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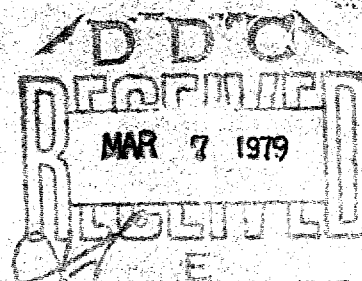
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CONTRACTOR REPORT ARSCD-CR-78009

THERMAL ANALYSIS OF FOLDED AMMUNITION

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JANUARY 1979



US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
SMALL CALIBER
WEAPON SYSTEMS LABORATORY
DOVER, NEW JERSEY

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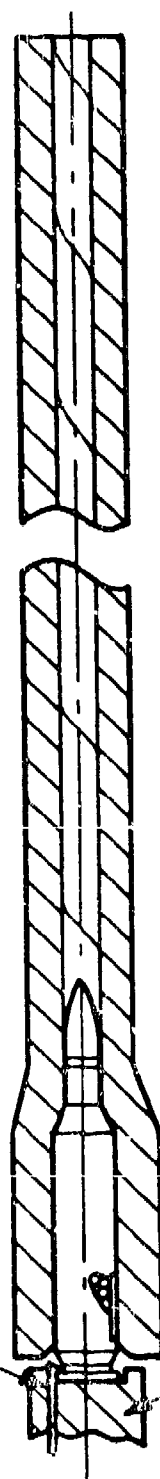
INTRODUCTION

The objective of this investigation was to determine the temperature response of the "U-shaped" folded cartridge. Figure 1 presents a comparison of the conventional and folded cartridges. The interpose, or web region between the projectile and propellant reservoir, is of particular interest. Because of the unique geometry of the folded cartridge, this region of the weapon will experience heating on both sides, and the possibility of excessive temperatures or structural distortion exists.

To determine the temperature response of the interpose region, the heat input during a typical firing of 100 msec had to be established. In addition, analytical models describing the heat transfer of the folded cartridge geometry had to be developed. These models, one and two-dimensional, describe the transient temperature distribution using a finite difference technique. The models have been checked numerically to insure that nodal size provides an accurate representation. Since a time period longer than 100 msec is required for the weapon's structure to experience temperature change, the analytical model includes multiple firing bursts.

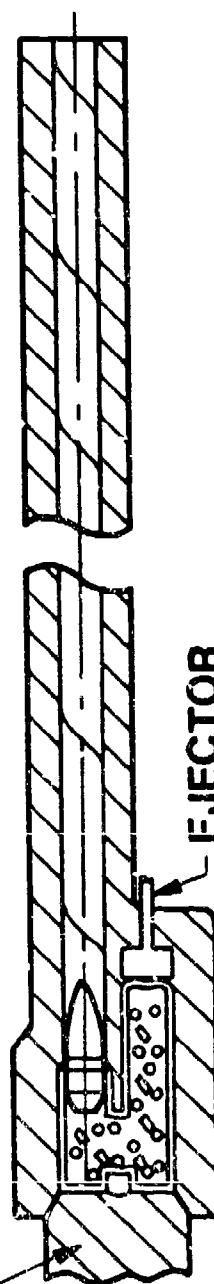
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EXTRACTOR



CONVENTIONAL

BOLT



EJECTOR

FOLDED AMMUNITION

Figure 1. Geometry of folded ammunition.

HEATING ANALYSIS

The heat input cycle is 100 msec in duration. This period includes the firing of one cartridge, a dwell period, the extraction of the spent cartridge, and the insertion of a new cartridge. The highest heat fluxes occur during the firing time, or ballistic portion of the cycle. During this period the cartridge case is heated to its maximum temperature. Following this ballistic period, the energy deposited in the cartridge case dissipates into the weapon. To determine the heat transfer coefficient and gas temperature during the initial period, the local gas pressure, temperature, and velocity must be determined using the applicable ballistic model.

The ballistic model used in this study was supplied by U.S. ARRADCOM. This model, in the form of a computer code, is described in detail in reference 1. The code was developed for standard shape ammunition. The code, as supplied, has been modified to incorporate methods for determining thermochemical properties (ref. 2). Figure 2 presents the space mean pressure history for the folded cartridge calculated with the computer code.

As stated above, the model was not developed for ammunition of the present geometry; however, a review of reference 1 indicates that the model is insensitive to shape. The model does not provide for flame propagation through the propellant bed. Nonsimultaneous ignition is provided by the surface ignition function, which is equal to the total propellant surface area divided by the ignition time range. The latter quantity, ignition time range, is determined by experiment. Since the test case for the folded cartridge compares favorably with test firings, it appears that the ignition time range currently in the program is satisfactory. The three major pressures calculated by the program are the space mean pressure, the breech pressure, and the projectile base pressure. Both the breech and projectile base pressures are constant functions of the space mean pressure. All three pressures are made equal prior to movement of the projectile (approximately 0.34 msec for the present case).

The test case considers the breech to be 9.14 in. from the projectile. This corresponds to a straight cartridge 9.14 in. long from the base of the projectile to the end of the cartridge. A test case with the breech located 1.5 in. from the projectile was run. This corresponds to the folded geometry. The resulting pressures, temperatures, and muzzle velocities were not affected. It appears, therefore, that the only significant parameter is the propellant volume. The gas temperature and velocity are uniform over the entire region behind the projectile. This is significant because it indicates uniform heating.

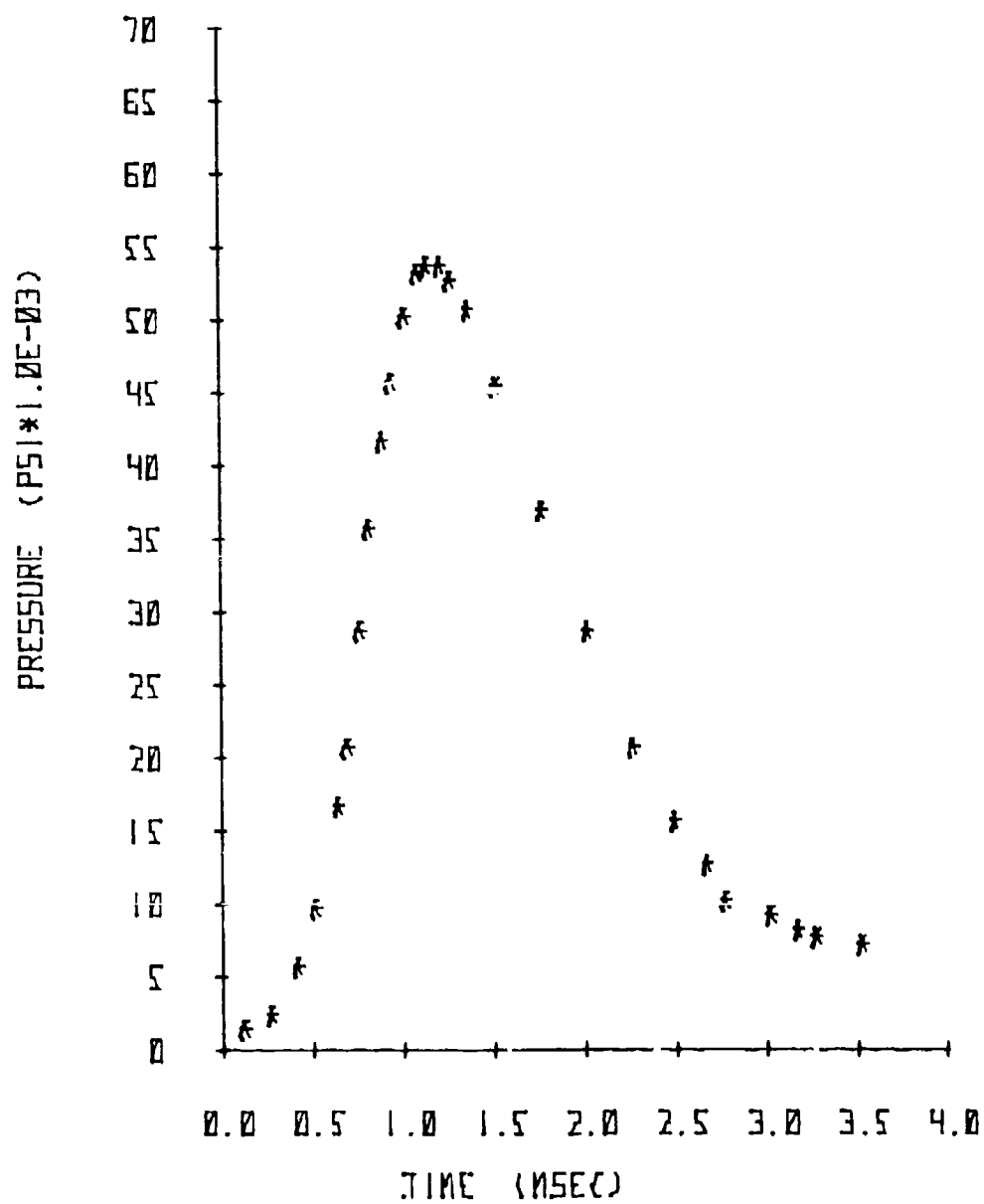


Figure 2. Space mean pressure versus time.

To accurately model nonuniform heating, a new ballistic model would have to be developed. This model would have to consider a one-dimensional transient flow allowing for finite flame propagation. This model could correctly position the initiation point and yield space dependent velocities, temperatures, and pressures. The decision regarding whether such a model should be developed will depend upon the need for improved ballistic data and the magnitude of the heating problem. However, the decision was made to use the existing model to establish the heating conditions in the folded geometry.

The flow conditions and temperature levels in the folded cartridge pose a severe heating environment for the cartridge case and surrounding weapon. Prediction of the heat transfer coefficient is also difficult because of the unique operating conditions.

Reference 3 provided heat transfer coefficients and temperature data for an environment similar to the present case. Unfortunately, the method used to make the calculations is not given. The maximum heat transfer coefficient is approximately $35 \times 10^3 \text{ Btu/ft}^2 \text{ hr}^\circ \text{F}$. In addition, the maximum adiabatic wall temperature is 5700°F . This is considerably higher than the value of 4065°F obtained with the ballistic code, and it is also higher than the adiabatic flame temperature of the propellant.

Reference 4 was reviewed as a possible source of a heat transfer coefficient prediction method. This report examined a variety of possible prediction methods, but all required more flow field information than presently available. In addition, the report was more involved with the gun barrel, rather than the breech area. Some of the data presented indicated heat transfer coefficients in the range from $30 \times 10^3 \text{ Btu/ft}^2 \text{ hr}^\circ \text{F}$ to $70 \times 10^3 \text{ Btu/ft}^2 \text{ hr}^\circ \text{F}$. It should be noted that these extreme levels exist for only 1 or 2 msec. Reference 5 evaluated the results of a method of characteristics study of the interior ballistics problem. The Colburn analogy, which is given by:

$$St Pr^{2/3} = C_f/2$$

where,

St = Stanton Number = $Nu/Re Pr$
 Nu = Nusselt Number
 Pr = Prandtl Number
 Re = Reynolds Number
 Cf = Friction factor

was used. The resulting heat transfer coefficients were in the same range as the previous references.

Reference 6 considered the problem of flow field development in a solid rocket motor. The operating conditions and dimensions were similar to the folded cartridge problem. This reference recommends

the Dittus Boelter correlation for local heat transfer coefficient. The Dittus Boelter equation is

$$Nu = 0.023 Re^{.8} Pr^{.4}$$

The above equation is widely used in turbulent heat transfer calculations, and is relatively easy to apply to the present case. The decision was therefore made to use this relationship.

Assuming the gas to be ideal, and that the viscosity varies with the temperature to the 0.65 power, the heat transfer coefficient is given by:

$$h = 0.023 \left(\frac{PV}{R} \right)^{.8} C_p R_T^{-.6} \left(\frac{\mu_o}{D(530)^{.65}} \right)^2 T^{-.67}$$

where,

- P = pressure
- V = gas velocity
- C_p = specific heat
- μ_o = viscosity at 530° R
- D = diameter of chamber.

For the present case, the various constants are given by:

$$\mu_o = .87 \times 10^{-6} M^{.5} (530)^{.65} \quad (\text{ref. 6})$$

$$R = \frac{F}{T_o} = \frac{\text{propellant impetus}}{\text{flame temperature}} \quad (\text{ref. 2})$$

$$M = R_o / R$$

Using the thermochemical properties for the folded cartridge propellant and the ballistic data from the computer code, the heat transfer coefficients can be determined as a function of time. Figure 3 presents the variation of heat transfer coefficient versus time, based upon space mean pressure. Figure 4 presents the same data based upon projectile base pressure. For space mean pressure conditions, the peak heat transfer coefficient is approximately 52,500 Btu/ft²·hr° F. This method for calculating heat transfer coefficient has been incorporated into the ballistic code. In addition, the stagnation temperature, which will be used in computing the convective heat inputs, has also been determined and is represented graphically in figure 5. It is worth noting that the maximum temperature in figure 5 is below that given in reference 3. This aspect of the results in reference 3 is difficult to explain. The peak temperatures reported in that reference are higher than the adiabatic flame temperature of the propellant used for the folded ammunition.

