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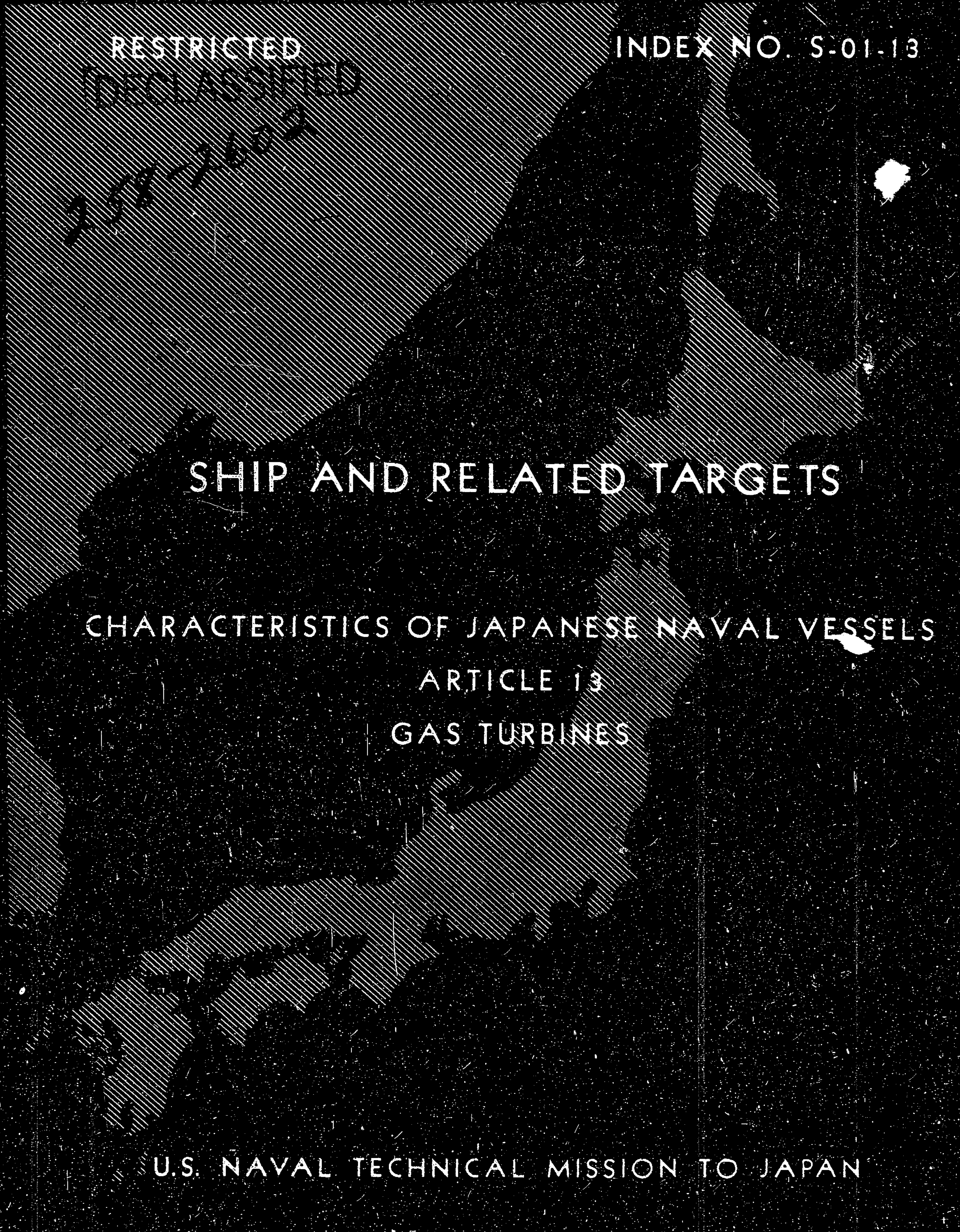

SHIP AND RELATED TARGETS

CHARACTERISTICS OF JAPANESE NAVAL VESSELS

ARTICLE 13

GAS TURBINES

U.S. NAVAL TECHNICAL MISSION TO JAPAN

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U. S. NAVAL TECHNICAL MISSION TO JAPAN
CARE OF FLEET POST OFFICE
SAN FRANCISCO, CALIFORNIA

21 March 1946

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From: Chief, Naval Technical Mission to Japan.
To : Chief of Naval Operations.

Subject: Target Report - Characteristics of Japanese Naval Vessels, Article 13 - Gas Turbines.

Reference: (a)"Intelligence Targets Japan" (DNI) of 4 Sept. 1945.

1. Subject report, dealing with Target S-01 of Fascicle S-1 of reference (a), is submitted herewith.

2. The investigation of the target and the target report were accomplished by Comdr. L. C. McCloskey, USNR, assisted by Lt. (jg) G. H. Sheeks, USNR, as interpreter and translator.

C. G. GRIMES
Captain, USN

CHARACTERISTICS OF JAPANESE NAVAL VESSELS
ARTICLE 13
GAS TURBINES

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945

FASCICLE S-1, TARGET S-01

MARCH 1946

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

SHIP AND RELATED TARGETS

CHARACTERISTICS OF JAPNESE NAVAL VESSELS
ARTICLE 13 - GAS TURBINES

The Japanese Navy attempted to design a gas turbine for PT's and similar craft. One unit which was being tested when the war ended, was actually a reaction steam turbine running at low pressure but with a high temperature fluid. Two-thirds of the total power generated was consumed in driving the rotary air compressor and the fuel pump. It had been anticipated that air in the ratio of 75 pounds of air to one pound of 18,000 BTU fuel would be taken in at 70°F, compressed to 30 psi gage, and delivered to the furnace at 300°F. The furnace was to have delivered the gases of combustion to the turbine at 30 psi gage and 1200°F. No successful runs were made.

Designing turbines and compressors always has been relatively simple but a design for a furnace which will perform economically the task assigned to it has not been developed. The Japanese were no exception. They did not succeed in developing a satisfactory furnace or burner, nor did they design the remainder of the unit with anything beyond standard textbook ideas.

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LIST OF ENCLOSURES

REFERENCES

Location of Target:

St. Joseph's College, YOKOHAMA.

Japanese Personnel Interviewed:

Vice Admiral AMMARI, Navy Ministry, TOKYO.

S. YASUI - Department Head, Ishikawa Jima Shibaura Turbine Co.

I. WATANABE, Naval Civilian Technician.

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INTRODUCTION

The information in this report was obtained through interrogation of Japanese engaged in gas turbine design, through study of drawings and reports, and by observation of the test model.

THE REPORT

I. FOREWORD

The Japanese Navy was experimenting with gas turbine propulsion for small ships when the war ended. A unit which was being tested was expected to deliver 2000 hp through consumption of 2200 lbs/hr of 18,000 BTU fuel at an efficiency of 12.8%. No satisfactory runs were achieved.

II. DIMENSIONS

The assembly of the unit, without the starting device, weighed 14 tons, its length was 15 ft., and height and width were about 5½ ft.

III. DESCRIPTION

The unit consisted of two cylindrical furnaces which burned fuel oil and delivered their products of combustion to a gas turbine. This turbine, in addition to delivering a useful load, had to supply power to drive an air compressor for the furnace, and a fuel pump. External power was needed to start the unit; a clutched-in diesel engine was used for this purpose. (See Enclosures (D), (E), (F), and (G) which show the burner-furnace assembly as well as the general assembly and side elevation section of the unit.)

A. Turbine

The turbine was developed from conventional steam turbine design. It was a four-stage, reaction design with pitch circle of 28 3/4 inches. Blading in the first two rows was of 18 chrome-8 nickle-2 tungsten-steel. The last two rows were made of 13 chrome steel. Rotor blades had a double tongue and rivet construction, and were shroud-banded. Stator blades were slotted-in and shrouded. Labyrinth packing was used on both ends, and both ends were arranged for pressure leak-off. It was essentially a steam turbine with the following minor variations: blade material, lack of carbon packing, and use of ball bearings for both main and thrust.

B. Air Compressor

The air compressor was essentially a steam turbine running in reverse. It was a reaction-bladed compressor of 20 stages. Blades, both rotor and stator, were made of stainless steel, slotted-in, and unshrouded. The rotor shaft was a closed-end hollow cylinder with an outside diameter of 18½ inches. Pitch circle average about 24 inches. Packing and bearing design was similar to that of the turbine.

C. Fuel Pump

The fuel pump was of conventional gear-pump design, and was driven through reducing gears at the discharge end of the compressor.

D. Burner and Furnace

Mechanically the burner design was similar to early diesel engine atomizers. Oil under pressure was fed at the center of and between two parallel discs, and escaped in the form of a thin sheet from a periphery annulus. Supply from the burner barrel was through a tube 2mm in diameter. The discs were 5mm in diameter an 1mm apart. Resemblance to a diesel atomizer ended there however, because of the departure from conventional atomizing pressure. Supply to the burner barrel was at 228 psi. Passage through a strainer and a small diameter supply channel doubtless reduced the pressure available for atomizing to roughly 40% of the supply pressure. It is believed that the quality of atomization from such a device and pressure must have been low.

The furnace was a long cylinder having a perforated concentric sleeve to jacket the flame at ignition. The attempted release rate was extraordinarily high (1,600,000 BTU/hr/ft^3 of furnace volume). The air-fuel ratio also was extraordinarily high (450% excess air). There appears to be little doubt that this burner-furnace design was destined to fail because of inadequacy in degree of atomization.

