AD-A135448

12

TECHNICAL REPORT
NATICK/TR-83/046

DEVELOPMENT OF A PROTOTYPE MILITARY FIELD SPACE HEATER

BY
WILLIAM NYKVIST

APRIL 1983

UNITED STATES ARMY NATICK
RESEARCH & DEVELOPMENT CENTER
NATICK, MASSACHUSETTS 01760

AERO-MECHANICAL ENGINEERING LABORATORY

83

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NATICK/TR-83/046	2. GOVT ACCESSION NO. AD-A135 448	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) DEVELOPMENT OF A PROTOTYPE MILITARY FIELD SPACE HEATER		5. TYPE OF REPORT & PERIOD COVERED Jan 79 – Oct 82 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) William Nykvist		8. CONTRACT OR GRANT NUMBER(s) N/A
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Natick Research and Development Laboratories Aero-Mechanical Engineering Laboratory Natick, MA 01760		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 6.2, 1L162723AH98 AF008
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Natick Research and Development Laboratories Aero-Mechanical Engineering Laboratory Natick, MA 01760		12. REPORT DATE April 1983 13. NUMBER OF PAGES 35
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approval for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

HEATING
FIELD HEATING
COMBUSTION
HEATERS
TENT HEATERS
LIQUID FUELS
LIQUID FUEL BURNERS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers the design, fabrication, test, and evaluation of a prototype field space heater intended as a possible replacement for the M1941 heater. This prototype features a large triple-stage burner obtained from Holland that uses staged combustion to achieve clean burning with diesel fuel. The heater is designed to operate primarily with diesel fuel, but can burn any liquid fuel, and wood or coal when a grate/plate is added. The development covers two prototype designs, the prototype 1 unit and the improved prototype 2 heater. The prototype 2 heater achieved the goals outlined at the beginning of the development but may require further design interations to be an acceptable field heater.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

PREFACE

There is a trend to dieselize Army fuel-burning field equipment to reduce the logistic burden of supplying several fuels. The existing M1941 space heater is capable of burning diesel fuel but generates a substantial amount of smoke and soot; it works best with more refined fuels, such as kerosene or gasoline. A need exists for a nonpowered field space heater that can burn diesel fuel cleanly. This report describes the development of such a heater. The author would like to thank John Roche and James McLaughlin for the fine job they did in performing many hours of tedious test work, and Joe Doyle and "Tex" Teixeira for the excellent sheet metal fabrication work.

This work was performed under Task AH98, Clothing, Equipment and Shelter Technology, work unit AF008, Field Heater Prototype Evaluation.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

DEVELOPMENT OF A PROTOTYPE MILITARY FIELD SPACE HEATER

INTRODUCTION

The presently used field space heater, the M1941, was introduced to the military over 40 years ago. The original design has been changed very little since then. Over the years, users have made complaints concerning the frequent cleaning necessary, especially when using diesel fuel. Exhaust stacks were claimed to become plugged solid with soot, and tents with M1941s were described as coated with soot and permeated with an objectionable diesel fuel smell. Cleaning the heaters was often used as a form of punishment.

An exploratory development program was initiated in the late 1970's to study the design problems in liquid fuel space heating and to investigate alternative designs. It was found that nonpowered space heating technology was more advanced in Europe than the U.S., and that a triple-stage burner developed in Holland had the most potential to replace the aged M1941. This Dutch burner features staged combustion, which results in complete and very clean burning of diesel fuel. This report covers fabrication and tests of two prototype heaters that employ a large triple-stage burner.

The effort was directed toward developing a heater that would meet the following objectives:

- have a heat output of at least 14.6 kW (50,000 Btu/h);
- operate with diesel fuel as the primary fuel, gasoline and jet fuel as alternate fuels, and wood and coal as emergency fuels;
- have smoke spot number of three or less (ANSI/ASTM Test D 2156–80) with all liquid fuels;
- self-store all components;
- be physically stable;
- be incapable of being overfired;
- be as compact and lightweight as possible;
- have a flat top for heating rations;
- have a permanently mounted, protected, fuel metering valve;
- be as safe as possible;
- be as maintenance-free as possible.

PREVIOUS WORK

Early research and test work with field space heaters[1] evaluated the standard military heaters (the M1941 and M1950) as well as several developmental and foreign heater models. Conclusions of that report indicated candidate heaters with the most promise of replacing the M1941 were a heater with an exhaust gas return duct, and a triple-stage heater. A heater with an exhaust gas return duct, called the return-stack heater was then designed, fabricated, and tested. The development effort achieved only a limited success and was documented in a Technical Note[2] along with three other developmental heater designs.

The concurrent development work with the triple-stage heater, however, was much more successful.

The first triple-stage heater tested was obtained on loan from England, a commercial British heater modified for military use, the Aladdin 30T. The heat output at maximum fire with diesel fuel (15 cc/min) was 4.7 kW (16,330 Btu/h), about one third of the desired output. The tests indicated the heater was very clean-burning with diesel fuel. The developer of the triple-stage burner, Sesto Research Institute, was contacted, and a larger capacity burner was obtained. A heater body was fabricated and the resulting heater was called the triple-stage heater, type 2. The heat output at maximum fire with diesel fuel (31.6 cc/min) was 13.3 kW (45,380 Btu/h). Again the heater performance was excellent with low smoke emission at maximum output. The maximum output, however, was below the goal of 14.6 kW (50,000 Btu/h), so an in-house effort was undertaken to build a larger capacity burner. The burner design was basically a 40% scaled-up version of the Sesto burner. A heater body was fabricated, and the resulting unit was called the triple-stage heater, type 3. The performance of this heater was disappointing. It generated considerable smoke and exhibited unstable burning at 30 cc/min. Several modifications were made, which improved performance only slightly. The heat output at maximum fire with diesel fuel (35.3 cc/min) was 13.9 kW (47,310 Btu/h), with a smoke reading of 5. This performance was below our goal of 14.6-kW heat output and smoke reading of 3 or less. Sesto Research Institute was contacted, and indicated it could fabricate a burner meeting the desired requirements for a reasonable cost.

A contract was awarded to Sesto in November 1977 to fabricate a triple-stage burner and install it in the government-furnished heater body. Sesto had trouble achieving the desired performance with its burner in the government heater body, so the company designed its own heater body. The resulting unit was called the triple-stage heater, type 4. The performance

[1] W. Nykvist. Evaluation of Liquid Fuel Space Heaters: Standard Military, Developmental, and Foreign. US Army Natick Research and Development Laboratories, Technical Report NATICK/TR–79/021, October 1978 (AD A075800).

[2] W. Nykvist. Field Space Heaters: Design and Test of Four Alternative Concepts. US Army Natick Research and Development Laboratories, Technical Note NATICK/TN–82/006-AMEL, July 1982.

was genera excellent, but maximum heat output was only 13.1 kW at 37.5 cc/m diesel fuel input with a smoke reading of 4. The heater operated with more excess combustion air than the type 2 and 3 units and had a smaller heated surface area. This combination resulted in a lower thermal efficiency, and a heat output below the desired goal. Also, the lack of a flat top for ration heating, no solid fuel capability, external stack storage, and excessive weight (55.3 kg compared to 22.7 kg for the M1941) were liabilities.

All of the above development work is detailed in Reference 1. In addition to the triple-stage heater development work, several other heaters were tested and evaluated: the UK 10-kW gasoline heater, the Kawabe 800S, the return stack orchard heater, the LWL experimental heater, the round triple-stage heater, the variable-air pot burner, and the extended body M1941 heater. Details of tests of these units are also in Reference 1.

The present work covers additional development work on two heater designs, that house the largest Sesto (90 x 550-mm combustion opening) triple-stage burner, which originally was in the type 4 heater. Concurrent with this work was a parallel effort, reported in Reference 2, which involved in-house design and test of alternative heater designs: the round triple-stage heater, the return-stack heater, the double-stack heater, and the low-profile heater. The round triple-stage heater was designed and fabricated in-house, intended as a direct replacement for the pot burner in the M1941 heater. The concept was to curl the rectangular triple-stage burner into a circular shape. The performance was generally good, but there was a persistent problem of soot buildup within the heater. In spite of many modifications, tests and retests, the internal soot buildup could not be reduced. The return-stack and double-stack heaters both employed the M1941 pot burner in heater bodies designed to achieve exhaust gas recirculation. Both heaters exhibited poor performance. The low profile heater featured a unique 12-mm (5.5-in) high burner with small burner pot and S-shaped combustion path. The burner was designed with three combustion stages. Performance was poor due to excessive heat buildup in the burner interior and uneven burning.

TEST PROCEDURES AND EQUIPMENT

Heater tests were conducted as much as possible during the winter season in a small hard-walled shelter located out-of-doors in an open area. The shelter was 3.5 m long, 3 m wide, and 2 m high, with a hatch in the roof through which stacks protruded during tests. This is the same shelter used in tests documented in the Reference 1 Technical Report.

In a typical test, the heater was started and the fuel-metering valve was set on the desired setting until temperatures stabilized. Temperatures of the stack gases and heater body were measured with type J thermocouples and recorded on a Leeds and Northrup Speedomax model G temperature recorder. After temperature stabilization, the following data were recorded: fuel flow rate, stack draft, percent CO_2 in exhaust gases, smoke reading, outside wind speed, and ambient temperature. Two readings of percent CO_2, fuel flow rate, and smoke number were taken, and averaged. The metering valve setting was then increased, and the procedure repeated. The smoke, draft, and CO_2 measurements were made from a hole in the stack 330 mm (13 in) above the heater top surface.

Smoke readings were taken with a Bacharach model RCC–B True-Spot Smoke Tester, percent CO_2 was measured with a Fyrite model CND CO_2 tester, and draft was measured with a Dwyer model 2000–00 magnehelic pressure gage. Ambient temperature was measured with a type T thermocouple connected to an Omega Trendicator temperature sensor, model 410AT, and wind speed was measured with a hand-held Dwyer wind meter. Fuel flow rate was found by measuring, with a stopwatch, the time for the fuel level to drop 20 cc in a burette.

TRIPLE-STAGE BURNER

Sesto Research Institute, Hilversum, Holland, designed the triple-stage burner so it would achieve hydroxylative combustion. In this type of combustion, the hydrocarbons oxidize slowly, during which several intermediate products, alcohols and aldehydes, are formed. Aldehyde degradation occurs, and in each step of the reaction, carbon monoxide and water vapor are formed. The subsequent oxidation of the carbon monoxide to carbon dioxide colors the flame blue. The slow oxidation process allows all carbon to be converted to carbon dioxide and all hydrogen to water vapor. Combustion is complete, and the flame is very regular and quiet.

The undesirable type of combustion is the carbonic type. In this type of combustion, high temperatures break down the hydrocarbon molecules immediately into carbon and hydrogen, which oxidize independently. The hydrogen combines explosively with the oxygen, and the slower oxidizing carbon does not burn completely. Carbonic combustion is characterized by yellow flames (incandescent, unburned carbon particles), smoke, and soot.

