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WRIGHT-PATTERSON AIR FORCE BASE
DAYTON, OHIO
ENGINEERING DIVISION
MEMORANDUM REPORT ON

31 pages

FORM 32/JJ (2-1) 783

Date 31 March 1949

STI

ATTN NO. 177409

SUBJECT: Pulse-Jet Ground Heating
Devices

OFFICE: Equipment Laboratory

Contract or Order No.

SERIAL No. WORMX-057-136-F

Expenditure Order No.

657-216

A. PURPOSE:

1. To present preliminary findings on the development of pulse-jet ground heaters producing contaminated and uncontaminated heated air.

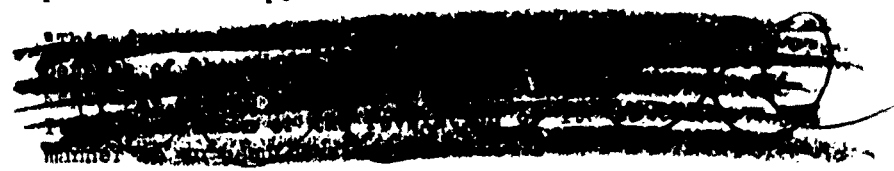
B. FACTUAL DATA:

2. The locally fabricated experimental pulse-jet heater set delivering contaminated air was made the subject of continued studies and testing. Experiences gained in starting and running the unit under varying conditions guided the development outlined in this report.

3. Starting tests under extreme cold weather conditions as realized in the local Frigidarium and the Climatic Hangar, Eglin Field revealed an excessive consumption of compressed air by the preheater installed at that time. They further showed the compressed air method of starting the pulse-jet burner to be inconvenient under such conditions.

4. A new preheater and starting system was developed to be incorporated in and tested with the experimental heater unit. It eliminates completely the need for compressed air. Gasoline gas under pressure is created in a sealed kettle by applying heat, and a jet of this gas maintains its own combustion air supply by means of an aspirator delivering a good torch flame for preheating and for igniting the start charge of the pulse burner. The initial charge of the pulse burner is provided in the same way as the combustible mixture for the torch flame by delivering a gas jet into a special air mixture tube attached to the neck of the combustion chamber of the pulse jet. Details of this development are presented herein as Appendix A. The resulting starter assembly now being used is outlined in Figure 6A. The system was built into the experimental heater unit and proved satisfactory in the Frigidarium and during tests at Ladd Field, Alaska, discounting minor imperfections inherent in a still experimental set-up.

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5. Running tests made under normal ambient conditions show that the heater fulfills the requirement for an outlet temperature not higher than 280°F when a standard 12" duct is used, within an ambient temperature range from minus 65°F to plus 20°F. Total pressure delivered at minus 65°F ambient and 280°F outlet temperature is .9 inches W.G. A performance chart is presented in Appendix B as Figure 1B.

6. To widen the design basis, the influence of geometrical modifications of the pulse-jet burner was studied in continued measurements of performance values such as, fuel consumption, thrust, exit pressure, frequency and their relationship. Thus for instance, the thrust of a unit varies proportional to the third power of the fuel consumption. This is shown in Figure 3B of Appendix B, as the result of numerous measurements.

7. As aspirating of ambient air contains a major problem in the use of the contaminated air pulse-jet heater, theoretical treatment was given to it. Using experimental findings and the physics of the process, a precalculation of the performance of an aspirator when driven by a pulse-jet was completed. Results of the evaluation of the method for the experimental heater under consideration are presented in Figure 6B of Appendix B showing rate of air flow, total and static pressure as a function of the temperature rise.

8. A noticeable reduction of the noise level was found possible by adding a suitably dimensioned air inlet duct to the cabinet without sacrificing too much of the available pressure. This inlet duct is not included in the experimental unit for reasons of saving space but will be a feature of later units.

9. Lifetime of the valves while in use was unsatisfactory and in the order of 15 to 30 minutes mainly due to the increased load present in the modified heater unit. Studies were conducted which resulted in a modified design capable of withstanding similar load conditions for 12 hours without signs of deterioration. So far, plates of this design of a size sufficient to be used in the actual heater are not available due to supply and fabricating difficulties. For more detailed information, reference is made to Appendix C of this report.

10. Utilizing all findings, Exhibit WCREXE-657-1, Heater; Engine Ground, Portable Gasoline Burning, Pulse Jet Driven, Contaminated Air, 100,000 BTU/Hr, Type R-1, dated 17 January 1949, was prepared.

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11. Based on the suggestion of a pulse-jet burner rotating under the impact of its own exhaust jet as set forth in Invention Disclosure No. 56 "Heating Devices Especially Adaptable to Preheating Aviation and Automotive Engines" and sketches in Figure 1D of Appendix D, action was initiated on approximately 1 January 1946, to collect basic design data for a design utilizing such a burner as a blower and heat source for uncontaminated air heating system.

12. Calculations have been conducted to determine main dimensions and efficiency to be expected of a unit rated at approximately 100,000 BTU/Hr. in the form of uncontaminated heated air with no more than 200°F outlet temperature. It may be expected to transfer 70 per cent of the fuel heat into the uncontaminated air and forward it under a total pressure of from 3 to 4 inches water column.

13. Design studies were conducted to realize the idea of a rotating pulse-jet burner comprising simultaneously a blower and partial heat exchanger for the uncontaminated air. Figure 2D, Appendix D shows a sketch of the solution taken into consideration. In this unit, air is compressed and heated by a blower forming one side of the spiraled tubes of the pulse-jet burner. The air then is led through a stationary heat exchanger to utilize the heat still contained in the exhaust gas of the burner. After passing this heat exchanger, the air gives off part of its energy in the turbine formed by the other side of the burner tubes and thereby again utilized the heat created by the burner.

14. The rather complicated shape of the burner design is currently approached step by step in stand still models which allow for easy testing of their performance. Thrust and fuel consumption obtained so far with proposed dimensions of the design keep in line with precalculations. Further details of the development, may be found in Appendix D.

15. A valve assembly has been designed and tested which will be capable of rotating with the burner without detrimental effect of centrifugal forces. As may be seen from Figure 4D of Appendix D, it makes use of ring shaped valve bodies arranged in concentric rings made out of cold rolled steel .007" thick.

C. CONCLUSIONS:

16. Sufficient data have been accumulated on the contaminated air pulse jet motor upon which to base procurement of a quantity of service test items.

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17. Data obtained from studies on pulse jet heater for uncontaminated air show that such a unit is feasible but is not sufficient for a complete design.

D. RECOMMENDATIONS:

18. It is recommended that the following action be taken by the organization designated below:

a. Maintenance Equipment Unit, Ground Equipment Branch, Equipment Laboratory, Engineering Division, AEC (MORRIS-2).

- (1) Initiate procurement of a service test quantity of pulse-jet ground heaters for contaminated air, to study the feasibility of using contaminated air for preheating aircraft engines. (Action Initiated).
- (2) Continue studies for the development of pulse-jet ground heaters delivering uncontaminated air. (Action Initiated).

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APPENDIX "A"

DEVELOPMENT OF A NEW PREHEATING AND STARTING SYSTEM

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APPENDIX "A"

DEVELOPMENT OF A NEW PREHEATING AND STARTING SYSTEM

Preheating Torch Operating without Compressed
Air

The preheater intended to be used in the cabinet heater set is outlined in Figure 1A. A porous stone or metal body is soaked with fuel and air from an air container is pumped through the pores thereby evaporating part of the fuel. The rich mixture enters the flame duct and burns as a torch flame at the open end where it mingles with ambient air. Due to the necessary size of this preheater, it consumed more air as could conveniently be furnished by hand pumping. The arrangement therefore was to replace by one using a sealed fuel container pressurized by the heat of a primer flame. Blow torch operation was then to maintain by the gas jet coming from a nozzle on the container. The first torch model used and tested in the Oglin Field Cold Hangar is sketched in Figure 2A. It consists of a pressure tight vapor kettle, a bowl containing a wick used as the primary heat source to warm the contents of the kettle and a fuel nozzle, which delivers a jet of hot gasoline gas into an air aspirator. The system was satisfactory in operation, as long as heat was supplied by the primer. But heat induced into the kettle from the torch was too little to keep the torch running. In the next development step, this was overcome by building the fuel container around the aspirator of the torch. A sufficient and regulated amount of heat could now be provided to evaporate the fuel continuously. Several modifications of this arrangement were tested, a first one being completed as early as May 1948. A modification with horizontal torch aspirator is shown in Figure 3A. A chimney inclosing the fuel kettle is added to secure more complete combustion in the primer bowl. The further development of the preheater lamp is closely related with the development of the new starting system and will be perceptible from the next section.