E. Air and Gas Flow

The compressor and turbine shafts were connected by a flexible coupling near their inlet ends. Air entered the compressor near this coupling and flowed away from the turbine. From the collector chamber at the far end it was led to the inlet end of the burners, to flow again through the furnaces and the turbine. The hot gases entered the turbine near the flexible coupling and flowed away from it.

IV. ANTICIPATED PERFORMANCE

It was anticipated that the air compressor would take air at 60°F, and by consumption of 4000 hp, deliver 170,000 lbs/hr at 300°F and 30 psi gage to the burners. The burners were expected to atomize and burn 2205 lbs/hr of 18,000 BTU fuel and deliver the resulting gas to the turbine at 1200°F. The turbine, rotating at 5500 RPM was to extract 6000 hp from the energy in this high velocity gas. Consumption of 4000 hp by the air compressor would have left only 2000 hp for delivery at the coupling.

V. TEST RESULTS

Performance of the unit was unsatisfactory and demonstrated the shortcomings of the furnace. A physical research group was set to work and the following three investigations resulted:

"Research on Gas Turbine Combustion Chamber"
by T. INAGAWA and Y. NOGAMI.

"Research on the Basic Phenomena of Combustion"
by M. SAKAMOTO.

"Research on Refractory Materials"
by Y. ITO.

Synopses of these three papers, prepared in English by the Japanese, are included as Enclosures (A), (B), and (C) respectively. Activities in gas turbine were discontinued at the end of the war. It is believed that the researches described contributed little toward the development of the gas turbine.

ENCLOSURE (A)

RESEARCH ON GAS TURBINE COMBUSTION CHAMBER

by T. INAGAWA and Y. NOGAMI
30 November 1945

I. EXPERIMENT ON COMBUSTION OF BUNKER OIL

A. Objective of Experiment

We investigated the combustion phenomena of bunker oil in a small scale model of a gas turbine combustion chamber to obtain necessary data for design of the gas turbine engine planned at the Technical Department of the Japanese Navy.

B. Description of Apparatus

General view of the apparatus used in the experiment is shown in Figure 1(A) in which:

(1) is the axial compressor, 20 stage driven by a starting motor (2) at a speed of 2000 RPM.

(3) is a model combustion chamber made of mild steel plate. Its volume is one-half of the original plan. Various forms were tried and final one is shown in Figure 2(A).

(4) is the fuel injection nozzle of an air injection type as shown by the rough sketch in Figure 3(A).

(5) is the fuel feed pump which is an IMO pump (worm-gear). Maximum delivery pressure is 20 kg/cm^2 (gauge).

(7) is the fuel preheater. At first, a coil of fuel pipe was passed through the exhaust pipe, but owing to difficulty in adjusting the fuel temperature, an electric furnace was later used.

(10) is the ignition coil which is of nickel-chromium steel wire of 0.5mm diameter and was heated electrically.

C. Measurements of Various Quantities (cf. Figure 1(A))

At (a), (b), and (c), the amount of air passed is measured by means of Pitot tubes.

At (d), the temperature of gas is measured by an Almel-Chromel thermocouple and the composition of exhaust gas is analyzed by an Orsat gas analyzer.

At (e) and (f), the temperature and pressure of fuel and injection air are measured by mercury thermometers and manometers.

At (g), the displacement of fuel level is read. The fuel consumption is calculated from it.

Apart from exhaust gas analysis, the state of combustion is judged by observing the color of the flame and smoke from a window in the combustion chamber wall.

ENCLOSURE (A), continued

D. Conditions of Experiments

Kind of fuel .... bunker oil
Fuel injection system .... air injection type
Pressure of air .... 2.5 - 4.0 kg/cm^2 (gauge)
Pressure of fuel .... 0.5 - 1.0 kg/cm^2 (gauge)
Amount of fuel .... up to 50 gr/sec
Preheating of fuel .... up to 80°C
Pressure in combustion chamber .... 0 - 100mm in mercury column above atomospheric pressure
Amount of air .... up to 2.26 kg/sec
Maximum combustion chamber load .... 8500 $kg/m^3/hr$

E. Summary of Results

Chief factors which influence the combustion are:

Air ratio
Temperature in combustion chamber
Form and atomization of fuel spray
Mixing of air and fuel
Velocity of gas in combustion chamber.

The most favorable air ratio is about 16 - 17. The length of flame decreases with increasing air ratio, so that we can have a smaller combustion chamber. But when the air ratio is increased, gas temperature becomes lower and gas velocity higher in the combustion chamber; consequently, the efficiency of combustion is not good at too great an air ratio.

The secondary air for lowering gas temperature must not be added before combustion is completed.

Gas velocity in combustion chamber must not exceed a certain limit (40 - 50 m/sec in our experiment), or combustion becomes unstable and sometimes the fire is extinguished. This limit varies with the condition of combustion.

The air injection type fuel nozzle used in the experiment gives good atomization with low pressure. Its drawback is the necessity of an additional air compressor.

By rotating combustion air, we can improve the mixing of air and fuel but, as it increases flow resistance in the combustion chamber, its advantage is doubtful.

Under the best conditions we were able to burn 8500 $kg/m^3/hr$ of fuel, so that the maximum combustion chamber load of 9000 $kg/m^3/hr$ aimed at in original plan would be possible at 3 kg/cm^2 (gauge) of combustion chamber pressure.

The cylindrical combustion chamber used in the experiment seems to be most suitable for the requirements of compactness, small resistance and high combustion efficiency.

II. EXPERIMENT ON COMBUSTION OF PINE OIL

A. Object of Experiment

We investigated the possibility of utilizing pine oil as the fuel of a gas turbine rocket engine KIKKA 20.

ENCLOSURE (A), continued

B. Description of Apparatus (cf. Figure 1(A))

(1) is the axial compressor which has 20 stages and is driven by a starting motor (2) at 2000 RPM.

(3) is the model combustion chamber (cf. Figure 4(A)) and is made of mild steel plate. Its volume is 1/12 of the original.

(4) are the fuel injection nozzles. Both solid injection and air injection types are used.

(5) is the fuel feed pump. It is an IMO pump (worm-gear) whose maximum delivery pressure is 20 kg/cm^2 (gauge).

(7) is the fuel preheater. A coil of fuel pipe is passed through a small electric furnace.

(10) is the ignition coil which is of nickel-chromium steel wire of 0.5mm diameter and is heated electrically.

C. Measurements of Various Quantities (cf. Figure 1(A))

At (a), (b), and (c), the amount of air passed is measured by means of Pitot tubes.

At (d), the temperature of gas is measured by an Almel-Chromel thermocouple and the composition of gas is analyzed by means of an Orsat gas analyser.

At (e), and (f), the temperature and pressure of fuel and injection air are measured by mercury thermometers and Bourdon gauges.

At (g), the displacement of fuel level is read and the amount of fuel consumption is calculated from this.

At (h), the amount of injection air is measured by an orifice.

D. Condition of Experiments

Kind of fuel	heavy pine oil and crude pine oil
Fuel injection	
Air injection type	
Air pressure	2.5 - 4.0 kg/cm^2 (gauge)
Fuel pressure	10 kg/cm^2 (gauge)
Solid injection type	
Oil pressure	15 kg/cm^2 (gauge)
Amount of fuel	up to 20 gm/sec
Preheating of fuel	up to 90° C
Pressure in combustion chamber	atmospheric pressure
Amount of air	up to 2.26 kg/sec
Temperature of gas	nearly 800°C
Maximum combustion chamber load	12,000 kg/m^3/hr

E. Results of Tests

Crude pine oil can be used as fuel without change in the construction.

Heavy pine oil does not burn well by solid injection. By using air injection and preheating it would be usable.

ENCLOSURE (A), continued

When the preheated oil cools, it becomes very viscous and clogs the pipe line.

Pine oil contains many impurities and nozzles are easily choked. The capacity of filter must be increased.

PROPERTIES OF PINE OIL USED IN THE TEST

	Crude Oil	Heavy Oil
Specific weight (15/4°C)	0.9769	0.9890
Chemical reaction	Acid	Acid
Flash point (°C)	35.0	55.0
Water content (%)	0.7	1.0
Ash content (%)	0.011	0.139
Freezing point (°C)	lower than -20°C	lower than -20°C
Viscosity (Redwood 30°C)	51.6	190.2
Cetane number	22.4	- -
Calorific value (kcal/kg)	8406 (mean) (8171 - 8915	9439 (mean) (9172 - 9541)

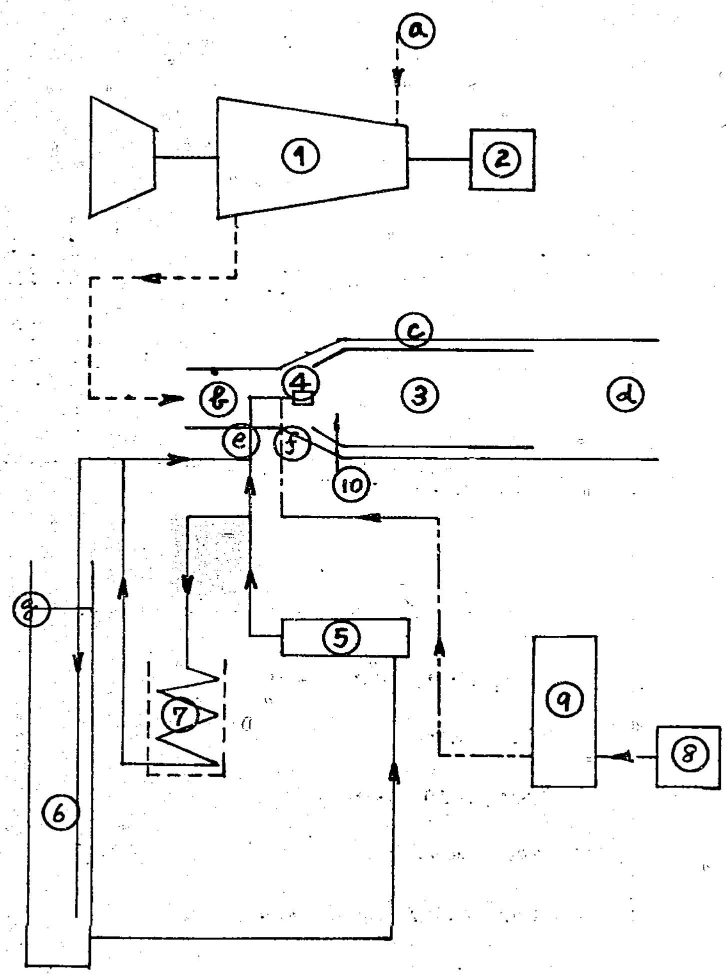
Note: As regards the "Experiment on the Cooling of Gas Turbine Blades", we have done very little because the idea is impractical for the following reasons:

1. The cooling device is generally complicated and simple construction, a chief advantage of the gas turbine, would be lost.

