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#### ACKNOWLEDGEMENTS

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## INTRODUCTION

Tests of inert Sidewinder 1C missiles, carried by supersonic aircraft, have shown that motor-tube temperatures were increased considerably by aerodynamic heating. This raised the question whether the sustainer propellant grain could endure repetitive aerodynamic-heating cycles over several missions.

The objective of this study was to learn how the transfer of heat from a motor tube to its contained propellant affected the propellant grain and its peripheral ethyl cellulose inhibitor. The Sidewinder 1C sustainer grain of X-14 propellant was subjected to a temperature-time relationship simulating an aircraft intercept mission.

## TEST APPROACH AND EQUIPMENT

Work began with an experimental determination of the heat-softening temperature of the propellant inhibitor and the percentage of radiant energy transmitted through it. The next phase consisted of finding the heat requirements to produce the desired temperatures. The standard motor tube was a heat sink, which would hinder the fast temperature rises desired. Even if the thick-walled motor tube were eliminated, full-sized grain tests presented heating-rate requirements beyond the capabilities of existing local surveillance ovens. Need for a special electric heating element to be fitted over the grain was evident. Power requirements and a survey of controls available dictated the use of a nichrome-ribbon heating element of approximately 3 ohms resistance.

For the first four tests, the nichrome ribbons were wrapped directly on the exterior inhibited surface of the grain. This was found to be unsatisfactory. In all subsequent tests, the grain was placed in a close-fitting, very-thin-walled steel tube. The nichrome heating element was wrapped around the insulated external surface of the tube. Thermocouples, connected to the steel tube and to the heating element, enabled permanent recording of temperature versus time. A Variac and temperature recorder, located remotely from the grain, were used to control the heat applied to the grain. During testing, the grain was suspended with its longitudinal axis vertical in an insulated jacket to prevent heat loss to atmosphere during heating. To cool the grain, the power was shut off and the grain lowered into a cooling jacket by use of a pulley system remotely controlled from the Variac site. Variac manipulation, with cooling at the end of a heating cycle, enabled either the grain inhibited surface or the steel-tube temperatures to conform to a pre-programmed temperature-time curve drawn on the recorder chart prior to testing. A recording ammeter simultaneously plotted current versus

time curves corresponding to the temperature versus time curves. Figure 1(a) schematically shows the arrangement of test apparatus; Fig. 1(b) through 1(e) show the component parts.

Thermocouples, placed at predetermined locations depending on the particular test, gave temperatures at those sites. Characteristics and findings of individual tests are given in the succeeding paragraphs.

## TEST RESULTS

### THERMAL PROPERTIES OF THE INHIBITOR

When preparing for the first test, it was not known whether or not radiant energy could be transmitted through the translucent inhibitor to the propellant. Two ethyl cellulose samples, one 0.0075 inch and a second 0.052 inch thick were tested on an infrared spectrophotometer which measured the percentage of transmittance versus wavelength. As shown in Fig. 2 and 3, the 0.0075-inch-thick sample allowed transmission of appreciable radiant energy, but the 0.052-inch-thick sample allowed only a negligible amount. Since the 0.052-inch-thick sample came from a freshly wrapped grain, it appeared reasonable to assume that energy transfer from either the motor tube or heating element to the propellant would be essentially all conduction.

In an additional test, ethyl cellulose tape was wrapped on a 5-inch-diameter aluminum tube simulating an actual grain wrapping. Tape was wrapped on the tube both with and without ELBA solvent. Thermocouples were placed under the tape and the tube placed in an oven. When the tape reached 265°F, bubbles appeared, indicating evaporation or boiling of solvent. Between 265 and 350°F, the tape softened to the extent that some of the thermocouples placed between the tape and tube surface sheared through and moved away from the tape. At 402 to 415°F, the tape turned brown and softened to the consistency of bearing grease. After cooling, the tape was everywhere smooth and uniformly bonded to the aluminum tube.

### WRAPPING HEATING ELEMENT AROUND GRAIN

The grain for the first test was spirally wrapped with seven adjacent 1/8-inch-wide nichrome ribbons plus one 3/32-inch-wide strip of fiberglass tape over the grain length as shown in Fig. 4. Thermocouples were fastened in the valleys of the grain perforation, at mid depth in the propellant grain web, at the interface of the propellant surface and peripheral inhibitor, and on the outside of the inhibited surface so as to be between the inhibitor and heating element. The freshly wrapped grain with its heating element was then mounted on

