimental data. During the XM188 cook-off test at Aberdeen Proving Ground in January 1975, thermal analysis by Watervliet saved the time and cost of refiring the test. The test plan required that the XM201 cannon be fired continuously at one round per minute until one of the three thermocouples in the tube wall recorded a temperature of 350°F. The charge used was XM188 zone 8 conditioned to 145°F, along with unconditioned M106 projectile.

In actuality, the firing rate was less than one round per minute, the firing was not continuous, and none of the thermocouples reached the 350°F level as required by the test plan. At the end of the day's firing, thermocouple number 3, which was located over the forcing cone at a

depth of 2.25" into the wall, recorded 282°F. Based upon previous computer studies, it was decided that enough data was available to reasonably predict the number of rounds needed to achieve the required 350°F temperature level.

Figure 3 is a graphical representation of raw temperature data (recorded at forcing cone) vs time. Time axis begins at 1054 hours on 7 January 1975. Initially, 35 rounds were fired at the approximate rate of two rounds per three minutes before a break was taken. At this point the tube began cooling at a rate of .17°F/minute. When firing was resumed, it took seven or eight rounds to "catch up" to the temperature achieved before the break occurred. A second series of rounds (36-89) were then fired at approximately the same rate before another 15 minute break was taken. This time the cooling rate was .26°F/minute and it took 9-10 rounds to "catch up" to the temperature which was achieved before the break. Of the 136 rounds fired, only 120 were usable for computer analysis since 16 rounds were needed for "catching up" after breaks in firing. The experimental data was modified by eliminating the 16 "catch up" rounds and reporting temperature against the number of rounds.

In Figure 4, the modified experimental data and computer analysis are superimposed. The bull's eye points represent the modified forcing cone temperature data. The overall firing rate for the test schedule was taken to be two rounds per three minutes. Wind data for the day was an average of 10 MPH. The curve in Figure 4 represents the computer analysis of the modified firing conditions. It can be seen that there is close correlation.

During the zone 9 wear test (Yuma Proving Ground 12239) of the 8" Howitzer, XM201, (Serial #5) forcing cone temperatures were recorded during expenditure firing. This output is plotted as a function of time in Figures 5 and 6.

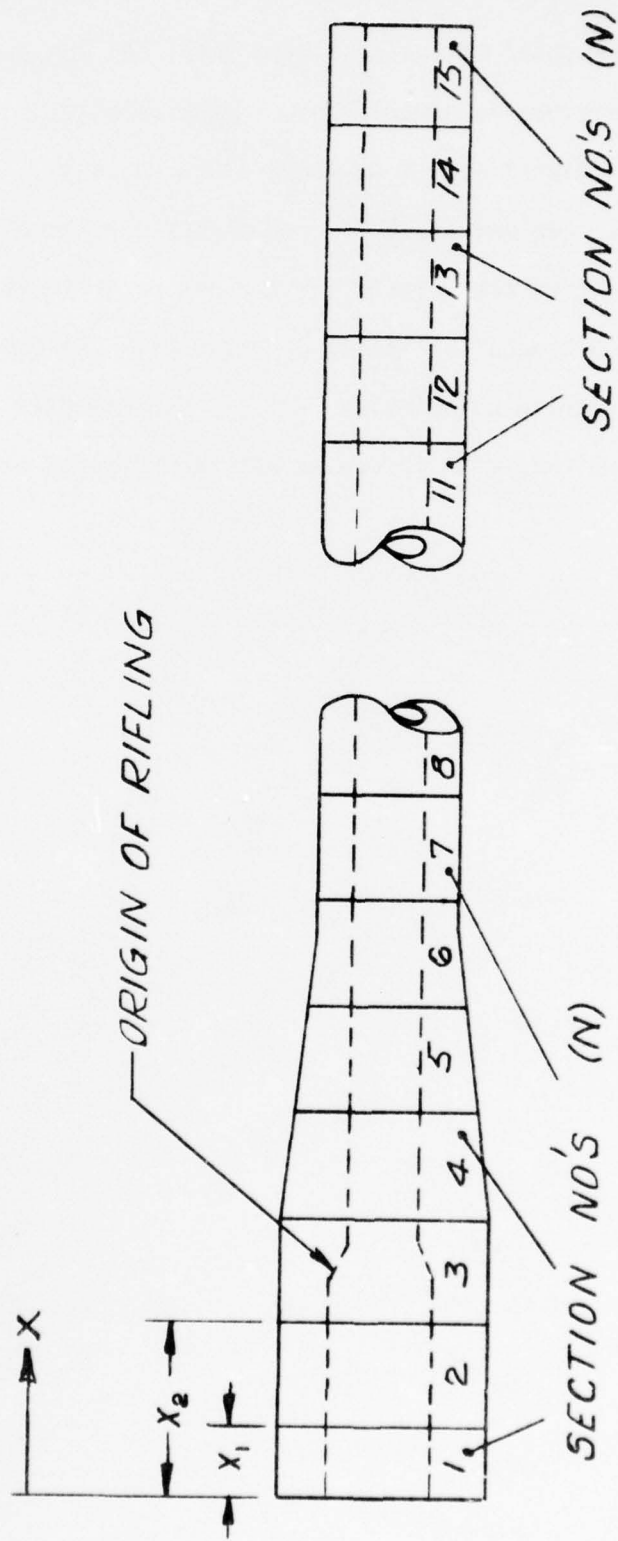
In Figure 5, firing schedule begins with tube round number 350 at 0905 on 5 September 1972. A break of approximately one hour occurred after round 390 and a 20 minute break occurred after round 410. Tube cooling between rounds 390 and 391 is $.26^{\circ}\text{F}/\text{minute}$ and between rounds 410-411, it is $.38^{\circ}\text{F}/\text{minute}$. In Figure 6, the firing schedule begins with round 435 at 0915 on 6 September 1972 with a break of 50 minutes occurring after round 475. Tube cooling rate between rounds 475-476 is $.42^{\circ}\text{F}/\text{minute}$.

The analysis follows the same format as analysis of cook-off data. All "catch up" rounds were eliminated, an overall firing rate and ambient conditions were assumed, and computations made. Figures 7 and 8 show experimental data and computed results plotted as a function of round number with firing rates and ambient conditions fixed at roughly the same conditions as achieved during firing. Again, the data and analysis are shown to be in close correlation.

Figures 9-17 present calculated origin of rifling temperatures vs number of rounds for the 8" M201 cannon. Various zones, firing rates, ambient and tube initial temperatures are used. The parameters include:

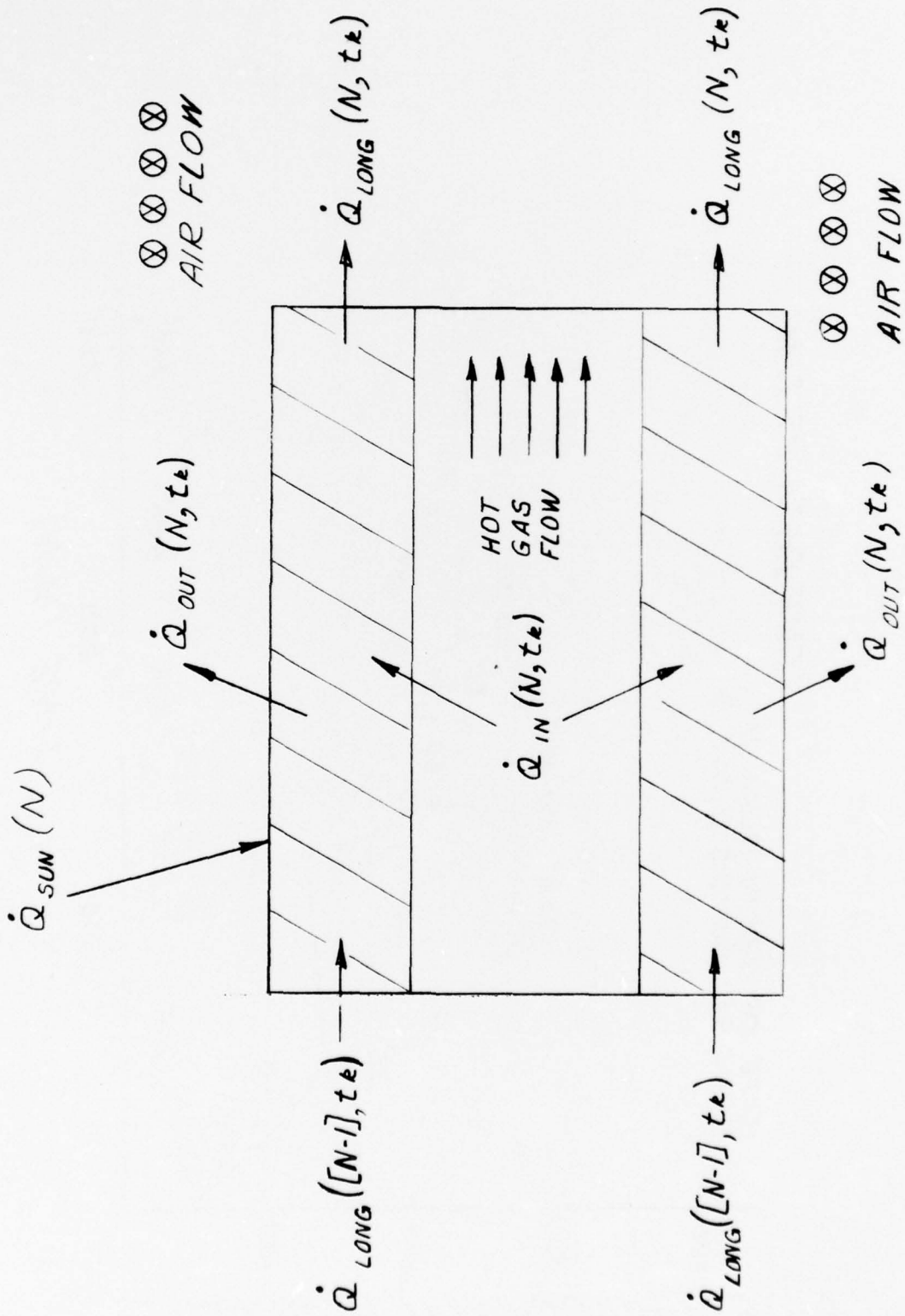
1. Zones: 7, 8, 9
2. Firing Rates: one round/minute; three rounds/four minutes; one round/two minutes
3. Ambient and Initial Temperatures: 50° , 70° , 100° , 145°F