The triple-stage burner is shown in a cut-away sketch, along with the flame position at several firing rates in Figure 1. The three stages are created by removable baffles. Air is admitted under each baffle through carefully sized holes, so the fuel is oxidized slowly, in stages. Hydroxylative combustion is achieved over a large range of firing rates because air is admitted in stages and oxidation is carried out slowly. At low fuel-flow rates, flames occur under the first baffle, as there is enough oxygen there to support combustion. As the fuel flow increases, flames move up within the burner until at maximum flow only flameless (hydroxylative) oxidation occurs within the burner and flames are seen only at the top row of holes.

TRIPLE-STAGE HEATER PROTOTYPE 1

Description

The type 4 triple-stage heater, obtained under contract from Sesto exhibited excellent performance but several aspects of the design were undesirable. Needed were a flat top for ration heating, a solid fuel capability, smaller overall size, and a lower weight. Therefore, the on-hand type 3 triple-stage heater upper body was modified in-house and a new burner housing was designed and fabricated to accept the Sesto triple-stage burner. The resulting heater was called the triple-stage heater prototype 1 but will be more conveniently referred to as the prototype 1 heater; several photographs of this heater are shown in Figure 2.

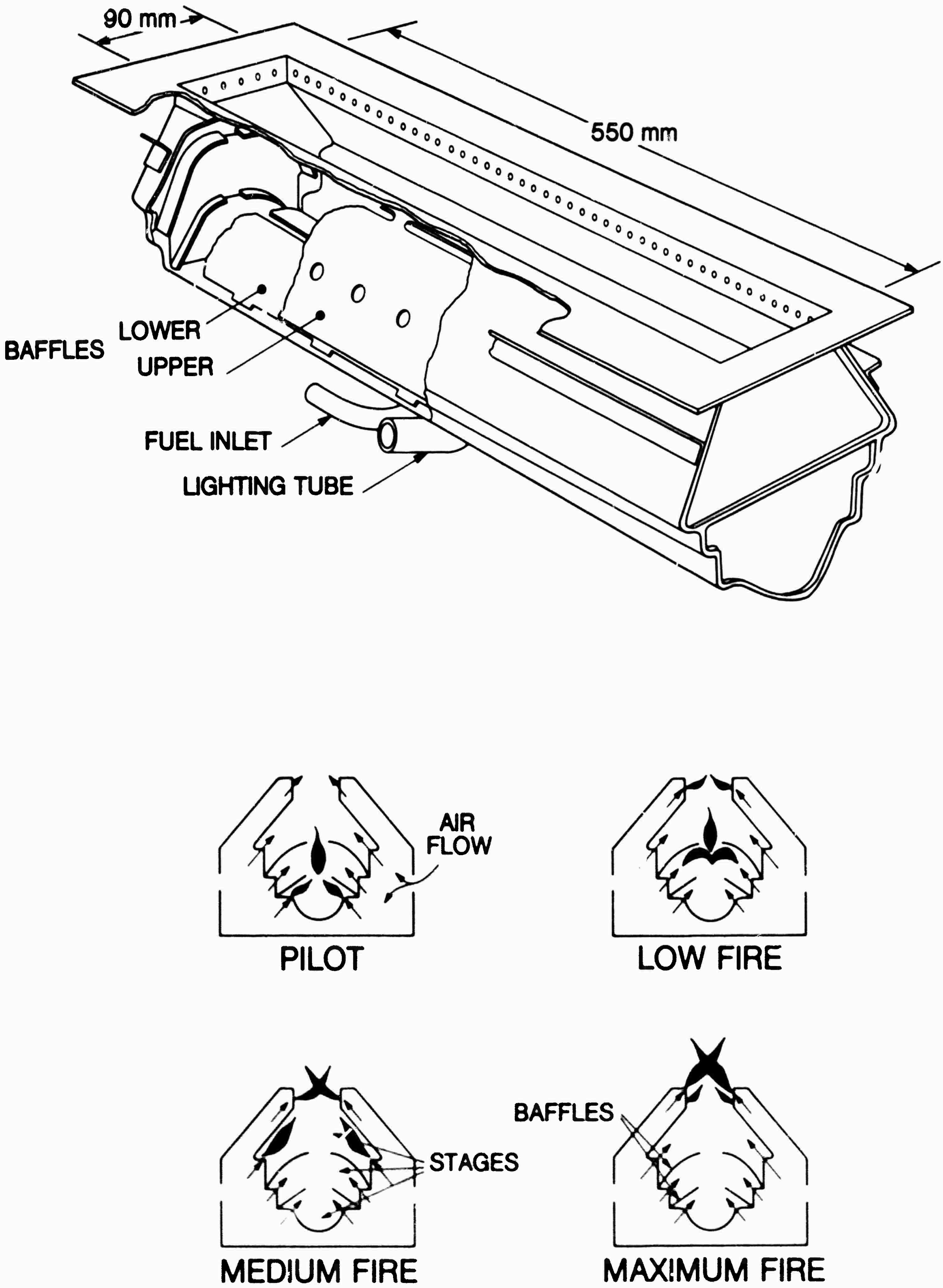

Figure 1. Triple-stage burner and position of flame at various firing rates

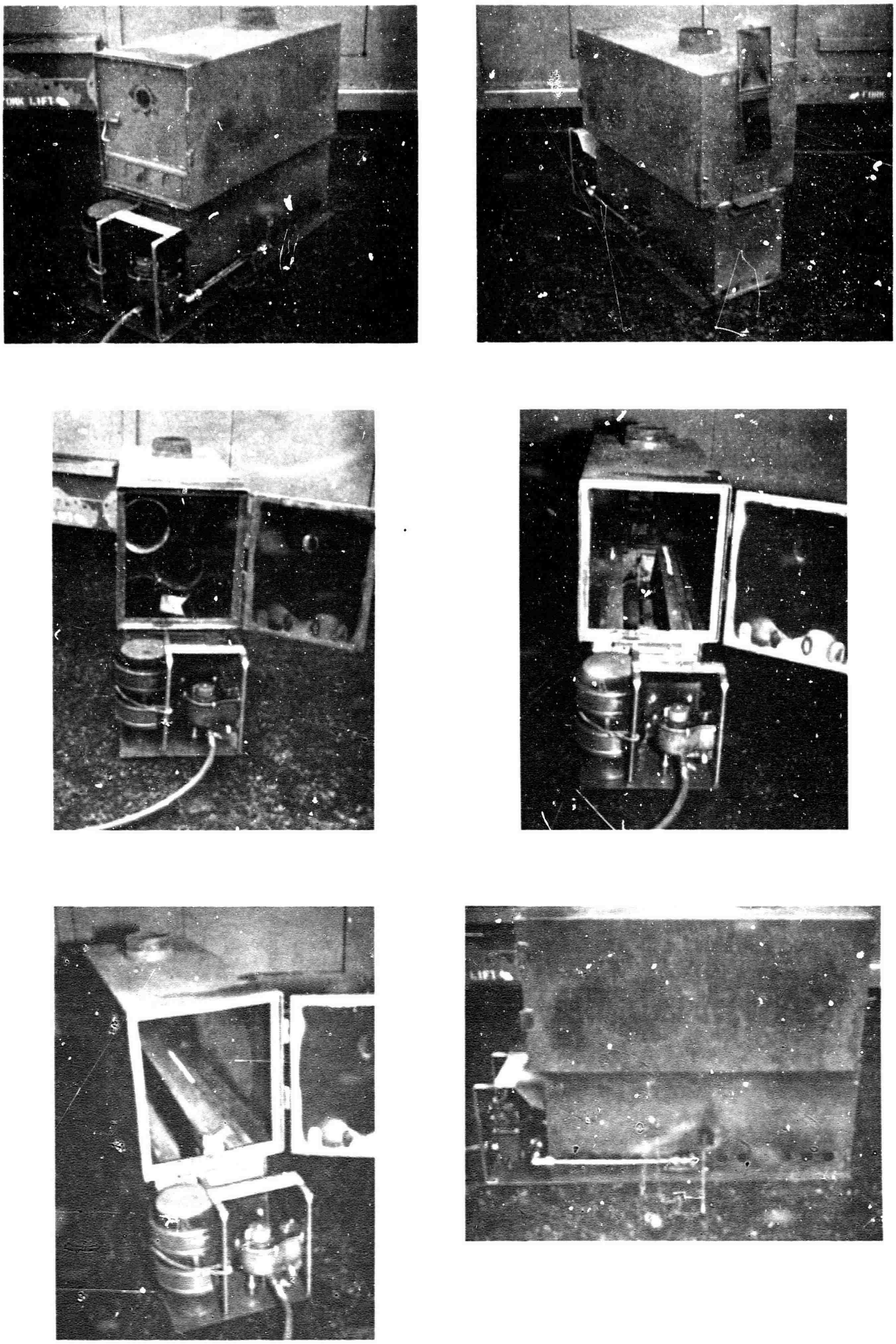

Figure 2. Triple-stage heater, prototype 1

The dimensions of this heater (L x W x H) are 755 x 254 x 508 mm (29–1/2 x 10 x 19–3/4 in), excluding the stack collar which is 44-mm (1–3/4-in) high. The weight of the heater, including five stack sections and flue cap, is 26.8 kg (59 lb). The heater self-stores all components and has a solid fuel capability if the burner is removed and a combination plate and grate is inserted on top of the burner opening. The hinged door is large enough to insert good-sized pieces of wood, and there is an air shutter to adjust the solid fuel burning rate. A mica sight glass is included to permit viewing of the interior of the heater. This is necessary in the liquid fuel lighting procedure, and handy when burning solid fuel. An explosion hatch was included at the rear of the heater. This hatch is held closed only by its own weight and will automatically relieve any buildup of internal pressure that may occur when the lighting procedure is not carefully adhered to, or when a warm heater is mistakenly relighted. The Sesto-designed type 4 triple-stage heater had a similarly sized explosion hatch. The fuel metering valve used is the same one used with the M1941 heater. In contrast with the way the metering valve is mounted on the M1941 heater, here it is permanently mounted with machine screws, is protected from damage due to rough handling, and is shielded from radiant heat.

Due to the closed design of the burner, lighting is accomplished by means of a lighting tube and taper. The taper consists of a metal strip with a nonflammable wicking material attached to one end. To light the burner, the fuel metering valve is turned on to admit fuel to the burner. The taper is inserted in the lighting tube and is periodically withdrawn to see if the fuel has wetted the wick. Once wetted with fuel, the wick is ignited and inserted into the bottom of the burner through the lighting tube. The metering valve must be at a low setting during the lighting procedure so the burner is not flooded with fuel. After about five minutes of warmup, with wick sustaining the fire and plenty of combustion air being admitted through the open lighting tube, the burner interior is sufficiently heated to sustain the fire without need for the wick. The flames will appear at the top of the burner, and a audible combustion noise will be heard at the lighting tube. At this time the wick should be withdrawn and the lighting tube cap should be replaced. The metering valve setting can then be gradually increased, over a period of about 10 minutes, to the maximum value. The lighting tube cap and the taper are captivated by means of a chain to prevent accidental loss.