The heat transfer coefficients calculated with the Dittus Boelter equation are higher than those cited in reference 3, but are

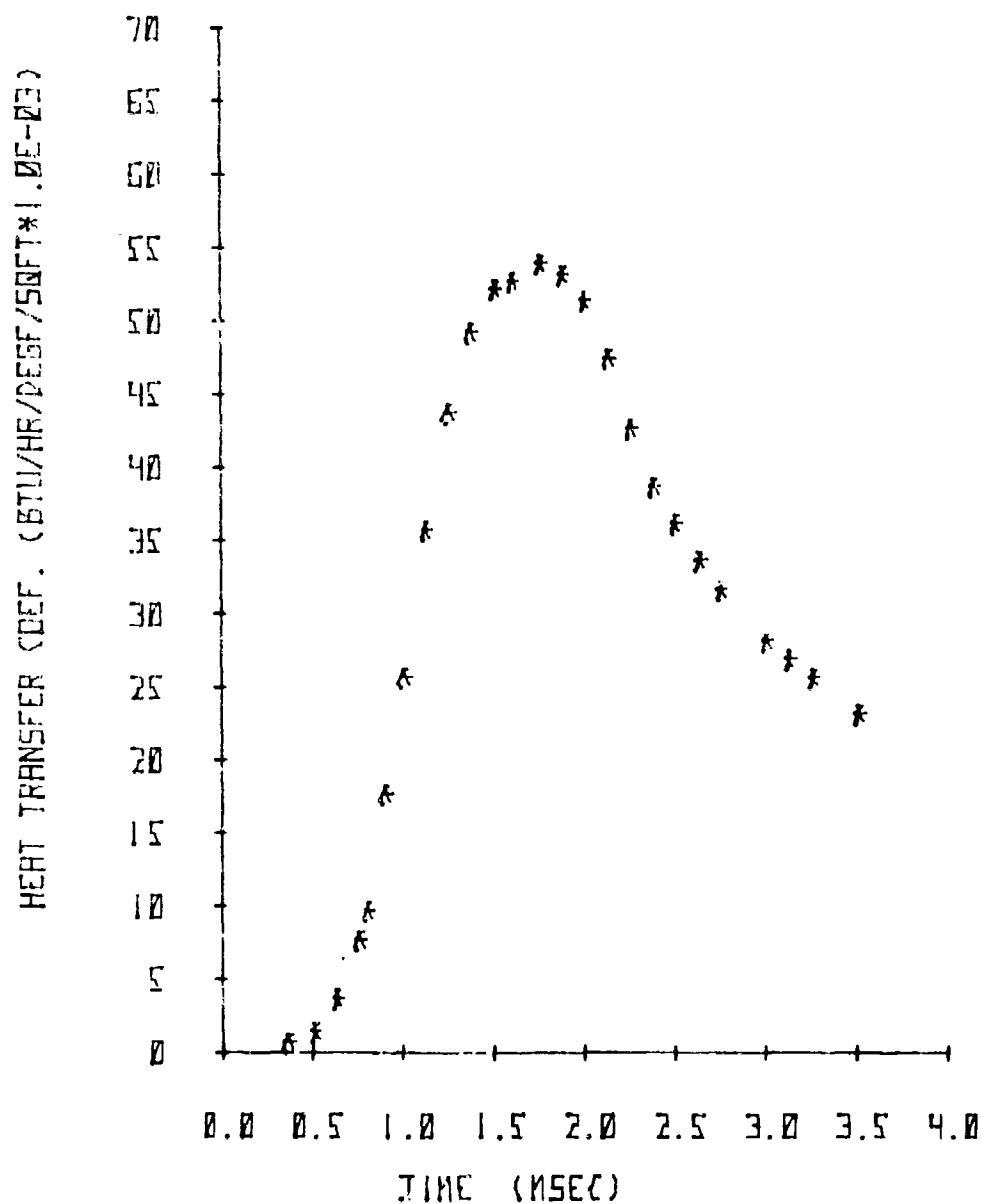


Figure 3. Heat transfer coefficient versus time - based upon space mesh pressure.

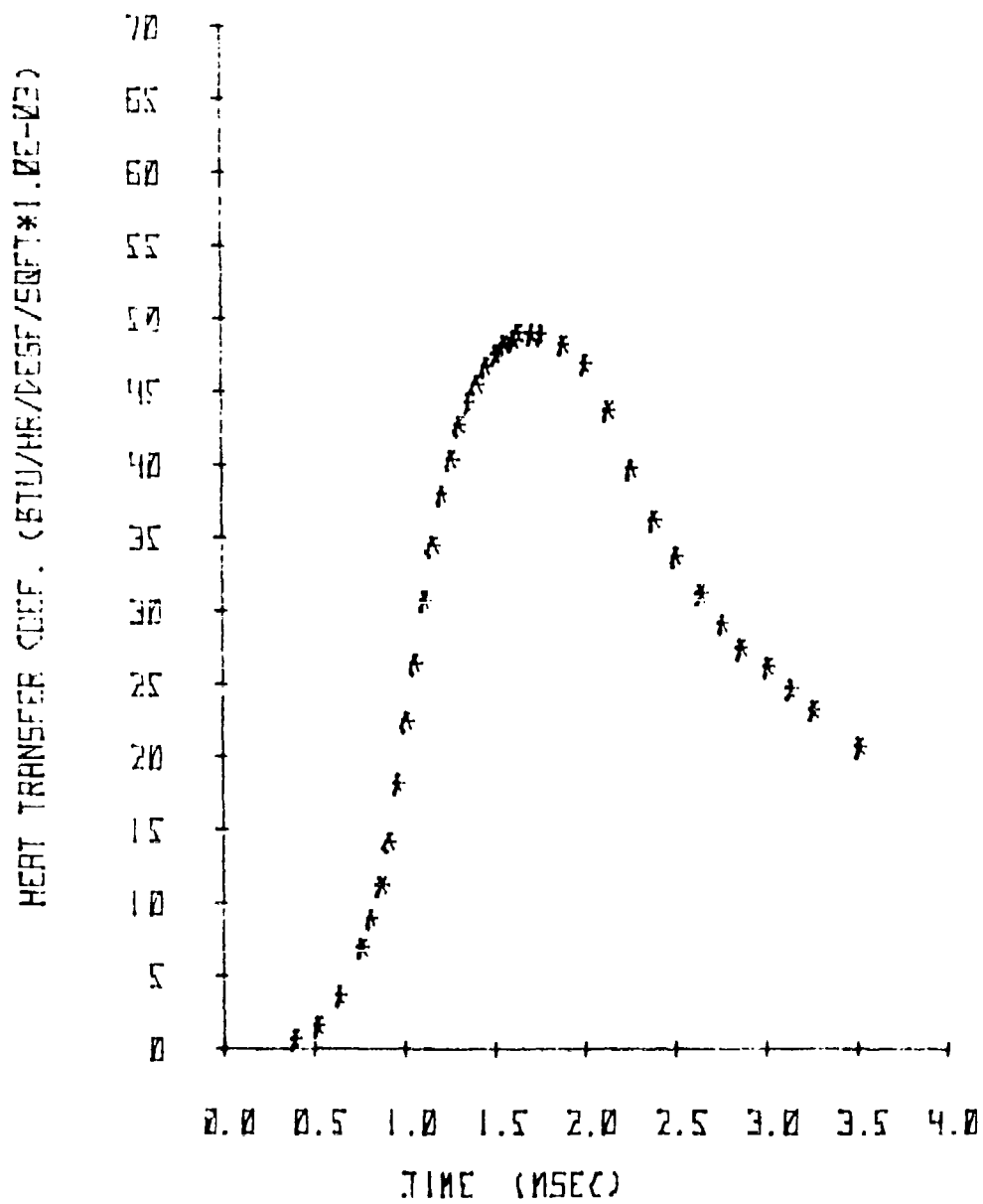


Figure 4. Heat transfer coefficient versus time - based upon projectile base pressure.

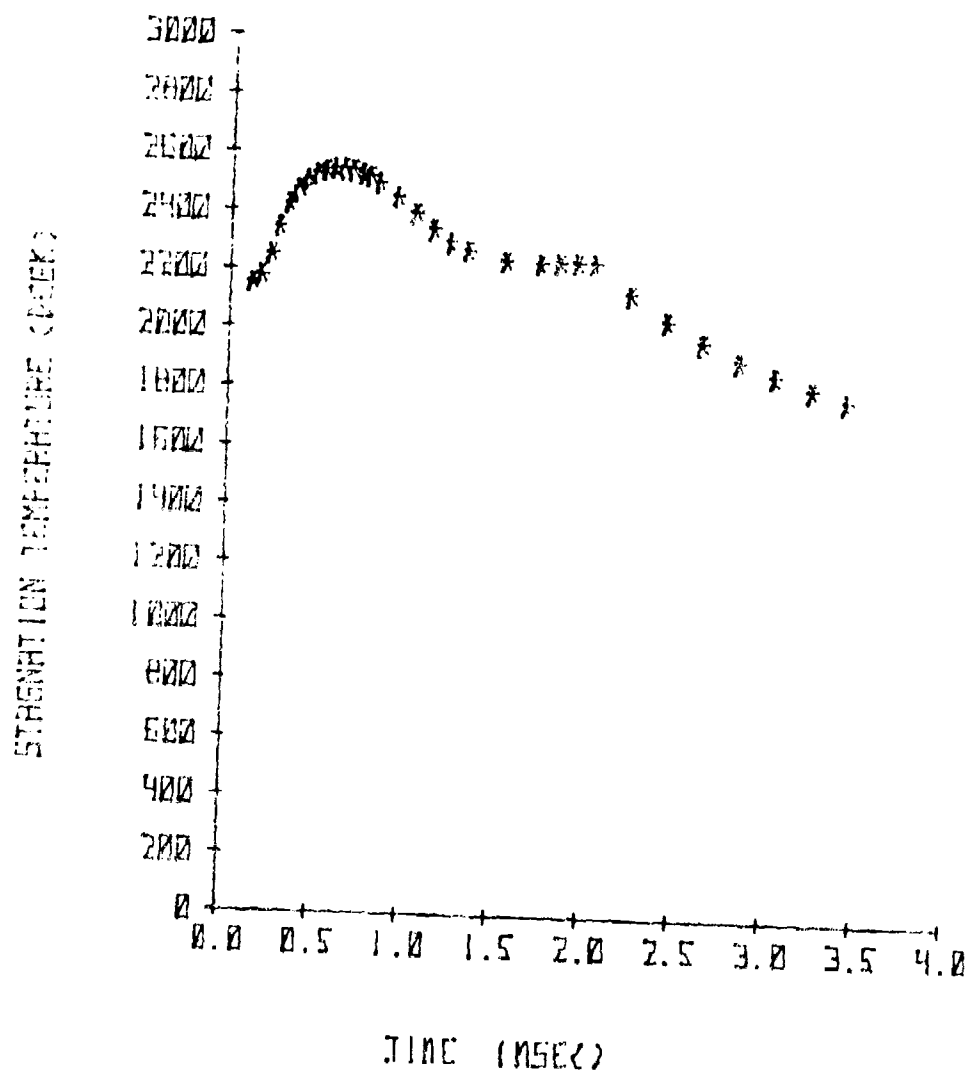


Figure 5. Stagnation temperature versus time.

well within the range reported by other references.

The heating conditions presented in figures 3 and 5 occur during the initial ballistic portion of the cycle, and last for approximately 3.5 msec. The peak surface temperature of the cartridge occurs during this portion of the cycle. However, the total time for the firing of a single cartridge is approximately 100 msec. It is during this longer period that the heat permeates into the weapon's structure and causes the highest structural temperatures.

The time history of a firing cycle is composed of the following four periods:

<u>Time</u>	<u>Event</u>
0 to 3.5 msec	Firing of projectile (ballistic portion)
3.5 to 35 msec	Dwell time
35 to 65 msec	Extraction of expended cartridge
65 to 100 msec	Loading of unspent cartridge

For the preceding firing cycle, the following heat inputs have been developed:

<u>Time</u>	<u>Heat Inputs</u>
0 to 3.5 msec	Convective heat input based upon Dittus Boelter equation (ref. 1). Figures 3 and 5 present the heat transfer coefficient and gas temperature profile.
3.5 to 35 msec	Exponential decay of the heat transfer coefficient to 100 Btu/ft ² hr F and of the gas temperature to 200° F.
35 to 65 msec	Constant heat transfer coefficient and gas temperature at 100 Btu/ft ² hr F and 200° F, respectively.
65 to 100 msec	Zero external heating. In addition, the cartridge nodes are returned to 100° F at 65 msec and then allowed to heat up due to the heat flow from the structure.

During the dwell time (3.5 to 35 msec), exponential decay of the gas pressure, gas temperature, and gas velocity is felt to be a reasonable approximation following the pressure decay. The value of 100 Btu/ft² hr F for the heat transfer coefficient at 35 msec is conservative. The form of the heating boundary condition, during extraction and loading, is very difficult to describe. During future studies, experimental data would be examined to provide better insight into the thermal conditions during these phases of the operating cycle. For the present effort, the decision was made to use a conservative

approach and combine extraction and loading into a single instantaneous event at 65 msec. At 65 msec, the heat transfer coefficient was set at zero, and the nodes representing the cartridge case were set to 100°F. This simulates the chambering of an unspent cartridge. During the period from 65 to 100 msec, the cartridge case is cooler than the structure, and the heat flows into the cartridge.

Although the heat input profile used for this study is considered to be conservative, it should be examined further to determine the significance of the various assumptions made. This activity would be an interesting area for further effort.

ANALYTICAL MODELS

The detailed geometry of the folded cartridge case is given in figure 6. Since the heating during firing is uniform, based upon the present model, the problem reduces to the determination of two-dimensional temperature distributions. However, the results presented in reference 3 indicate that the depth of penetration of heat was small; therefore, the heat flow was essentially one-dimensional. Initial studies during this investigation verify this result. The majority of the results presented in the report will therefore be based upon one-dimensional models. However, in the web region near the breech, the geometry causes two-dimensional effects to occur. Two-dimensional results were obtained for this region.