ORIGINAL PREHEATER SYSTEM

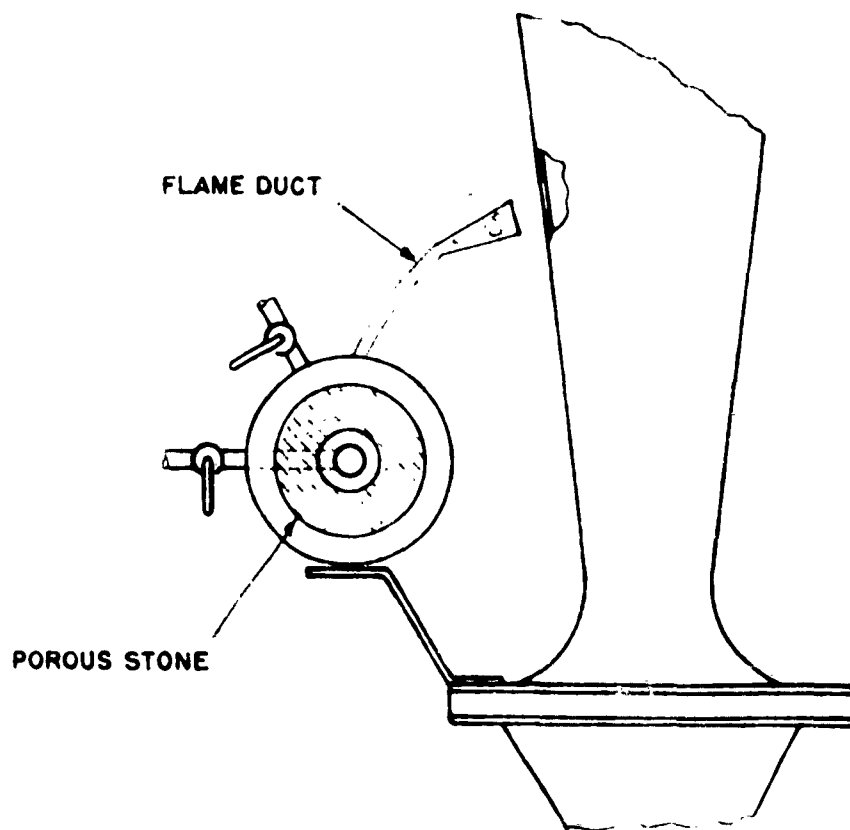
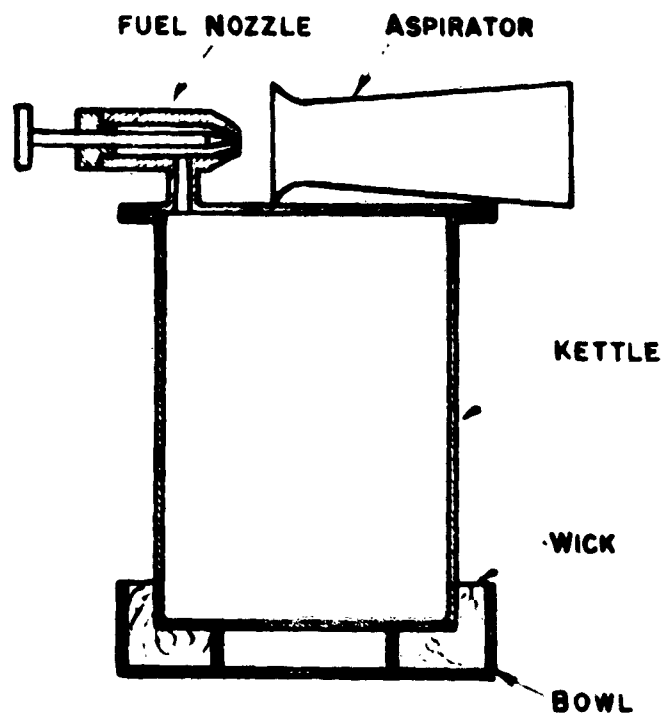
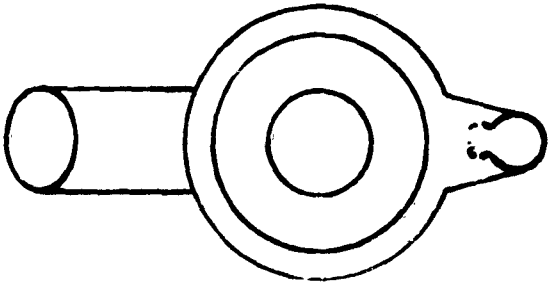
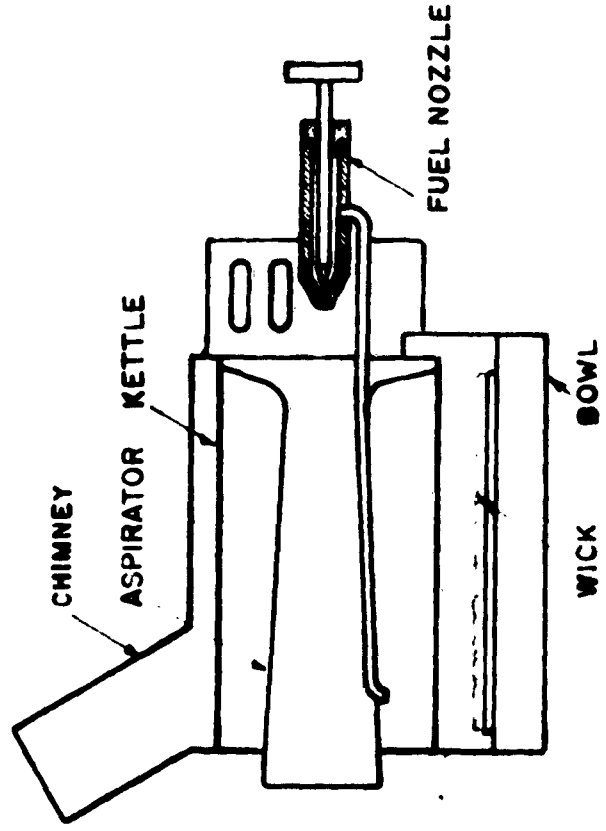


FIG. 1, A



FIRST PREHEATING TORCH MODEL



HORIZONTAL TORCH MODEL

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APPENDIX "A"

DEVELOPMENT OF A NEW STARTING SYSTEM OPERATING WITHOUT COMPRESSED AIR

1. Thus far pulse-jet engines were started by blowing in a stream of compressed air for a few seconds. Fuel was either atomized by this stream and mixed in the right amount or injected under pressure from separate fuel nozzles. The method is satisfactory as long as an ample supply of compressed air may be maintained, which is hard to do for the set under consideration. A new method now developed makes use of the torch principle of supplying combustion air in an aspirator operated by a jet of pressurized gas, for providing the start mixture of the pulse-jet. A gas generator (which may be the same as for the preheater torch) delivers a (hot) gas jet into a mixing tube of suitable length and diameter where it mingles with air to form a highly combustible mixture. This then may be led into the combustion chamber by virtue of its own kinetic energy, the way chosen for the inlet thereby establishing the new starting arrangements described below as Methods a, b and c.

a. External Gas Start Method.

In this arrangement, the gas air mixture is simply led into the carburetor funnel just below the valve plate as is exemplified in Figure 4A. The same gas generator is used for starter and preheater torch. After the combustion chamber is warmed by the torch flame and a glowing spot is maintained for ignition, several shots of gasoline gas from the starter nozzle will throw the set into operation. Figure 4A outlines at the same time a further development of the torch, which is again of the vertical type. The aspirator flame duct is used as a chimney for the primer flame burning in the wick bowl at the bottom of the lamp. Air for primer and torch is led through a jacket around the fuel kettle which serves both as a windshield and an insulator against heat loss. As it is very important for a good start to have dry gas, a superheating coil was added between the generator and the nozzles. Several tests were made with the system with good results in the cold chamber. Temperatures ranged from minus 40°F to minus 65°F and from 3 to 5 minutes were necessary for preheating and starting the heater. The one disadvantage inherent with the system is that only a small part of the start mixture really enters the combustion chamber and the remainder blows back through the funnel into the heater cabinet. Except for extreme low ambient temperatures, danger of ignition of this gas may exist which is highly objectionable. Efforts to separate the path of the start mixture from the ambient space by means of a baffle, which is indicated by dotted lines in Figure 4A failed. Too many of the valves had to be reserved for the start path. Therefore, method b was developed which avoids straining of combustible mixture into the cabinet.