2. The strength of a turbine blade is considerably lowered by making a hole through the blade.

Consequently, we have no results to report.

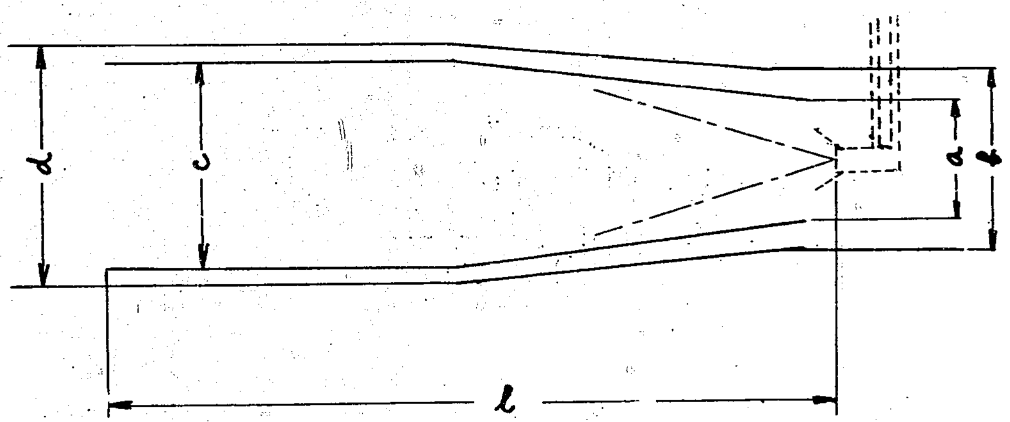
ENCLOSURE (A), continued



① AXIAL COMPRESSOR
② STARTING MOTOR
③ COMBUSTION CHAMBER
④ FUEL NOZZLE
⑤ FUEL PUMP
⑥ FUEL TANK
⑦ FUEL PREHEATER
⑧ AIR COMPRESSOR
⑨ AIR RESERVOIR
⑩ IGNITION COIL

Figure 1(A)
EXPERIMENTAL APPARATUS

ENCLOSURE (A), continued



a = 160, 170, 180 mm

b = 310 mm

c = 350, 380 mm

d = 400 mm

l = 1500, 1600, 1800 mm

Figure 2 (A)
COMBUSTION CHAMBER NO. 1

ENCLOSURE (A), continued

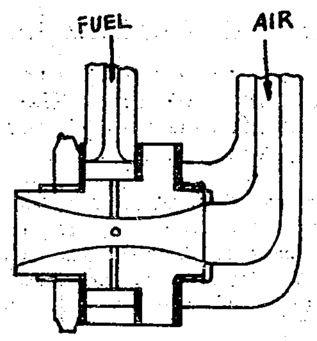


Figure 3(A)
FUEL NOZZLE

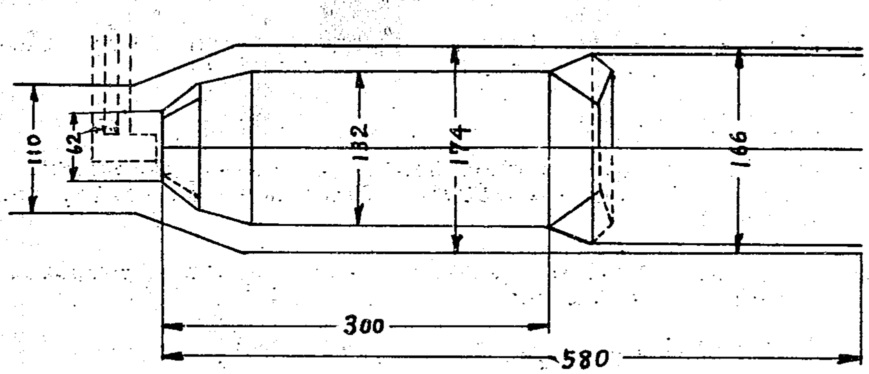


Figure 4(A)
COMBUSTION CHAMBER NO. 2

ENCLOSURE (B)

RESEARCH ON REFRACTORY MATERIALS

by Y. ITO

1. Refractory Materials: Proofing Against Quick Heating and Cooling

Generally, fireproofing materials have properties of good refractivity but are not proof against quick heating or cooling. The object is to discover fireproofing materials which are easily mass produced, have good refractivity and are proof against quick heating and cooling.

To this end, we studied the crystal component of the $MgO-Al_2O_3-SiO_2$ series to develop resistance to quick heating and cooling. We measured the thermal expansion coefficient when the component was similar to the molecular formula of $2MgO.2Al_2O_3.5SiO_2$ (Cordierite). However, Cordierite does not have sufficient strength against external mechanical shock, and has poor refractivity.

Then aluminum oxide powder was used and sintered at about 1380°C with a small quantity of a bonding component similar to Cordierite.

Example of bonding material:

Magnesite	12.9%	(by weight)
Diaspore	72.8	(by weight)
Silica	14.3	(by weight)

Results of spalling test (quick heating and cooling test) in which the sample was thrown into water at room temperature and then heated to 800°C, the process being repeated ten times or more:

As an insulator the electric resistance was $2x10^9 - 2x10^5 \Omega$ at 200 - 600°C.

These results will be applied to lining of combustion chambers, ignition plugs, and metal casting dies. (A patent has been requested.)

2. Fire Proofing Special Cement

Portland cement is usually crushed when heated to about 400-800°C. A fireproofing cement capable of standing 1600°C, which will be easily and quickly set by H_2O, was demanded.

Molecular formula ($3CaO.5Al_2O_3$) was suitable for the above purpose. Calcium aluminate will be changed as follows:

$$3\ CaO.5Al_2O_3 \xrightarrow{H_2O} 2CaO.nH_2O + Al(OH)_3$$

$$\begin{cases} 2\ CaO.Al_2O_3\ nH_2O \xrightarrow{burned} 2CaO.Al_2O_3 \\ 2\ Al(OH)_3 \xrightarrow[170-300^oC]{} Al_2O_3.H_2O \xrightarrow[300-500^oC]{} \gamma\ Al_2O_3 \end{cases}$$

$$7\left[Al_2O_3\right] + 3\left[2CaO.Al_2O_3\right] \longleftrightarrow 2\left[3CaO.5Al_2O_3\right] \quad \text{Reversible}$$

Aluminate ($3CaO.5Al_2O_3$) was produced by heating the mixture of limestone and diaspore at about 1400°C for four hours, and, for the purpose of lowering the sintering temperature, 3% of magnesite was used successfully. A rotary kiln was tried a few times for producing $3CaO.5Al_2O_3$ at 1400°C.

Testing results indicated that it would stand 1600°C, a pressure of 195.6 kg/cm^2, and a bending force of 37.0 kg/cm^2 after setting seven days. Strength was maximum after setting 28 days.

ENCLOSURE (B), continued

3. Application of Crystalline Mullite as Refractory

a. Synthesis of Pure Mullite Crystal. Catalyzers for artificial mullite, $3Al_2O_3.2SiO_2$, were studied, and selected as follows:

Oxide	MnO, MnO_2	MgO	CuO	ZnO	$CaCl_2$	Al
Chloride	$MnCl_2$	$MgCl_2$	$CuCl_2$	$ZnCl_2$		
Carbonate	$MnCO_3$	$MgCO_3$	$CuCO_3$		$CaCO_3$	
Sulfate	$MnSO_4$	$MgSO_4$	$CuSO_4$	$ZnSO_4$	$CaSO_4$	$Al_2(SO_4)_3$
Nitrate	$Mn(NO_3)_2$		$Cu(NO_3)_2$		$Ca(NO_3)_2$	$Al(NO_3)_3$
Hydroxide		$Mg(OH)_2$	$Cu(OH)_2$		$Ca(OH)_2$	$Al(OH)_3$

Cr_2O_3

$Cr_2(SO_4)_3$

$(NH_4)_2MoO_4$

Of these catalyzers, the most effective for producing mullite crystal at the lowest temperature was aluminum sulfate, $Al_2(SO_4)_3$, which was found by chemical analysis, density measurements and X-ray tests. This result should be applied practically in the production of mullite refractories.

b. Crystalline State of Korean Minerals (Al_2O_3 group) in Burning Utilizing physical chemistry procedures, crystal forming state of Korean aluminum silicate minerals, andalucite, cyanite and silimanite were studied. They were burned at 1000-1700°C, and complete mullite crystals were found at 1200°C in cyanite, at 1600°C in andalucite and silimanite. We measured atomic plane distances (spacing) by X-ray.