One-Dimensional Model

The one-dimensional model consists of a 0.04 in. cartridge case thickness, and 0.50 in. of steel, which represents the weapon structure. The properties of the case material, cartridge brass and steel (SAE 4340), were obtained from reference 3. The temperatures were determined by dividing the model into a number of isothermal nodes, and solving the following equation using a digital computer:

$$T_i^{t+\Delta t} = \frac{\Delta t}{m_i c_i} \left\{ \sum_j K_{ij} T_j^t + h A_i T_\infty \right\} + \left\{ 1 - \frac{\Delta t}{m_i c_i} (\sum_j K_{ij} + h A_i) \right\} T_i^t$$

where,

- K_{ij} = the conductive coupling between nodes
- $T_i^{t+\Delta t}$ = temperature of the i^{th} body at time $t + \Delta t$
- A_i = surface area of nodes exposed to convective (zero for all but surface node) heat transfer
- h = convective heat transfer coefficient
- T_∞ = gas temperature.

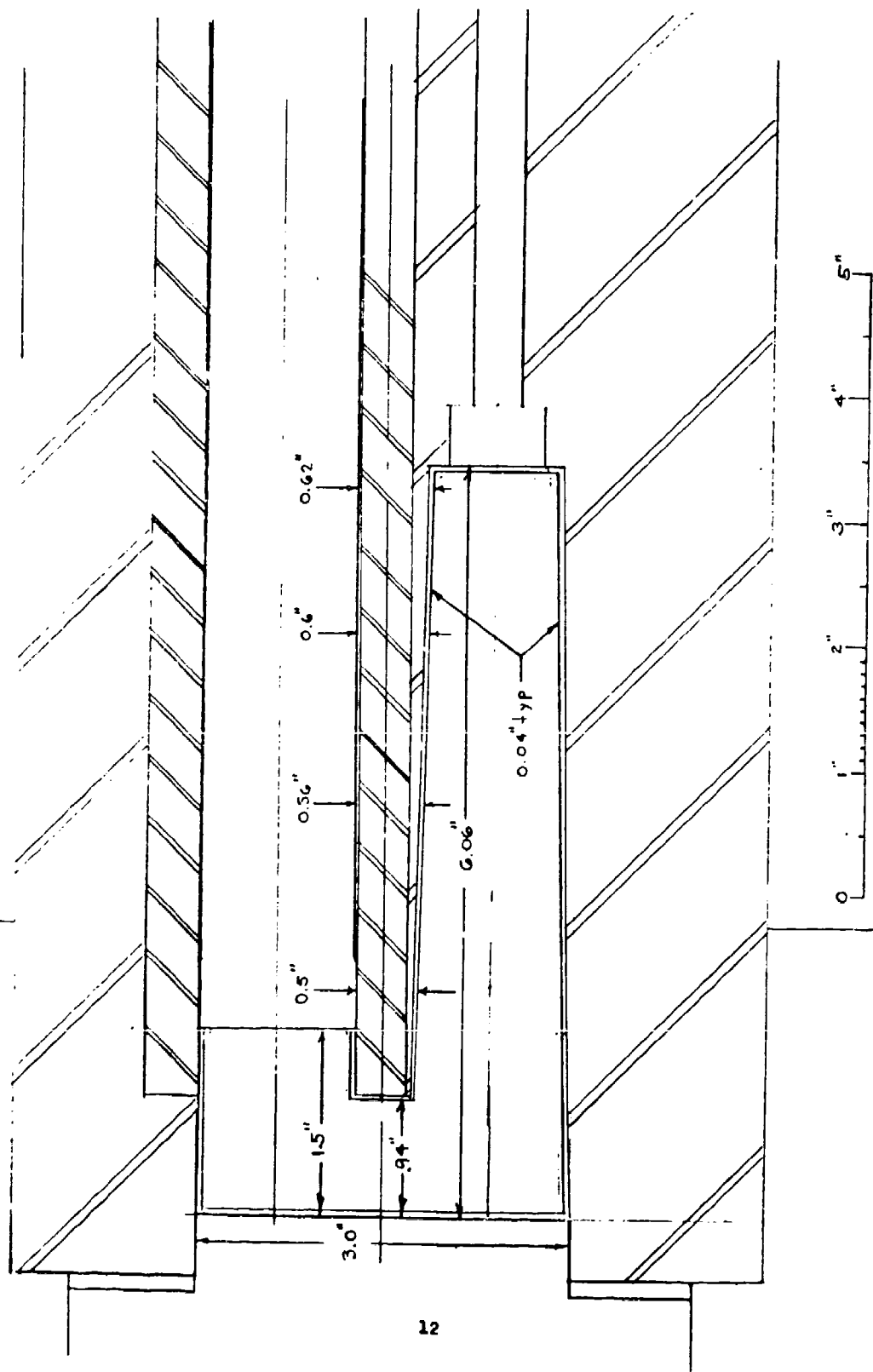


Figure 6. Detailed geometry of folded cartridge case.

Appendix A presents a listing of the computer program. In this analysis, both the heat transfer coefficient and the gas temperature are functions of time, as described in the Heating Analysis section of this report.

Two grid systems were initially used in the analysis. These are presented in table 1. The first system contains 26 bodies, with 11 bodies in the cartridge case, while the second contains 31 bodies, with 21 in the cartridge case. The use of more bodies in the cartridge case was initially felt to be necessary because of the rapid temperature changes occurring in the region. However, examination of the results from both grid systems did not yield any significant differences (ref. 7). Since the 26 body model could be run at a larger time step, and therefore require less computer time, it was used for most of the analysis.

Table 1. One-dimensional model

1st Grid (26 bodies)		2nd Grid (31 bodies)	
Node Number	Thickness (in.)	Node Number	Thickness (in.)
1	.002	1,2	.001
(inter- 2 to 10	.004	(inter- 3 to 20	.002
face) 11	.002	face) 21	.004
12	.004	22	.004
13	.008	23	.008
14	.012	24	.012
15	.020	25	.024
16 to 25	.040	26,27,28	.05
26	.054	29,30,31	.1

Two-Dimensional Model

Although one-dimensional modeling is adequate for most of the folded geometry thermal analysis, certain regions require two-dimensional studies. The web, or interpose region near the breech end, will experience two-dimensional heating. To analyze this region, an isothermal model, shown in figure 7, has been developed. This model consists of 62 bodies, with 50 bodies in the cartridge case. Initially a smaller model consisting of 37 bodies, with 25 bodies in cartridge case, was considered. However, nodalization studies showed that this grid was too large. Because of the symmetry in the web, only half of the web was modeled. The rectangular region is 0.23 in. by 0.56 in. and contains the web region up to the base of the projectile.

The computer program used to analyze the two-dimensional problem is essentially the same as the one described in the One-Dimensional Model section. The major difference is that surface and

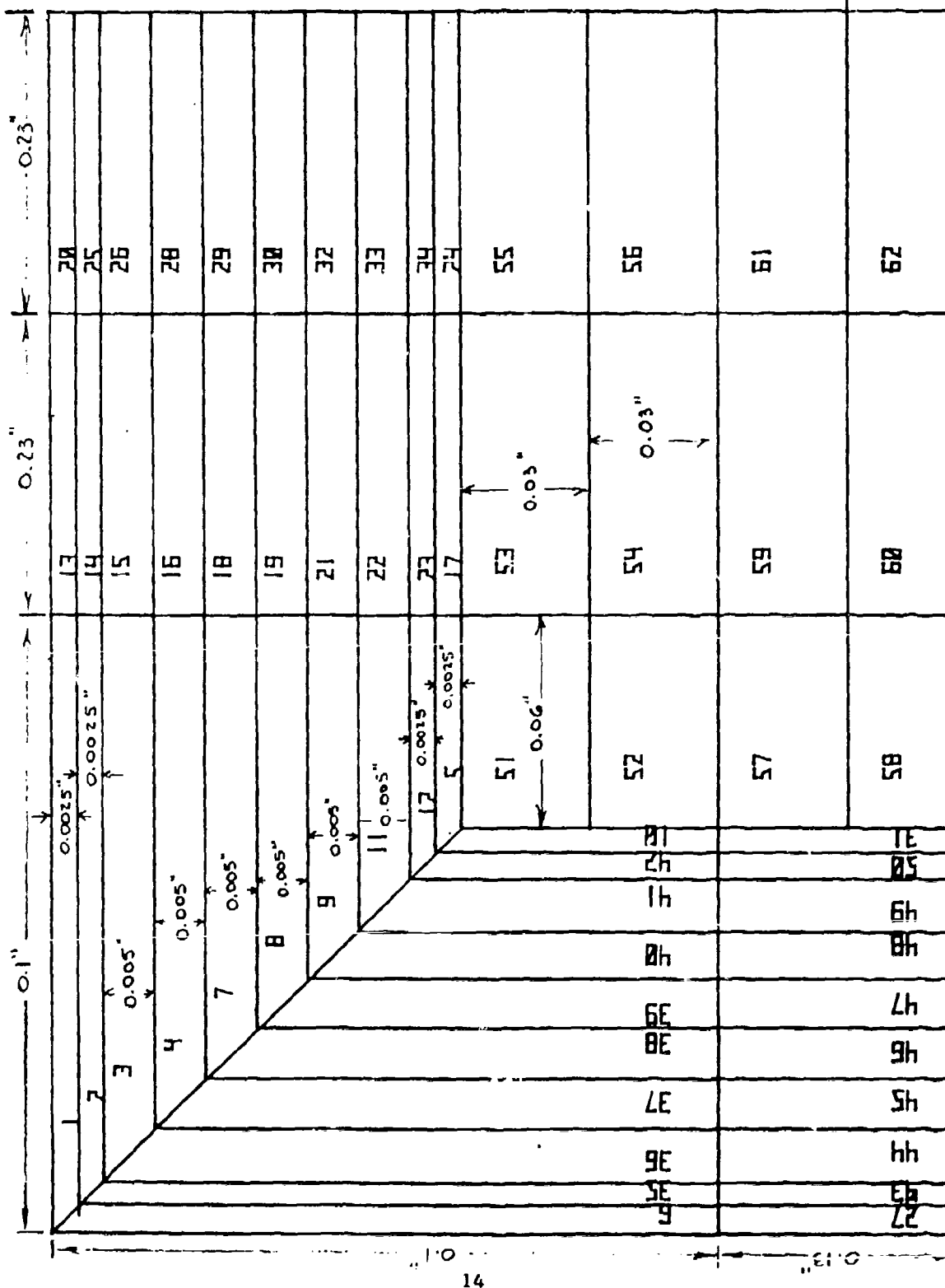


Figure 7. Two dimensional model.

interior nodes are identified, and surface nodes are allowed to experience convection. Appendix B contains the Fortran listing of the program.

RESULTS

One-Dimensional

Using the one-dimensional model described previously, temperature profiles have been determined for 29 cycles or rounds.

During any cycle, the surface of the cartridge exposed to the hot gases experiences a rapid temperature rise, with the peak occurring at approximately 2 msec. Figures 8 through 11 present the surface temperature history for rounds 1, 10, 20, and 29. These profiles are similar, with the peak temperature reaching a maximum value of approximately 1346°F. The sharp drop in temperature, occurring at 65 msec, results from the extraction of the spent round and the insertion of an unspent cartridge with the cartridge case at 100°F. The unspent cartridge is then heated by the warmer weapon chamber. Figure 12 presents a composite of the profile for rounds 1, 10, 20, and 29. From this figure it can be seen that by the tenth round, the surface temperature profile is stabilized. Figure 13 presents the peak surface temperature as a function of round number. It would appear that by round 4, the peak surface temperature has reached equilibrium at approximately 1345°F. However, examination of the detailed computer printouts shows that between rounds 19 and 29, the peak surface temperature rose 0.5°F. This rate, of course, is decreasing with each round, but extrapolation would yield a conservative estimate of the peak temperature after a one minute burst of 600 rounds. Using a rate of 1°F per 20 rounds, the extrapolated peak surface temperature is 1374°F.