APPENDIX "A"

(continued)

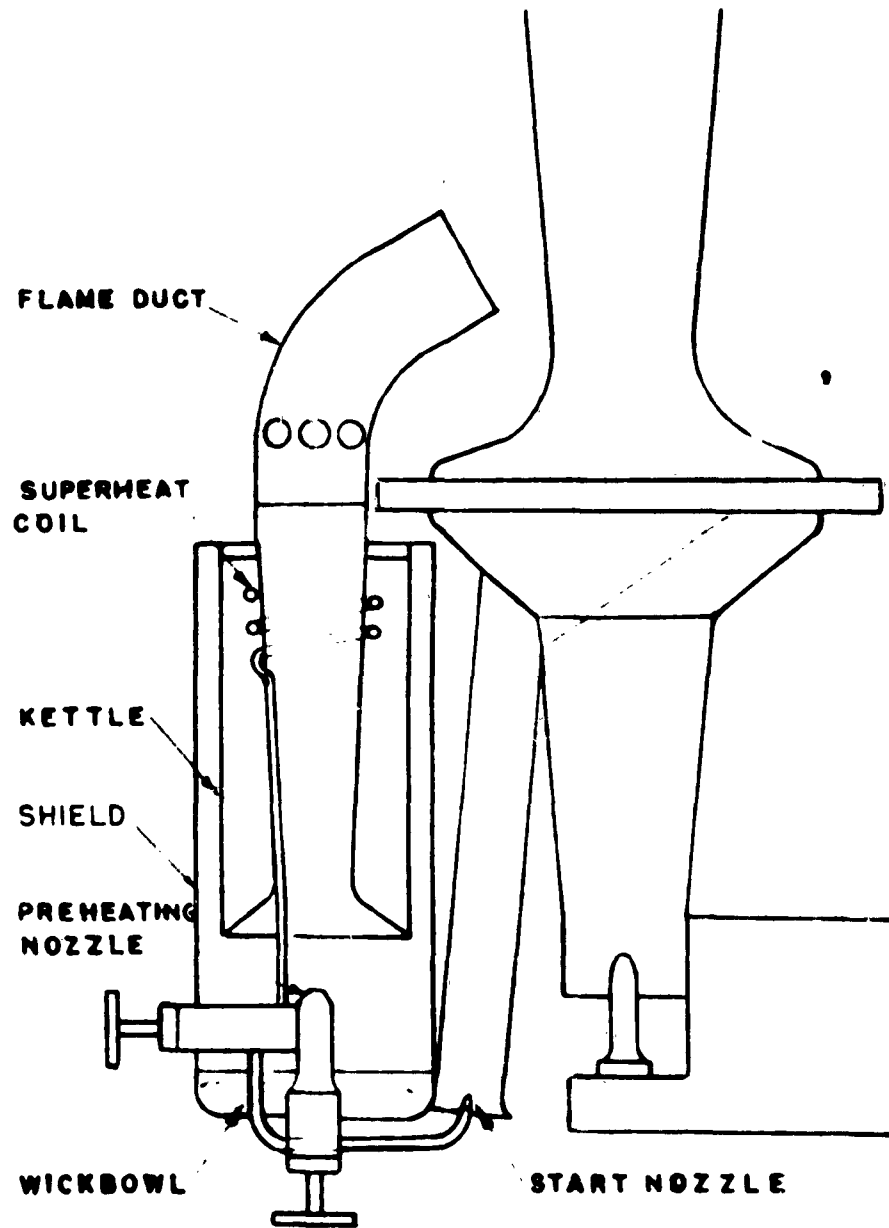
b. Internal Gas Start Method.

A pulse jet will operate even if a second open tube is attached to the neck of the combustion chamber, provided the ratio between length and diameter of the tube is properly chosen. When gas was injected into the open end of such a tube, as is indicated in Figure 5A, it caused the burner to start. To avoid backfire from this secondary tube, it was then closed by a second valve plate as is shown in Figure 5bA. Start is still possible and no gas can reach the cabinet. This method was called internal gas start method. A slight deterioration of the running performance of the burner was noticeable but it did not seem important. When tests with the arrangement were to be made in the Eglin Cold Hangar, it failed to operate and it was discovered that the valves of the auxiliary plate were frozen to their seats. Rearrangement of the system to warm the plate from the preheater lamp proved very inconvenient from the design standpoint and a new and better method was developed instead. The new method is known as the Internal Gas Start Method with Choke.

c. Internal Gas Start Method with Choke Valve.

Figure 6a outlines the method finally chosen for use as a starter arrangement. The end of the mixing tube is now provided with a ring air valve which opens when the start control linkage is depressed. Further depressing the lever opens the starter fuel valve and a gas jet is injected into the mixing tube. As soon as the pulse burner starts to operate, the choke valve opens and closes under the influence of the alternating pressure in like manner as the valves in the main valve plate do. By this way, it aids very much to a smooth passage from the starting cycles to normal running. This action of the choke valve continues until the starter lever is released whereby the choke valve becomes permanently closed leaving the pulse burner uninfluenced by the start system during normal operation.

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EXTERNAL GAS START ASSEMBLY

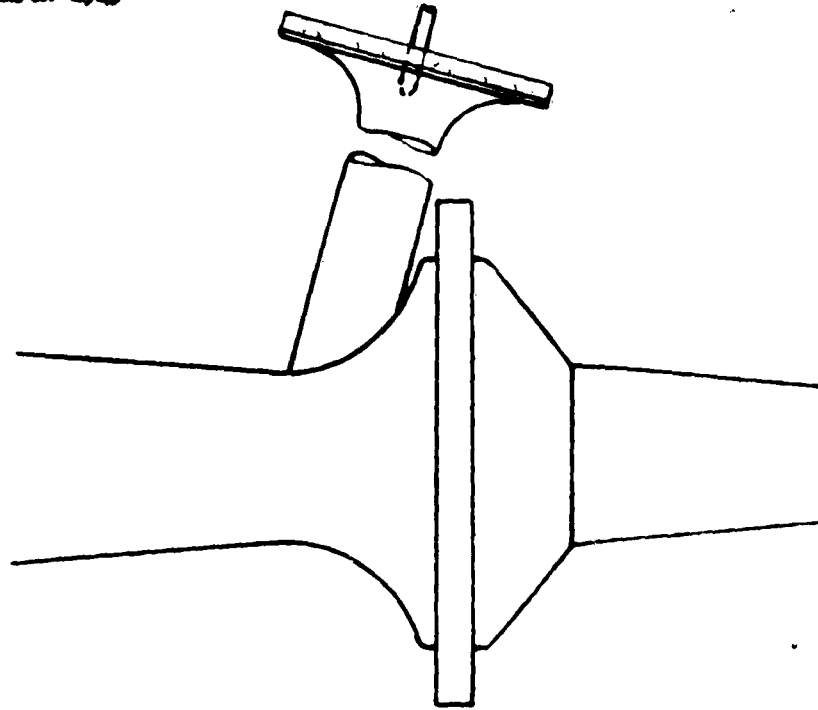
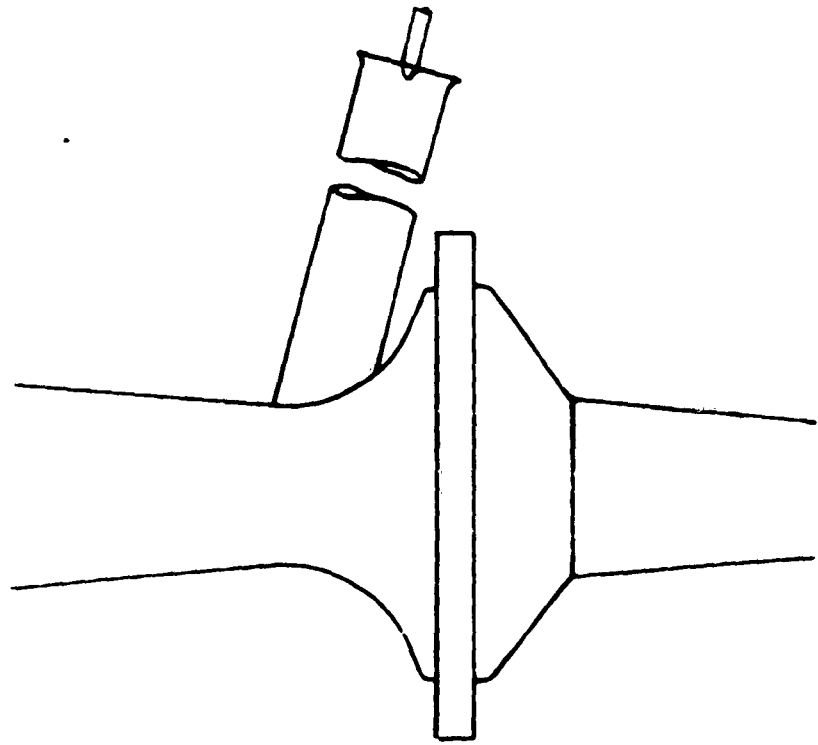


