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THE MUNICIPAL UNIVERSITY OF WICHITA

A STEAM POWERPLANT FOR AN AIRPLANE EQUIPPED WITH BOUNDARY-LAYER CONTROL

by William J. Besler and Stanley J. Whitlock
of the Besler Corporation

Engineering Study 157
(Besler Engineering Report No. 551)

for the Office of Naval Research
Contract No. Nonr-201(01)

September 1954
University of Wichita
School of Engineering
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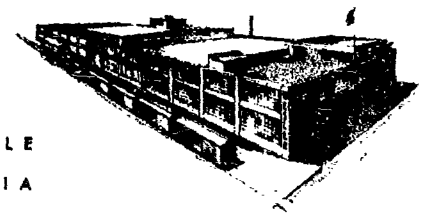

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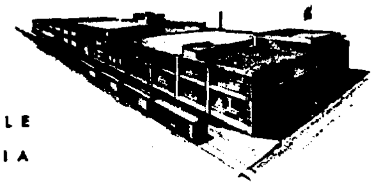

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FOREWORD

This report covers a nearly silent, light-weight steam power plant for aviation, that is particularly well suited to the special requirements of a fixed-wing, boundary-layer-control airplane capable of wide-speed-range and short-field performance. This steam power plant will be able to burn all military vehicle or aircraft fuels. Atomic fuels can undoubtedly be adapted when available. Therefore, a re-examination of steam for power and propulsion is timely and desirable.

The Besler Corporation in the last quarter century has made a number of diversified applications of steam power, including the conversion of a Travelair Biplane (#4259) to steam power in April 1933. This plane was designed, constructed and flown by the writer and associates who remain with the organization as key engineers and executives.

There have been other applications of steam to road vehicles, a streamlined train for the New Haven Railroad and a marine installation. All of these operated successfully and in addition to the commercial steam products, form a background of knowledge and experience pertinent to this report.

A description of the 1933 Besler steam airplane in Appendix A documents what has been accomplished. The report illustrates how a steam cycle fits the special power requirements of a fixed-wing airplane for very short field operation and describes an improved, silent steam plant for 1954.

William J. Besler

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INTRODUCTION

As the speed of airplanes has reached the point where they are hardly suitable for airport operation, future developments must be concerned with lower-speed takeoffs and landings, and shorter-field performance. Boundary-layer control of fixed-wing aircraft is a very promising method of achieving this goal in a rugged, uncomplicated air frame. A steam powerplant has some unique characteristics that are applicable to a boundary-layer control plane. The engines can be expected to be reliable and not subject to sudden cutout, and the boilers through interconnection by small, light-weight pipes can supply their energy to either thrusting or lifting devices, or both. Therefore, the failure of one power generator would not cause undue concern or loss of control. It is the objective of this report to present the essentials of a powerplant system to furnish quiet, reliable, flexible, multi-fuel engine power for a boundary-layer control airplane.

Extreme latitude exists in a steam-powered airplane in the matter of component disposition. The engines may be placed in the wings or other outlying positions while the boilers with the auxiliaries consolidated in an engine room, or the complete powerplant may be housed in the engine nacelle. Power can be diverted from thrusting engines to boundary-layer control engines to eliminate the necessity of providing separate sources of power generation. Other advantages will become apparent throughout the report.

A documentation of the Besler steam airplane of 1933 is presented as Appendix A. Under almost every topic there is continual reference to the technical data acquired by this organization over the last twenty-five years.

A few words about turbines are appropriate since it is very appealing to visualize a completely rotating engine. It is generally appreciated that small turbines are not efficient and that turbines are best utilized in installations such as central power generating stations where 10,000 kw. can be transmitted by a single rotating shaft. Turbines have severe limitations; they must operate at a relatively constant speed and a high load factor. Regrettably, no turbine exists today in the 150 h.p. range that can operate at the pressure necessary for a cycle of high efficiency, and can therefore compete with the highly-developed piston engine shown in this report.

In the author's opinion, if the funds and time were available, a combination piston engine and turbine could be constructed with reduced overall dimensions and weights and a slight increase in efficiency might be expected. It is possible that a small turbine could be produced if an extremely high-speed gearing could be developed. However, for the purposes of this report it is preferred to stay on the conservative side and show the proven efficient piston construction.

Possibly this report will be criticized for its conservatism and the final proposal might not stand up too well in comparison with calculations made from purely theoretical considerations not tempered with practical experience. But in defense of conservatism, it must be emphasized that reliability is the essence of an aircraft power plant. Accordingly, in the machinery of this report the stresses will be lower than in contemporary internal combustion engines and pressures and temperatures will not be placed at the high values now utilized in industry.

Other applications of this power plant besides aircraft should be considered, such as submarines, or perhaps a small NAUTILUS, or silent PT boats, or multi-fuel locomotives or electric-power generators. When atomic fuel becomes available, modifications of this system might be a very convenient, light-weight power source for Arctic or island bases. The waste, exhaust steam would provide heat and the energy would generate electricity for operation of mechanical devices, radar, cooking, air conditioning and other uses.

THERMODYNAMICS OF THE PROPOSED HIGH-PRESSURE STEAM PLANT

As a general statement, the efficiency of the steam power-plant in this study falls between the high efficiency of the piston propeller engine and the turbojet. By utilizing high pressures, reheat, high vacuums, regenerative-cycle apparatus, highly efficient heat interchangers, etc. the theoretical thermal efficiency of a steam powerplant is about 48 percent which correspond to a theoretical fuel consumption of about .232 pounds of fuel per horsepower hour. Needless to say, this cannot be realized. All attempts to achieve such an efficiency would be at the sacrifice of weight and complication together with additional control mechanisms. There would then be the question of reliability as well as problems of maintenance, etc.

It is possible to fabricate boilers with efficiencies of 90%, but there are attendent problems of corrosion occurring in such constructions which have proved desirable to avoid. The additional weight involved would also not be justified, except in some special instances. Similarly, in the matter of engine design multi-expansion construction involving more weight and complication can enhance the thermodynamic efficiencies. These same general ideas also hold true for condensing surfaces and other components.

The powerplant proposed is considered a practical thing--- something that will not require complicated instrumentation or highly skilled technicians for maintenance and that efficiency is somewhat sacrificed to simplicity, ruggedness, light weight and reliability. This is particularly true for the specific application of this powerplant to an airplane with boundary-layer control. Such an aircraft will be capable of carrying greater loads over much greater distances at much greater speeds than rotary-wing craft. By the nature of the missions for this type of airplane it seems probable that the slightly greater fuel consumption over a gasoline piston engine will require only an additional stop for fuel on long-range missions. On short-range missions there should always be an opportunity to refuel at some point in the circuit of operations with any type of fuel suitable for the burner.

The following is a thermodynamic analysis of the proposed powerplant selected on the basis of existing knowledge of aircraft power requirements. A steam temperature of 780° was selected, because lubrication is satisfactory in this range. The steam pressure was chosen as 1200 pounds for take-off and 900 pounds for cruising. Dynamometer tests included in the Appendix showed that these are practical operation conditions for the compound engine proposed with saturated steam delivered to the condensing surfaces.

The calculations show the Rankine cycle efficiency obtained from the steam tables and/or Mollier chart, and the percentage of Rankine cycle which the engine will realize (from supporting data on file and partly included in the Appendix). The calculated fuel rate is given for a combination of diesel oil, kerosene, and gasoline (equivalent to 19,000 B.t.u./lb.). It is contemplated that the powerplant will operate on any of these fuels, but should have better performance when utilizing a higher percentage of gasoline with intermixed fuels.

Steam conditions: Temperature 780° F.
Pressure 1,200 p.s.i.a.

Rankine Cycle:

Steam heat content at initial conditions of 780° and 1200 p.s.i.a. = 1,366 B.t.u.

Heat in steam (assuming feedwater at condensing temperature and 2 p.s.i.g.)	=	186 B.t.u.
Heat added by boiler	=	1,180 B.t.u.
Steam heat content at final conditions after the drop in pressure at constant entropy or isentropic expansion to 2 p.s.i.g.	=	1,004 B.t.u.
Heat drop B.t.u.		362 B.t.u.

$$\frac{\text{Heat usable}}{\text{Heat supplied}} = \frac{362}{1,180} = \text{Rankine Cycle Eff.} = 30.7\%$$

From Besler Test No. 3 on May 18, 1931 of a 3" x 5-1/4" x 5" compound engine an efficiency of 72% of the Rankine Cycle efficiency at 785° F. and 890 psi was measured (see the appendix). If it is assumed the proposed engine would be at least as efficient, then 72% of 30.7% = 22.1% engine thermal efficiency. Assuming a boiler efficiency of 80%, the thermal cycle efficiency would be 80% of 22.1% or 17.7%. If 5% of the power is required for all auxiliaries from the steam cycle, then the overall cycle thermal efficiency would be 95% of 17.7% = 16.8% for the power unit.

Fuel consumption calculation:

For a combination fuel with a heat content of 19,000 Btu/lb. the fuel consumption of the whole plant would be

$$\frac{2,545}{19,000 \times .168} = .797 \text{ lb./hp./hr.}$$

An engine capable of 75% of the Rankine Cycle and a boiler efficiency of 84% would decrease the fuel rate to about .73 lbs./hp./hr.

ENGINE

The engine is the heart of any steam powerplant and its efficiency more than anything else determines the overall efficiency of the plant, the fuel rate, the size and weight of the boiler, condenser, feed heaters, and all other components. Obviously, if an engine has a 20 pound water rate instead of 10, the boiler has to be twice as big and all the other components must have twice the capacity. (A steam engine's water rate is defined as the number of pounds of water, evaporated into steam and passed through the engine of this report is expected to have a ten pound water rate at cruise power.

A V-type, compound engine developed by the Besler Corp. has been selected for this illustration as a compromise of weight, complication and efficiency. This two-cylinder, double-acting engine is simple, reliable, and remarkably efficient. A large amount of work has been done on this particular type and size of engine, so that performance can be predicted with assurance.

A drawing of the 200 h.p., 2-cylinder, double-acting engine is shown in fig. 1. The construction features are obvious from the drawing. The crankcase is aluminum and the other parts are steel. Note that it is only 6" from the propeller shaft centerline to the top of the engine and 17-1/4" to the lowest extremity.

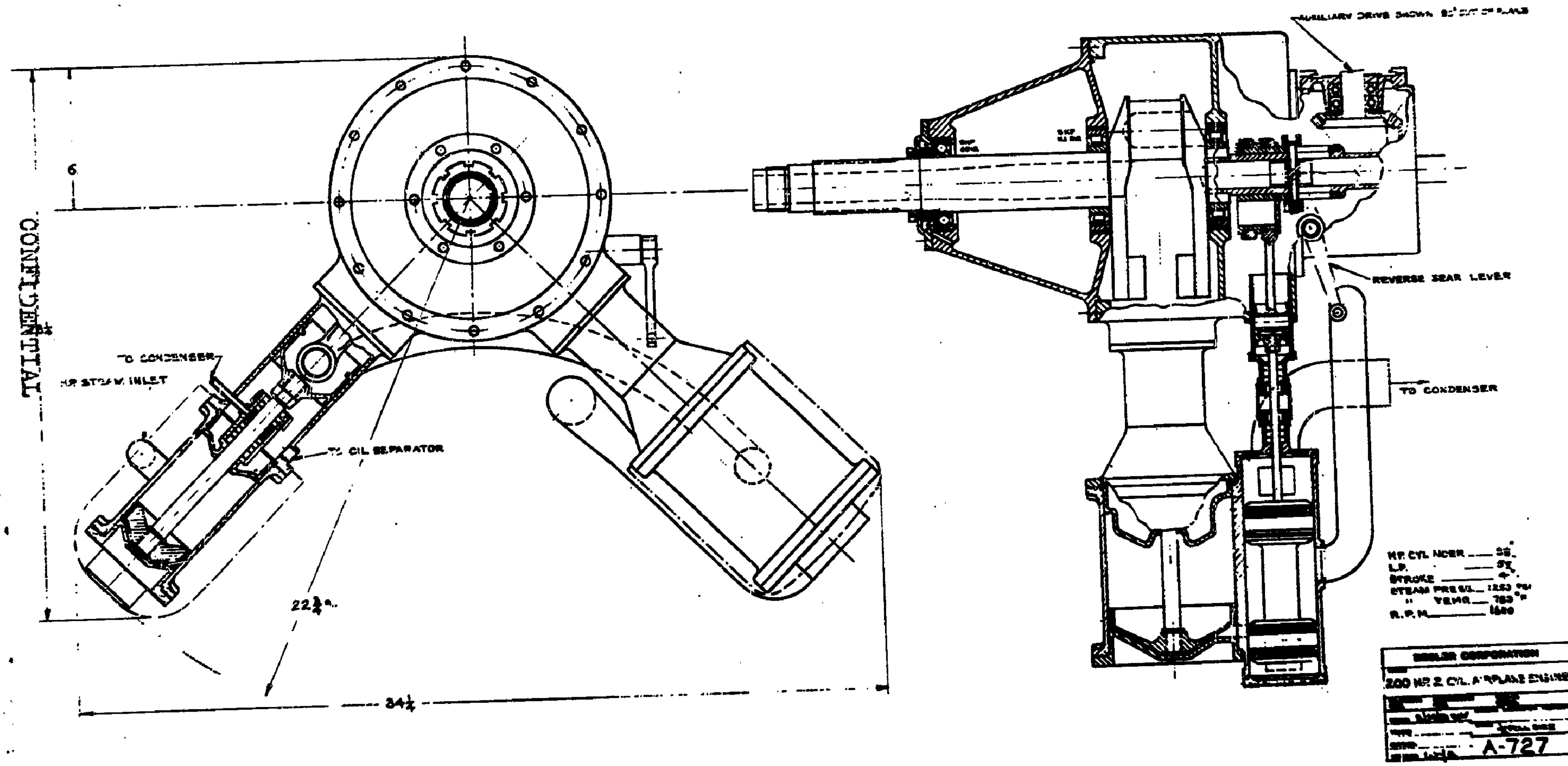

Figure I. - 200-horsepower, 2-cylinder airplane steam engine

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A variable-pitch propeller will hardly be justified with a steam engine, because the power output is dependent on the boiler output. Over a reasonably wide range of speeds the steam pressure may rise or fall as necessary, but the power and the efficiency remain substantially constant.

Reversible-pitch propellers will not be needed either, since a simple reverse mechanism can be provided to reverse the engine. It is reasonable to expect the engine to go from full forward to full reverse in about one second as it did in the airplane of 1933. It will not be necessary to close the throttle during this reversing operation, so that the airplane contemplated may stop in about one length after touch-down under favorable conditions.

In the preceding discussion, a case was made for the V-compound engine. For illustration an inverted V has been chosen, but other arrangements are possible and perhaps desirable. The flying steamer of 1933 utilized a V-engine but the cylinders were up from the crankshaft as shown in the Appendix.

The V arrangement presents considerably more frontal area than necessary with an in-line engine. A 2-cylinder, in-line engine presenting an extremely narrow profile, which would probably be placed with the cylinders downward from the propeller shaft, could be employed if the boilers were arranged in an engine room or submerged within the wing.

The balance of a 2-cylinder, in-line engine is more difficult, because the primary forces are unbalanced and the secondary forces remain as a couple. It is usual to provide reciprocating weights or rotating counter shafts with counter weights thereon arranged to absorb the primary forces, while the secondary forces are balanced as necessary.

The big advantage of the V-type engine is that the primary forces are inherently balanced by counter weighting opposite the crank pin with the weight of the pistons, which are identical in weight. The secondary forces are unbalanced and act as a couple in a horizontal plane with a frequency of twice crankshaft speed. These secondary forces can be balanced if desired by two synchronized counter rotating weights although in the 1933 machine they were unbalanced and there was little noise or vibration. While on the subject, the quietness of the ship was the most surprising thing to most bystanders. Except for the low-frequency beat of the propeller turning 1400 r.p.m., there was so little noise that it was possible to talk to people on the ground 300 feet below. The sound of the air flowing over the wings could be distinguished from the air flowing across the guy wires. It was even possible to detect the direction to the various air flow-sound sources.

There is extreme latitude in the component arrangements and it does not matter if one or four engines or boilers are employed. If a 4-cylinder engine is chosen in preference to a 2-cylinder engine, either the engine becomes smaller and more compact at a slight sacrifice in efficiency, or the power doubled. In the 4-engined illustration a V engine is shown with one of the cylinders down and the other horizontally submerged in the leading-edge of the wing. This arrangement provides good balance and a minimum of frontal area. In the Appendix dynamometer test data for comparable engines are given for both the V-type and in-line engines.

STEAM GENERATOR

Only one type of boiler meets the requirements of the external combustion powerplant, namely, the forced-circulation, water-tube boiler. This type of boiler was used in the 1933 flying steamer and has reached a stage of high development. Thousands of boilers of this general classification have been built by the Besler Corporation for a wide variety of uses. This type of boiler provides a light, but adequate,combustion chamber without any weight-consuming brickwork or conventional firebox constructions. The tubing can be conservatively rated and a construction is employed that has been proved by experience. Literature is in the Appendix on Besler commercial and testing boilers to illustrate general construction features.

The few modifications incorporated in the boiler chosen for the proposed steam airplane powerplant are shown in the drawings of the Appendix. The combustion chamber has been reduced about 2 inches in diameter from the standard commercial testing boiler rated at 2,500 pounds of steam per pour. The proposed boiler will evaporate substantially this same amount of steam and, while the choice of an essentially commercial boiler may be considered conservative, reliability is an important objective.

Super-atmospheric combustion has received much publicity recently, but appears difficult to justify. The power required for high-pressure blowers and the complications of turbodraft control systems must be balanced against the small gain of reducing the combustion chamber diameter by about 5 inches in the contemplated construction. Space is not that valuable and the increased heat transfer to the tubes presents reliability problems, so the theoretical gains are questionable.

200 H.P. STEAM GENERATOR

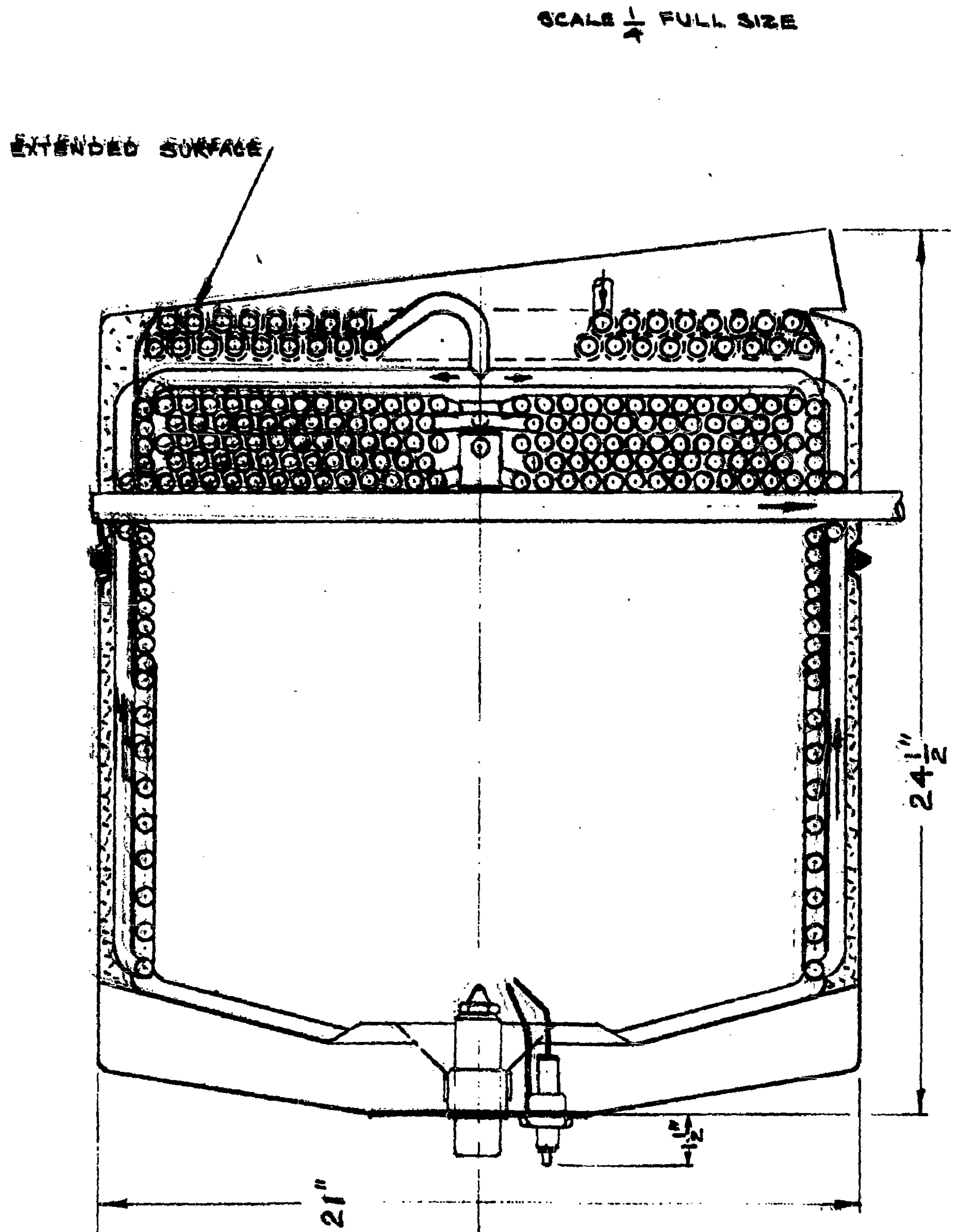


Figure 2.- 200-horsepower steam generator

One difference, however, is a very significant improvement in the proposed boiler and that is the use of extended heating surfaces in the economizer. For some years a line of commercial heaters have been built in which one row of extended surface tubes over a gas fire is used with efficiencies over 70 percent. This tubing can be made of aluminum, copper or steel and is fabricated by a special machine in the Besler factory. In the preceding boiler drawing five rows of plain tubes are used as final evaporators and superheaters and then two passes of spined extended heating surface tubes are employed to give a considerable saving in space and weight.