In Figures 9-17, the computed effect of firing rates and ambient temperatures on tube temperature is clearly seen. Wind velocity, another input variable, has a significant effect on temperature response. For these computations, it has been set at 10 MPH and directed perpendicular to the tube axis. These curves are helpful for a close determination of temperature levels that would occur in firing programs with the indicated parameters (i.e., firing rate, wind velocity, etc.). Experimental data can also be modified and matched with curves as was demonstrated earlier.



1. $X_1, X_4, X_5, \dots, X_{15}$ VALUES ASSIGNED ARBITRARILY
2. POINTS X_2 & X_3 MUST BE EQUIDISTANT FROM ORIGIN

Figure 1. Tube sectioning.



TIME = t_k

Figure 2. Nth section.

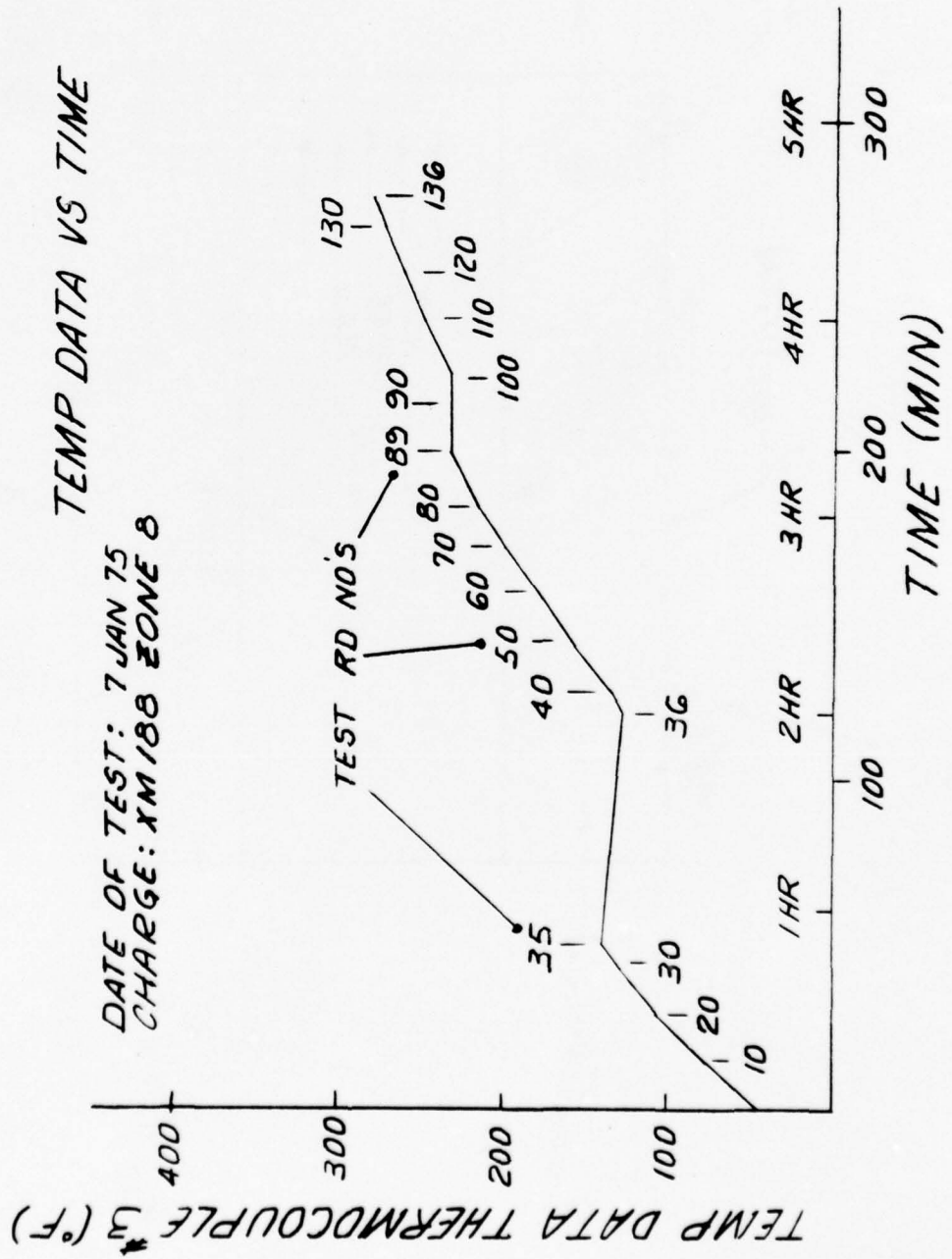


Figure 3. Thermal data, 8" Howitzer XM201/XM188 cook off test.

