NRL REPORT NO. E-3095

FR-3095

ELECTRICALLY INDUCED HEATING OF 20-MM AIRCRAFT MACHINE GUN

by

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June 1947

Problem no. E03-01

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CONTENTS

ABSTRACT

Tests were conducted to determine the feasibility of induction heating of the 20-mm aircraft machine gun Type M-3. Comparisons of the induction heater with a resistance heater indicate:

1. A 2000-watt induction heater will be needed at an ambient temperature of -30° C if there is an air blast through the gun barrel, and a 500-watt heater will be needed if the air blast is eliminated.

2. A 650-watt resistance heater in the present position for the T-2 heater should be sufficient at -30° C, provided the air blast is eliminated.

3. For a given power input to the heater element, the induction heater produced a more even heat distribution and a greater temperature rise in the gun than the resistance heater, except in the immediate vicinity of the resistance heater.

4. For either type of heater, it is essential that the air blast through the gun barrel be eliminated. If this is not possible, at least a muzzle cap should be used, and the pilot should delay firing his test burst as long as operationally possible.

AUTHORIZATION

The work done on this project was authorized by BuAer letter to NRL, Aer-AR-25, Serial No. 62250, dated 26 August 1946. Subject TED Project No. NRL AR-2502, Electricity Induced Heating of Guns.

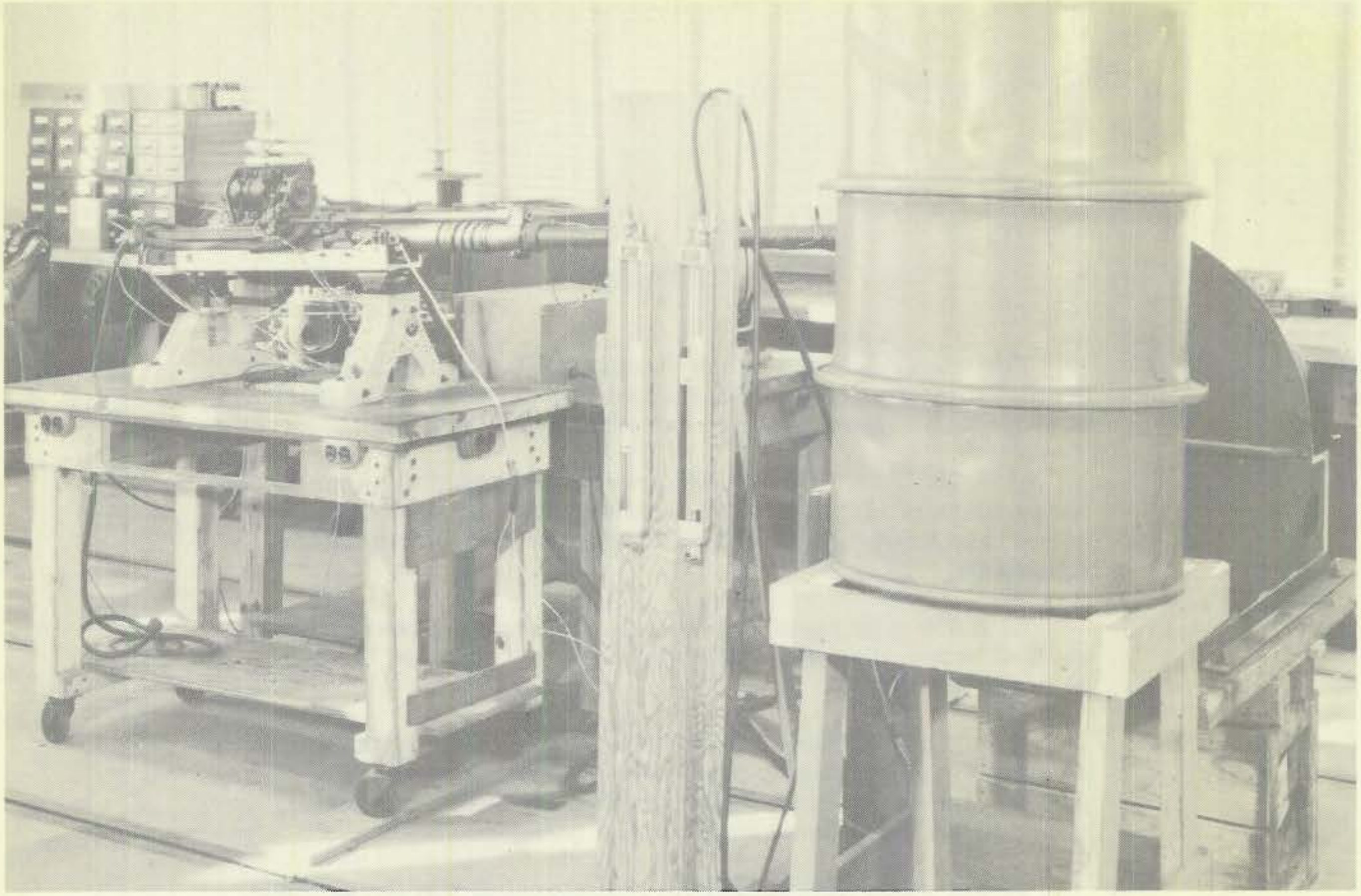
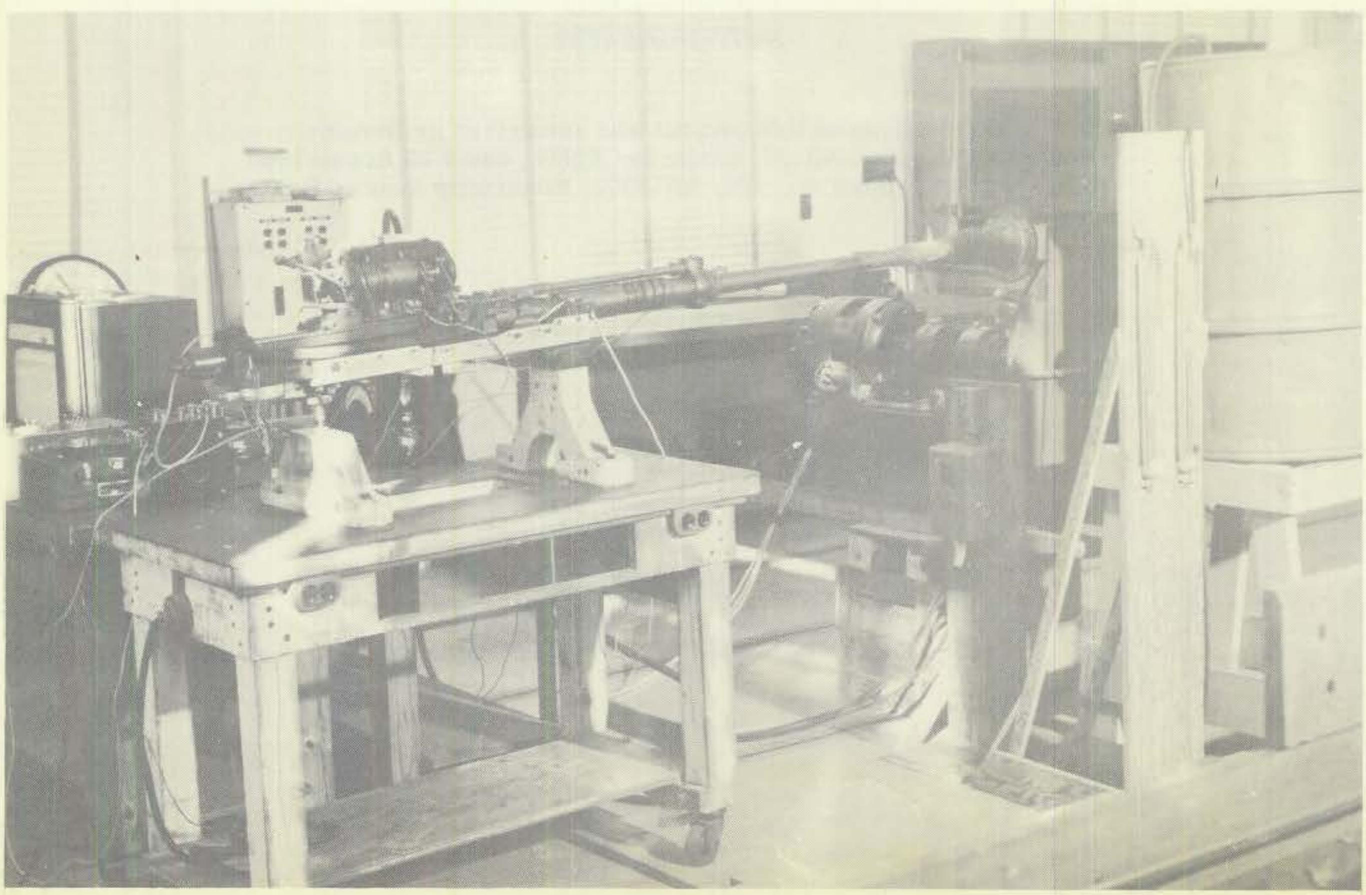


Fig. 1 General View of Experimental Setup (Right Front View)

Fig. 2 General View of Experimental Setup (Right Rear View)



ELECTRICALLY INDUCED HEATING OF 20-MM AIRCRAFT MACHINE GUN

INTRODUCTION

1. The purpose of this test was to investigate the practicability of heating the standard 20-mm aircraft machine gun (M-3) by high-frequency alternating current. At the same time, comparative tests were run using other types of heaters in order to determine their relative efficiencies.

EXPERIMENTAL PROCEDURE

2. The machine gun was mounted and equipped to simulate operating conditions as nearly as possible. The setup included hydraulic charging equipment, standard T-2 type resistance heater, dummy shells, and a high-pressure blower to simulate the air blast through the gun barrel under flight conditions.

3. Figures 1 and 2 give a general view of the setup used for preliminary tests at room temperature. Figure 3 shows the instrumentation used, consisting of current-, voltage-, power-, frequency-, and temperature-measuring instruments. Figure 4 shows the high-pressure blower used to produce the air blast through the gun barrel. A similar setup was made for the low-ambient temperature tests, with the gun, blower, and air-input-metering drum placed inside the weather chamber, and all instruments and controls placed outside the chamber.

4. The air input was determined by measuring the pressure difference across a two-inch diameter orifice in the top of the orifice drum. Since the orifice had been calibrated previously, this measurement, plus the barometric and temperature conditions, was sufficient to permit calculating the pounds of air per hour through the gun barrel.

5. Temperatures at various points in the gun were recorded by copper-constantan thermocouples connected to a Brown recording potentiometer Model No. 153 X62 P12-X-26. The positions of the thermocouples are listed in Table 1.

6. The a-c power was supplied by an 8-kw, 115-volt, single-phase, 800-cps aircraft alternator, Type 1474X, manufactured by the Bendix Aviation Corporation. The field of the alternator was separately excited from a 30-volt d-c supply. The electrical circuit used for the induction heater is shown in Figure 5.

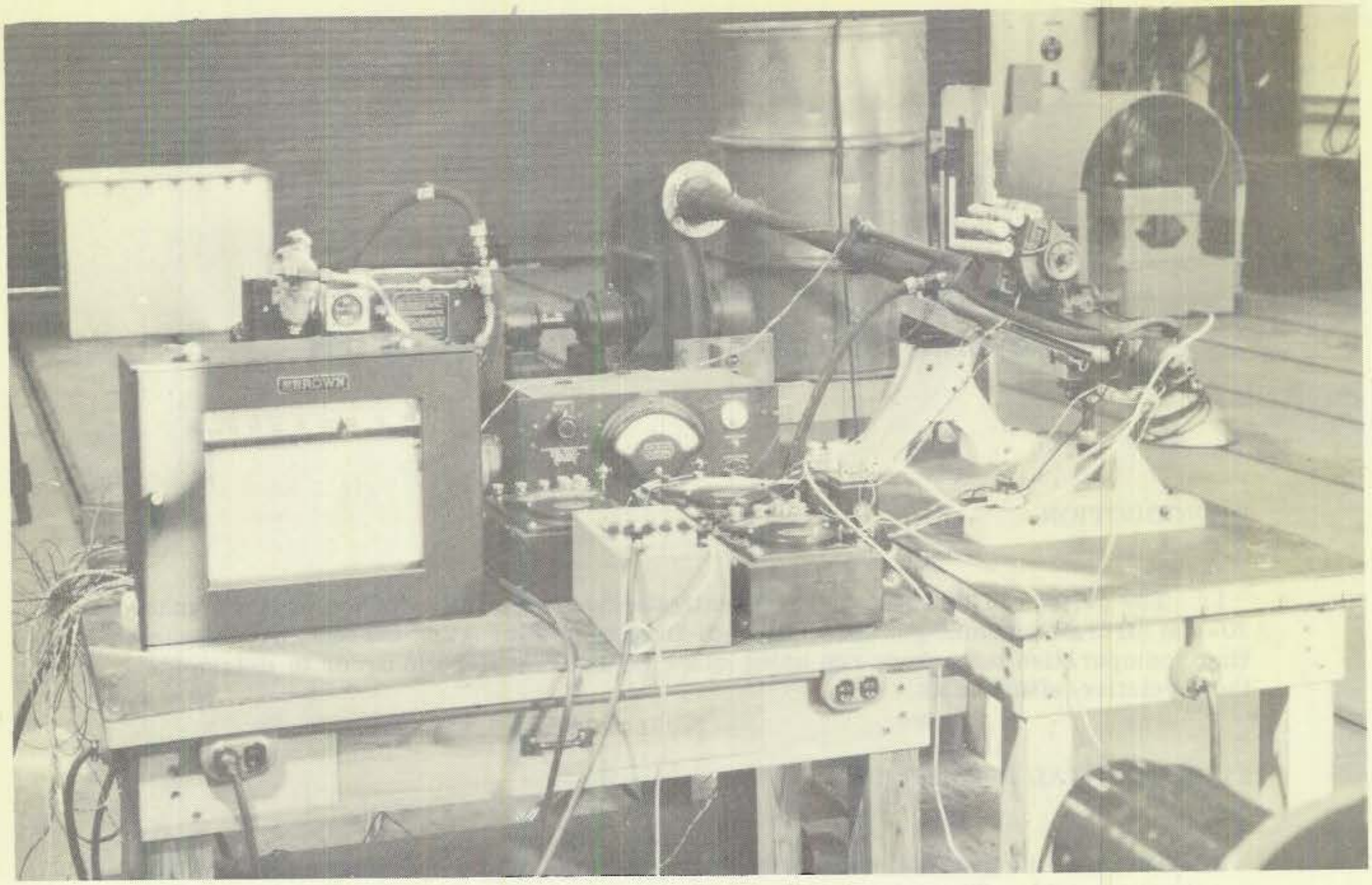
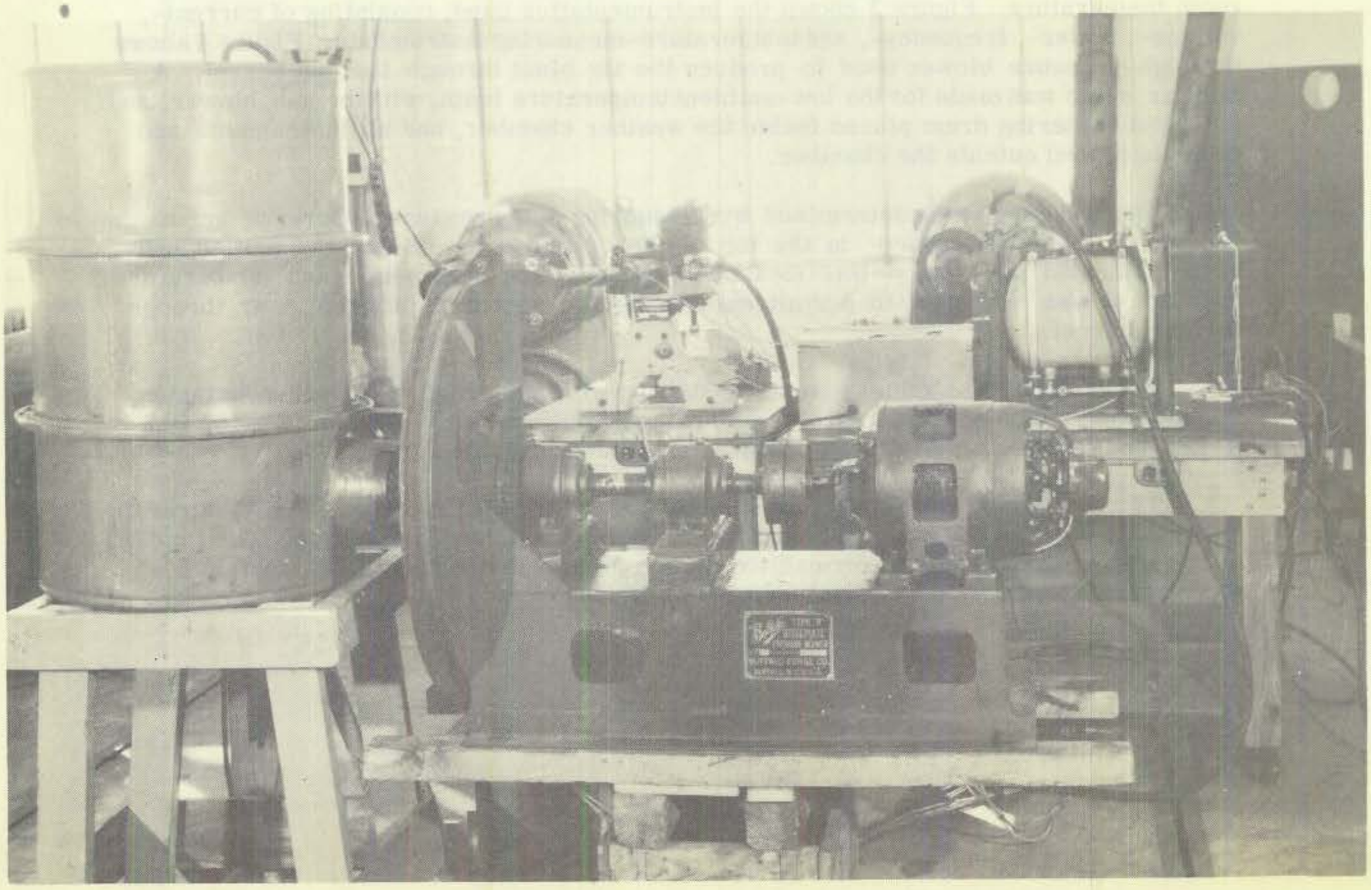