ENCLOSURE (C)

RESEARCH ON THE BASIC PHENOMENA OF COMBUSTION

by M. SAKAMOTO

A. CONSTANT VOLUME COMBUSTION OF HEAVY OIL

1. Analysis by Pressure Diagram

Into a constant volume combustion chamber, a single charge of fuel is injected and ignited spontaneously, and pressure change in the chamber is measured by a piezo-indicator. The ignition lag, combustion pressure and combustion period are studied on the pressure card, and then we know the relation between these factors and the initial temperature and density or CO_2, N_2, and O_2 content in the combustion chamber.

Figure 1(C) is a diagrammatic sketch of the assembled apparatus. The motor is revolved first, and when the number of its revolutions reach the desired value, the cam stopper is taken off. Then the cam is slid to the right direction of the state of revolution due to the stress of spring, the nozzle spindle is lifted, and fuel is injected into the combustion chamber.

A typical record for an initial condition of 600°C and 40 kg/cm^2 is shown in Figure 2(C).

We can measure from these oscillograms the ignition lag, maximum combustion pressure, duration of effective combustion and the end of combustion.

The relation between the ignition lag and the initial density or initial temperature are shown in Figure 3(C) and Figure 4(C).

The relation between the value of $Pm/_P$ and initial temperature is shown in Figure 5(C) and the influences of CO_2, N_2 or O_2 content in the combustion chambers are shown in Figure 6(C).

When the moisture content in the combustion chamber is moderate, the combustion is good, but if it is too much, combustion is prevented. Too much dryness of air is also harmful to combustion.

2. Photographic Study

Into the constant volume combustion chamber, which has glass windows at both sides, a single charge of fuel is injected and ignited spontaneously, and the state of ignition and flame propagation are photographed by a high speed camera.

The growth of the flame nucleus, the state of flame propagation, and the relations between these phenomena and the pressure change, measured by the piezo-indicator were observed.

Figure 7(C) is a diagrammatic sketch of the assembled apparatus.

We ascertained the following facts: the growth of flame nucleus differs with ignition lag, and the growth of flame nucleus does not coincide with the start of pressure rise. Moreover, these differences arise owing to the kind of fuel or fuel injection pressure used.

B. COMBUSTION OF AN OIL DROP

The speed of vaporization and ignition lag of a drop of oil, suspended in high temperature and high pressure air, was measured and thus the spontaneous

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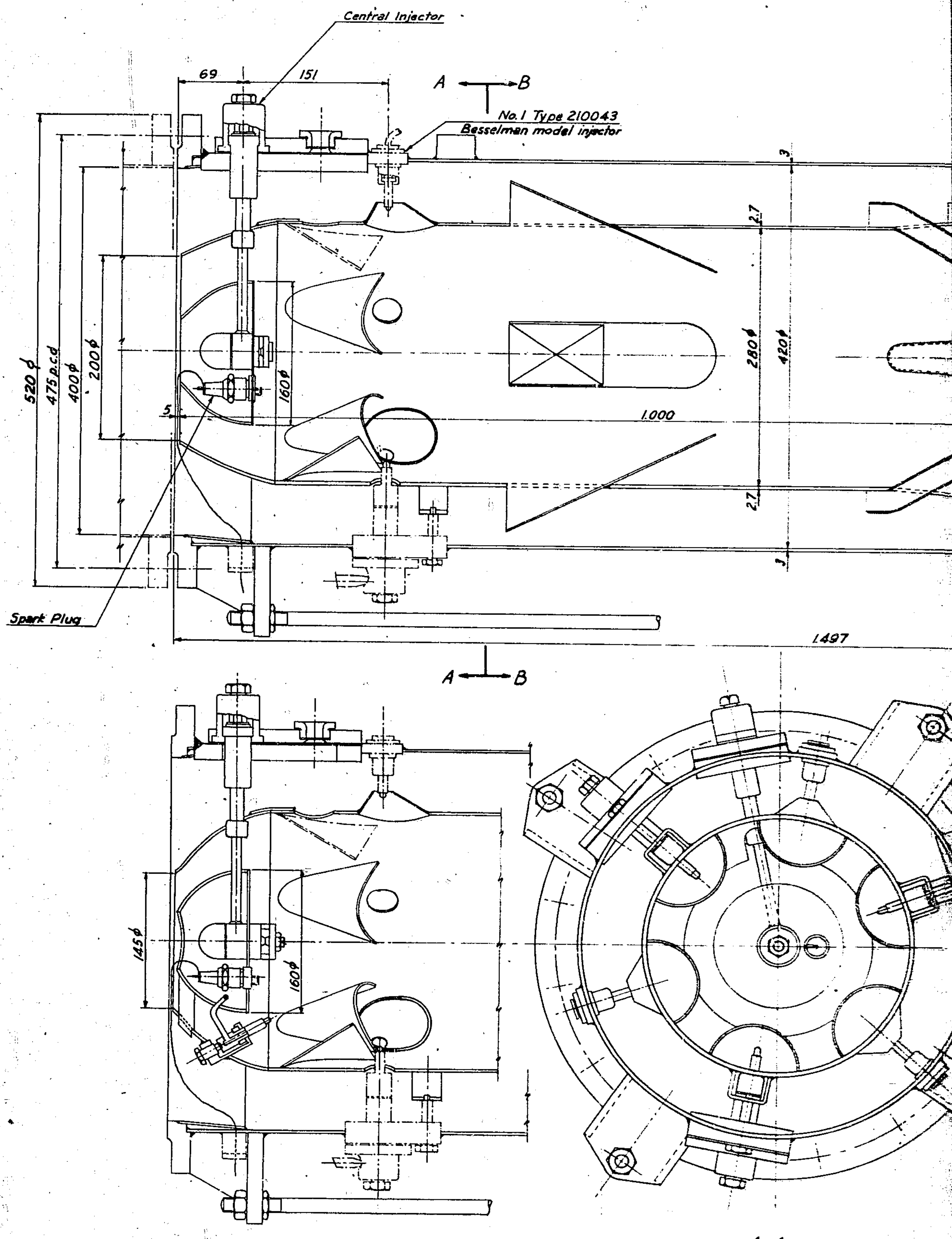
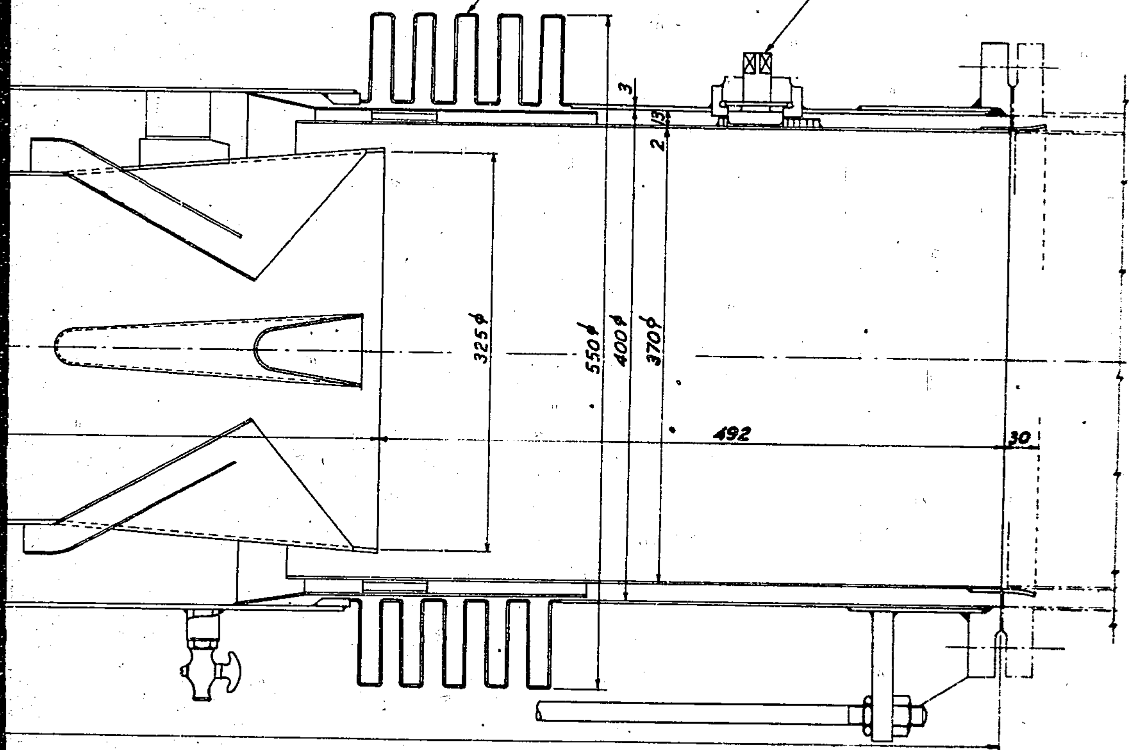
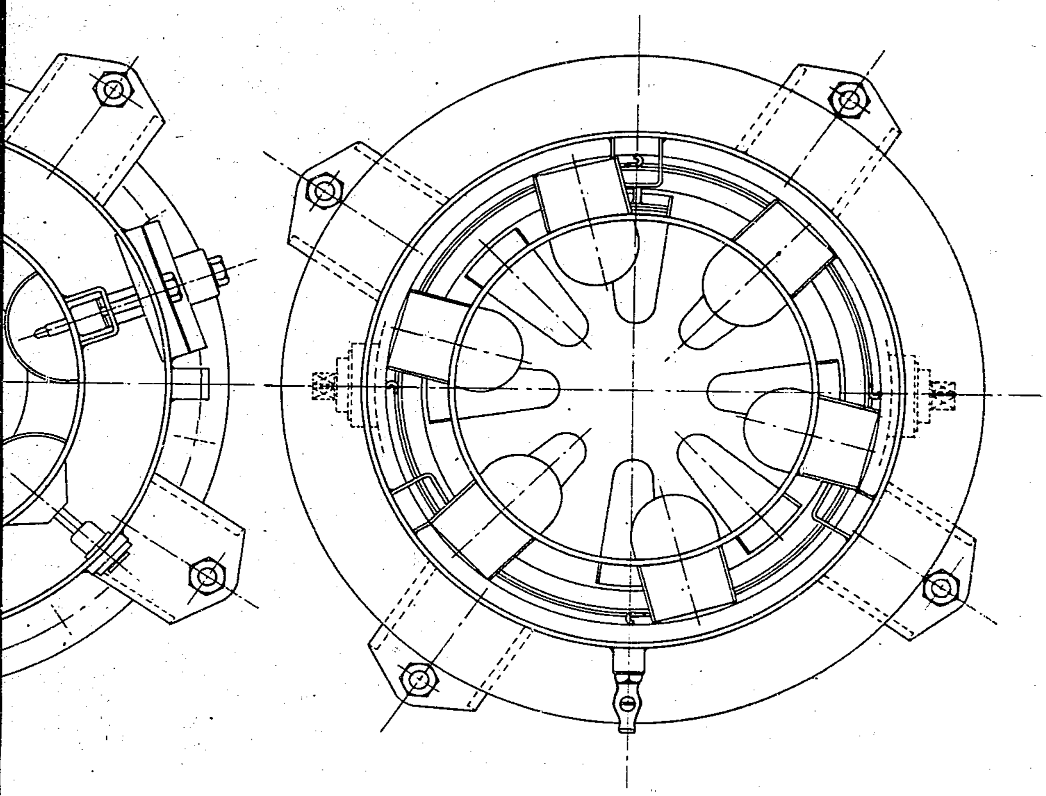
ENCLOSURE (E)