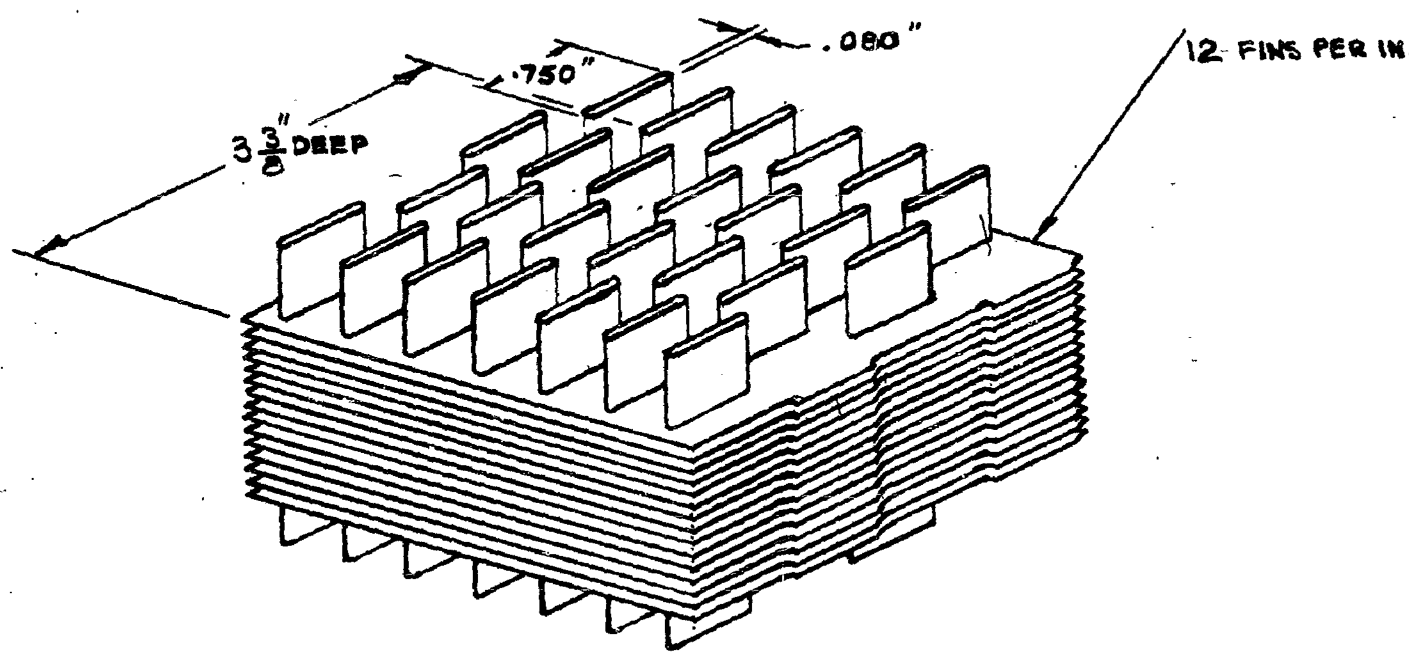
Test performance curves in the Appendix show typical boiler performance. It is to be emphasized that the boilers have an evaporative capacity of 2500 pounds per hour, but under cruise conditions at 75 percent power the blowers are not operating, so the boilers would only evaporate 1500 pounds, or 60 percent of capacity. This low load factor should provide greater reliability and longer life.

CONDENSER

Considerable progress has been made in the last two decades in light-weight automobile radiators, aircraft oil coolers, and other heat exchangers. In a steam power plant it is desirable to reduce the exhaust pressure as much as possible, but as the pressure of saturated steam is lowered the temperature is also lowered. Unfortunately, it is not possible to reach low pressures in a flying power plant, because the temperature difference between the cooling air and the steam decreases to the extent that a very large condenser would be necessary.

Physical size, weight, and air horsepower to force air through the condenser cores are the three variables that must be examined to arrive at the most desirable condensing surface. The two condensers chosen for illustration consist of cores 23-3/4 inches square or 3.9 square feet each for a total frontal area of 7.8 square feet. They would be fabricated entirely from aluminum with four rows of staggered tubes on 5/8-inch centers, .08 by .75 inches in cross-section, and made of .012-inch thick material with ten fins per inch of .006-inch thick material bonded to the tubes. The headers and side plates would be made of .0625-inch material and the tanks of .0937-inch thick material. The condenser would be 3-1/2-inches thick with the weight of one square foot of core at 6 pounds, so the weight will be 28-1/2 pounds for each condensor complete with side plates and headers for a total of

CONDENSER CORE CONSTRUCTION



gure 3.- Condenser core construction

57 pounds. If the condensers were made of copper, studies indicated the weight would be substantially double that of aluminum construction. Curves and other data on this subject will be found in the Appendices.

Installation of cooling radiators within an airplane wing are shown in N.A.C.A. Report No. 743; however, in this report condensers are not shown in the airframe structure. The condensing surfaces could be installed partially in the wing leading edge to act as de-icers, or as shown in the engine nacelle or wherever selected by the air frame designer.

The quantity of steam condensate from a given size of condenser core depends upon the temperature difference between the air and the steam, and the air flow through the core. At takeoff the steam generation requirements are a maximum and the cooling air temperature may be higher than at altitude. Under these conditions the exhaust steam must be condensed at higher temperatures and pressures in order to have adequate condensation. At cruising speed the steam requirements are reduced and at altitude the steam will be condensed at a lower temperature and pressure.

One 200 horsepower engine at a water rate of 10 lb/hp. hr. will use 2,000 lb/hr. of steam.

Ambient air temperature	=	90° F.
Steam condenser pressure	=	2 psi gage
Steam condenser temperature	=	218° F
Available temperature difference	=	128° F.
Enthalpy of steam at 2 psi gage	=	1152 Btu/lb.
Enthalpy of liquid at 2 psi gage	=	186 Btu/lb.
		966 Btu/lb.

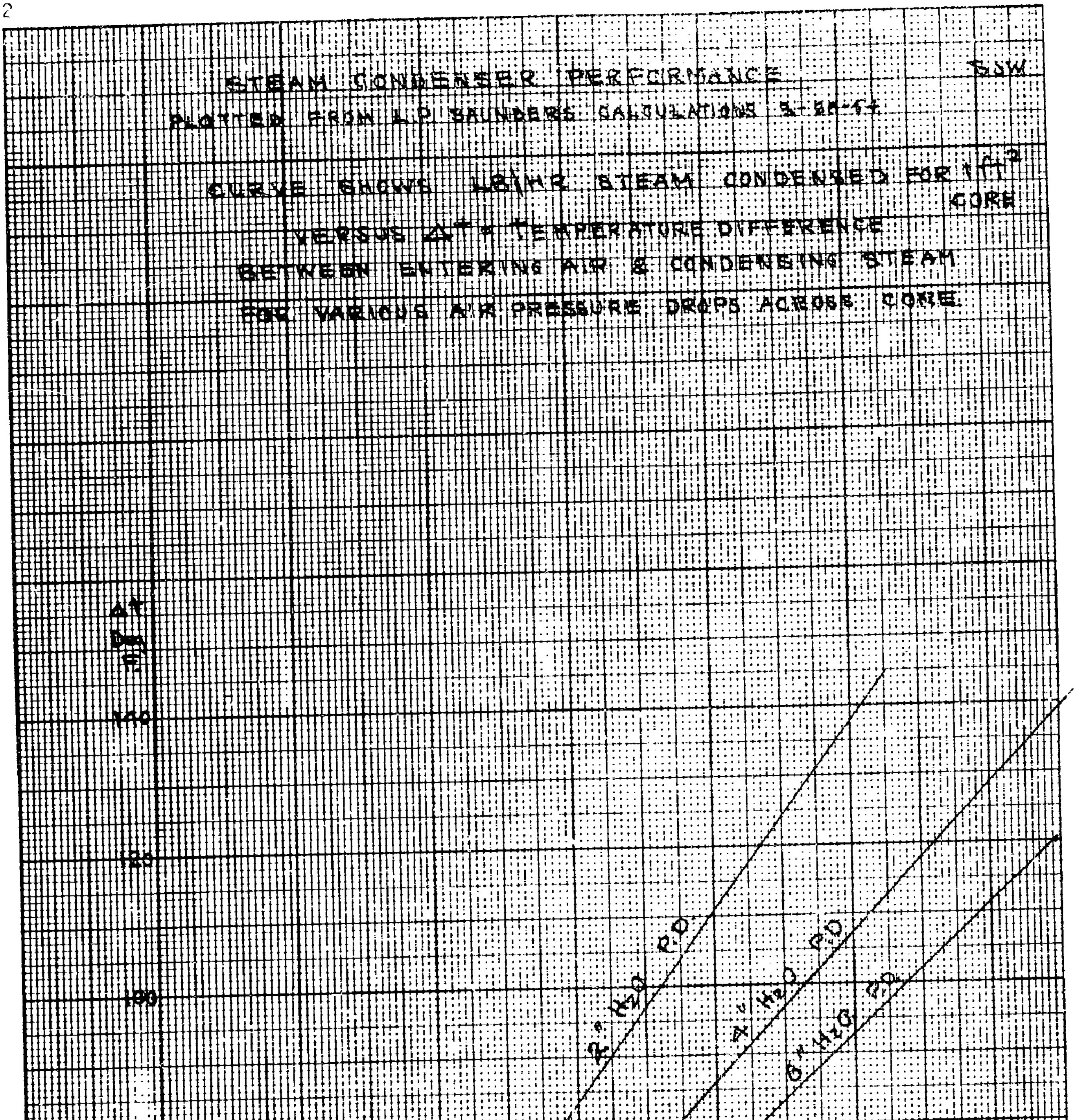
or, 966 x 2000 = 1,032,000 Btu/hr. to be removed.

At 4 inches of water static air pressure differential across the condenser and 100° F temperature differential the condenser has a capacity be test of 3100 Btu/min per square feet of condenser core. For the 128° temperature difference the required area will be

$$A = \frac{100 \times 1,932,000}{128 \times 3,100 \times 60} = 8.1 \text{ sq. ft.}$$

If a saturated steam pressure of 5 psi gage is maintained in the condenser the temperature of the steam will be 226° F. and with an ambient air temperature of 90° F the temperature differential of 136° F is available. Then

$$A = \frac{100 \times 1,932,000}{136 \times 3,100 \times 60} = 7.64 \text{ sq. ft.}$$


SJW
STEAM CONDENSER PERFORMANCE
PLOTTED FROM L.P. SAUNDERS CALCULATIONS
CURVE SHOWS LB/HR STEAM CONDENSED FOR 1 FT² CORE
VERSUS ΔT = TEMPERATURE DIFFERENCE
BETWEEN ENTERING AIR & CONDENSING STEAM
FOR VARIOUS AIR PRESSURE DROPS ACROSS CORE
ΔT
Deg.
F
140
120
100
80
60
2" H2O P.D.
4" H2O P.D.
6" H2O P.D.
LB/HR CONDENSED
FOR 1 SQ.FT. CORE
100
150
200
250

Figure

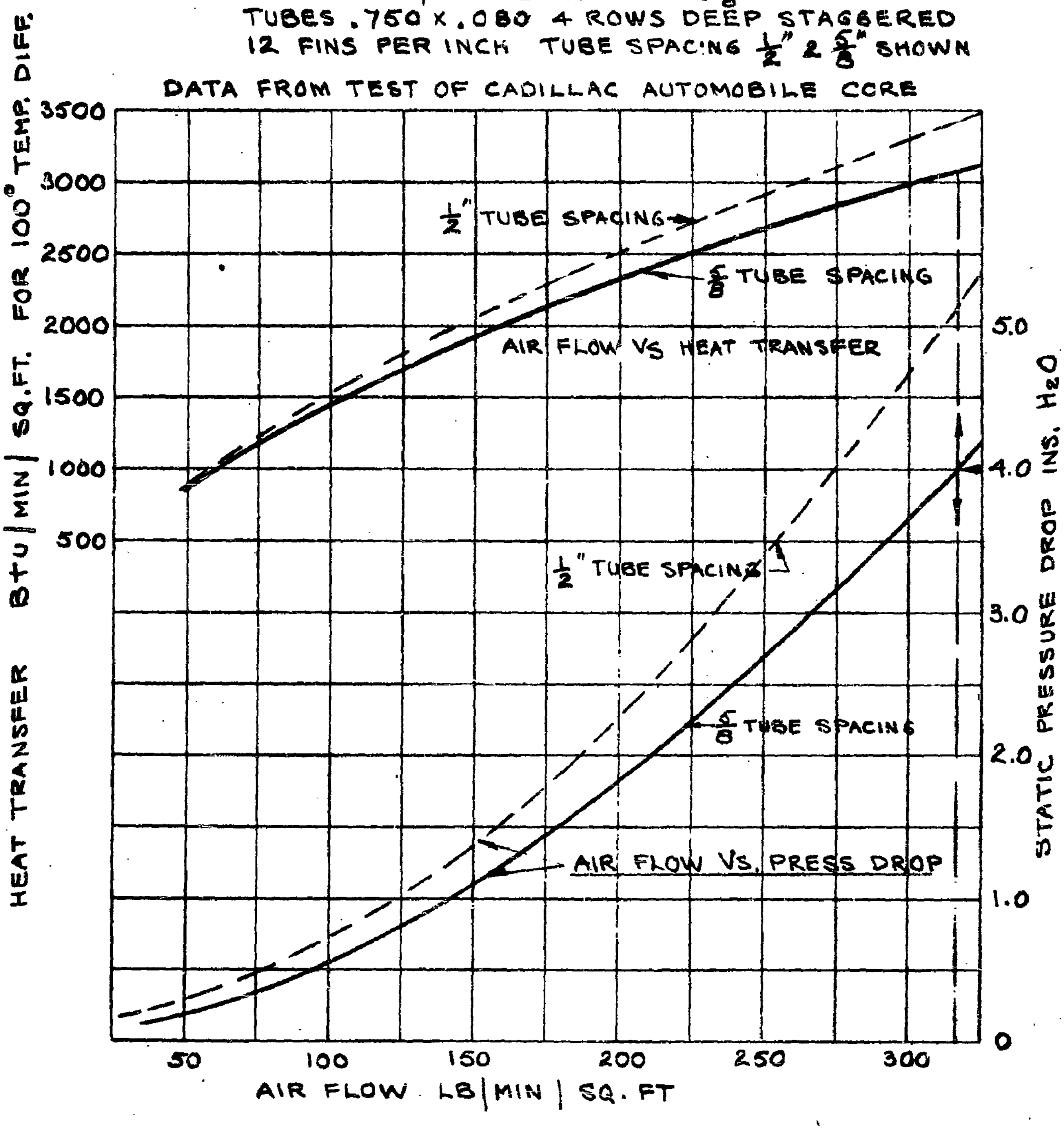
CONDENSER PERFORMANCE

TYPE :- FIN & TUBE, CORE 12" x 12" x 3 3/8

TUBES .750 x .080 4 ROWS DEEP STAGGERED

12 FINS PER INCH TUBE SPACING 1/2" & 5/8" SHOWN

DATA FROM TEST OF CADILLAC AUTOMOBILE CORE



EXAMPLE

4.0" H_2O PRESS. DROP ON 5/8 TUBE SPACING CURVE READ 316 LB | MIN | SQ.FT. AIR FLOW & 3100 Btu | MIN | SQ.FT. HEAT TRANSFER FOR 100°F TEMP. DIFF.

Figure 5. Condensor performance

The air temperature will seldom be as hot as 90°; if it is higher then water will be spilled for a few seconds during takeoff, or the reserve capacity of the water tank may absorb the heat (as indicated by the exhaust piping arrangement of the flow diagram).

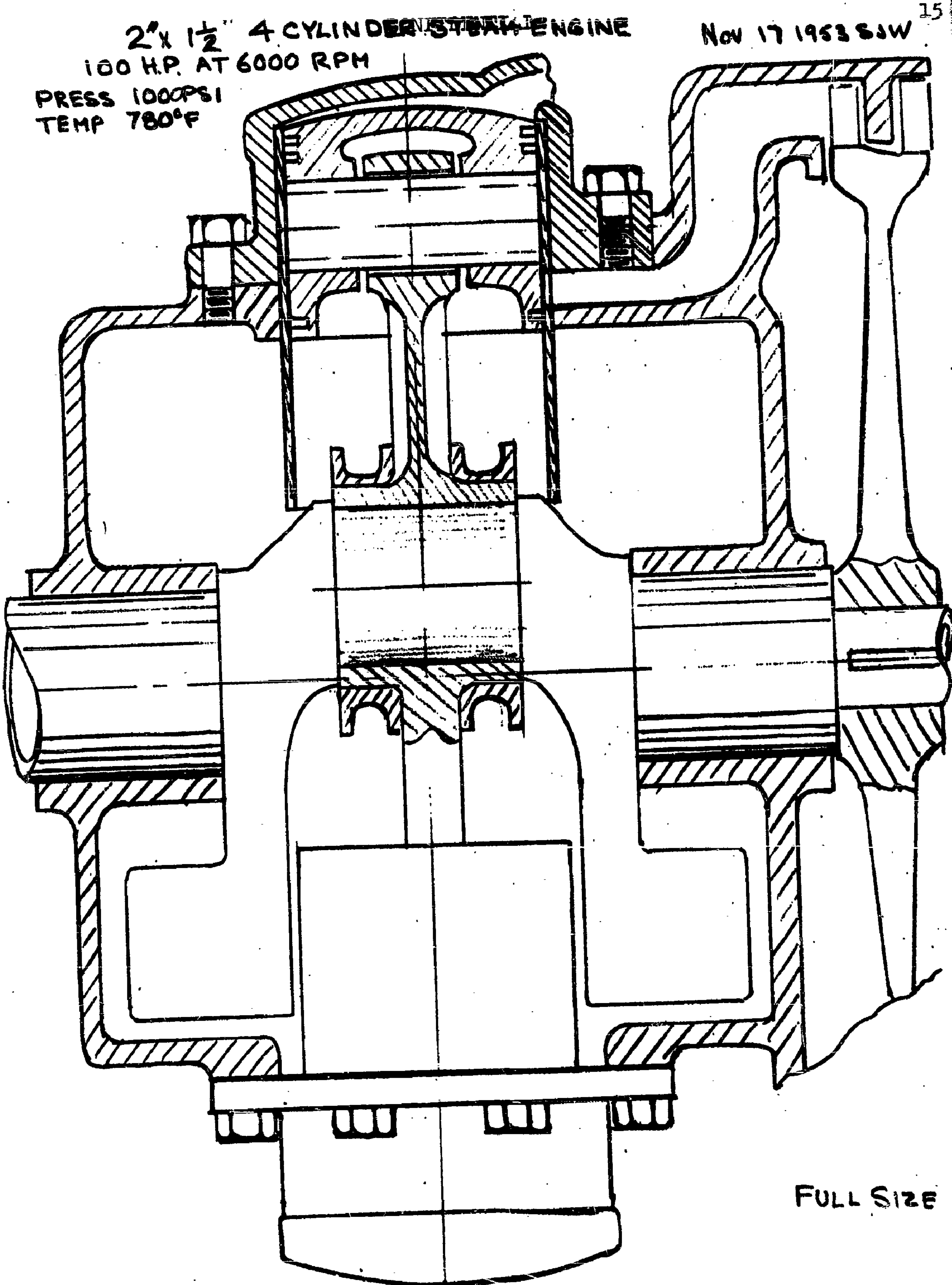
Other core configurations were calculated for different tube spacing, fin spacing and depth, but the example given represents good commercial practice. The air face has been arbitrarily selected as a square since the capacity of any condenser is a function of its face area and its air flow dimensions. The limiting factor in size is when the surface becomes too large for practical manufacture. The core weight is constant for a given frontal area, however, the header and tank weights will be reduced with a reduction in the core width and an increase in tube length.