In the design pictured in Figure 2, the stack collar is located to the rear of the top surface of the heater to present a larger open area for ration heating. Later the stack collar was moved to the center to assure more even burning. The heater door has a sliding latch that locks the door closed when the latch is in the leftmost position; the latch pin engages a hole in the heater body. The flue cap is stored adjacent to the metering valve for transit, and is held in place by an extension spring. The flame spreader is removable, and must be removed and repositioned so five standard stack sections can be stored in the heater interior. The fuel inlet to the burner has a "T" pipe connector with the outer part plugged with a standard threaded plug. The fuel entrance to the burner can get a buildup of carbon after hundred of hours of operation; to remedy this situation, the plug can be simply removed and a rod or twig can be used to unplug the opening. Connected to this pipe "T" connector is a flare fitting that joins the connector to copper tubing. The flare fitting must be disconnected to remove the burner. The upper heater body is attached to the burner housing at the front and rear ends by a total of four machine screws. The stack sections used with this heater are the standard ones used with the M1941 heater, with a diameter of 102 mm (4 in) and a length of 610 mm (24 in). The heater was fabricated from mild steel, with sheet metal thickness of 1.6 mm (0.0625 in) for the upper body and 1.3 mm (0.050 in) for the burner housing. The flame spreader, however, was made from type 304 stainless steel. The burner, made by Sesto, was fabricated from type 430 stainless steel.

The heated surface area consists of the top, sides, and ends of the upper heater body and is 6425 cm^2 (996 in^2). The heated surface area of the M1941 heater is approximately 4000 cm^2 (620 in^2). The increased heated surface area was necessary to be able to store five stack sections, but also was expected to increase efficiency.

The type 4 heater incorporated five Sesto-made stack sections having a total length (to the top of the flue cap) of 2972 mm (117 in). The prototype 1 heater, which uses the same burner, therefore was designed to use five of our standard stack sections with flue cap, having a total height (to the top of the flue cap) of 300 mm (118 in).

Development Tests

A total of 42 tests were run with the prototype 1 heater. As diesel fuel is the most difficult of the three fuels (gasoline, jet fuel, diesel) to burn cleanly, it was used in most tests. The burner was successfully tested previously with gasoline and kerosene when it was installed in the type 4 triple-stage heater. Original test data for the prototype 1 heater is located in NLABS Laboratory Notebook 7232.

Results from nine tests were chosen for inclusion in this report. These tests detail heater performance in several configurations and after several modifications, and effectively summarize the development effort with the prototype 1 heater. Results are shown in Table 1. Thermal efficiency values were calculated using the formula outlined in Appendix B of Reference 1.

Initial tests with the prototype 1 heater indicated an uneven flame pattern at the high firing rates. It was thought than an uneven fuel puddle on the bottom of the burner was contributing to the heavy flames at the burner rear. It was found that a level heater body did not provide a level burner, and that shims were necessary at the rear of the heater to level the fuel puddle. Test designation A shows the heater performance with a leveled burner. At the high setting the flames were very large at the front and rear ends of the burner, but were much smaller in the middle. The burner was subsequently removed and the bottom contour examined. A profile of the burner bottom was made by measuring the distance from the top surface to the bottom in seven places. The profile is shown in Figure 3.

Table 1. Test Data for Triple-Stage Heater Prototype 1

	Test Designation	Diesel Rate (cc/min)	Smoke (BACH) (%)	CO_2 (%)	Draft (mm H_2O)	Temperature (°C) Stack	Body	Ambient	Thermal Efficiency (%)
PILOT	A	6.4	1	1.0	1.02	193	154	-7	
	B	6.7	2	1.5	0.97	227	127	-6	
	C	10.7	6	1.5	1.14	271	199	7	
	D	7.0	6	1.0	1.27	204	171	2	
	E	7.5	6	1.0	1.14	216	138	19	
	F	6.9	8	1.0	1.17	246	110	23	
	G	10.3	2	2.0	1.14	282	193	8	
	H	6.8	2	0.5	0.97	199	132	4	
	I	7.9	6	3.0	0.97	237	166	5	
LOW	A	17.1	1.5	4.8	1.40	449	310	-7	47.5
	B	17.2	0.5	4.0	1.40	427	299	-5	41.9
	C	16.4	4	3.5	1.40	338	277	7	47.9
	D	19.7	3	3.5	1.91	443	327	3	32.7
	E	17.4	4	4.0	1.91	466	307	17	36.9
	F	21.8	1	6.5	1.78	521	338	25	52.7
	G	19.4	0	5.0	1.46	427	316	9	51.5
	H	21.8	1.5	4.0	1.45	510	288	6	31.3
	I	16.7	7	5.0	1.32	371	293	6	57.3
MEDIUM	A	29.6	1.5	7.5	1.65	627	421	-6	50.0
	B	29.6	1	8.0	1.60	627	421	-4	52.4
	C	32.4	0	6.0	1.78	599	399	7	42.9
	D	30.4	1.5	6.0	2.24	599	421	4	42.9
	E	31.6	5	8.0	2.21	682	435	19	48.7
	F	27.9	1	9.0	1.78	649	399	26	55.1
	G	31.2	1	7.5	1.65	604	421	10	51.7
	H	30.8	2	6.5	1.57	674	343	8	40.3
	I	29.3	1	6.5	1.57	516	404	6	53.2
HIGH	A	38.7	8	10.0	1.78	710	493	-4	55.0
	B	36.9	7.5	9.0	1.78	693	482	-2	52.4
	C	37.5	5	9.5	1.91	671	477	7	55.6
	D	38.1	3	8.5	2.34	671	482	4	51.7
	E	40.0	9+	10.5	2.41	693	516	22	57.5
	F	38.1	7	11.5	1.91	729	477	28	58.4
	G	40.0	3	11.0	1.75	671	482	12	60.0
	H	37.5	7	8.5	1.80	732	391	8	47.8
	I	36.9	3	8.0	1.65	588	460	7	55.1

Designation	Configuration or Modification	Stack* HT (mm)	Test Date
A	Burner leveled, 5 stack sections with flue cap	3000	01/05/79
B	Burner bottom contour changed to reduce dip at ends; pie-shaped piece removed and bottom rewelded	3000	01/15/79
C	Sixth stack section added	3560	02/13/79
D	Seventh stack section added	4115	03/28/79
E	Changes recommended by Sesto: 48 holes in upper baffle, 12 holes in flame spreader, 16 holes at top end of burner, 6 stacks	3560	08/10/79
F	Heater sealed around door and periphery	3560	08/27/79
G	Stack opening moved 15 cm; now in center of heater top, flame spreader tips bent upward, six holes uncovered in burner top, baffle fit adjusted	3560	10/29/79
H	Thermocouples silver-soldered 3 places on burner inner bottom	3560	02/12/80
I	Ground off thermocouples, straightened burner in press, sealed air leaks	3560	09/02/80

*Include flue cap.

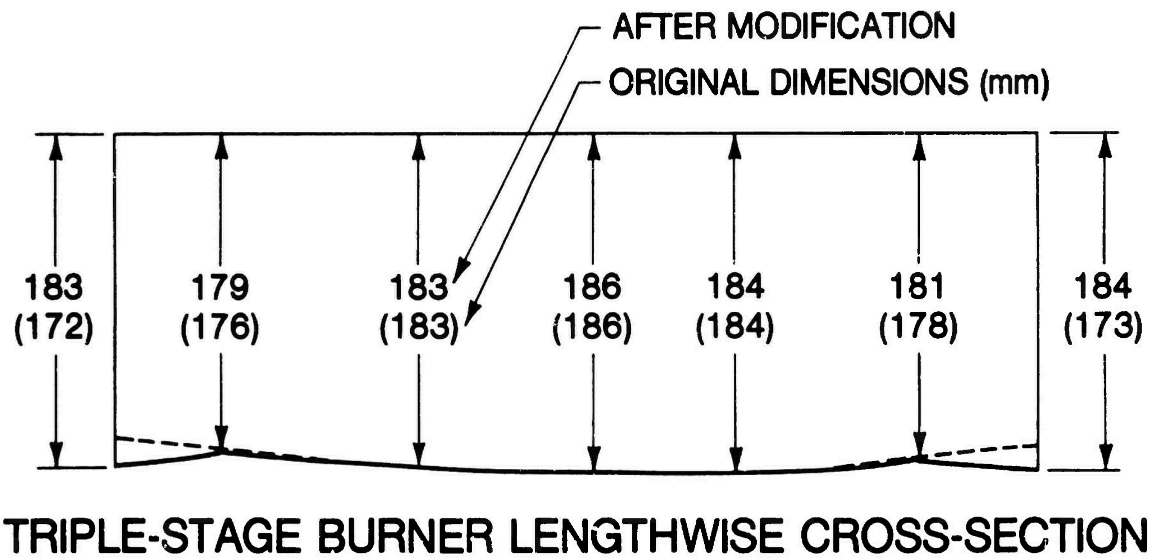

Figure 3. Bottom profile of triple-stage burner before and after modification

Sesto Research Institute made this burner by lengthening the combustion opening of its standard model from 400 to 550 mm (15.7 to 21.7 in). To accomplish this, the company welded a 75-mm (3-in) section on each end. The ridge in the bottom contour is where the weld was made. The large flames at both ends of the burner were attributed to this irregularity, so a modification was made at each end to eliminate the ridge. A wedge-shaped piece of metal was cut out, and the bottom was pulled together and welded. The resulting contour is shown by the dotted lines in Figure 3. The burner was replaced and another test was run; results are shown in Table 1, test B. The results showed only slightly cleaner burning, but the size of the flames at the ends of the burner was substantially reduced. The smoke reading at high fire was still excessive, however. A sixth stack section was added to increase the draft and reduce the smoke readings at high fire. The results, test C, showed a smoke decrease at medium and high fire, but some increase in smoke at low fire. It is noted that the M1941 heater requires six stack sections. Test D shows the results of adding a seventh stack section. Smoke readings at low, medium and high fire were excellent, all three or less; the smokiness at the pilot setting was not too much of a concern.

The need for six- or seven-stack sections poses a problem with the prototype 1 heater, as there is only room for internal storage of five stacks. Also, the performance of the triple-stage burner was disappointing. A letter was written to Sesto that included a description of the heater test results and a sketch similar to Figure 3. In response to our letter, Sesto built and tested a triple-stage heater with a 650 x 250 x 425 mm (25.6 x 9.8 x 16.7-in) rectangular upper body. To get satisfactory performance the company had to use six stack sections, and modify the burner as follows: add 48 holes to the upper baffle, 12 holes in the flame spreader, and 16 holes at each end of the burner top. With diesel fuel at 37 cc/min, Sesto recorded 0 smoke and a draft of 2.1 mm (0.083 in) water. Zero smoke readings were also recorded for kerosene at 38.8 cc/min and gasoline at 38.4 cc/min.

The recommended modifications were made to our burner, and test E was conducted. Results were poor. The heater was sealed to eliminate air leaks as a possible factor, and retested, test F. Except for the pilot setting, smoke levels were lower, but were still well above the 0 smoke claimed by Sesto. Unstable burning, accompanied by a roaring noise and heavy smoke, was observed at a fuel rate of 41.4 cc/min.

The next modifications made were to move the stack collar 150 mm (5.9 in) forward so it was centered over the burner, to bend the edges of the flame spreader upward as Sesto did in its tests, and to uncover six small holes (previously plugged) in the top of the burner. These changes made the heater configuration identical with the one tested by Sesto. Also, the upper baffle was bent outward so its fit in the burner was improved. The results, test G, were excellent. Tests were next carried out using gasoline (smoke 5 to 9 at 40 cc/min) and jet fuel JP–4 (smoke 5 at 41.4 cc/min). These tests were not included in Table 1.

