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SHIP AND RELATED TARGETS

JAPANESE NAVY DIESEL ENGINES

U.S. NAVAL TECHNICAL MISSION TO JAPAN

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U. S. NAVAL TECHNICAL MISSION TO JAPAN
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From: Chief, Naval Technical Mission to Japan.
To : Chief of Naval Operations.

Subject: Target Report - Japanese Navy Diesel Engines.

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

1. Subject report, dealing with Targets S-42 and S-85(N) of Fascicle S-1 of reference (a), is submitted herewith.

2. The report was prepared by Comdr. R.S. Lorimer, USNR, who was assisted by Lt.(jg) W.M. Weil, USNR.

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RESTRICTED S-42

JAPANESE NAVY
DIESEL ENGINES

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

FASCICLE S-1, TARGETS S-42 AND S-85(N)

DECEMBER 1945

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

SHIP AND RELATED TARGETS

JAPANESE NAVY DIESEL ENGINES

The diesel engine industry of Japan did not play as important a part in the war effort as did the American diesel engine industry. Two major reasons were:

1. The lack of ability to design suitable engines of high horsepower output.

   a. The crux of the design problem in Japan at the outbreak of the war was not so much the scarcity of trained engineers and designers, but rather the lack of originality which these designers displayed. Most of the engines adopted by the Japanese for standard use during the war had been designed eight to ten years previously and were approximate copies of European engines. Little change was made to adapt them to the tempo of modern warfare operations.

   b. With Japan almost entirely cut off from the western world, this traditional lack of originality in basic technical design proved too great an obstacle for Japanese engineers to surmount. As a result, no high speed, high output engines comparable to American models became operational, and only one experimental engine of the type ever approached successful completion. This was the ZC 707, designed by MITSUBISHI, which was completed and tested under NavTechJap supervision.

2. Factors limiting production:

   a. Complicated design.

   b. Inadequate knowledge of "tooling up to do the job."

   c. Inability to make the maximum use of available labor.

   d. Lack of coordination between the Army and Navy in respect to engine design, development and production.

Investigation of the closed cycle diesel engine revealed that the Japanese have been unsuccessful in experimenting on or in adapting this principle to diesel operation.

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INTRODUCTION

The subject of this investigation is the study of Japanese diesel engines and diesel engine plants with respect to their exploitation by the Japanese Navy. In order to appraise the contribution of Japan's diesel industry to the Japanese Navy during the war, it was necessary to make a careful study of the design of the engines and the tooling of the major manufacturing plants. Specifically, the objects in view were:

1. To report the function and performance of the various diesel engines which were used in naval combatant ships and in auxiliary craft.

2. To estimate the productive capacity of the diesel plants supplying the Navy.

3. To ascertain in general the stage of development of Japanese diesel design, and particularly to study the progress which Japanese designers had made toward higher speed, lighter weight engines of high horsepower.

The method of obtaining information included the following procedures:

1. Inspection of diesel engine plants.

2. Interrogation of officials of various diesel engine companies.

3. Interrogation of naval officers whose duties pertained to the design, construction, or maintenance of diesel engines.

4. Interrogation of control associations which had cognizance over diesel engine production.

5. Examination of documents obtained from the Japanese Navy and from diesel engine manufacturers.

In many instances, adequate records were not available, due to the bombing or burning of the plants. It was, therefore, often necessary to rely upon the memories of the officials interrogated. However, in most of these cases, it was possible to cross-check the information. The inaccuracies discovered were slight and did not affect the over-all picture.

THE REPORT

Section I - USE AND PERFORMANCE

The principal models of diesel engines used by the Japanese Navy were as follows: Models No. 2, No. 22, No. 23, Medium Speed 400 HP, No. 51-6 and No. 51-10. The function and performance of each is discussed below.

Model No. 2

Number of cylinders	10
Horsepower	7000
Type of engine	Double acting, two cycle
Bore	470mm (18½")
Stroke	490mm (20 7/8")
RPM	350
BMEP	70
Piston speed	1218
Fuel consumption, (lbs/BHP/hr)	0.45
Exhaust temperature	740° F
Maximum firing pressure	650
Type of injection	Air injection
Piston cooling	Yes
Weight	154,000 lbs

As noted above, this engine is a ten cylinder, two cycle, double-acting engine, developing 7000 hp at 350 RPM. This engine is of the Sulzer design. Manufacture was begun in Japan in 1932. From its weight of 154,000 pounds, is evident that little effort has been made toward weight reduction. As in the case of all diesel engines used by the Japanese Navy, this engine is cooled with sea water; the temperature of the discharged water is kept below 115°F. A large capacity lubricating oil cooler, capable of reducing the temperature of the lubricating oil from 138° to 128° F., is used.