FIG. 5B,A

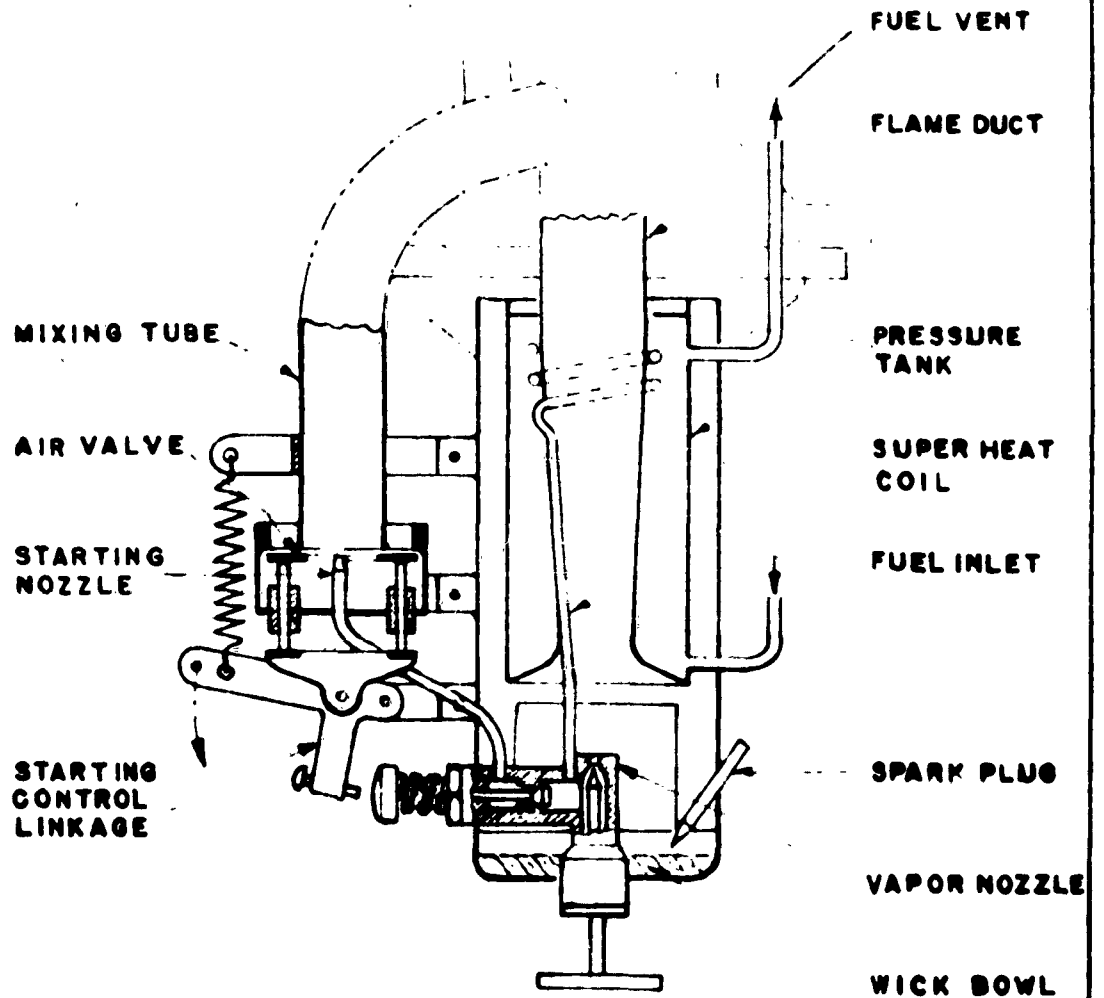


START MIXING TUBE ARRANGEMENTS

FIG. 5A,A

FIG. 5A,A, 5B,A

STARTING ASSEMBLY



INTERNAL GAS START ASSEMBLY WITH CHOKE VALVE

FIG. 6,A

FIGURE 4
EXHIBIT NO
MCREXE-3-94

APPENDIX "B"

HEATER AND PULSE-JET PERFORMANCE

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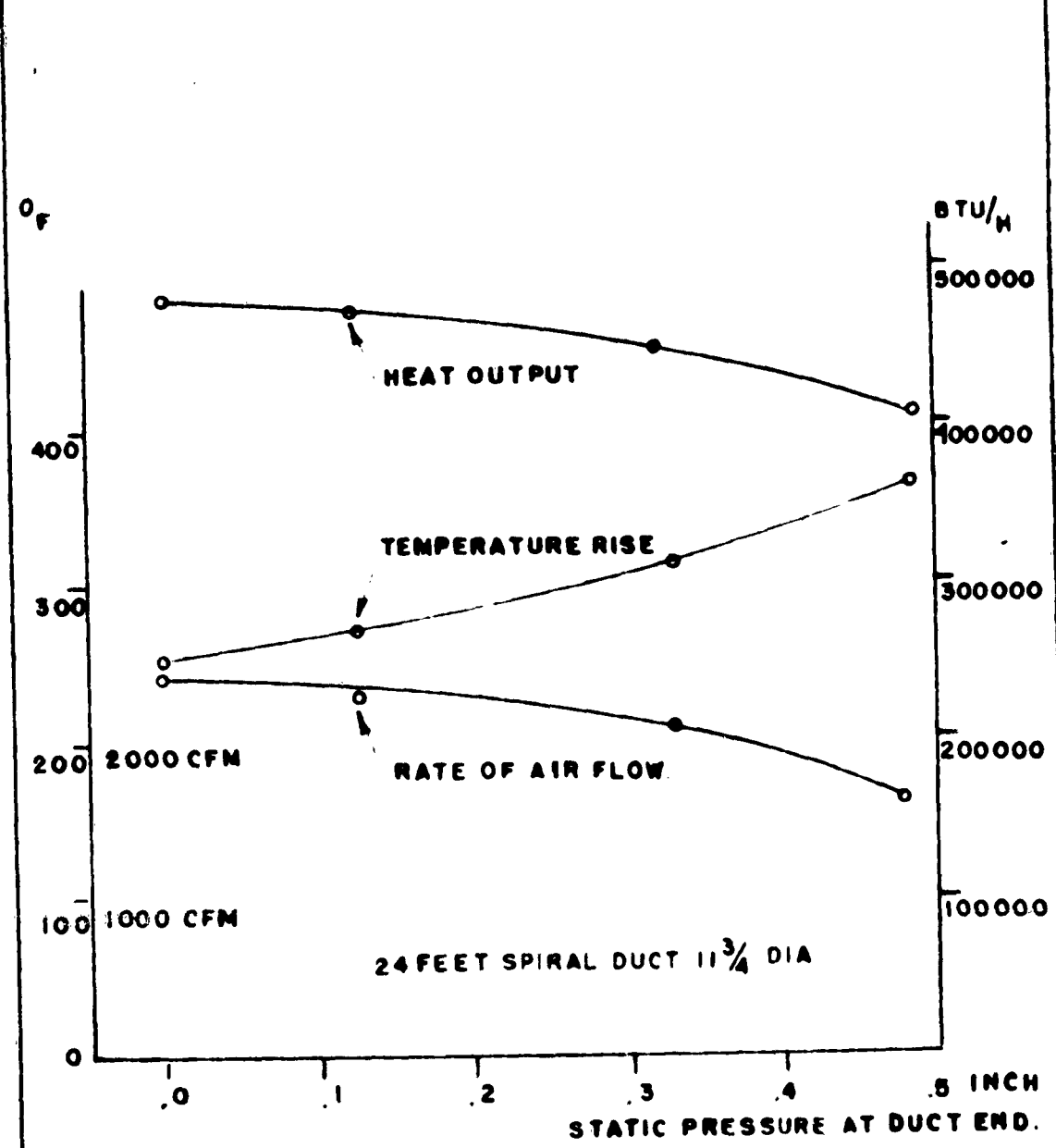
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APPENDIX B

HEATER AND PULSE-JET PERFORMANCE

Performance of Modified Experimental Heater

Chart Figure 1B shows the performance of the heater with attached 24', 12" spiral duct. The top curve represents heat output which exceeds both values specified with the experimental unit and the heater exhibit having a maximum of 470,000 BTU/Hr. Next curve below is the temperature rise (that is excess temperature at duct end over ambient temperature²) vs static pressure at duct end. When preheating an engine, this pressure is low probably within 0 to .1" W.C. and the heater then remains within the specified maximum outlet temperature of 280°F ±25°F up to ambient temperatures of +20°F. At -65°F, a static pressure at duct end up to .5" W.C. may be overcome without exceeding 300°F outlet temperature. Total outlet pressure in this case is .9 W.C. as may be calculated from the bottom curve which shows the rate of air flow.



PERFORMANCE OF HEATER AND SPIRATOR DUCT.

FIG. 1, B

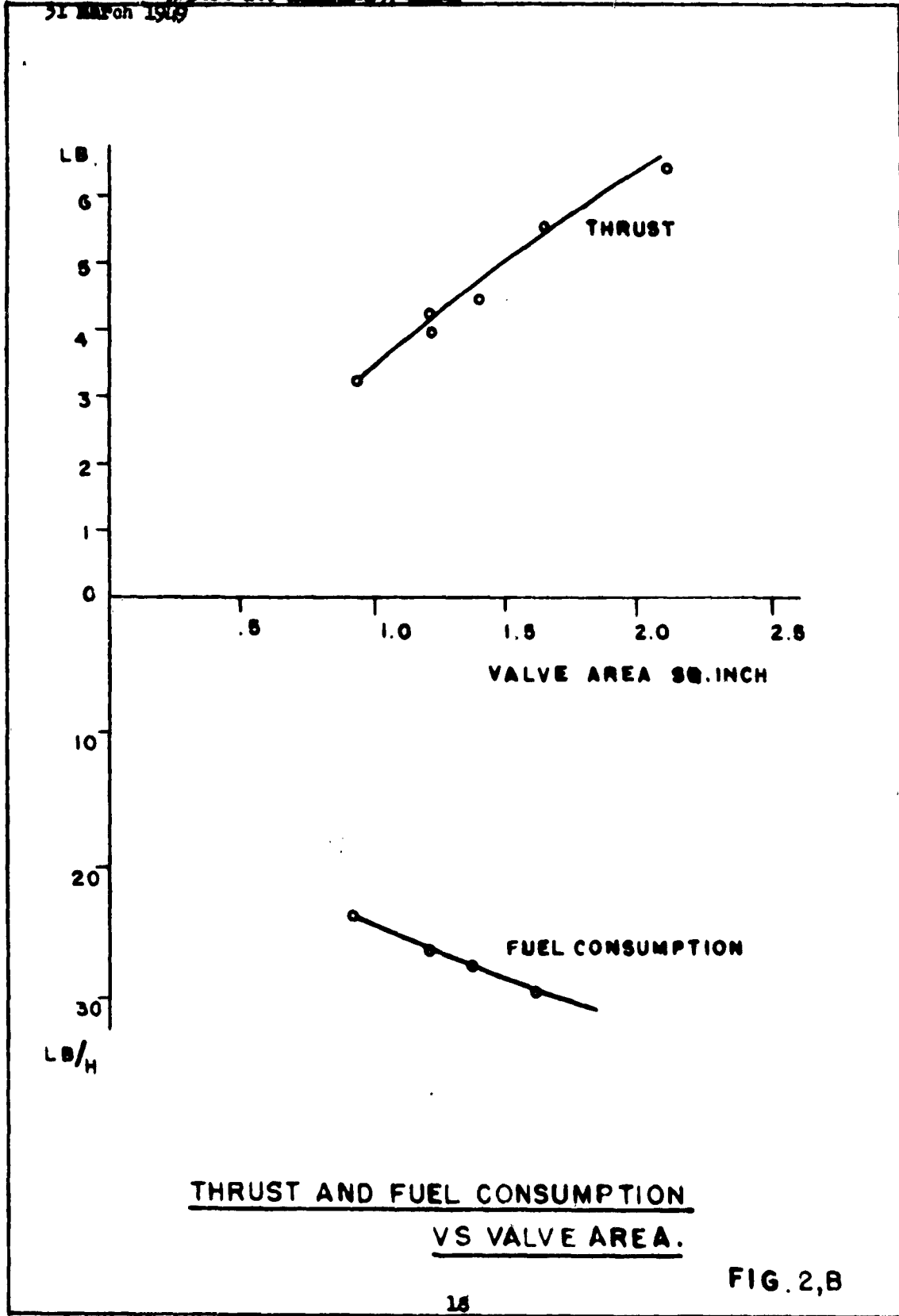
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APPENDIX "B"