During the ballistic portion of any firing cycle, there is very little penetration of the thermal wave into the weapon chamber. Reference 7 states that at the conclusion of the ballistic period (approximately 3.5 msec), the interface between the cartridge case and steel portion of the weapon experienced less than a 1°F rise. Over the 100 msec firing cycle, however, the thermal wave does penetrate into the steel structure. Figures 14 through 17 present the temperature distribution across the model at the end of the cycle for rounds 1, 10, 20, and 29. After 20 rounds, the temperature rise in the steel, at a depth of 0.25 in., is still less than 20°F. Figure 18 presents a composite of figures 14 through 17. From this figure, the propagation of the thermal wave can be seen. The peak temperature shown in figure 18 is not the highest steel temperature, but rather the condition existing at the end of the cycle for a particular round. Figure 19 presents the peak interface temperature as a function of round number. This represents the maximum steel

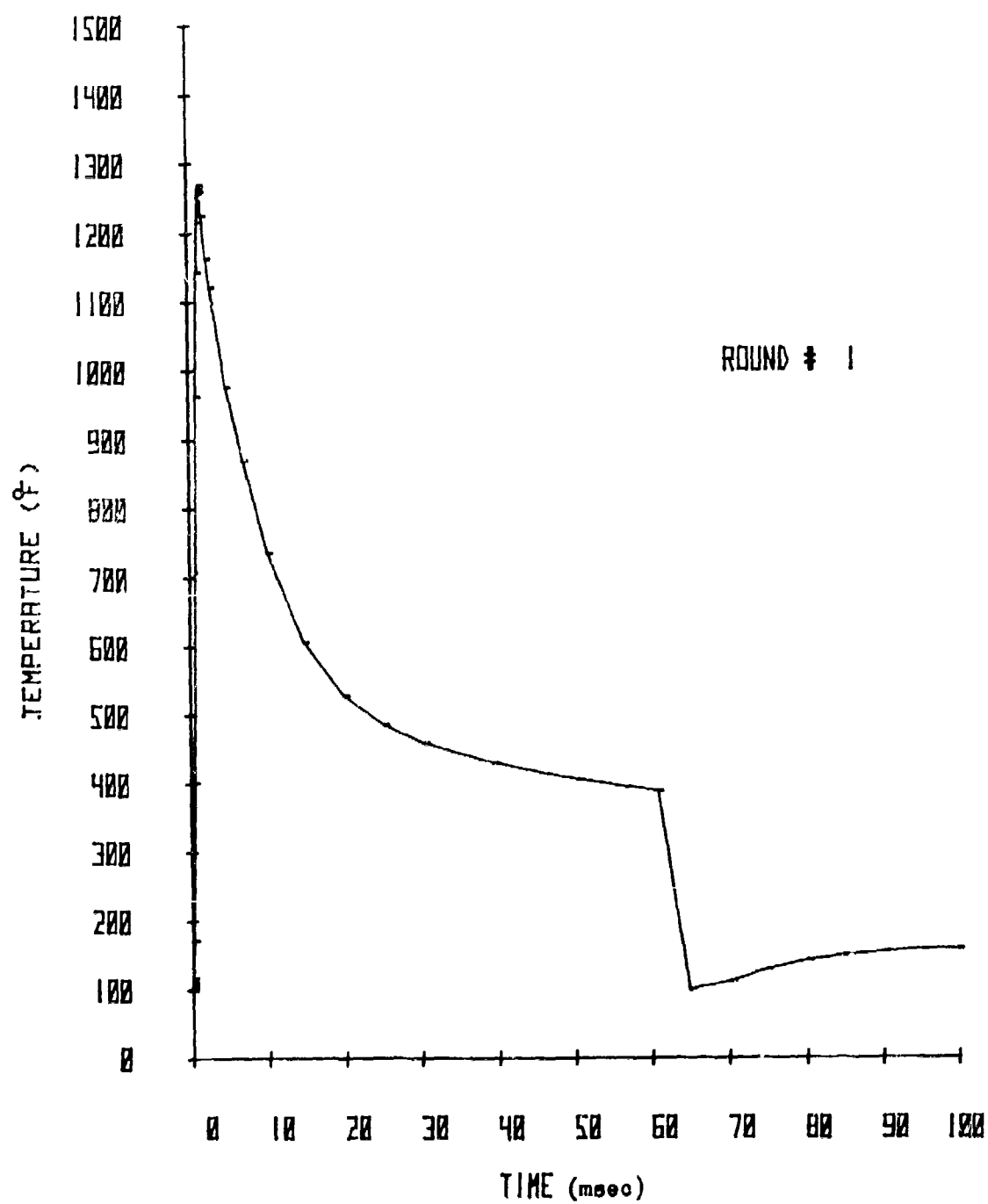


Figure 8. Surface temperature versus time, round 1.

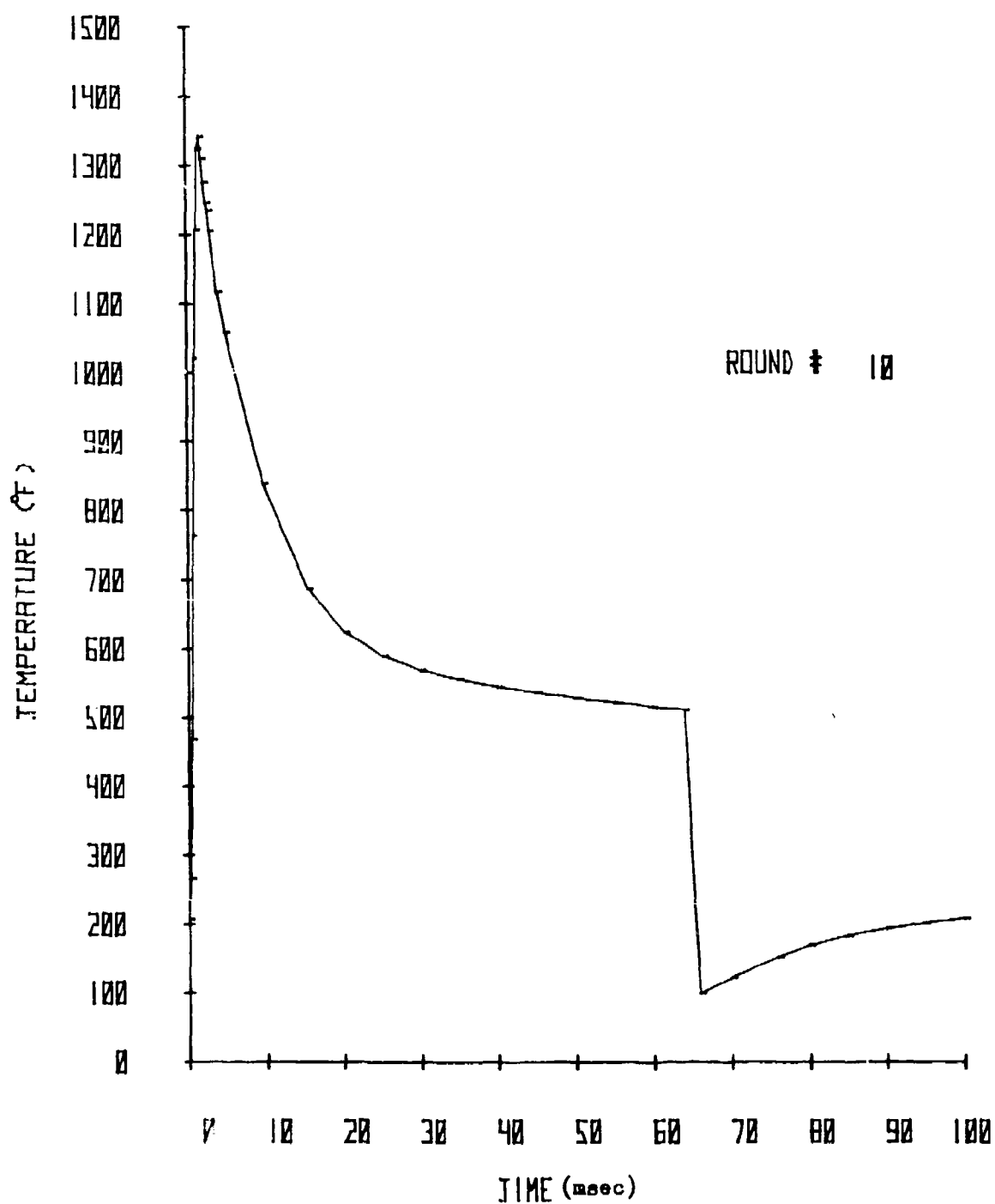


Figure 9. Surface temperature versus time, round 10.

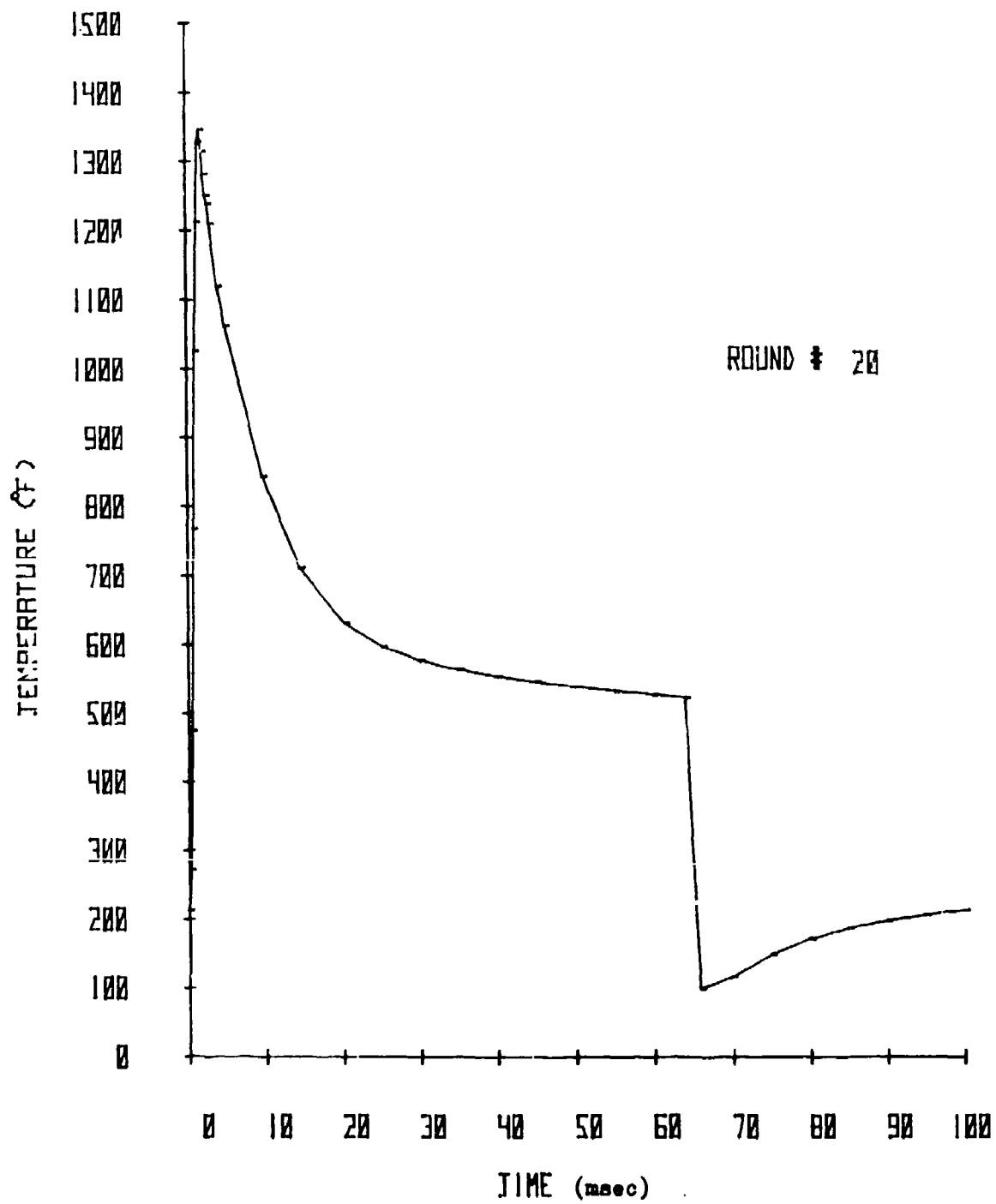


Figure 10. Surface temperature versus time, round 20.

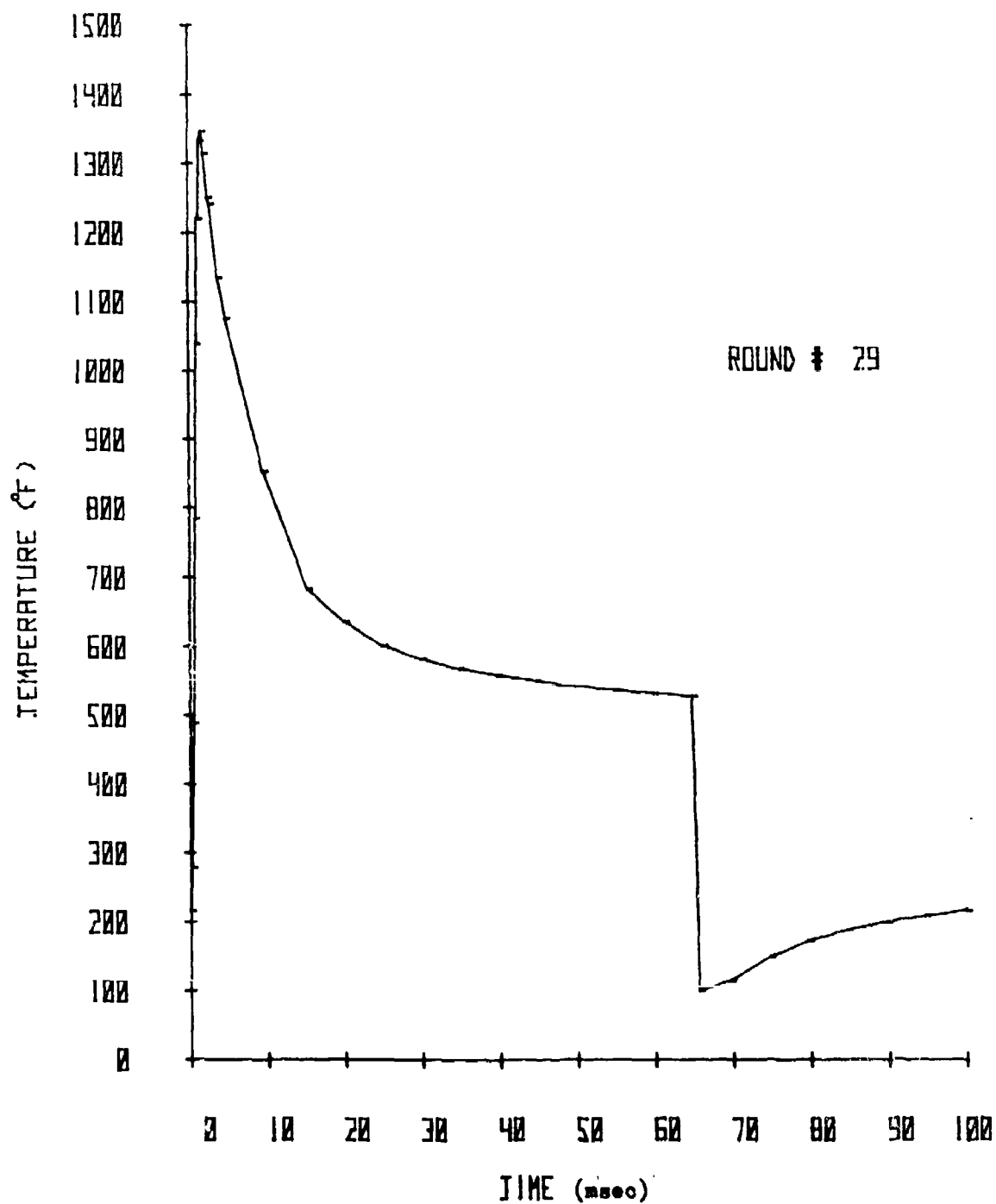


Figure 11. Surface temperature versus time, round 29.