Approximately 360 GPM of lubricating oil is circulated through the engine, the greater proportion of which is passed through the oil cooler. During conference with various naval officers, it was indicated that a pump of smaller capacity had originally been used. It is obvious that this installation of a larger capacity pump represented an attempt to solve the problem of cooling the pistons and piston rods.

Little basic design change has been made on this engine since its manufacture was started in Japan. Such changes as had been made were to correct faults which developed in operational training and war patrols. The critical need for spare parts was evident. New engines which were found in the Sasebo Navy Yard had been cannibalized to obtain spare parts.

When discussing this engine, Admiral KONDO, head of the Engine Design and Construction Section, Navy Technical Department, said that the Model No. 2 was manufactured until February 1943, and was discontinued at that time. He stated that operating conditions during the war necessitated continued high output. Under these conditions they were unable to properly cool the pistons. KONDO also stated that the lack of operating skill among their personnel was a contributing factor. Further, on account of the complicated design of the engine, manufacturers who were located in many parts of Japan were unable to meet the demand of the Japanese Navy.

In discussing the performance of this engine in submarines, Commander CHUMA of the Sasebo Navy Yard stated that two of these engines, installed in I-type submarines, driving a seven foot propeller with an eight and one-half foot pitch at 340 RPM, gave the submarine a speed of 24 knots on the surface (underwater speed was 16 knots).

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Piston speed	1224
Fuel consumption (lbs/BHP/hr)	0.38
Exhaust temperature	710°F
Maximum firing pressure	720
Type of injection	jerk pump
Piston cooling	Yes
Weight	74,800 lbs

The Model No. 23 is a conventional four cycle engine and is basically of the MAN design. The engine is rated 950 hp at 360 RPM and was built in Japan prior to the war.

When the demand for smaller, longer range submarines became apparent, this engine was released for production to many plants in Japan.

A high rate of production was anticipated, and partial success of this plan is indicated by the fact that production increased from 38 in 1943 to 150 in 1944. This increase would have continued, had not the bombing become so effective in the spring of 1945.

This engine was used to power the RO type submarine, and in order to gain longer life and longer continuous operation, BMEP and piston speed were dropped to a conservative level. From all information gathered, this was the most reliable of the Japanese engines, but it still lacks many of the refinements embodied in engines used by the United States Navy. No attempt had been made to house working parts; therefore, much hand-oiling of parts was necessary.

<u>Navy Type Medium Speed 400 HP Engine</u>

Number of cylinders	6
Horsepower	400
Type of engine	4 cycle
Bore	300 mm (11 13/16")
Stroke	350 mm (13 3/4")
RPM	500
BMEP	69
Piston speed	1176
Fuel consumption (lbs/BHP/hr)	0.38
Exhaust temperature	700°F
Maximum firing pressure	780
Type of injection	jerk pump
Piston cooling	No
Weight	24,200

The Navy Type Medium Speed 400 hp engine is a conventional design of the four cycle type and was used to power the 15-man submarine.

When the demand for the smaller type submarine was made, contracts to manufacture this engine were spread all over Japan. As was the case with the Model No. 2 engine, in spite of the fact that special plants were set up, its design was too complicated to obtain the desired production.

In the design of the engine, little thought was given to the available tools with which to manufacture the engines.

There is nothing outstanding in the design. It compares with engines built in the United States some 15 years ago and contains few of the refinements found in the present day American diesel engine.

The low rated output of this engine indicates that the Japanese required and stressed continued operation rather than performance. American engines of this size would be expected to operate at considerably higher horsepowers and still meet the requirements of the Japanese Navy in respect to continuous operation.