BOUNDARY-LAYER CONTROL BLOWER ENGINE

It would be desirable for the boundary-layer blower engine to be as efficient as possible. However, the efficiency under landing conditions would not be particularly important, because there would be excess boiler and condenser capacity at this time with the thrusting engines operating at a light load. The following drawing shows a uniflow engine that produces 100 hp. at 6000 rpm. to drive the boundary-layer control blowers. This is shown as a combination turbine-piston engine which was mentioned in the Introduction.

Another way to handle the blower power requirement is the back-pressure steam turbine. This scheme could be used to advantage during takeoff, because each of the two 100 h.p. blowers, if driven by a turbine, would then have some 5000 pounds of steam flow available. This is a zone where a low-pressure turbine could be expected to have a high efficiency and do a satisfactory job at a low loss of main engine horsepower. For landing and approach conditions the blower turbines would take all of the steam available until the touchdown. If additional power is required, high-pressure steam through supersonic nozzles could supply more than a sufficient amount of power.

The above systems will work, but before further detailed thought and effort are devoted to this subject, it would be desirable to know the most advantageous plan for a particular air frame design.



gu 6 - 2 in. by 1-1/2 iCONFIDENTIALnder engine

AUXILIARY EQUIPMENT

Auxiliary equipment has usually been a troublesome part of steam powerplants and often accounts for the poor efficiencies. The principal auxiliaries are the water pump, the fuel pump and the combustion air blowers.

Besler Corporation has built all types of high-pressure pumps of 1, 2 and 3-cylinder design from very small capacities to 30,000 pounds of water per hour at 3,500 p.s.i.; 4-cylinder, 2-cylinder double-acting, and 5-cylinder pumps have been constructed for special applications. The Besler Corp. has a satisfactory business in special, high-quality pump construction including pumps for the boiler and agricultural-sprayer divisions.

It would be very appealing to use some of the gear or vane pumps now available; however, until experience is accrued the author would prefer to stick by the tried and proven, even at a sacrifice in space and weight until a test program proves their reliability. The fuel pump can certainly be a gear pump driven from the blower shaft. An electric starting motor would be provided or a suitable generator which could be motorized to operate the blower and fuel pump might be used for starting. A belt was used to synchronize the blower with the engine speed on the 1933 airplane, however, there is latitude on this matter. The type of operating conditions for the airplane has considerable to do with the final choice.

There are other minor auxiliaries such as a condenser vacuum pump, that it would be desirable to employ. This would be driven from one of the engine auxiliary drives along with a steam-cylinder lubricator. As a general rule the best efficiency can be obtained in a powerplant when all of the auxiliaries are driven from the prime mover and it is comtemplated that this arrangement would be employed. A pump brochure is included in the Appendix with a drawing of a pump designed for airplane application.

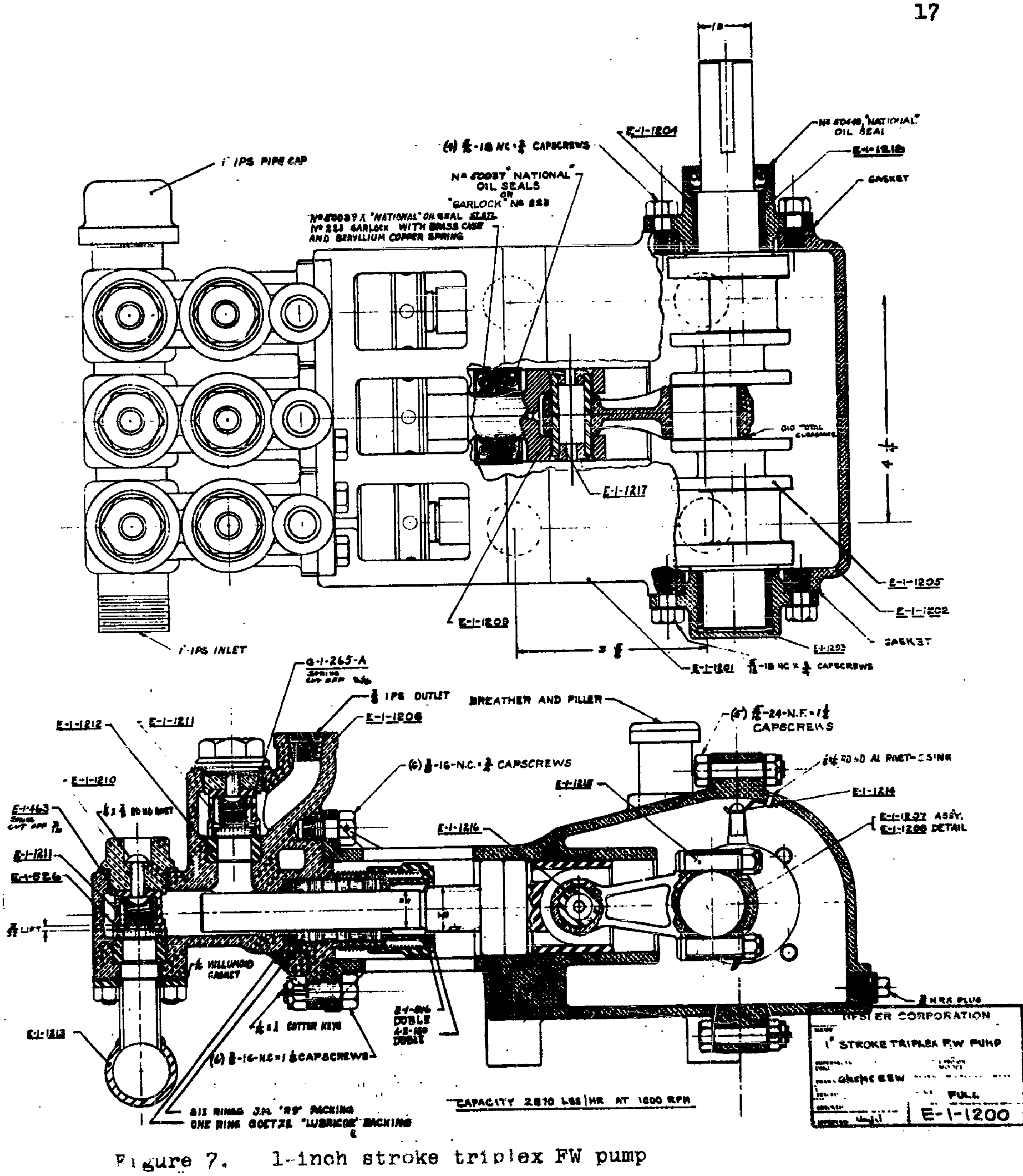


Figure 7. 1-inch stroke triplex FW pump

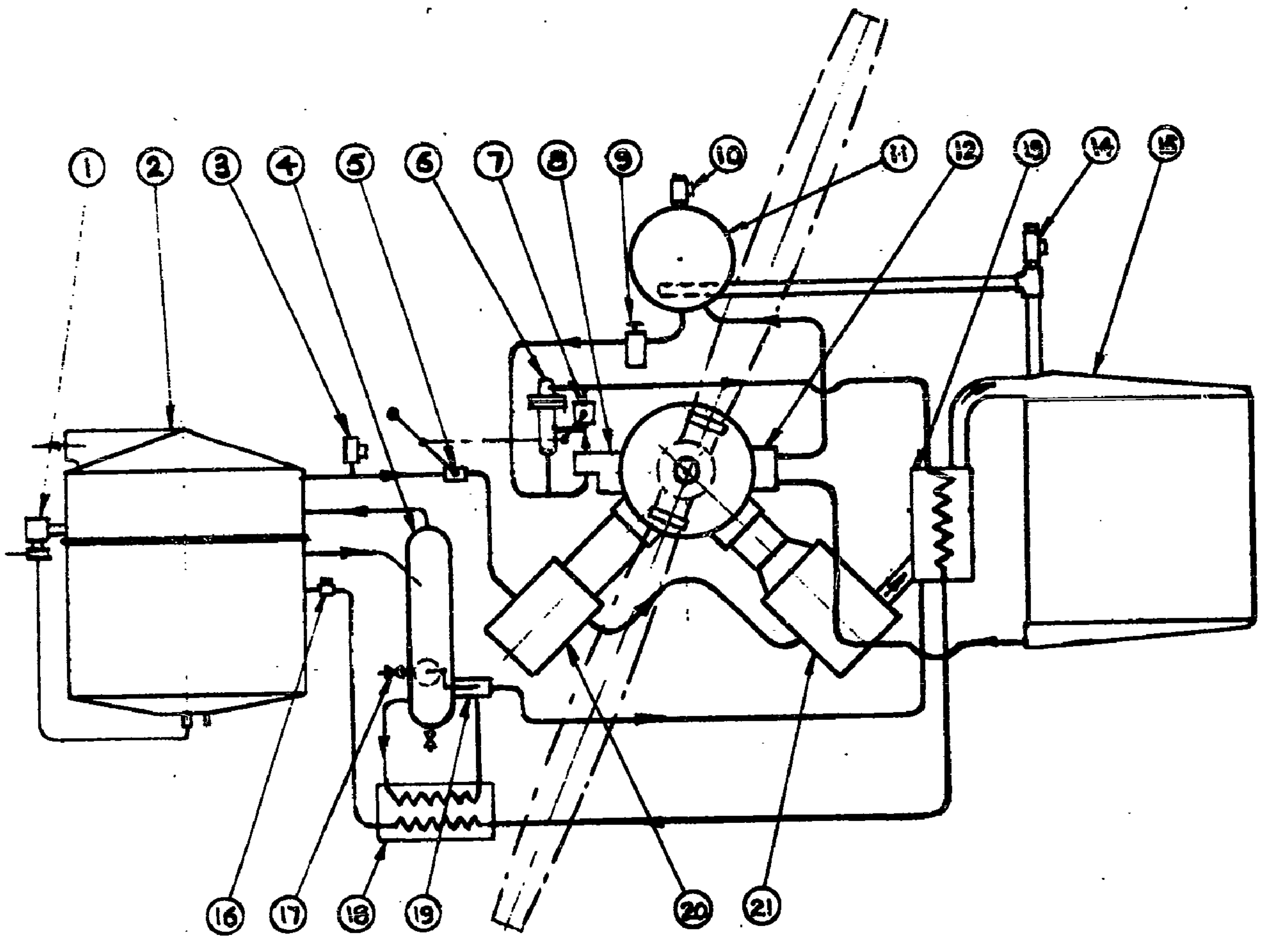
STEAM POWER-PLANT CONTROLS

The engine for aircraft propulsion must be supplied with steam at the design pressure and temperature for full-power performance and the auxiliaries can be geared in proportion to this condition with a few simple supervisory controls. At cruising or throttled-back conditions the demand for steam decreases and controls of the auxiliaries must sense this change in power requirements to produce a change in the stable steam conditions. Many successful control systems have been devised and used by the Besler Corporation on automobiles, railroad installations, industrial boilers and many different special testing boilers.

The system shown by the following flow diagram for the purpose of illustration has an excess amount of feedwater pumped to the boiler. When the steam is at about 90 percent quality (90 percent steam and 10 percent water), it leaves the boiler and enters a steam separator. The water and any lubricating oil present is trapped off, gives up its heat to the entering feedwater through a heat exchanger, and returns to the tank by way of the condenser. The dry separated steam re-enters the boiler to be superheated before flowing through a throttle to the engine.

Experience has shown that with a suitable location of the superheater tubing in the boiler, a satisfactory temperature may be maintained over a wide range of steam output. The boiler tubing internal volume is very small and the weight of metal in the tubing is very light, so that the boiler is very quick steaming and highly responsive. If the throttle is partly closed, the pressure immediately rises which causes a controlling device to make adjustment in the fuel flow to arrest the pressure rise.

STEAM, WATER, & FUEL FLOW DIAGRAM



1 TEMP. & PRESS. OPERATED FUEL VALVE
2 STEAM GENERATOR (BOILER)
3 STEAM SAFETY VALVE
4 STEAM SEPARATOR
5 ENGINE THROTTLE
6 FEED WATER RELIEF VALVE
7 " " CONTROL VALVE
8 " " PUMP
9 " " FILTER
10 WATER TANK RELIEF VALVE
11 WATER TANK
12 CONDENSATE RETURN PUMP
13 PRIMARY FEED WATER HEATER
14 CONDENSER RELIEF VALVE
15 CONDENSER
16 BOILER CHECK VALVE
17 LUBRICATING OIL BLOW DOWN
18 SECONDARY FEED WATER HEATER
19 STEAM TRAP
20 ENGINE HIGH PRESSURE CYLINDER
21 " LOW " "

Figure 8.- Steam water and fuel flow diagram

OPERATING PROCEDURE

It appears logical to describe the operation of the 1933 steamer as there should be little change in operating procedure, except as noted. When the Travelair was flown it was only necessary to enter the cockpit, close the blower switch and then open the engine throttle. In about 15 seconds sufficient pressure was available to turn over the engine and taxi to the takeoff position where the engine was warmed against the wheel brakes for perhaps one-half minute prior to takeoff. All boiler controls were automatic and the throttle was the only control requiring pilot attention.

In the proposed steamer an improved engine valve gear for initial starting and warming up will be installed because sometimes it was necessary on the Travelair steamer to reverse the engine a number of times to work the water out of the low-pressure cylinder. This will add another position labeled 'Start and Warm-up' to the reverse lever in addition to the positions 'Forward' and 'Reverse'. Running in 'Start' will not damage the engine in any way, but will not be as economical.

In the 1933 steamer the author made a number of very steep descents by keeping the engine in full reverse. This might be a very convenient feature for rapid descents from high altitude or for quick slow-down in case of running into severe turbulence. It would be only necessary to push the reverse lever into reverse for a few seconds without bothering to close the throttle to slow down the engine. It would not harm the powerplant to use full reverse power for an extended period, so it is conceivable that very rapid descent rates of perhaps 10,000 feet a minute could be employed. In a short field the airplane could be backed into a clearing or shelter, or even up an incline to provide a short, down-hill takeoff run.

Such an operating procedure as this was successfully worked out long ago and there are apparently no changes required for multi-engine operation.

SERVICE AND MAINTENANCE

Considerable knowledge is available on this subject from experience gained by over seven years successful operation of the New Haven streamlined high-pressure train some million miles road experience with automobiles, and a satisfactory marine installation. It is therefore expected that service and maintenance of the steam airplane will be a minimum, once all components have been thoroughly tested.

At refueling stops the fuel, water, and lubricating oil tanks must be checked and refilled as necessary. Between inspection periods nothing would need to be done except to visually inspect the condition of the extended heating surfaces to make sure that no soot has accumulated in which case it should either be blown off with air, washed out with water, or brushed clean.

Maintenance of all light-weight power plants is normal and should not be a serious problem. The disposed components of a steam plant readily lend themselves to replacement. For instance, if a water pump developed a knock the pump should be replaced as a unit. In the illustration it is not expected that a boiler or other major component would be repaired in the field. One man could lift any single component from its mounting for replacement or abandonment.

Regular overhaul would consist of removing every major component for inspection and replacement of any part which showed wear or damage. This could be at infrequent intervals, because the stresses are approximately the same as those used on working parts of the New Haven streamlined train, which showed the original tool marks on most wearing surfaces after one-half million miles of service.

Treated boiler water will not be necessary for this power plant because of the employment of the separating cycle shown in the flow diagram. It is desirable, however, to use the best feed water available, which experience has shown to be the softest water, or that with least permanent hardness or silica. In some one thousand steam-atomizing, 'Bes-Kil' sprayers scattered throughout the world, it has been learned that stream or ditch water is preferable to well water and would be the case with the projected flying steamer. Acid circulation is the accepted cleaning procedure with Besler forced circulation boilers, which would usually be done at overhaul periods.

ILLUSTRATION OF APPLICATION

The 4-engined illustration which follows should be kept in mind when reading the description of the components:

All engines including the boundary-layer blower engines are controlled by individual throttles from a common header through check valves to all boilers. Failure of a burner electrode or any part of one of the boiler systems would accordingly leave 75 percent power to all engines so that assymmetrical conditions would not exist. The blower throttles (E) are coupled to operate simultaneously, but are shown as independent units to simplify the diagram. One throttle and a branching pipe would be used in practice.

The boilers each have an evaporative capacity of 2,500 pounds or 10,000 pounds total and supply 2,000 pounds of steam to each of the four 200 hp. engines. The remaining 2,000 pounds capacity is divided between the two blower engines which deliver 100 hp. each. If one boiler is shut down during cruise (at which time the BLC blowers are inoperative and the main engines presumably are at 75 percent power), the steam requirement will be 6,000 pounds per hour, so that the remaining three boilers will operate at 80 percent load. Under this condition the landing procedure would allow full BLC blower power during approach plus 70 percent propeller power.

The steam engines are conservatively designed for reliability and should not suffer from sudden failure. For instance a bearing failure would result in a knock, but the engine would keep going and could be shut down during cruise and used later for landing. The condenser installation is not shown, but is visualized to be within the wing, or housed conveniently along the sides of the fuselage with suitable air scoops.

The single-engine nacelle illustration shows a complete single propeller, engine, boiler and condenser 'power package'. If a single-engine prototype were constructed, it might well take on such a form as this.