Fig. 3 General View of Experimental Setup (Rear View)

Fig. 4 General View of Experimental Setup (Front View)



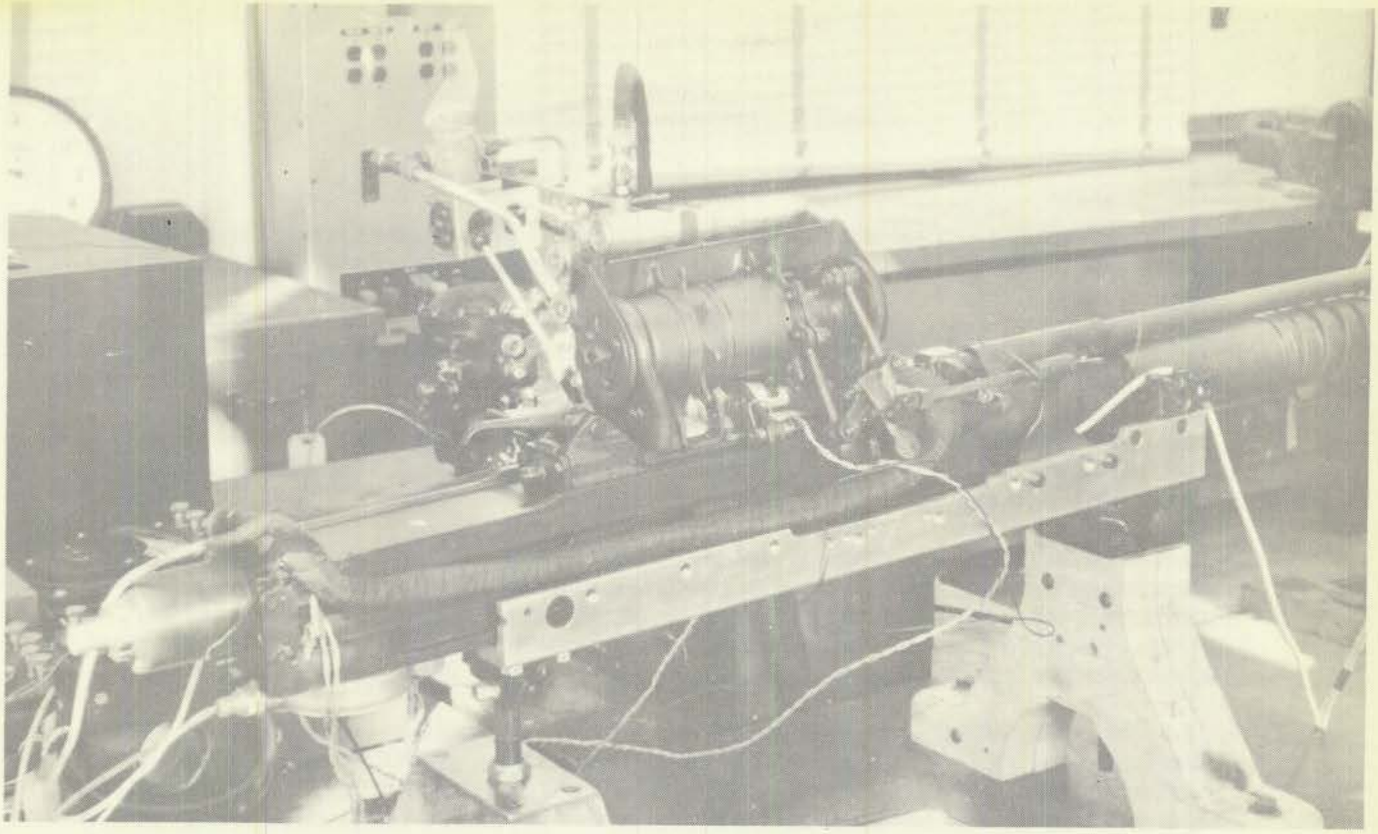
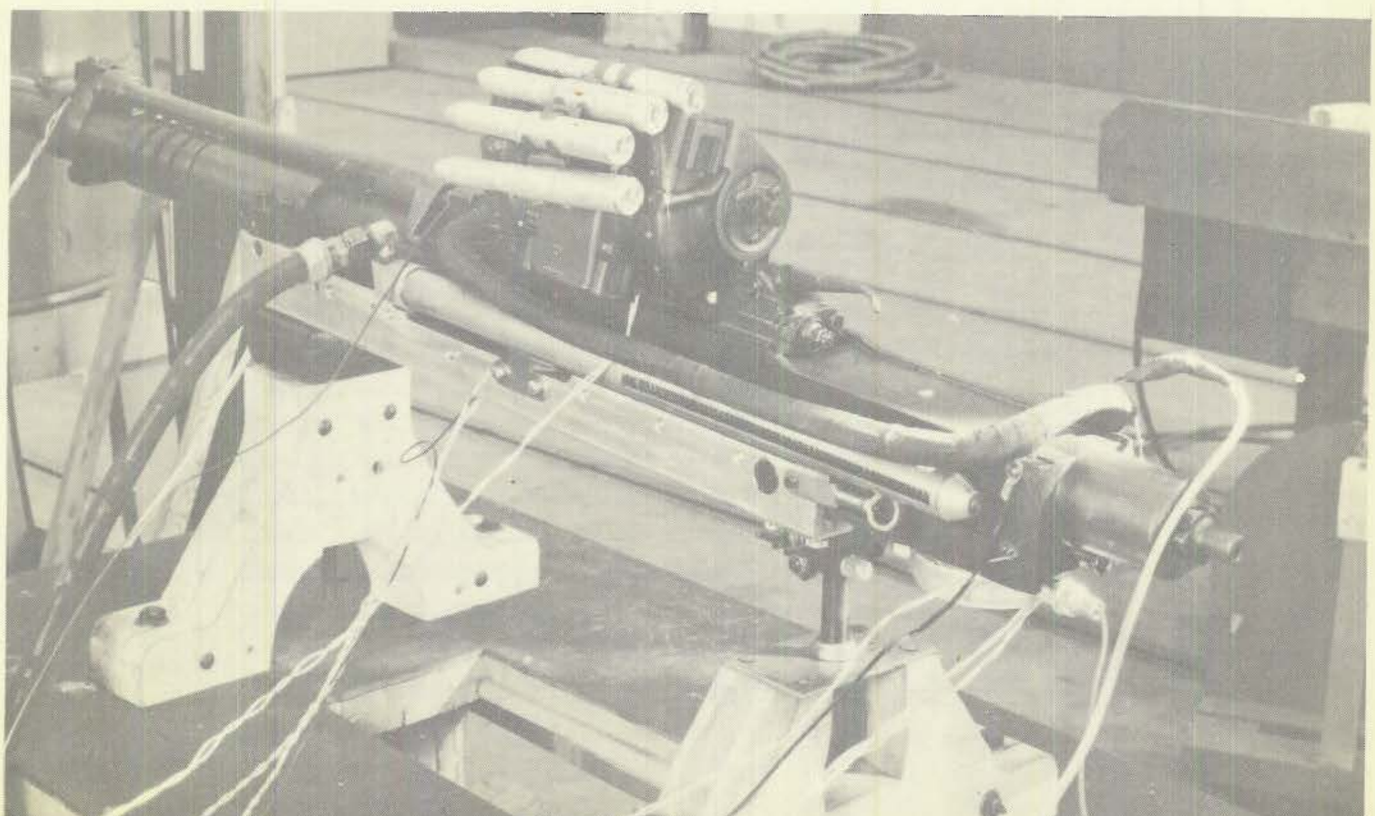


Fig. 6 Close-up of Gun Showing Induction Coil
(Right Rear View)

Fig. 7. Close-up of Gun Showing Induction Coil
(Left Rear View)



10. Tests of the central coil to determine the effect of frequency upon heating were made at 600, 800, and 1000 cps using 650 watts of power for 30 minutes with the air blast.

11. For comparison purposes, one test was made using 650 watts of 800-cps a-c power for 30 minutes without the air blast.

12. One test, to determine the effect of ambient temperature, was run with the air blast and 800 watts of 800-cps a-c power for comparison with a later identical test at -40°C. (See Table 3).

13. Preliminary tests were also run on several proposed methods of heating the gun. These tests consisted of: (1) passing large direct currents through the gun itself, (2) using resistance heaters placed on the exterior surface of the gun, and (3) using the present standard T-2 resistance heater installed on the gun. Except for the T-2 heater, no data were recorded; however, the general observations will be discussed below.

14. The gun was then placed in a chamber where low ambient temperatures could be maintained. With the gun and chamber initially stabilized at -40° C and using 800-cps a-c power, tests were run with 800, 1200 and 1600 watts for 60 minutes each. Temperature readings of each thermocouple were taken at five-minute intervals (see Tables 4, 5 and 6). The maximum air blast available (approximately 380 pounds per hour), using the air in the chamber, was forced through the gun barrel during these tests.

TABLE 3

EFFECT OF INDUCTION HEATER
(WITH AIR BLAST THROUGH GUN BARREL)

800 Watts - 800 Cycles/sec.
Ambient Temperature = +19°C.

Time (Min.)	GUN TEMPERATURE IN °C.								
	Rear of Bolt	Front of Bolt	Alum. Base	Inside of Recvr.	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0	19.0
5	30.0	27.5	25.0	25.5	30.5	40.0	28.5	36.0	31.5
10	35.0	33.0	27.5	29.0	37.5	52.0	34.0	40.0	35.5
15	38.5	36.0	30.0	32.0	41.0	58.0	37.0	41.5	36.5
20	41.5	37.5	30.0	32.5	43.0	61.0	38.0	43.0	38.0
25	44.0	39.5	30.0	33.0	45.0	64.0	38.5	44.0	38.0
30	45.0	39.5	30.0	33.0	47.0	66.0	38.5	44.5	38.5
35	46.0	39.5	30.0	33.5	48.0	67.0	39.0	45.0	38.5
40	46.5	39.5	30.0	33.5	48.5	67.5	39.5	45.0	38.5
45	47.0	39.5	30.0	34.0	49.0	67.5	39.5	45.0	38.5
50	48.0	39.5	30.5	34.0	49.0	67.5	40.0	45.5	39.0
55	48.5	39.5	30.5	34.5	50.0	68.0	40.0	46.0	40.0
60	49.0	39.5	30.5	35.0	50.0	68.0	40.0	46.0	40.0

TABLE 1

LOCATION OF THERMOCOUPLES

Rear of Bolt* -	small hole was drilled in lower right-hand corner of rear end of bolt and thermocouple was inserted from rear so junction was approximately 1/2 inch from rear of bolt block and 1/8 inch from side and bottom surfaces of bolt.
Front of Bolt* -	small vertical hole was drilled from top on right-hand side of bolt near forward end of bolt, and thermocouple was inserted so junction was approximately opposite center of bolt face on right-hand side, and 1/8 inch behind face.
Aluminum Base -	under bolt head approximately in center of aluminum base block on left-hand side of gun.
Inside Receiver* -	under bolt on inside of right-hand side of receiver and approximately centered under cartridge feed mechanism.
Rear of Receiver -	under bolt on outside extreme rear of lower left-hand side of receiver block.
Rear of Barrel -	under nut at rear of gas cylinder guide.
Upper Cartridge - Chute	held against inside of metal frame for cartridge feed mechanism and approximately 2 inches above base.
Lower Cartridge* Chute	on right-hand side between lower face of feed mechanism throat block and upper surface of magazine slide, and in approximate center of feed mechanism.
Air in Muzzle -	projecting downward at extreme forward end of barrel so that junction was held in approximate center of gun bore, and about 4 inches in front of end of barrel.

* Considered to be the most critical points for gun operation.

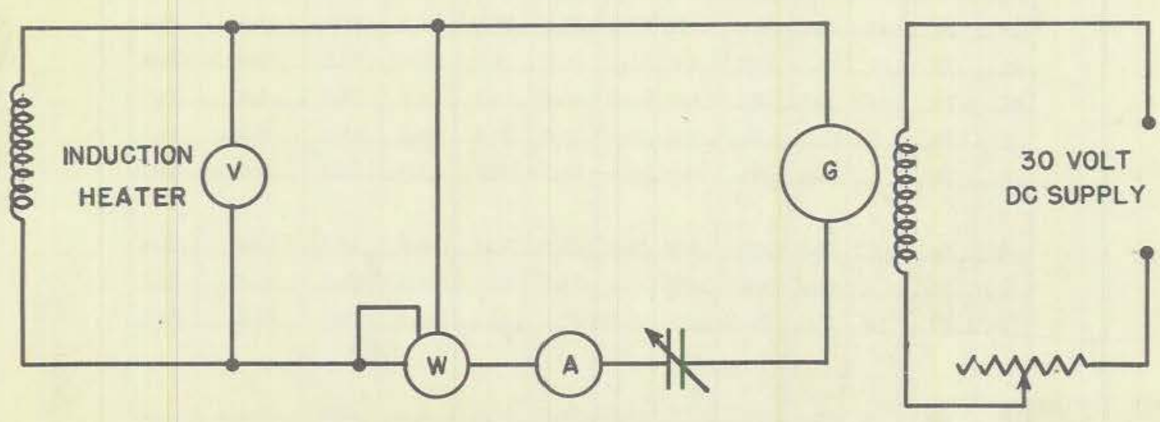


Fig. 5 Circuit Diagram for Induction Heater Test

7. Preliminary tests were conducted at room temperature to determine the best coil arrangement for obtaining the maximum temperature rise at the most important locations in the gun for a given power input of 800-cps alternating current. Coils equipped with taps were placed around the rear portion of the receiver and the rear portion of the barrel so that the axes of the coils coincided with the longitudinal axis of the gun. A third coil was placed around the cartridge chute with the coil axis at right angles to the longitudinal axis of the gun. These coils were connected in series. Various combinations of the number of turns used on each were selected by changing the tap connections. The coils were always connected in such a manner that, for an assumed direction of current flow, the magnetic fluxes produced by the forward and rear coils would be toward the center of the gun, and those produced by the center coil would be upward. In all tests, the active power (wattmeter reading) was kept constant at 650 watts (regardless of current and voltage), and the temperature rise at various points throughout the gun was determined after 30 minutes.

8. The maximum available air blast, approximately 380 pounds per hour, was used at all times (see Table 2). It is understood that an airframe manufacturer determined the air flow to be 450 pounds per hour at an airspeed of 550 miles per hour.

9. From these tests it was decided that a single elongated, flat, horizontal, central coil of 40 turns located on the upper portion of the receiver gave optimum results. This arrangement was therefore used in all subsequent tests. (See Figures 6 and 7).

TABLE 2

EFFECT OF LOCATION AND NUMBER OF TURNS
OF INDUCTION HEATING COIL ON GUN TEMPERATURE

Time - 30 minutes
Power - 650 watts
Ambient Temperature - +20°C.
Air Blast - Approximately 380 lbs./hr.

NO. OF TURNS			AMP.	VOLTS	FREQ.	GUN TEMPERATURE RISE IN °C.						
Rear Coil	Center Coil	Fwd. Coil				Rear of Bolt	Front of Bolt	Inside of Recvr.	Rear of Recvr.	Rear of Barrel	Lower Cartridge Chute	Air in Muzzle
82	15	82	8.0	207	800	33.5	13.0	6.0	32.0	40.0	6.5	18.5
82	0	82	9.0	204	800	35.0	12.0	2.0	35.5	43.5	3.0	18.0
0	15	82	11.8	118	800	10.0	12.5	11.0	6.0	46.0	10.0	12.5
82	15	0	10.0	173	800	50.5	15.0	4.0	52.0	5.0	6.5	17.0
45	15	45	13.3	120	800	38.5	17.5	8.0	32.5	43.0	9.5	17.0
45	15	82	10.3	152	800	21.0	11.0	5.5	16.0	59.5	5.5	13.0
82	15	45	9.3	182	800	44.0	24.0	5.0	44.0	19.0	6.0	16.0
0	30	0	21.2	80	800	25.0	19.0	18.5	16.5	24.0	18.5	19.5
0	40	0	15.4	138	800	25.5	16.0	19.0	25.5	22.5	19.5	20.0
0	40	0	17.3	122	600	21.5	14.5	18.0	21.0	19.5	20.0	18.5
0	40	0	15.4	138	800	25.5	16.0	19.0	25.5	22.5	19.5	20.0
0	40	0	14.2	150	1000	33.0	23.0	26.5	30.0	28.0	24.0	24.0
0*	40	0	15.4	138	800	52.0	45.0	57.0	41.0	41.0	58.0	.5

* No air blast through barrel.