Model No. 51-6

Horsepower	150
Number of cylinders	6
Type of engine	Four cycle
Bore	140mm (5½")
Stroke	200mm (7 7/8")
RPM	1300
BMEP	83
Piston speed	1629
Fuel consumption (lbs/BHP/hr)	0.45
Exhaust temperature	1050
Maximum firing pressure	880
Type of injection	Bosch
Piston cooling	No
Weight	3,300 lbs

Note: Model No. 51-10 has hp of 300, 10 cylinders, and weighs 5,500 lbs; otherwise specifications are same as for Model No. 51-6.

The Model 51 engine has been manufactured in Japan in the six cylinder model for the past seven years and was used to power the three man submarine. With slight modifications, it was also adapted for use in generating sets. These engines were constructed in many plants in all parts of Japan. Its design was conventional with the exception that the head and liner, both of which were water-jacketed, were cast integrally. This model engine was Navy designed, and its importance in the final defense of Japan was indicated by the trend of production of engines of this model shown in Figure 1.

Admiral KONDO was questioned in respect to the foundry problem on the head and liner of this model engine. He admitted that many foundry difficulties had been encountered and that rejects up to 50% were experienced. He attributed this to the lack of proper alloys and unskilled foundry help.

The injection system employed is the conventional Bosch injection which is manufactured in Japan by the Diesel Machine Tool Company, whose capital was subscribed by the major diesel engine manufacturing companies.

Because of a shortage of gasoline, a program of 1,000 engines of this model, having 10 cylinders, was started in October 1943. The following plants were set up to manufacture the engine: Niigata Iron Works, Yokosuka Navy Yard, Hiro Naval Engine Plant, Ube Iron Works and the Mitsubishi Shipbuilding Yard at KOBE. By the end of the war, approximately 97 engines of this design had been built. The delay in the program was partly due to the inability to tool up and partly to the bombing of Japan in the spring of 1945.

The original design of the 10 cylinder engine called for the crankshaft to be made in one piece, but very few engines with this type of crankshaft were produced. In discussing this matter, Commander NAGANO, Navy Ministry designer, stated that the change to a two piece crankshaft was to simplify machining, and that it was not done to stiffen the crankshaft itself. He stated that the engine had no serious criticals. Those that were present were within the acceptable limits of the Japanese Navy.

The 10 cylinder engine was to be used in an anti-aircraft Support Boat, the specifications of which were:

Length	58 feet
Beam	11 feet
Power	2 Model 51-10 engines
Speed	18 knots

STANDARD NAVY TYPE JAPANESE DIESEL ENGINES
MAIN SPECIFICATIONS AND ANNUAL PRODUCTION

Model	Number Cylinders	Brake HP	Type of Engine	Bore (in)	Bore (mm)	Stroke (in)	Stroke (mm)	RPM	Brake MEP	Piston Speed (FPM)	Fuel for lbs. per BHP	Weight (lbs)	Exaust Temp. (°F)	Maximum Firing Press. (psi)	Types of Fuel Inj.	Piston Cooling	Number Mfg. by Years 1942	1943	1944	1945	Total Mfg. Navy Use
1	8	5000	DA	18½	470	20 7/8	490	350	68	1218	.45	121,000	740	650	A.I.	Yes	(1)				(1)
2	10	7000	DA	18½	470	20 7/8	490	350	70	1218	.45	154,000	740	650	A.I.	Yes	(2)	14	(4)	(4)	14
22	10	2250	4 cycle	16 15/16	430	17 3/4	450	510	86.5	1506	.39	83,600	800	860	J.P.	Yes	(2)	99	111	19	229
23	8	950	4 cycle	14 9/16	370	19 11/16	500	360	81	1224	.38	74,800	710	720	J.P.	Yes	(2)	38	150	12	200
400	6	400	4 cycle	11 13/16	300	13 3/4	350	500	69	1176	.38	24,200	700	780	J.P.	No	(2)	86	105	57	248
51	6	150	4 cycle	5½	140	7 7/8	200	1300	83	1629	.45	3,300	1050	880	B	No	(2)	55	47	190	292
51	10	300	4 cycle	5½	140	7 7/8	200	1300	83	1629	.45	5,500	1050	880	B	No	(3)		75	22	97

Note: All engines are salt-water cooled.

(1) - Not manufactured during the war.
(2) - All records destroyed by fire.
(3) - Manufacture started in 1943.
(4) - Manufacture stopped in February 1943.