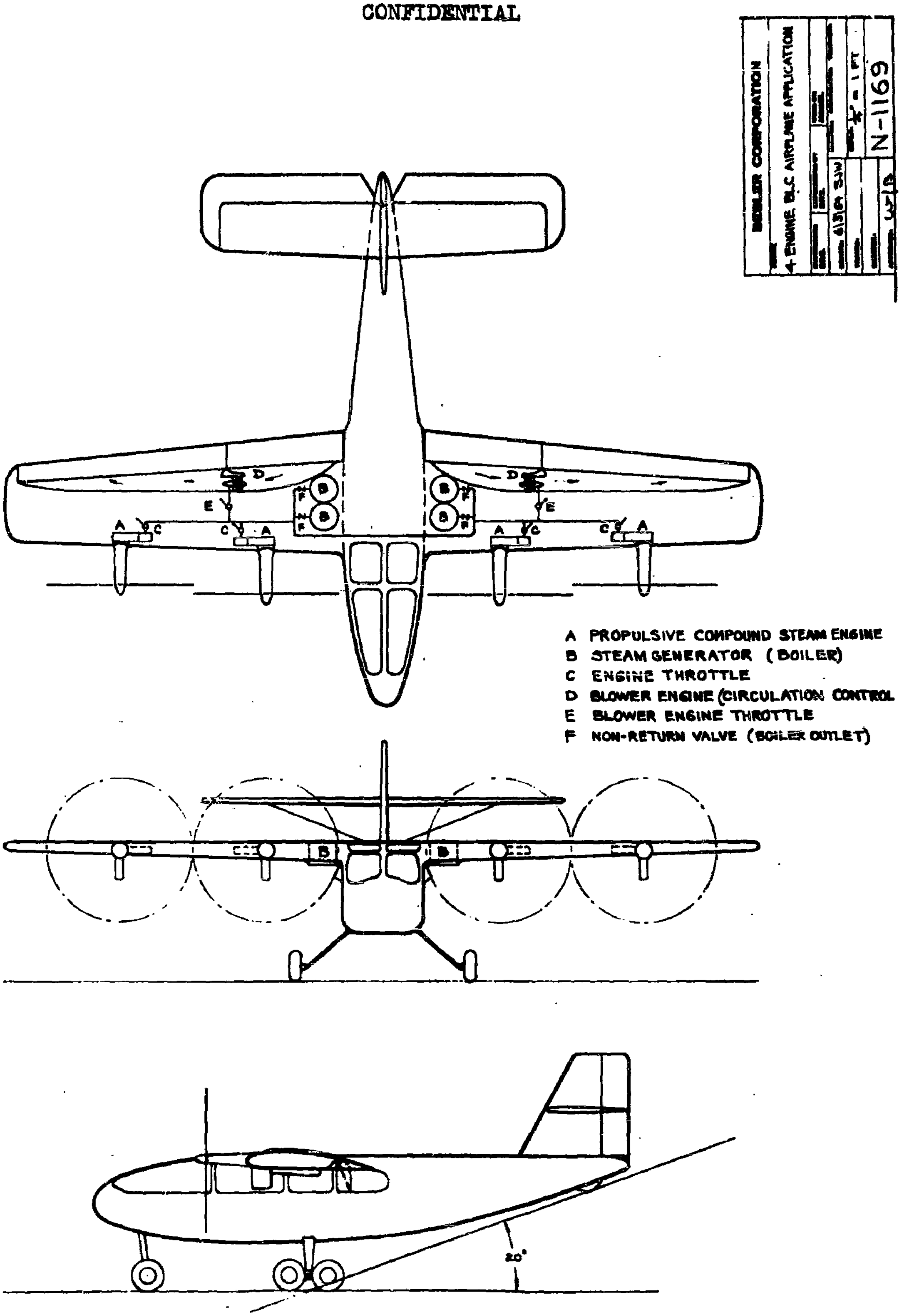


Figure 9.- 4-engine BLC airplane application

GENERAL ARRANGEMENT OF POWER NACELLE

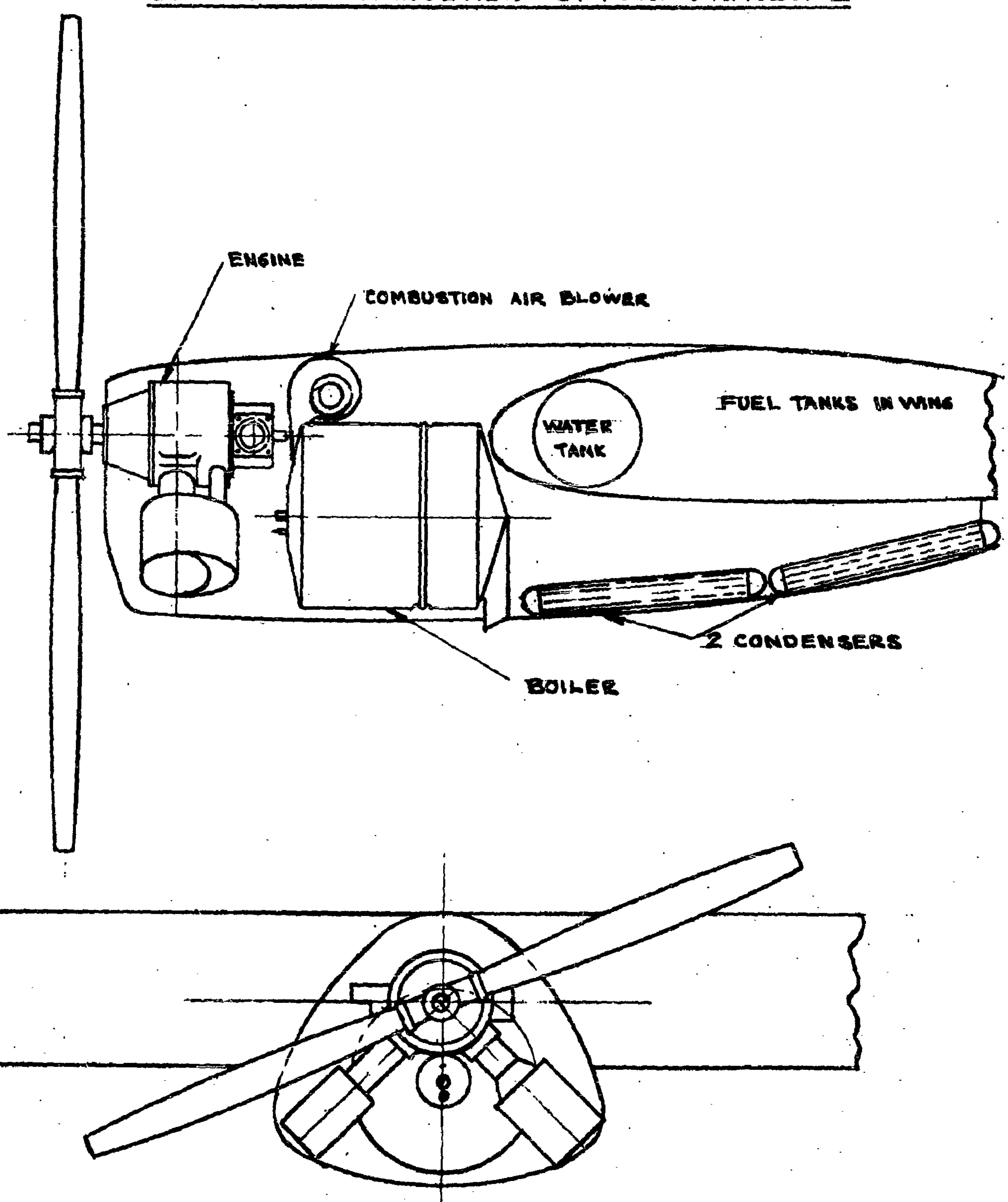


Figure 10.- General arrangement of power nacelle

OUTLINE DRAWINGS OF MAJOR COMPONENTS

SCALE $\frac{1}{16}'' = 1''$ FOR ALL SHOWN ON THIS PAGE

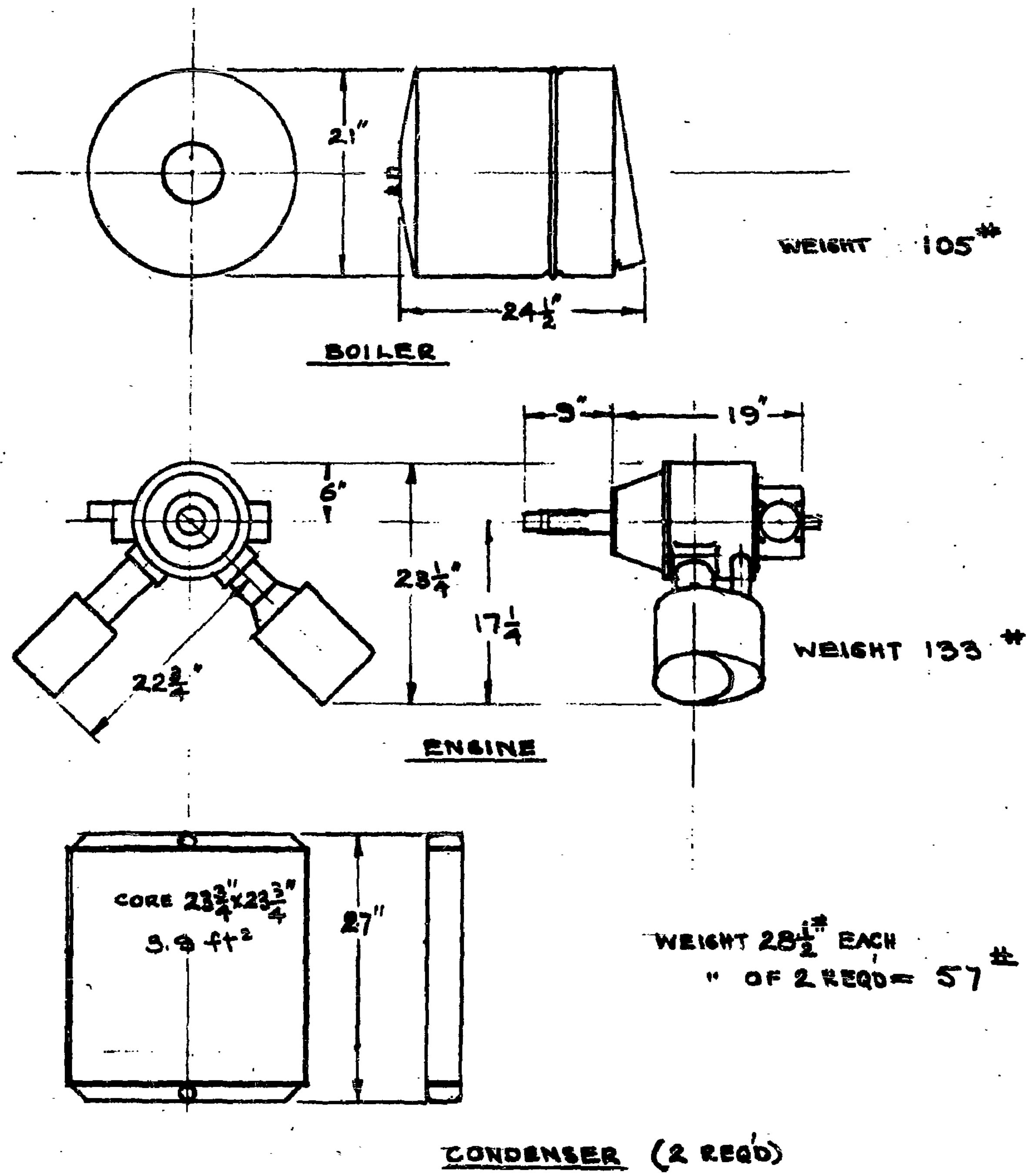


Figure 11 Outline drawings of major components

ENGINE WEIGHT ANALYSIS

Part		Weight Lbs.
Crankshaft		23.00
Crankcase		15.30
Bearings	1 SKF 6007 x Cat.	.35
	2 SKF 212 x Cat.	4.00
	1 SKF 6012 x Cat.	.92
Connecting Rod and Pins (2)		4.00
Piston Pods (2)		2.50
Crossheads (2)		2.44
Piston H.P.		2.36
Piston L.P.		2.36
Cylinder H.P.		9.44
Cylinder L.P.		14.60
Cylinder Head H.P. Head End		2.13
Cylinder Head L.P. Head End		2.80
Crosshead Guides (2)		9.12
Piston Valve and Stem H.P.		1.80
Piston Valve and Stem L.P.		2.15
Valve Gear Mechanism and Reverse Gear		9.00
Auxiliary Drive		2.00
Oil Pumps		3.00
Cylinder Head H.P. Crank End		2.00
Cylinder Head L.P. Crank End		3.30
Valve Cylinder Heads H.P. and L.P.		2.50
Receiver Pipe		2.14
Lagging and Covers		1.50
Nuts and Bolts, Lock Wires and Misc.		5.00
Total		129.7 Lbs.

AIRPLANE BOILER WEIGHTS

Part	Material	Size	Weight Basis	Weight Lbs.
5 Spiral Coils	Steel	170 ft 1/2" OD. 1/32" Wall	.158 lbs/ft	26.9
23 Turns Helical	Steel	115 ft 1/2" OD. 1/32" Wall	.158 lbs/ft	18.1
Extended Surface	Copper	55 ft 1/16" OD. 13/32" I.D.	.455 lbs/ft	25.0
Thermostat Tube	Steel	1" OD 16 GA. x 24"	.62 lbs/ft	1.24
Tube Connectors	Steel	----	----	1.1
Outer Casing	Alum.	21" D x 21 1/4" x .030"	.421 lbs/ft^2	4.1
Inner Casing	Steel	19" D x 10 1/2" x .030"	1.25 lbs/ft^2	5.44
Combustion Chamber Wall	Steel	18" D x 7 1/2" x .030"	1.25 lbs/ft^2	3.68
Combustion Chamber Bottom	Steel	18 1/2" D - 8" D	1.25 lbs/ft^2	1.90
Combustion Chamber Under Sheet	Steel	22" D - 8" D	1.25 lbs/ft^2	2.86
Top and Bottom of Casing 2 Discs	Alum	21" D x .030	.421 lbs/ft^2	2.02
Burner Ass'y	Steel	----	----	3.00
Clamp Band and Angles	Steel	----	----	2.5
Thermostat Switch Box	Steel	----	----	1.0
Lagging	---	----	----	4.00
			Total	102.8

SUMMARY OF WEIGHTS

For One 200 HP Power Plant

C = Calc.
E = Est.

	Item	Weight Lbs.
C	Boiler	102.8
C	Engine	133.7
C	Condensers (2)	57.0
E	Thermostatic Fuel Valve	1.0
E	Safety Valve	1.5
C	Steam Separator	7.0
E	Engine Throttle	1.5
E	Feed Water Relief Valve	4.0
E	Feed Water Control Valve	2.0
E	Feed Water Pump	20.0
E	Feed Water Filter	.5
C	Water Tank	2.75
E	Water Tank Relief Valve	.5
E	Condensate Return Pump	5.0
C	Primary Feed Water Heater	.9
E	Steam Trap	5.0
E	Blower and Drive	1.5
E	Fuel Pump	1.0
E	Water, Steam, and Fuel Piping and Misc.	16.0
E	Ignition Magneto	5.0
E	Condenser Relief Valve	.75
E	Boiler Check Valve	.5
E	Lubricating Oil Blow Down Valve	.5
C	Secondary Feed Water Heater	1.6
		372.0 Lbs.

Dry Weight = 372
Water = 50
Lub. Oil = 10
Wet Weight = 432 Lbs.

$$\frac{432}{200} = 2.16 \text{ Lb/Hp}$$

CONCLUSIONS

1. In the foregoing discussion a steam powerplant has been outlined that is particularly well adapted to the special requirements of an airplane equipped with boundary-layer control. This system is quiet, reliable and flexible.

2. All material in this report has been based on specific knowledge and information secured from a large number of tests and developments conducted by the Besler Corporation. The powerplant projected and described could be built with assurance of its performance and structural integrity.

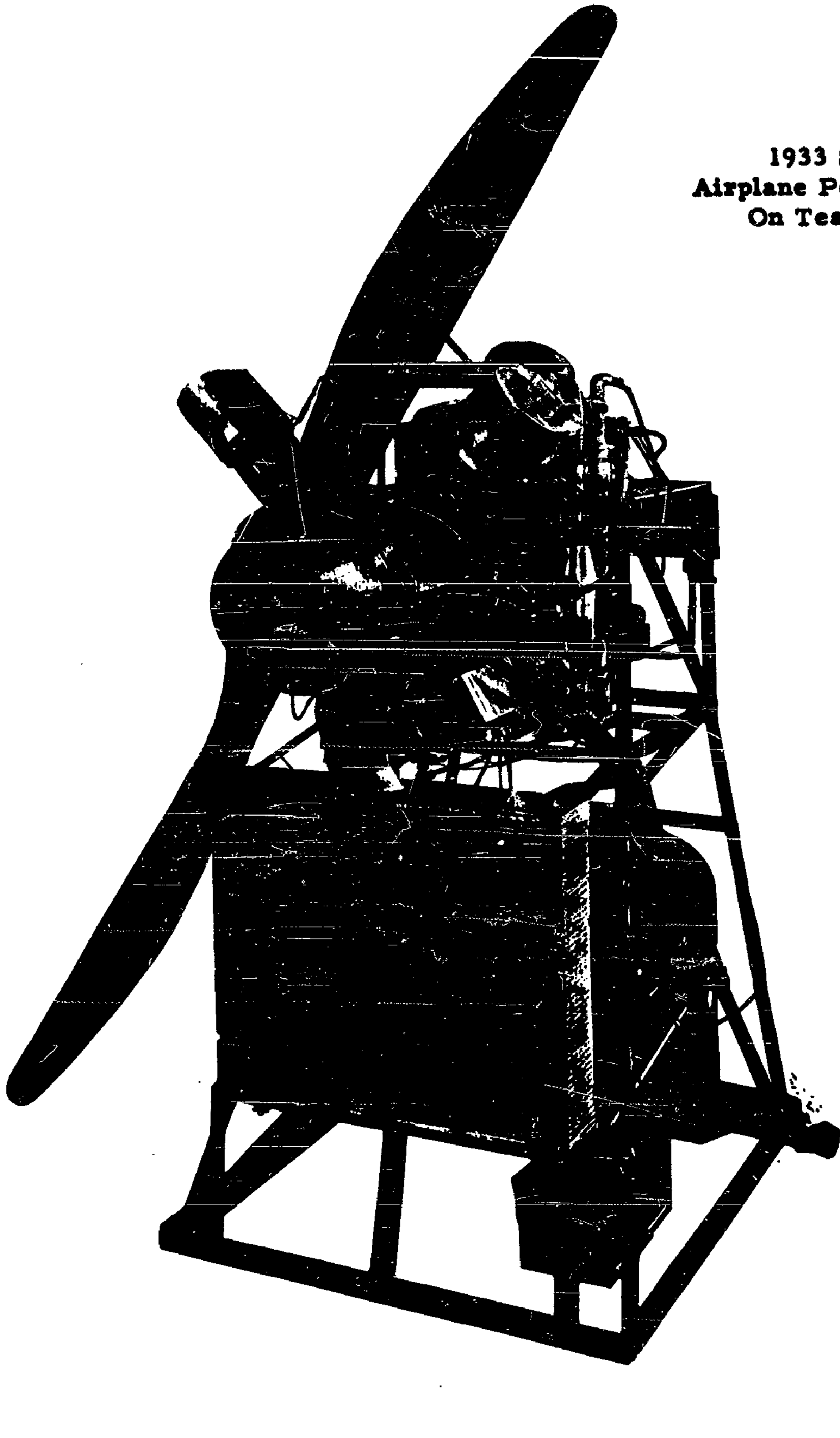
3. From operational experience with powerplants of this type it is expected that the steam airplane of this report would have unusual altitude performance. Improvements in fuel consumption, weight, and size could be expected through continued development.