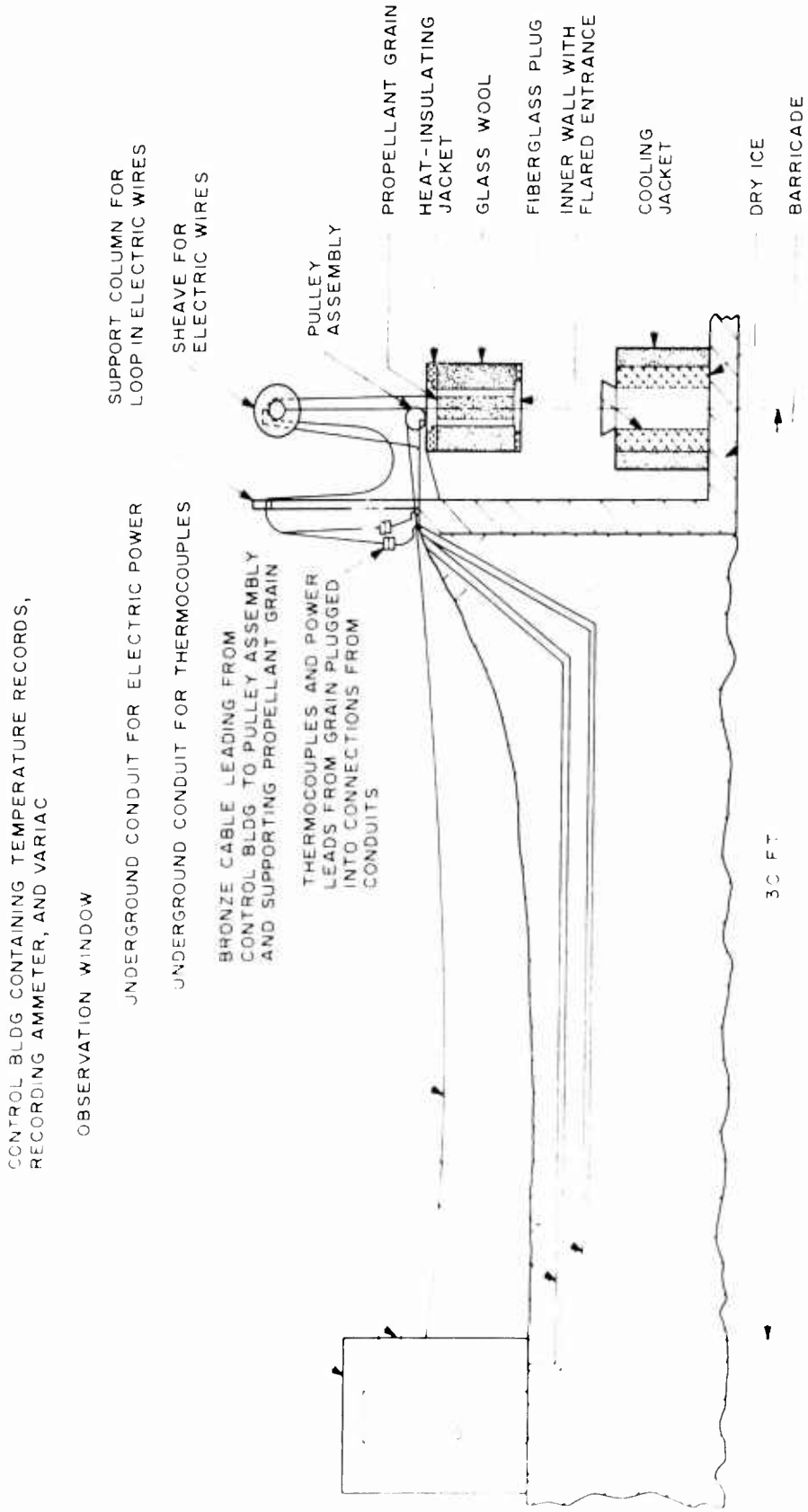


FIG. 1(a). Schematic of Test Equipment.



FIG. 1(b) Lowering Grain Into Insulating Jacket.



FIG. 1(c) Test Area Showing Control Building.



FIG. 1(d) Temperature Recorders.

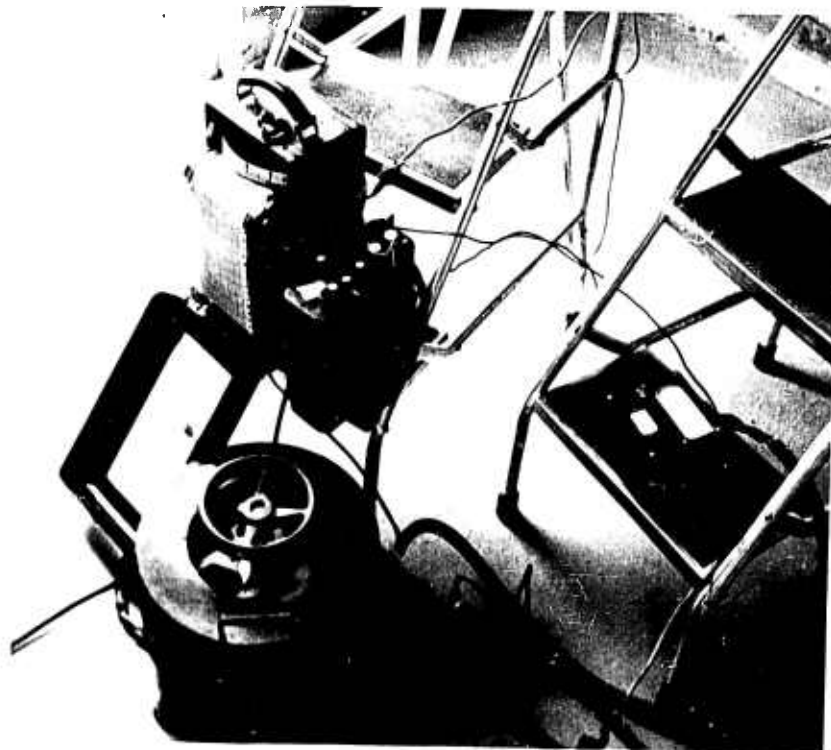


FIG. 1(e) Electrical Recording and Control Instruments

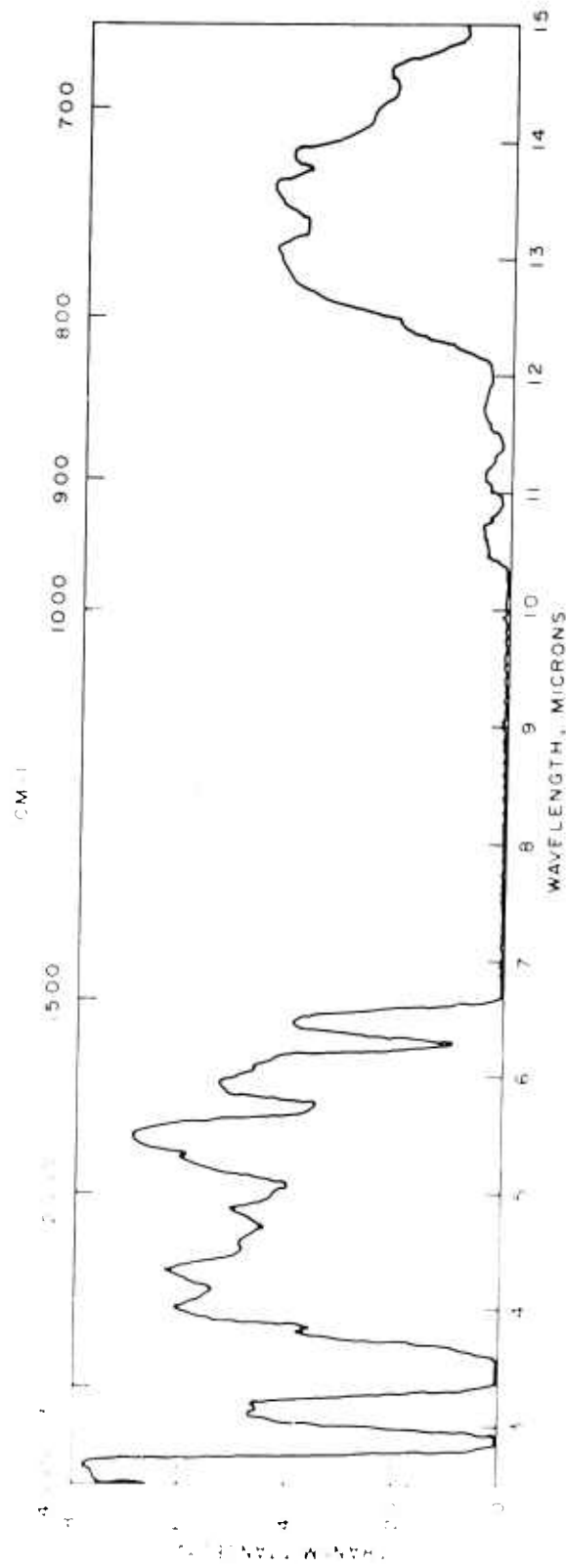


FIG 2. Radiant Energy Through a 0.0075-Inch Inhibitor.