TABLE 4

EFFECT OF INDUCTION HEATER
(WITH AIR BLAST THROUGH GUN BARREL)

800 Watts - 800 Cycles/sec.
Ambient Temperature = -40°C

Time (Min.)	GUN TEMPERATURE IN °C.								
	Rear of Bolt	Front of Bolt	Alum. Base	Inside of Recvr.	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	-38.0	-39.5	-39.5	-38.5	-39.5	-39.5	-39.5	-40.0	-38.0
5	-25.0	-28.0	-33.0	-27.5	-29.0	-28.0	-26.0	-27.0	-24.0
10	-16.5	-24.0	-30.0	-22.0	-20.0	-20.5	-20.5	-22.0	-18.5
15	-12.5	-21.5	-28.0	-20.0	-15.0	-15.5	-18.5	-19.5	-17.0
20	- 9.5	-20.0	-27.0	-18.0	-11.0	-13.0	-17.5	-18.0	-16.0
25	- 7.5	-19.0	-26.0	-17.0	- 8.5	-10.0	-17.0	-17.0	-15.0
30	- 6.5	-18.5	-26.0	-17.0	- 7.5	- 9.0	-16.5	-17.0	-15.0
35	- 6.0	-17.5	-25.5	-17.0	- 6.5	- 8.0	-16.5	-16.5	-15.0
40	- 5.0	-17.5	-25.5	-16.5	- 5.5	- 7.0	-16.5	-16.5	-14.5
45	- 5.0	-17.5	-25.5	-16.5	- 5.5	- 7.0	-16.5	-17.0	-14.5
50	- 5.0	-17.5	-25.0	-16.0	- 5.0	- 6.5	-16.5	-17.0	-14.5
55	- 5.0	-17.5	-25.0	-16.0	- 5.0	- 6.5	-16.5	-16.5	-14.5
60	- 5.0	-17.5	-25.0	-16.0	- 5.0	- 6.5	-16.5	-16.5	-14.5

TABLE 5

EFFECT OF INDUCTION HEATER
(WITH AIR BLAST THROUGH GUN BARREL)

1200 Watts - 800 Cycles/sec.
Ambient Temperature = -40°C.

Time (Min.)	GUN TEMPERATURE IN °C.								
	Rear of Bolt	Front of Bolt	Alum. Base	Inside of Recvr.	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	-41.0	-41.0	-41.0	-41.0	-41.0	-41.0	-41.0	-40.5	-37.5
5	-23.0	-28.0	-31.0	-24.5	-25.5	-22.5	-22.0	-23.5	-23.0
10	-11.0	-23.0	-27.0	-19.0	-14.0	-12.0	-13.5	-16.0	-20.0
15	- 4.0	-20.0	-25.0	-16.0	- 6.5	- 6.0	-11.0	-13.0	-17.5
20	- 1.0	-18.5	-24.0	-14.0	- 1.5	- 4.0	-10.5	-11.5	-17.0
25	+ 1.0	-17.5	-23.0	-13.0	+ 1.0	- 1.5	- 9.0	-11.0	-16.0
30	+ 2.5	-17.0	-22.0	-12.0	+ 3.5	0.0	- 9.0	-10.5	-15.5
35	+ 4.0	-16.5	-22.0	-12.0	+ 5.0	+ 1.0	- 8.0	-10.0	-15.5
40	+ 4.0	-16.0	-22.0	-11.5	+ 5.5	+ 1.0	- 8.0	-10.0	-15.5
45	+ 4.5	-16.0	-22.0	-11.0	+ 6.0	+ 1.0	- 8.0	-10.0	-15.5
50	+ 4.5	-16.0	-21.0	-11.0	+ 7.0	+ 2.0	- 7.5	- 9.5	-15.0
55	+ 5.0	-15.5	-20.0	-11.0	+ 7.0	+ 2.0	- 7.0	-10.0	-15.0
60	+ 5.0	-15.5	-20.0	-11.0	+ 7.5	+ 2.5	- 7.0	- 9.5	-15.0

TABLE 6

EFFECT OF INDUCTION HEATER
(WITH AIR BLAST THROUGH GUN BARREL)

1600 Watts - 800 Cycles/sec.
Ambient Temperature = -40°C.

Time (Min.)	GUN TEMPERATURE IN °C.								
	Rear of Bolt	Front of Bolt	Alum. Base.	Inside of Recvr.	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
5	-15.5	-27.5	-27.5	-19.5	-20.0	-15.5	-15.0	-16.0	-27.5
10	- 3.0	-21.5	-22.5	-11.5	- 6.0	- 4.5	- 7.0	- 9.5	-21.5
15	+ 3.5	-18.0	-20.0	- 8.0	+ 2.5	+ 3.0	- 4.0	- 6.0	-18.5
20	+ 8.0	-16.5	-19.0	- 6.0	+ 7.5	+ 6.5	- 3.0	- 4.0	-17.5
25	+10.0	-15.0	-18.0	- 5.0	+11.5	+ 8.5	- 2.0	- 2.5	-16.5
30	+12.0	-14.5	-17.0	- 4.0	+14.0	+10.0	- 1.0	- 2.0	-15.5
35	+13.5	-13.0	-16.0	- 4.0	+16.0	+11.0	0.0	- 1.5	-14.0
40	+14.5	-12.5	-15.0	- 3.5	+17.0	+12.5	+ .5	- 1.0	-11.5
45	+15.5	-12.0	-14.0	- 3.0	+17.5	+13.5	+ .5	- 1.0	-11.0
50	+15.5	-12.0	-14.0	- 2.5	+18.0	+14.0	+ .5	- 1.0	-12.0
55	+15.5	-12.0	-14.0	- 2.0	+18.5	+14.0	+ .5	0.0	-13.0
60	+15.5	-12.0	-14.0	- 2.0	+19.0	+14.0	+ .5	0.0	-14.0

15. A similar test was run using 800 watts of 400-cps a-c power (see Table 7).

TABLE 7

EFFECT OF INDUCTION HEATER
(WITH AIR BLAST THROUGH GUN BARREL)

800 Watts - 400 Cycles/sec.
Ambient Temperature = -40°C.

Time (Min.)	GUN TEMPERATURE IN °C.								
	Rear of Bolt	Front of Bolt	Alum. Base	Inside of Recvr.	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	-40.0	-39.0	-43.0	-49.0	-42.0	-42.0	-42.0	-50.0	-28.0
5	-32.5	-34.0	-41.0	-42.0	-34.0	-27.5	-32.0	-44.5	-26.0
10	-26.0	-30.5	-36.0	-37.0	-27.0	-20.0	-27.0	-41.5	-23.5
15	-22.0	-27.5	-34.0	-34.0	-22.0	-15.0	-23.0	-39.0	-21.0
20	-18.5	-25.5	-31.0	-31.5	-18.0	-12.0	-20.0	-37.0	-19.0
25	-16.0	-23.0	-29.0	-29.5	-15.0	- 8.5	-18.0	-36.5	-17.0
30	-14.5	-22.5	-29.0	-29.5	-13.0	- 7.0	-17.5	-36.5	-16.0
35	-13.5	-22.0	-29.0	-29.0	-12.0	- 5.5	-17.0	-36.5	-15.0
40	-13.0	-21.5	-28.5	-29.0	-11.0	- 5.0	-17.0	-36.5	-14.5
45	-12.5	-21.5	-28.5	-29.0	-11.0	- 4.5	-17.0	-37.0	-14.5
50	-12.5	-22.0	-28.5	-29.0	-10.5	- 4.0	-16.5	-36.5	-14.5
55	-12.5	-21.5	-28.5	-29.0	-10.5	- 4.0	-16.5	-37.0	-14.5
60	-12.5	-22.0	-28.5	-29.0	-10.5	- 4.0	-16.5	-37.0	-14.5

16. **Similar tests were made without the air blast using 400 and 800 watts of 800-cps a-c power (see Tables 8 and 9).**

TABLE 8

EFFECT OF INDUCTION HEATER
(NO AIR BLAST THROUGH GUN BARREL)

400 Watts - 800 Cycles/sec.
Ambient Temperature = -40°C.

Time (Min.)	GUN TEMPERATURE IN °C.								
	Rear of Bolt	Front of Bolt	Alum. Base	Inside of Recvr.	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0	-40.0
5	-31.5	-35.0	-38.0	-33.5	-34.0	-31.0	-32.0	-32.0	-38.5
10	-25.0	-29.5	-35.0	-27.5	-29.0	-26.0	-28.0	-25.0	-38.0
15	-17.5	-24.5	-32.5	-21.0	-23.5	-20.5	-24.5	-17.5	-38.0
20	-13.0	-21.0	-31.0	-17.0	-20.0	-18.5	-22.0	-13.0	-37.5
25	- 9.0	-18.0	-29.5	-13.5	-17.0	-16.0	-20.5	-10.0	-37.0
30	- 6.0	-14.5	-28.5	-11.5	-14.5	-14.5	-19.5	- 7.5	-37.0
35	- 2.5	-11.5	-27.5	-10.0	-12.0	-13.0	-18.0	- 6.0	-37.0
40	0.0	- 9.5	-27.0	- 9.0	-11.0	-11.5	-18.0	- 4.5	-37.0
45	+ 2.0	- 7.5	-27.0	- 7.5	- 9.0	-10.0	-18.0	- 3.0	-37.0
50	+ 4.0	- 5.0	-26.5	- 6.5	- 8.0	- 8.5	-17.5	- 2.0	-36.5
55	+ 5.5	- 3.5	-26.0	- 5.5	- 6.0	- 7.5	-17.0	- 1.5	-36.0
60	+ 7.0	- 2.5	-25.0	- 4.0	- 5.0	- 6.5	-17.0	- .5	-36.0

TABLE 9

EFFECT OF INDUCTION HEATER
(NO AIR BLAST THROUGH GUN BARREL)

800 Watts - 800 Cycles/sec.
Ambient Temperature = -40°C.

Time (Min.)	GUN TEMPERATURE IN °C.								
	Rear of Bolt	Front of Bolt	Alum. Base	Inside of Recvr.	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	-39.5	-41.0	-40.5	-40.0	-40.5	-40.5	-41.0	-41.0	-40.0
5	-26.0	-33.5	-35.0	-27.0	-29.0	-26.0	-26.0	-25.0	-39.0
10	- 9.0	-24.0	-29.5	-14.0	-18.0	-15.0	-16.0	- 8.0	-38.0
15	+ 1.0	-14.0	-27.0	- 5.0	-11.0	- 8.0	-11.0	+ 1.0	-37.5
20	+ 9.5	- 5.5	-25.0	+ 1.5	- 3.5	- 1.0	- 7.0	+10.0	-37.0
25	+17.5	+ 1.5	-24.0	+ 8.0	+ 2.0	+ 3.0	- 5.0	+16.0	-37.0
30	+23.5	+ 8.5	-22.5	+12.5	+ 7.0	+ 7.0	- 3.0	+20.5	-37.0
35	+28.5	+14.5	-22.0	+15.5	+10.5	+ 9.5	- 2.0	+23.0	-37.0
40	+33.0	+18.0	-20.5	+18.0	+14.0	+13.0	- .5	+26.0	-37.0
45	+37.0	+22.5	-19.0	+21.0	+17.0	+15.0	+ .5	+28.0	-37.0
50	+39.5	+25.5	-18.5	+23.0	+19.5	+16.0	+ 1.0	+30.0	-37.0
55	+42.5	+28.5	-18.5	+25.0	+22.5	+18.0	+ 2.0	+31.5	-37.0
60	+45.5	+31.0	-18.0	+26.5	+23.5	+19.5	+ 2.5	+33.0	-37.0

17. Using the standard T-2 resistance heater operating on d-c power, tests similar to those above were run for 200 and 400 watts with the maximum air blast (see Tables 10 and 11).

TABLE 10

EFFECT OF RESISTANCE HEATER (TYPE T-2)
(WITH AIR BLAST THROUGH GUN BARREL)

200 Watts - Direct Current
Ambient Temperature = -40°C.

Time (Min.)	GUN TEMPERATURE IN °C.							
	Rear of Bolt	Front of Bolt	Alum. Base	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	-41.0	-41.0	-42.6	-42.0	-42.5	-42.0	-42.0	-38.0
5	-38.8	-34.8	-41.8	-40.1	-41.0	-38.8	-40.0	-28.0
10	-34.5	-30.0	-38.8	-37.1	-38.0	-35.0	-37.0	-23.5
15	-31.2	-28.2	-36.8	-34.6	-35.0	-33.1	-36.0	-21.2
20	-29.1	-26.5	-35.0	-32.3	-33.0	-31.5	-35.5	-19.3
25	-28.0	-26.0	-35.0	-31.0	-32.2	-31.0	-35.7	-18.8
30	-27.2	-26.0	-35.0	-30.6	-32.0	-30.0	-35.2	-18.7
35	-26.8	-25.1	-34.8	-30.0	-31.0	-29.9	-35.0	-18.1
40	-26.4	-25.0	-34.5	-29.5	-30.5	-29.8	-35.2	-18.0
45	-26.0	-25.0	-34.2	-29.1	-30.2	-29.6	-35.1	-18.0
50	-26.0	-25.0	-34.5	-29.0	-30.0	-29.6	-35.2	-17.9
55	-26.0	-25.0	-34.2	-29.0	-30.0	-29.8	-35.1	-17.8
60	-25.8	-25.0	-34.2	-29.0	-30.0	-29.7	-35.0	-17.7

TABLE 11

EFFECT OF RESISTANCE HEATER (TYPE T-2)
(WITH AIR BLAST THROUGH GUN BARREL)

400 Watts - Direct Current
Ambient Temperature = -40°C.

Time (Min.)	GUN TEMPERATURE IN °C.							
	Rear of Bolt	Front of Bolt	Alum. Base	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	-40.0	-38.5	-47.0	-42.0	-42.0	-41.0	-41.0	-28.0
5	-37.0	-31.5	-43.0	-39.0	-39.5	-37.5	-38.0	-26.0
10	-32.5	-27.5	-39.0	-36.0	-36.5	-34.5	-34.5	-23.0
15	-29.0	-24.0	-36.0	-33.0	-33.5	-32.5	-31.5	-20.0
20	-25.5	-22.0	-34.0	-30.5	-31.0	-30.5	-30.0	-18.0
25	-24.0	-21.5	-33.5	-29.0	-29.5	-29.5	-29.0	-17.5
30	-23.0	-21.0	-33.0	-27.0	-28.5	-28.5	-28.5	-16.5
35	-22.5	-21.0	-33.0	-27.0	-28.0	-28.5	-28.5	-16.0
40	-21.5	-21.0	-33.0	-26.5	-27.0	-28.0	-28.0	-16.0
45	-21.5	-20.0	-32.0	-26.0	-26.5	-27.5	-27.0	-15.5
50	-21.0	-19.5	-31.5	-25.0	-26.0	-27.0	-27.0	-15.0
55	-21.0	-19.5	-31.0	-25.0	-25.0	-26.5	-26.5	-14.5
60	-20.5	-19.5	-31.0	-25.0	-25.0	-26.5	-26.0	-14.0

18. A test was made of the T-2 resistance heater with 400 watts d-c input and no air blast (see Table 12).

19. With the gun and chamber stabilized at 0°C and using 800-cps a-c power, tests were run using 500, 650, 800, and 1200 watts, and readings of gun temperatures were taken every five minutes while the chamber temperature was decreased at the rate of 1°C per minute (see Tables 13 through 16). The maximum air blast through the gun barrel was used continuously during these tests.

TABLE 12

EFFECT OF RESISTANCE HEATER (TYPE T-2)
(NO AIR BLAST THROUGH GUN BARREL)

400 Watts - Direct Current
Ambient Temperature = -40°C.

Time (Min.)	GUN TEMPERATURE IN °C.							
	Rear of Bolt	Front of Bolt	Alum. Base	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	-41.5	-40.0	-40.0	-40.0	-41.0	-40.0	-40.0	-40.0
5	-40.5	-27.5	-39.0	-40.0	-41.0	-40.0	-38.0	-39.5
10	-38.0	- 9.0	-36.0	-39.5	-38.5	-38.5	-34.0	-38.5
15	-34.0	+ 5.0	-33.0	-38.5	-34.0	-36.5	-29.0	-38.5
20	-29.5	+17.0	-30.5	-37.0	-30.0	-34.0	-24.5	-38.5
25	-25.5	+25.0	-28.5	-35.0	-27.0	-32.0	-20.5	-38.5
30	-22.0	+31.5	-26.5	-33.0	-24.5	-30.0	-16.5	-38.5
35	-18.0	+37.5	-25.5	-31.0	-22.0	-28.5	-14.5	-38.5
40	-14.5	+41.0	-24.0	-29.0	-19.5	-27.0	-12.5	-38.5
45	-11.0	+45.0	-23.0	-27.0	-17.5	-25.5	-11.0	-38.5
50	- 7.5	+48.5	-22.0	-25.5	-16.0	-25.0	- 9.5	-38.5
55	- 5.0	+51.0	-21.5	-23.5	-15.0	-23.5	- 8.5	-38.5
60	- 3.0	+53.0	-20.5	-21.0	-14.0	-22.0	- 8.0	-38.5

TABLE 13

EFFECT OF INDUCTION HEATER, UNDER A VARIABLE AMBIENT TEMPERATURE
(WITH AIR BLAST THROUGH GUN BARREL)

500 Watts - 800 Cycles/sec.
Ambient Temperature and Gun Initially Stabilized at 0°C.
Ambient Temperature Dropped Uniformly at Rate of 1°C. per min.

Time (Min.)	GUN TEMPERATURE IN °C.								
	Rear of Bolt	Front of Bolt	Alum. Base	Inside of Recvr.	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	0	0	0	0	0	0	0	0	0
5	+ 8.5	+ 7.0	+ 4.0	+ 6.5	+ 6.0	+ 6.0	+ 7.0	+ 6.0	+13.0
10	+13.0	+ 8.0	+ 3.0	+ 8.0	+10.0	+ 9.0	+ 8.0	+ 7.5	+14.0
15	+15.5	+ 6.5	+ .5	+ 6.0	+12.0	+11.0	+ 6.0	+ 6.0	+14.5
20	+15.0	+ 4.0	- 3.0	+ 3.0	+12.5	+10.5	+ 3.0	+ 3.5	+12.5
25	+13.0	+ 1.0	- 6.5	0.0	+11.0	+ 9.0	- 1.0	0.0	+ 9.0
30	+10.0	- 3.0	-10.5	- 4.0	+ 8.5	+ 5.0	- 5.5	- 4.0	+ 5.0
35	+ 6.5	- 7.5	-15.0	- 8.0	+ 6.0	+ 1.0	- 9.5	- 8.0	+ 1.5
40	+ 2.5	-12.0	-19.0	-13.0	+ 2.0	- 3.0	-14.5	-13.0	- 3.5
45	- 2.5	-16.0	-24.0	-17.5	- 2.0	- 6.5	-18.0	-17.0	- 8.0
50	- 7.0	-20.0	-27.0	-21.5	- 6.0	-10.5	-22.0	-21.0	-12.0

TABLE 14

EFFECT OF INDUCTION HEATER, UNDER A VARIABLE AMBIENT TEMPERATURE (WITH AIR BLAST THROUGH GUN BARREL)

650 Watts - 800 Cycles/sec.

Ambient Temperature and Gun Initially Stabilized at 0°C.

Ambient Temperature Dropped Uniformly at Rate of 1°C. per min.