APPENDIX A

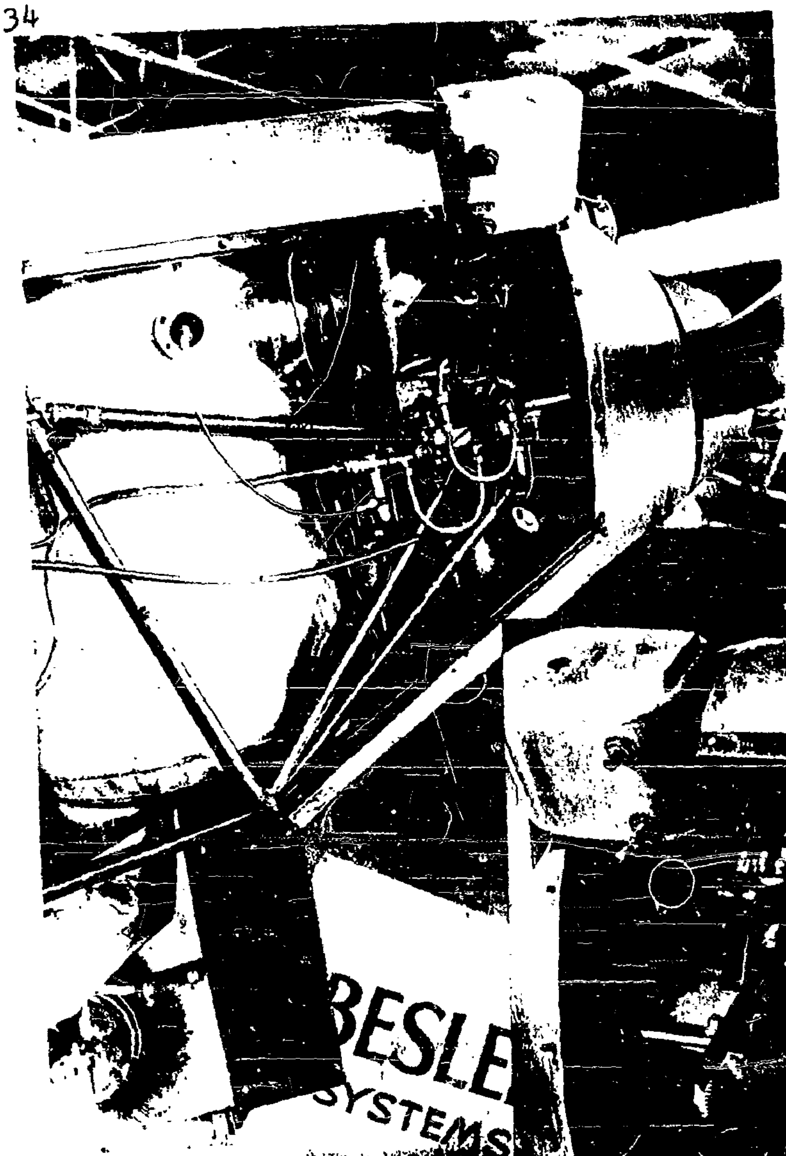
BESLER STEAM AIRPLANE OF 1933

Flying over Oakland Airport April, 1933

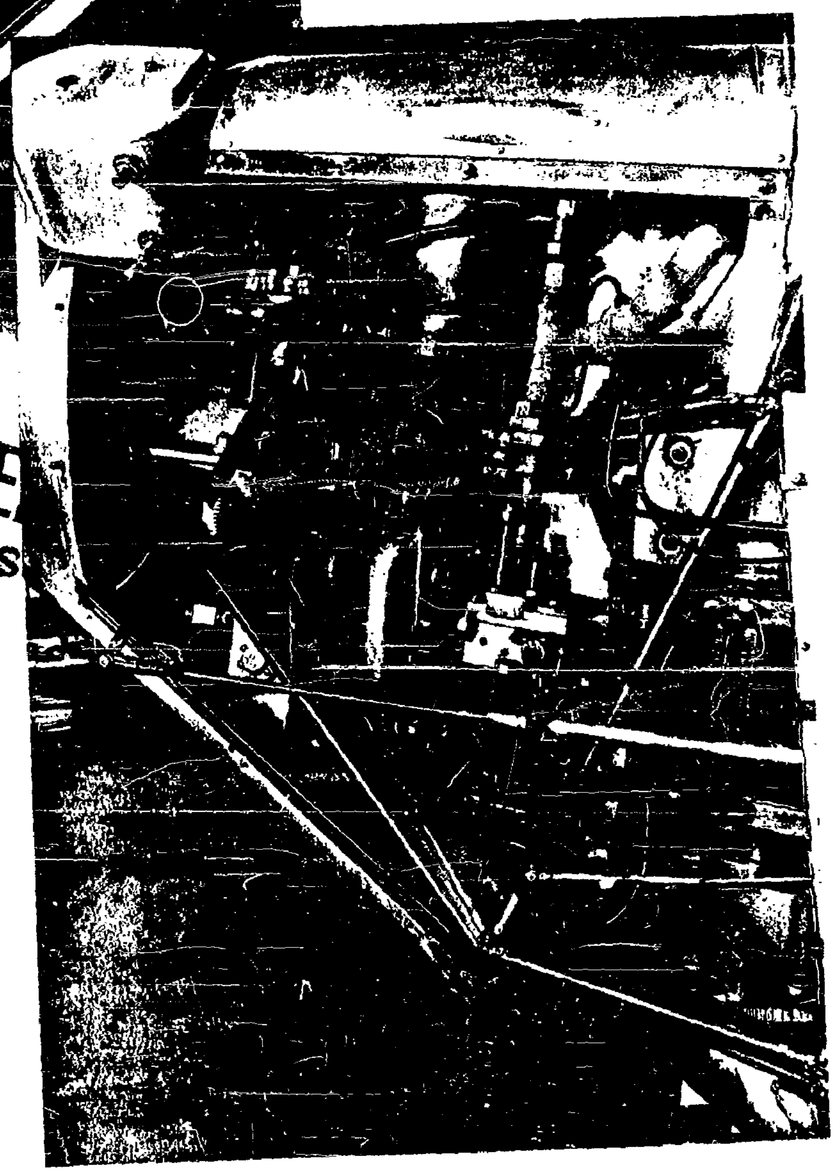
The Besler Steam Airplane and Author



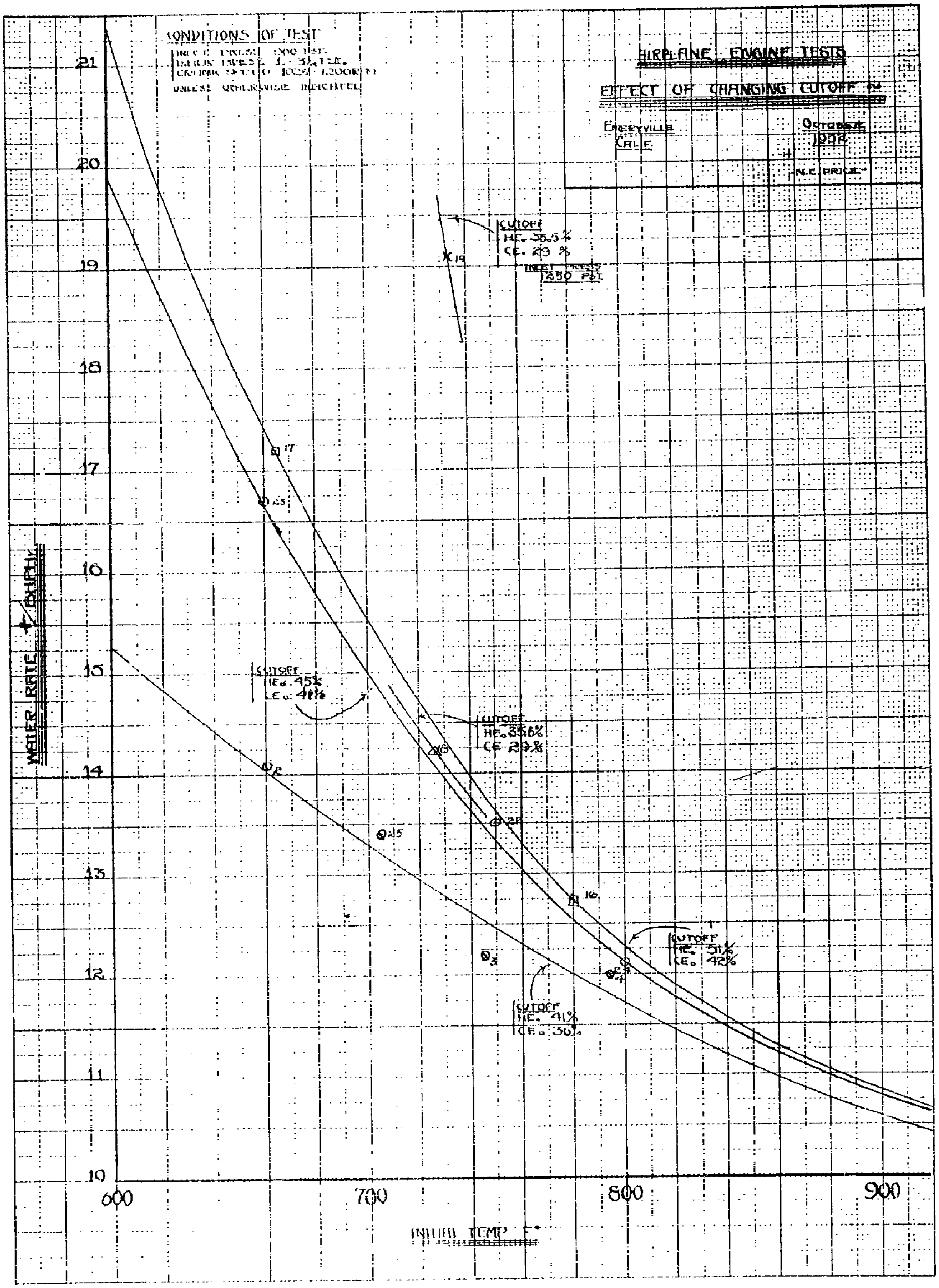
1933 Steam
Airplane Powerplant
On Test Stand

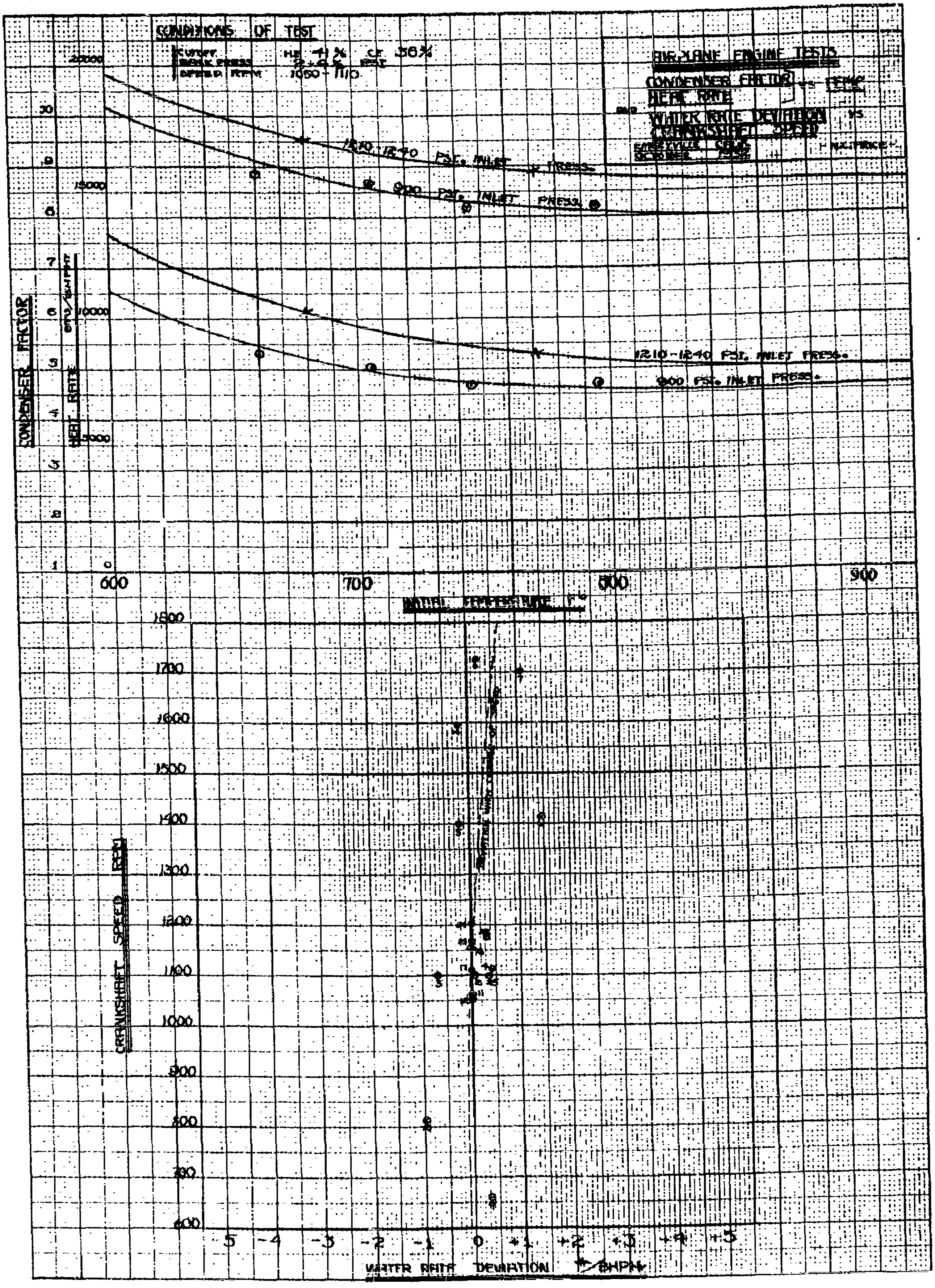


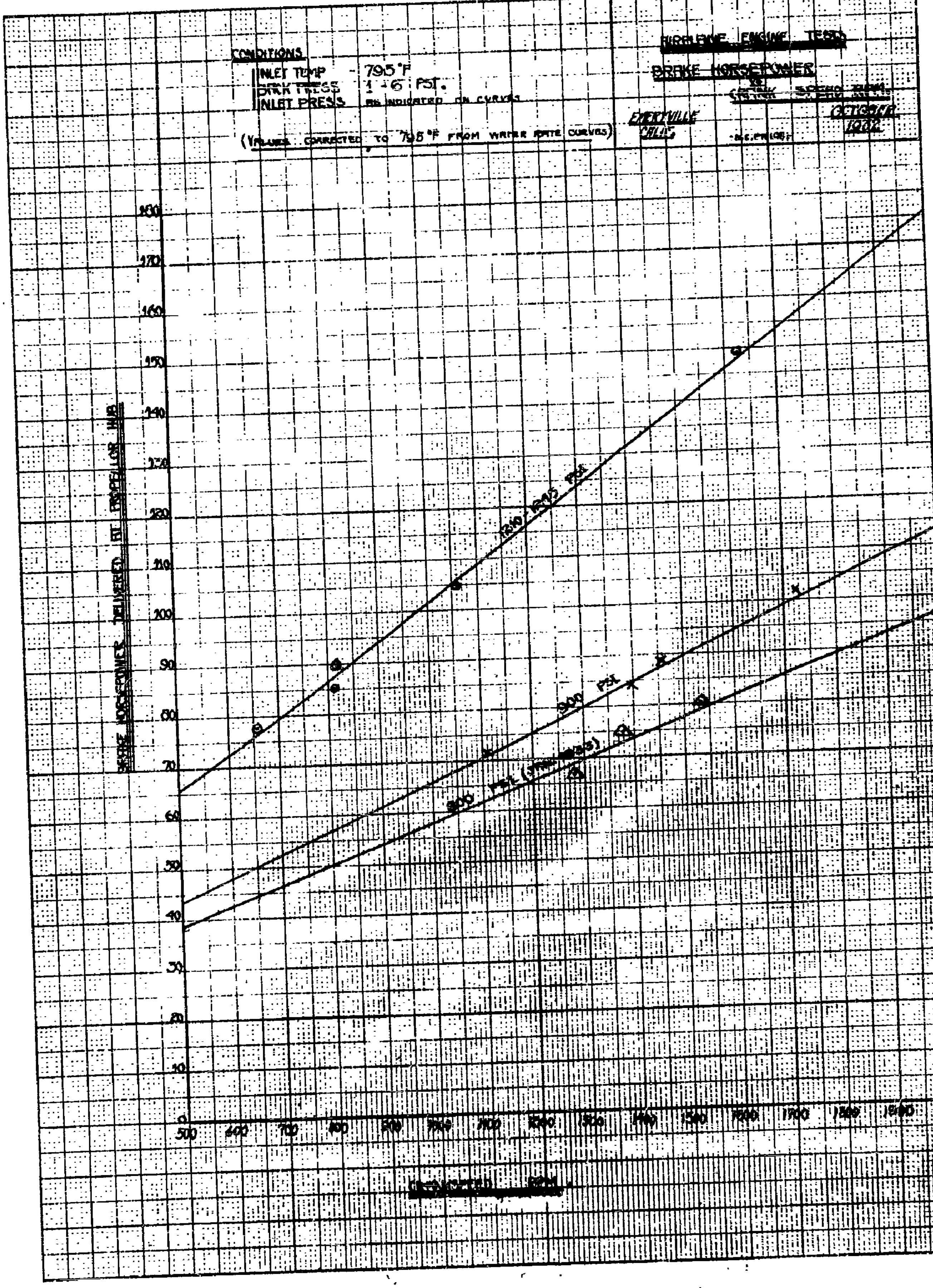
Right Side
1933
Steam Airplane

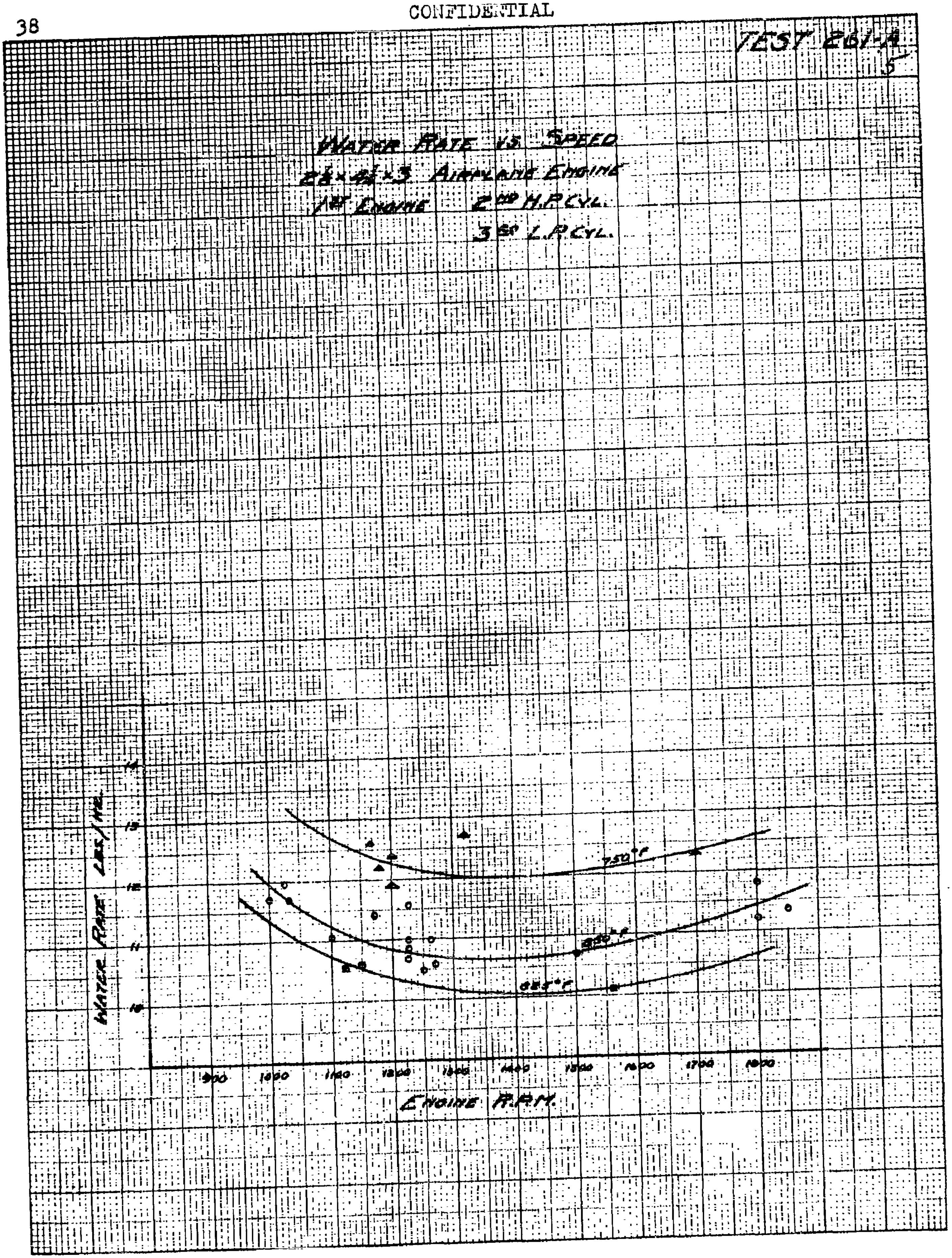


Left Side
Showing
Throttle
Feed Heater
Water Pump
Etc.


CONDITIONS OF TEST
UNLESS OTHERWISE INDICATED
AIRPLANE ENGINE TESTS
EFFECT OF CHANGING CUTOFF
EMERYVILLE CALIF
CUTOFF HE. 35.5% CE. 29%
INLET PRESS 250 PSI
CUTOFF HE. 45% CE. 41%
CUTOFF HE. 51% CE. 42%
CUTOFF HE. 41% CE. 36%
WATER RATE
INITIAL TEMP F°
10
11
12
13
14
15
16
17
18
19
20
21
600
700
800
900

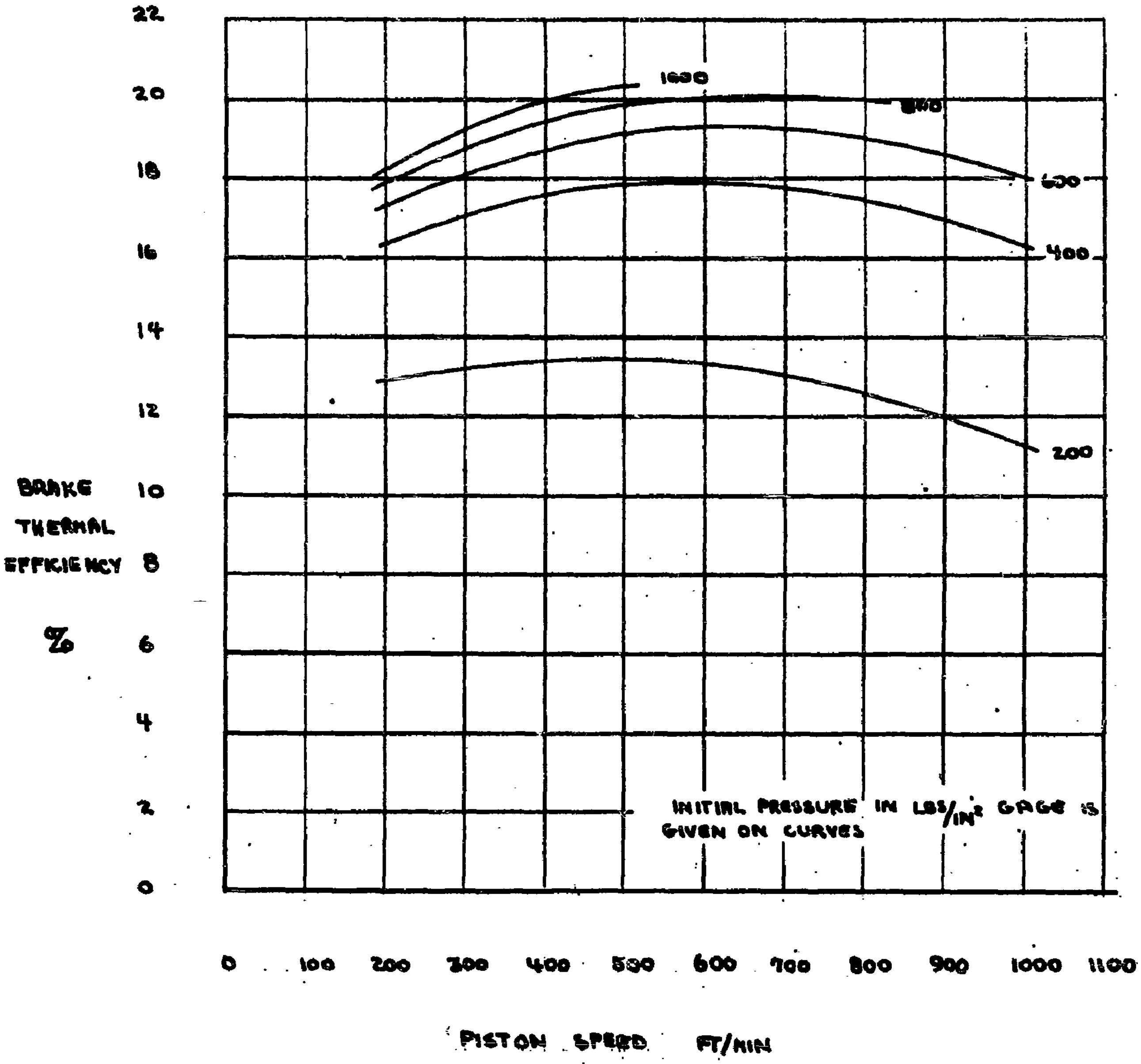

CONDITIONS OF TEST
AIRPLANE ENGINE TESTS
CONDENSER FACTOR
HEAT RATE
WATER RATE DEVIATION
CRANKSHAFT SPEED
1210-1240 PSI. INLET PRESS.
900 PSI. INLET PRESS.
CONDENSER FACTOR
HEAT RATE
CRANKSHAFT SPEED RPM
WATER RATE DEVIATION