DATA COMPARISON TO CALCULATED RESULTS

DATE OF TEST: 7 JAN 75
RATE OF FIRE: 2 RDS/3 MIN
CHARGE: XM188 ZONE 8
AMB CONDITIONS:
WIND 10 MPH
TEMP 45°-55° F

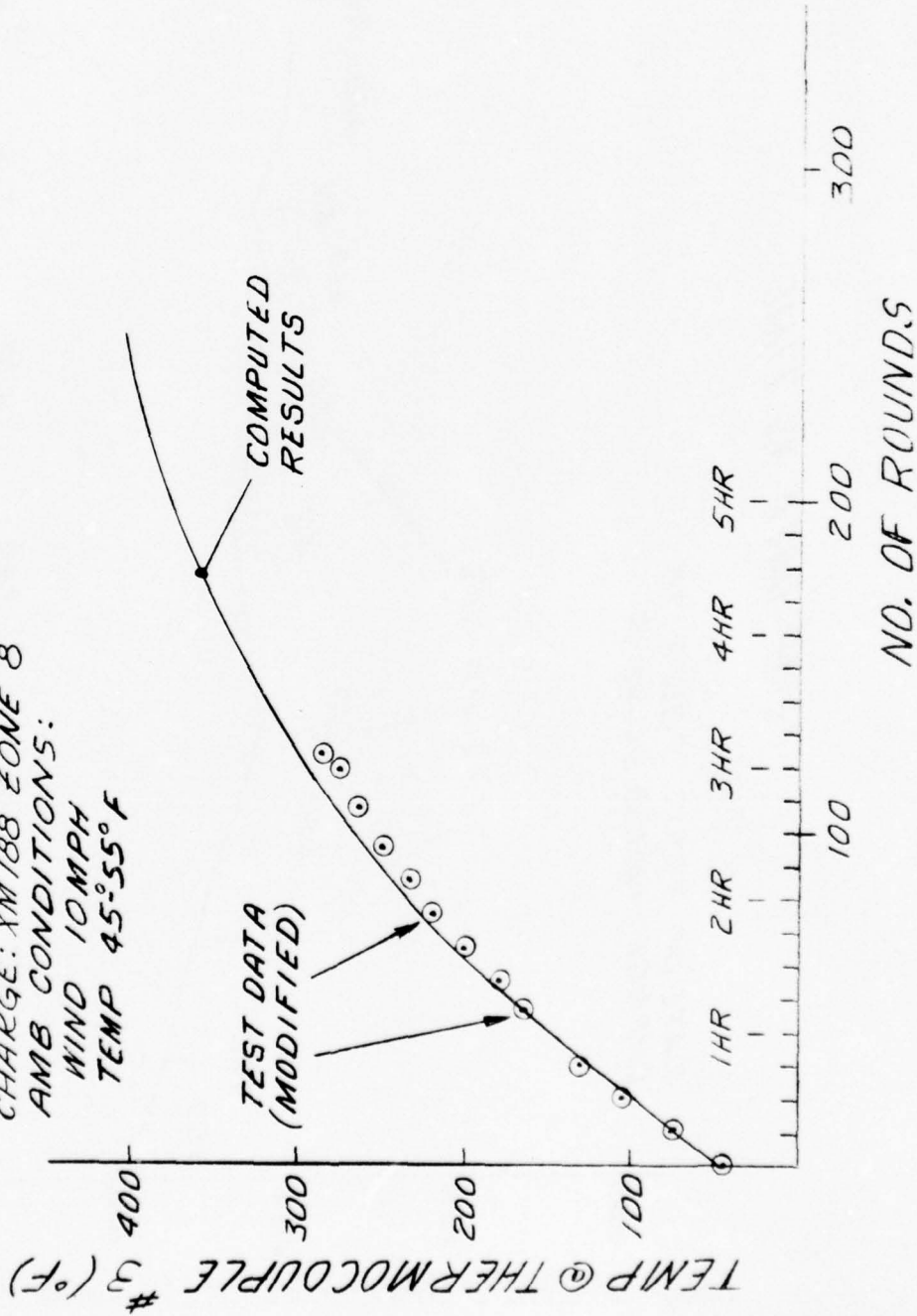


Figure 4. Thermal studies, 8" Howitzer XM201/XM188 cook off test.

TEMP DATA VS TIME

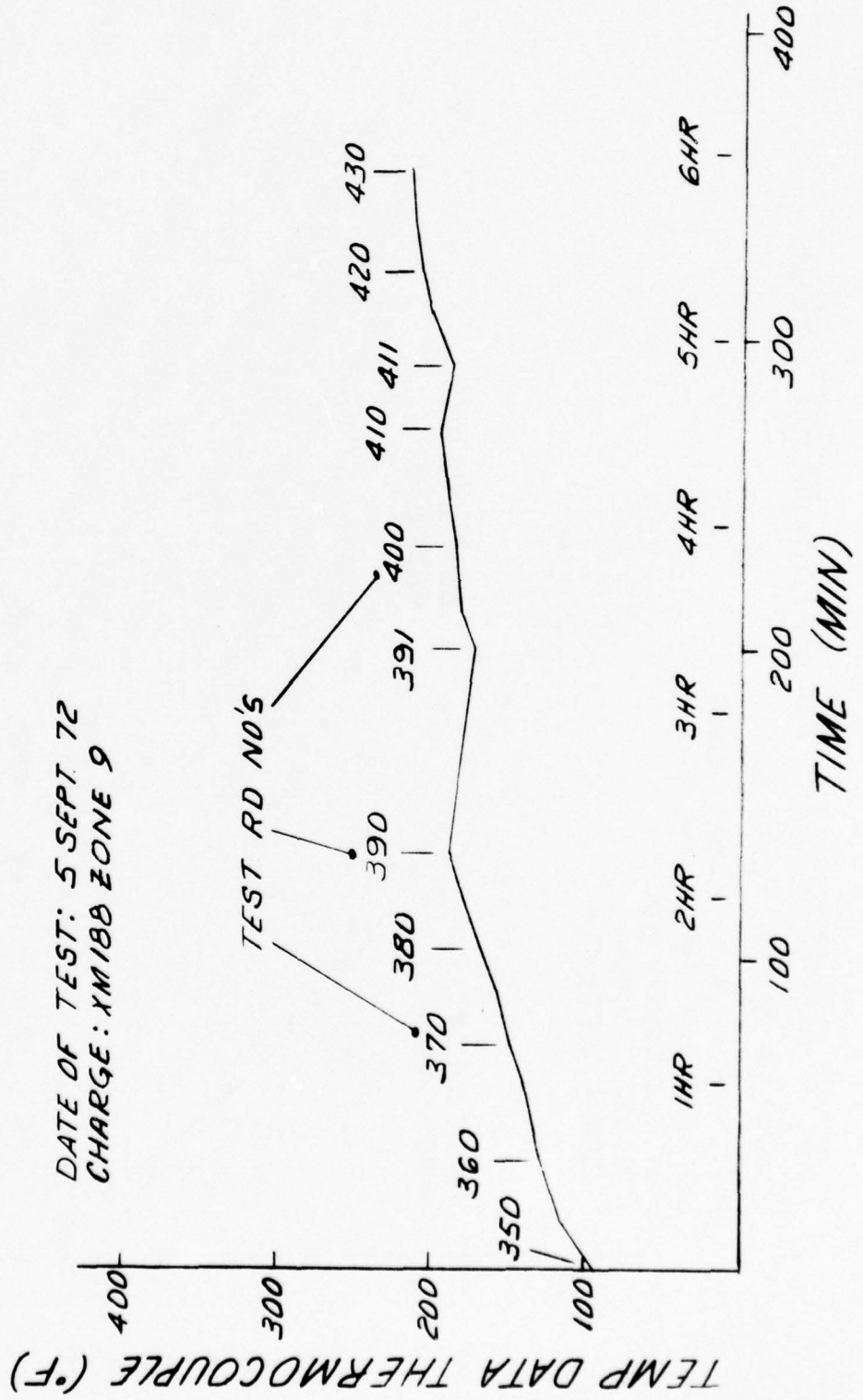


Figure 5. Thermal data, 8" Howitzer XM201/XM188 (5 Sep 72).

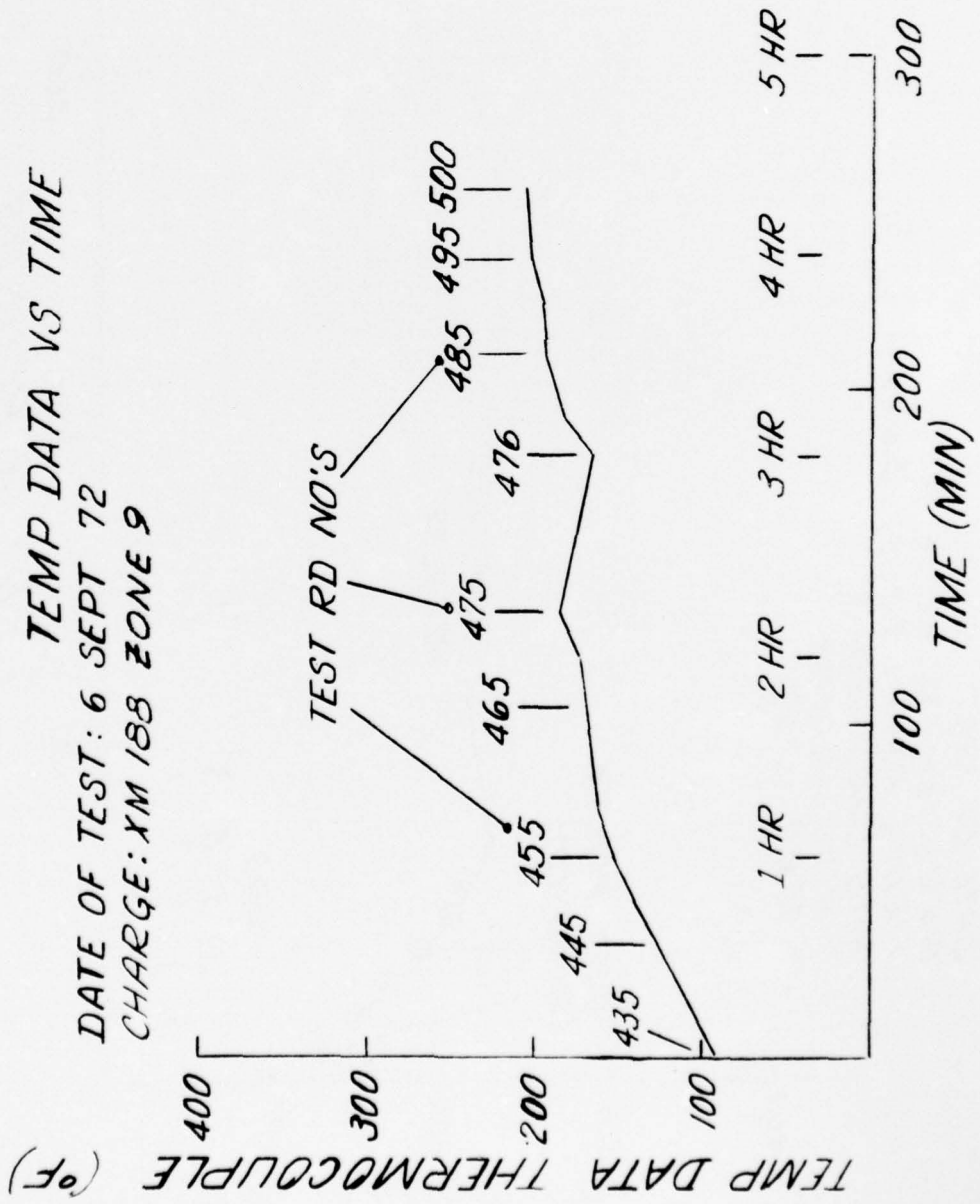


Figure 6. Thermal data, 8" Howitzer XM201/XM188 (6 Sep 72).