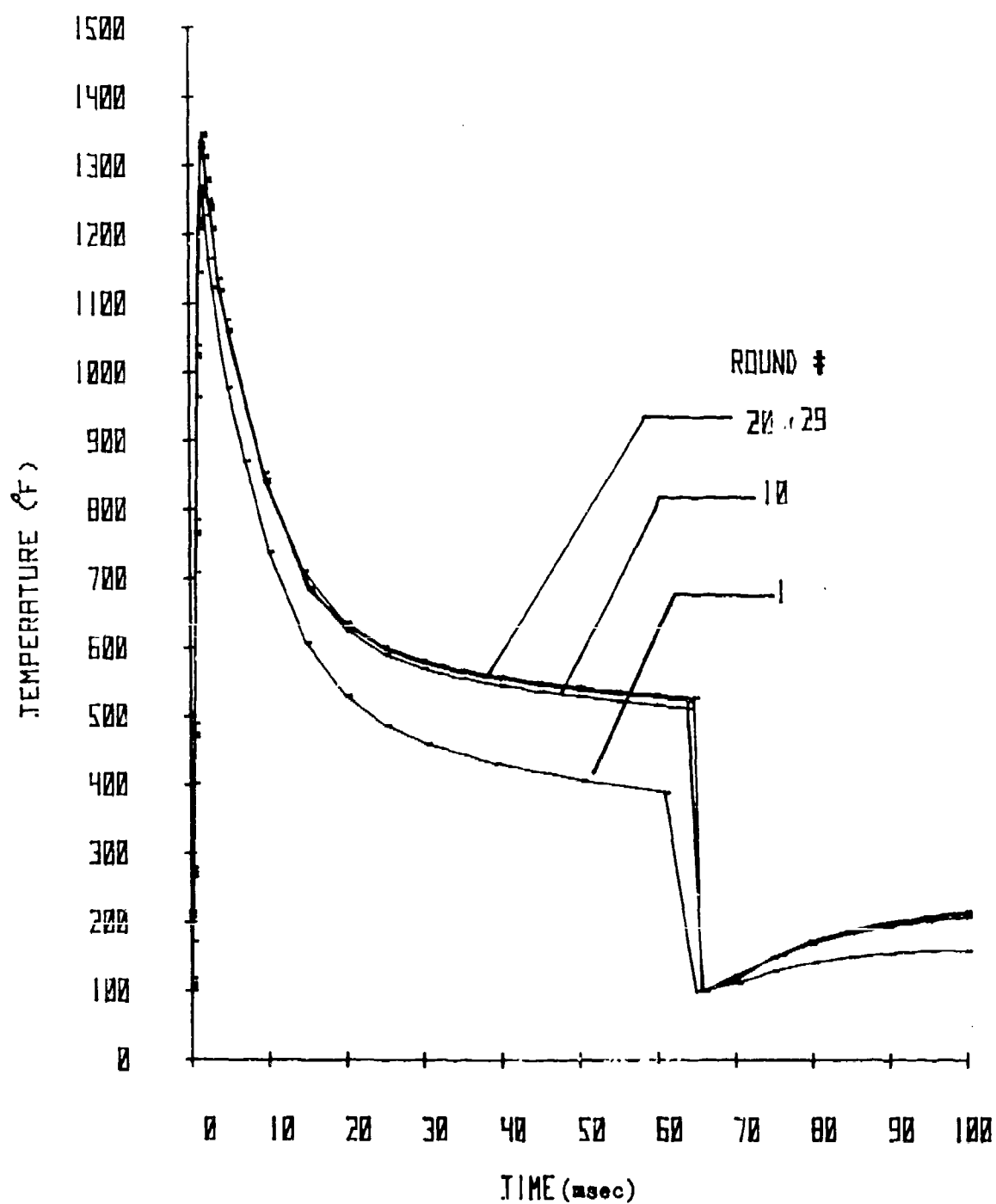


Figure 12. Surface temperature versus time, rounds 1, 10, 20 & 29.

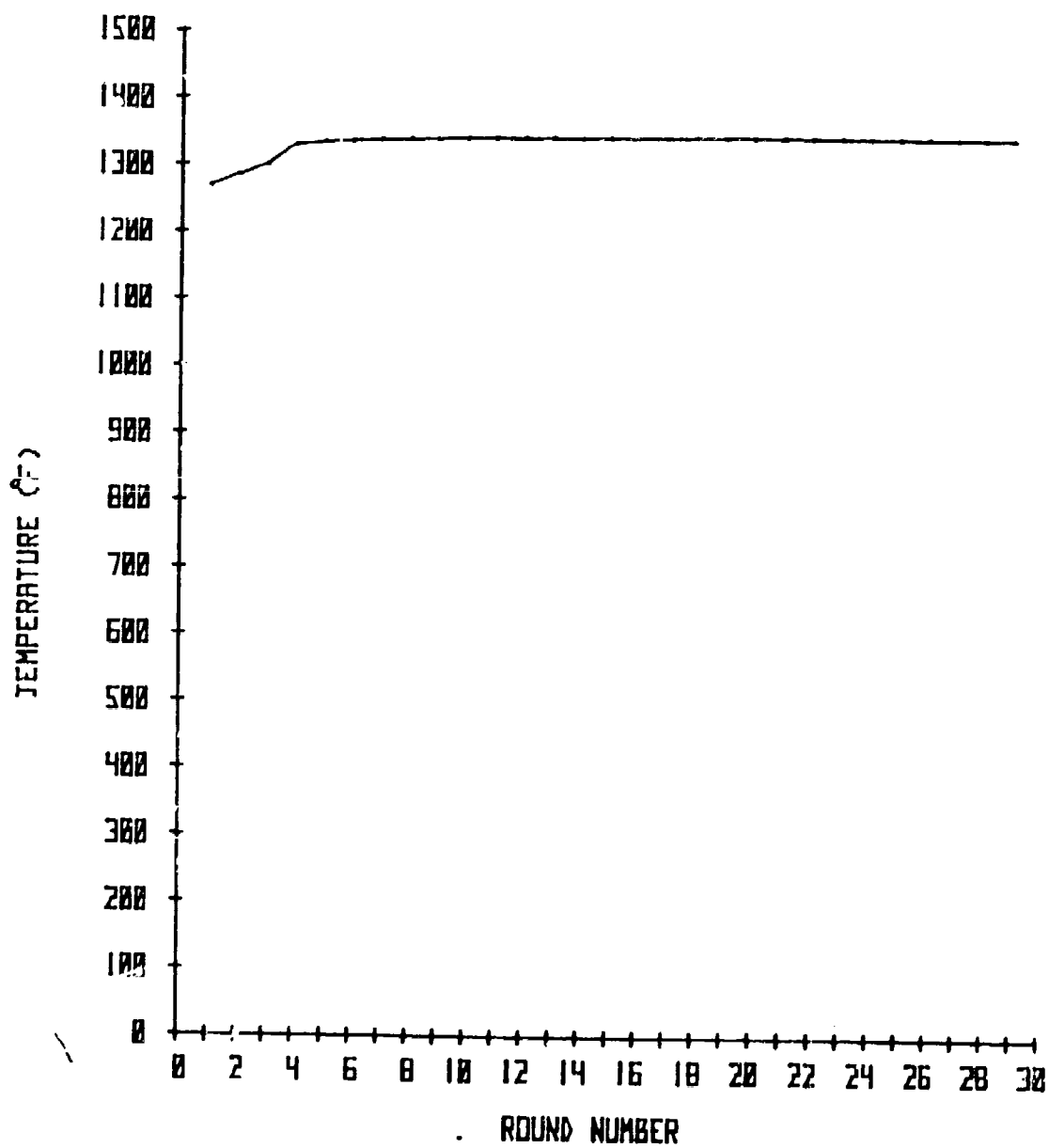


Figure 13. Peak surface temperature versus round number.

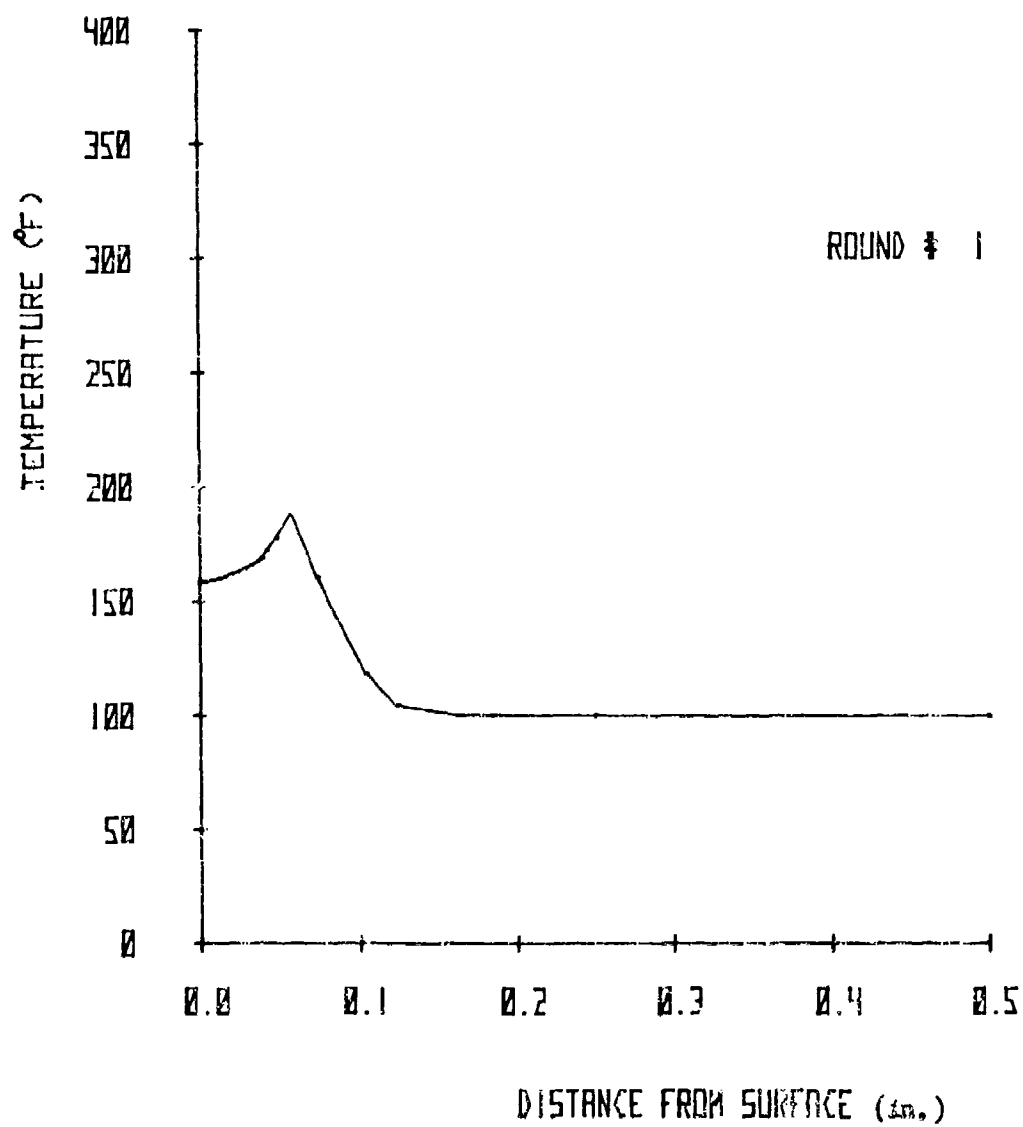


Figure 14. Temperature versus distance at 100 (msec).