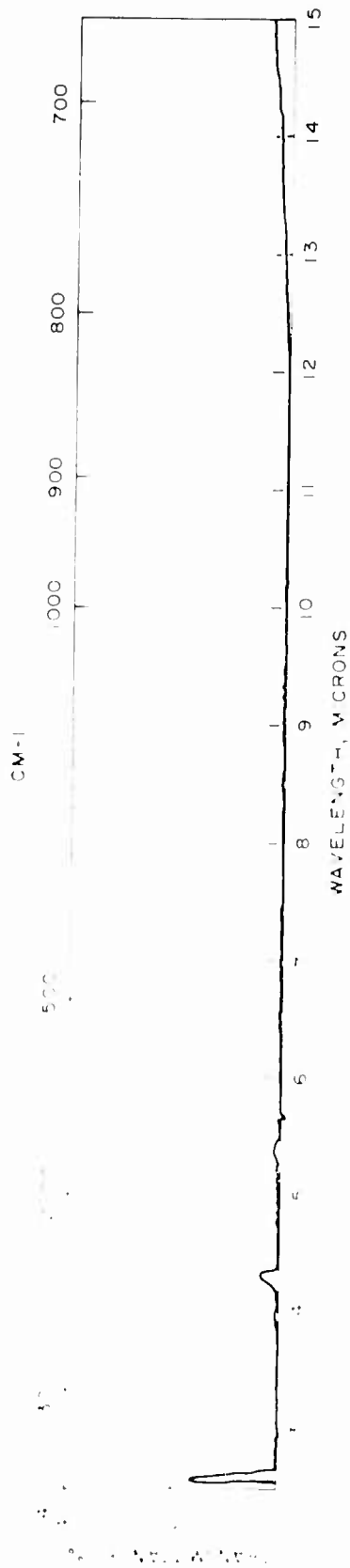


FIG. 3. Radiant Energy Through a 0.052-Inch Inhibitor

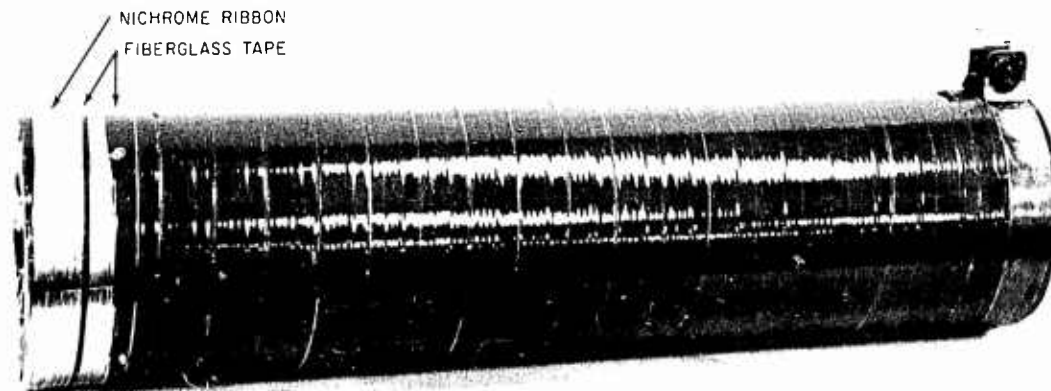


FIG 4. Nichrome Heating Element Wrapped on Grain

in a 130°F oven for 18 hours, following which it was suspended in the heat-insulating jacket, also conditioned at 130°F, and subjected to application of electric heating in accordance with Fig 5

Figure 6 is a family of curves showing the temperature versus radial distance inward from the outside of the grain corresponding to the four different heating cycles. This illustrates the temperature gradient resulting from low propellant thermal conductivity. The grain ignited after 19 minutes, the last recorded temperature being 320°F. This was undoubtedly not the highest temperature before ignition because of the limited number of temperatures that could be measured, and the recorder, at that time, was not geared for maximum printing speed.

Because of the differential expansion between grain and nichrome element and the low softening temperature of the grain inhibitor, there were some doubts about having applied the nichrome heating element directly to the inhibited grain surface. Figure 7 shows the effects of inhibitor expansion and softening. Therefore, consideration was given to modifying the method for transmitting heat to the grain in future tests. The first test was made using a fresh grain, succeeding tests utilized grains removed from Sidewinder IC motors. These later grains were representative of moderately aged grains in which a partial migration of nitroglycerin and 2-nitrodiphenylamine (2-NDA) into the inhibitor had occurred.

Tests 2 through 6 consisted of development work performed before reliable results were obtained in heating the grain in the jacket.

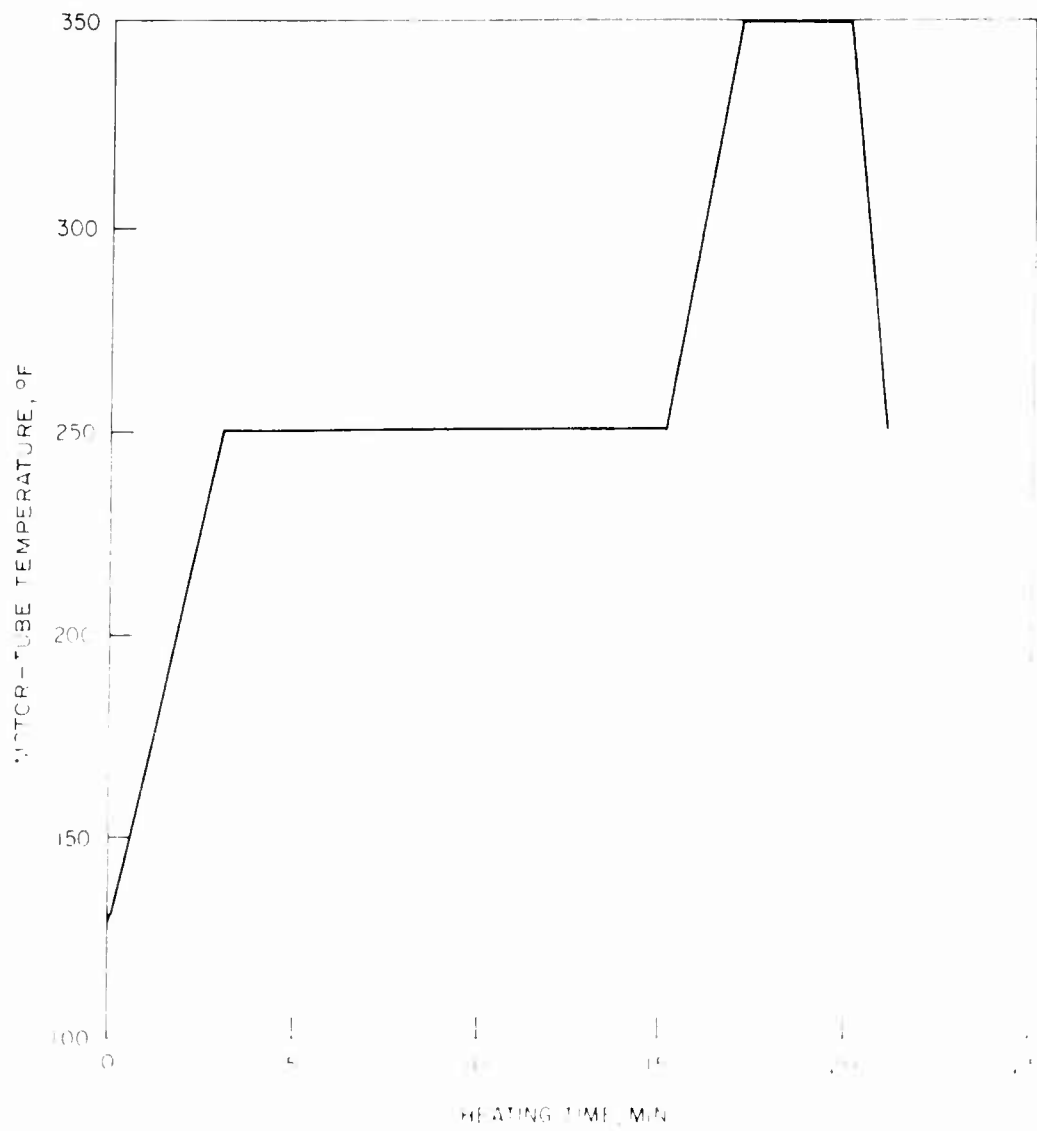


FIG 5. Temperature vs. Time During Aerodynamic Heating of the 5.0-Inch Rocket Motor Mk 24 Mod 0