DATA COMPARISON TO CALCULATED RESULTS

DATE OF TEST: 5 SEPT 72
CHARGE: XM 188 ZONE 9
FIRING RATE: 3 RDS/10 MIN
AMB CONDITIONS
WIND 6 MPH
TEMP 95°F

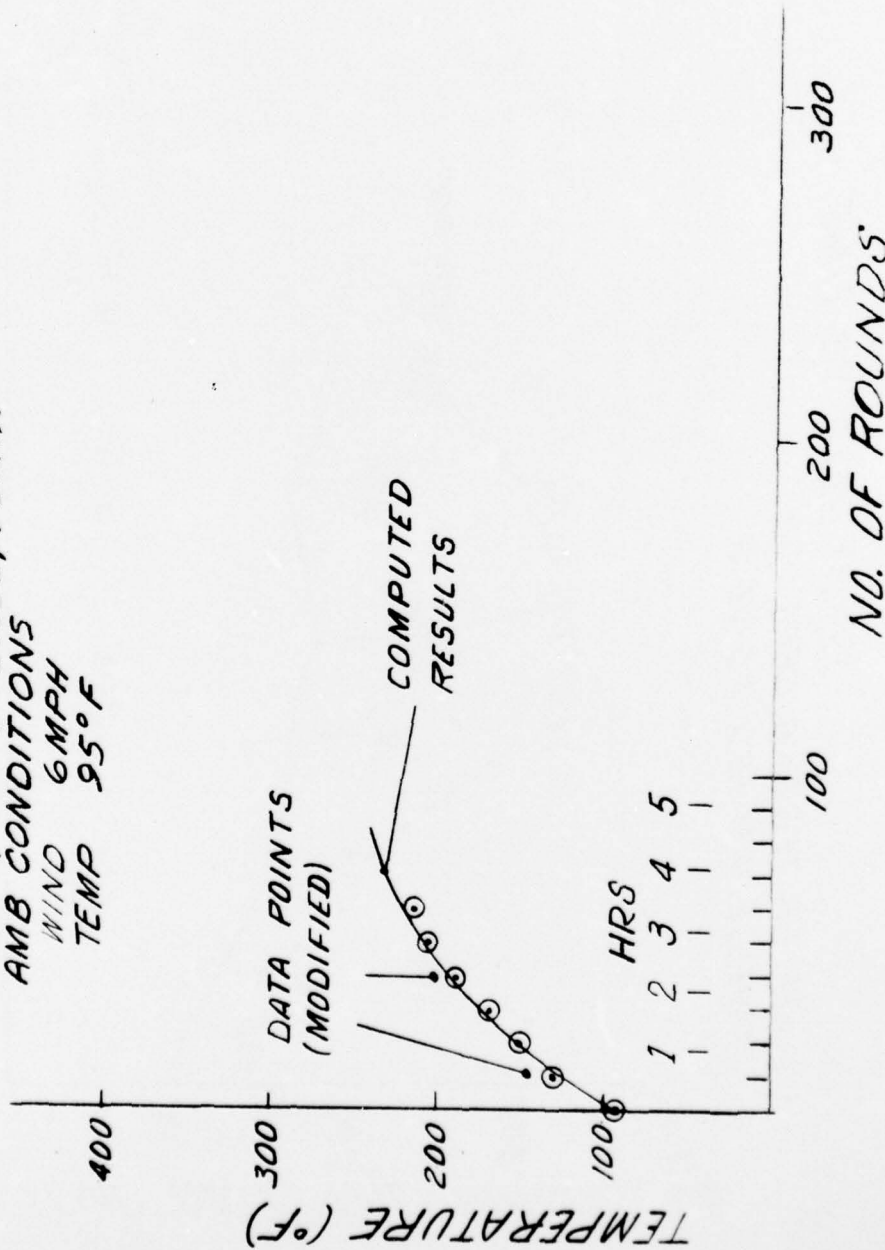


Figure 7. Thermal studies, 8" Howitzer XM201/XM188 (5 Sep 72).

DATA COMPARISON TO CALCULATED RESULTS

DATE OF TEST: 6 SEPT 72
RATE OF FIRE: 3 RDS/10 MIN
CHARGE: XM188 ZONE 9
AMB CONDITIONS
WIND 8.2 MPH
TEMP 91°F

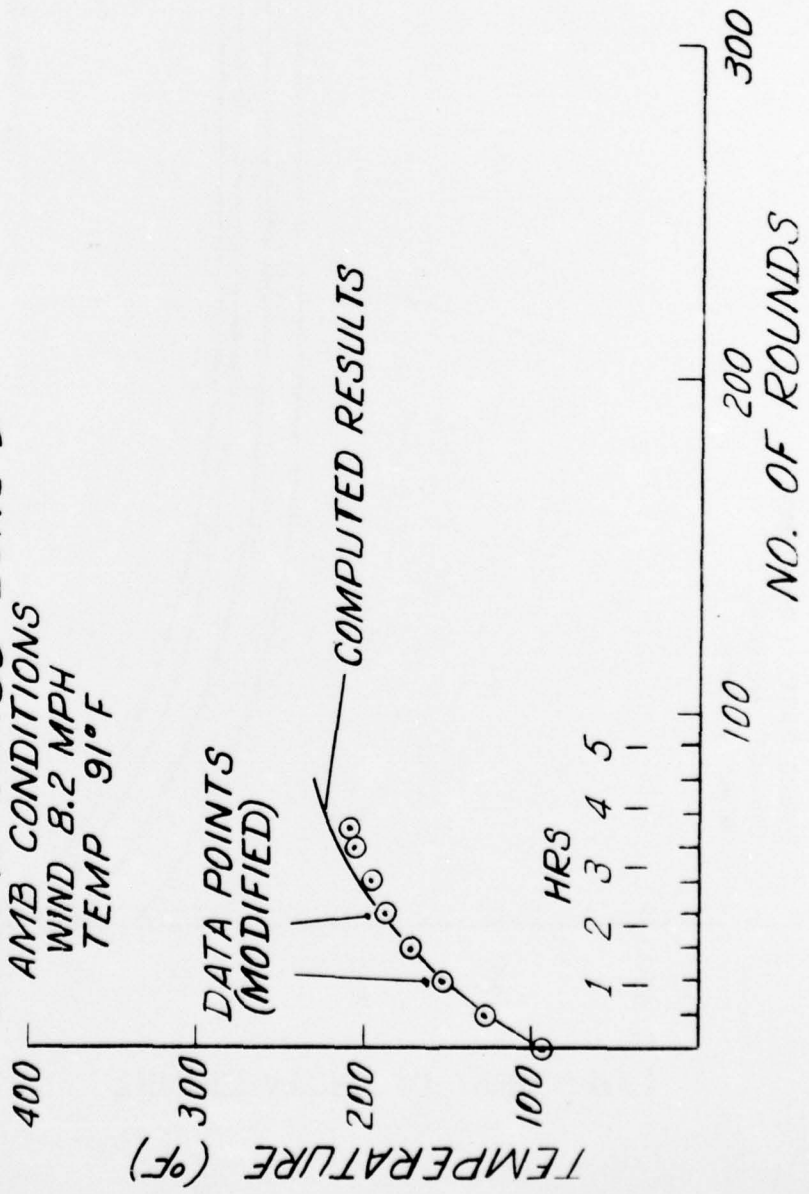


Figure 8. Thermal studies, 8" Howitzer XM201/XM188 (6 Sep 72).