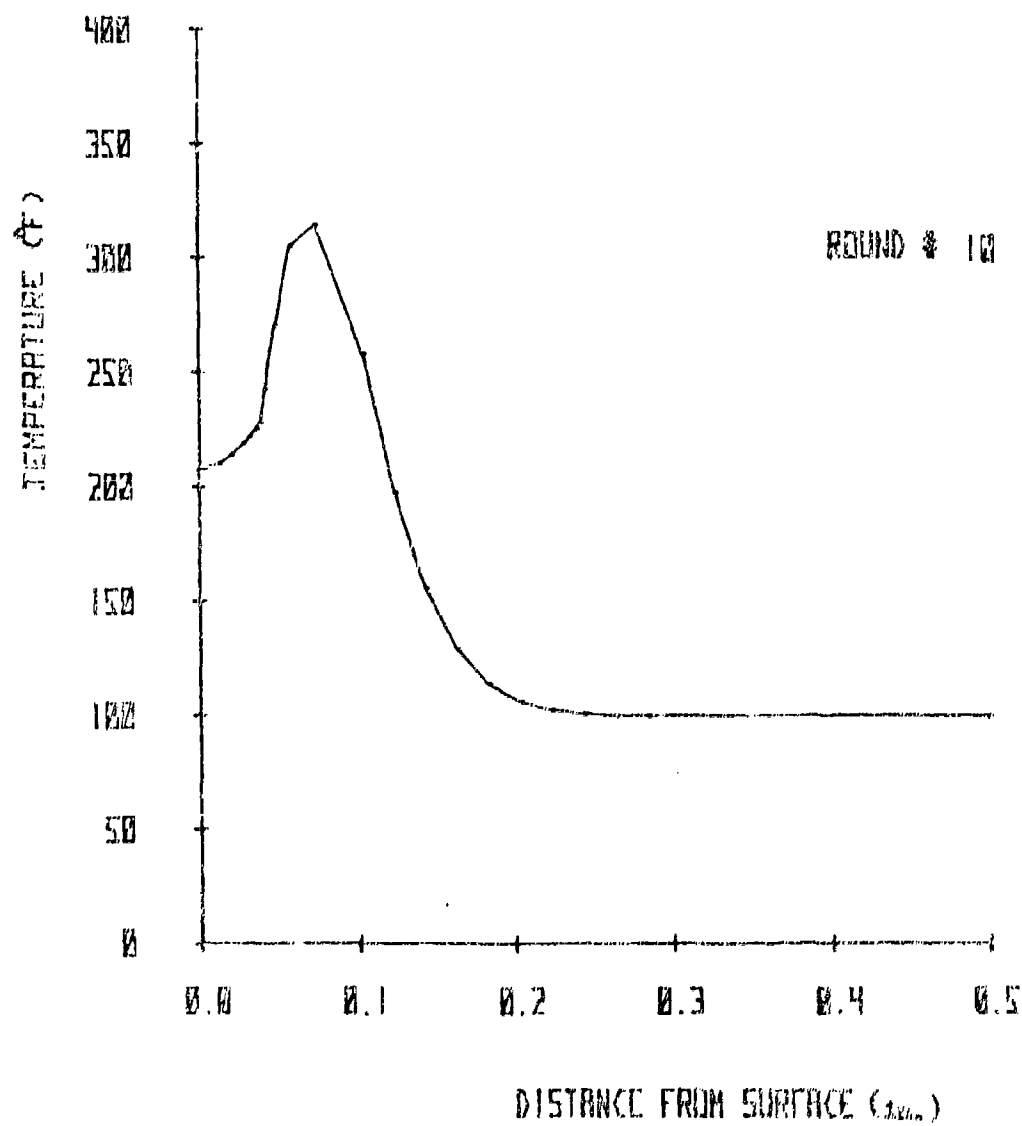


Figure 15. Temperature versus distance at 2000 (msec).

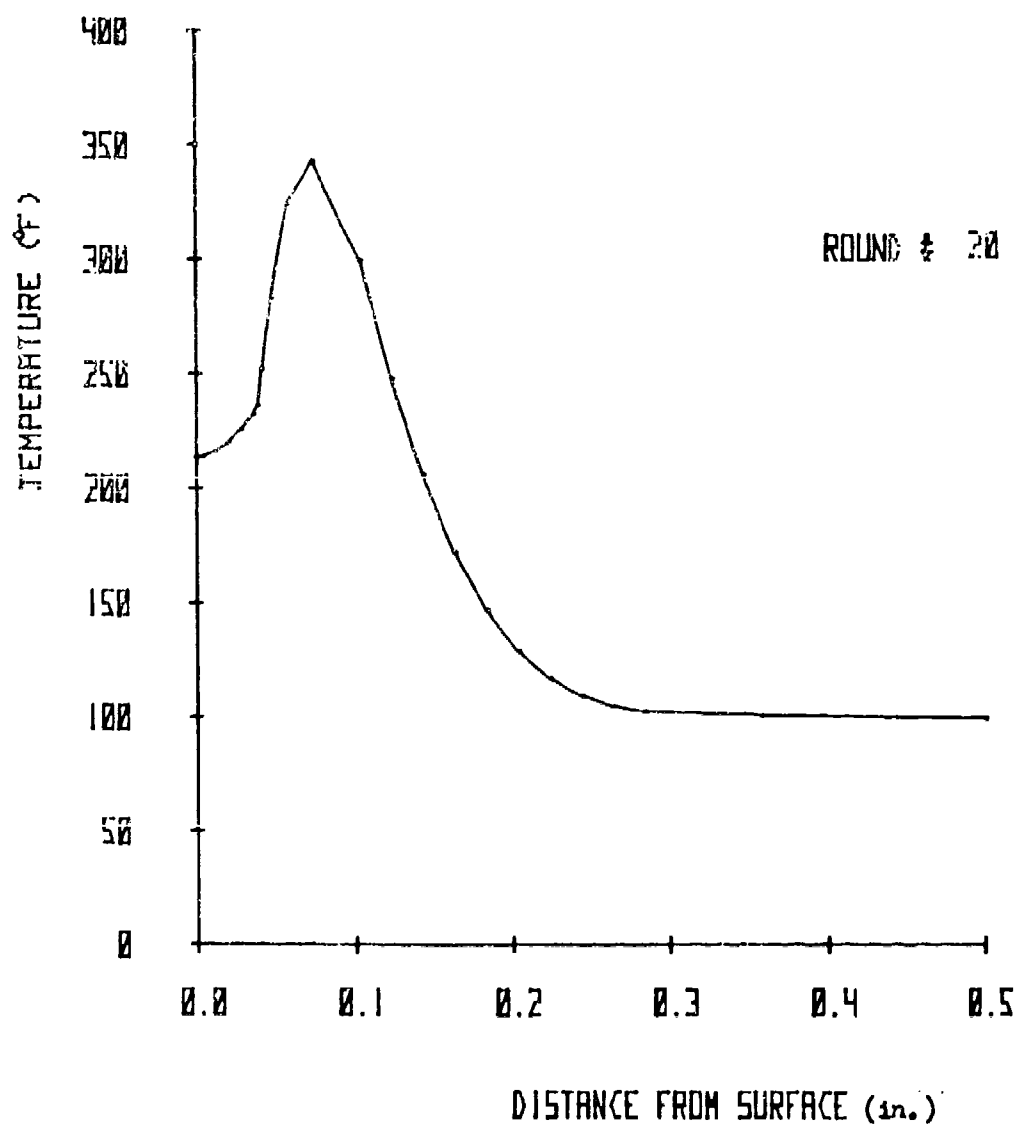


Figure 16. Temperature versus distance at 2000 (msec).

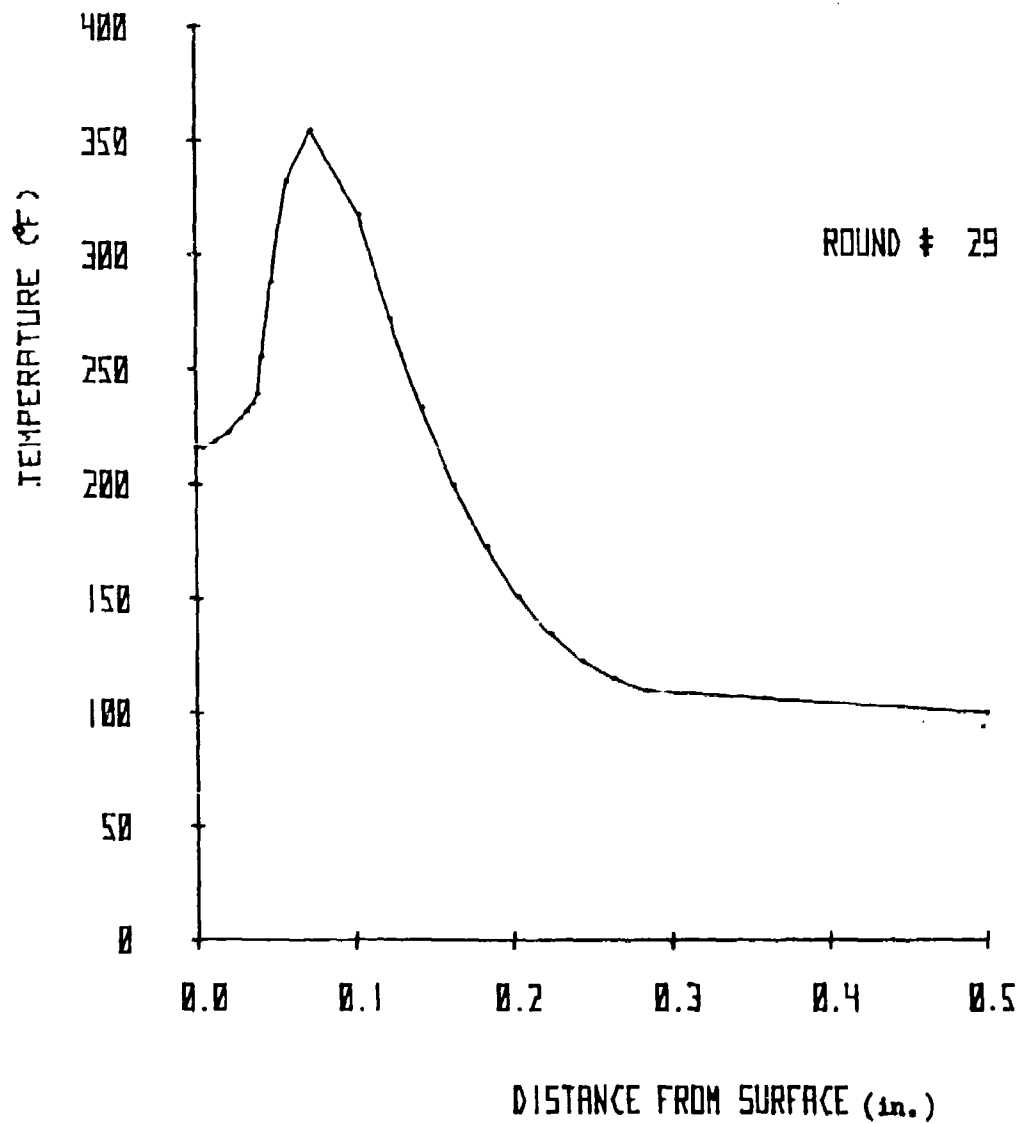


Figure 17. Temperature versus distance at 2900 (msec).

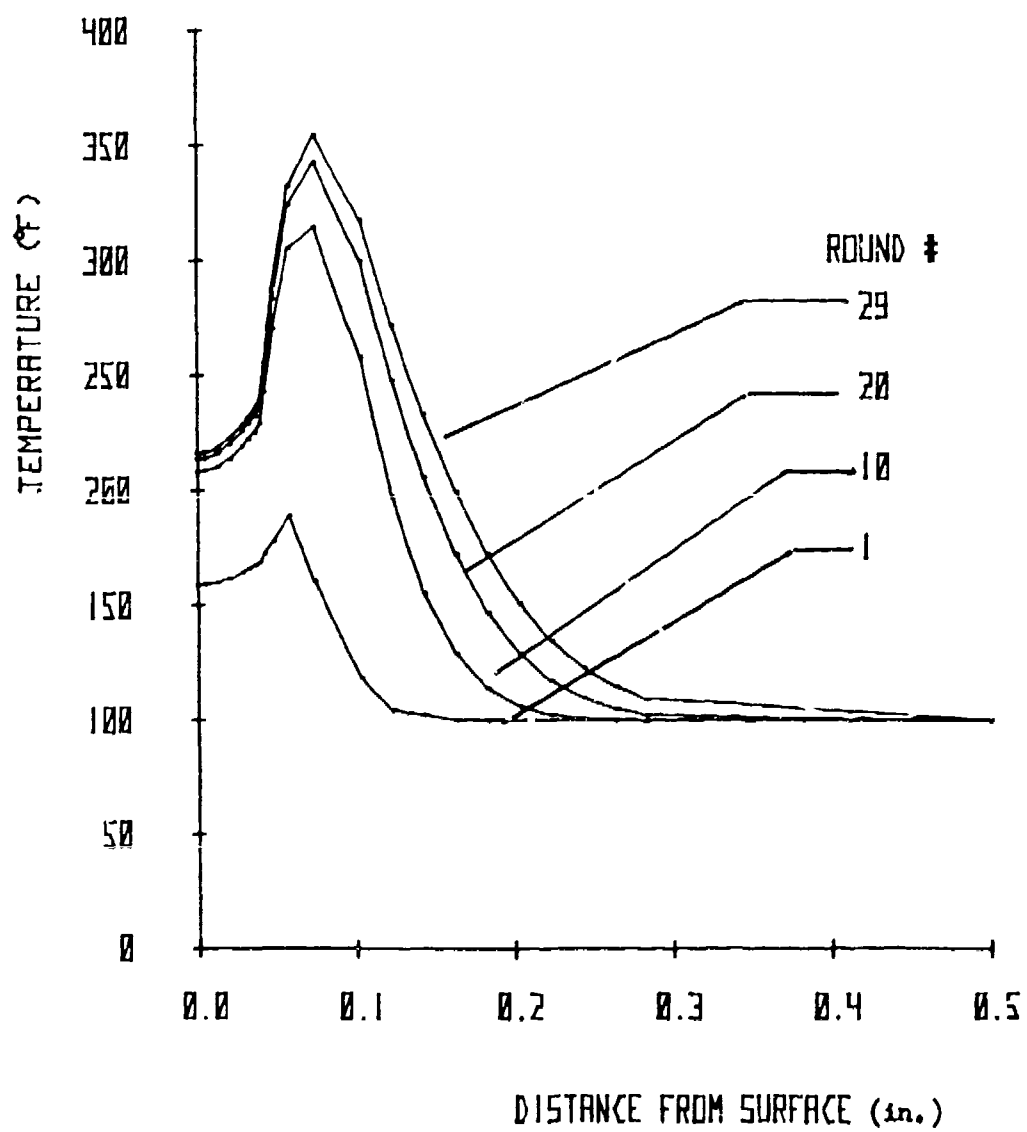


Figure 18. Temperature versus distance.