DA - Double-Acting
AI - Air Injection
JP - Jerk Pump
B - Bosch Injection

Section II - PRODUCTION

Diesel engines were not produced in any great volume in Japan prior to the war. It was common practice for the larger plants to build both the diesel engine and the equipment in which the engine was to be installed. Accordingly, this left little opportunity to develop plants which specialized in diesel construction exclusively. Even now, evidences of engine assembly resembling American line production are extremely difficult to find.

With the attack upon Pearl Harbor and the consequent increase in Japan's military activity, the need for both automotive and marine diesels grew rapidly. Both the Navy and Army called upon the diesel industry to increase production sufficiently to satisfy wartime needs, but the efforts of the industry failed. As a result, the National War Mobilization Laws set up in 1942 a plan to rationalize the diesel industry. It provided for three agencies: The Shipbuilding Control Association which controlled the construction and allocation of large diesels to power cargo vessels and certain auxiliary naval craft; the Marine Internal Combustion Engine Control Association which had cognizance over all small marine diesels and semi-diesels; and the Industrial Engine Control Association which controlled industrial and automotive diesels.

Through the last-named organization, the government ordered the major diesel manufacturers to subscribe to the capital of a new organization, the Diesel Automotive Industry Company. This move was a dual attempt to make the production of automotive diesels more efficient, and at the same time, to free certain well-tooled diesel plants and their skilled workers for high priority aircraft production. Measured in terms of Japanese production standards, this plan for automotive diesels proved rather successful.

On the other hand, no such plan was approved for marine diesels. As a result, marine diesel plants, both large and small, were spread all over Japan with comparatively little specialization in any of them. Moreover, it was the control associations which drew up the contracts with the individual firms and, in the end, determined where each engine was to be shipped. There was a great deal of secrecy attached to the transaction so that it was quite common for a manufacturer to build engines without ever knowing to what use his engine would eventually be put. This situation was not particularly conducive to bringing forth the utmost effort upon the part of either the management or the workers.

However, the most important error which the Japanese committed in their plans to increase marine diesel production was the utter lack of cooperation between the Army and Navy in respect to the landing craft program. It was found that the Army and Navy both were engaged in the development of engines of different bores and strokes, whereas it was quite apparent that a common design would have resulted in greater production in the same manner as in the U.S. landing craft program.

The majority of Japanese diesel plants were inadequately equipped with modern machine tools. It was also apparent that those few plants which were well equipped such as the Tokyo Engineering Company (a Mitsubishi subsidiary), Kubota Engineering Works at OSAKA, and the Ikegai Iron Works in TOKYO, had little knowledge of "tooling up to do the job". For example, the lack of drop forging capacity necessitated the machining of practically all crankshafts from solid forgings. This resulted in a waste of valuable manpower and in a lack of crankshaft capacity.

Furthermore, the Japanese Navy very often did not give proper consideration to the adaptablility of machine tools when assigning the manufacture of engines to various plants. This resulted in the inefficient use of tools which would have been better adapted to other essential war work. For example, in November, 1943, the Mitsubishi Plant at KOBE was directed to build the Model No. 51 in the ten cylinder version. This plant always had concentrated on engines used to power large ships. Consequently, in spite of the tremendous