With the heater performance finally excellent with diesel fuel, a series of tests were carried out to determine performance with the heater unlevel, front to rear. At this time, three thermocouples were soldered to the inside burner bottom to obtain basic temperature data to learn more about burner operation. This series of tests is covered in the next section of this report. The operation of the heater when level (baseline data for the "unlevel" series of tests) is included in Table 1 as test H. It is seen that CO_2 readings went down and smoke readings went up, especially at the high setting. It is possible that the thermocouples interfered with the fuel puddle as three fair-sized lumps of silver solder were on the inner burner bottom. Another possibility is that the baffles were accidentally bent and did not fit as well as in previous tests. At this time during the development work, the importance of close-fitting baffles was not known.

After the series of unlevel tests, the thermocouples were removed and the silver solder was ground off. The burner appeared to be warped, with the center of the baffle shoulders 3-mm (0.12-in) higher than the ends. The burner was supported by the two ends in a hydraulic press, and the center was pushed down to straighten it. The burner sides had warped outward in the center, so were also pushed inward with the press. Measurements of the burner bottom profile before and after straightening indicated less than a 1 mm (0.04-in) change in the bottom contour. The shoulders within the burner were much flatter, however, so the baffle fit was improved. The heater was reassembled, air leaks around the door were sealed, and test I was conducted. In this test smoke readings increased at the pilot and low settings, but decreased at medium and high.

At this point, testing was suspended with the prototype 1 heater. The design was inadequate in that only five stacks could be internally stored for shipment but six stacks were identified as necessary in tests. The method of attaching the upper body to the burner housing was also unsatisfactory.

Unlevel Performance

In all the tests with the prototype 1 heater, care was taken to insure the burner was level. To get the burner level, the upper heater body was removed, a puddle of fuel was allowed to collect in the burner bottom, and the rear of the heater was raised so the fuel puddle was centered. A 13-mm (1/2-in) shim was required. Because the curvature of the burner bottom is slight, with the center only 14 mm (0.55 in) lower than the ends, only a slight tipping of the heater can move the fuel puddle substantially off center. Figure 4 shows a top view of the fuel puddle at several tilt angles. The shim height necessary to tilt the 755-mm (29.7-in) long heater 1.5° was 19.5 mm (0.77 in).

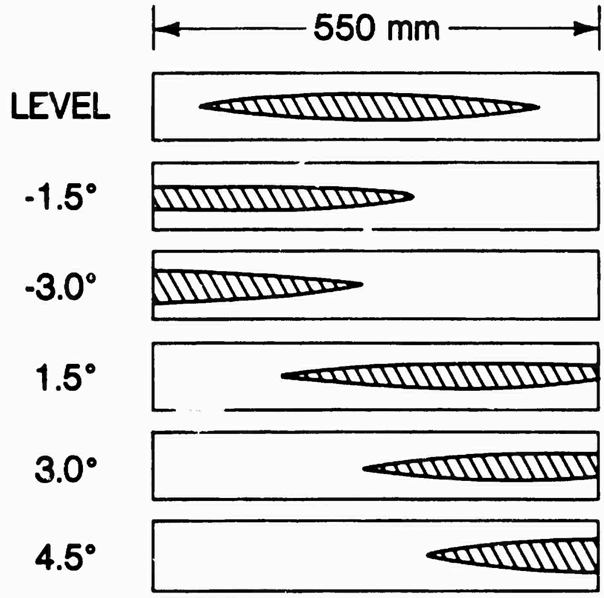

Figure 4. Top view of triple-stage burner fuel puddle at several tilt angles

As mentioned earlier, before any tests of an unlevel heater were run, three type-J thermocouples were silver-soldered to the inside bottom of the burner. One was located at the center, and the other two were 133 mm (5.25 in) from the burner ends; spacing between the thermocouples was 142 mm (5.6 in). Also, two thermocouples were silver-soldered to the inside bottom of the M1941 pot burner, located 13 mm (1/2 in) from the center air tube and 13 mm from the outer edge. Spacing between these thermocouples was 83 mm (3.25 in). Tests were run with both these heaters to obtain comparative data of the burner inside bottom temperatures. Figure 5 shows the results.

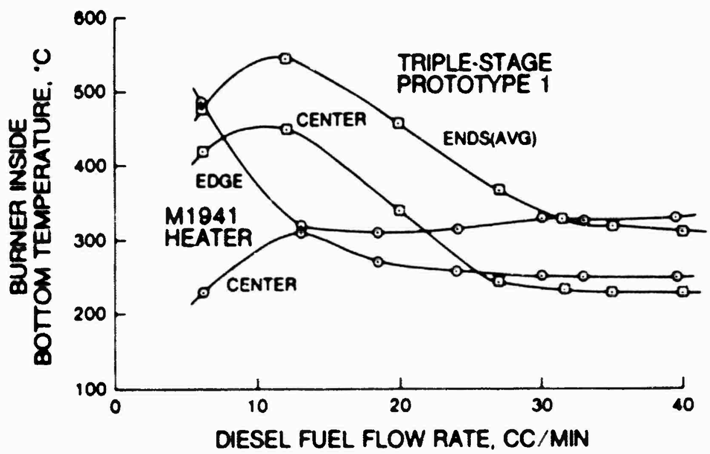

Figure 5. Comparison of burner bottom temperature for M1941 and prototype 1 heaters

For the triple-stage heater, the burner bottom temperature was highest at low fuel-flow rates. This result was expected due to the staged oxidation and baffle arrangement (see Figure 1). The M1941 heater is dependent on circulation of oxidizing vapors within the burner to heat the burner bottom, and exhibits a much different set of curves out to about 30 cc/min. In both heaters, the relatively cold fuel entering the burner kept the center temperatures lower than the ends or edges.

With this baseline information determined for burner bottom temperatures, a series of tests were run to record the effect of tilting the heater. Two diesel fuel flow rates were chosen, 30.0 and 37.5 cc/min, and six tilt angles were used: −3.0, −1.5, 0, 1.5, 3.0 and 4.5 degrees, were negative angles denote the rear of the heater raised. Results are shown in Figure 6. Also included in Figure 6 are smoke readings for each tilted condition. At 30 cc/min there was a large temperature difference (250°C) between the front and rear thermocouples at an angle of 0 degrees, indicating that there was an uneven burning or the burner really was not level. Possibly the heat caused some stresses that warped the burner bottom. The data suggest the burner was actually level at an indicated angle of 1.5 degrees. The center temperature was only slightly affected by tilting, but the front and rear thermocouples indicate an increasing temperature as the fuel puddle moved further away. The fuel inlet is approximately 30 mm (1.2 in) on the front side of the center thermocouple, so when the front of the heater was tilted up, the cool fuel entering the burner washed over the center thermocouple. The opposite of this happened when the rear was tilted up. The rear thermocouple is 60 mm (2.4 in) further from the fuel entrance than is the front thermocouple; this explains why the rear thermocouple recorded generally higher temperatures than did the front. At 37.5 cc/min fuel flow, the curves appear very similar to those at 30 cc/min.

When the rear end of the heater was raised, the fuel feed system was tipped so the fuel had to flow uphill from the metering valve to the burner. Since the metering valve is the constant level type operating with about a 25 mm (1 in) head, tilting the heater rear upward more than 3° reduced the head to such a low value that the desired flow rate could not be achieved.

When the burner was tilted, the flames became much larger above the fuel puddle at the low end of the burner. This out-of-position fuel puddle caused an imbalance in the staged combustion process. It appears that there was a shortage of air in the vicinity of the fuel puddle, resulting in local incomplete oxidation within the burner. When the partially oxidized fuel-rich vapor exited the top of the burner and mixed with air from the far end, carbonic combustion resulted and large yellow flames were observed. Accompanying the large flames were smoke and soot. The smoke reading increased substantially when the heater was out-of-level by two to three degrees, which is equivalent to one end of the heater being 25 to 38 mm (1 to 1−1/2 in) higher or lower than the other end. To achieve optimum performance from this heater, it should be within 25-mm (1-in) of level.

NETHERLANDS ARMY TENT HEATER

Technical details of a new Royal Netherlands Army tent heater are given below. This heater (abbreviated RNLA heater) is presented and discussed in this report because it is a

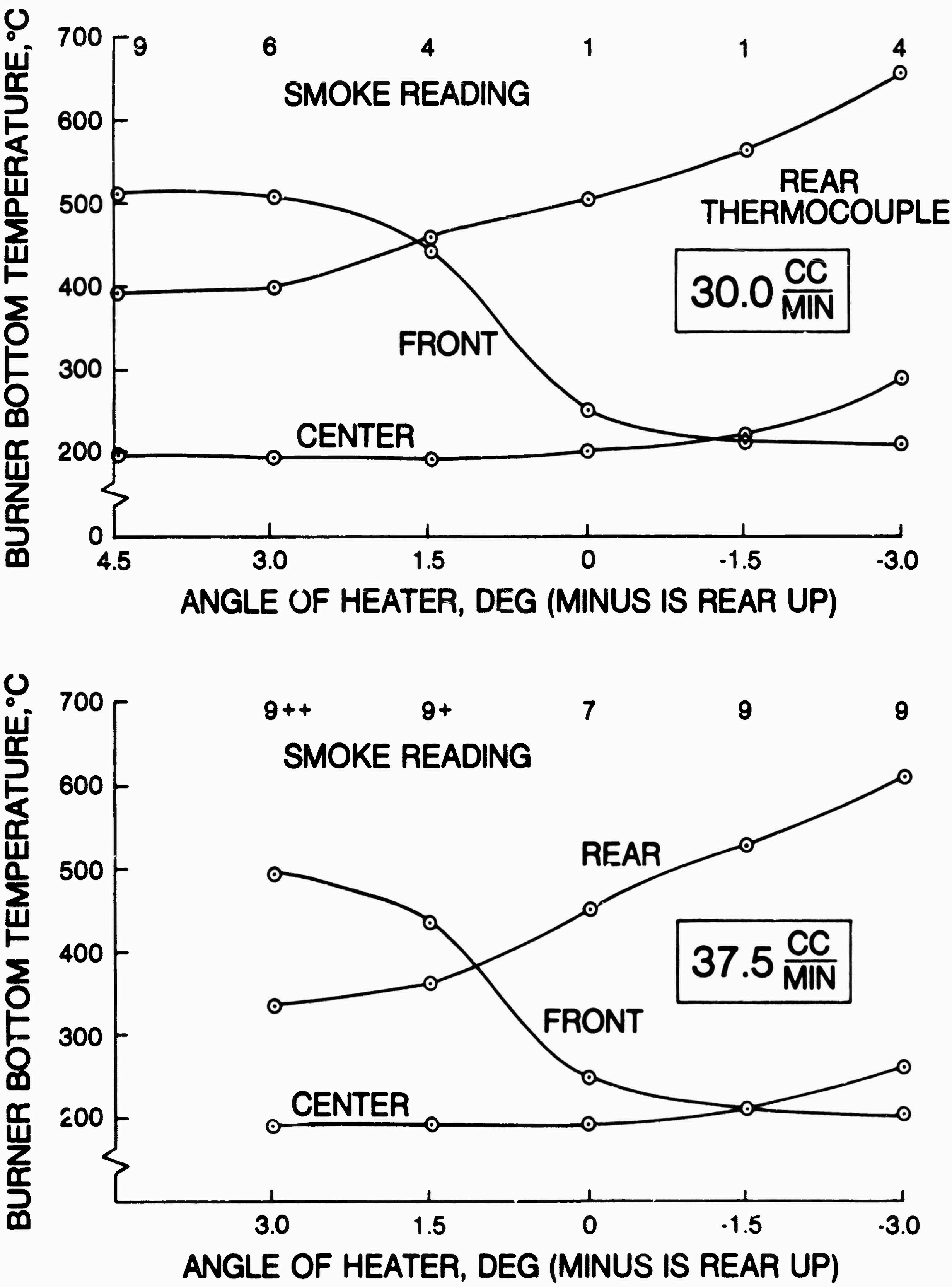

Figure 6. Prototype 1 heater unlevel performance

very similar developmental item: a military field space heater that uses a Sesto triple-stage burner to achieve clean burning with all three liquid fuels.