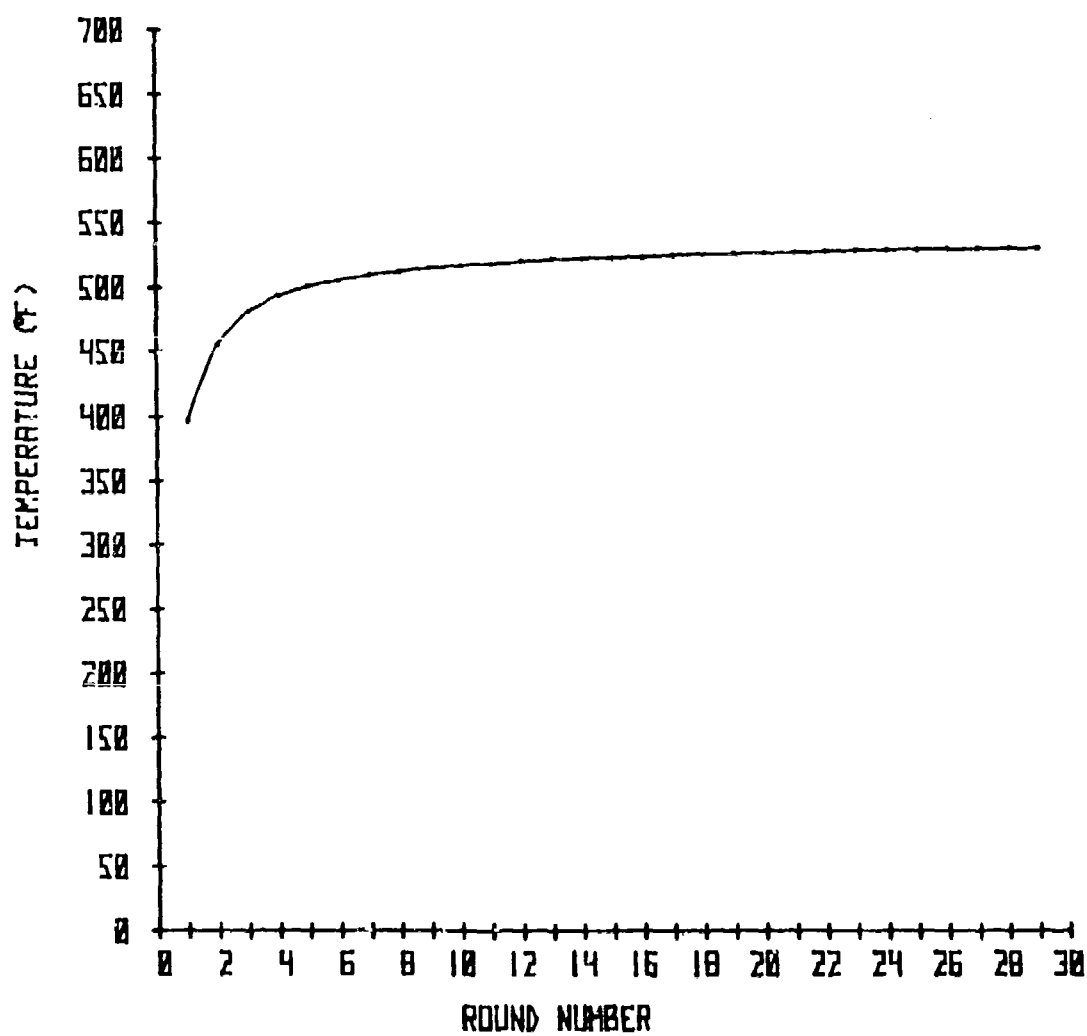


Figure 19. Peak interface temperature versus round number.

temperature. The peak temperature is still increasing at the rate of 0.3° F per round at round 29. Extrapolation of this rate out to 600 rounds is very dangerous. It would result in a peak steel temperature of approximately 700° F. This is an unrealistically high value. In addition, the question of depth of penetration must be considered. Examination of figure 18 shows that a 100° F temperature rise over the initial temperature has penetrated only 25% of the steel thickness. During future studies, additional cycles would be run.

The results of the one-dimensional analysis show that the penetration of the thermal wave is very slow, and therefore in those regions where this analysis is valid, conditions for the folded geometry are no worse than for conventional ammunition. In addition, since the severe heating during the ballistic phase is very short, this environment will heat the weapon uniformly and result in one-dimensional heat flow. A major factor affecting the structural temperature is the timing of the firing cycle. A shorter dwell time would greatly reduce the peak temperatures.

The major effect of the folded geometry is evidenced at the small interpose region near the base of the projectile. In this region the two-dimensional effect may be significant. The following section presents the two-dimensional results obtained for this region.

Two-Dimensional

Temperature distributions have been obtained for the model, and are described in the Two-Dimensional Model Section. The region examined is the base of the interpose region near the projectile base. Since the heating is uniform, only half of the web has to be considered. Figures 20 through 23 present the peak temperature occurring in this region for 4 complete cycles. The peak surface temperature in the corner is slightly higher than the peak temperature for the one-dimensional analysis. However, the temperature difference is approximately 1%, well within the accuracy of the analytical model. In figure 23, to the right of the model, the maximum temperatures corresponding to the same approximate location in the steel are given. For instance, the maximum interface temperature for round 4, node 24, in the one-dimensional analysis, is 493° F. The highest two-dimensional interface temperature at node 10 is 628° F. Node 10 is in the corner. However, node 24, located 0.41 in. from the corner, has a maximum of 521° F, as compared to 493° F in the one-dimensional interface temperature.

The results obtained from the two-dimensional calculations indicate that the temperature will be higher near the base of the interpose region. However, this level, at least after 4 rounds, is not prohibitive. In evaluating the temperature profiles, it will be necessary to assess the structural effect of small penetrations of high temperatures into the steel. This would be a major part of future efforts.

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2	980	14	936	25	936
3	816	15	754	26	754
4	695	16	621	28	621
7	630	18	546	29	545
8	618	19	508	30	507
9	574	21	485	32	484
11	554	22	466	33	466
12	539	23	452	34	451
5	523	17	438	24	437
51	319	53	240	55	238
52	198	54	140	56	139
57	161	59	104	61	103
58	160	60	101	62	100
31	483	63	100	63	100
32	491	64	100	64	100
33	499	65	100	65	100
34	512	66	100	66	100
35	526	67	100	67	100
36	532	68	100	68	100
37	592	69	100	69	100
38	608	70	100	70	100
39	633	71	100	71	100
40	695	72	100	72	100
41	816	73	100	73	100
42	1298	74	100	74	100
43	1273	75	100	75	100
44	755	76	100	76	100
45	622	77	100	77	100
46	552	78	100	78	100
47	526	79	100	79	100
48	512	80	100	80	100
49	499	81	100	81	100
50	491	82	100	82	100
51	483	83	100	83	100

Figure 20. Peak temperatures for round 1 (°F)

1	1328	13	1301	20	1302
2	1014	14	966	25	966
3	851	15	783	26	782
4	736	16	657	28	656
7	674	18	586	29	584
8	645	19	553	30	551
9	625	21	532	32	529
11	608	22	514	33	511
17	594	23	501	34	499
5	581	17	489	24	487
51	400	53	302	55	299
52	280	54	181	56	179
57	217	59	114	61	112
58	209	60	103	62	101
5	1319	5	1319	5	1319
35	1004	35	1004	35	1004
36	839	36	839	36	839
37	723	37	723	37	723
38	664	38	664	38	664
39	641	39	641	39	641
40	628	40	628	40	628
41	617	41	617	41	617
42	608	42	608	42	608
43	601	43	601	43	601
44	770	44	770	44	770
45	639	45	639	45	639
46	577	46	577	46	577
47	551	47	551	47	551
48	538	48	538	48	538
49	528	49	528	49	528
50	519	50	519	50	519
51	512	51	512	51	512
27	1290	27	1290	27	1290
43	954	43	954	43	954

Figure 21. Peak temperatures for round 2 (°F).

1	1338	13	1311	20	1311
2	1025	14	978	25	977
3	864	15	802	26	801
4	750	16	672	28	671
5	690	18	603	29	601
6	662	19	572	30	569
7	644	21	552	32	549
8	628	22	535	33	532
9	616	23	523	34	520
10	604	17	512	24	509
11	51	53	335	55	331
12	52	54	212	56	208
13	57	59	129	61	124
14	58	60	108	62	103
15	59	61	103	63	103
16	60	62	103	64	103
17	61	63	103	65	103
18	62	64	103	66	103
19	63	65	103	67	103
20	64	66	103	68	103
21	65	67	103	69	103
22	66	68	103	70	103
23	67	69	103	71	103
24	68	70	103	72	103
25	69	71	103	73	103
26	70	72	103	74	103
27	71	73	103	75	103
28	72	74	103	76	103
29	73	75	103	77	103
30	74	76	103	78	103
31	75	77	103	79	103
32	76	78	103	80	103
33	77	79	103	81	103
34	78	80	103	82	103
35	79	81	103	83	103
36	80	82	103	84	103
37	81	83	103	85	103
38	82	84	103	86	103
39	83	85	103	87	103
40	84	86	103	88	103
41	85	87	103	89	103
42	86	88	103	90	103
43	87	89	103	91	103
44	88	90	103	92	103
45	89	91	103	93	103
46	90	92	103	94	103
47	91	93	103	95	103
48	92	94	103	96	103
49	93	95	103	97	103
50	94	96	103	98	103
51	95	97	103	99	103
52	96	98	103	100	103
53	97	99	103	101	103
54	98	100	103	102	103
55	99	101	103	103	103
56	100	102	103	104	103
57	101	103	103	105	103
58	102	104	103	106	103
59	103	105	103	107	103
60	104	106	103	108	103
61	105	107	103	109	103
62	106	108	103	110	103
63	107	109	103	111	103
64	108	110	103	112	103
65	109	111	103	113	103
66	110	112	103	114	103
67	111	113	103	115	103
68	112	114	103	116	103
69	113	115	103	117	103
70	114	116	103	118	103
71	115	117	103	119	103
72	116	118	103	120	103
73	117	119	103	121	103
74	118	120	103	122	103
75	119	121	103	123	103
76	120	122	103	124	103
77	121	123	103	125	103
78	122	124	103	126	103
79	123	125	103	127	103
80	124	126	103	128	103
81	125	127	103	129	103
82	126	128	103	130	103
83	127	129	103	131	103
84	128	130	103	132	103
85	129	131	103	133	103
86	130	132	103	134	103
87	131	133	103	135	103
88	132	134	103	136	103
89	133	135	103	137	103
90	134	136	103	138	103
91	135	137	103	139	103
92	136	138	103	140	103
93	137	139	103	141	103
94	138	140	103	142	103
95	139	141	103	143	103
96	140	142	103	144	103
97	141	143	103	145	103
98	142	144	103	146	103
99	143	145	103	147	103
100	144	146	103	148	103
101	145	147	103	149	103
102	146	148	103	150	103
103	147	149	103	151	103
104	148	150	103	152	103
105	149	151	103	153	103
106	150	152	103	154	103
107	151	153	103	155	103
108	152	154	103	156	103
109	153	155	103	157	103
110	154	156	103	158	103
111	155	157	103	159	103
112	156	158	103	160	103
113	157	159	103	161	103
114	158	160	103	162	103
115	159	161	103	163	103
116	160	162	103	164	103
117	161	163	103	165	103
118	162	164	103	166	103
119	163	165	103	167	103
120	164	166	103	168	103
121	165	167	103	169	103
122	166	168	103	170	103
123	167	169	103	171	103
124	168	170	103	172	103
125	169	171	103	173	103
126	170	172	103	174	103
127	171	173	103	175	103
128	172	174	103	176	103
129	173	175	103	177	103
130	174	176	103	178	103
131	175	177	103	179	103
132	176	178	103	180	103
133	177	179	103	181	103
134	178	180	103	182	103
135	179	181	103	183	103
136	180	182	103	184	103
137	181	183	103	185	103
138	182	184	103	186	103
139	183	185	103	187	103
140	184	186	103	188	103
141	185	187	103	189	103
142	186	188	103	190	103
143	187	189	103	191	103
144	188	190	103	192	103
145	189	191	103	193	103
146	190	192	103	194	103
147	191	193	103	195	103
148	192	194	103	196	103
149	193	195	103	197	103
150	194	196	103	198	103
151	195	197	103	199	103
152	196	198	103	200	103
153	197	199	103	201	103
154	198	200	103	202	103
155	199	201	103	203	103
156	200	202	103	204	103
157	201	203	103	205	103
158	202	204	103	206	103
159	203	205	103	207	103
160	204	206	103	208	103
161	205	207	103	209	103
162	206	208	103	210	103
163	207	209	103	211	103
164	208	210	103	212	103
165	209	211	103	213	103
166	210	212	103	214	103
167	211	213	103	215	103
168	212	214	103	216	103
169	213	215	103	217	103
170	214	216	103	218	103
171	215	217	103	219	103
172	216	218	103	220	103
173	217	219	103	221	103
174	218	220	103	222	103
175	219	221	103	223	103
176	220	222	103	224	103
177	221	223	103	225	103
178	222	224	103	226	103
179	223	225	103	227	103
180	224	226	103	228	103
181	225	227	103	229	103
182	226	228	103	230	103
183	227	229	103	231	103
184	228	230	103	232	103
185	229	231	103	233	103
186	230	232	103	234	103
187	231	233	103	235	103
188	232	234	103	236	103
189	233	235	103	237	103
190	234	236	103	238	103
191	235	237	103	239	103
192	236	238	103	240	103
193	237	239	103	241	103
194	238	240	103	242	103
195	239	241	103	243	103
196	240	242	103	244	103
197	241	243	103	245	103
198	242	244	103	246	103
199	243	245	103	247	103
200	244	246	103	248	103
201	245	247	103	249	103
202	246	248	103	250	103
203	247	249	103	251	103
204	248	250	103	252	103
205	249	251	103	253	103
206	250	252	103	254	103
207	251	253	103	255	103
208	252	254	103	256	103
209	253	255	103	257	103
210	254	256	103	258	103
211	255	257	103	259	103
212	256	258	103	260	103
213	257	259	103	261	103
214	258	260	103	262	103
215	259	261	103	263	103
216	260	262	103	264	103
217	261	263	103	265	103
218	262	264	103	266	103
219	263	265	103	267	103
220	264	266	103	268	103
221	265	267	103	269	103
222	266	268	103	270	103
223	267	269	103	271	103
224	268	270	103	272	103
225	269	271	103	273	103
226	270	272	103	274	103
227	271	273	103	275	103
228	272	274	103	276	103
229	273	275	103	277	103
230	274	276	103	278	103
231	275	277	103	279	103
232	276	278	103	280	103
233	277	279	103	281	103
234	278	280</			

1	1343	13	1317	20	1316
2	1031	14	986	25	985
3	869	15	804	26	802
4	757	16	681	28	679
5	698	18	613	29	610
6	671	19	582	30	579
7	654	21	563	32	560
8	638	22	547	33	544
9	628	23	536	34	532
10	615	17	524	24	521 (493)
11	458	53	355	55	(445) (409) (347)
12	361	54	230	56	(270) (187) (134)
13	293	59	144	61	(113) (101)
14	277	60	114	62	(100) (100)
15	1301	7	1350	1	1301
16	968	35	1016	35	968
17	784	36	853	36	784
18	660	37	739	37	660
19	596	38	683	38	596
20	573	39	662	39	573
21	562	40	650	40	562
22	553	41	641	41	553
23	546	42	634	42	546
24	540	43	628	43	540

Figure 23. Peak temperatures for round 4 (°F).