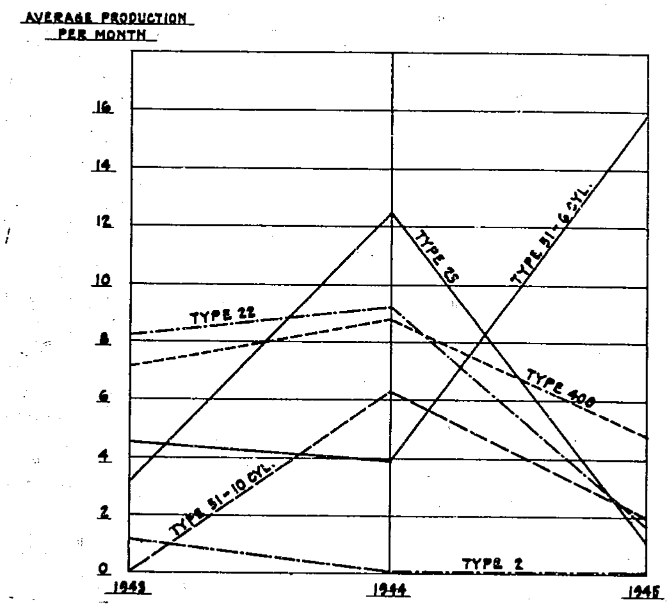
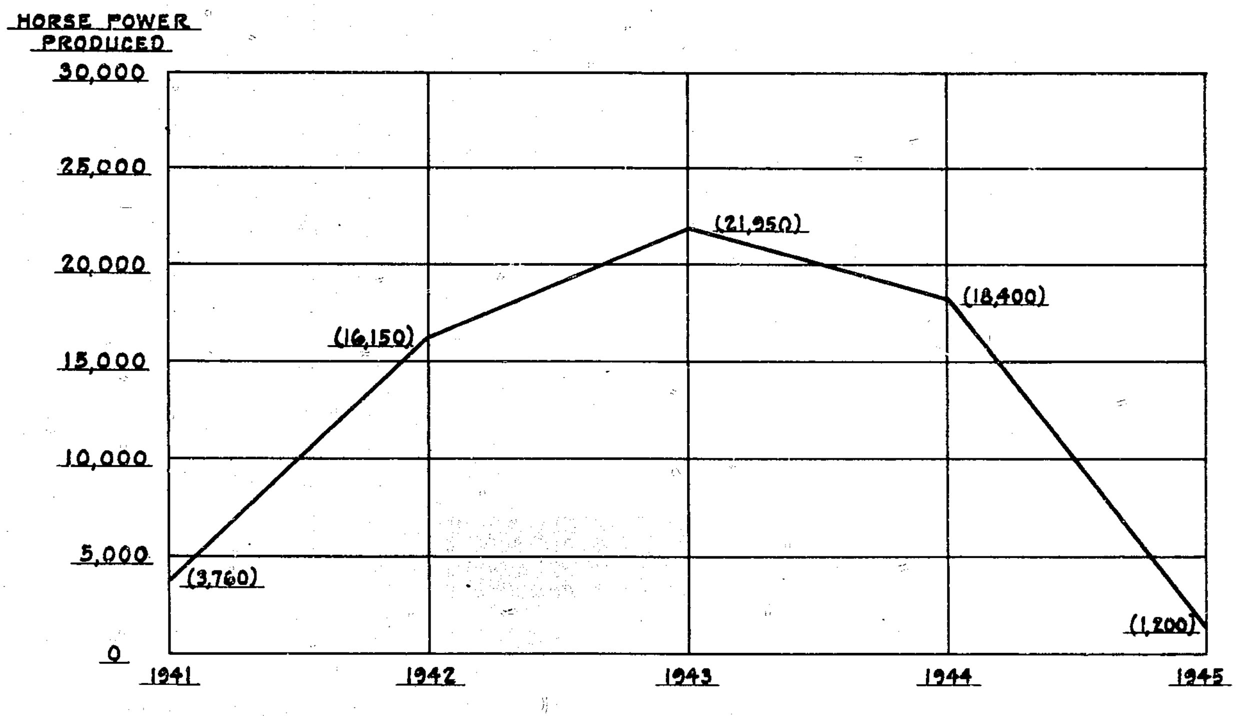