Lt.Col. R. DuMee of the Royal Netherlands Army visited NLABS on September 18, 1980 to discuss several areas of research with NLABS personnel. One of the areas was space heater research. The RNL Army had recently contracted with Sesto Research Institute to develop a new field space heater, and Col. DuMee was interested in the results of our heater that uses Sesto's triple-stage burner. Col. DuMee provided draft copies of a technical manual, instruction manual, and test report of the newly developed RNLA heater, called the Geraedts Hellendoorn Sesto Tent Heater, Model III.[3]

This heater features a Sesto triple-stage burner, which appeared to be the same burner (90 x 400 mm top opening) previously tested here in the type 2 triple-stage heater in Reference 1. The technical manual referred only to the burner as the "patented enlarged Sesto three-stage burner." The burner was housed in a sloped-top heater body (similar to the type 4 triple-stage heater, Reference 1), which was mounted in a protective steel-mesh cage. Heater dimensions (L x W x H) were 474 x 200 x 554 mm (18.7 x 7.9 x 21.8 in), while cage dimensions were 740 x 450 x 665 mm (29.1 x 17.7 x 26.2 in). Total heater mass was 62.5 kg (weight 137.5 lb).

A very tall stack was used, consisting of seven sections, with total assembled length (including flue cap) of 3980 mm (156.7 in). All sections were 95-mm (3.9 in) in diameter; six were 620 mm (24.4 in) long and the top one with exit slots was 560 mm (22 in) long. The steel mesh cage was large enough for storage of all seven stack sections in addition to a folded-up fuel can tripod and fuel line hose. The cage had a hinged top for access, and part of the cage side was also hinged for access to the fuel metering valve. Directions for use required that the heater be leveled prior to igniting. A plumb bob device was included on the heater unit to determine when it was level.

The test report presented laboratory performance data for the heater operated with gasoline, kerosene, and diesel fuel. Results are shown in Table 2.

Table 2. Performance Data for RNLA Heater (From Reference 3)

Parameter	Units	Diesel		Kerosene		Gasoline	
Fuel Flow	cc/min	6.7	29.5	10.4	32.7	13.0	35.2
Stack Draft	mm H_2O	1.45	2.65	1.8	2.45	1.8	2.5
CO_2	%	2.7	9.4	3.6	9.4	3.7	10.2
Stack Temp	°C	215	490	270	495	302	515
Smoke	BACH	0	0	0	0	1	1
Gross Input	kW	4.0	17.5	6.0	18.7	6.8	18.4
Efficiency	%	62.0	70.3	63	70.7	60.0	71.6
Heat Output	kW	2.5	12.3	3.7	13.2	4.1	13.1
	BTU/hr	8416	42013	12805	45000	13930	44630

[3]Technical Manual, Instruction Manual, and Test Report for Geraedts Hellendoorn Sesto Tent Heater, Model III, Netherlands.

The performance was excellent regarding smoke, with readings of 0 to 1 recorded over the entire operating range with three fuels. Stack drafts were quite high, as expected, due to the tall stack. Efficiencies were higher than those we obtained with a similar burner, in the type 2 triple-stage heater. Using the above values for stack temperature and CO_2 percent with the efficiency formula in Reference 1, efficiencies were approximately five percent lower.

Compared to the design goals for a U.S. military field space heater (see Introduction), the RNLA heater has too little output, cannot operate with solid fuels, is too heavy and bulky, and does not have a flat top for heating rations. The RNLA heater does, however, have two new features: use of seven stack sections and a plumb bob leveling device. When field-tested by the Netherlands Army, this heater may provide valuable user acceptance data.

TRIPPLE-STAGE HEATER, PROTOTYPE 2

Description

The prototype 2 heater is similar to the prototype 1 heater as it has the same basic shape, uses the same burner, the same fuel metering valve, and the same flue cap. Main differences are the stack sections, door, body attachment, and sheet metal material. Photographs of the prototype 2 heater are shown in Figure 7.

The overall dimensions (L x W x H) are 771 x 267 x 471 mm (30.4 x 10.5 x 18.6 in) less flue collar, which adds 38 mm (1.5 in) to the height. Total mass is 32.7 kg (weight 72 lb), which is 5.9 kg (13 lb) more than the prototype 1 heater due to the thicker sheet metal of the burner housing, the rugged frame, and the two additional stack sections. Heated surface area is 5490 cm^2 (851 in^2), 85% of that of the prototype 1 heater.

Seven stack sections were incorporated into the prototype 2 heater design. Tests with the prototype 1 heater indicated the need for at least six stack sections, and the Netherlands Army Heater required seven. In order to keep the heater as compact as possible, internal stack storage was again chosen; to accomplish this the stack sections were designed to be nestable in two groups. Four straight stack sections with diameters 133, 122, 112 and 102 mm (5.25, 4.81, 4.41 and 4.0 in) and three tapered stack sections with diameters 133 to 122 mm, 122 to 112 mm, and 112 to 102 mm were designed. The four straight sections, 610 mm (24 in) long, fit inside each other; the three tapered sections, 559 mm (22 in) long, fit inside each other, creating two stack nests for storage inside the heater. The difference in stack length helps the user separate stacks for nesting. The assembled stack, 3960 mm (155.9 in) high including flue cap, consists of a 133 mm (5.2 in) straight section on the bottom, followed by alternating straight and tapered sections, topped by the 102 mm (4 in) straight section and flue cap. If only six stacks are needed, the flue cap will also fit on the 102 mm end of the uppermost tapered stack. The stacks were made of on-hand 0.8 mm (0.032 in) galvanized steel with spot-welded overlap seams. For a production heater, 0.55 mm (0.022 in) aluminized steel should be used.

Aluminized steel, 16 gage (1.61 mm), was used in the fabrication of almost all heater components. Aluminized steel is steel sheet with a special hot-dip coating of aluminum,

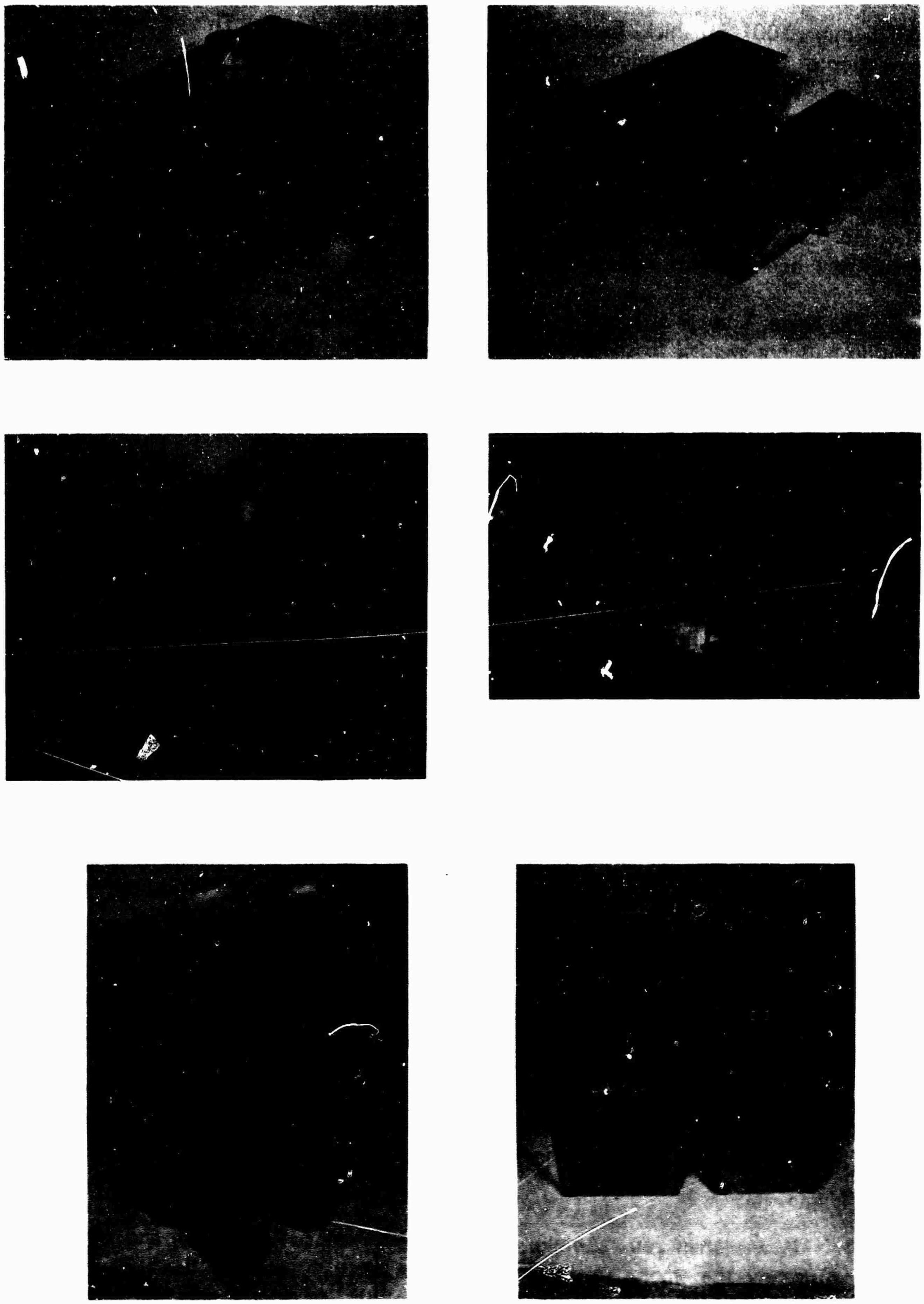

Figure 7. Triple-stage heater prototype 2

0.025 mm (0.001 in) thick, fused to both sides of the steel base. This coating greatly reduces oxidation of the steel at high temperatures, providing outstanding heat and corrosion resistance. The cost was only 20% more than ordinary steel sheet.

The door on the prototype 2 heater is hinged at the top and does not have a latch, so it doubles as an explosion hatch. Accordingly, no special rear-mounted explosion hatch was required. The door is mounted at a 30° angle, which assures closure by gravity; to get the door closed when stacks are stored inside, the 610 mm (24 in) long stack nest must be below the 559 mm (22 in) stack nest.