GAS TURBINE FURNACE ASSEMBL

E (E)





B-B

CE ASSEMBLY

ENCLOSURE (C), continued

ignition temperature was determined in the state more nearly resembling actual conditions than possible with the Moore apparatus which is in ordinary use. That is, an oil drop 0.3mm-1.2mm in diameter, on the tip of a tungsten wire about 15 micron in diameter, was inserted into the high temperature combustion chamber under high pressure. Then the oil drop was vaporized and ignited spontaneously.

The relation between ignition lag and initial temperature of combustion chamber is shown in Figure 8(C) and the spontaneous ignition temperature for the same ignition is determined from this curve. Thus, the relation between spontaneous ignition temperature and diameter of oil drop or initial pressure of combustion chamber are as shown in Figure 9(C) and Figure 10(C).

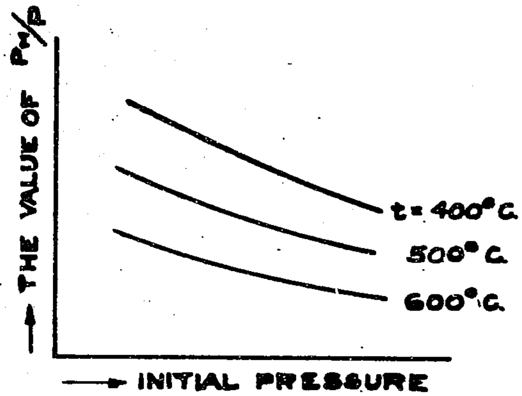


Figure 5(C)
CONSTANT VOLUME COMBUSTION
INITIAL PRESSURE VS. Pa/p

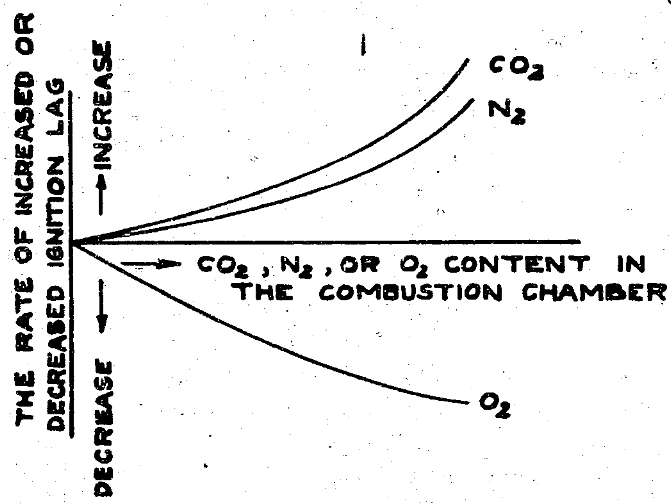


Figure 6(C)
CONSTANT VOLUME COMBUSTION
EFFECT OF CO_2, N_2, and O_2.

ENCLOSURE (C), continued

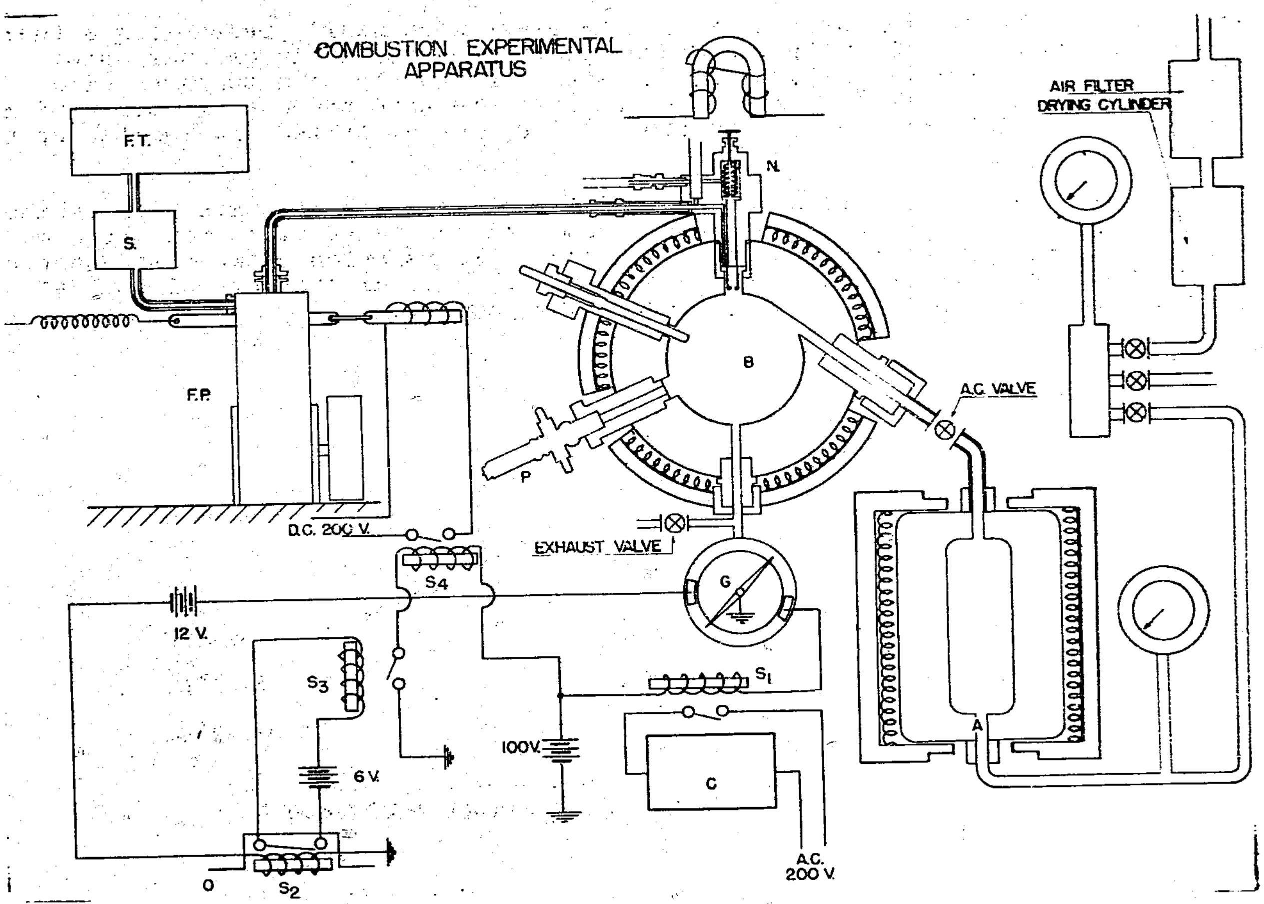


Figure 7(C)
APPARATUS FOR PHOTOGRAPHIC STUDIES OF CONSTANT VOLUME COMBUSTION

B: Combustion chamber (electrically heated; it has diameter of 130mm, width of 40mm)

A: High pressure air bomb (electrically heated)

P: Piezo-indicator

T: Thermocouple

N: Nozzle (Bosch type)

F.T: Fuel tank

S: Strainer

F.P: Fuel pump (Bosch type)

G: Pressure gauge (whose index closes the circuit of the high speed camera, the oscillograph and the fuel pumps at desired pressure of the combustion chamber).