FIRING RATE: 1 RD/2 MIN
CHARGE: M2 ZONE 7
WIND: 10 MPH

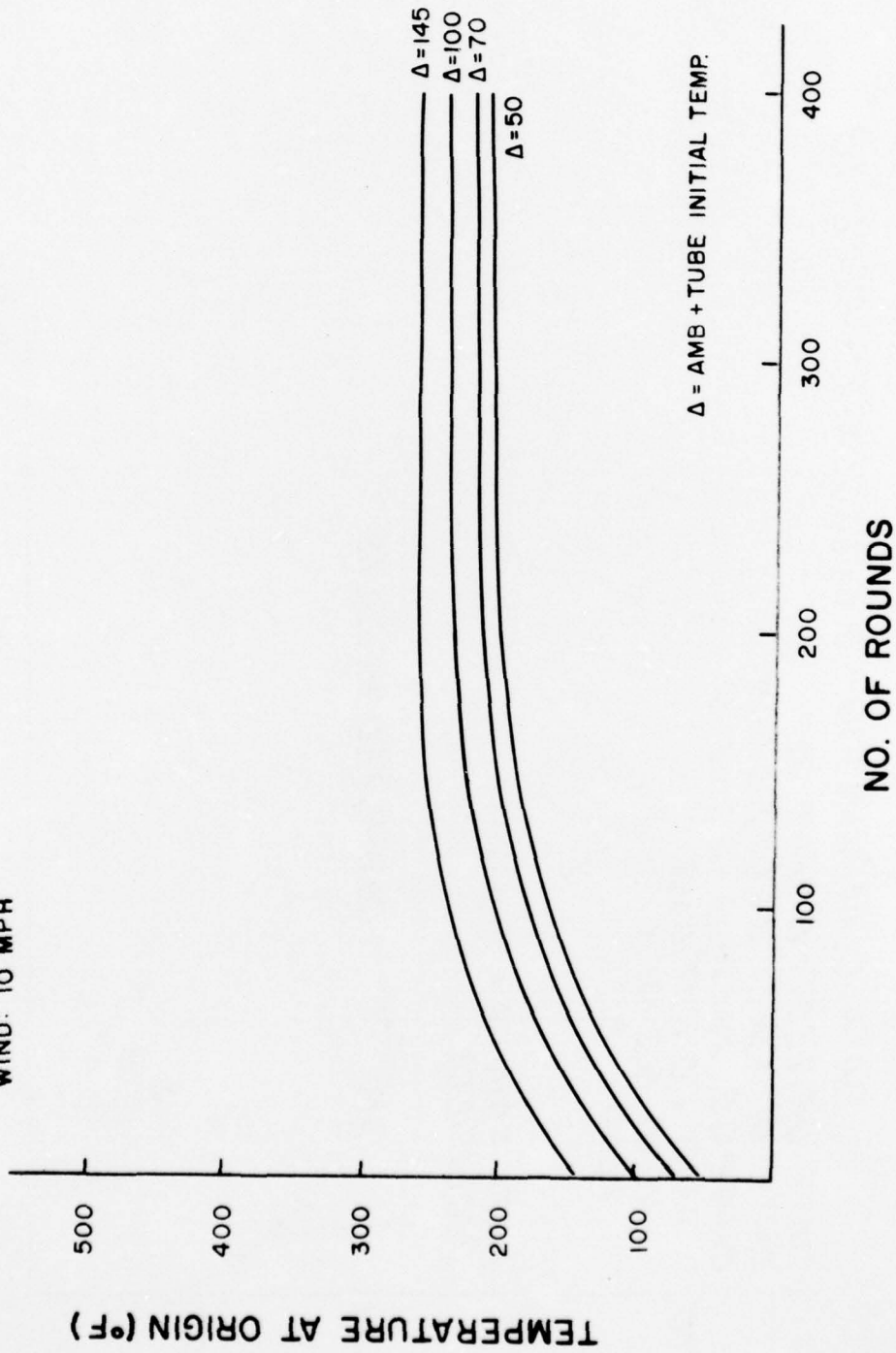


Figure 9. Thermal studies, 8" Howitzer M201 (M2 Zone 7).

FIRING RATE: 1 RD/2 MIN
CHARGE: XM188 ZONE 8
WIND: 10 MPH

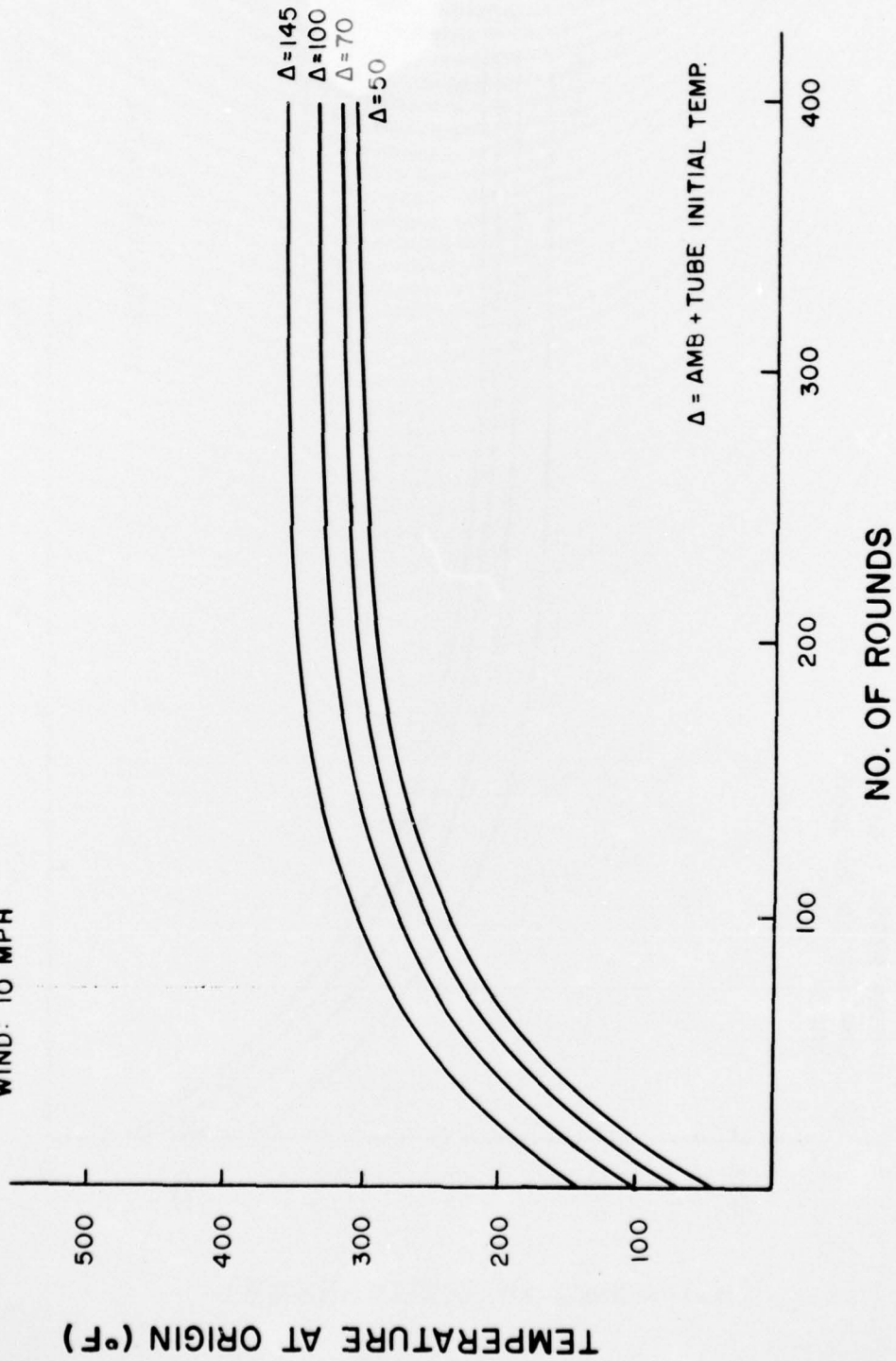


Figure 10. Thermal studies, 8" Howitzer M201 (XM188 Zone 8).