The heater body is attached to the burner housing by seven stainless steel machine screws; mating nuts are welded to the burner housing. The lighting tube cap and taper are captivated with stainless steel wire, and a storage slot was provided for the taper. No air shutter for solid fuel burning was provided, since the door can be propped open to admit combustion air.

Development Tests

A total of 12 tests were run with the prototype 2 heater, all using diesel fuel. Original test data for this heater are located in NLABS Laboratory Notebook 7678. Table 3 summarizes the results of the most significant six tests. Prior to the first test, the baffles were modified to achieve a better fit. Cuts were made approximately 90 mm (3.5 in) from the ends so the baffle could be bent down to conform to the slightly warped burner shoulders. Test designation K gives results for the first test, using seven stack sections. Drafts were higher than the prototype 1 heater achieved with six stack sections, but less than it achieved with seven stack sections. The smoke readings were excellent at medium and high settings, but poor at the low setting.

The effect of draft on the smoke reading was investigated at the low setting by stabilizing the fuel rate at 20 cc/min and reducing the draft in 0.25-mm (0.02-in) increments by shimming open the door. It was found that reducing the draft by 33% reduced the smoke reading from 6^+ to 4. Also, a part of one of the baffle end caps broke off so a new set of two caps was fabricated. The new end caps had a 10 mm (0.4 in) shoulder, twice as large as the old caps, and provided a much better fit with the baffles.

Test L was run, using only six stack sections to see what effect a lower draft would have with this heater. The new baffle end caps and the shorter stack seemed to have increased CO_2 readings, but also increased smokiness at pilot and low firing rates. Examination of the burner after the test revealed a broken spot weld at the top flange which caused a small air leak; it was repaired. Also, the lower baffle was adjusted for a better fit especially at the heater rear.

Test M was then run. Smoke readings were reduced at the low and pilot firing rates, but surprisingly the smoke reading increased substantially at high fire. Flames were larger at the rear of the burner. A seventh stack section was added, and test N was conducted. Smoke readings were generally better, and draft readings were higher. The flames near the

Table 3. Test Data for Triple-Stage Heater Prototype 2

Test Designation		Diesel Rate (cc/min)	Smoke (BACH)	CO_2 (%)	Draft (mm H_2O)	Temperatures (°C) Stack	Body	Ambient	Thermal Efficiency (%)
PILOT	K	7.5	4	1.5	1.27	206	166	9	33.5
	L	6.9	8	2.5	1.02	210	171	17	56.2
	M	6.8	5	2.0	1.02	216	143	24	45.9
	N	6.5	2	-	1.40	193	149	11	-
	P	6.8	5	2.0	1.02	215	150	24	46.1
	Q	11.8	2	3.0	*1.19	299	266	17	47.3
LOW	K	20.0	7	4.0	1.78	386	332	11	47.1
	L	20.9	8	6.5	1.52	438	371	16	59.5
	M	20.7	4	6.5	1.52	471	382	14	56.8
	N	20.0	4	5.5	1.78	427	349	11	55.0
	P	21.4	5	6.0	1.52	515	350	24	50.2
	Q	20.0	3	5.5	*1.40	432	343	17	54.5
MEDIUM	K	31.2	2	7.5	1.98	526	438	8	57.3
	L	32.0	1	8.5	1.70	599	471	15	56.4
	M	32.4	2	8.5	1.78	604	460	15	56.0
	N	31.8	3	9.0	1.91	560	454	12	60.5
	P	33.8	2	9.0	1.78	615	470	26	57.2
	Q	32.4	2	8.5	*1.57	577	460	17	57.8
HIGH	K	40.0	2	9.0	2.03	589	482	8	58.8
	L	40.7	2	11.0	1.91	654	521	12	60.9
	M	38.7	5	12.5	1.91	654	527	16	64.2
	N	40.0	4	11.5	2.16	599	510	13	64.8
	P	40.0	5	11.5	2.03	660	530	26	61.8
	Q	40.0	2	11.0	*1.65	649	527	17	61.2

*Readings low due to draft leak at manometer.

Designation	Description	Stack* HT (mm)	Test Date
K	First test, baffle ends lowered by means of cutting nd bending, 7 stack sections	3960	03/19/82
L	New end caps for baf es, 6 stacks	3400	04/21/82
M	Adjusted fit of lower baffle, broken spot weld repaired	3400	04/30/82
N	Seventh stack section added	3960	05/10/82
P	Lowered lower baffle 1.6 mm, 6 mm rear heater shim	3400	06/16/82
Q	Repeat, 19 mm rear shim	3400	07/22/82

*Include flue cap.

center of the burner were orange and "lazy" at the pilot and low settings. Reducing the draft by cracking open the door made the flames larger and a brighter yellow. At the medium setting, the orange flame area disappeared.

It was theorized that there was too much airflow around the edges of the lower baffle, so the tabs at the edge were bent upward, lowering the baffle about 1.6 mm (0.062 in). This change was expected to restrict vapor flow from the first stage, allowing for more complete oxidation, especially when the draft was high. Six stack sections were used, and test P was run. Smokiness generally increased and flames were large in the front and rear of the burner, but very small in the center. The lower baffle tabs were bent back downward, the rear of the heater raised 19 mm (0.75 in), and test Q was run. Results were excellent, with smoke readings no higher than 3. Draft readings were low, but artificially so due to a draft leak at the manometer discovered when the test was over. At high fire, the flames were 230-mm (9-in) high in the center of the burner, tapering off to 100-mm (4-in) at the front and 50-mm (2-in) at the rear.

At this point, development tests were stopped. The heater achieved the difficult goal of having smoke readings no higher than three over the operating range with diesel fuel. The prototype 2 heater had also reached the remaining goals outlined in the Introduction. A detailed performance comparison with the M1941 heater follows in the next section.

COMPARATIVE TESTS: PROTOTYPE 2 V.S. M1941

General Performance

The test data for the M1941 heater from Reference 1 are compared with data from the previous section for the prototype 2 heater, in Table 4.

Table 4. Performance Data Comparison, M1941 v.s. Prototype 2

Setting	Heater	Diesel Fuel Flow Rate (cc/min)	Stack Exhaust Smoke (BACH)	Stack Exhaust CO_2 (%)	Stack Exhaust Temp (°C)	Thermal Efficiency (%)
Pilot	M1941	10.1	8	1.5	310	0
	Proto 2	11.8	2	3.0	299	47.3
Low	M1941	20.3	1.3	5.2	573	37.7
	Proto 2	20.0	3	5.5	432	54.5
Medium	M1941	33.5	4	8.8	770	46.7
	Proto 2	32.4	2	8.5	577	57.8
High	M1941	39.3	7	10.8	816*	52.3
	Proto 2	40.0	2	11.0	649	61.2

The M1941 data are the average of three tests.

The prototype 2 heater had superior performance at all settings; largest differences occurred in exhaust stack temperature and smoke readings. Due to the lower stack temperatures of the prototype 2 heater, thermal efficiencies were substantially higher. The pilot setting for the M1941 heater had such a low CO_2 reading (1.5%) that the thermal efficiency came out to be zero. This is caused by a very large amount of excess air, in this case 840%, being heated and lost up the stack; the stack losses actually equal the heat input of the fuel. However, since there is so much excess air, substantial errors may occur in measurement of CO_2 due to imperfect mixing within the stack. If the CO_2 percentage were 2.0 instead of 1.5, efficiency would be 23%.

The larger heated surface area of the prototype 2 heater, 5490 cm^2 (851 in^2) compared to 4000 cm^2 (620 in^2) for the M1941, and the flame pattern within the heater resulted in much lower stack temperatures. With the M1941 heater at the high setting, the stack temperature exceeded the 816°C (1500°F) upper limit of the temperature recorder. The M1941 heater registered high smoke readings at the pilot and high settings. This smoke level would lead to rapid sooting within the burner.

The maximum output of the two heaters is compared to the expected maximum cold weather diesel fuel flow rates: 38.0 cc/min for the M1941 and 40.0 cc/min for the prototype 2 heater. Using a high heating value for diesel fuel of 39.6 kJ/cc (142,000 Btu/gal), and the efficiency values from Table 4, maximum outputs for the two heaters are: 16.14 kW (55,100 Btu/h) for the prototype 2, and 13.1 kW (44,730 Btu/h) for the M1941. The flow of diesel fuel through the metering valve depends on the fuel viscosity, as metering is accomplished by varying the size of an orifice. The colder the diesel fuel, the less will get through the orifice. Also, the specification for the metering valve[4] gives a calibration range of 38 to 44 cc/min with gasoline at 15 ± 5°C at setting 7. Therefore the maximum M1941 heater output with diesel fuel depends on the fuel temperature and specific metering valve used; the 38.0 cc/min fuel flow rate used, in our experience, is a realistic cold weather maximum value. The value of 40 cc/min for the prototype 2 heater is a maximum design value. In view of the uncertainties above, the M1941 heater output is rounded off to 13.2 kW (45,000 Btu/h), its rated output, and the prototype 2 output to 16.1 kW (55,000 Btu/h).

The above tests were conducted with the heaters operating a short time at each setting, 15 to 30 minutes. The next section covers an extended time test, where the M1941 and prototype 2 heaters were operated at a high setting (35 cc/min) for up to 100 hours.

[4] Military Specification MIL–C–43343A, Control, Fuel Flow, Oil Burner, 13 December 1974.

Extended-Time, High-Fire Performance

An extended-time high-fire performance test was run on both the M1941 and prototype 2 heaters. Data for the former is in NLABS Laboratory Notebook 7232, and the latter in Notebook 7678. A 100-hour test was planned, but for the M1941 heater the test was stopped at 67 hours as smoke output had become extremely heavy.

To begin the extended time test a new M1941 burner was obtained and the on-hand upper and lower halves were cleaned by sandblasting. These heater components were assembled in the standard configuration, with six new stack sections and flue cap. Throughout the test: diesel fuel was used, a flow rate of 35 cc/min was maintained (except during warm-up), and the heater was not moved. After each hour of operation, a full set of performance data was recorded, including CO_2 percent, smoke reading, temperature of exhaust gases, heater body and ambient temperatures, and outdoor wind speed. The M1941 heater was operated six to seven hours daily, resulting in 10 test periods over about two-week period in February and March, 1982; the average outdoor temperature during the test was $-1.5°C$ (29°F). After 55 hours of testing the smoke output had become very heavy, and the test was continued to 67 hours and stopped. The burner was removed and inspected, and as expected there were substantial carbon deposits within the burner. The prototype 2 heater was tested in an identical manner in September and October 1982. The average outdoor temperature during the test was 17°C (63°F). Six stack sections with flue cap were used, and there were 17 test periods making up the 67-hour test. The burner, cleaned six test-hours prior to this test, did not need recleaning.

Results of the two tests are shown in Figure 8. The M1941 heater held a smoke reading of 4 (moderate performance) for about 30 hours, but it gradually increased to 9 (extremely poor) by 50 hours. The prototype 2 heater operated at number 1 and 2 smoke (excellent to very good) for about 45 hours, but increased to a much lower smoke level 5 (fair), at 55 hours.