C: High speed camera

O: Oscillograph

ENCLOSURE (C), continued

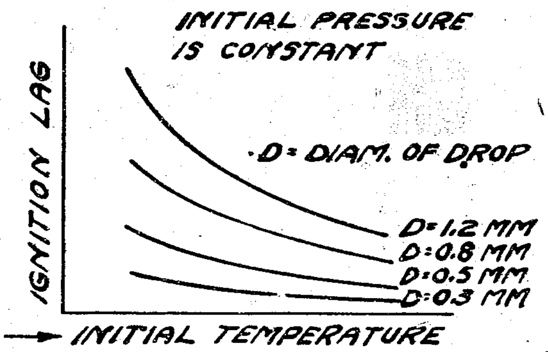


Figure 8(C)
IGNITION LAG VS. INITIAL TEMPERATURE
FOR VARIOUS DIAMETER OIL DROPS

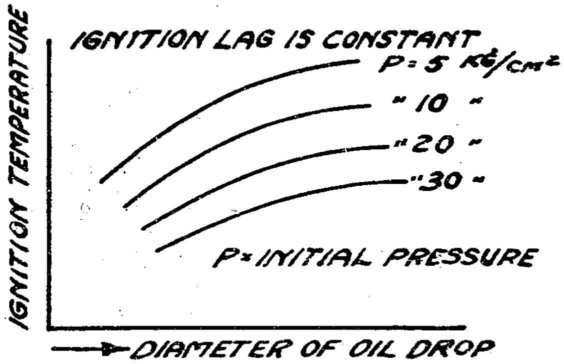


Figure 9(C)
SPONTANEOUS IGNITION TEMPERATURE VS.
DIAMETER OF OIL DROP

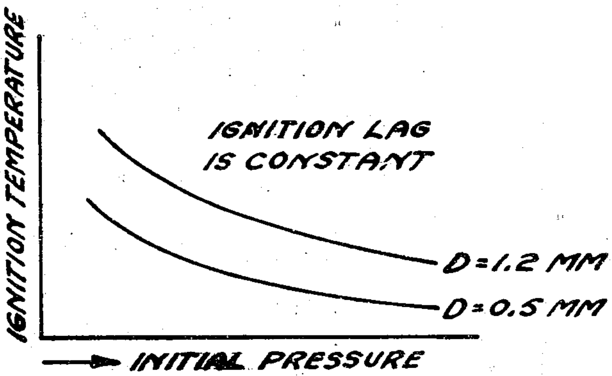
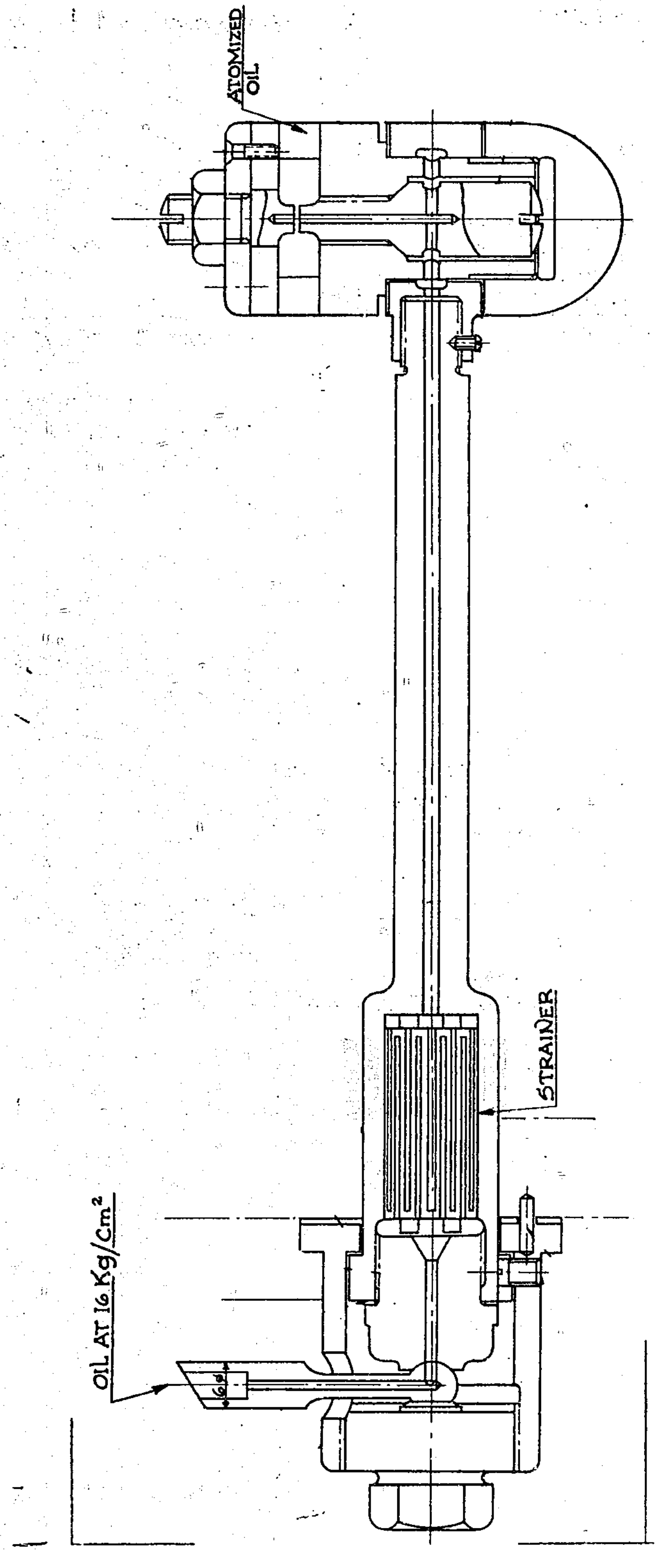
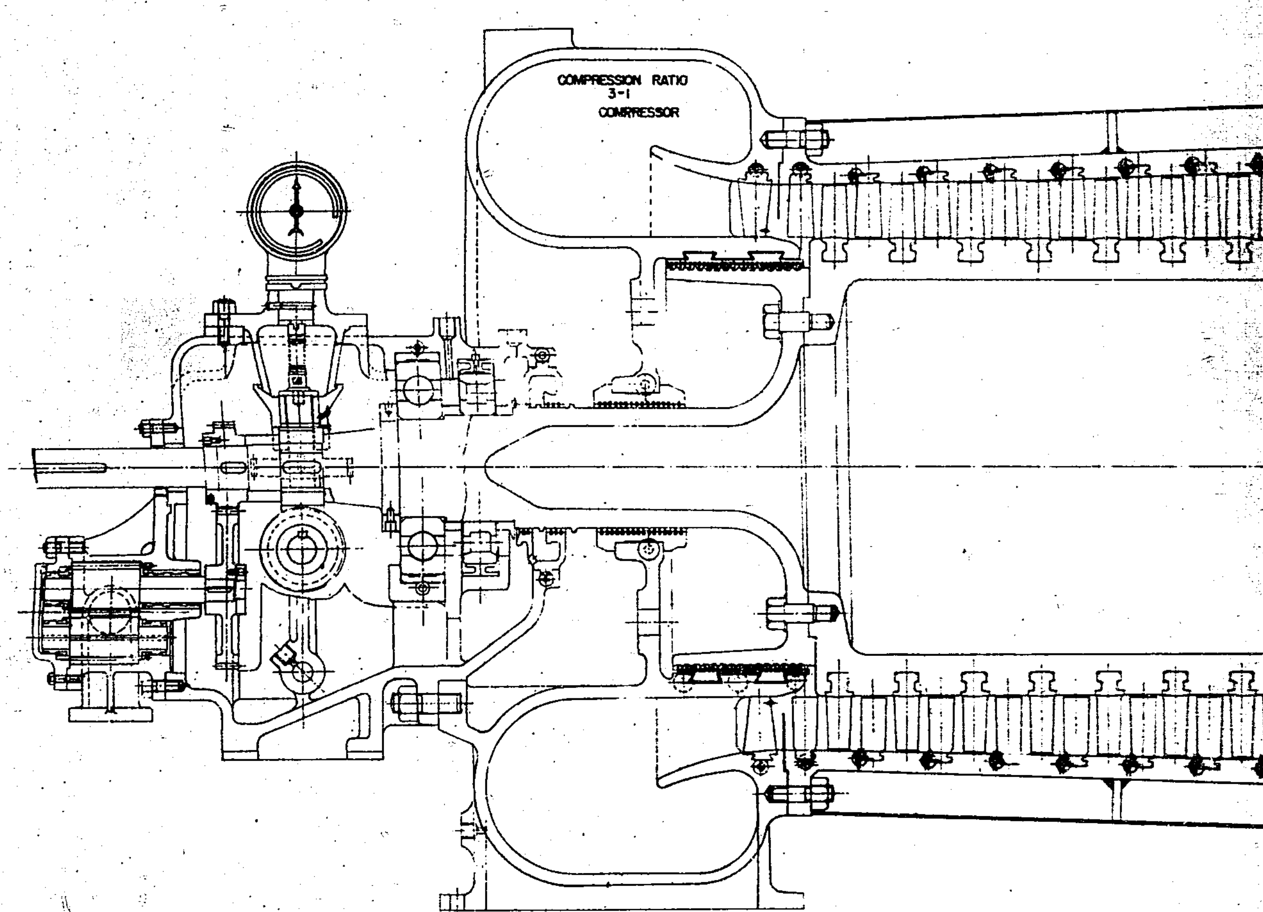