FIRING RATE: 1 RD/2 MIN
CHARGE: XM 188 ZONE 9
WIND: 10 MPH

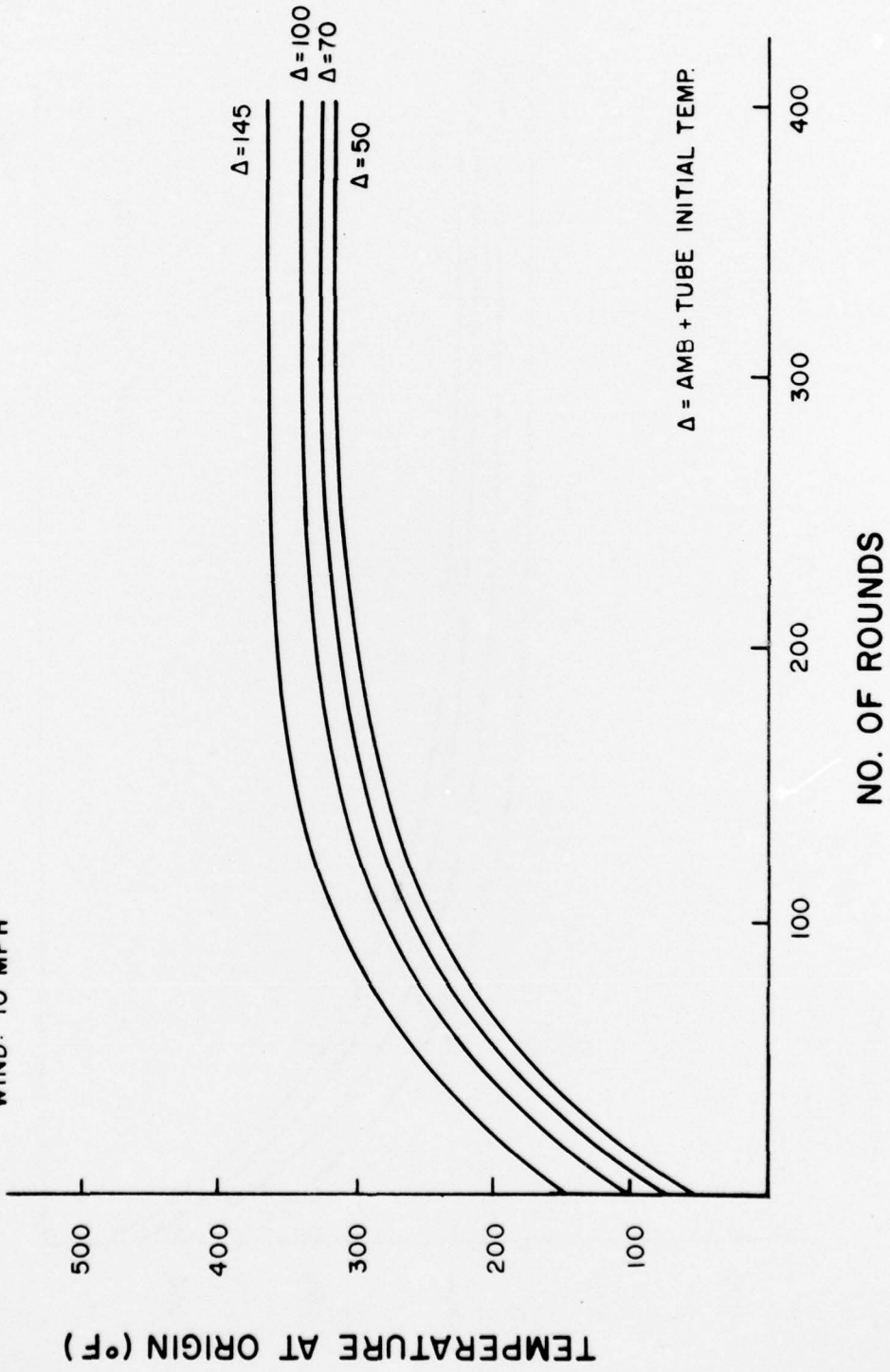


Figure 11. Thermal studies, 8" Howitzer M201 (XM188 Zone 9).

FIRING RATE: 3 RD/4 MIN
CHARGE: M2 ZONE 7
WIND: 10 MPH

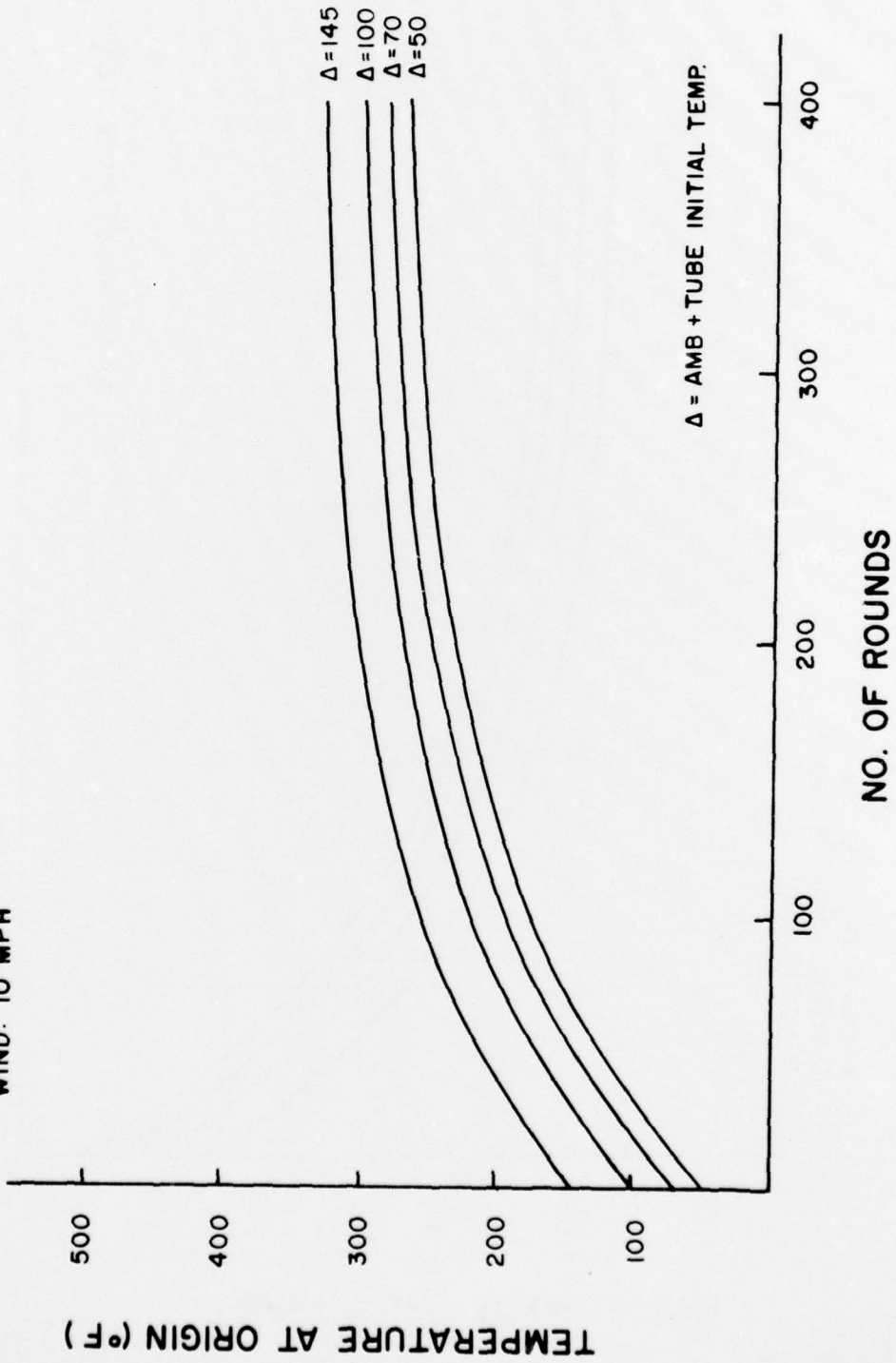


Figure 12. Thermal studies, 8" Howitzer M201 (M2 Zone 7).