The level of stack CO_2 showed a slight decline for the prototype 2 heater over the 67 hours of testing, but there was no clear trend for the M1941 heater. The average stack CO_2 value for the prototype 2 heater was 9.7% while that for the M1941 heater was much lower, 7.6%. Complete combustion with no excess air would result in 15.1% CO_2 in the stack exhaust; the 9.7% and 7.6% CO_2 values for the two heaters indicate 52% and 92% excess combustion air, respectively. Prior to each 67-hour test, the CO_2 test device was refilled with new fluid. Two readings of CO_2 were taken each hour, and if the two readings differed, additional measurements were taken until a clear consensus was reached. It is not known why the M1941 heater experienced such low CO_2 readings. Previous tests (Reference 1) with diesel fuel at 35 cc/min resulted in CO_2 values of 9% to 10%. It is interesting to note that, while the values of CO_2 were lower than expected, the stack temperatures were also approximately 200°C lower than expected. This would indicate a substantial air leak. Prior to the extended-time M1941 test, however, care was taken to assure the burner was properly seated and locked in place, and the top half of the heater body was evenly seated on the adapter ring.

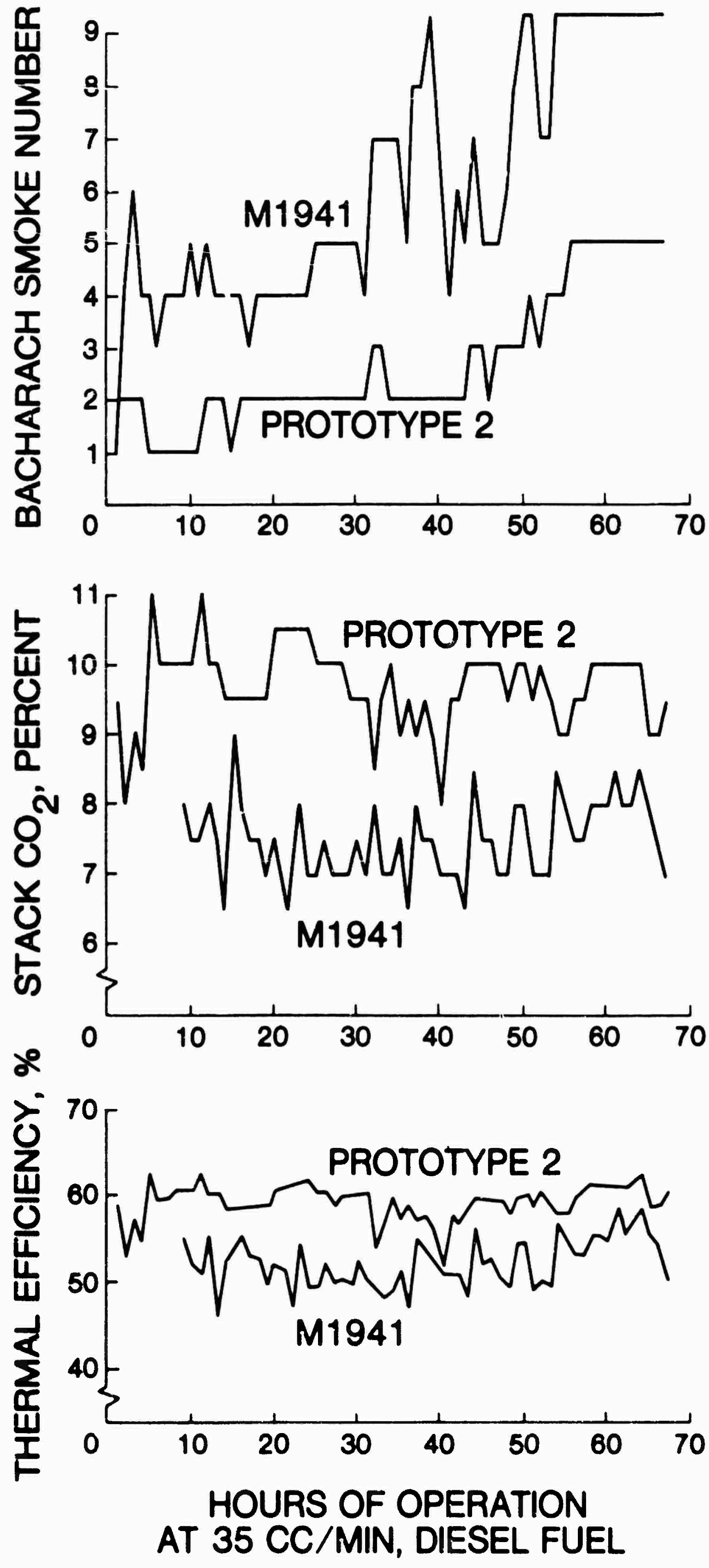

Figure 8. Comparison of smoke, CO_2, and efficiency for extended-time operation, M1941 v.s. ptototype 2 heaters

The thermal efficiency was calculated from each hourly set of performance data using the formula in Reference 1. The prototype 2 heater achieved an average efficiency of 59.1% while the M1941 heater averaged 52.4%. Using an input heating value of 23.1 kW (78,777 Btu/h) for diesel fuel at 35 cc/min, the heater outputs were 13.6 kW (46,560 Btu/h) for the prototype 2 heater, and 12.1 kW (41,280 Btu/h) for the M1941. Although the stack temperatures of the prototype 2 heater averaged 30°C (54°F) higher than the M1941, the higher CO_2 values for the prototype 2 heater resulted in the 7% higher efficiency.

The prototype 2 and M1941 burners both accumulated substantial carbon deposits after 67 hours of operation. Photographs of the two burners at the end of testing appear in Figure 9.

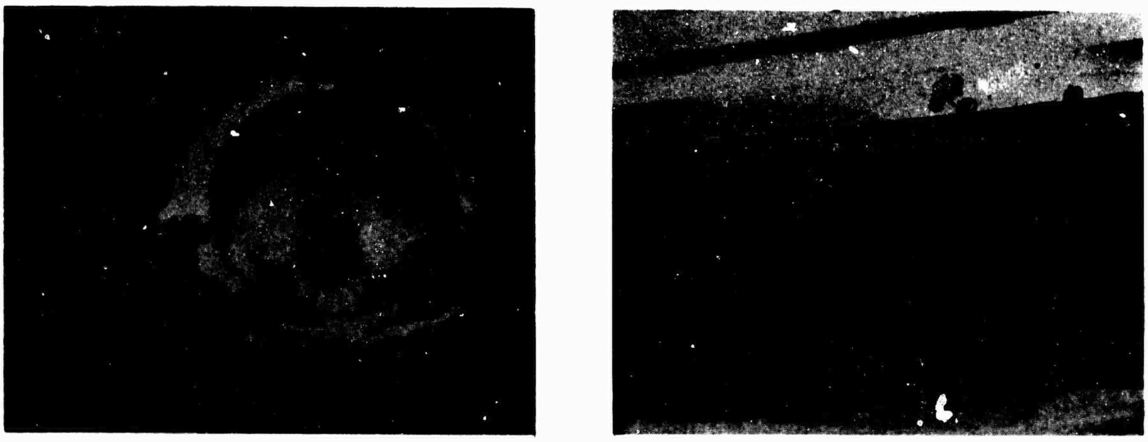

Figure 9. Appearance of M1941 and prototype 2 burners after 67 hours of testing

Care was used when removing the upper heater bodies so the burners were not bumped. The carbon deposits just below the burner holes extended as much as 38 mm (1.5 in) into the burner. Normal handling would cause substantial portions of these deposits to break off and fall into the burner.

The M1941 heater was reassembled and run for 33 more hours to make a total of 100 hours of testing. In the reassembly process, many of the carbon protrusions broke off and fell into the burner, so that there was an average of 13 mm (1/2 in) of carbon deposits around the top periphery of the burner. The average ambient temperature during the five test periods was 5°C (41°F). Test data are shown in Figure 10.

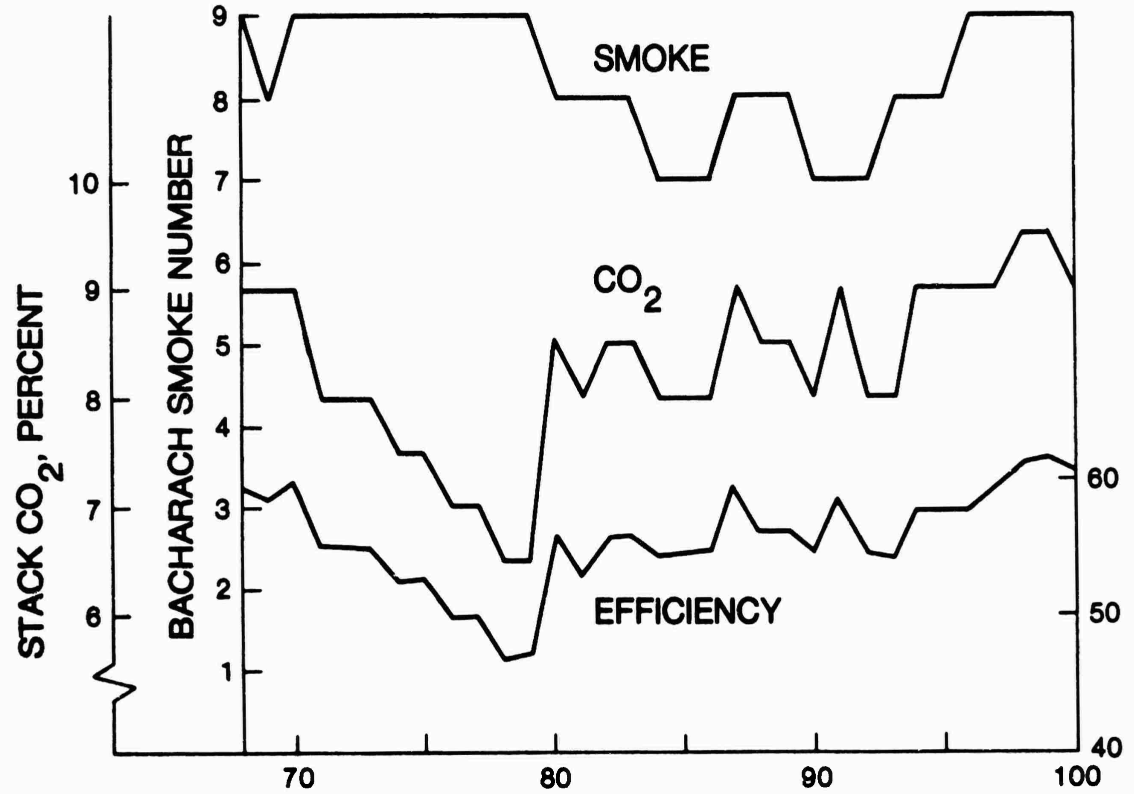

Figure 10. Extended-time operation data to 100 hours, M1941 heater

The downward trend of percent CO_2 and efficiency during hours 70 to 80 is primarily due to strong winds; winds averaged 3 to 7 m/s (6.7 to 16 mph) during this portion of the test, with gusts to 14 m/s (31 mph). During test hours 80 to 100, winds were very light. The strong winds increase the stack draft, which pulls in more combustion air into the burner. The excess combustion air then lowers the stack gas CO_2 by dilution. During the 33-hour test, average values were: 8.3% CO_2, and 55.8% efficiency. These values were better than those of the first 67 hours, which were 7.6% CO_2 and 52.4% efficiency. Even better average values were recorded over hours 80 to 100: 8.6% CO_2 and 56.9% efficiency.