Figure 10(C)
SPONTANEOUS IGNITION TEMPERATURE
VS. INITIAL PRESSURE

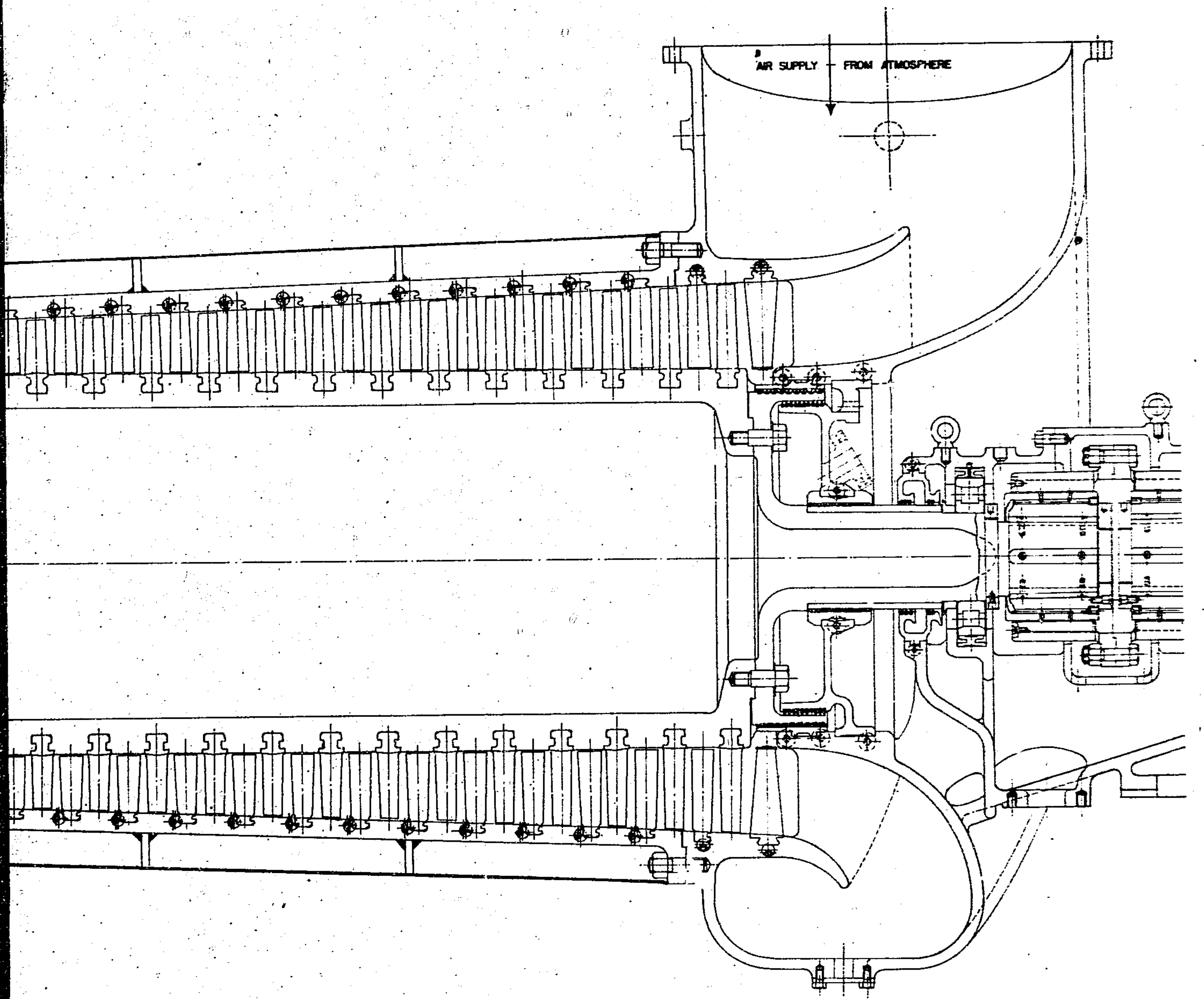
ENCLOSURE (D)



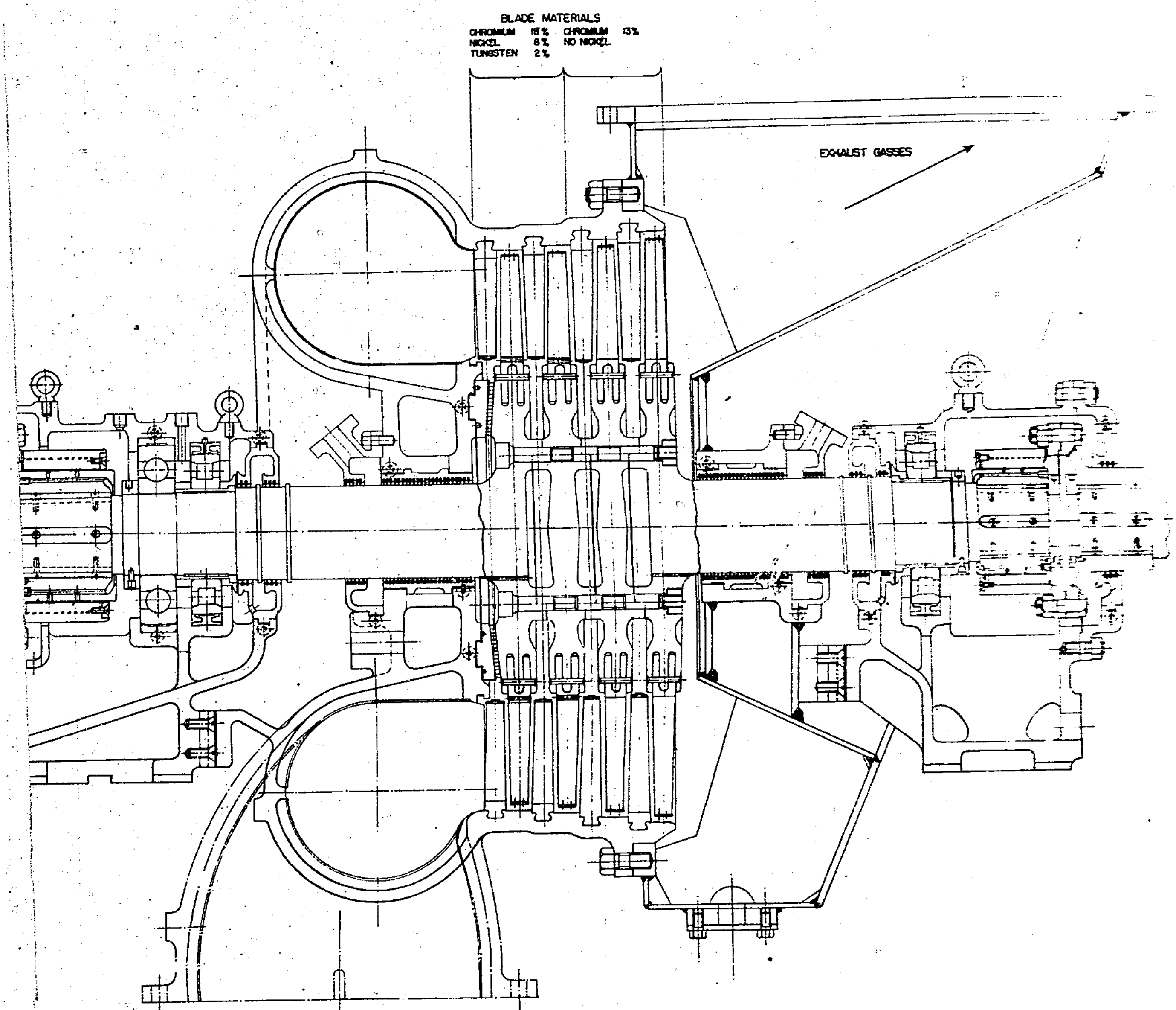
GAS TURBINE AUTOMIZER


COMPRESSION RATIO
3-1
COMPRESSOR

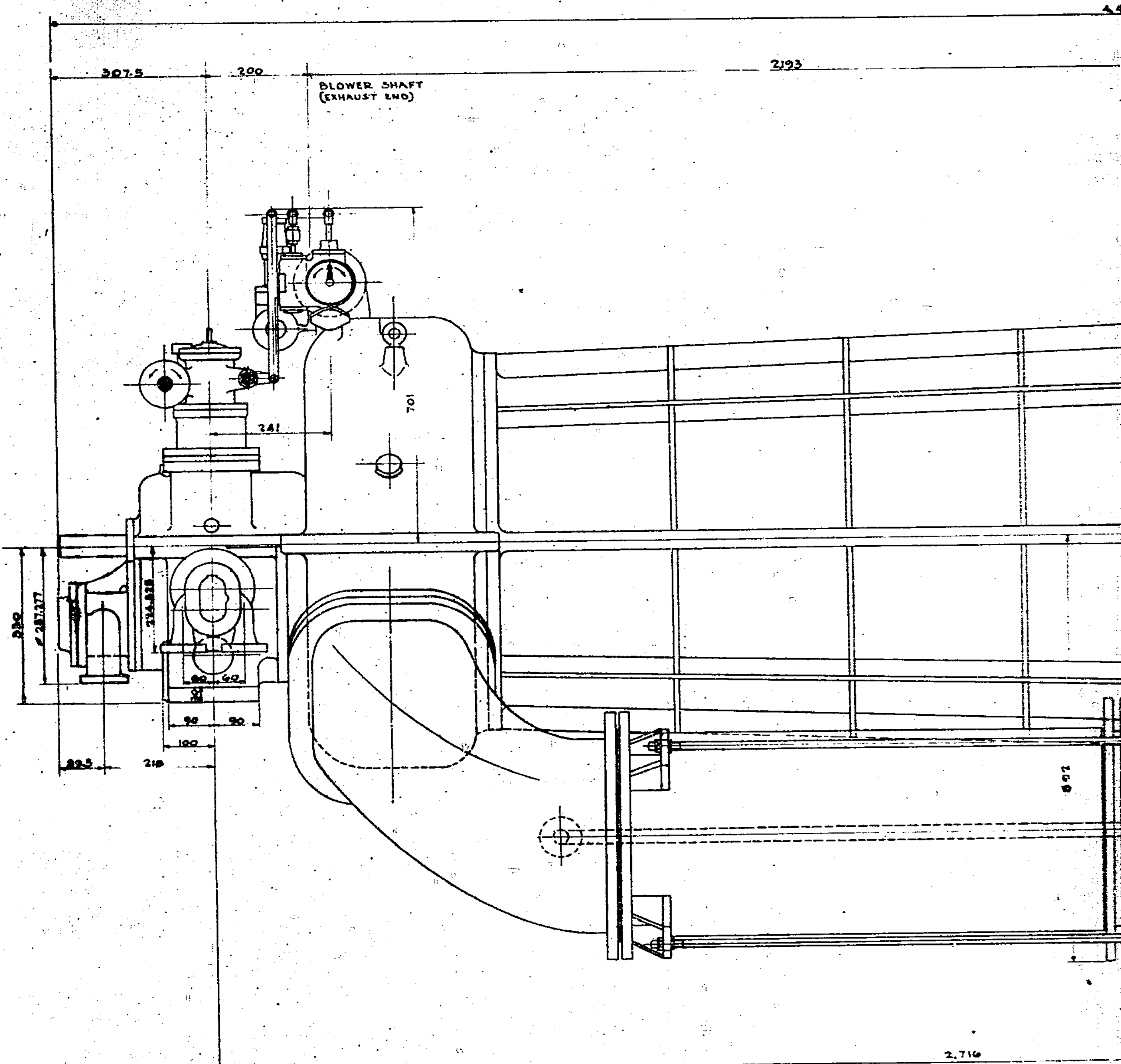
ENCLOSURE (F)