Figure 1

MONTHLY AVERAGE PRODUCTION OF STANDARD NAVY DIESEL ENGINES SHOWN BY TYPE AND YEAR, 1943-1945



IKEGAI IRON WORKS

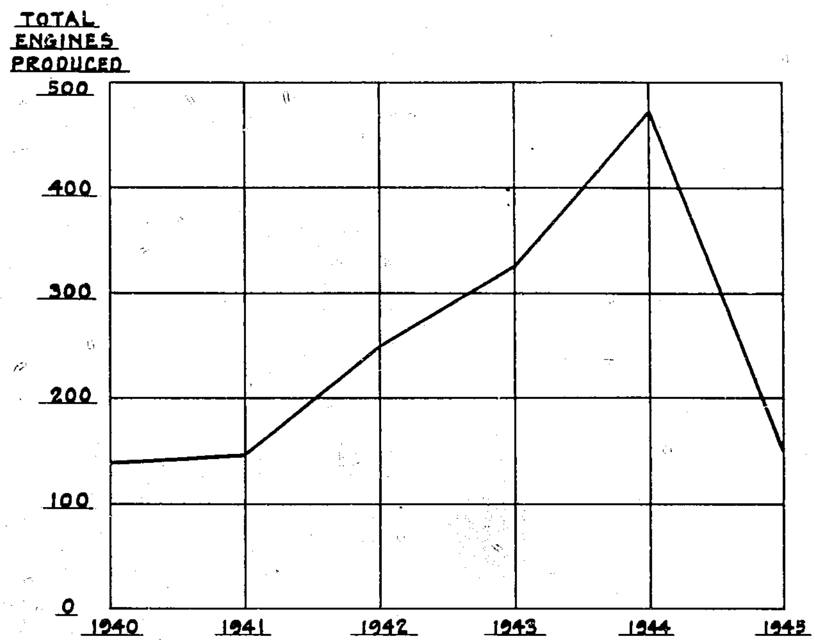


Figure 3

ANNUAL PRODUCTION OF HITACHI LIMITED

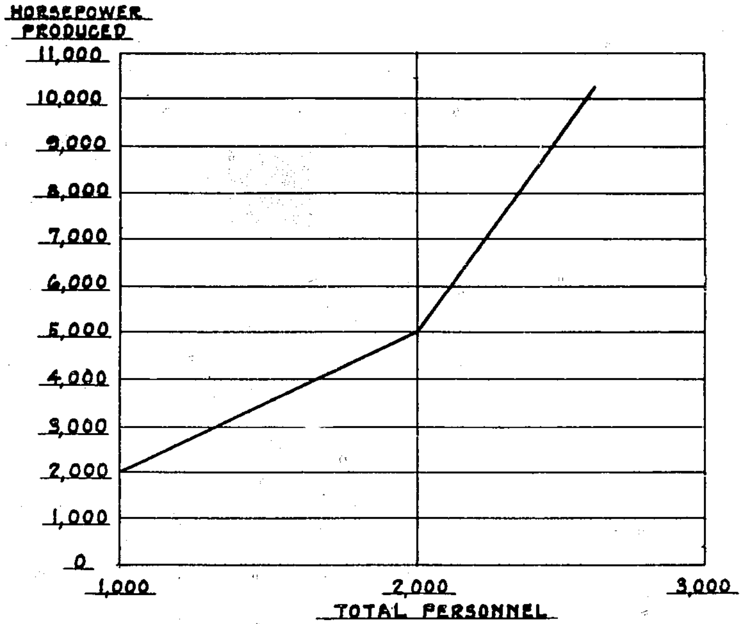


Figure 4

MAJOR JAPANESE DIESEL ENGINE MANUFACTURERS
MONTHLY AVERAGE OUTPUT VS TOTAL MANPOWER

pressure exerted upon them to build up production on this engine, by the end of the war they had completed only 40 engines of this model.

Another factor contributing to low production was the absence of molding machines in the iron foundries. Because the Japanese did not use molding machines in the iron foundries, all work was necessarily done by hand. The number of employees needed was, therefore, greater. This, in turn, took skilled men away from other industries which undoubtedly could have employed them in equally essential war work. From observations such as these, it was apparent that the wasteful use of labor at low wages during peacetime was a policy which the Japanese were unsuccessful in changing during wartime. (In passing, it is interesting to note that there was no particular shortage of iron castings, although the Japanese were considerably concerned about their relative inability to obtain acceptable cast steel).

Production was also limited by the fact that aircraft consistently enjoyed the highest priority, and many of the diesel industry's skilled workers were drafted into aircraft work.

Figures 2 and 3 are representative of large plants and show the inability of these plants to meet the requirements of the armed forces. Attention is called to the effectiveness of the bombing which necessitated the dispersal of machine tools and personnel from the highly industrialized areas to less vulnerable locations. However, the process of reassembling machinery and personnel in the new locations was extremely slow. In fact, very few of the tools which had been moved were ever again utilized for wartime production. Figure 4 shows the average horsepower produced per month per man. It is approximately 25% of that produced in the average American plant. The information for this chart was gathered from eight major companies. It is interesting to note that the differences between the plants in respect to rate of horsepower produced are slight, and that production of diesel engine horsepower per man in Japan is uniformly low.