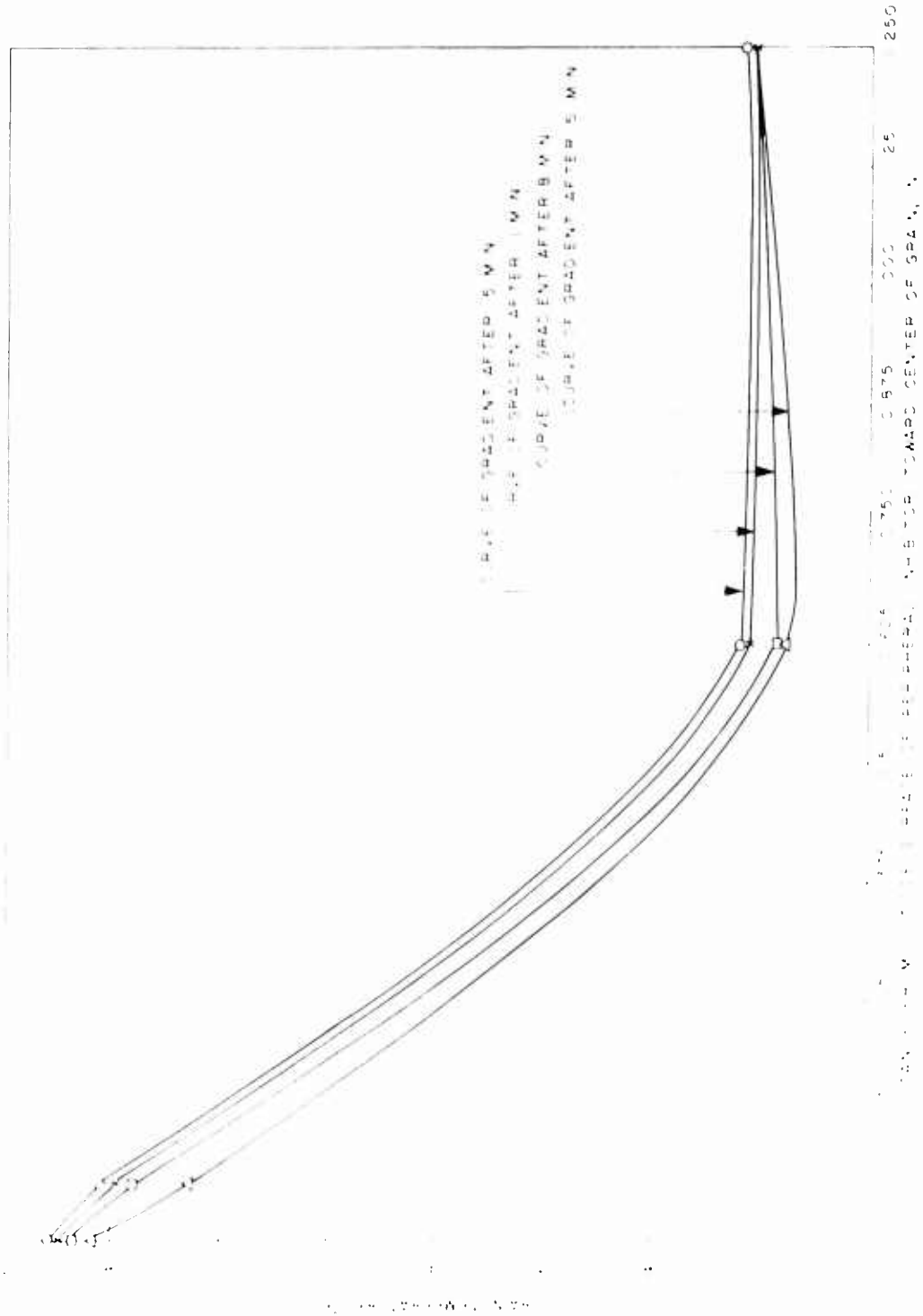


FIG. 6. Grain Temperature vs. Inward Radial Distance.