Time (Min.)	GUN TEMPERATURE IN °C.								
	Rear of Bolt	Front of Bolt	Alum. Base	Inside of Recvr.	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	0	0	0	0	0	0	0	0	0
5	+ 9.5	+ 8.0	+ 4.0	+ 8.0	+ 7.3	+ 8.5	+10.0	+ 8.5	+12.0
10	+17.0	+11.0	+ 5.0	+11.6	+14.2	+14.0	+13.5	+12.0	+17.0
15	+20.0	+ 9.0	+ 1.8	+10.0	+17.0	+16.0	+10.5	+10.0	+15.0
20	+19.6	+ 6.0	- 1.0	+ 6.7	+17.6	+15.0	+ 6.0	+ 7.0	+12.5
25	+18.0	+ 2.5	- 4.0	+ 4.0	+16.5	+13.0	+ 2.5	+ 3.9	+ 9.0
30	+15.0	- 2.0	- 8.0	0.0	+14.0	+ 9.0	- 2.0	- .5	+ 5.0
35	+10.5	- 6.5	-13.0	- 4.9	+11.0	+ 6.0	- 7.0	- 5.0	+ .9
40	+ 6.0	-10.8	-17.5	- 9.5	+ 7.0	+ 2.0	-11.3	-10.0	- 4.0
45	+ 1.5	-15.0	-22.0	-14.0	+ 3.0	- 1.0	-16.0	-14.5	- 8.0
50	- 2.5	-19.0	-26.0	-18.0	- .8	- 5.0	-20.0	-19.0	-11.5

TABLE 15

EFFECT OF INDUCTION HEATER, UNDER A VARIABLE AMBIENT TEMPERATURE (WITH AIR BLAST THROUGH GUN BARREL)

800 Watts - 800 Cycles/sec.

Ambient Temperature and Gun Initially Stabilized at 0°C.

Ambient Temperature Dropped Uniformly at Rate of 1°C. per min.

Time (Min.)	GUN TEMPERATURE IN °C.								
	Rear of Bolt	Front of Bolt	Alum. Base	Inside of Recvr.	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	0	0	0	0	0	0	0	0	0
5	+10.0	+ 7.6	+ 5.8	+ 9.8	+ 7.0	+ 8.5	+11.0	+ 8.8	+11.2
10	+18.0	+11.5	+ 6.6	+15.0	+15.0	+15.0	+15.2	+13.0	+16.0
15	+22.6	+11.0	+ 4.5	+13.6	+20.0	+18.0	+13.5	+12.5	+15.0
20	+23.8	+ 8.5	+ .5	+10.0	+21.0	+18.5	+ 8.5	+ 9.0	+12.0
25	+21.5	+ 4.3	- 3.5	+ 6.0	+19.8	+17.0	+ 4.3	+ 4.8	+ 8.0
30	+17.5	0.0	- 8.0	+ 2.0	+17.0	+13.6	0.0	0.0	+ 4.0
35	+13.4	- 4.5	-12.5	- 2.5	+14.5	+10.0	- 4.2	- 3.2	0.0
40	+ 9.4	- 8.5	-16.5	- 6.2	+11.0	+ 6.0	- 8.5	- 8.0	- 4.2
45	+ 5.3	-13.0	-20.5	-10.8	+ 7.6	+ 2.2	-12.8	-11.8	- 9.0
50	+ 2.0	-17.0	-23.9	-14.5	+ 4.0	- 2.0	-17.0	-16.5	-13.0

TABLE 16

EFFECT OF INDUCTION HEATER, UNDER A VARIABLE AMBIENT TEMPERATURE (WITH AIR BLAST THROUGH GUN BARREL)

1200 Watts - 800 Cycles/sec.

Ambient Temperature and Gun Initially Stabilized at 0°C.

Ambient Temperature Dropped Uniformly at Rate of 1°C. per min.

Time (Min.)	GUN TEMPERATURE IN °C.								
	Rear of Bolt	Front of Bolt	Alum. Base	Inside of Recvr.	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	0	0	0	0	0	0	0	0	0
5	+17.0	+10.5	+ 8.0	+15.5	+14.0	+16.5	+17.5	+16.0	+16.0
10	+27.0	+13.0	+ 8.5	+19.5	+24.0	+24.0	+21.5	+20.0	+17.0
15	+31.0	+13.0	+ 7.0	+18.5	+29.0	+28.0	+20.5	+20.0	+15.0
20	+32.0	+11.5	+ 4.0	+16.5	+31.0	+28.5	+17.0	+17.0	+12.5
25	+31.0	+ 8.5	+ 1.0	+14.0	+31.0	+26.0	+14.0	+14.0	+ 9.0
30	+29.0	+ 5.0	- 3.0	+10.5	+30.5	+23.5	+10.0	+10.5	+ 5.5
35	+25.0	+ 1.0	- 6.0	+ 5.5	+27.5	+21.0	+ 5.0	+ 6.0	+ 1.0
40	+21.5	- 3.0	-10.0	+ 1.0	+23.5	+18.0	+ 1.0	+ 1.5	- 3.0
45	+18.0	- 7.0	-14.0	- 3.0	+20.5	+14.5	- 2.5	- 1.5	- 6.0
50	+14.5	-11.0	-17.0	- 6.5	+17.0	+12.0	- 7.0	- 6.0	- 9.0

20. A test similar to those above was made for 800 watts of 800-cps a-c power, using a chamber rate of temperature drop of 3°C per minute (see Table 17).

TABLE 17

EFFECT OF INDUCTION HEATER, UNDER A VARIABLE AMBIENT TEMPERATURE (WITH AIR BLAST THROUGH GUN BARREL)

800 Watts - 800 Cycles/sec.

Ambient Temperature and Gun Initially Stabilized at 0°C.

Ambient Temperature Dropped Uniformly at Rate of 3°C. per min.

Time (Min.)	GUN TEMPERATURE IN °C.								
	Rear of Bolt	Front of Bolt	Alum. Base	Inside of Recvr.	Rear of Recvr.	Rear of Barrel	Upper Cartridge Chute	Lower Cartridge Chute	Air in Muzzle
0	0	0	0	0	0	0	0	0	0
3	+ 7.5	+ 3.5	+ 2.5	+ 4.0	+ 4.0	+ 5.0	+ 6.0	+ 3.5	+ 8.0
6	+12.0	+ 4.5	+ 1.0	+ 5.5	+ 6.5	+ 7.5	+ 7.5	+ 4.5	+10.0
9	+15.0	+ 1.5	- 4.0	+ 6.0	+ 9.0	+10.0	+ 5.0	+ 2.0	+ 8.5
12	+15.0	- 2.0	- 8.0	+ 4.0	+10.0	+ 9.0	+ 1.0	- 1.5	+ 4.0
15	+13.5	- 5.0	-13.0	0.0	+ 9.0	+ 7.0	- 4.0	- 5.5	+ .5
18	+11.5	- 7.5	-16.0	- 4.0	+ 7.5	+ 5.5	- 8.0	- 8.5	- 3.0

EXPERIMENTAL OBSERVATIONS

21. The observations of tests of various coil arrangements are given in Table 2. These figures show that the heat generated in the gun can be shifted to any desired location by suitable design and placement of the coils. The final selection of coil size and arrangement (40-turn central coil on upper portion of receiver) was based both on the results obtained, which indicated a fairly even distribution of heat throughout the gun, and also on the practicability and simplicity of installing such a coil where it would not interfere with gun operation and would be adaptable to either right- or left-hand ammunition feed. Such a coil could be rigidly clamped to the receiver, and should extend from a point just forward of the rear plate (in order not to interfere with its removal) to a point just forward of the feed mechanism. The sides of the coil should be placed below the upper surface of the receiver--above the hydraulic charger and under the link discharge chute on one side, and below the feed mechanism operating arm on the other side. Such a coil could be made adaptable to either right- or left-hand feed by shifting it slightly to the right or left on the gun, or by rotating the coil 180° in the horizontal plane.

22. No attempt was made to design an actual coil because wire size, number of turns, and exact location on the gun will depend largely upon the current, voltage and frequency rating of the power supply, the means employed for the correction of power factor, and the regulation of frequency or voltage. The coil used in these tests was wound with 40 turns of No. 12 AWG enamel-covered copper wire, taped together in order to be self-supporting. It is shown on the gun in the proper location in Figures 6 and 7. In an attempt to reduce the I^2R loss in the coil itself, a similar coil was wound using No. 9 wire, but its size and weight were deemed excessive for the additional heating of the gun obtained, and it was discarded.

23. It was noted that frequency did have some effect on the heating of the gun, even though the active power input to the working coil was maintained constant (as shown in Table 2 and by a comparison of Tables 4 and 7). This may have been caused by the variation of the current-voltage relationship at different frequencies. Since the higher frequencies require lower currents and hence produce less I^2R loss in the coil itself, a larger percentage of the total power input is absorbed by the gun at the higher frequencies. The additional energy may, therefore account for the additional heating of the gun.

24. In the test of direct heating of the gun by passing large direct currents through the gun, no data were recorded, but 200 amperes was conducted from a terminal at the rear of the receiver to one at the forward mounting bracket on the trunnion block (the aluminum base block was not insulated electrically from the gun) and a voltage drop of approximately 2 volts was registered between terminals, indicating a power input of approximately 400 watts. The only noticeable heating effect was produced in the immediate vicinity of the terminals, and the heating effect on the critical portions of the gun was negligible. Consequently, this type of heating was not investigated further.

25. Two standard commercial 250-watt strip heaters (one on each side of the receiver) externally to the gun, produced high temperature rises in the immediate vicinity of the strip heater, but had very little effect at even a relatively short distance from the heater. Furthermore, considerable radiation from the exterior surface of the heater indicated the necessity of either limiting or reflecting this radiation in order to secure maximum efficiency, or of placing this type of heater internally so that the total radiation would be effective in heating the gun. Since better means of heating the gun was available, no further investigation of the external resistance heater was conducted.

26. Tests using the T-2 heater indicated excellent design as to physical location in the gun to produce a maximum heating effect in the portions of the gun where it was most desired, but the total heating produced by it was grossly inadequate. The T-2 heater is rated at 200 watts, but since these tests were conducted at an ambient temperature of -40°C, 400 watts was used without destruction of the heater. A larger heater placed in the same location might offer a practical solution; however, the space provided is extremely critical, and it is not known whether a heater of adequate rating could be put in this limited space.

27. The observations made at -40° C ambient temperature for the induction heater are given in Tables 4 through 9 and Figures 8 through 14, which are largely self-explanatory. Comparable tests have been plotted on the same sheet to facilitate direct comparison, and the same scales have been used in plotting all curves in this report. It is obvious from these curves that the heating effect is not the same in all portions of the gun, particularly when an air blast exists through the gun barrel. For example, as can be seen from Figure 9, the front of the bolt, which is directly in the air stream, has a relatively small increase in temperature rise even for a large increase in power input. Comparison of the curves of Figures 8 through 14 for each gun position with and without the air blast shows that the air blast has a tremendous effect upon the cooling of the gun. These tests were all conducted, however, with a dry gun. Should the gun have a coating of ice, such a coating would act as a thermal insulator, and since the induction method of heating applies the heat internally to the metal, the temperature rise at the surface might be larger than if the metal were not shielded by the ice. The ice might, therefore, crack loose by melting at the surface of the metal under the impact of the bolt, without actually melting entirely. It is obvious from these curves that the air blast through the gun barrel must be eliminated if the gun heater rating is to be kept within reasonable bounds.

28. In order to secure the quantity of air desired through the gun barrel, it was necessary to compress the air at the muzzle to maintain a difference of pressure between the muzzle and the breech. This air was necessarily heated by the compression so that the temperature of the air in the barrel was above ambient temperature; it thus contributed slightly to the heating of the gun barrel. As the air passed through the barrel, it expanded again and cooled. It is understood that this phenomenon has also been noticed under flight conditions.

29. The data given in Tables 10, 11 and 12, showing the heating effect of the T-2 type resistance heater, have been plotted on Figures 15 through 20. The effect produced varies widely throughout the gun, depending upon the physical proximity to the heater. The cooling effect of the air blast is clearly shown, particularly at the front of the bolt (Figure 16).

30. Figures 21 through 26, show that for a given power input, the induction-type heater, with one exception, causes a larger temperature rise than the resistance type. In addition, it reacts faster, since it does not rely entirely upon thermal conduction in the metal to distribute the applied heat, as does the resistance type. These curves were plotted from the data in Tables 8 and 12, both of which were obtained using 400 watts without the air blast. At each point that temperatures were recorded, except the front of the bolt (which is in close proximity to the T-2 heater), the induction heater produced a greater temperature rise in the gun for the same power input, and showed a more even distribution of heat throughout the working portions of the gun.

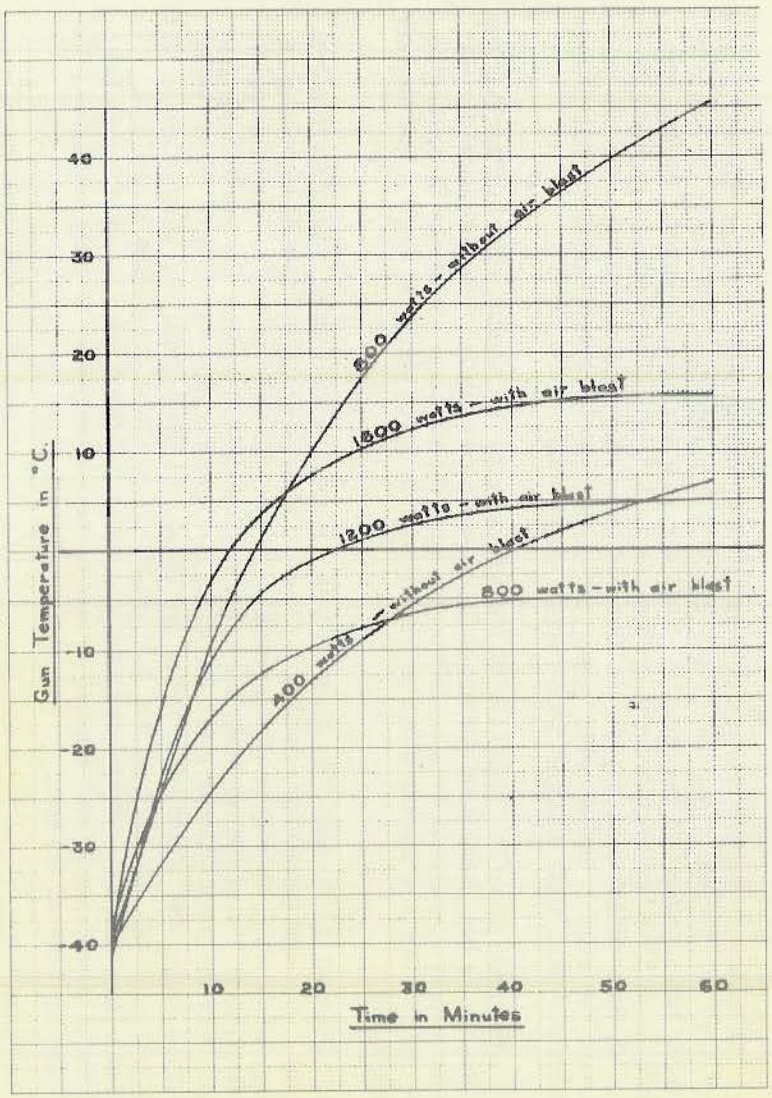


Fig. 8 Induction Heater, Ambient Temperature -40°C. (Rear of Bolt)

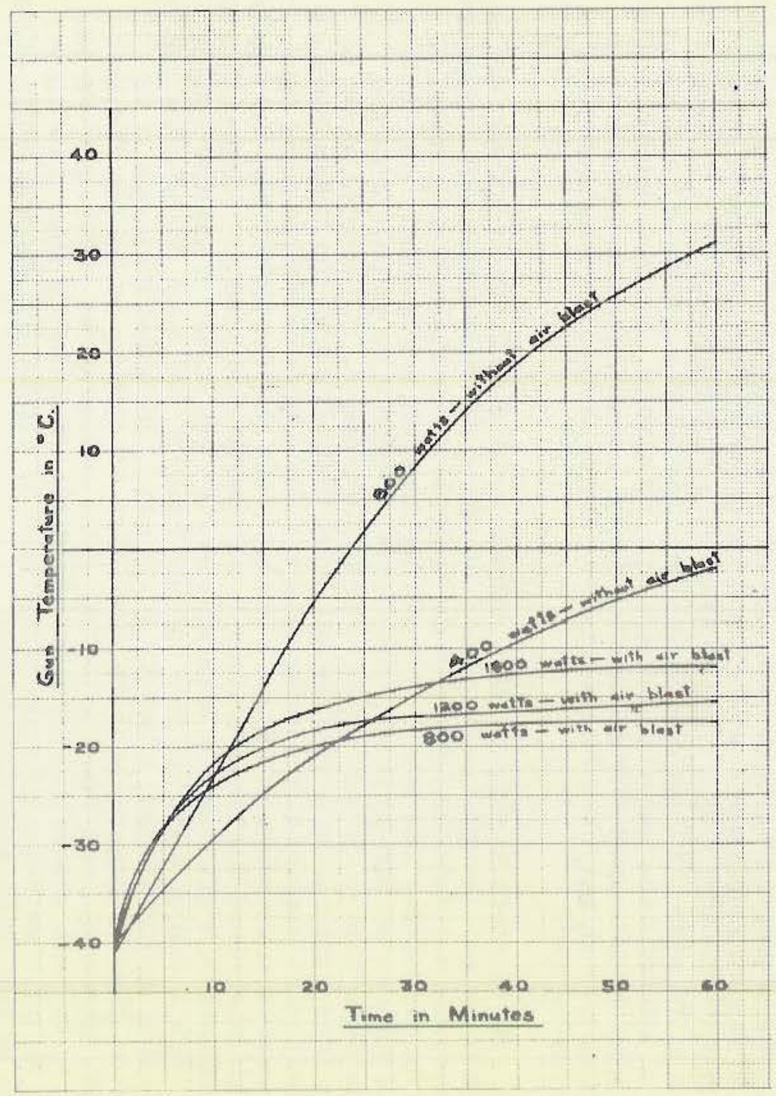


Fig. 9 Induction Heater, Ambient Temperature -40°C. (Front of Bolt)