Section III - DESIGN

It is evident from the study of both operational and experimental Japanese diesel engines that little basic design had been achieved by Japanese engineers. The majority of engines produced in Japan were copied from European designs and were then modified to some extent to meet Japanese requirements. In general, there was little change in the over-all design. However, there were certain exceptions to this practice, and these constituted practically all of the original diesel engine research and experimentation performed in Japan during the war. A discussion of these developments follows.

A two cycle engine which has a unit injector and is capable of operating at 1600 RPM was developed by the Tokyo Engineering Works at Kamata, TOKYO, a Mitsubishi company. It is a 20 cylinder,V-shaped engine which was designed by the Mitsubishi engineers in collaboration with Admiral KONDO of the Navy Technical Department. The design was developed in response to an order from the Navy for an engine to be used in high speed motor torpedo boats.

The company first built and tested a single cylinder pilot model. Under test conditions, this experimental model was operated at BMEPs up to 140 psi. A complete analysis of the tests which were made in July 1944 is submitted with this report. (Enclosure (I)). At the request of NavTechJap, a duplicate test, the data for which is also included in this report, was run on 16 November 1945 in order to evaluate the engine.

Because of the satisfactory results achieved in the first tests of July 1944, the company proceeded to build the 20 cylinder model; at the end of the war, it was still incomplete.

The company was ordered to complete and test the engine. The tests were made at the Mitsubishi Plant by its highly trained engineers and the results were forwarded to NavTechJap. It should be noted that the results did not measure up to design performance. In the time allowed, the company barely was able to complete the engine and it failed to eliminate the various defects which developed during the tests. It is believed that only actual study of the engine will yield the information necessary for evaluation. Therefore, the engine has been forwarded to the Bureau of Ships, identified by NavTechJap Equipment Nos. JE50-1130 and JE50-1131. The report, too, has been forwarded to the Bureau of Ships. (See Enclosure (C) for the forwarding letter.)

Representatives of NavTechJap were present during the tests of the single cylinder engine. During the entire test, the engine operated very smoothly up to and including speeds of 1600 RPM. Combustion was relatively clean during the entire range of horsepower. (A piston design change has been put into effect on the 20 cylinder model and should improve combustion.) The engine was extremely quiet with little or no combustion knock.

Attention is invited to the unique design of the piston. The top of the piston is of forged steel and is bolted to the main body of the piston which is of cast iron and contains the wrist pin boss. The camel-back piston is cored out for oil cooling, and the oil is led into this chamber by an oscillating pipe that fits tightly into the entrance to the chamber. This pipe oscillates on the top of the piston rod and is secured to the piston rod by a snap spring. In spite of this unusual heavy piston construction, the operation of the engine was at all times exceptionally smooth.

The Mitsubishi Heavy Industry Company at NAGASAKI was attempting to develop a compound diesel engine. No data or tests were available other than those which are included in the inspection report (Enclosure (E) Plant Report No. 1) and the "Report on Experimental Compound Diesel Engine" (Enclosure (H)).

Because of the bombing effects, operation of the engine was not possible, and with the little information on hand, suitable comments cannot be made. This engine was discussed with Admiral KONDO who stated that he was of the opinion that development of such an engine was not an immediate prospect. Air-cooled engines of 240 horse power were developed for use in Army tanks with apparent success. Engines were of two types: one had a closed type combustion chamber; the other, an open type. They were built with the same bore and stroke, as indicated in the following table:

Bore	120 mm (5 11/16")
Stroke	160 mm (6 1/4")
RPM	2000
Cylinders	12 V-type

In the closing stages of the war, an engine was built developing 400 hp at 1600 RPM and having the same characteristics, but with a bore of 145 mm and a stroke of 190 mm. The engine was supercharged and the RPM increased to 2000; horsepower developed was 500. Two engines of this type were built; the first was installed in a tank and was undergoing tests at the end of the war. The United States Army has taken over this tank and the engines, and they are being shipped to the United States for additional tests.

In response to orders to develop a high speed, light-weight diesel engine for use in the proposed high speed torpedo boat, the Yokosuka Experimental Station which also was under the command of Admiral KONDO, proceeded to design engines believed to be suitable.