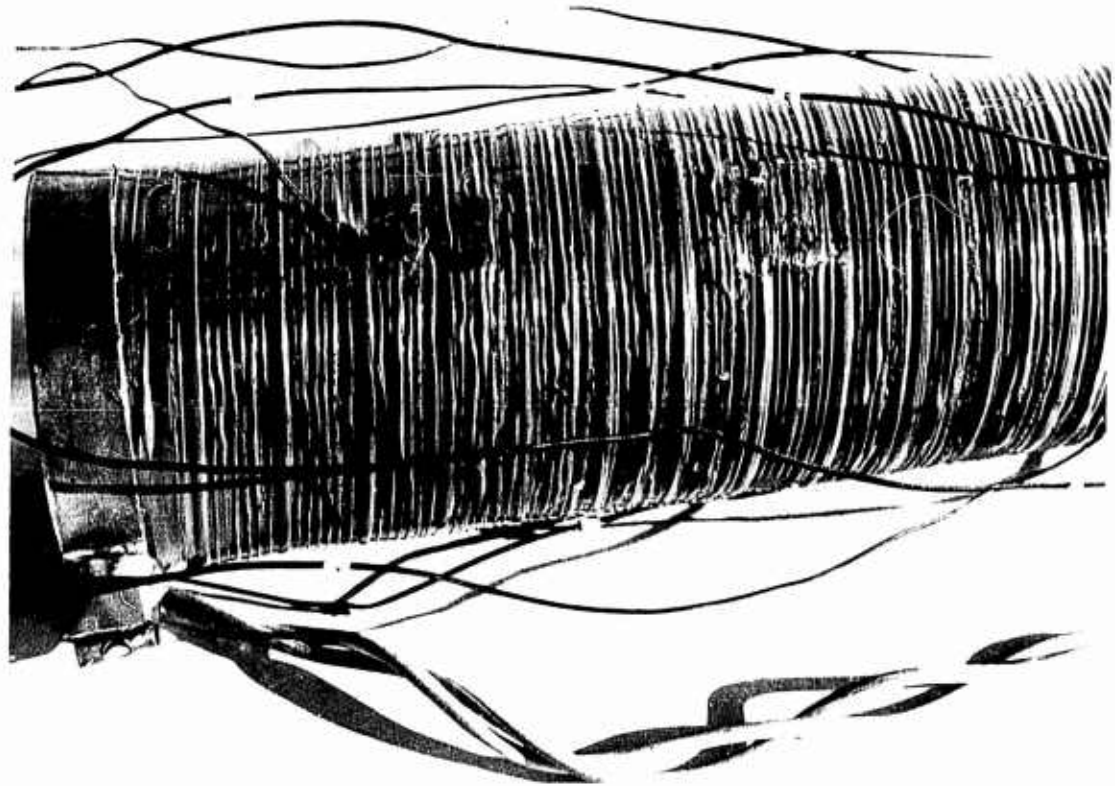


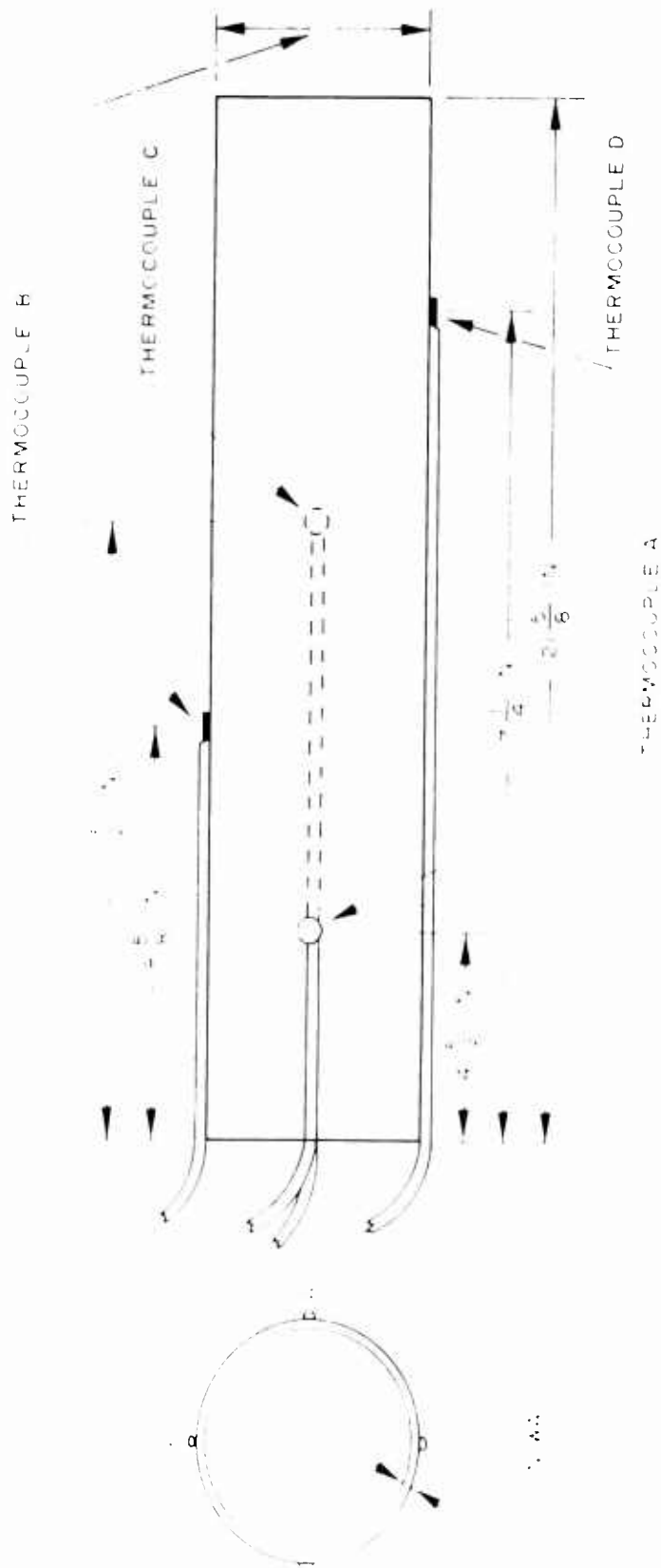
FIG. 7. Grain Showing Extrusion of Inhibitor Between Nichrome Ribbons.

motor tube having a heating element wrapped around its outside surface. Since these earlier tests demonstrated that severe inhibitor damage resulted from temperatures between 275 and 350°F, a less severe temperature versus time program was developed to determine the maximum thermal treatment a grain could withstand.

#### HEATING GRAIN IN LOOSE FITTING TUBE

Tests 10 and 11 made use of a tube machined from the sustainer section of a Sidewinder 1C motor tube. The machined wall thickness was 0.010 inch and the length was 21.58 inches. Thermocouples (No. 24 gage) were mounted along the external tube surface as shown in Fig. 8. Junctions were silver soldered to the tube by a weld in which the thermocouple junction, silver solder, and tube metal were fused together. Two layers of glass insulation were wrapped over the external tube surface and over the thermocouple wires along the tube surface (Fig. 9). This technique prevented the insulation from being

0.0 CF LARGE TUBE = 4.985 IN.  
 0.0 CF MEDIUM TUBE = 4.850 IN.  
 0.0 CF SMALL TUBE = 4.825 IN.



NOTE: WALL AND THERMO-COUPLE SIZES ARE OVERSIZE

FIG. 6 Motor-Tube Thermocouple Locations.



maintain the round shape of the thin-walled tube, copper bands were cemented tightly to the tube and partially clamped (Fig. 10). The grain and tube assembly were placed in the insulating jacket, current was regulated by a Variac, and temperatures were recorded as in previous tests, except that the temperature versus time program of Fig. 11 was chosen for use in these and later tests. The program of Fig. 11 differed from that of Fig. 5 in that the highest temperature was 275 instead of 350°F.

Using this equipment in Test 10, a grain was subjected to two cycles with the highest thermocouple reading within  $\pm 5^\circ\text{F}$  of the temperature-time program of Fig. 11. Following this test, examination of the grain