GAS TURBINE
SIDE ELEVATION IN SECTION

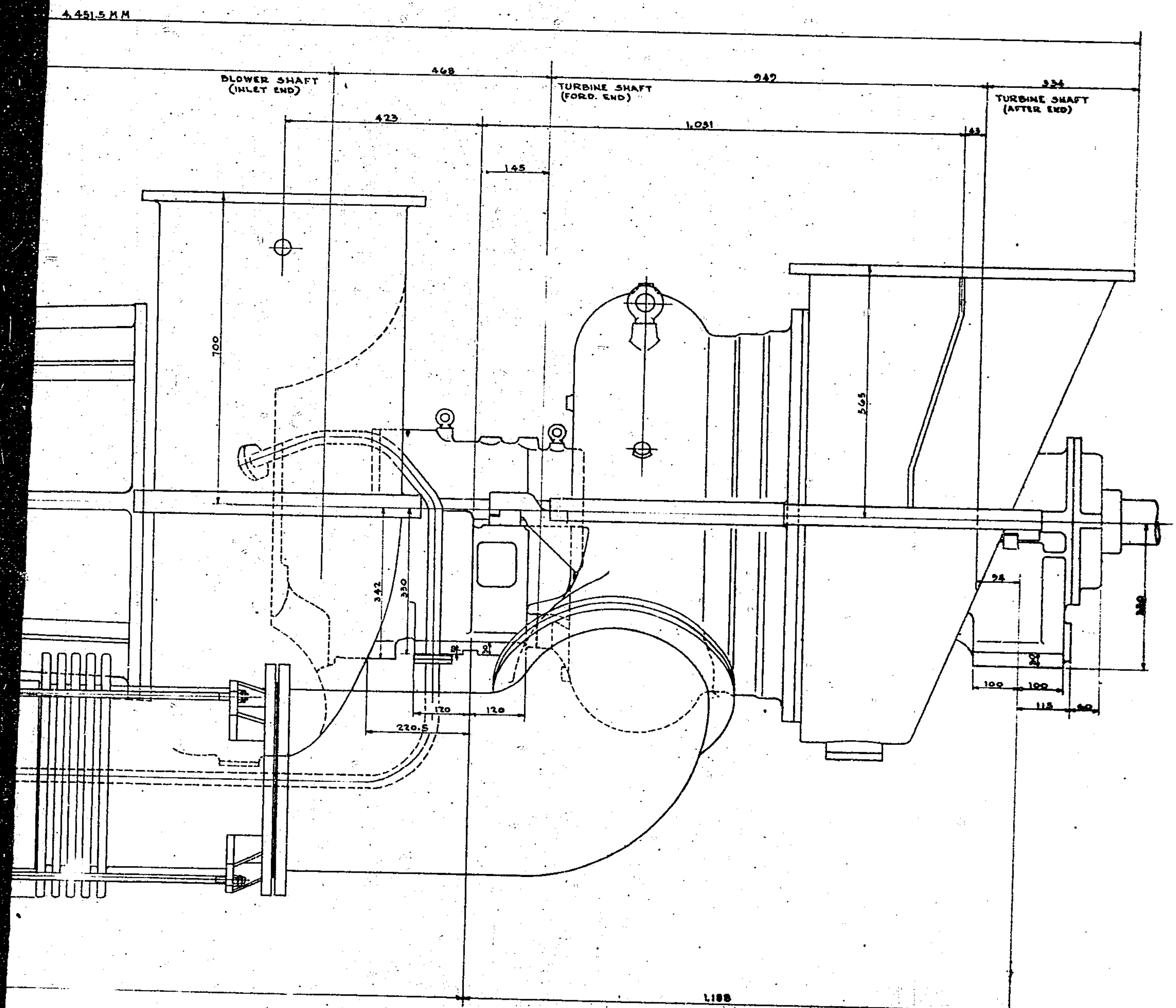

BLADE MATERIALS
CHROMIUM 18% CHROMIUM 13%
NICKEL 8% NO NICKEL
TUNGSTEN 2%
EXHAUST GASSES

ENCLOS



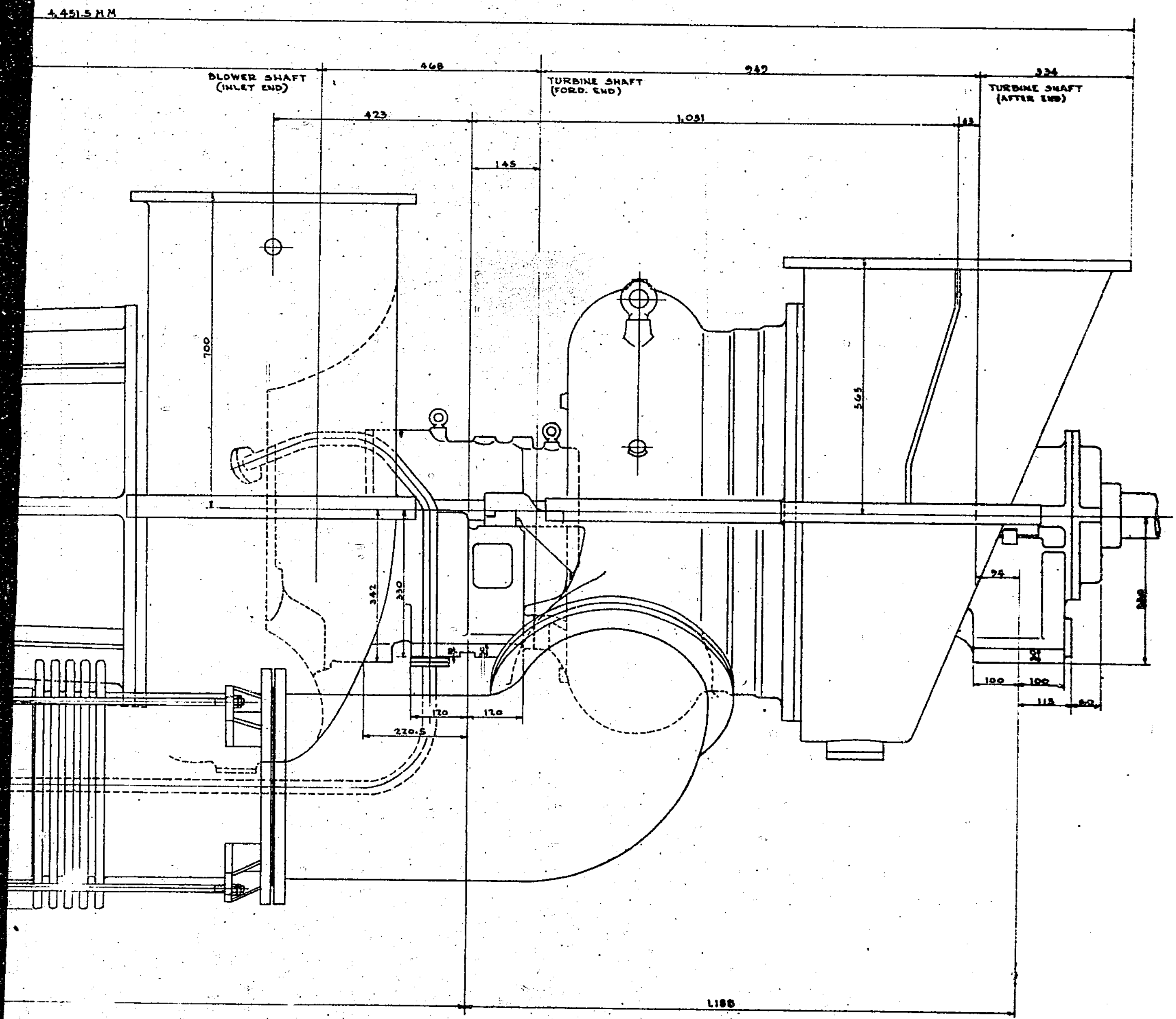
GAS TU

GENERAL A



AS TURBINE
RAL ASSEMBLY

OSURE (G)



AS TURBINE
RAL ASSEMBLY