CONDITIONS
INLET TEMP - 795°F
1-6 PSI.
INLET PRESS
BRAKE HORSEPOWER
EMERYVILLE
900 PSI
BRAKE HORSEPOWER DELIVERED AT PROPELLER HUB
RPM
500

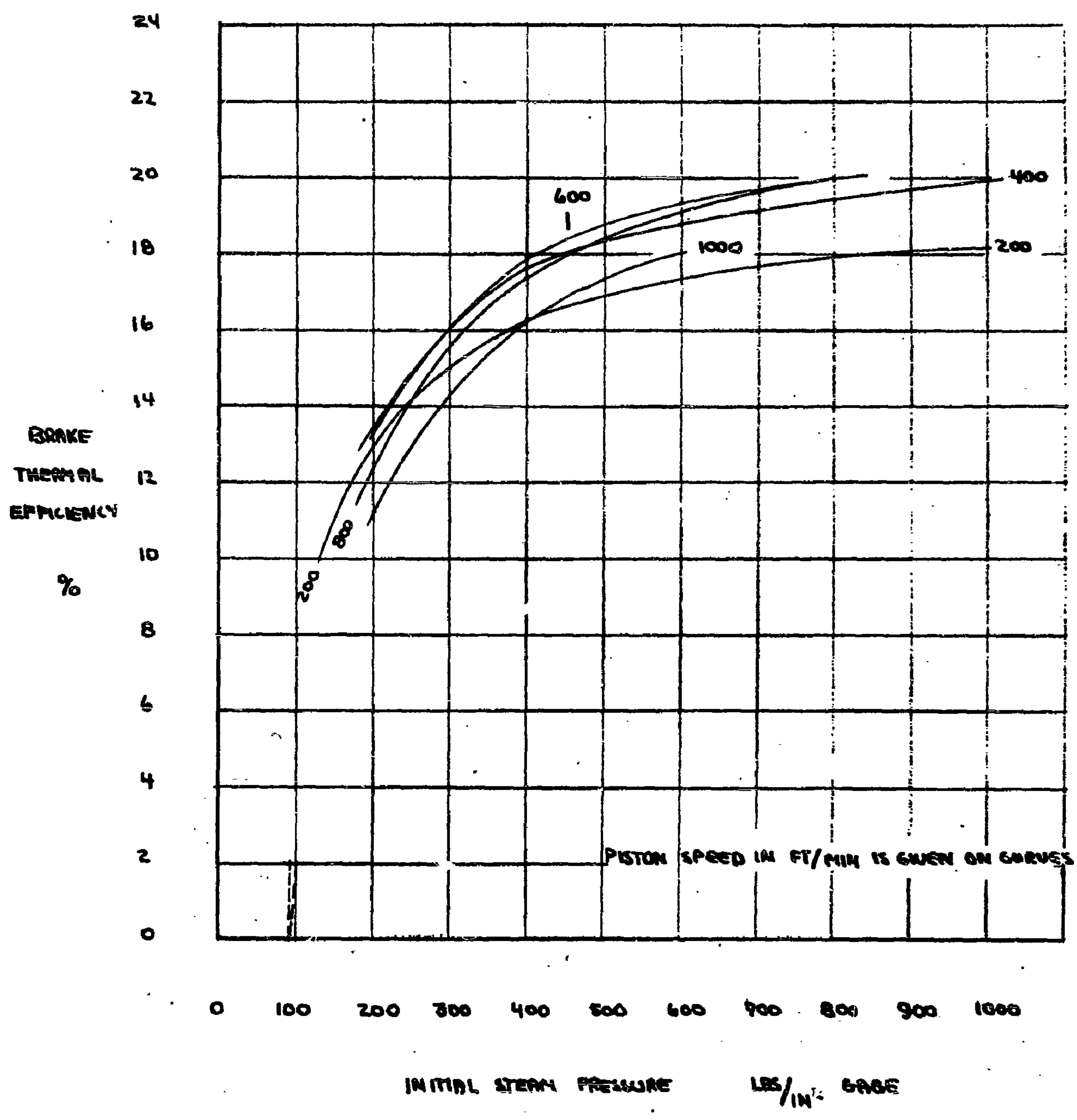

TEST 261-A
5
WATER RATE VS. SPEED
AIRPLANE ENGINE
1ST ENGINE 2ND H.P. CYL.
3RD L.P. CYL.
WATER RATE LBS./HP.
14
13
12
11
10
750°F
650°F
685°F
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
ENGINE R.P.M.

APPENDIX B

1933 ENGINE DATA AND CURVES

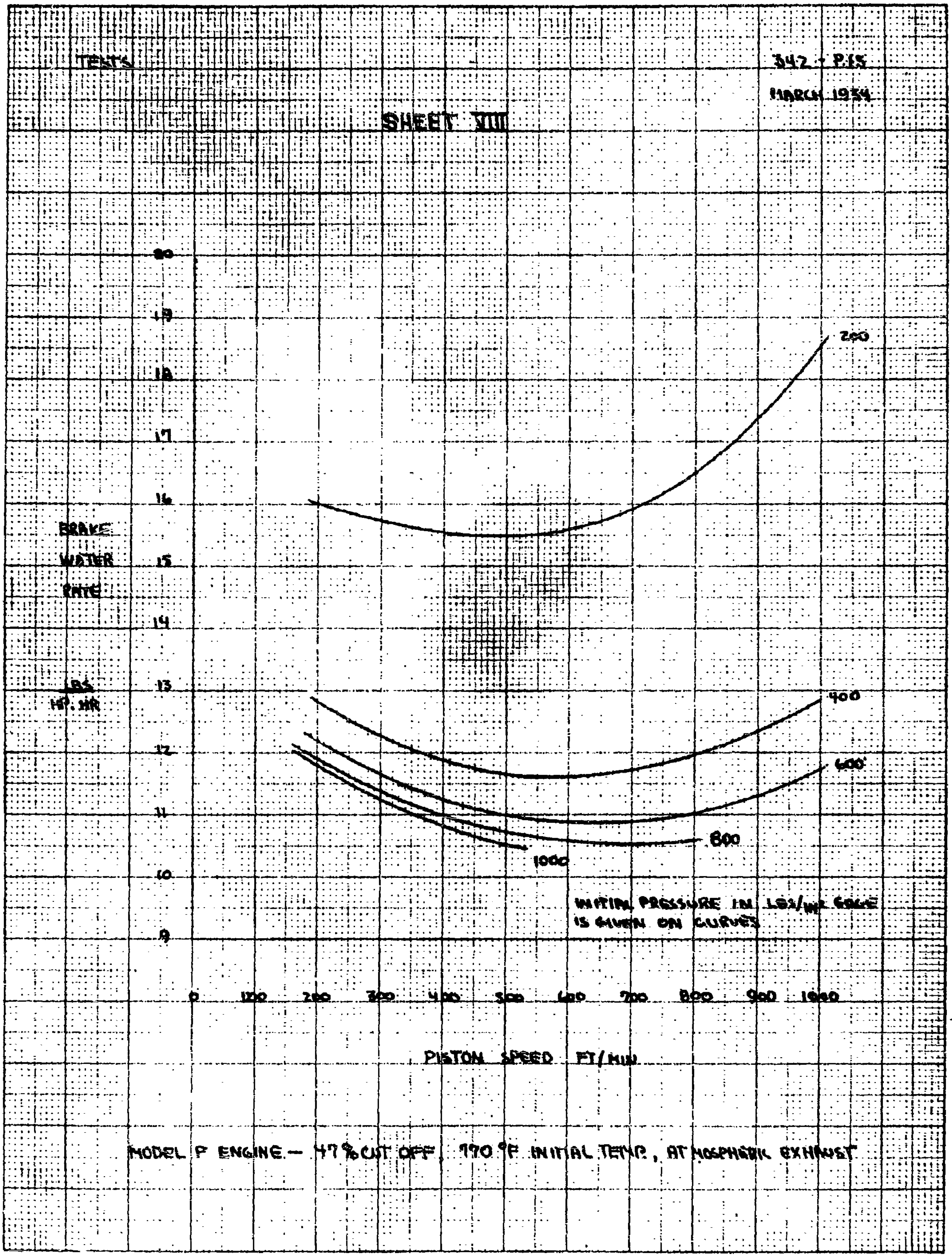


MODEL F ENGINE - 47 % CUT OFF, 170 °F INITIAL TEMP., ATMOSPHERIC EXHAUST

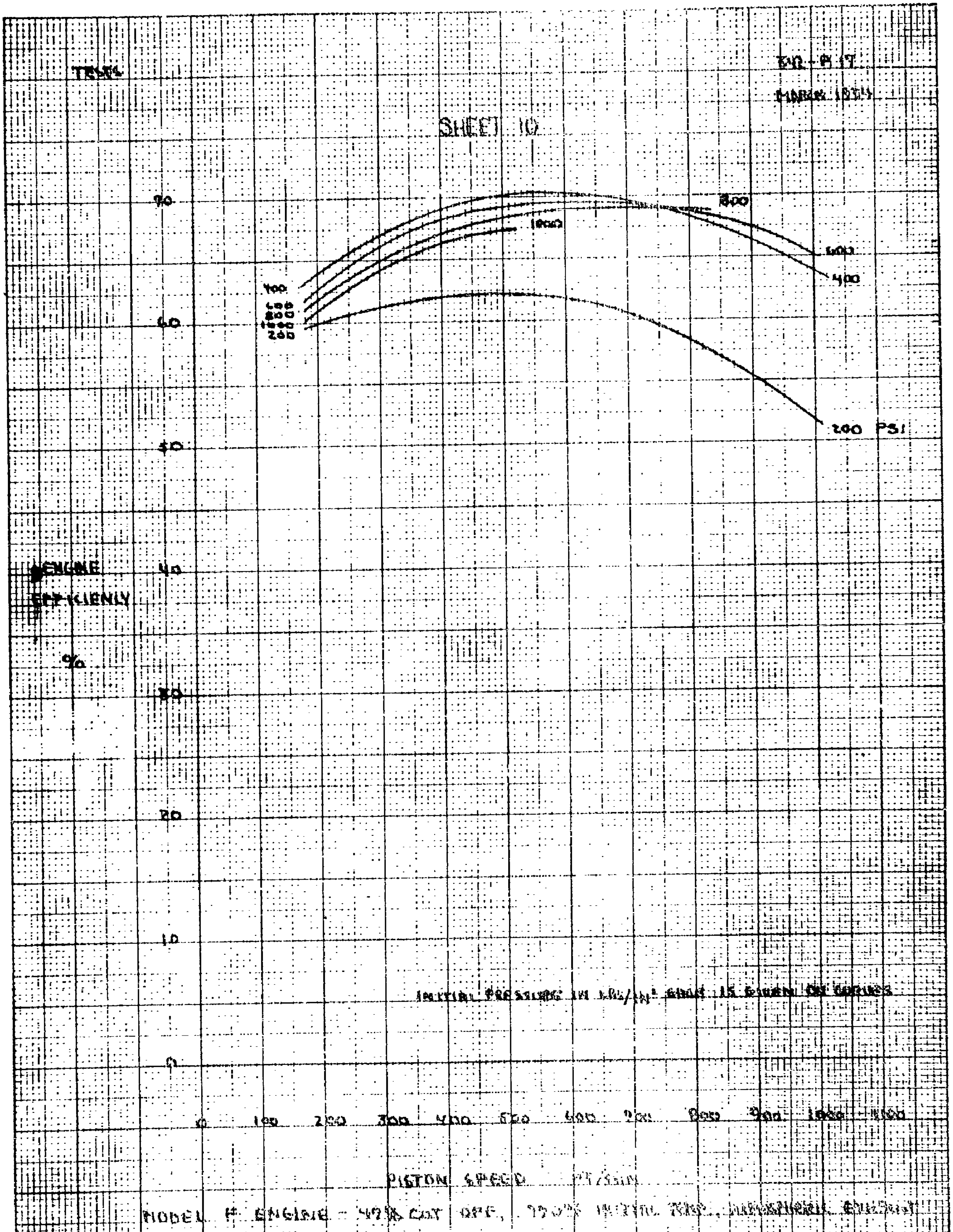


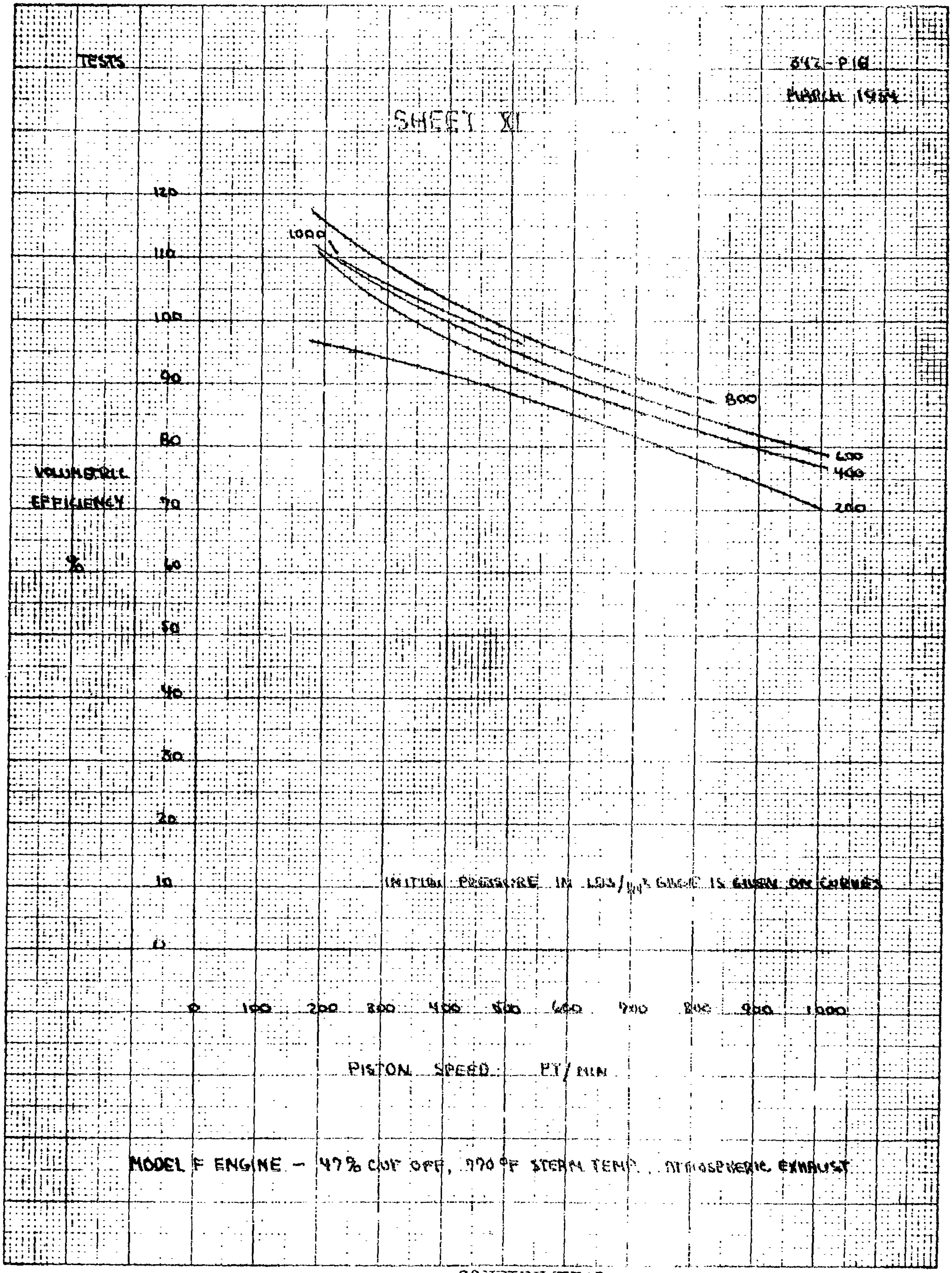
MODEL F ENGINE – 47% CUT OFF, 770°F INITIAL TEMP., ATMOSPHERIC EXHAUST

CONFIDENTIAL



CONFIDENTIAL


SHEET 10
70
60
50
40
30
20
10
0
700
600
400
200 PSI
ENGINE
%
0
100
200
300
400
600
800
900
PISTON SPEED
MODEL


TESTS
SHEET XI
MARCH 1954
120
110
100
90
80
70
60
50
40
30
20
10
0
VOLUMETRIC
EFFICIENCY
%
1000
800
600
400
200
INITIAL PRESSURE IN LBS/IN² GAGE IS GIVEN ON CURVES
0 100 200 300 400 500 600 700 800 900 1000
PISTON SPEED FT/MIN
MODEL F ENGINE – 47% CUT OFF, 770°F STEAM TEMP., ATMOSPHERIC EXHAUST

CONFIDENTIAL

SUMMATION OF WATER RATE TESTS

'F' SINGLE COMPOUND ENGINE - 3" H.P. - $5\frac{1}{2}$" L.P. - 5" STROKE

EXCERPT FROM TEST NO. 255, PAGE 3, OF MAY 20, 1931

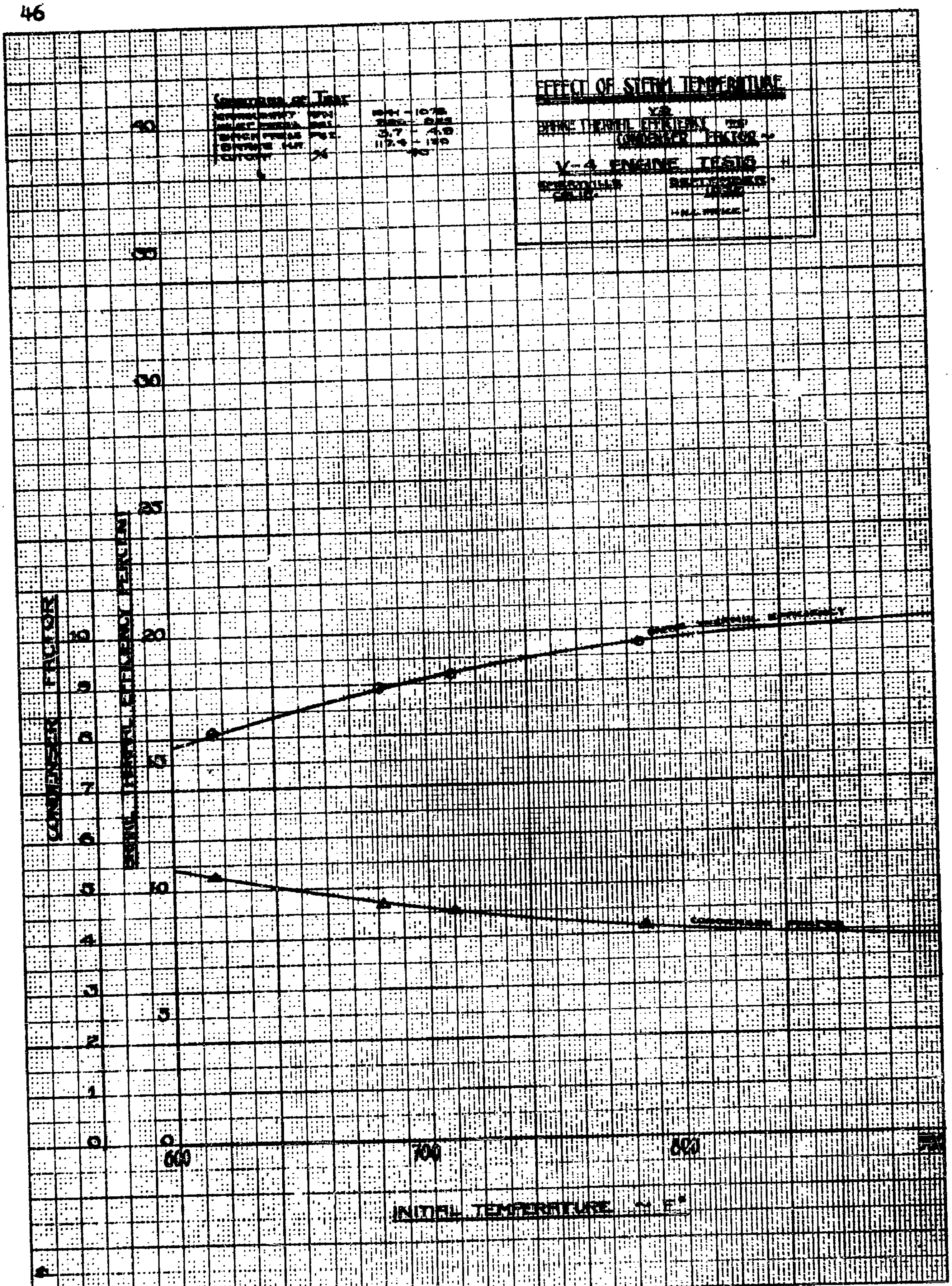
DATE	RUN NO.	CYL. BLOCK (2)	VALVES	CAR SPEED	CUT OFF	TEMP. OFF.	STEAM PRESS. GAGE	BACK PRES. GAGE	C.S. SPEED	H.P. 95%	WATER RATE	COR. W.R. (1)	BRAKE THERM. EFF.	RAN-KINE EFF.	ENGINE EFF. % RANK.
6-10-30 Test 2222	1	1st	A-4-318	40	50	814	820	8	716	84.5	10.5	10.3	20.1	29.4	68.4
4-23-31 Test 253	2	2nd	A-4-319 336 339 End exh. rings removed	40	55	775	600	8	650	60	11.5	11.2	18.7	27.6	68
5-12-31	3	2nd	336 337	41	40	785	770	4.5	650	60	10.9	10.75	19.5	28.8	68
"	4	2nd	336 337	40	55	785	575	5.25	645	60	11.6	11.4	18.3	27.3	67
5-18-31	5	3rd	338 339	41	40	785	800	4.25	685	65	10.3	10.2	20.6	28.6	72
"	6	3rd	" "	42	55	785	575	4.5	670	63.5	10.9	10.8	19.3	27.3	71
"	7	3rd	" "	41	80	785	380	5.0	650	53.5	13.1	12.9	16	24.6	65
5-15-31	8	3rd	" "	41	40	795	825	14X	650	61	10.7	10.25	20.3	29.2	69.5
"	9	3rd	" "	42	40	875	835	5	670	70	9.4	9.3	21.6	30	72
"	10	3rd	" "	60	40	875	725	5	925	67	9.4	9.25	21.7	29.2	74.5
"	11	3rd	" "	83	40	875	575	5	1300	62	10.4	10.1	19.8	27.9	71