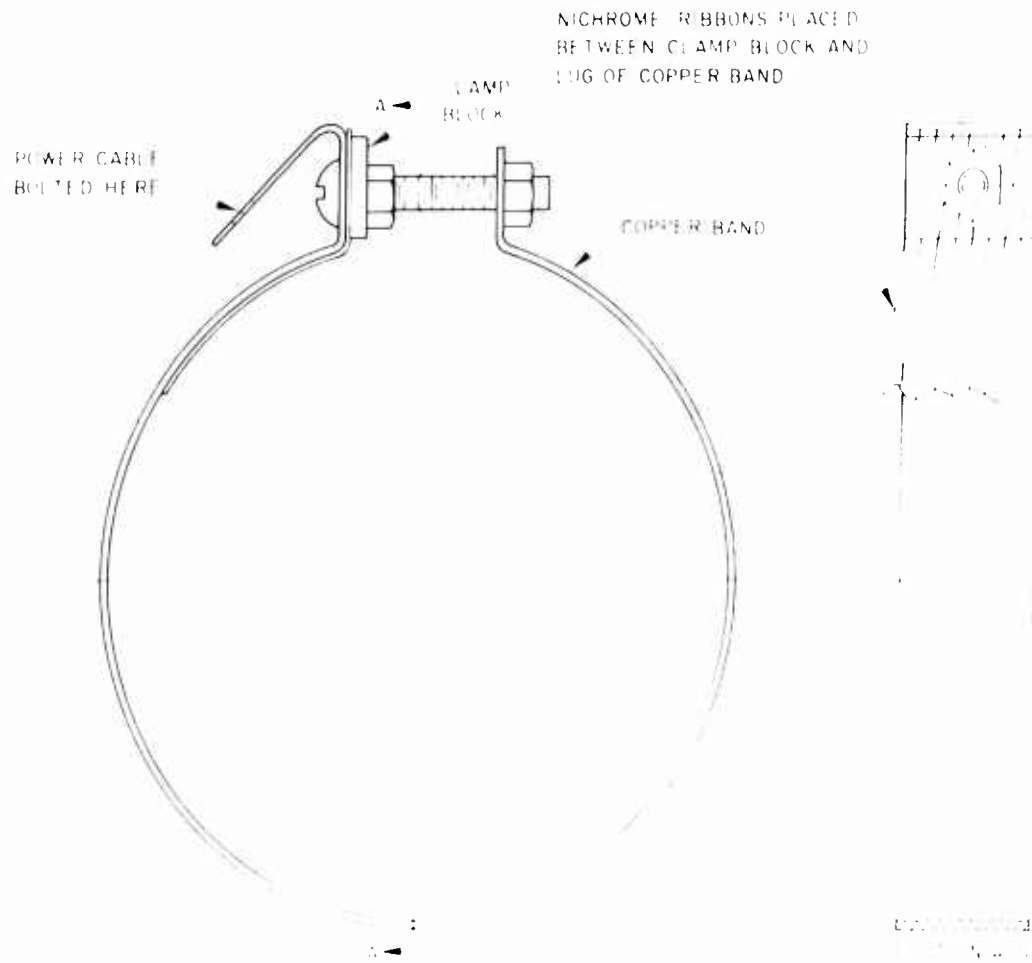


FIG. 10. Method of clamping copper bands to thin-walled tube.

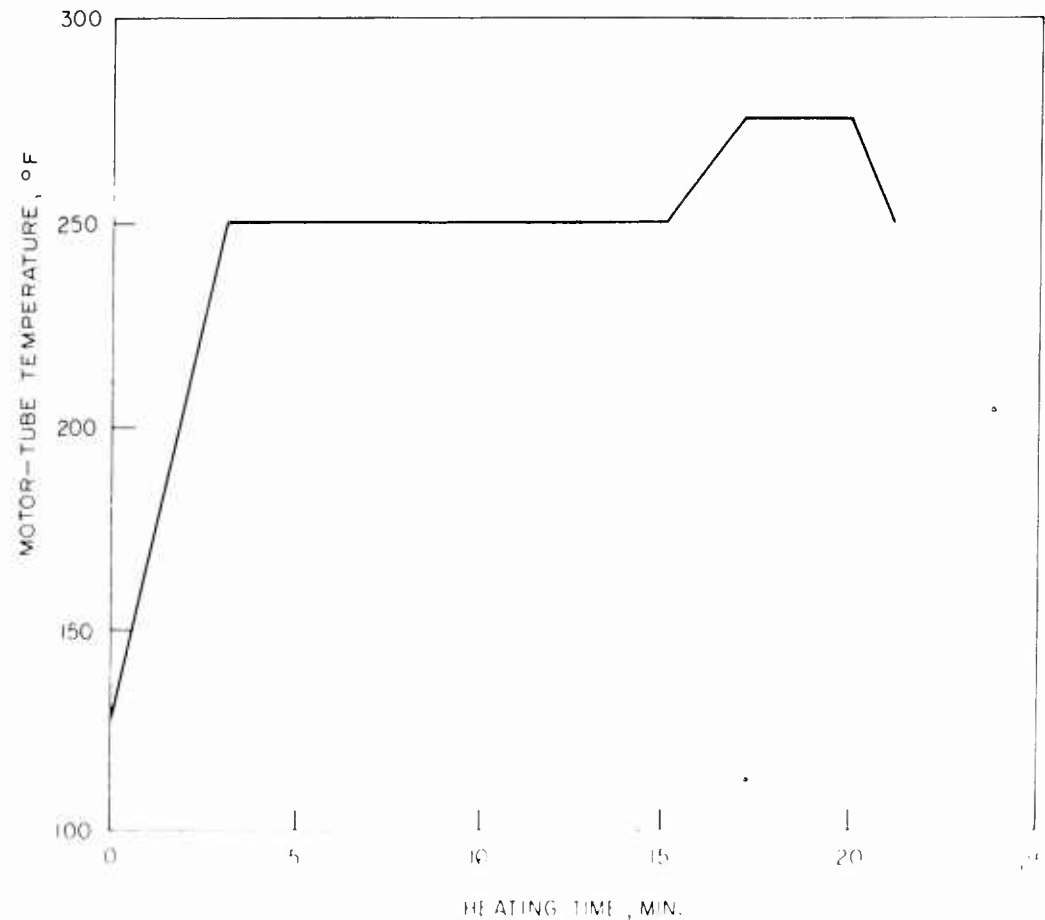


FIG. 11. Tentative Allowable Heating Cycle for the 5.0-Inch Rocket Motor Mk 24 Mod 0

revealed a group of several dozen "pock marks" on the peripheral inhibitor. These areas were  $1/8$  to  $3/16$  inch in diameter with depths between 0.003 and 0.007 inch, the majority being 0.003 inch deep.

In Test 11, the grain of Test 10 was given three full cycles repeating the Test 10 procedure. Examination of the grain revealed three types of inhibitor deterioration: pock marks, cracks, and blisters. Cracks, approximately 20, were  $1/16$  to  $5/16$  inch long, 0.006 to 0.012 inch wide, and 0.005 to 0.020 inch deep. There were 18 blisters with diameters ranging from  $1/4$  to  $3/8$  inch and heights approximately 0.015 inch above the normal surface. The pock marks and blisters are shown in Fig. 12.

Tests 10 and 11 accelerated the inhibitor aging. This was particularly emphasized after three cycles of Test 11. A review of the current demand during Test 11 indicated that the energy supplied to the system was the same as that supplied in Test 10. Table 4 summarizes

TABLE 1. Grain Measurements Before and After Tests

Item	Average grain O. D. in.	Average grain I. D. a in.	Average wall thickness, in.	Average over-all length in.	Grain weight, lb
Before Test 10...	4.8006	1.5287	1.2967	23.680	22.279
After Test 11...	4.7965	1.5305	1.2931	23.690	22.250
Difference...	0.0041	0.0018	0.0036	0.010	0.029
Before Test 12...	4.800	1.534	1.2931	23.695	22.253
After Test 12...	4.775	1.517	1.3041	23.748	22.180
Difference...	0.025	0.017	0.0110	0.053	0.073
Before Test 13...	4.801	1.530	1.2978	23.826	22.17
After Test 15...	4.778	1.534	1.2949	23.873	22.15
Difference...	0.023	0.004	0.0029	0.047	0.02

<sup>1</sup> This grain I. D. is a measurement of the distance from the bottom of a valley to the top of the diametrically opposite star point.