HEATER AND PULSE-JET PERFORMANCE

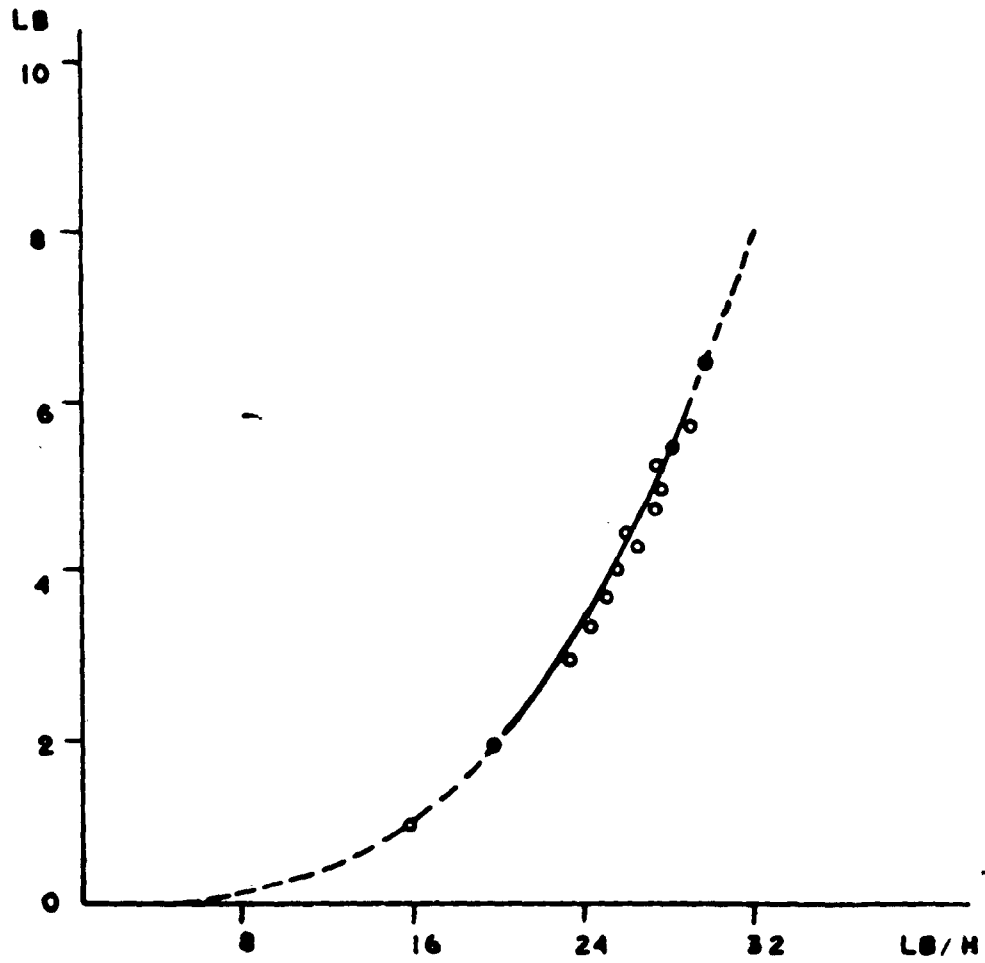
Outline of Measurements on the 50 Cycles/Sec Pulse-Jet Burner

Measurements on the pulse-burner were taken to find how the power and heat output is influenced by changes in the geometrical setup. Table Figure 2B shows how fuel consumption and thrust depend on the (geometrical) area of the valve plate. Cup valves in plates with different numbers of valves were used with slight changes in stroke. Figure 3B shows thrust as a function of fuel consumption averaged from a large number of measurements on the 2 inch, 50 cycles/second burner. Most valuable feature of this graph for theoretical consideration is that the function may closely be approximated by one of the third power, that is $P = C.g^3$ where P means thrust and g fuel consumption. Other measurements served to clarify the influence of changes in the shape of the tube end. Special interest was given to a tapered end with different expansion angle. Table Figure 4B shows increasing static thrust up to a half angle of 4° . Only a slight influence on the fuel consumption was noticed and the higher thrust therefore means a true gain in specific power output. Table Figure 5B shows thrust loss due to winding up of the tube (360°turn) and the additional loss due to forwarding cooling air for the burner tube. It is valuable for the conversion of results gained from a straight burner to a jacketed built in heater unit.



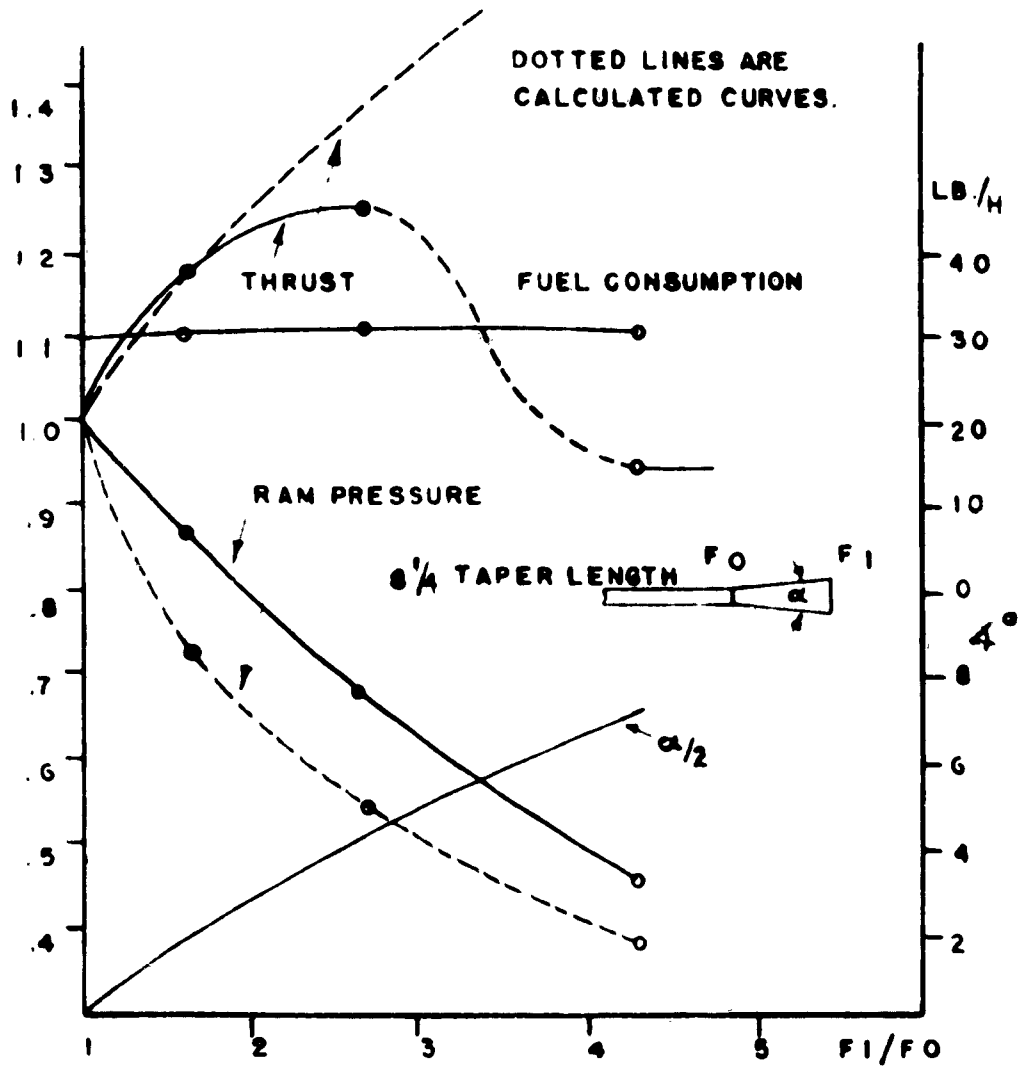
THRUST AND FUEL CONSUMPTION
VS VALVE AREA.