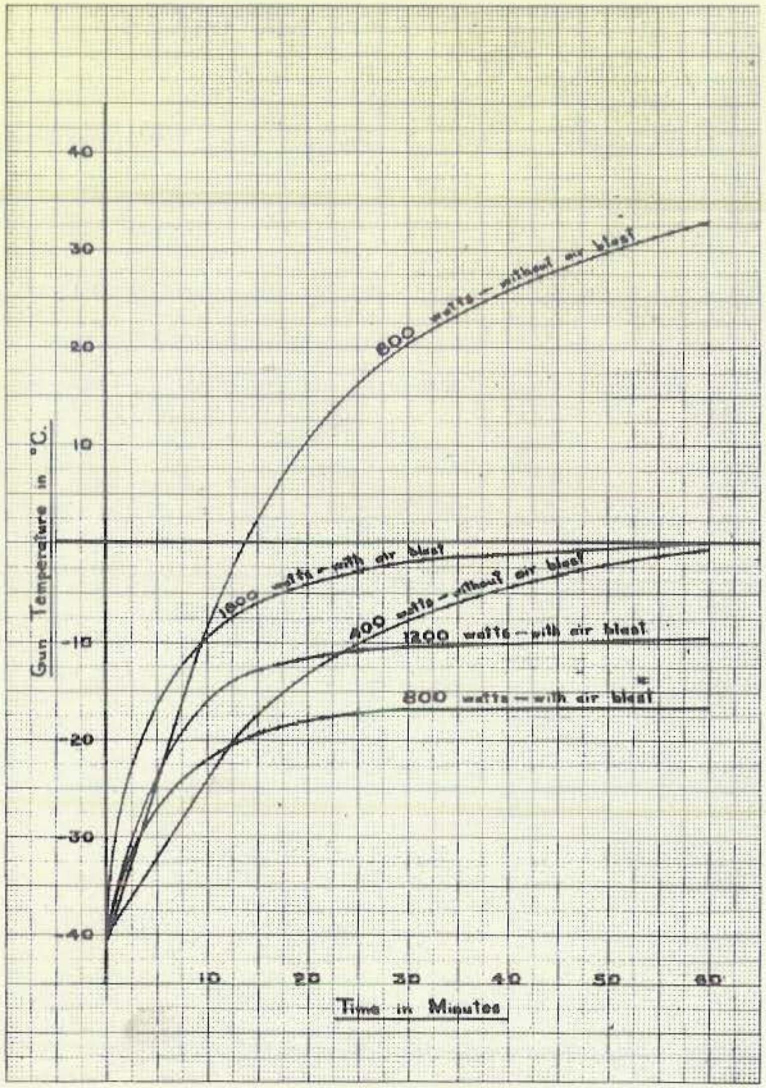


Fig. 10 Induction Heater, Ambient Temperature -40°C.
(Inside Receiver)

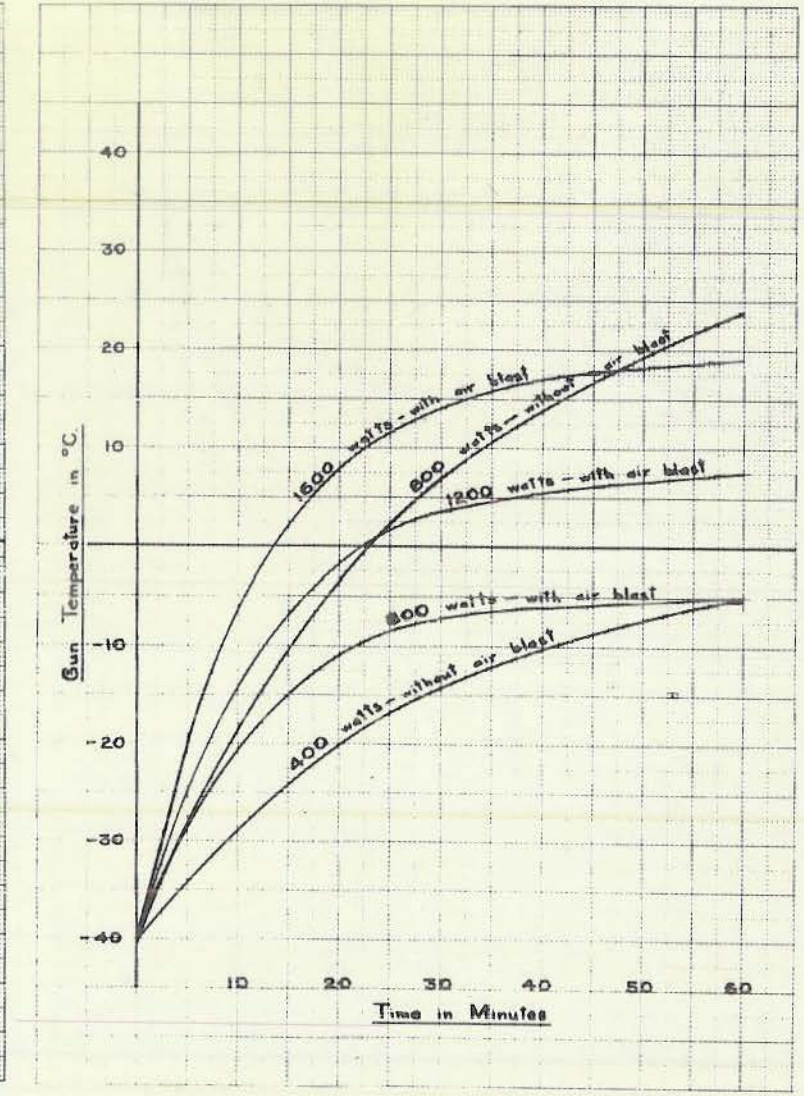


Fig. 11 Induction Heater, Ambient Temperature -40°C.
(Rear of Receiver)

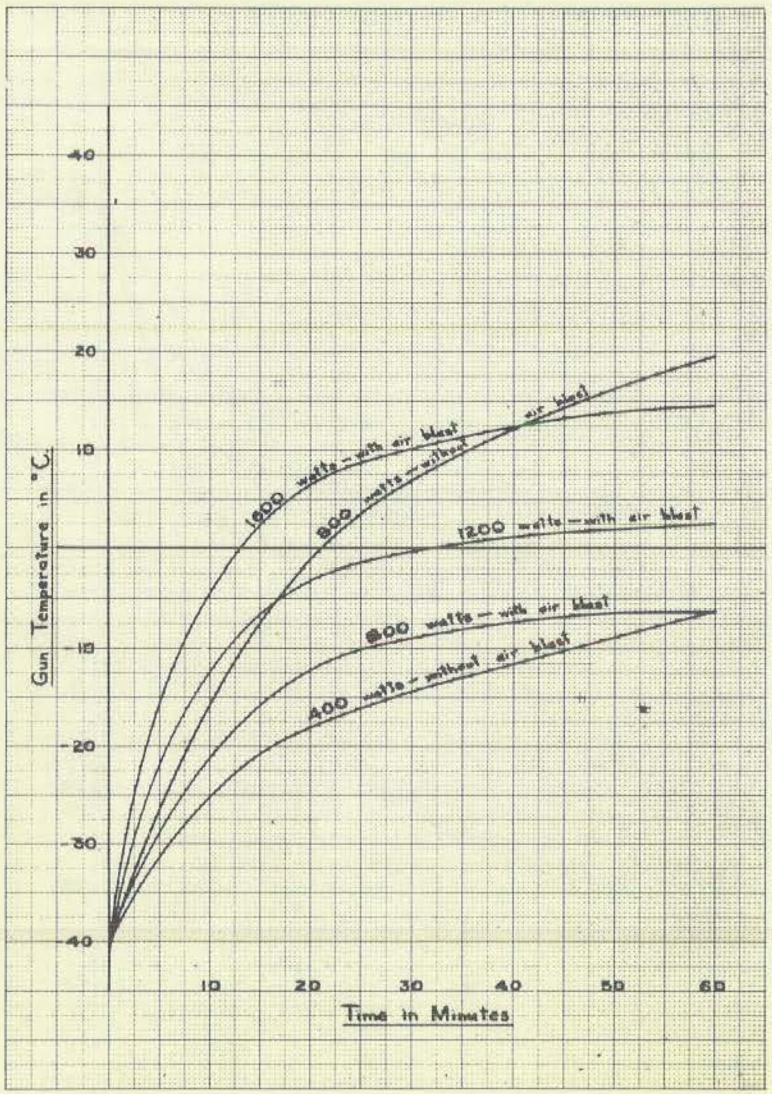


Fig. 12 Induction Heater, Ambient Temperature -40°C.
(Rear of Barrel)

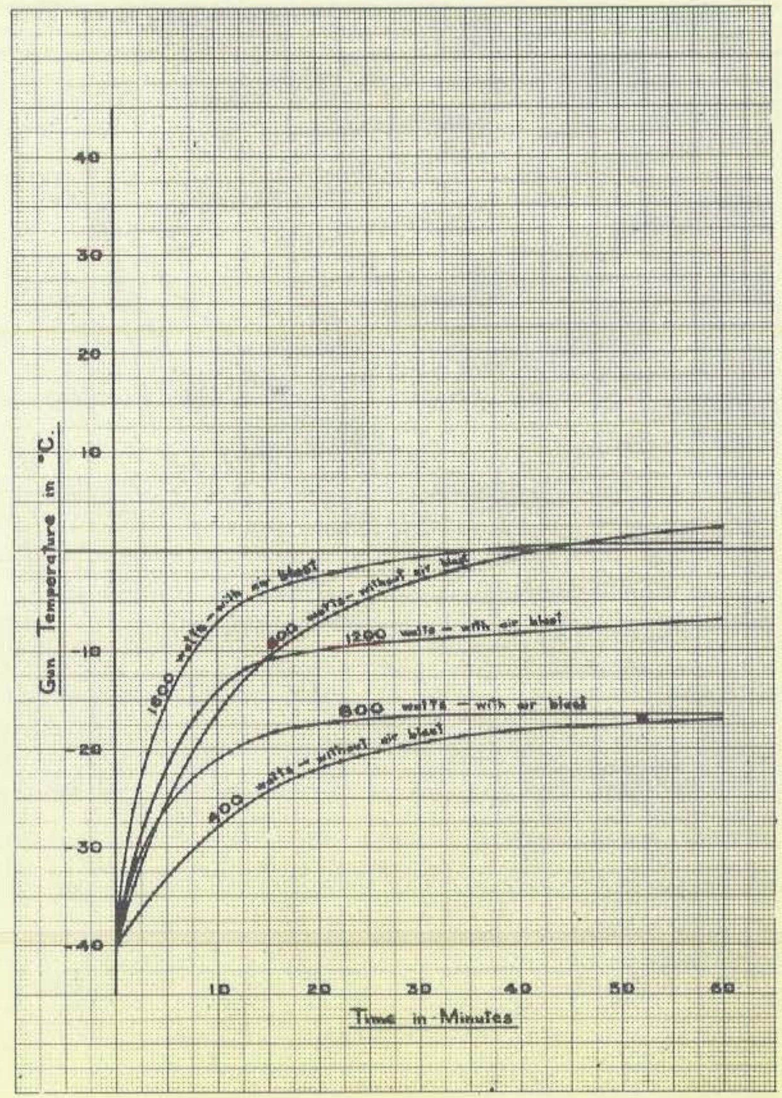


Fig. 13 Induction Heater, Ambient Temperature -40°C.
(Upper Cartridge Chute)

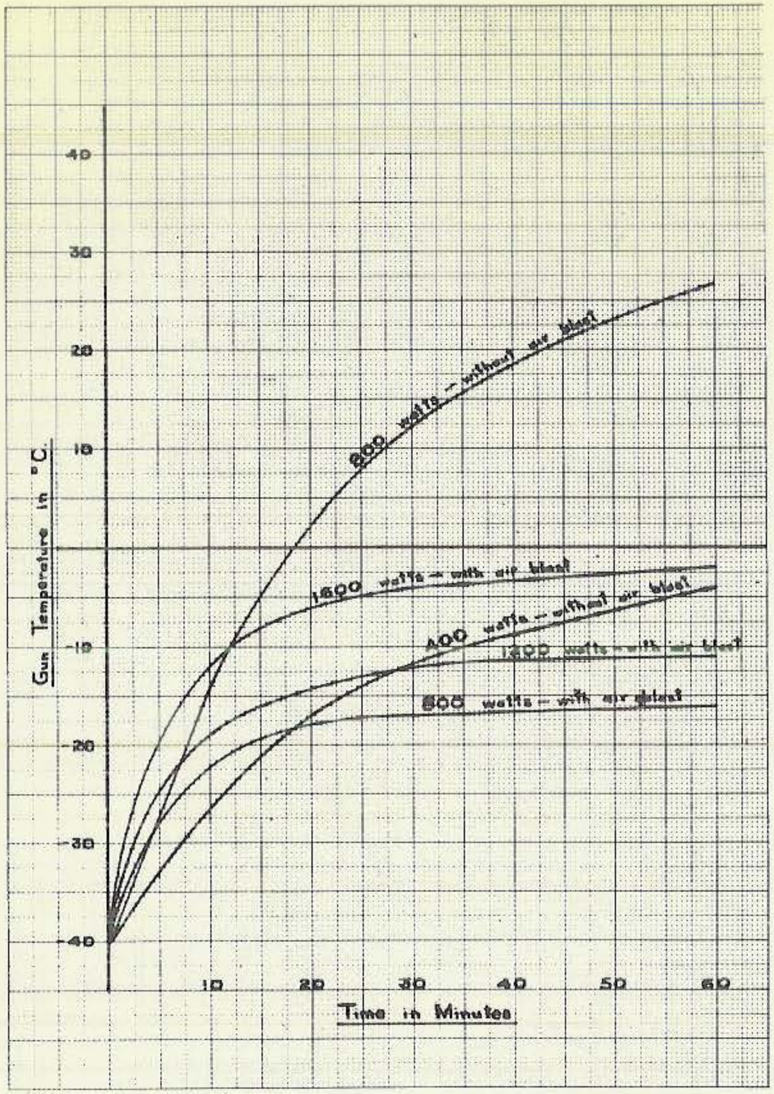


Fig. 14 Induction Heater, Ambient Temperature -40°C.
(Lower Cartridge Chute)

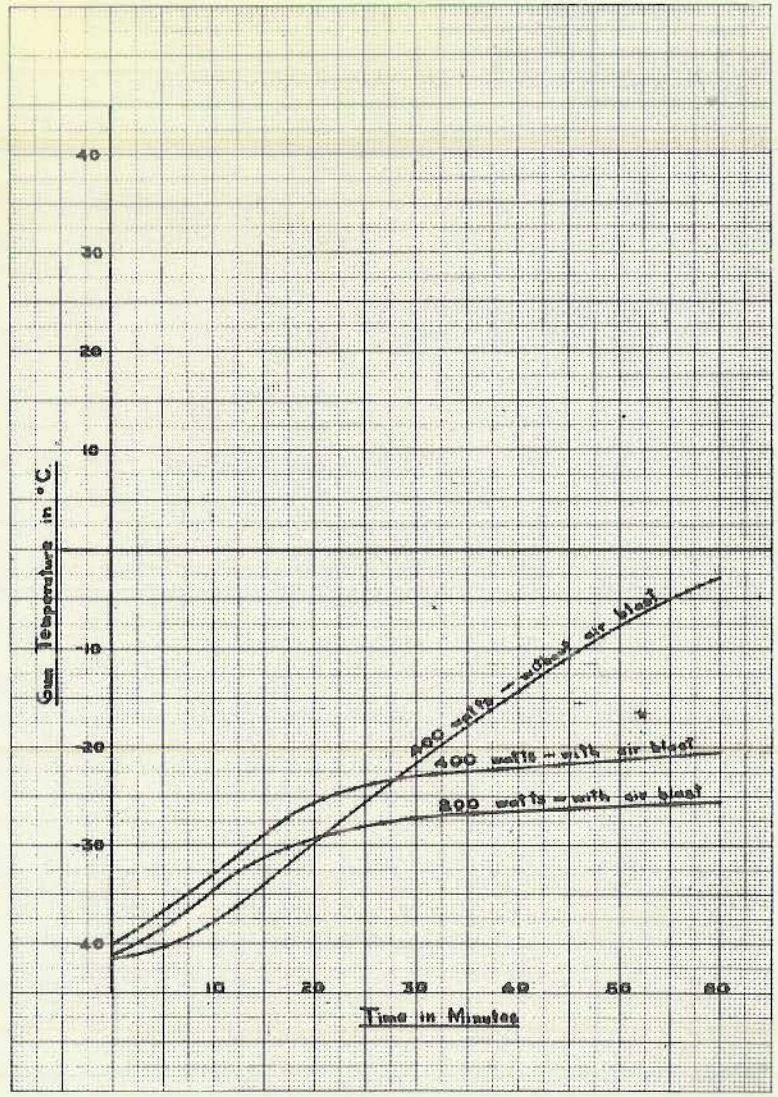


Fig. 15 Resistance Heater, (Type T-2) Ambient
Temperature -40°C (Rear of Bolt)

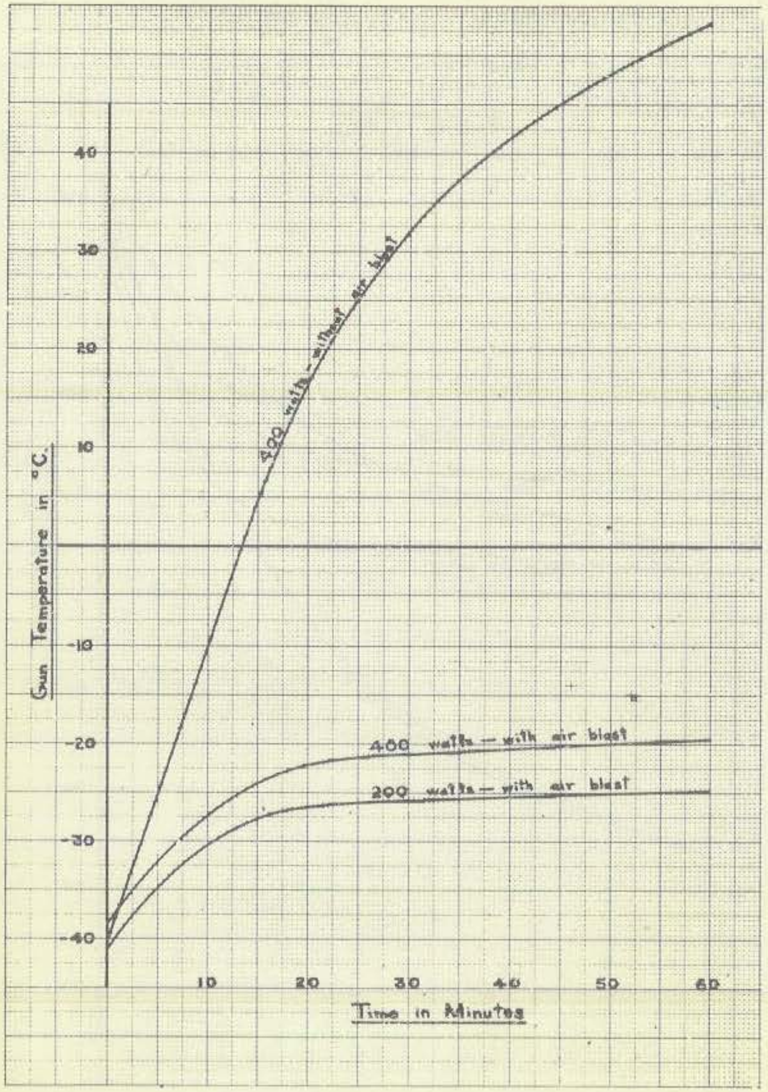


Fig. 16 Resistance Heater, (Type T-2) Ambient Temperature -40°C (Front of Bolt)