CONCLUSIONS

The thermal response of the folded geometry cartridge has been determined for one and two-dimensional models, and also for single and multiple firings. The results show that the surface of the cartridge case heats very rapidly due to the propellant combustion. The one-dimensional model has been run for 29 rounds, and the two-dimensional model for 4 rounds.

The peak cartridge case temperature occurs at the base of the interpose region, based upon two-dimensional calculations. At round 4, this peak is 1343°F . For the one-dimensional model, the corresponding peak is 1331°F . The two-dimensional effect on peak cartridge temperature is therefore very small. Extrapolating the one-dimensional results to 600 rounds would yield a peak of 1370°F . By applying the same difference of approximately 1.0%, for the worst two-dimensional results, the peak cartridge temperature would be less than 1400°F after 600 rounds. This result would indicate that with respect to peak cartridge temperature, the folded geometry cartridge is no worse than conventional rounds.

With respect to the weapon chamber, the interface temperature at the base of the interpose region will be hotter, due to the folded geometry. After 4 rounds, the peak interface temperature is 628°F for the two-dimensional analysis, compared to 493°F for the one-dimensional analysis. Extrapolation of these results, to conditions after 600 rounds, is not possible at this time. However, it seems reasonable to conclude that the base of the interpose region will experience more severe temperatures than would exist with conventional ammunition.

Future effort should concentrate on additional firings with the two-dimensional model, an investigation of the heating cycle during the period after the ballistic portion of the cycle, and thermal stress calculations of the effect of thermal distortion and elevated temperatures upon material strength.

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3. N. E. Banks, and G. J. Klem, "A Study of Heat Transfer in Folded Ammunition Gun Tube Chambers," BRL 1, November 1976.
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APPENDIX A

ONE-DIMENSIONAL PROGRAM LISTING

// JOB MCA>SEY,3610****10/*****CLASS=LIF2;
// EXEC MATFIV,SIZE=0256K

DATE 06/12/74,CLOCK 13/2

/PROGRAM MCASSEY,PAGES=500,TIME=15

***** ONE DIMENSIONAL THERMAL ANALYSIS PROGRAM *****

```

1  REAL M
2  DIMENSION TFREE(50),FILM(50),TIME(50),M(100),C(100),AREA(100),TI(1
3  100),COY(100,100),TEMP(100),INER(100)
4  READ(5,1000) DELTA,NBUDY,NCJUP,N
5  DELTA=DELTA/3600
6  WRITE(6,2002) DELTA,NBUDY,NCJUP,N
7  READ(5,1002) ICT,INC,INTER,CDEL
8  CDEL=CDEL/3600
9  WRITE(6,2008) ICT,INC,INTER,CDEL
10 READ(5,1001) TFREE(1),FILM(1),TIME(1),I=1,N
11 PRINT=1.35E-07
12 PROC=0.0
13 DO 4 I=1,N
14   TFREE(I)=TFREE(I)-450.0
15   TIME(I)=TIME(I)/3600.0
16   WRITE(6,2003)
17   DO 5 J=1,NBUDY
18     READ(5,1005) M(I),C(I),AREA(I),TI(I)
19     DO 6 I=1,NBUDY
20       COY(I,J)=0.0
21       COY(J,I)=0.0
22       READ(5,1007) I,J,COND(I,J)
23       COND(J,I)=COND(I,J)
24       DO 10 I=1,NBUDY
25         CONTINUE=1.0
26         DO 15 J=1,NBUDY
27           TFREE(I,J)=M(I),C(I),AREA(I),TI(I)
28           DO 16 J=1,NBUDY
29             COND(I,J)=0.0
30             WRITE(6,2007) I,J,COND(I,J)
31             CONTINUE
32             TIME(I,J)=3.6E6
33             DO 17 I=1,NBUDY
34               TFREE(I,J)=0.0
35               WRITE(6,3000) I,J,TI(I),J=1,NBUDY
36               DO 37 I=1,NBUDY
37                 IF (CT-EG-ICT) DELTA=COEL
38                 IF (CT-EG-INC) PRINT=9.8*DELTA
39                 IF (CT-EG-INC) GO TO 40
40                 GO=INTER-1
41                 DO 41 I=1,NBUDY
42                   TFREE(I,J)=100.
43                   CONTINUE
44                   TIME(I,J)=TIME(I)
45                   IF (WORK=0.0) GO TO 40
46                   IF (TFREE(I,J)-TFREE(I,J+1))/WORK
47                   IF (TFREE(I,J)-TFREE(I,J+1))/WORK
48                   IF (TFREE(I,J)-TFREE(I,J+1))/WORK
49                   IF (TFREE(I,J)-TFREE(I,J+1))/WORK
50                   IF (TFREE(I,J)-TFREE(I,J+1))/WORK
51                   IF (TFREE(I,J)-TFREE(I,J+1))/WORK
52                   IF (TFREE(I,J)-TFREE(I,J+1))/WORK

```

```

50 IF I=1 THEN STOP; TT=TTSTOP
51 IF I=1 THEN GO TO 100
52 CONTINUE
53 IF I=1 THEN GO TO 100
54 IF I=1 THEN GO TO 100
55 IF I=1 THEN GO TO 100
56 IF I=1 THEN GO TO 100
57 IF I=1 THEN GO TO 100
58 IF I=1 THEN GO TO 100
59 IF I=1 THEN GO TO 100
60 IF I=1 THEN GO TO 100
61 IF I=1 THEN GO TO 100
62 IF I=1 THEN GO TO 100
63 IF I=1 THEN GO TO 100
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77 IF I=1 THEN GO TO 100
78 IF I=1 THEN GO TO 100
79 IF I=1 THEN GO TO 100
80 IF I=1 THEN GO TO 100
81 IF I=1 THEN GO TO 100
82 IF I=1 THEN GO TO 100
83 IF I=1 THEN GO TO 100
84 IF I=1 THEN GO TO 100
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97 IF I=1 THEN GO TO 100
98 IF I=1 THEN GO TO 100
99 IF I=1 THEN GO TO 100
100 IF I=1 THEN GO TO 100
101 IF I=1 THEN GO TO 100
102 IF I=1 THEN GO TO 100
103 IF I=1 THEN GO TO 100
104 IF I=1 THEN GO TO 100
105 IF I=1 THEN GO TO 100
106 IF I=1 THEN GO TO 100
107 IF I=1 THEN GO TO 100
108 IF I=1 THEN GO TO 100
109 IF I=1 THEN GO TO 100
110 IF I=1 THEN GO TO 100

```

```

111      $, / 1X, 'INTERFACE AT BODY NUDE', I2, / 1X, 'NEW TIME STEP=', E20.5)
112      3600 FORMAT(1X, 'BODY NUMBER=', I5)
      END
      , GO

```

APPENDIX B

TWO-DIMENSIONAL PROGRAM LISTING

// JOB MCASSEY,3610****10/****,CLASS=L(FZ)
 // EXEC MATFIV,SIZE=0256K

DATE 06/12/78,CLOCK 13/4

/PROGRAM MCASSEY,PAGES=500,TIME=6

CCCCC

***** TWC DIMENSIONAL TEMPERATURE PROGRAM *****

```

1  REAL M
2  DIMENSION TFREE(20),FILM(20),TIME(20),M(100),C(100),AREA(100),TI(1
3  00),N(100),DELTA(100),TEMP(100),INEN(100)
4  DIMEN=100
5  READ(5,1000) DELTA,NBODY,NCOUP,N
6  WRITE(6,2002) DELTA,NBODY,NCOUP,N
7  READ(5,1001) TFREE(1),FILM(1),TIME(1),I=1,N
8  PRINT=675E-07
9  PRG=0.C
10 CC=0.I=1,N
11 TFREE(1)=TFREE(1)-460.0
12 TIME(1)=TIME(1)/3600.0
13 WRITE(6,2003)
14 WRITE(6,2004) (TFREE(I),FILM(I),TIME(I),I=1,N)
15 DO 5 I=1,NBODY
16 READ(5,1005) M(I),C(I),AREA(I),TI(I),I=1,N)
17 DO 6 J=1,NBODY
18 CC(J)=1,NBODY
19 COND(I,J)=0.0
20 DO 7 K=1,NCOUP
21 READ(5,1007) I,J,CCND(I,J)
22 CCND(J,I)=CCND(I,J)
23 CONTINUE
24 WRITE(6,3001) M(I),C(I),AREA(I),TI(I),I=1,N)
25 WRITE(6,3002) M(I),C(I),AREA(I),TI(I),I=1,N)
26 IF(COINC(1,J).GT.0.0) WRITE(6,2007) I,J,COND(I,J)
27 CONTINUE
28 PLT=M-N-1
29 TT=TIME(1)*3.6E6
30 CC=0.I=1,NBODY
31 TNE(1)=1.I=1
32 WRITE(6,3003) TT
33 WRITE(6,3004) (J,TI(J),J=1,NBODY)
34 DO 100 IT=1,100
35 SLCPE=(TFREE(IT+1)-TIME(IT))
36 HSLUP=(FILM(IT+1)-FILM(IT))/MDRK
37 TSTGRT=TIME(IT+1)
38 TSTGRT=TIME(IT)
39 IT=IT+1
40 IF(IT.GT.TSTOP) TT=TT+DELTA
41 IF(IT.GT.TSTOP) TT=TT+DELTA
42 DO 52 I=1,NBODY
43 TEMP(I)=TNE(I)
44 TEMP(I)=TNE(I)
45 CC=0.I=1,NBODY
46 CUR=DELTA/M(I)/C(I)
47 IF(I=1) GO TO 50
48 SUM=MDRK*AREA(I)*(FILM(IT)+HSLUP*(TT-TSTART))+TFREE(IT)+SLOPE*(TT
49 1-TSTART)
50 GC=TC 61
51 SUM=0.C
52
```

```

53 SUM1=0.0
54 DO 70 J=1,NBODY
55   SUM1=SUM1+CCNC(I,J)
56   SUM=SUM+WCNK*CCNC(I,J)*TEMP(I,J)
57   CCATINUE
58   IF(I,TYPE(I)-EQ.1) GO TO 72
59   TNEW(I)=SUM+(1.-WCNK*(SUM1+AREA(I))*(FILM(IT)+HSLCP*(TT-TSTART))))
60   1*TEMP(I)
61   IF(TNEW(I).LT.50.) STOP
62   IF(TNEW(I).LT.50.) WRITE(6,3500)
63   GC TO 100
64   TNEW(I)=SUM+(1.-WURK*SUM1)*TEMP(I)
65   IF(TNEW(I).LT.50.) WRITE(6,3500)
66   IF(TNEW(I).LT.50.) STOP
67   CCNTINUE
68   TTT=TT+3.6E6
69   PRC=PRC+DELTA
70   IF (PRC.LT.PRINT) GC TO 102
71   PRC=0.0
72   WRITE (6,3000) TTT
73   WRITE (6,3002)
74   WRITE (6,3001) (J,TNEW(J),J=1,NBODY)
75   CCNTINUE
76   IF (TT.EC.TSTOP) GC TO 500
77   GC TO 50
78   CCNTINUE
79   TTT
80   WRITE (6,3000) TTT
81   WRITE (6,3002)
82   WRITE (6,3001) (J,TNEW(J),J=1,NBODY)
83   STOP
84   FORMAT (E20.5,3I4)
85   FORMAT (3F20.5)
86   FORMAT (4F10.5,12)
87   FORMAT (2I5,F10.5)
88   STEP=,E20.5,DX,NUMBER OF BODIES=,I4,1X,NUMBER
89   OF TIME INTERVALS=,I4,1X,NUMBER OF TIME
90   INTERVALS=,I4,1X,HEAT INPUT PROFILE,771X,FREE STREAM TEMP.,10X,H
91   EAT TRANSFER COEFF.,10X,TIME,10X,
92   EAT TRANSFER COEFF.,10X,TIME,10X,
93   EAT TRANSFER COEFF.,10X,TIME,10X,
94   EAT TRANSFER COEFF.,10X,TIME,10X,
95   EAT TRANSFER COEFF.,10X,TIME,10X,
96   EAT TRANSFER COEFF.,10X,TIME,10X,
97   EAT TRANSFER COEFF.,10X,TIME,10X,
98   EAT TRANSFER COEFF.,10X,TIME,10X,

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