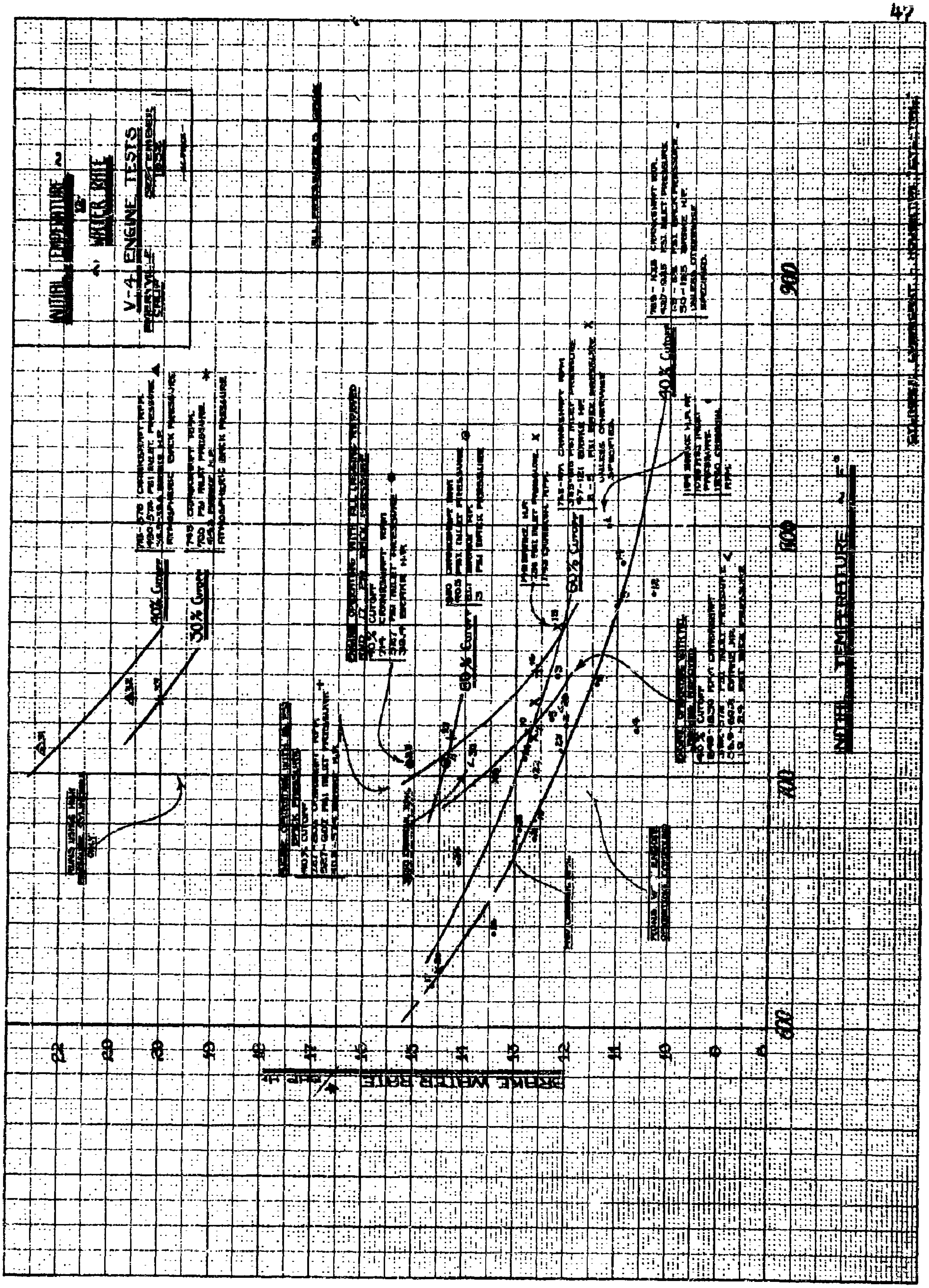
SAMPLE CALCULATIONS. **RUN NO. 1**

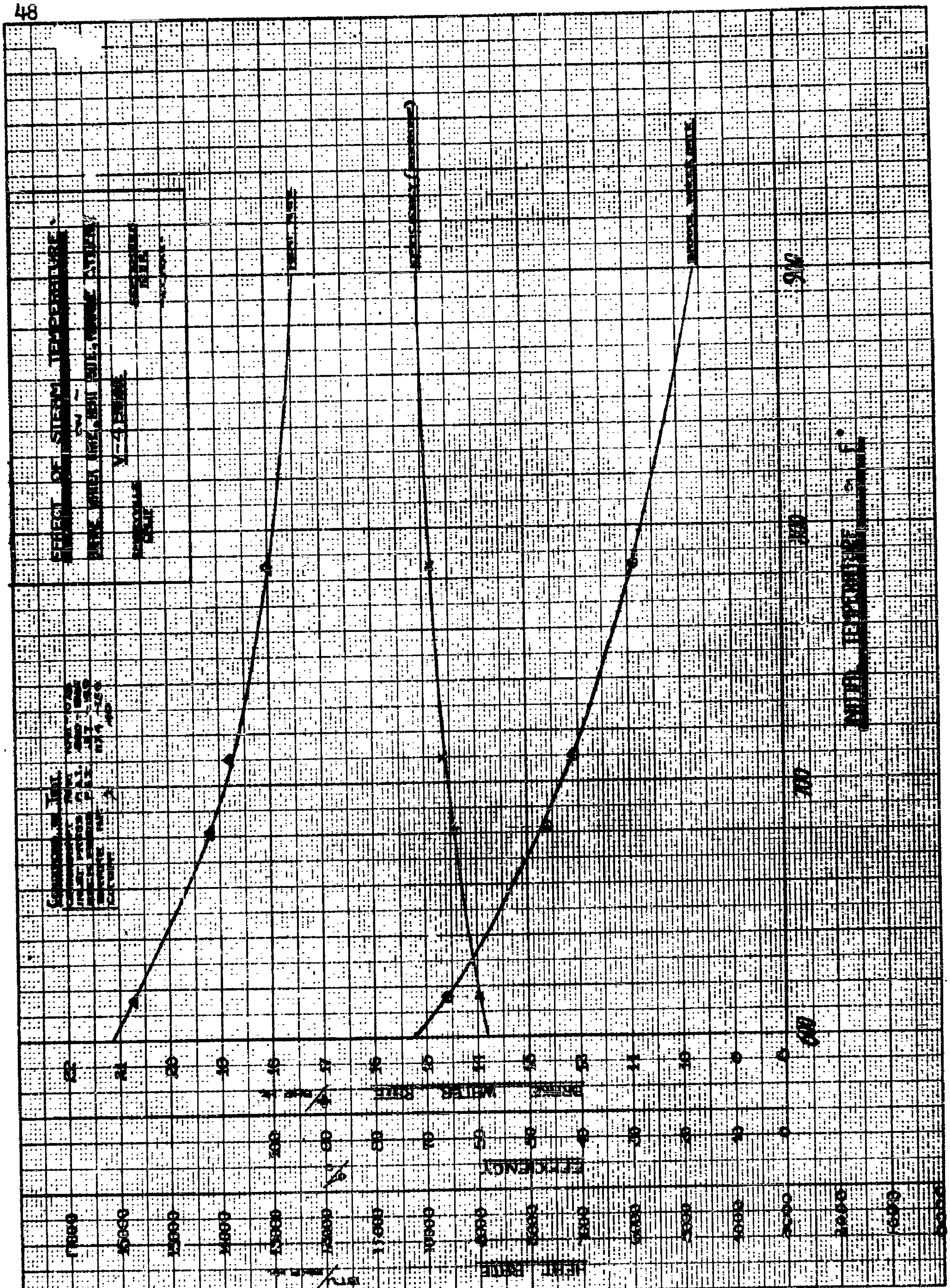
Brake Thermal Eff. of engine $= \frac{\text{B.T.U. equivalent of 1 H.P./hr.}}{\text{(heat supplied per lb.)(water rate)}} = \frac{2543}{1229 \times 10.3} = 20.1\%$

Rankine eff. $= \frac{\text{heat utilized}}{\text{heat supplied}} = \frac{1409-1047}{1409-180} = 29.4\%$

CONFIDENTIAL


EFFECT OF STEAM TEMPERATURE
VS
BRAKE THERMAL EFFICIENCY
CONDENSER FACTOR
V-4 ENGINE TESTS
3.7 - 4.9
117.4 - 139
40
35
30
25
20
15
10
5
0
CONDENSER FACTOR
BRAKE THERMAL EFFICIENCY PERCENT
600
700
800
INITIAL TEMPERATURE °F


INITIAL TEMPERATURE vs WATER RATE
V-4 ENGINE TESTS
BRAKE WATER RATE
INITIAL TEMPERATURE
700
800
900
30% Cutoff
50% Cutoff
90% Cutoff



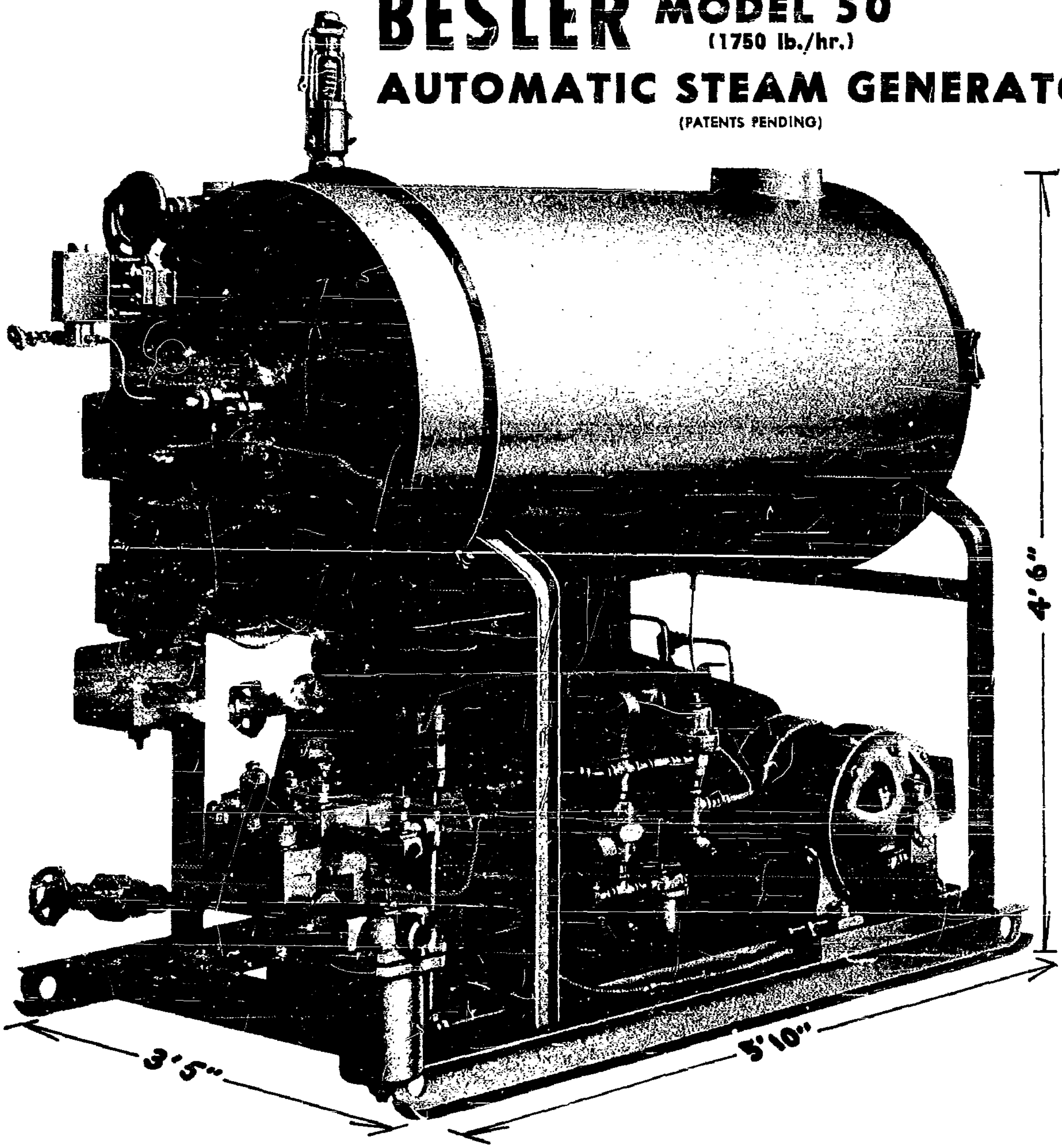
APPENDIX C

BESLER COMMERCIAL BOILERS

BESLER MODEL 50
(1750 lb./hr.)

AUTOMATIC STEAM GENERATOR

(PATENTS PENDING)



A completely automatic, forced circulation, forced draft steam generator, with a wide variety of applications in power, processing and heating.

CHECK THESE OUTSTANDING FEATURES:

- Compactness
- Flexibility
- Light weight
- Fast steaming
- Oil or gas firing
- Simple installation
- No explosion danger
- No foundation or stack
- New ease of maintenance
- Push button starting and stopping
- High operating efficiency and economy
- Automatic operating and safety controls
- Instant response to variations in steam load
- Automatic over-temperature safety fire cut-off

(See reverse side for condensed specifications)

BESLER CORPORATION

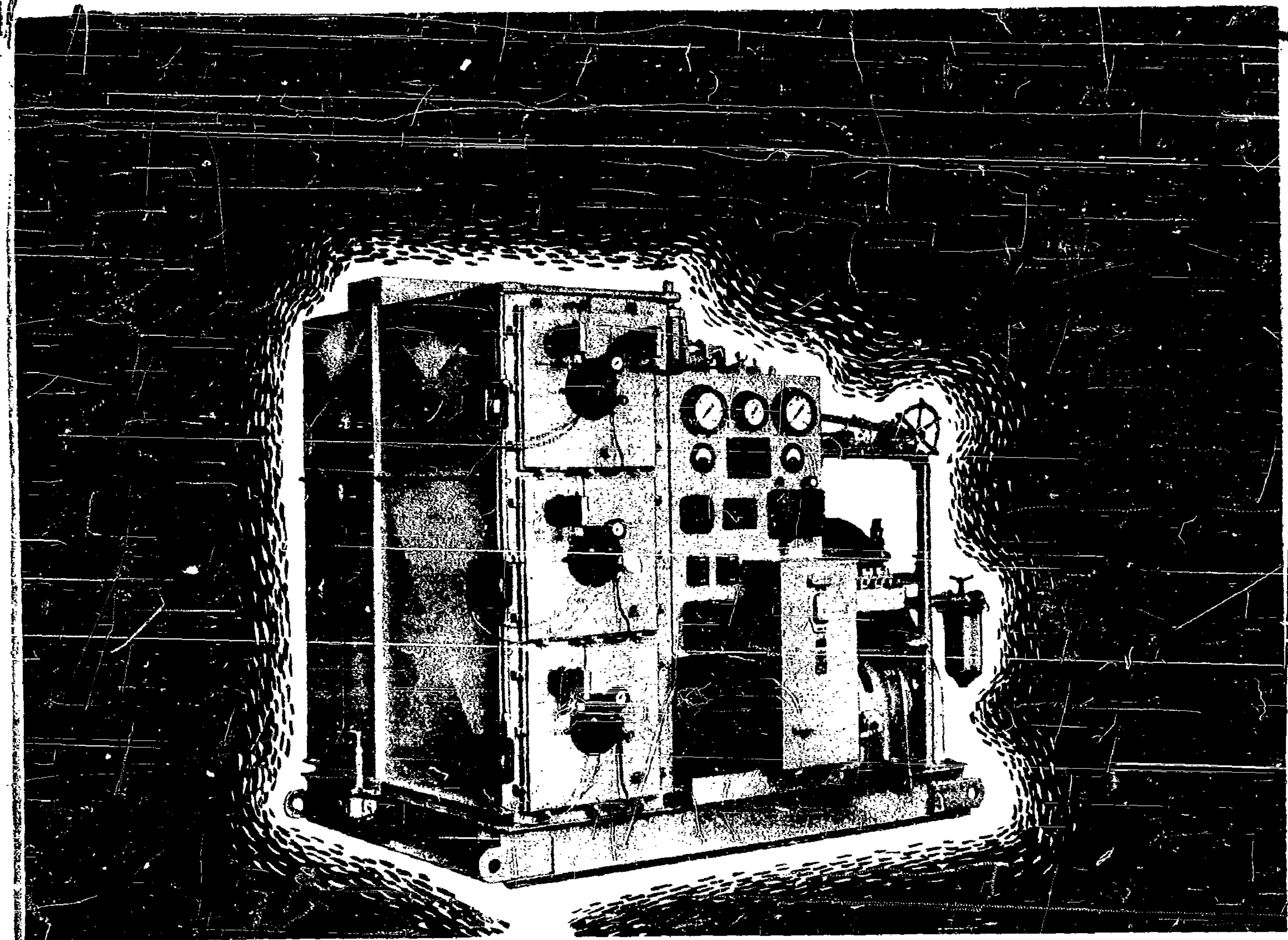
Engineers 4053 HARLAN STREET EMERYVILLE 8, CALIFORNIA *Manufacturers*

CONDENSED SPECIFICATIONS

Capacity—Maximum	1750 lb./hr.
Minimum	350 lb./hr.
Working Pressure	Up to 400 psi. max. 75 psi. min.
Temperature	Saturation temperature at working pressure
Overall Dimensions—Length	5 ft. 10 in.
Width	3 ft. 5 in.
Height	5 ft. 4 in.
Flue Size	8 in. diameter
Feed Water Inlet	1 in. I.P.S.
Steam Outlet	1¼ in. I.P.S.
Blowdown	¾ in. I.P.S.
Fuel Oil Connection	⅜ in. I.P.S.
Electrical Connected Load	5 H.P.
Fuel Consumption at Maximum Output	152 lb. per hr. Diesel oil or 2800 cu. ft. hr. natural gas at 1050 Btu. per cu. ft.
Total Heating Surface	94 sq. ft.
Safety Valve Outlet	1¼ in. I.P.S.
Approximate Weight	2800 lb.

★ ★ ★

The Model 50 is one of a series of Besler Standard Steam Generators, which will also include Model 75 (2500 lb./hr.) and Model 150 (5000 lb./hr.)



FEATURES AND ADVANTAGES

FLEXIBILITY Besler Test Boilers fully meet this important requirement with an extremely wide range, not only of steam pressures and temperatures, but also of capacity. For example, the Model 15 may instantly be cut down from 1500 to 400 lbs. per hour. The range is even greater on the larger Besler Sectional Boilers; the 6B will efficiently handle any load from 500 to 15,000 lbs. per hour!

EASE OF INSTALLATION Compact and light in weight, Besler Test Boilers are easy to move in and set up for operation. No brick work, no stack, no special buildings (unless required by law) are necessary. All connections are of maximum simplicity. Besler Test Boilers may even be used as portable units which can be moved to the equipment to be tested, when conditions make such procedure desirable.