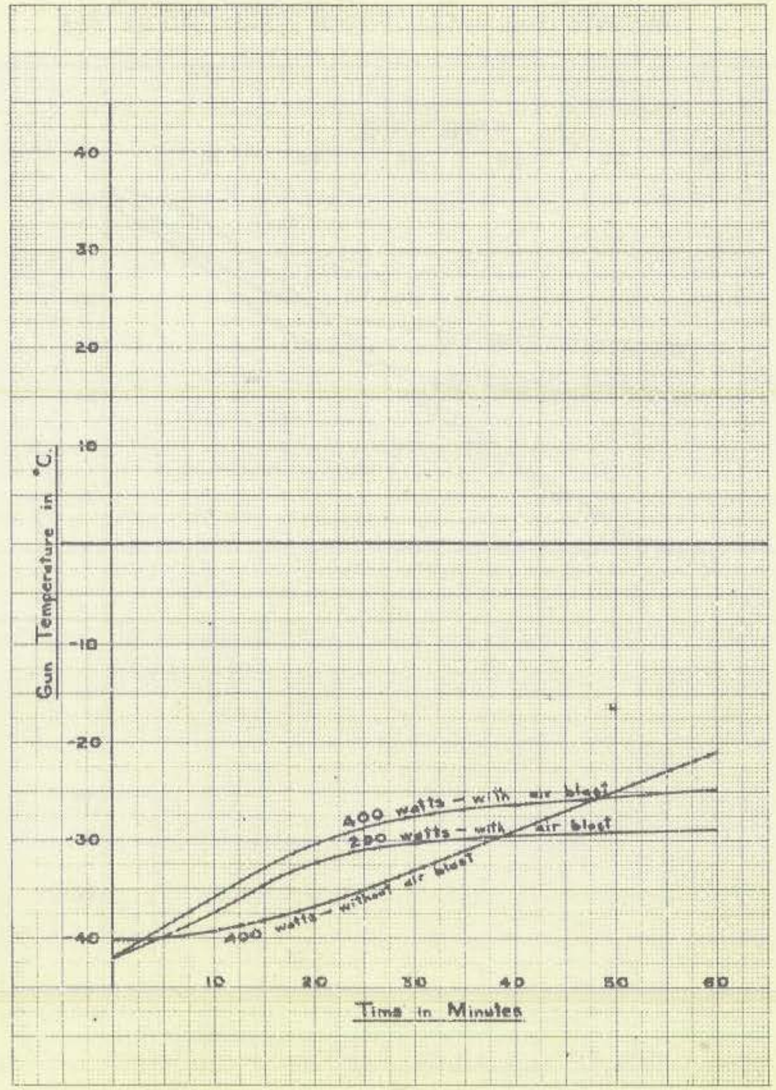


Fig. 17 Resistance Heater, (Type T-2) Ambient Temperature -40°C (Rear of Receiver)

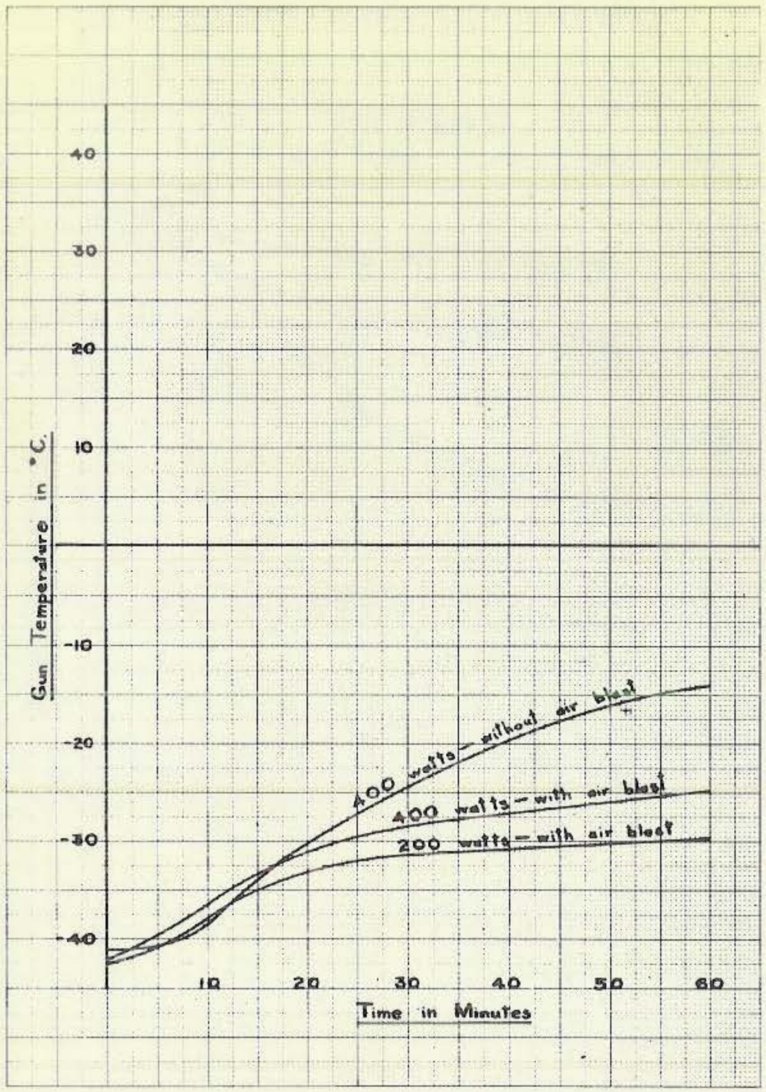


Fig. 18 Resistance Heater, (Type T-2) Ambient Temperature -40°C (Rear of Barrel)

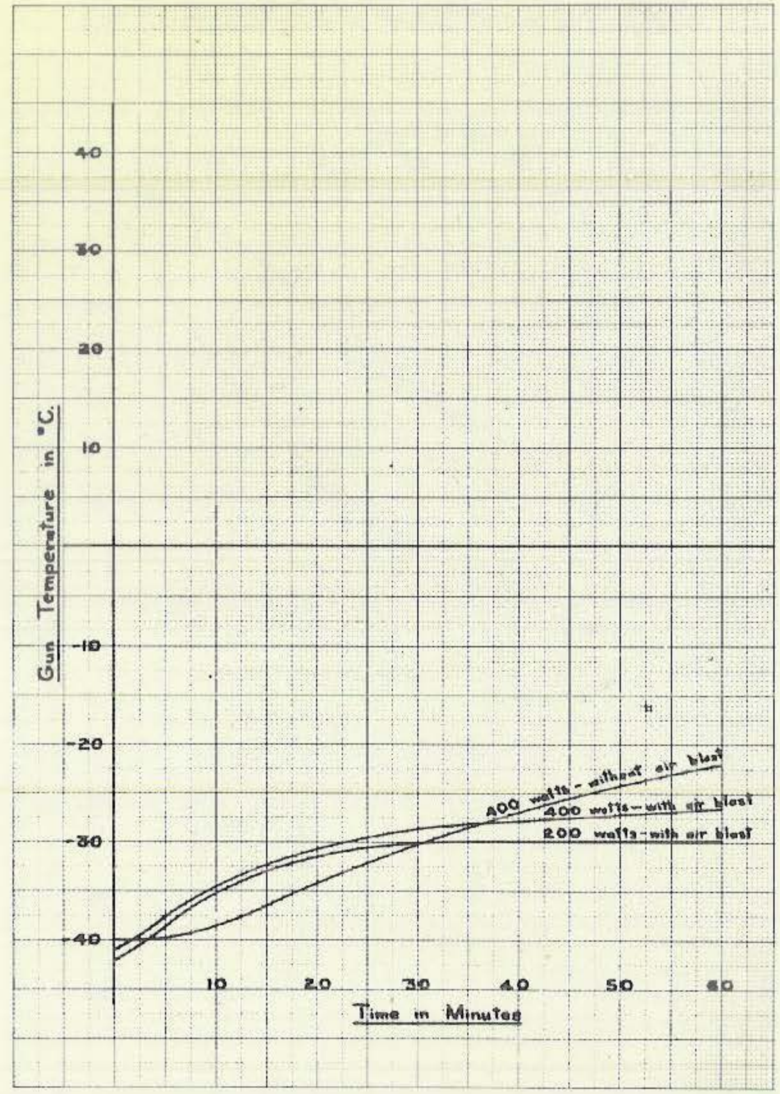


Fig. 19 Resistance Heater, (Type T-2) Ambient Temperature -40°C (Upper Cartridge Chute)

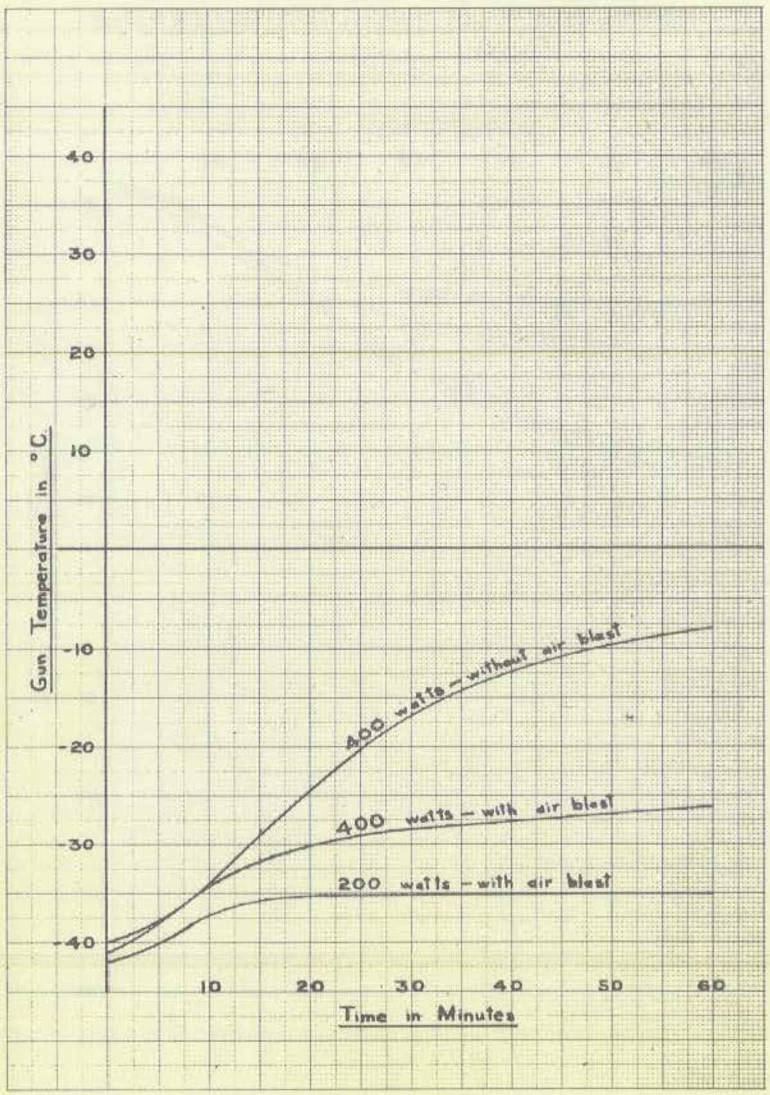


Fig. 20 Resistance Heater, (Type T-2) Ambient Temperature -40°C (Lower Cartridge Chute)

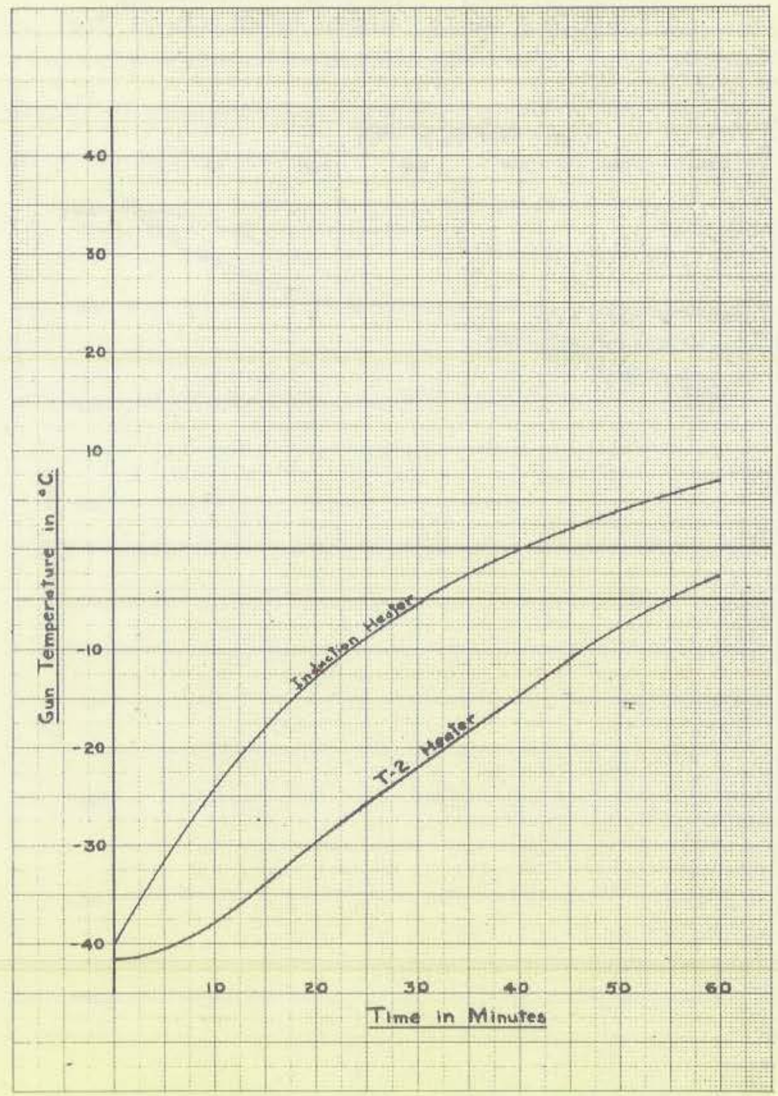


Fig. 21 Comparison of Induction and Resistance Heater (Type T-2) Ambient Temperature -40°C, No air blast through gun barrel, 400 watts. (Rear of Bolt)

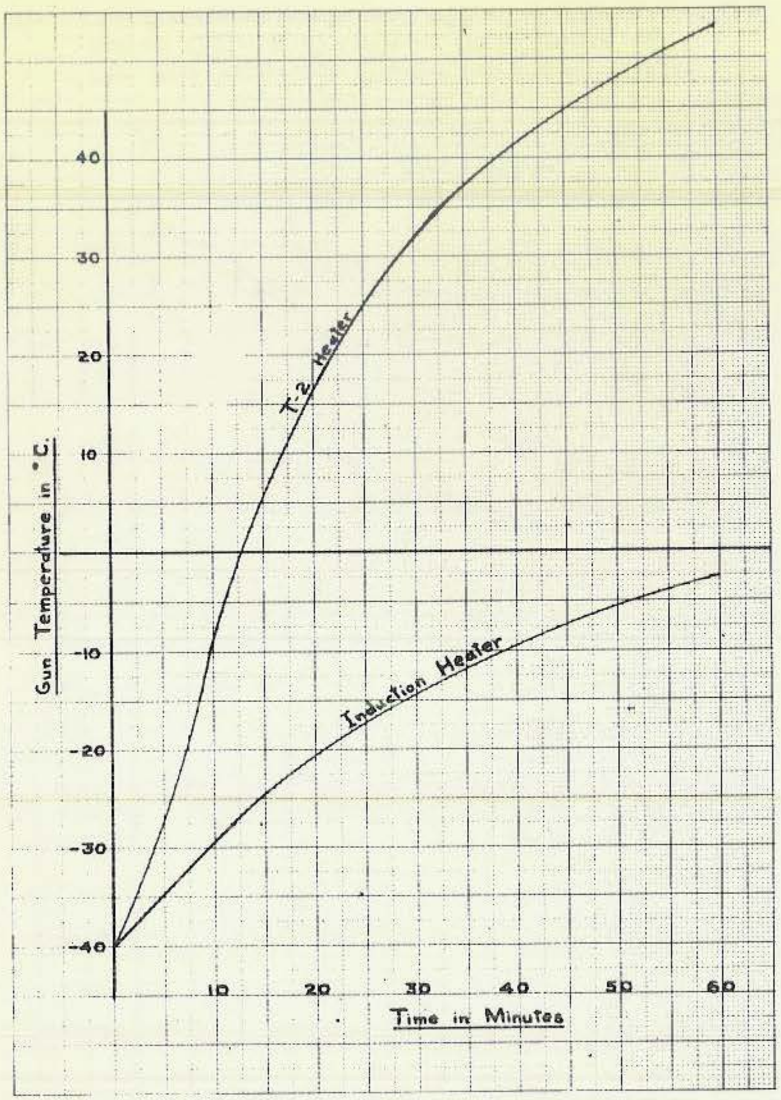


Fig. 22 Comparison of Induction and Resistance Heater (Type T-2) Ambient Temperature -40°C, No air blast through gun barrel, 400 watts. (Front of Bolt)

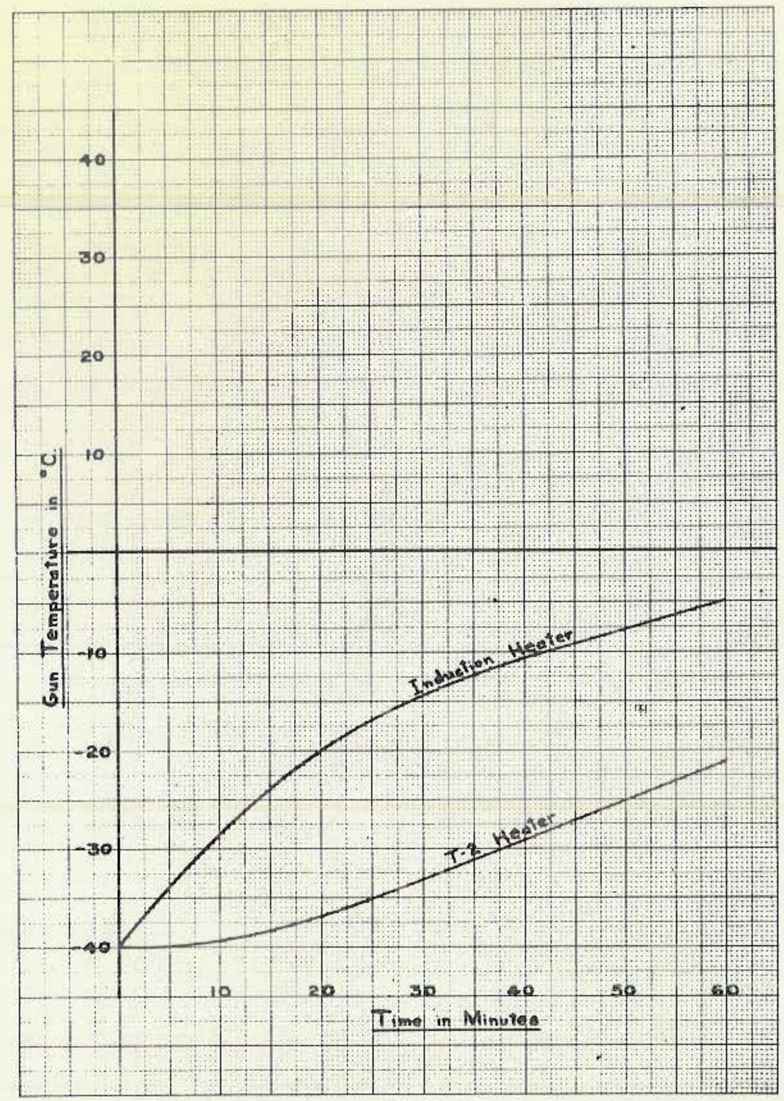


Fig. 23 Comparison of Induction and Resistance Heater (Type-T-2) Ambient Temperature -40°C, No air blast through gun barrel, 400 watts. (Rear of Rcvr.)