The smoke number was very high during the windy portion of the test (hours 70 to 80), but the lowest reading recorded during the remainder of the test was only 7, moderately poor. Examination of the burner after the 100th hour of test revealed carbon deposits very similar in appearance and size to those seen after 67 hours of testing.

The buildup of carbon is disturbing, especially in the cleaner-burning prototype 2 heater. More information is needed on this subject regarding what amount is normal or expected, and what can be done to minimize it.

DISCUSSION

The prototype 2 and M1941 heaters both have design features that are good but also have some areas of weakness. The discussion is opened by a frank comparison of the advantages of each heater.

Advantages of Prototype 2 Heater

Twelve advantages of the prototype 2 heater were identified.

1. Higher output: a diesel fuel rating of 16.1 kW (55,000 Btu/h) compared to 13.2 kW (45,000 Btu/h) for the M1941.

2. Cleaner burning: smoke number of 3 or less with diesel fuel up to 40 cc/min compared to 8 at 37.5 cc/min for the M1941.

3. Higher efficiency: diesel fuel efficiencies were 9, 11, and 17 percent greater than the M1941 at high, medium and low settings, respectively.

4. Completely self-storing: internal storage of stacks prevents loss and damage in transit.

5. Smaller volume when packed for transit: 0.097 m^3 (3.42 ft^3) compared to 0.109 m^3 (3.85 ft^3) for the M1941.

6. Larger heated surface area: 5490 cm^2 (851 in^2) compared to 4000 cm^2 (620 in^2) for the M1941.

7. Protected metering valve: metering valve is permanently mounted, physically protected, and shielded from heat. On the M1941 it protrudes, is unshielded, and is frequently damaged.

8. Welded stack section construction: Prototype 2 stacks are welded, whereas M1941 stacks must be assembled (a difficult task) and riveted the first time used. If not riveted (often the case) seams tend to pop open.

9. Longer service life: aluminized steel body will last much longer even at elevated temperatures. Resists corrosion.

10. More stable construction: the prototype 2 upper and lower halves are bolted together, not simply resting on each other as in the M1941.

11. Flame monitoring port: a mica sight glass is included so the fire can be observed without opening the door.

12. Easier lighting: a captivated lighting taper is provided. The M1941 requires a wad of paper or rag to light it, which might not be available.

Advantages of M1941 Heater

For the M1941 heater, six advantages were identified.

1. Lower mass: 23.2 kg compared to 32.7 kg for the prototype 2 heater (51 lb vs 72 lb weight).

2. Better unlevel performance: performance does not degrade when out of level as it does with the prototype 2 heater.

3. Interchangeable stack sections: all M1941 stacks are identical whereas the prototype 2 heater has six different stacks.

4. Easier assembly and disassembly: no tools are needed while a screwdriver is needed for the prototype 2 heater. Both heaters require a wrench to attach fuel lines.

5. Lower production cost: components are uncomplicated and easy to manufacture, and the M1941 has 9.5 kg (21 lb) less material.

6. Easier to clean: the round shape of the heater and burner promote easy cleaning.

One military space heater already uses tapered stack sections, the M1950 or Yukon Stove. This heater has five tapered stack sections which nest, so all stacks fit inside the largest section. The stack nest fits inside the heater body, resulting in a completely self-storing lightweight heater with dimensions (L x W x H) of 609 x 247 x 203 mm (24 x 9.75 x 8 in). The tapered stacks result in a tremendous space savings, but have the disadvantage of the need to replace the identical stack section if one becomes damaged or lost. This heater is designed for gasoline or solid fuels, and is for use only in small tents as the assembled stack (less flue cap) is only 2600 mm (103 in) high. The combined tapered and straight stack sections of the prototype 2 heater have an advantage over the Yukon Stove all-tapered stack design, since any one of the three straight stacks could be excluded and the stack could still be assembled.

The need for the prototype 2 heater to be level may be viewed as a serious impediment since very few areas out in the field are level. The Netherlands Army tent heater, however, uses a triple-stage burner and is required to be level in use. No leveling device is supplied on the Netherlands Army heater, but a plumb bob is permanently attached to the heater body to determine if it is level. The addition of a built-in means to level the prototype 2 heater has been avoided because the rough handling experienced by field heaters, as well as mud and ice, would most probably damage or render such a device useless. Leveling the prototype 2 heater is expected to be done by using an extra tent peg, a mound of dirt, or a tree branch; it need only be leveled front-to-rear. A plumb-bob device could be added to indicate when the prototype 2 heater is level. It should be mentioned that the M1941 heater was never tested for performance degradation due to being out-of-level. The 250-mm (10-in) diameter round burner has a contoured bottom with the same slope as the triple-stage burner, with the center 6.3 mm (1/4 in) lower than the edges. The fuel puddle would be substantially off center with the burner tipped only 2.5 degrees. Although this suggests some unlevel performance deterioration, the fuel vapor circulation and mixing within the burner and the relatively small diameter tend to minimize the effect of the off-center puddle. For the same tilt angle, it can be assumed with a good deal of confidence that the prototype 2 heater would exhibit much greater performance degradation than would the 1941.

Burning of solid fuel in the prototype 2 and M1941 heaters requires removal of the burner and addition of a grate or a grate/plate. In the design of the prototype 2 heater, solid fuels were considered to be emergency fuels. The prototype 2 development work concentrated on liquid fuel performance, and it was never tested with solid fuel. Insertion of a grate attached to a plate that covers the inside bottom surface of the heater upper body would permit burning of solid fuel. The burner should be removed (but does not have to be) so ashes cannot sift around and under the plate, and into the burner. The grate would be hinged at the rear where it is attached to the plate, so the front could be lifted and ashes shoveled out beneath it. Air for combustion must enter through the hinged door, so it would need to be propped open slightly when burning solid fuel. One way of holding the door open to admit combustion air would be to add a rotatable cam device to the inside of the heater, which would provide an adjustable means of holding the door open.

A possible problem in fielding a heater which uses the triple-stage burner is in the area of patents. Sesto Inc., Hilversum, Holland, received a U.S. patent for the triple-stage design, number 4095936, dated 20 June 1978. Rights to manufacture a triple-stage burner in this country would need to be obtained from Sesto, resulting in potential expense, legal, and manufacturing problems.

The buildup of carbonaceous material within the burners during the extended-time test was disturbing. Even though the smoke output was much less during the 67-hour test for the prototype 2 heater, both the M1941 and prototype 2 burners built up a substantial amount of carbonaceous material. During the 67-hour test, the heaters were not moved or bumped, so the carbon crust was able to grow, undisturbed, such that it protruded several inches into the burner interior. Under field conditions it may be argued that a substantial amount of the frail carbon crust would break off and fall onto the bottom of the burner. This may result in a slower buildup of crust, and in better extended-time performance. However, the amount of carbonaceous material that was built-up during the extended time test indicated that frequent cleaning would be necessary, weekly or possibly even more often. It is surprising that the triple-stage heater, which is used as a residential space heater in many European countries, would require such frequent cleaning. In any further development work with the prototype 2 heater, Sesto should be contacted to determine its experience with carbon crust buildup.

Since the primary fuel of the prototype 2 heater is diesel fuel, overfiring should not be too much of a problem. Overfiring is exceeding the fuel input capacity of the burner, resulting in large flames, more heat output, copious smoke, and rapid soot buildup. With a properly calibrated metering valve and the use of diesel fuel, overfiring is not possible. However, if gasoline is used, overfiring will result if the recommended maximum setting of 7 (of a possible 9) is exceeded on the metering valve. With the trend to use diesel fuel for all field operations, the perception of the prototype 2 heater as a diesel fuel heater, and the clean burning it exhibits with diesel fuel, the only time it would be used (and possibly overfired) with any other fuel would be when diesel fuel was unavailable. Tampering with the metering valve to increase flow, which can be accomplished with a small screwdriver, also will result in overfiring. Redesign of the metering valve is necessary to eliminate this problem.

The prototype 2 heater was designed with safety in mind. The door is hinged on the top and mounted at a 30° angle so a latch was not needed. If a warm heater were relighted (specifically prohibited due to the explosion hazard), the door would open to relieve any explosion pressure, preventing the heater from blowing apart and causing injuries due to flying metal fragments. In any further development work with this heater design, a warm heater should be relighted in a suitable test area to assure that only a nonfragmenting explosion takes place. Another safety matter, containment of fuel within the burner if the flames become extinguished, is no problem if the prototype 2 heater is level. As in the M1941 burner, the bottom row of air holes in the prototype 2 burner is above the highest level the fuel puddle can reach. The physical stability of the prototype 2 heater appears to be somewhat less than that of the M1941 heater, since it has a base plate width of 267 mm (10.5 in) compared to the 417 mm (16.4 in) diameter round base of the M1941. Tests with a mechanical force gage showed it took a horizontal force of 71.2 N (16 lb) applied at the top edge to tip the stackless prototype heater to its sidewise balance point, an angle from the vertical of 31.5 degrees. In a similar test with the M1941 heater, the top half lifted up from the rest of the heater when a horizontal force of only 35.6 N (8 lb) was applied. Because there is no quantitative yardstick for stability, the judgement must be made qualitatively; the prototype 2 heater seems to be adequate in terms of physical stability.

The goals of the prototype 2 heater development effort have all been met. The capability of clean burning with gasoline and jet fuel, though not tested with the prototype 2 heater, was proven with the same burner in previous heater bodies. Also, the capability of burning wood or coal was designed into the heater, but never tested. The goal of having the heater as lightweight as possible amounts to a trade-off between weight, ruggedness, and service life. Further refinements to the design may well find that thinner sheet metal can be used in some areas resulting in weight savings.

CONCLUSIONS

Compared to the current M1941 heater, the prototype 2 heater is superior in performance and design features. As is often the case, however, these improvements come with certain drawbacks. The major ones are increased weight, the need to be level, noninterchangeable stack sections, and expected higher production cost. Of these four, the only one that cannot be reduced in severity is the need to be level. Further design iterations can concentrate on reducing the weight and production cost; the present design is only a prototype and there is room for improvement. If interchangeable stack sections are determined to be a necessity, that design change could be made. Of course internal stack storage and the self-storing design feature would be compromised.

During the test work it was found that close-fitting baffles are important in achieving clean burning. Also, further investigation of the carbon buildup within the burner is needed. The amount built up during the extended time high fire test appeared to be excessive.

The prototype 2 heater met all the goals outlined at the beginning of the development and has good potential as a replacement for the M1941 heater. Further design refinements may be necessary to make the prototype 2 unit an acceptable field heater.

LITERATURE CITED

1. Nykvist, W. Evaluation of Liquid Fuel Space Heaters: Standard Military Developmental, and Foreign. US Army Natick Research and Development Laboratories, Technical Report NATICK/TR–79/021, October 1978 (AD A075800).

2. Nykvist, W. Field Space Heaters: Design and Test of Four Alternative Concepts. US Army Natick Research and Development Laboratories, Technical Note NATICK/TN–82/006–AMEL, July 1982.

3. Technical Manual, Instruction Manual, and Test Report for Geraedts Hellendoorn Sesto Tent Heater, Model III, Netherlands.

4. Military Specification MIL–C–43343A, Control, Fuel Flow, Oil Burner, 13 December 1974.