FAST STEAMING Besler Test Boilers, starting cold, can deliver steam at full operating pressure and temperature in *two minutes!*

ACCURATE CONTROL Equipped with reliable Besler-designed controls, Besler Test Boilers provide desired steam temperatures and pressures accurately and maintain them uniformly over any required period. With the Besler forced-circulation "once through" counterflow design, and all-metal firebox devoid of refractories, heat storage is negligible and response to controls therefore extremely rapid.

LOW MAINTENANCE Every feature to reduce the cost, in time and money, of boiler maintenance has been incorporated in Besler design. Built-in rotary soot blowers cut soot-blowing time to minutes rather than hours; de-scaling can be done, under normal conditions, in two to three hours with the Besler acid treatment. Even major repairs can be accomplished in a short time; for example, replacing an entire boiler "section" on a Besler sectional unit can be done in but four hours!

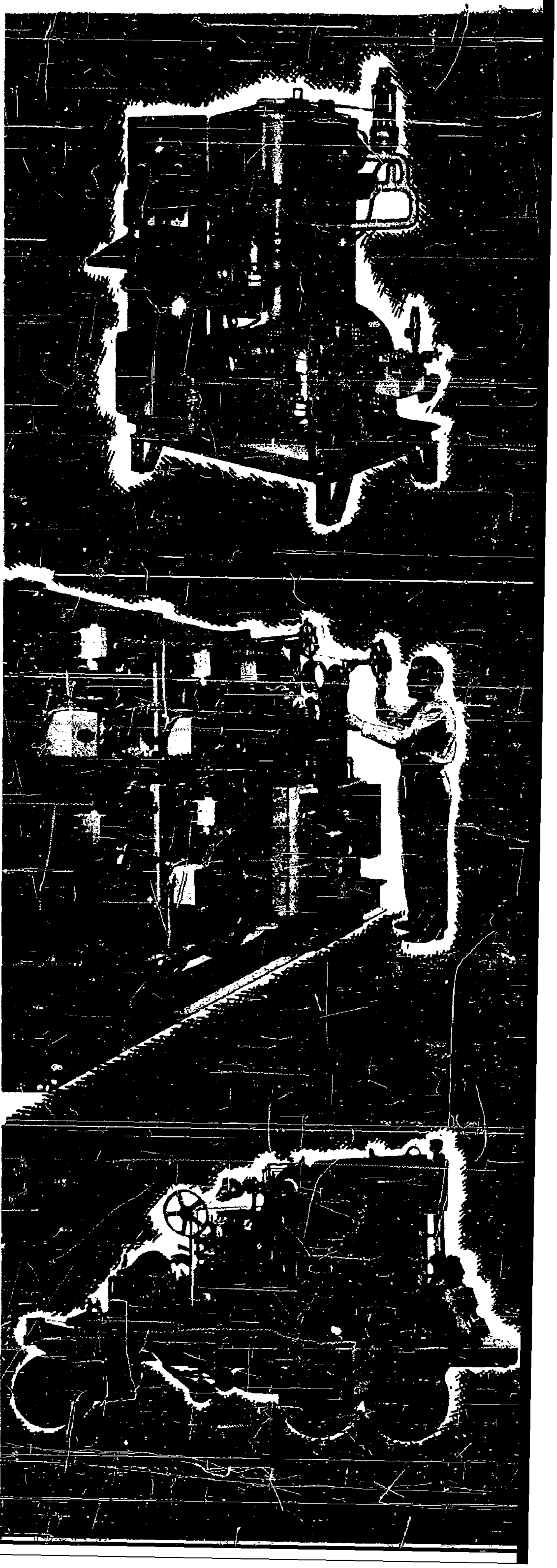
COMPLETE SAFETY Two features of Besler design assure safe operation under all conditions. With no drums or headers, and with minimum steam storage capacity, Besler Test Boilers virtually eliminate the explosion hazard. Reliable Besler controls automatically shut off the fire and feedwater if pressure or temperature becomes excessive, and approved safety and water relief valves are provided.

MANUFACTURED BY **BESLER CORPORATION** 4053 HARLAN STREET · EMERYVILLE 8, CALIFORNIA

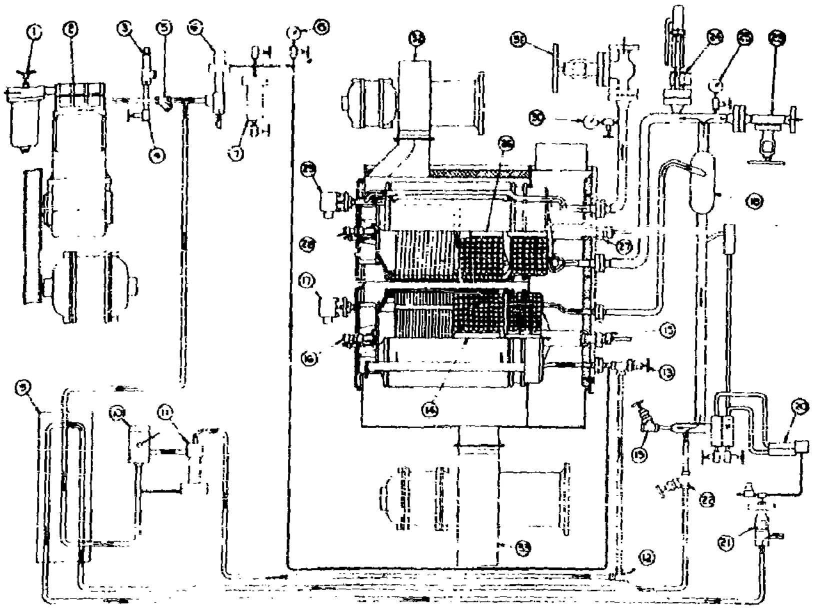
DESIGNED *by test engineers for test engineers*, the Besler Sectional Test Boiler is an innovation in steam generator design offering maximum flexibility, utmost conservation of space and weight, high efficiency at all capacities, and minimum maintenance expense in time and money.

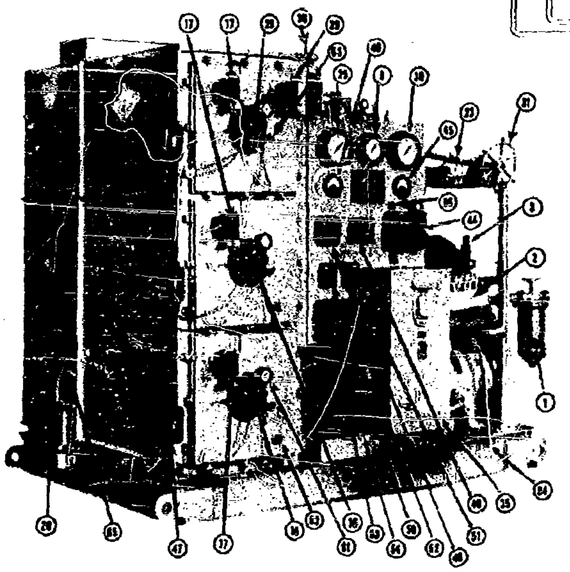
Basic unit in the Besler Sectional Test Boiler is the standard saturated steam-producing section. These independently-fired sections may be combined to provide any capacity up to 15,000 lbs. of steam per hour. Matched, standard superheat sections may be added to saturated section combinations as required to produce high-temperature steam. Thus it is possible to furnish a test boiler "tailored" exactly to your requirements, from standard components; the uncertainties and delays of special boiler design are eliminated.

Besler Sectional design provides a range of capacity heretofore impossible to achieve. For example, the Model 6B (six saturated, two superheat sections) will efficiently produce any amount of steam from 500 to 15,000 lbs. per hour. The minimum output of any Sectional model is that of a single section (500 lbs. per hour); maximum output is in proportion to the number of saturated sections employed. Capacity range is consequently far greater than that possible with any single steam-producing unit of equal maximum capacity. Condensed specifications given on page 4.



OPERATION OF BESLER SECTIONAL BOILERS





Front View

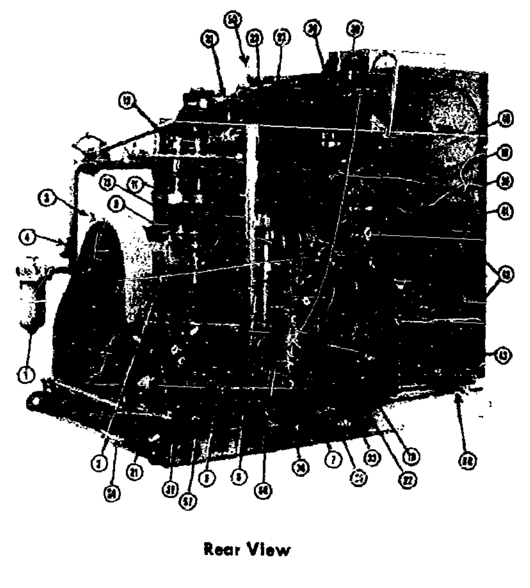
THE ABOVE flow diagram shows water and steam flow only. Feed water is admitted to feedwater pump 2 through strainer 1. Relief valve 3, bleed valve 4 and outlet strainer (high pressure) 5 are connected to feed pump outlet. Water then flows through heat exchanger 9 to distributing valve 10. Distributing valve 10 contains as many outlet ports as boiler sections in the boiler assembly. Only one outlet is shown here for simplicity. This valve is in effect a variable orifice across which is connected regulating valve 11. Regulating valve 11 maintains a constant pressure drop across orifice in valve 10 at any flow, thereby accurately metering the flow of water to the boiler. Water rejected by this valve is discharged back to the source of supply by differential relief valve 6. Differential relief valve 6 is spring loaded and pressure loaded to 150 p.s.i. above the maximum boiler inlet pressure by a pressure line from the boiler inlet. 7 is an air cushion designed to eliminate control pressure pulsations. Distributing valve 10, damper of main blower 33 and the fuel distributing valve (not shown) are linked together and automatically controlled by boiler pressure.

In passing through the heat exchanger, the temperature of feed water has been raised by spillover water returning from separator 18. From feed water regulator 11, feed water passes through inlet check valve 12, inlet stop valve 13 and to boiler section 14 where saturated steam of approximately 85 to 90% quality is generated. Item 15 is a rotary soot blower extending into the boiler section. 16 is the burner and ignition assembly which automatically starts and supports combustion at any load. 17 is a safety thermostat which shuts off fire in the event of excessive temperature or water failure. From boiler section 14, steam passes to separator 18. Water is conducted down through standpipe and to heat exchanger 9 and then back to the source of water. 19 is the flushing valve. 20 is the trap pilot valve which responds to changes in water head and opens trap valve 21 discharging water from the separator system. Saturated steam of 99.2% quality or better issues from the top of separator 18 and can be used through stop valve 23 for any purpose requiring dry saturated steam.

The dry saturated steam also passes to separately fired superheater 26. 24 is the safety valve. 25 is the saturated steam pressure gauge. Separately fired superheater 26 also contains a rotary soot blower 27. Burner and ignition assembly 28 is similar to that in the boiler section. Thermostat control box 29 automatically controls superheater outlet temperature by simultaneously controlling fuel flow and combustion air supplied by superheater blower 32 to the amount required for a given temperature condition. Superheated steam is taken off through stop valve 31. 30 is the superheater outlet pressure gauge.

When steam demand is increased or reduced, the main combustion control responds and supplies the proper quantities of water, air and fuel to the boiler section automatically. When lower or higher steam temperatures are desired, a simple adjustment of thermostat control box 29 produces the desired temperature quickly and accurately.

Any desired pressure, load, or temperature within the limit capacity of the boiler can be attained and accurately and automatically maintained. The boiler automatically adjusts itself to changes in load. Saturated steam and superheated steam can be taken off separately or simultaneously at any load or in any proportion within the minimum and maximum capacity limits of the boiler.



Rear View

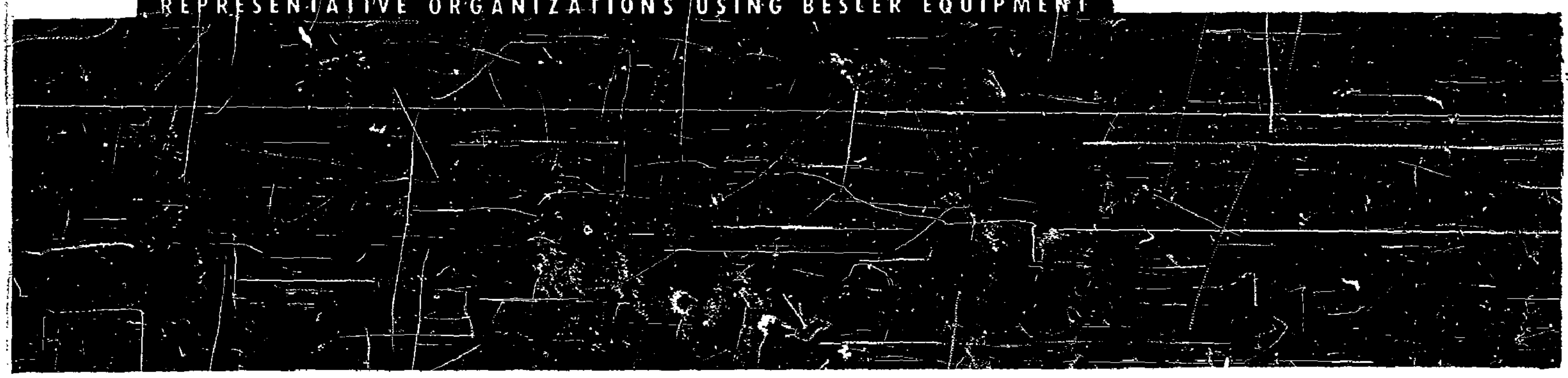
TEST BOILER CONDENSED SPECIFICATIONS

MODEL	15	1	2	3	4	5	6	1A	2A	3A	4A	4B	5B	6B
Capacity (in hundreds of lbs. of steam per hr.) Maximum	15	25	50	75	100	125	150	25	50	75	100	100	125	150
Minimum*	4	5	5	5	5	5	5	5	5	5	5	5	5	5
Working Pressure P.S.I. Maximum	2000	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Minimum	500	300	300	300	300	300	300	300	300	300	300	300	300	300
Working Temperature F Maximum	900	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	900	900	900	800	900	900	900
Minimum	100 Sup.							Sat.	Sat.	Sat.	Sat.	Sat.	Sat.	Sat.
Overall Dimensions Length (inches)	48	61	72	72	132	132	150	80	90	133	132	132	174	174
Width (inches)	36	54	66	66	66	66	66	66	66	67	66	66	66	66
Height (highest pt. Ins.)	80	84	92	104	104	110	110	77	89	91½	118½	118½	118½	118½
Flue Size, Length (inches)	10 dia.	24	25	25	49	49	49	24	24	49	49	49	49	73
Width (inches)		11½	11	11	11	11	11	18	18	18	11	11	11	11
Feed Water Inlet I.P.S.		¾	1¼	1¼	2	2	2	1	1¼	2	2	2	2	2
Steam Outlet (1500 lb. A.S.A. flange)** Saturated Steam		¾	1	1	1½	1½	2	¾	1	1	1½	1½	1½	2
Superheated Steam	¾							1	1½	1½	2	2	2½	2½
Blowdown, I.P.S.	½	¾	½	¾	1	1	1	¾	1	1	1	1	1	1
Fuel Oil Connection I.P.S.	⅜	⅜	⅜	½	½	½	½	½	½	¾	¾	¾	¾	¾
Electrical Auxiliary Load h.p.	8¾	13¼	20¼	30½	40¾	45¾	60¾	13¾	29	42½	43¾	45¾	50	65¾
Fuel Consumption lb. per hr. at Max. Capacity Based on Diesel Oil 19,500 Btu. per lb.	160	215	430	645	860	1080	1290	270	530	795	1010	1060	1380	1590
Total Heating Surface sq. ft. (Including Superheater)	91	94.5	189	283.5	378	472.5	567	168	266.5	366	455.5	533	627.5	722
Safety Valve Outlet I.P.S.	1	1	1½	1½	1½	1½	(2)1½	1	1½	1½	1½	(2)1½	(2)1½	(2)1½
Approx. Weight (hundreds of lbs.)	25	34.5	55	75	100	115	130	50	75	100	120	130	156	165

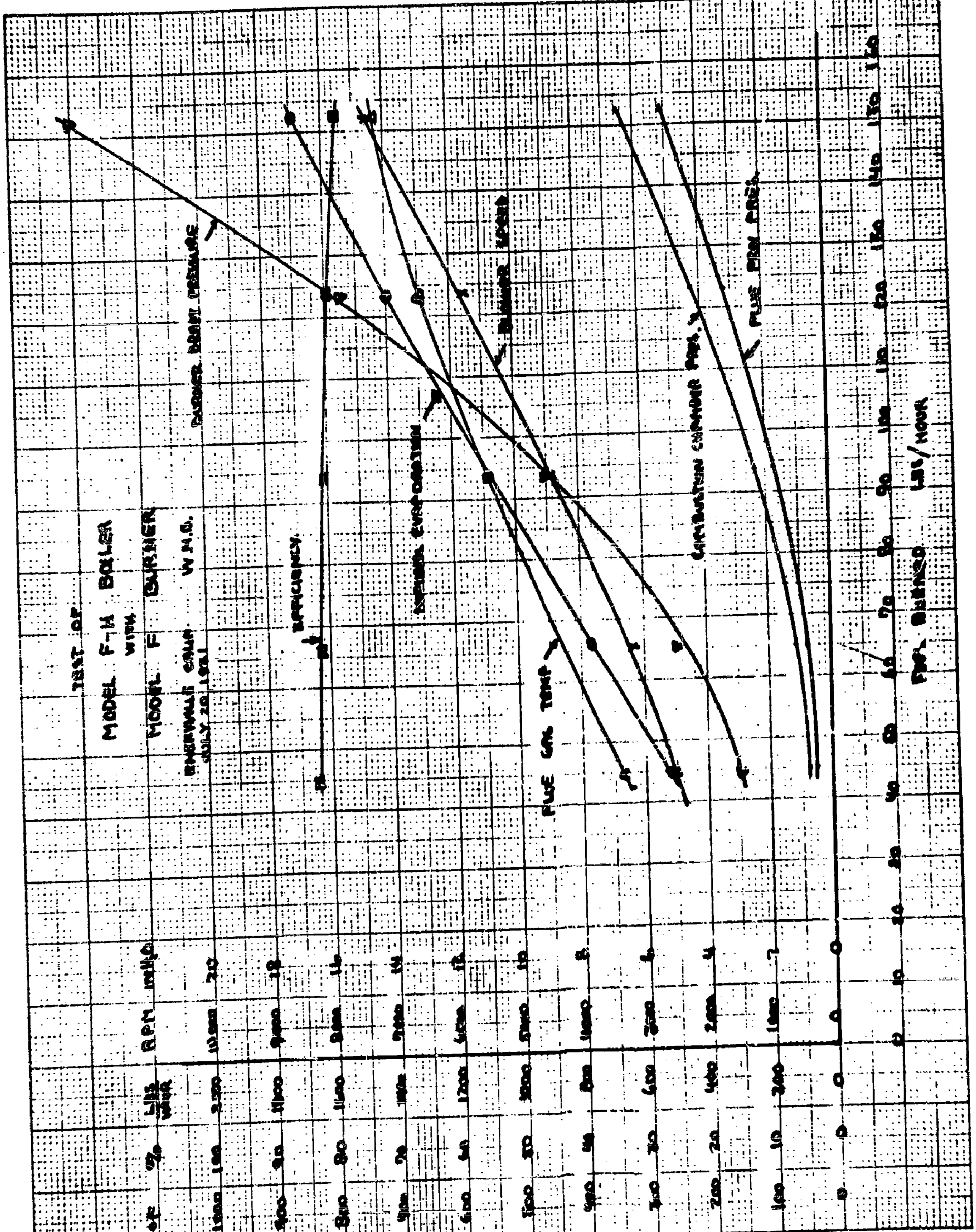
*Minimum capacity obtained by operating one section only at 1 5 load.
**All steam flanges large groove face; 2500-lb. A.S.A. flange on Model 15 only.

Other sizes, capacities and special designs quoted on request.
Manufactured under United States and foreign patents and patents pending.

REPRESENTATIVE ORGANIZATIONS USING BESLER EQUIPMENT



MANUFACTURED BY **BESLER CORPORATION** 4053 HARLAN STREET · EMERYVILLE 8, CALIFORNIA


TEST OF
MODEL F-M BOILER
WITH
MODEL F BURNER
EFFICIENCY
FLUE GAS TEMP.
FUEL BURNED LBS/HOUR

UNCLASSIFIED

AD 51752

Armed Services Technical Information Agency

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ARLINGTON 12 VIRGINIA

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CLASSIFICATION CHANGED TO UNCLASSIFIED

BY AUTHORITY OF ASTIA RECLASS. BULLETIN 12

Date 1 Sept. 58 Signed Richard L. Ready
OFFICE SECURITY ADVISOR