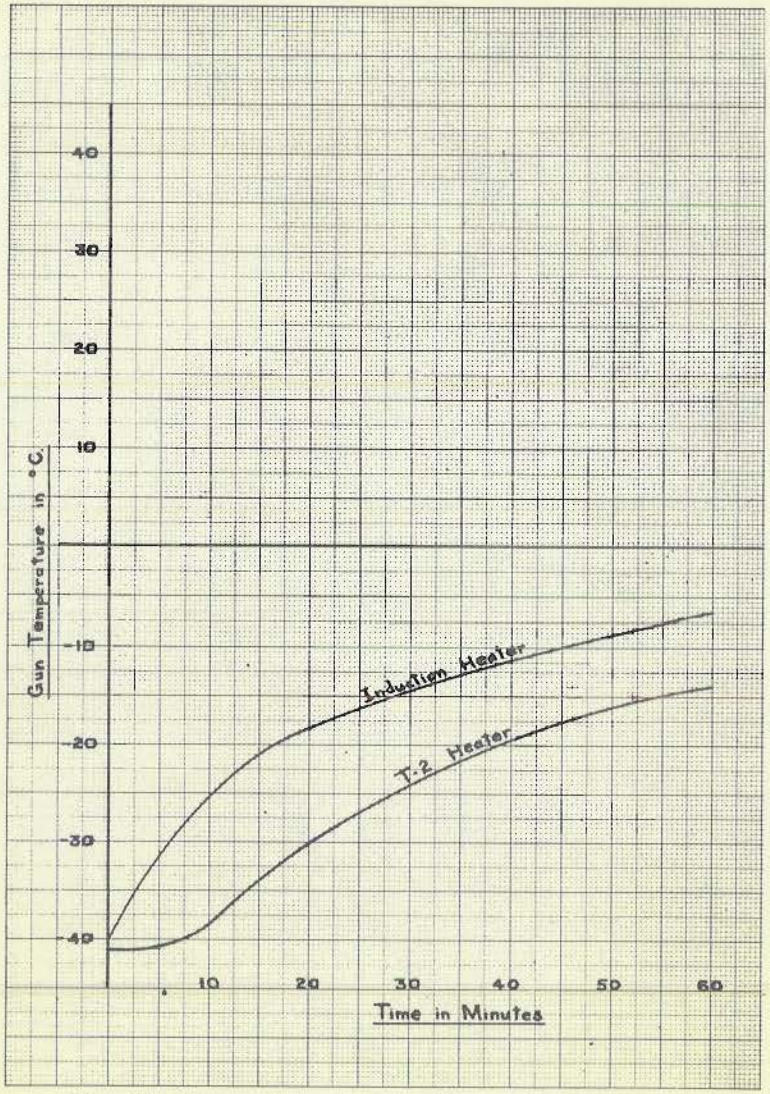


Fig. 24 Comparison of Induction and Resistance Heater (Type T-2) Ambient Temperature -40°C, No air blast through gun barrel, 400 watts. (Rear of Barrel)

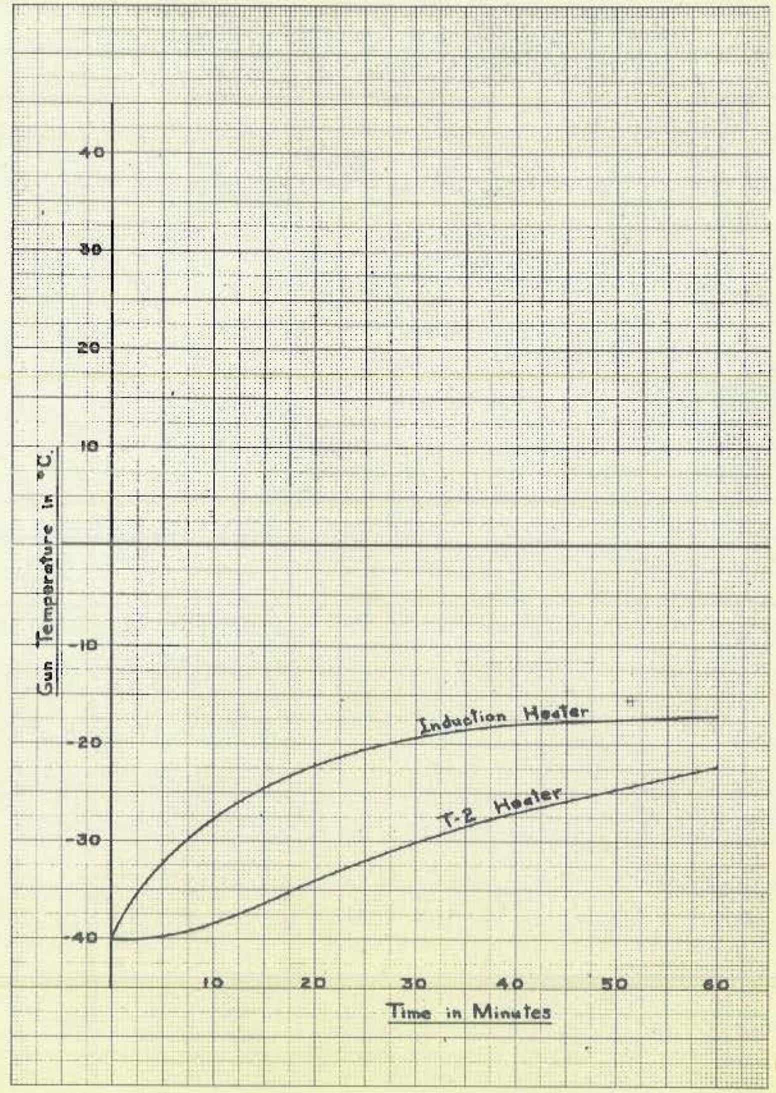


Fig. 25 Comparison of Induction and Resistance Heater (Type T-2) Ambient Temperature -40°C, No air blast through gun barrel, 400 watts. (Upper Cartridge Chute)

31. The above data were obtained at an ambient temperature of -40° C and the curves have been plotted accordingly. Comparison of the test for 800 watts, 800 cycles per second and air blast at room temperature (Table 3), with the test at -40° C ambient (Table 4) shows that the temperature rise in both cases was approximately the same. Accordingly, for all practical purposes, the same data can be used with only slight errors for any ambient temperature within the range encountered by aircraft; consequently, the same curves can be used by merely translating the temperature axis.

32. The tests conducted with a drop in chamber temperature at a rate of 1°C per minute were undertaken to simulate approximately the conditions which might be encountered by a plane taking off from a carrier deck (at 0°C) and climbing through a moderate temperature gradient, with gun heaters turned on continuously. It can be seen from Figures 27 through 33 (plotted from data in Tables 13 through 17) that the gun would be warmed above 0°C for a time, depending upon the rate of ambient temperature change and upon heater input. This time interval, if sufficiently long, might enable the pilot to melt any ice that may have been formed, and to dry the gun by evaporation. Under these conditions the gun would remain operative regardless of low ambient temperatures, since it is ice and not low temperatures that renders the gun inoperative, and very little moisture is normally present in the air at very low temperatures. Should the pilot fly through atmospheric conditions conducive to icing, however, the ice might re-form on the gun (as well as on all exposed parts of the plane). All these tests were conducted under conditions of maximum air blast (approximately 380 pounds per hour).

33. The de-icing effect would be heightened by the elimination of the air blast through the barrel, or by use of a cap over the gun barrel, provided the pilot delayed the firing of his test burst after taking off, since the interval during which the gun temperature is above freezing would be lengthened. For comparative purposes, one test was included for a chamber-temperature drop of 3°C per minute, under which conditions neither the maximum gun temperature nor the length of time that the gun remained above 0°C was as great as that obtained by a lesser rate of temperature change.

RESULTS

34. From the standpoint of simplicity, practicability, and efficiency, the best arrangement is an elongated, horizontal coil placed on the upper portion of the receiver and extending from just forward of the rear buffer to a point just forward of the feed mechanism.

35. Induction heating produces a larger temperature rise than resistance heating (except in the immediate vicinity of the resistance heater) for a given power input to the heating element. The heat is more evenly and rapidly distributed when a proper coil design is used.

36. At an ambient temperature of -30°C and with an air blast through the gun barrel, at least 2000 watts will be required by the induction heater under continuous operation to insure gun operation under all reasonable conditions.

37. With the air blast through the gun barrel eliminated and an ambient temperature of -30°C, at least 500 watts will be required by the induction heater under continuous operation (see paragraph 47, below) to insure gun operation under all reasonable conditions. (See Figures 8 to 14).

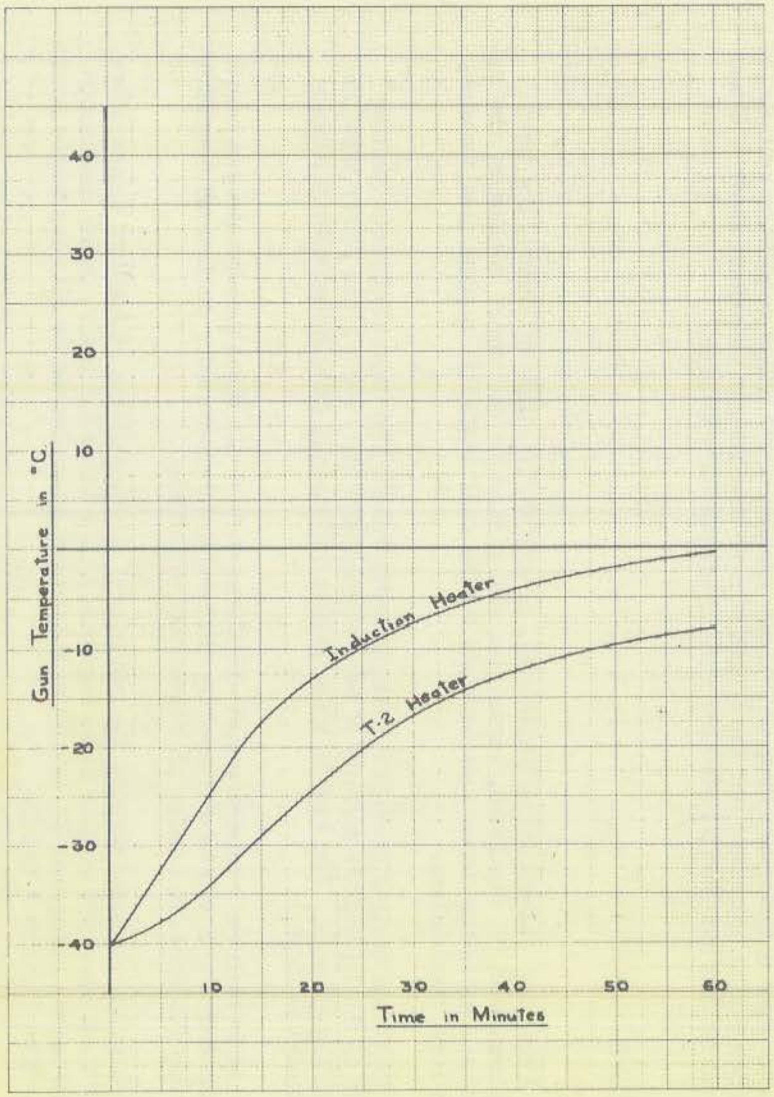


Fig. 26 Comparison of Induction and Resistance Heater (Type-T-2) Ambient Temperature -40°C, No air blast through gun barrel, 400 watts. (Lower Cartridge Chute)

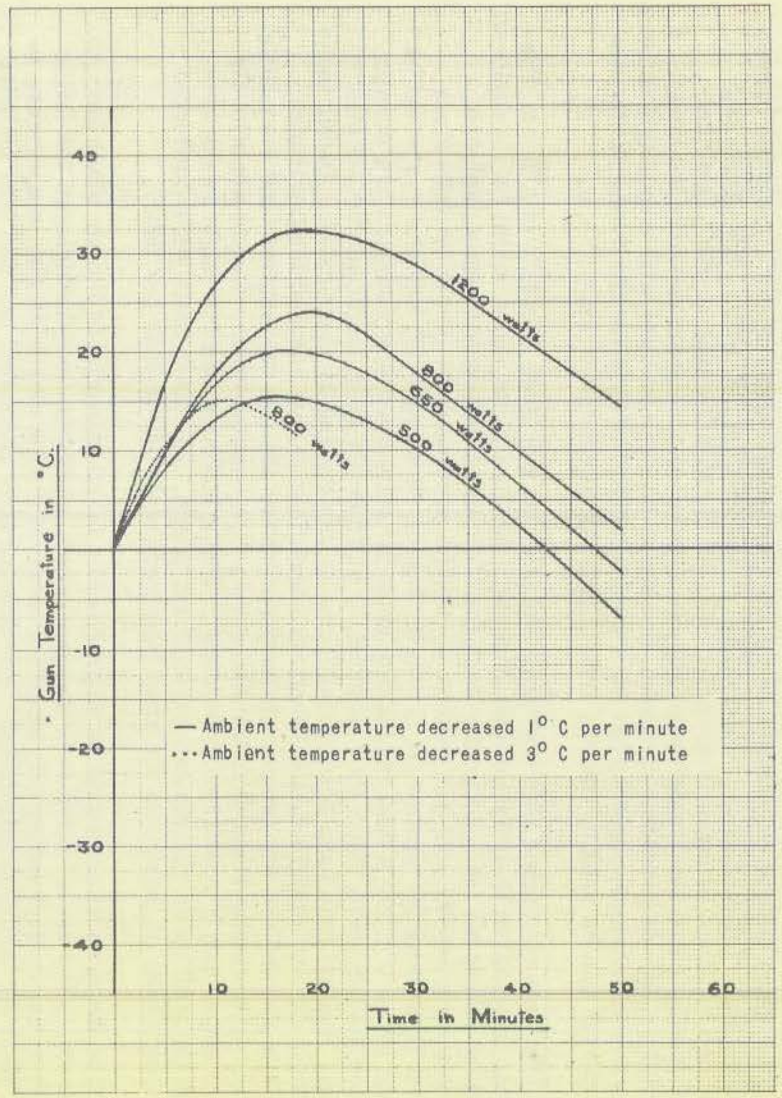


Fig. 27 Effect of Variable Ambient Temperature - Induction Heater, Maximum air blast through gun barrel. (Rear of Bolt)

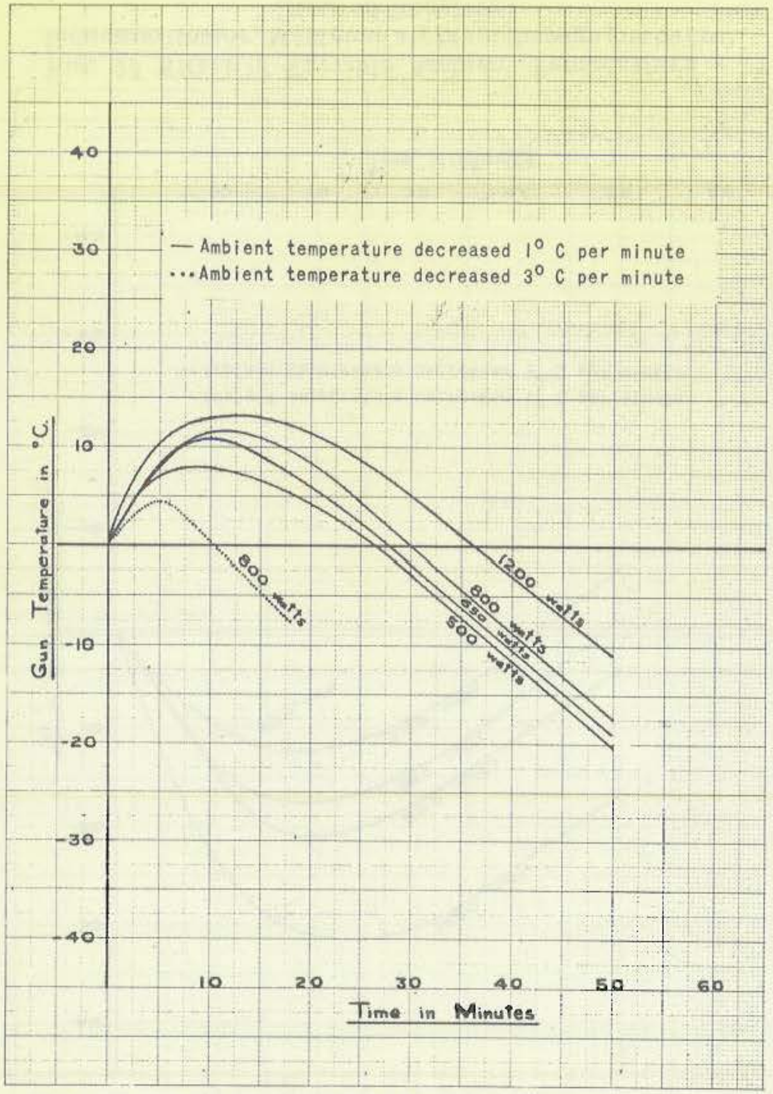


Fig. 28 Effect of Variable Ambient Temperature - Induction Heater, Maximum air blast through gun barrel. (Front of Bolt)