FIRING RATE: 3 RD/4 MIN
CHARGE: XM188 ZONE 8
WIND: 10 MPH

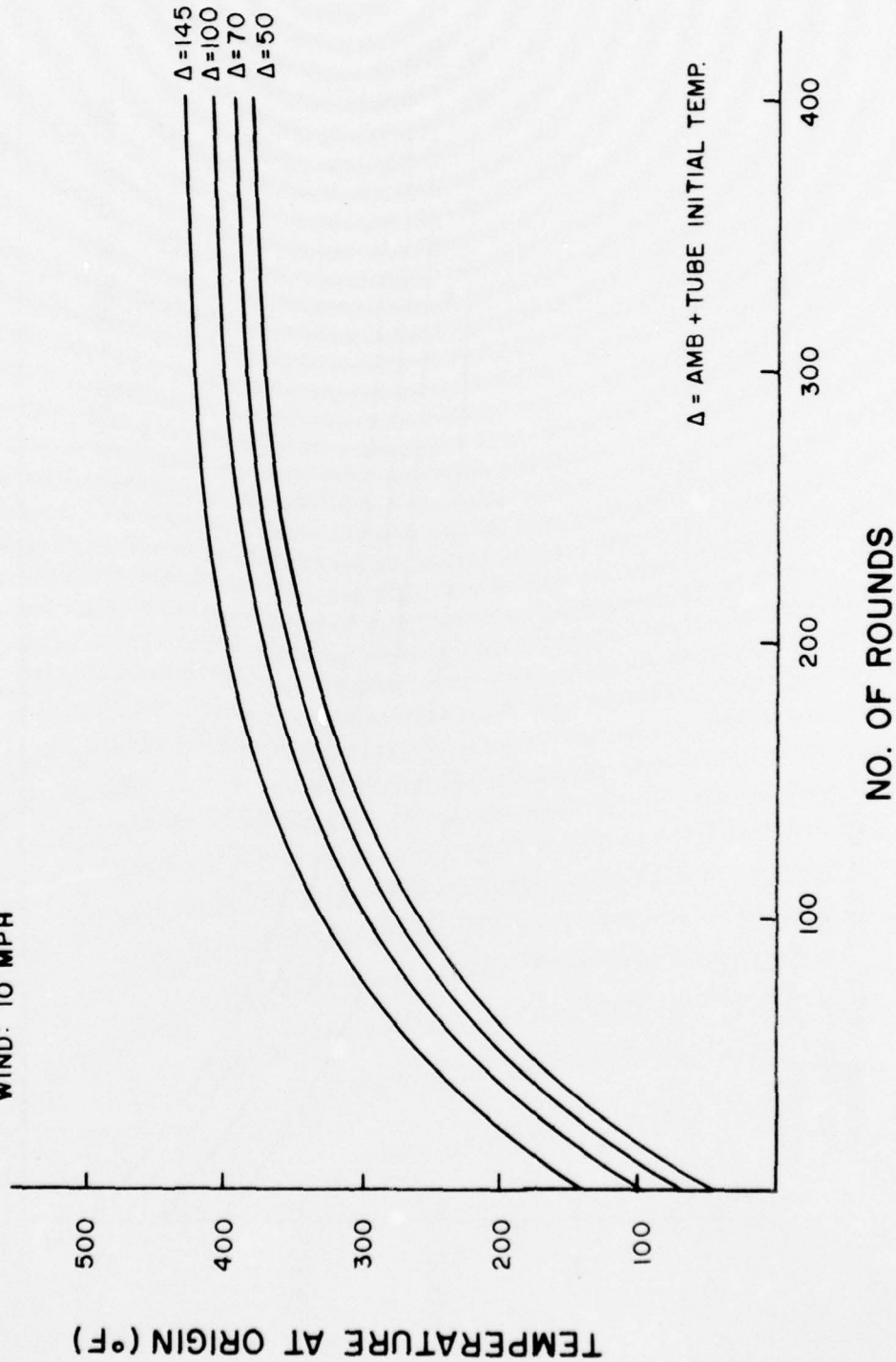


Figure 13. Thermal studies, 8" Howitzer M201 (XM188 Zone 8).

FIRING RATE: 3 RD/4 MIN
CHARGE: XM188 ZONE 9
WIND: 10 MPH

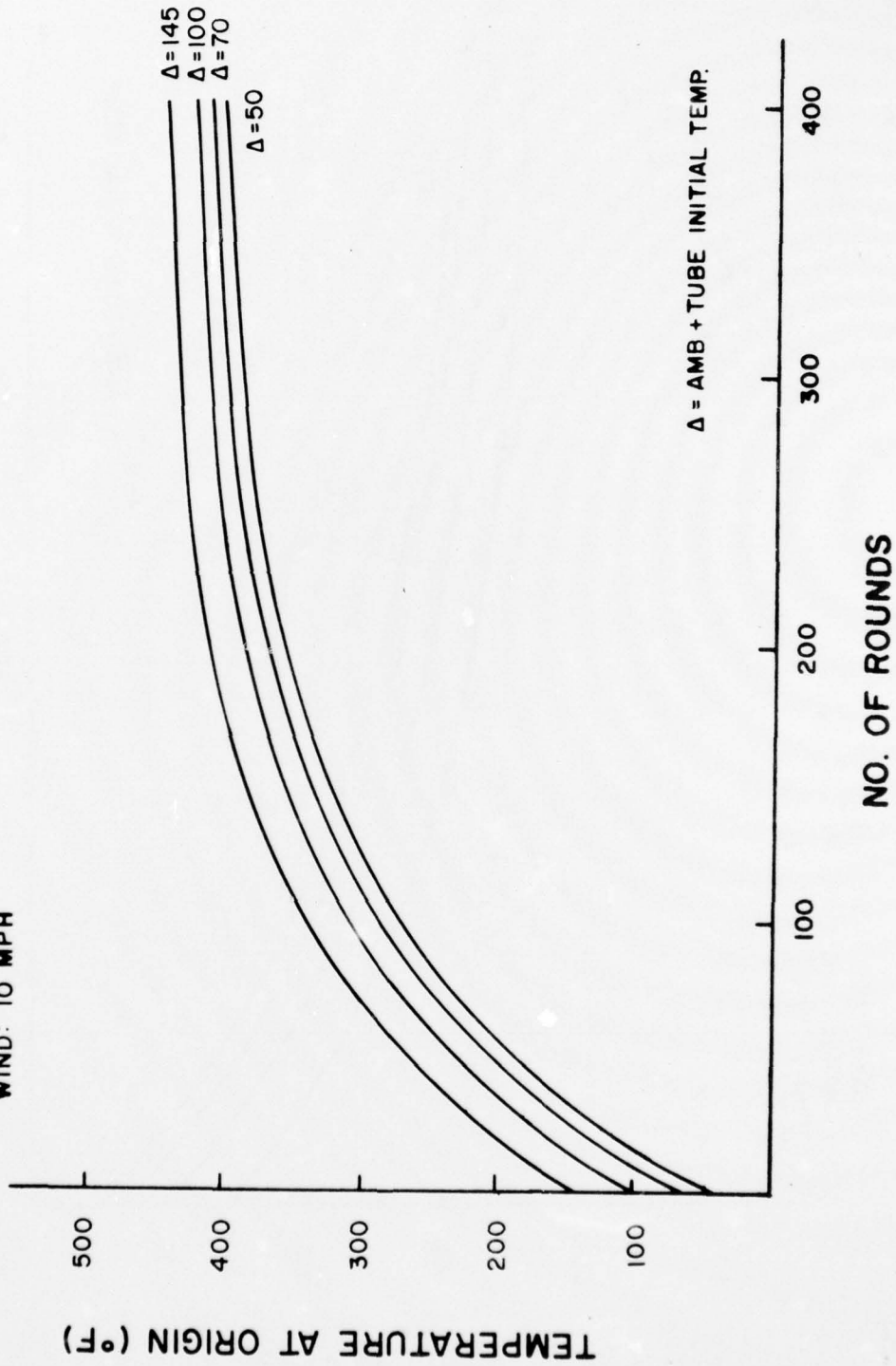


Figure 14. Thermal studies, 8" Howitzer M201 (XM188 Zone 9).

FIRING RATE: 1 RD/MIN
CHARGE: M2 ZONE 7
WIND: 10 MPH

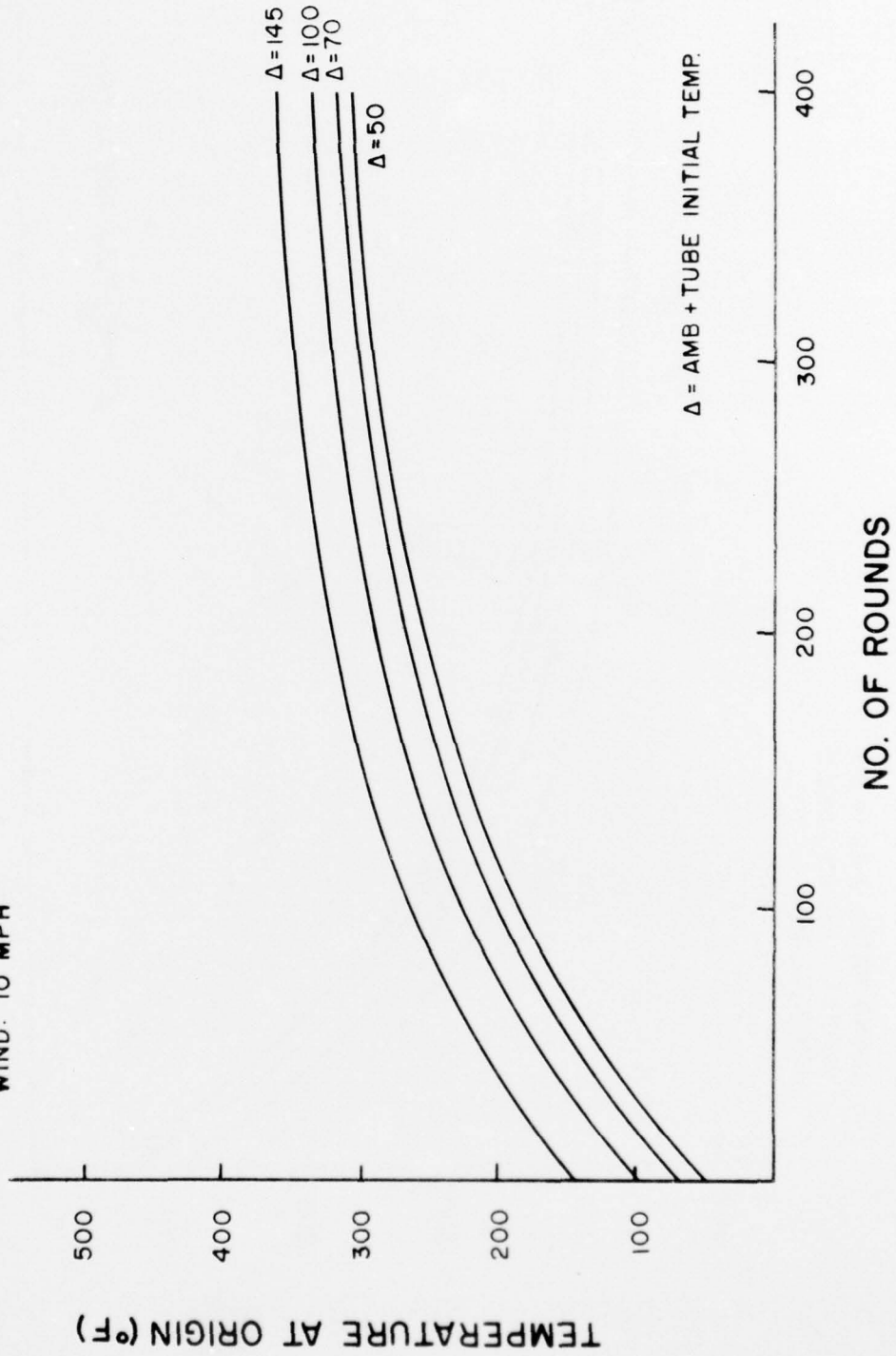


Figure 15. Thermal studies, 8" Howitzer M201 (M2 Zone 7).