FIG. 2, B



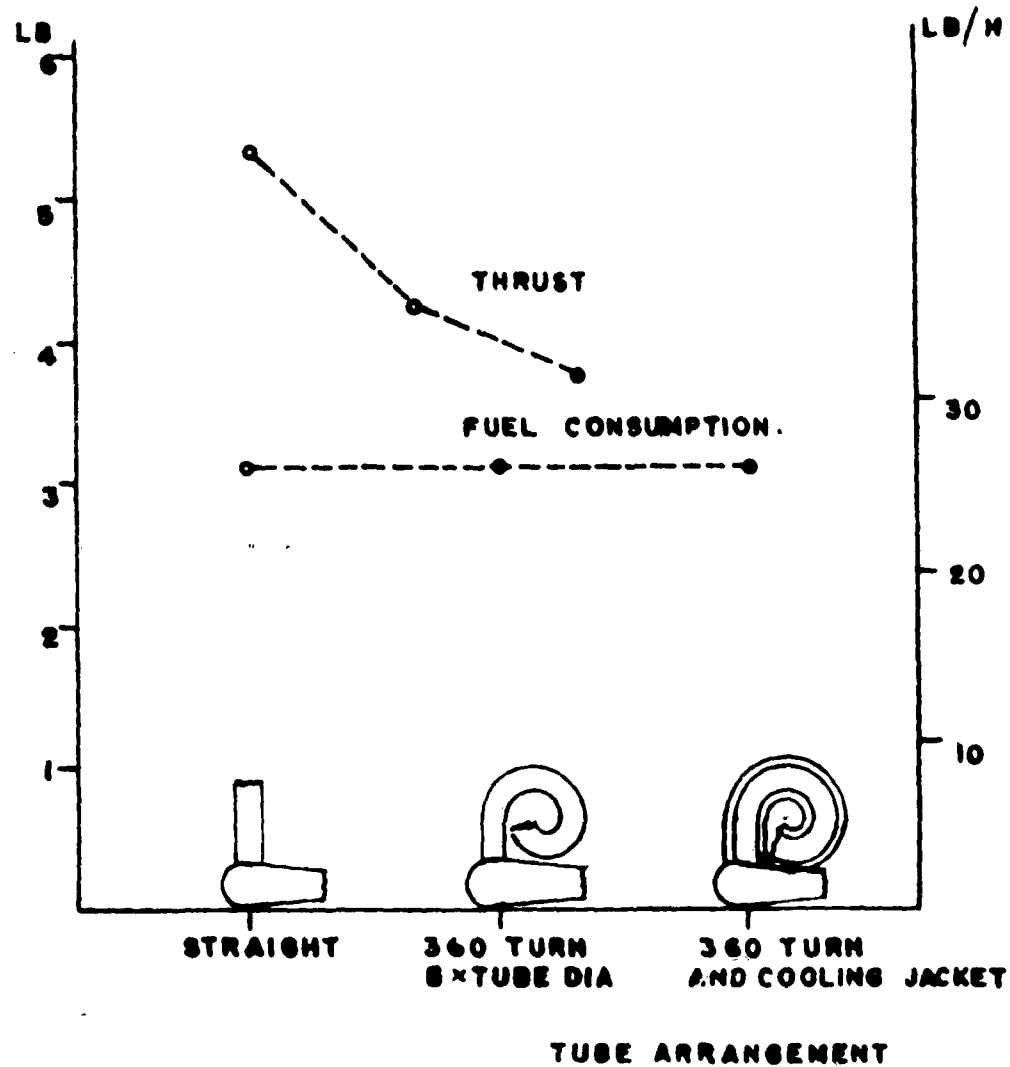
THRUST VS FUEL CONSUMPTION.

FIG.3,B



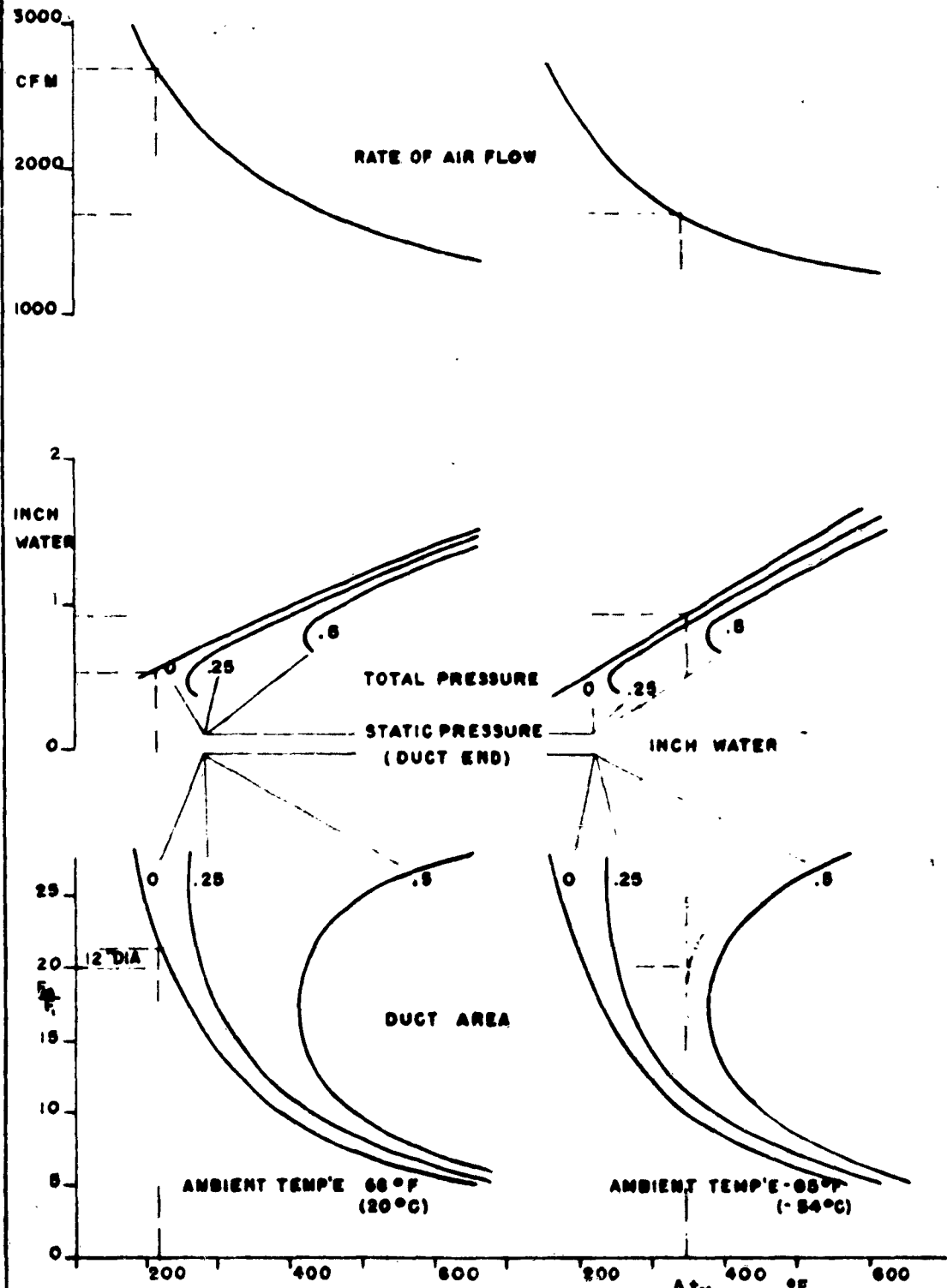
INFLUENCE OF END TAPER ON 2" 80 CYCLE BURNER.

FIG. 4, B



INFLUENCE OF TUBE ARRANGEMENT ON THRUST
AND FUEL CONSUMPTION.