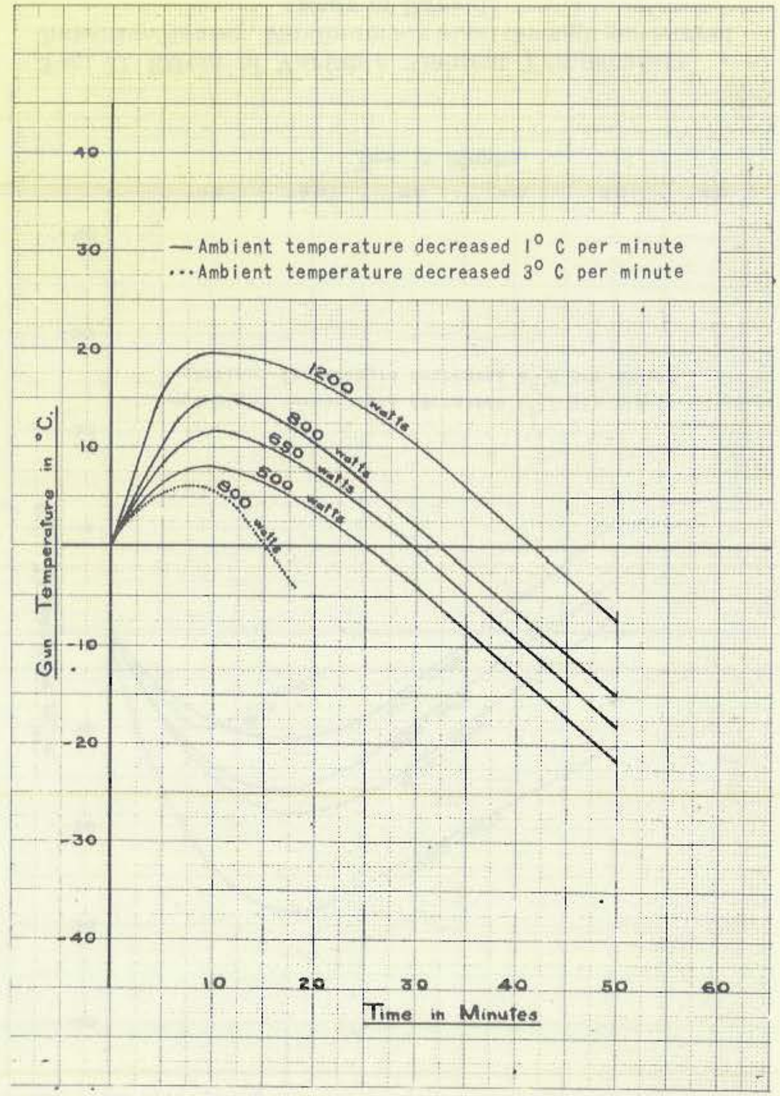


Fig. 29 Effect of Variable Ambient Temperature - Induction Heater, Maximum air blast through gun barrel. (Inside Receiver)

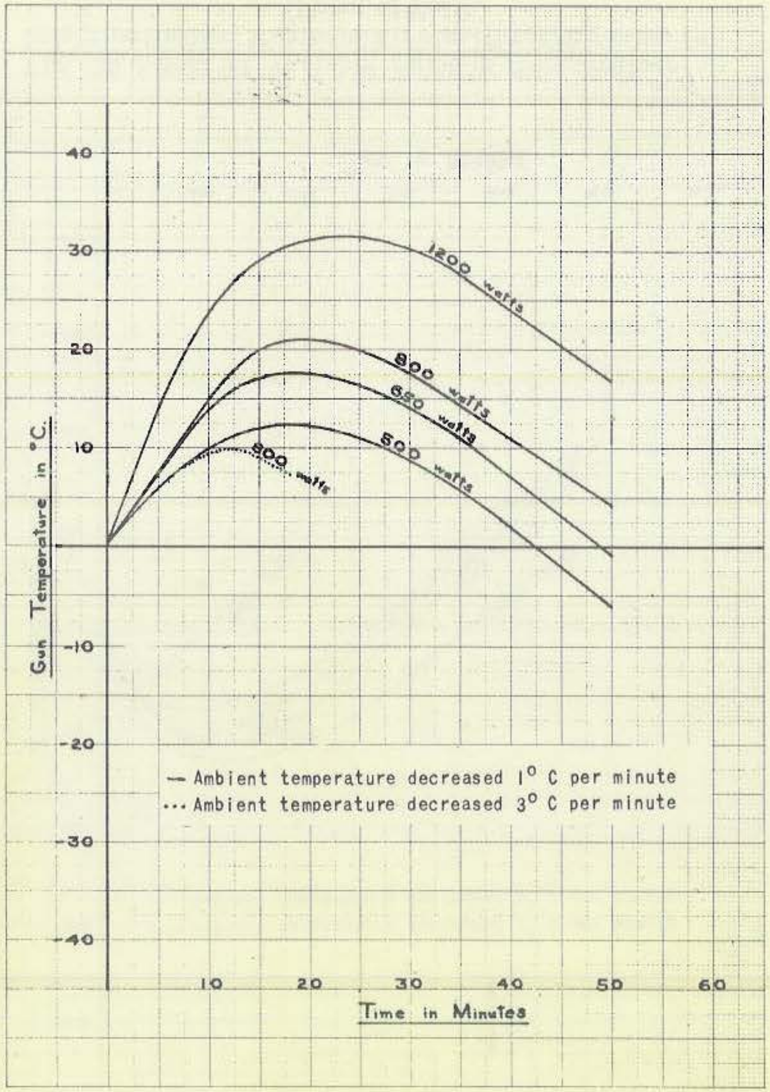


Fig. 30 Effect of Variable Ambient Temperature - Induction Heater, Maximum air blast through gun barrel. (Rear of Receiver)

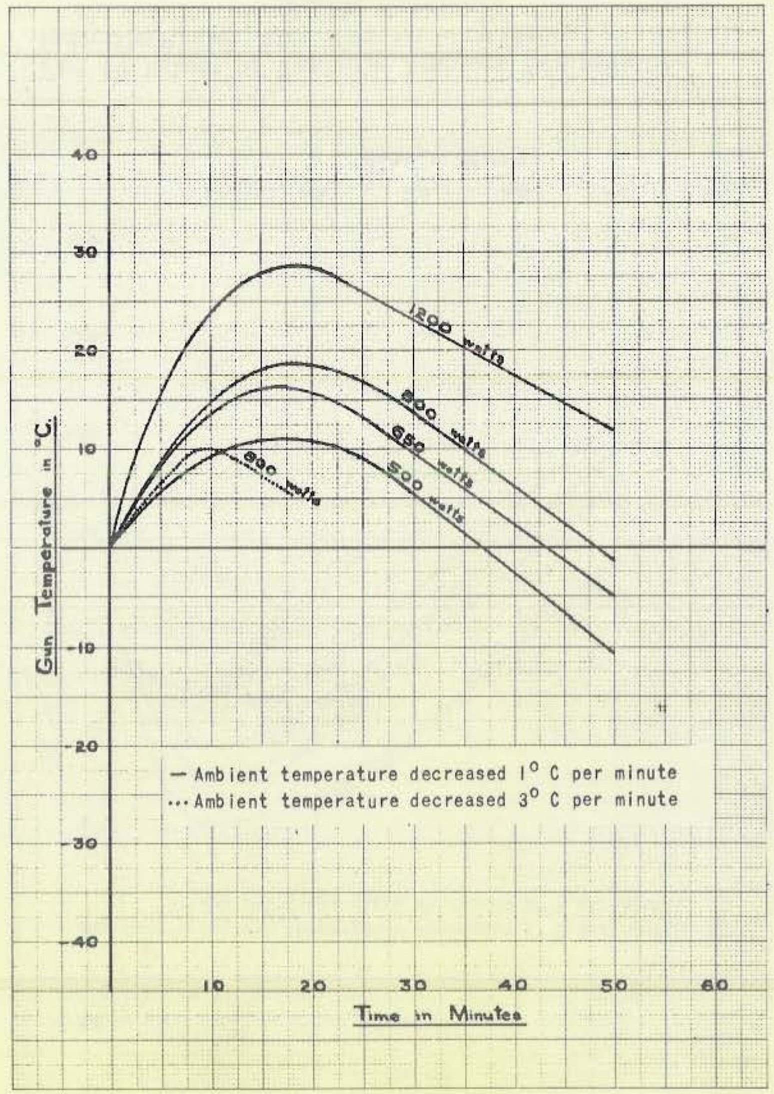


Fig. 31 Effect of Variable Ambient Temperature - Induction Heater, Maximum air blast through gun barrel. (Rear of Barrel)

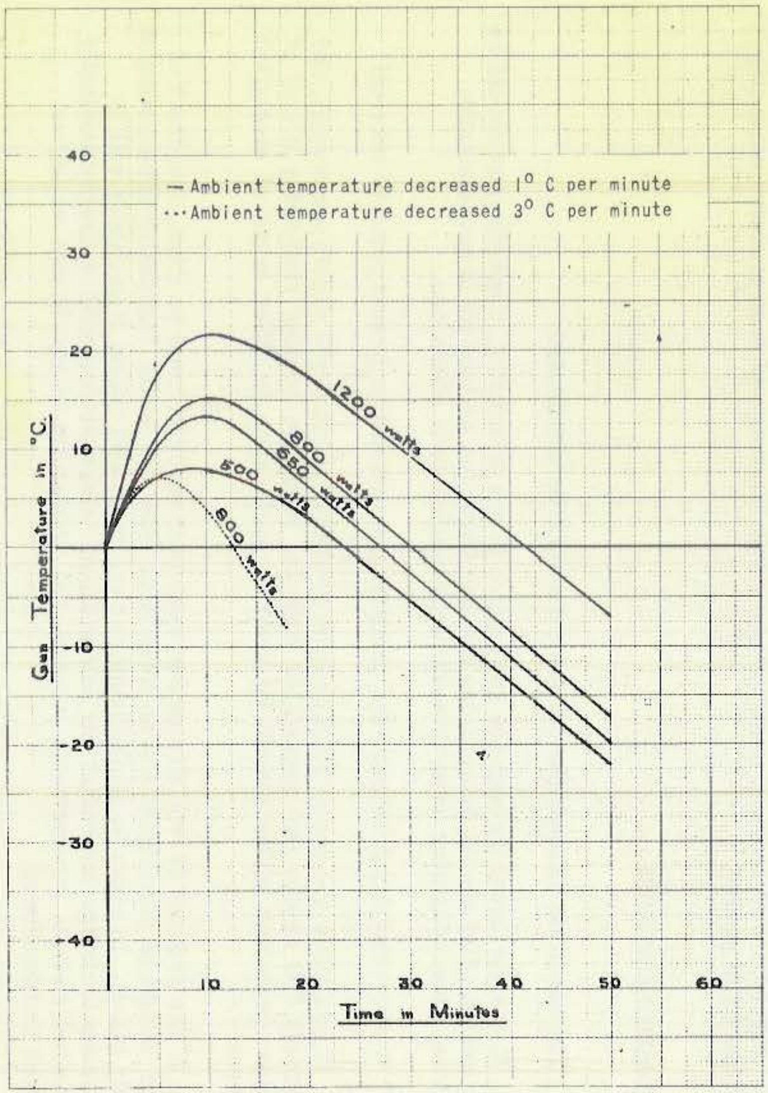


Fig. 32 Effect of Variable Ambient Temperature - Induction Heater, Maximum air blast through gun barrel. (Upper Cartridge Chute)

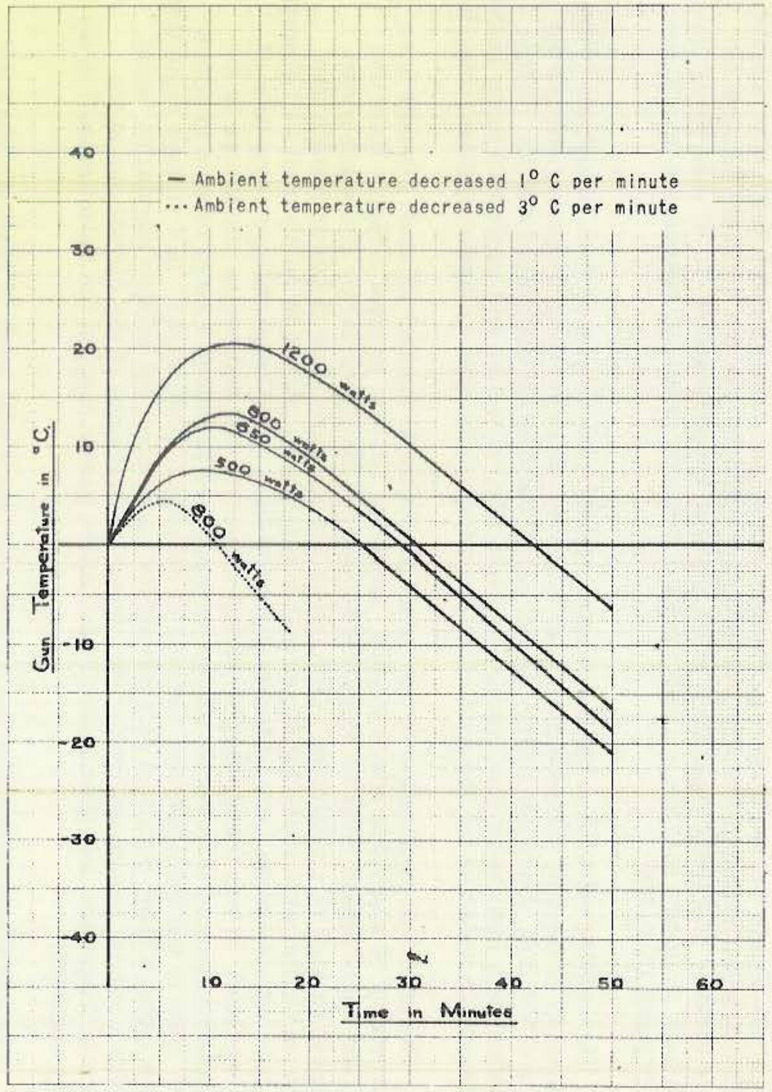


Fig. 33 Effect of Variable Ambient Temperature - Induction Heater, Maximum air blast through gun barrel. (Lower Cartridge Chute)

38. A resistance heater located in the same position as the present T-2 heater should have a minimum rating of 650 watts (assuming elimination of the air blast through the gun barrel) for continuous operation at an ambient temperature of -30° C (see paragraph 47, below), to insure that the gun will function properly under all reasonable conditions (see Figures 15 to 20).

39. The heating effect of a coil increases slightly with frequency even though the active power input to the coil remains constant. However, the operating frequency effects the design of the coil, since for a given power input, the current decreases and the voltage increases with increasing frequency. Consequently, wire size and number of turns in the coil should be selected for the particular frequency to be used to insure optimum results.

40. The practical application of the induction heater to present aircraft depends upon the provision of a suitable power supply. Induction heaters present a highly inductive load, and some means must be employed to correct the power factor if the generator size is to be kept at a minimum. Also, a reasonable regulation of power input to the heater under the wide variation of generator speed encountered in an aircraft will almost certainly require some form of frequency regulation, or at least voltage regulation of the generator. It was found that for a fixed induction coil and series condenser in an unregulated system, a moderate change in frequency produced a large change in active power input to the induction coil because of resonance phenomena. In a voltage regulated system using a fixed induction coil and series condenser, the voltage regulation would produce a partial compensation for the change in reactance of the circuit due to the change in frequency, and thus maintain the active power input to the induction coil more nearly constant.

41. The gun temperature rise for a given coil and power input is approximately the same, regardless of ambient temperature within the range of temperatures normally encountered in nature.

RECOMMENDATIONS

42. The air blast through the gun barrel should be eliminated.

43. If the air blast through the gun barrel is not eliminated, a muzzle cap should be used and the pilot should delay firing his test burst for as long as is operationally possible, when operating under low ambient temperature conditions.

44. If operationally practical, the machine guns should be heated prior to take-off.

45. If a suitable a-c power supply can be provided (at least 400 cycles per second, and preferably 800 cycles per second, or higher), induction heating employing a coil of the type described above should be used in preference to other types of electrical heaters.

46. If the present 24-volt d-c power system in aircraft must be used, then the T-2 heater should be redesigned for an input of at least 650 watts (assuming elimination of the air blast). In order to fit the heater in the available space, it probably will be necessary to design the heater for low ambient temperatures with a thermostatically controlled switch, strategically located, for protection of the heater at higher ambient temperatures.

47. Regardless of whether induction or resistance heaters are used, consideration should be given to the installation of a thermostatically controlled heater switch, strategically located on the gun, to remove the heater load from the generator at higher ambient temperatures, making the use of a smaller generator possible since the rating for a given generator depends upon ambient temperature. The use of a smaller generator would be feasible, since the critical need for gun heaters occurs at low ambient temperatures, which is also the condition under which the generator and associated equipment may be safely overloaded. Because of space limitations and the protection required by the heater element, the use of a thermostatically controlled switch is probably more important with the resistance heater than it would be with the induction heater.

48. This final report concludes the project as of the date of this report.

PRNC-2126-5-29-47-100