FIRING RATE: 1 RD/MIN
CHARGE: XM188 ZONE 8
WIND: 10 MPH

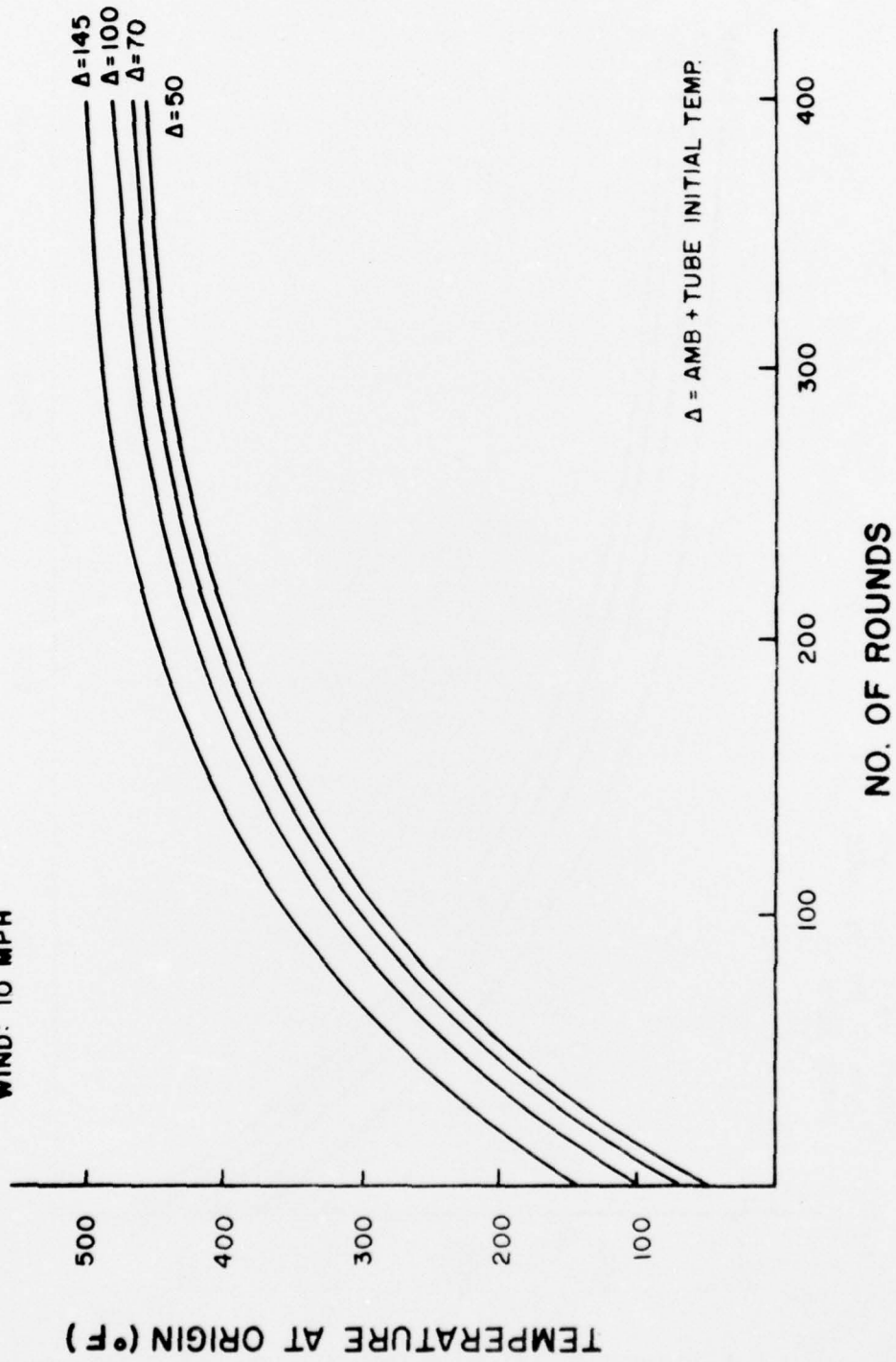


Figure 16. Thermal studies, 8" Howitzer M201 (XM188 Zone 8).

FIRING RATE: 1 RD/MIN
CHARGE: XM188 ZONE 9
WIND: 10 MPH

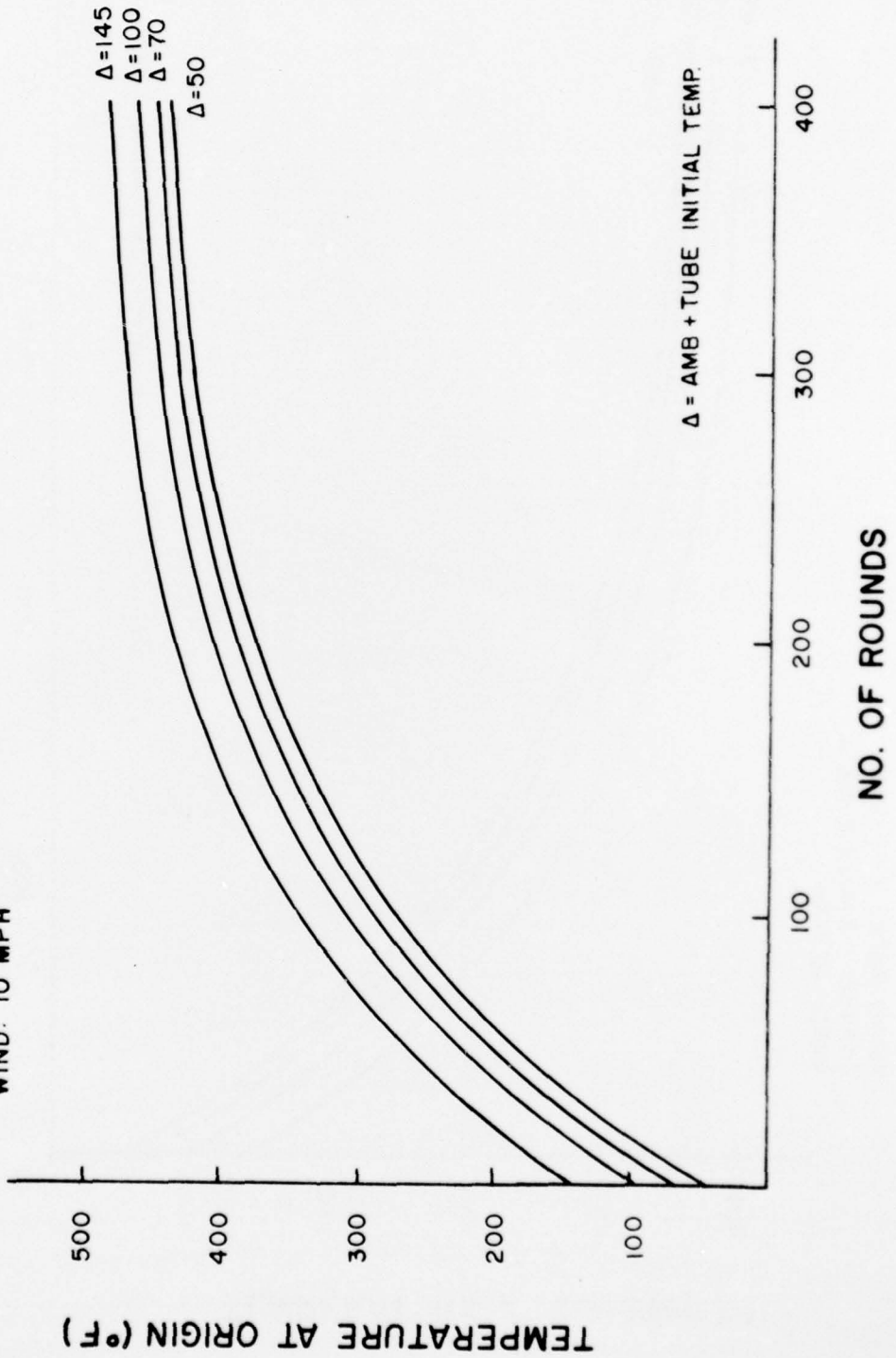


Figure 17. Thermal studies, 8" Howitzer M201 (XM188 Zone 9).

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