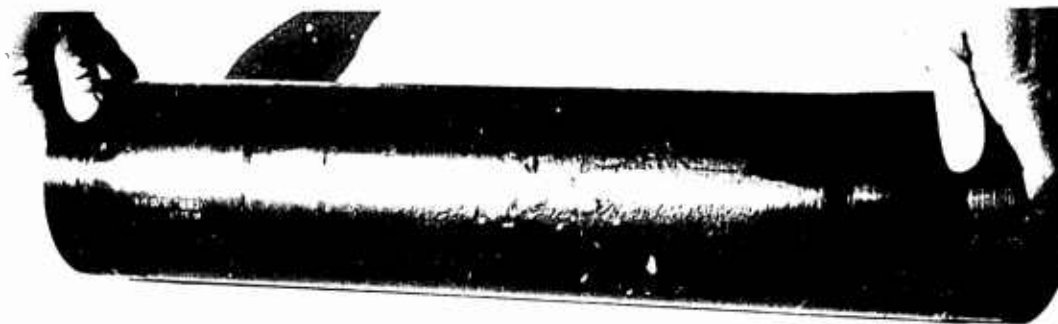


FIG. 12. Blistered and Pock Marked Side of Grain Resulting From Five Cycles.

the changes in grain dimensions resulting from the tests. Outside and inside diameters of the grain were changed little because the loose fit allowed room for thermal expansion.

#### HEATING TIGHT-FITTING GRAIN

In Test 12, a grain, having an outside diameter (O. D.) of 4.800 inches, was placed in a stainless steel tube having an inside diameter (I. D.) of 4.805 inches. The tube of Test 12 differed from that of Tests 10 and 11 in that 12 had a smaller I. D. and used 30-gage instead of 24-gage thermocouples. Wall thickness, thermocouple placement, and heating elements were the same as before. The grain was given two full cycles following the procedure of Fig. 11. Since Tests 10 and 11 indicated a heating efficiency much less than 100%, a sensing element was placed on the inside wall of the heat-insulating jacket to record wall temperature of the jacket during the test.

Table 2 shows the values of current through the heating element. Heating efficiency was obtained for each minute by squaring current values from Test 12 for that particular minute, multiplying this by 2.645 ohms (resistance) and dividing this product into the corresponding instantaneous power as given in Fig. 13. For Test 12 the average heating efficiency for the first 15 minutes of heating was 49.1%. Heat losses across the 1/2-inch air gap between the motor tube and the inner wall of the heat insulating jacket were sufficient to cause the inner wall temperature to be only 10 to 35°F lower than the grain temperature.

The information of Table 1 proved that heating the grain in the tight-fitting tube of Test 12 permanently reduced the grain outside and inside diameters, slightly reduced the weight, and slightly increased the grain length. The visual appearance of the grain showed a strange condition in its inhibitor. An area 2 inches wide by 2 1/2 inches long contained hundreds of pock marks and small pin holes with many of the

TABLE 2. Comparison of Currents in Heating Element

Time, min.	Test 10		Test 11			Test 12	
	Run 1	Run 2	Run 1	Run 2	Run 3	Run 1	Run 2
	current, amp	current, amp	current, amp	current, amp	current, amp	current, amp	current, amp
0	0	0	0	0	0	0	0
1	17.4	15.6	18.6	15.9	16.5	19.2	15.9
2	18.3	20.4	17.4	18.6	20.4	21.0	20.4
3	18.0	21.0	15.0	22.5	20.7	21.1	20.4
4	14.4	18.3	15.0	17.4	16.7	17.4	16.5
5	14.8	16.2	15.0	14.5	12.9	15.0	12.0
6	15.0	15.0	14.4	17.1	13.8	14.7	13.5
7	14.5	14.7	13.5	12.9	13.9	13.0	12.0
8	14.1	14.1	13.8	12.3	13.2	11.7	12.0
9	13.5	13.8	12.9	12.9	13.4	11.7	11.4
10	13.5	13.5	12.7	13.2	12.3	12.0	11.1
11	12.0	13.6	12.6	12.0	12.0	12.0	10.8
12	12.0	14.1	12.3	11.7	12.0	12.0	10.8
13	11.5	13.5	12.3	11.0	11.4	12.0	10.8
14	11.5	12.6	11.5	11.4	12.9	10.8	10.7
15	11.7	12.0	12.0	11.1	12.9	10.2	10.7
16	13.5	17.1	13.5	17.1	17.1	13.6	13.8
17	13.5	18.0	14.2	14.4	12.6	15.0	14.4
18	13.2	12.9	13.2	10.8	12.0	13.2	16.9
19	14.5	12.9	10.8	11.4	12.7	11.1	11.4
20	14.5	13.5	10.8	11.4	12.7	11.6	11.4
21	0	0	0	0	0	0	0