FIG.5,B



CALCULATED PERFORMANCE CURVES OF AIR ASPIRATOR

FIGURE 6,8

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APPENDIX "C"

DEVELOPMENT OF VALVES WITH HIGHER LIFETIME AND BETTER
PERFORMANCE

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APPENDIX "C"

DEVELOPMENT OF VALVES WITH HIGHER LIFETIME AND BETTER PERFORMANCE

Outline of Valve Development

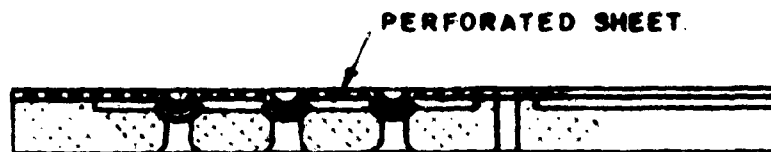
Following the German development, the first pulse-jet burners were equipped with hemispherical valve cups seated on countersunk holes of an aluminum plate and able to move freely between their seats on the plate and a limiting screen. Dimensions of the first cups were $1/4$ " diameter, $1/64$ " thick, stamped out of cold rolled steel. Even after the output of the burner was raised from 250,000 BTU/Hr to almost 500,000 BTU/Hr by enlarging the free valve area, these cups withstood all mechanical stresses. However, their performance in the burner was nevertheless unsatisfactory causing excessive back pressure to the carburetor, uneven running and unreliable starting of the burner. We can see the reason for that by considering that a free moving valve should be accelerated from closed to open position and VV in a very short part of the whole cycle. The first valves were too heavy to allow for a suitable opening and closing time even at 80 cycles/second. Whereas, a relatively long opening time only shortens the effective time area of the valve and could be balanced to a certain degree by increasing the number of valve cups, a long closing time is of a more adverse influence. During the closing time of the valve, a back flow of air from the combustion chamber into the carburetor funnel takes place. It means a loss in power output from the burner and it greatly decreases the average available suction pressure in the carburetor. Above a certain limit, a stable suction process becomes even impossible and the burner fails to operate. Improvement of the performance by limiting stroke and enlarging the number of cups is more involved than with the opening of the valves. One cannot make the stroke too small without excessive increase in flow resistance and an unfavorable change in the ratio between effective valve area and valve leakage. A considerable cut in the weight of the cup valve was a necessary way to improve performance. Aluminum valves of same thickness as the original steel valves, steel valves of $.01$ " and $.007$ " thickness were used and their number was increased from 86 to 126 and later 206 to limit the stroke to a minimum. A good running performance of the burner was obtained but neither arrangement withstood the mechanical stresses for any length of time. Breakage occurred starting from the edge of the cups after short periods of running time depending on stroke and special load and ranging from 5 to 30 minutes. The kind of breakage seems only natural as the edge is the weakest part of the valve cup. It was concluded that

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APPENDIX "C"

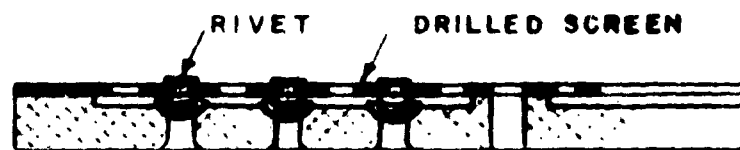
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relieving the edge of the alternating stress should greatly improve the valve performance. A design suggestion realizing this thought is shown in Figure 1aC. Thereby, the cups do no longer hit the limiting screen with their edge but rather with a larger part of their inner surface. This is due to the bosses stamped into the screen which have a slightly smaller radius than the cups. The screen itself consists of a piece of perforated sheet metal with small holes and about 50 per cent open area. Thus far, this design could not be fully realized as it was impossible to get the perforated sheet installed for the screen. A makeshift arrangement shown in Figure 1bC was manufactured locally and tested utilizing rivet heads for the bosses in a regular drilled screen instead of a stamped perforated sheet. With the stroke of the valve reduced to .018", this valve plate was run for eleven hours without any signs of deterioration. At a frequency of 80 cycles per second, this means a total of 3.17 millions of changes in load and one may be pretty sure from this figure that the valve will stand the stresses indefinitely. To realize a sufficient effective area with .018" stroke calls for increasing the number of valves per plate above 126 to about 200 at least which unfortunately cannot be done with the rivet head makeshift arrangement. Therefore, the experimental unit must be run with a larger valve stroke and consequently the possibility of valve breakage after about one hour running time must be taken into the bargain until ordinary plates are available. Further tests were made with a different type of valve plate designed to give more effective area for the same plate size with less and larger valve bodies. Straight strips out of shin steel were used in the arrangement of Figure 2C. With this plate, almost twice the effective area would be possible as with the cup valves retaining the same stroke. But so far, not more than 40 minutes lifetime could be reached. Breakage again starts at the edges of the strips.



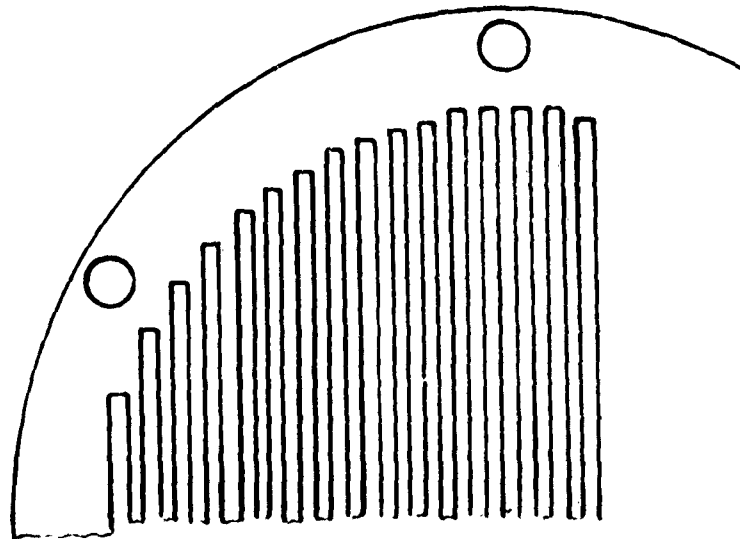
VALVE PLATE DESIGN WITH PERFORATED SHEET SCREEN

FIG. 1A,C



VALVE PLATE DESIGN WITH RIVET HEAD SCREEN

FIG. 1B,C



STRIPES VALVE PLATE DESIGN

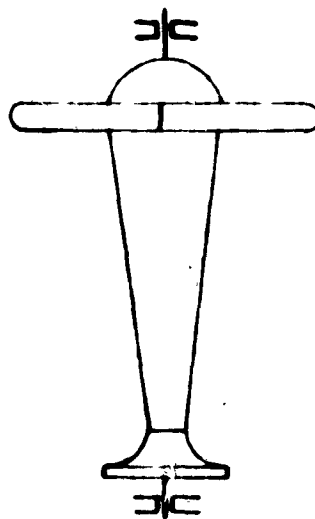
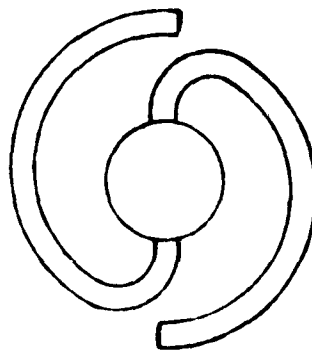
FIG. 2,C

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APPENDIX "D"

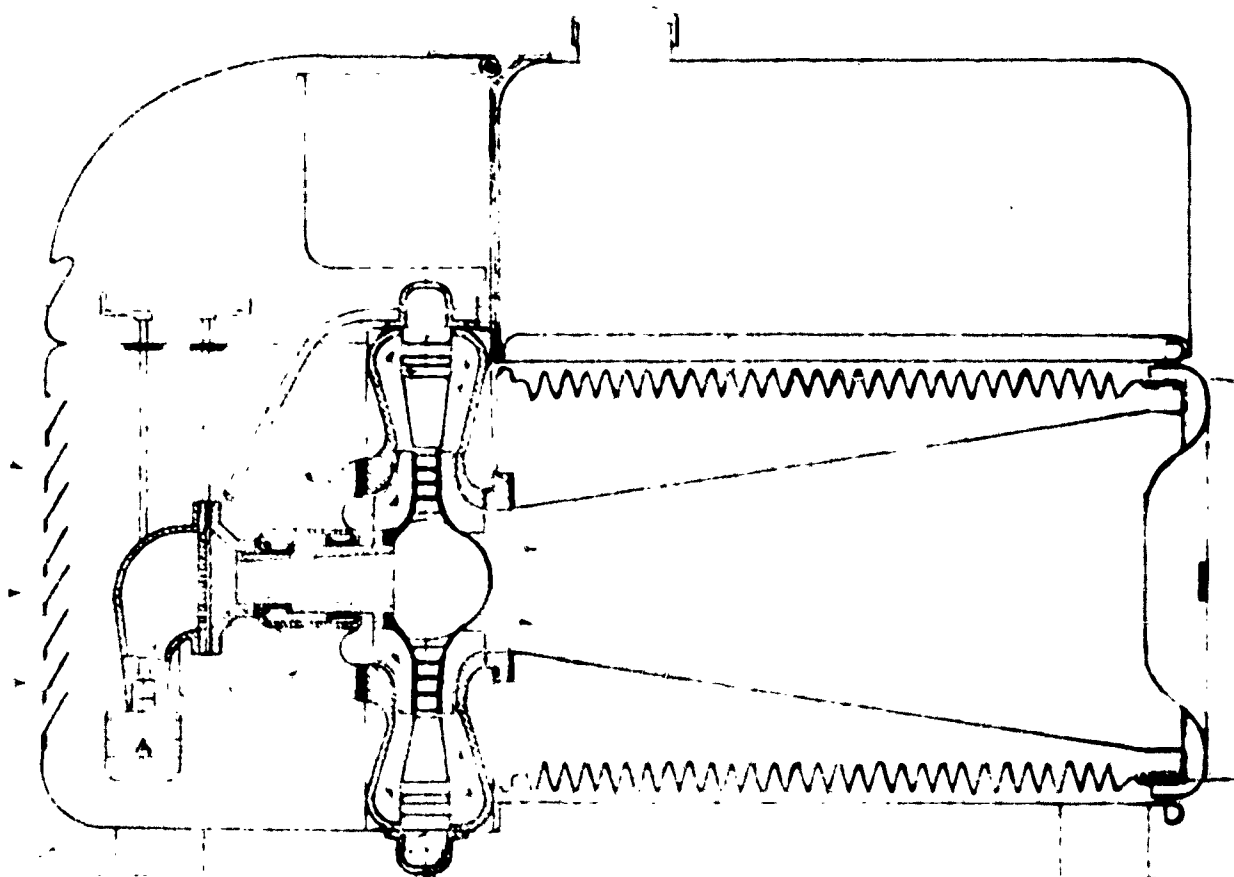
STUDIES FOR THE DESIGN OF A PULSE-JET HEATER DELIVERING
UNCONTAMINATED AIR

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5. Figure 4D - Valve Plate with Concentric Ring Shaped Valve Bodies	33