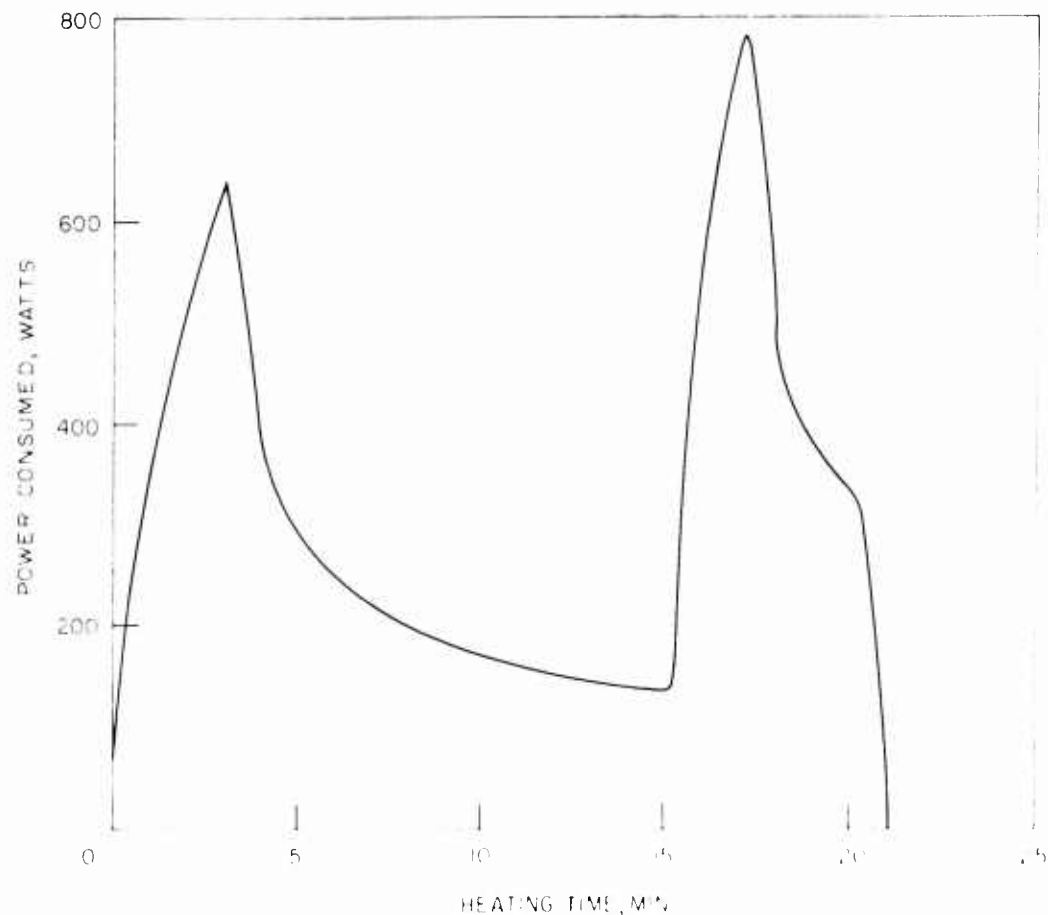


FIG. 13. Electric Power Theoretically Needed for Heating Grain

- pock marks having one or more pin holes. Pock-mark count was approximately 240 per square inch and pin-hole count approximately 800 per square inch. Pin holes were approximately 0.009 inch diameter by .010 inch deep. The condition suggested that solvent, and possibly plasticizer, evaporated out of the peripheral inhibitor causing the pock marks and pin holes.

#### TESTING OF AVERAGE FITTING GRAIN

The loosest and tightest expected fits between grain and motor tube had been used to simulate special conditions of aerodynamic heating. In Test 13, an inhibited grain having a 4.800 inch O. D. was placed in a tube having an I. D. of 4.830 inches, the tube, thermocouples, and heating element were identical to those of Test 12 except for the tube I. D. This grain was given two heating cycles in accordance with Fig. 11. Subsequent inspection showed no pock marks, cracks, pin holes, or blisters in the peripheral inhibitor. In Test 14, the grain and tube of Test 13 were reassembled as before and given three additional

heating cycles, a total of five cycles for the grain. Upon grain inspection, after Test 14, no inhibitor damage was found. Five additional heating cycles were given this assembly in Test 15, bringing the total up to 10 cycles for this grain. Inspection after 10 cycles showed blisters, cracks, and pock marks in the inhibitor outer surface. Thirty blisters had diameters ranging from 1/8 to 1/4 inch; four ranged from 1/2 to 3/4 inch diameter; and two others had areas approximately 1 1/2 to 2 1/2 square inches. Heights of blisters ranged between 0.015 and 0.040 inch. Pock mark diameters were 1/32 to 3/16 inch, depths 0.001 to 0.005, and distribution about 50 to the square inch in the affected areas. The inhibitor also contained several hundred cracks 0.003 to 0.031 inch wide, 1/32 to 3/8 inch long, and 0.001 to 0.040 inch deep. Only four or five cracks had the larger dimensions. (Note in Table 2 that the grain O. D. and length changed during the test.)

## SUMMARY OF RESULTS

### GRAIN DIMENSIONAL CHANGE AND ITS IMPORTANCE

Reduction of O. D. and increase of length resulting after Tests 12 and 15 were caused when the motor tube limited radial expansion of the grain. This resulted in a permanently decreased O. D. and increased grain length. For large diameter grains initially fitted in motor tubes, O. D. and I. D. decreased and length increased. A conclusion is that a Sidewinder IC motor carried by a plane cruising for unusually long periods at higher speeds would produce grain dimensional changes. This would warrant further study in areas of safety and ballistic performance of the missile.

### TIGHTNESS OF FIT AND INHIBITOR DAMAGE

The fit of the grain in the tube appeared to have little effect on inhibitor damage caused by aerodynamic heating. Inhibitor damage occurred no matter what the degree of fit.

### AERODYNAMIC HEATING AND INHIBITOR DETERIORATION

Results of Test 10 (Table 2) indicated no inhibitor deterioration to be continuous under temperature cycling. The effects were initially not observable but became obvious after several cycles with deterioration appearing suddenly. It is not possible to make a comparison of the grain's condition from 25 to 70 F. and structure from the tube. At high temperatures, certain areas of the inhibitor deteriorated the inside surface of the grain, but the inhibitor deteriorated only on the outside between 25 and 70 F. The grain was not damaged by the

Pock marks and pin holes probably formed as solvent boiled or evaporated. Existence of cracks after the last five cycles of Test 15 suggested that repeated heating and cooling resulted in a dried out, and less resilient, aged inhibitor.

#### CONCLUSIONS AND RECOMMENDATIONS

The tests of this study have shown that the grain withstood 10 of the cycles of Fig. 11 without cook-off or autoignition, and without causing damage to the inhibitor sufficiently to expose the propellant. Ten cycles, however, probably resulted in a marginal grain, perhaps unacceptable from the standpoint of unbonded area. Bonding requirement drawings for the sustainer grain of a Sidewinder 1C have specified that no single unbonded area be greater than 1 1/2 square inches.

The thin-walled tube and nichrome heating element used in these tests enabled an aerodynamic-heating study, using a maximum of 30 amperes, to get the required heating rates. Application of this method for studying liner deterioration when heating either short sections or scaled-down models of larger missiles appears to be possible.

It is recommended that a heat-barrier material be applied to the external surface of a motor for use where temperatures reach 275° F or higher. Application of a thin coating of Teflon, or equivalent, to the inner surface of a motor-tube wall would prevent the grain inhibitor from adhering to the tube. An environmental test program should be undertaken in which several grains subjected to a series of heating cycles could be fired in motors to evaluate effects of aerodynamic heating on ballistic performance.

#### NEGATIVE NUMBERS OF ILLUSTRATIONS

Fig. 1(a), None; Fig. 1(b), L054112; Fig. 1(c), L054116;  
Fig. 1(d), L054117; Fig. 1(e), L054118; Fig. 2, None;  
Fig. 3, None; Fig. 4, L050337; Fig. 5, None; Fig. 6,  
None; Fig. 7, L050955; Fig. 8, None; Fig. 9, None;  
Fig. 10, None; Fig. 11, None; Fig. 12, L054198.

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ABSTRACT CARD

U. S. Naval Ordnance Test Station  
Effect of Aerodynamic-Heating Simulation on  
Mark 24 Sidewinder IC Sustainer Grains by W. W.  
Boyle. China Lake, Calif., NOTS, September 1962.  
22 pp. (NAVWEPS Report 7905, NOTS TP 2912),  
UNCLASSIFIED.

ABSTRACT. Sidewinder IC sustainer grains were given aerodynamic-heating cycles to determine damaging effects on the propellant and its peripheral inhibitor. Propellant grains were heated in a thin-walled motor tube having a nichrome-ribbon heating element on its outer surface. Ethyl cellulose

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inhibitor on the propellant grain proved to be most susceptible to degradation. Cracks in the inhibitor and large unbonded areas developed after five to ten mission cycles. A mission cycle consisted of increasing the skin temperature from 130 to 250°F in 3 minutes, remaining at 250°F for 12 minutes, rising from 250 to 275°F in 2 minutes, then remaining at 275°F for 3 minutes followed by cooling to 130°F.

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NAWWEPS Report 7905

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