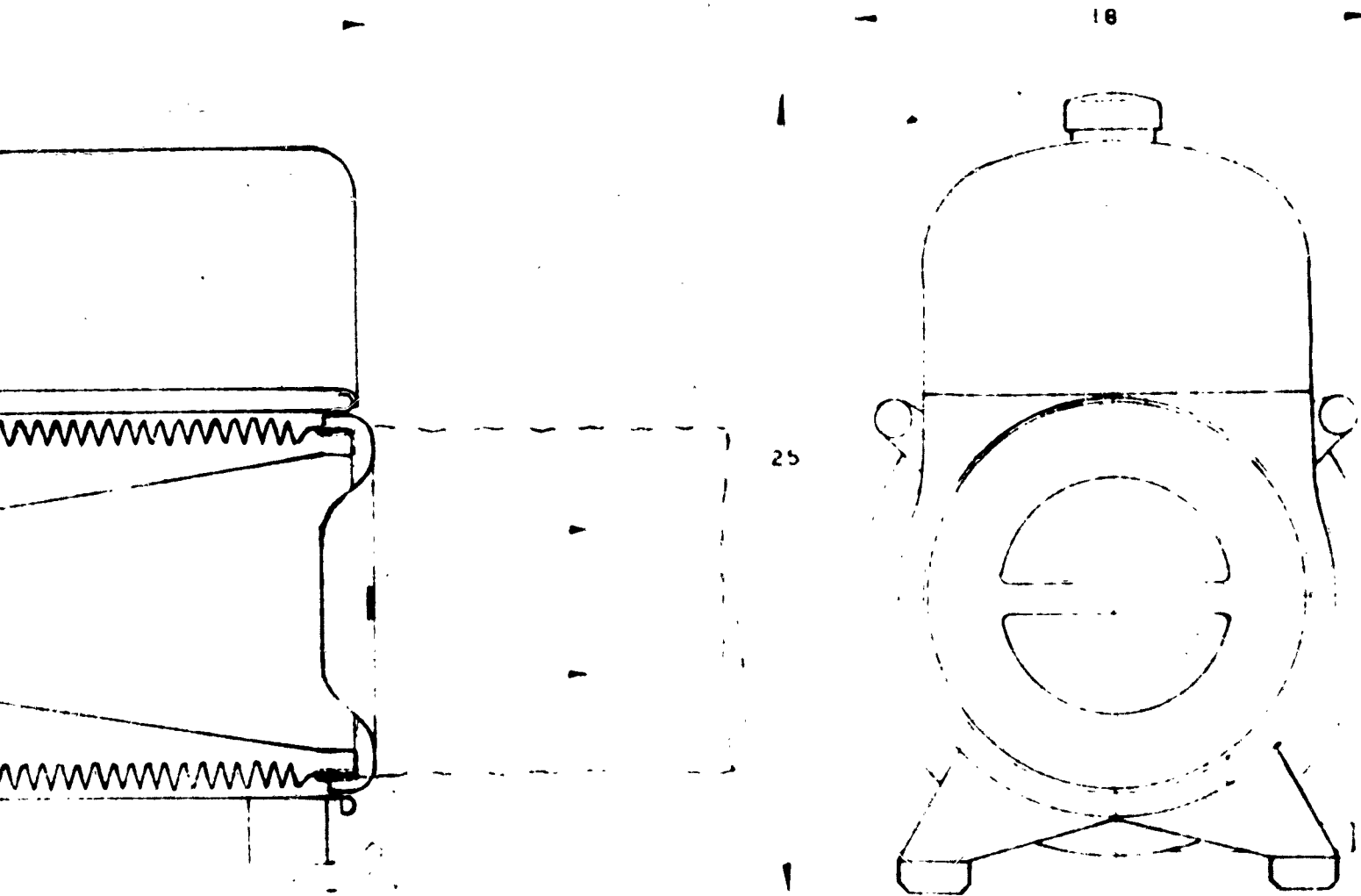
SKETCH OF A ROTATING PULSE JET BURNER

FIG. 1, D



DESIGN SKETCH OF A PULSE JET HEAT

CLEAN-AIR PULSE JET HEATER



SKETCH OF A PULSE JET HEATER DELIVERING UNCONTAMINATED AIR

30

FIG. 2, D

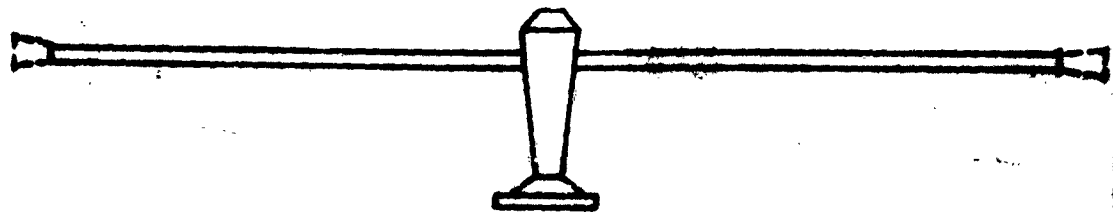
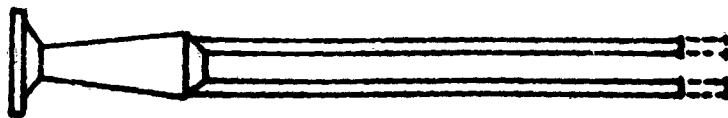
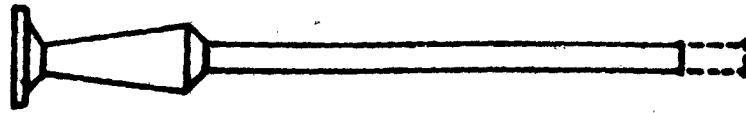


APPENDIX "D"

**STUDIES FOR THE DESIGN OF A PULSE-JET HEATER DELIVERING
UNCONTAMINATED AIR**

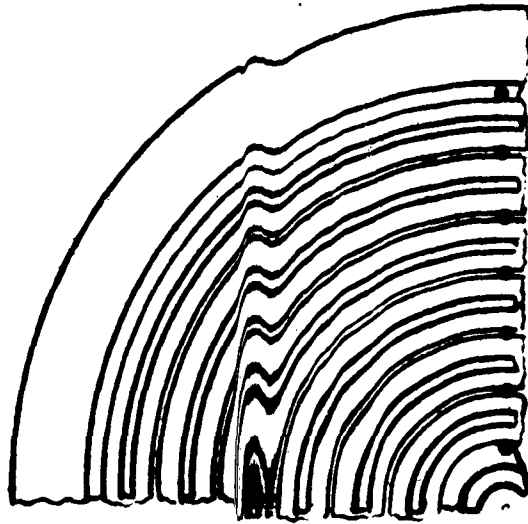
Outline of Studies on Preliminary Burner Forms

To secure the correct operation of the burner in the heater design of Figure 2D, tests were made on several standstill models approaching the outlines of this design in steps. The first step in testing was a burner arranged in a straight line using but one tube, as is shown in Figure 3D top picture. Volume of the combustion chamber, area and length of the tube coincide with the assumed design values. A valve plate with ring shaped valves as pictured in Figure 4D was used to run this burner. In order to get stable running conditions, a free area in the valve plate of 1.5 times the tube area was necessary. The fuel consumption of 12.4 lb./hr then obtained and the thrust of 2.5 lba, keep within the range of assumptions made for the calculations of the uncontaminated air unit. The next step was to replace the one burner tube by two tubes with the same length and the same total area, but the burner failed to operate in this arrangement shown in the next to top picture of Figure 3D. Not until the tube areas and the tube length were enlarged, approximately 10 per cent, running was obtained with practically same performance values as in step one. The last step tested up to date is shown in Figure 3D bottom picture, and characterized by placing the two tubes rectangular to the axis of the combustion chamber opposite to each other. Two different heights on the chamber were tried for attaching the tube and but slight differences in performance against step 1 and 2 were stated. All arrangements were tested with and without funnels on the ends of the tubes as indicated in Figure 3D in dotted lines. Whereas running stability seemed to be increased by use of the funnels, a definite increase in thrust was not noticeable.



BURNER FORMS TESTED IN DEVELOPING A
HEATER FOR UNCONTAMINATED AIR

FIG. 3, D



ANNULAR VALVE.

VALVE PLATE WITH CONCENTRIC RING-SHAPED VALVE BODIES

FIG. 4, D