Three types of engines were built and were in various stages of testing. Their characteristics are as follows:

	Model No. 61	Model No. 63
Bore	140mm (5½")	190mm (7½")
Stroke	180mm (7 3/32")	250mm (9 27/32")
No. of Cylinders	V-16	V-8
RPM	1600	1600
Injection	Bosch	Bosch

* Model No. 62 same as No. 61 except for V-12 Cylinders.

Model No. 61 was designed for port scavenging and Models No. 62 and No. 63 for valve scavenging. All engines worked on the two cycle principle.

Some success was had with these engines but numerous failures were reported because of bearings and rings sticking. Reported "number of hours" varies, but indications are that the total hours did not exceed 100 on any of them. Because of the pressure of other and more important projects, this program was abandoned in November 1944. The Experimental Station suffered a direct bomb hit in May 1945, and the engines were practically destroyed.

When the oil shortage became apparent, the Experimental Station devoted its entire resources to the use of substitute oil in all diesel and gasoline engines used in the Japanese Navy.

Some idea of the shortage of fuel can be had from the fact that 20 tons of fuel were allocated to the Mitsubishi Company to experiment on a 20 cylinder, 2000 hp Mercedes-Benz engine brought from Germany by submarine for study by Japanese engine designers.

A complete study of substitute oils has been made by this Mission (see NavTechJap Reports, "Japanese Fuels and Lubricants, Articles 1 to 10," Index Nos., X-38(N)-1 to X-38(N)-10), but the following interesting facts should be noted.

Creosote oil, soya bean oil and pine root oil were tested and were found suitable for semi-diesel and small diesel engines. The creosote and soya bean oils were acceptable, but the pine root oil was not satisfactory because of the sticking of the injector and fuel pumps.

The combined use of coal gas and fuel injection on semi-diesel and small diesel engines had been studied and accepted; the reported saving of fuel was 50%. The engines were started on diesel oil, and coal gas was used only when loads were 50% and above. This innovation was being installed in small craft in the latter stages of the war.

Some experimental work had been done on chromium liners. Navy engineers spoke of the Vander Horst system but stated that little or no success was had because of the fact that the chromium flaked and resulted in serious ring trouble. This experimental work was started some time in 1942.

It is interesting to note that in Japan, little was known about hardening of crankshafts. No evidence was found to indicate that crankshafts were being hardened.

Crankpin and wrist pin bearings of all standard Navy engines with the exception of the Model 51 are of hard white metal with a very high tin content. Lubricating oil pressures are maintained at 30 psi, and bearing life is very satisfactory. The use of precision bearings or even replaceable shells with the exception of the 51 Model have not been provided for. If a crankpin bearing is burned out or otherwise fails in service, the entire crankpin box is replaced.

It is quite apparent that the loss of outside contact during the last four years materially affected the progress of diesel engine design in Japan. Many refinements incorporated in the design of American engines are unknown in Japan. Japanese engine designers have given little consideration to the availability of machine tools with which to build the engines they design and in many cases have approached design without due regard for production. This has been one of the major causes for their failure to meet the demands of the armed forces. Moreover, the Japanese are followers and not leaders, and this fact accounts for their entering the war with diesel engines which were designed up to ten years before the attack on Pearl Harbor.

As indicated above, little can be learned from the standard types of diesel engines used by the Japanese Navy, but it is felt that the experimental type engine built by Mitsubishi warrants special study because it contains many interesting features. Both the single cylinder and 20 cylinder models were forwarded to the Bureau of Ships at the conclusion of the tests mentioned in the foregoing material.

* * * * *

Design with Reference to the Closed Cycle System

The closed cycle operation of diesel engines, using oxygen, was discussed with Admiral KONDO, and the following was learned:

> In 1937, the Japanese received information that experimental work had been done in Germany on this system. Admiral KONDO did not indicate how this information was received, but from the results of their experimental work, it was apparent that little knowledge was transmitted to them.
>
> The Japanese started their experimental work in 1937 and in the very early stages, a serious explosion took place with a number of deaths and serious injuries. Admiral KONDO stated that at that time, the project was abandoned, and that no Japanese submarine had been equipped with this device during the war.
>
> On 28 November, 1945, Mr. NAKAMURA of the Yokosuka Navy Yard was questioned on this subject. All the information submitted by him substantiated entirely the statements made by Admiral KONDO. Mr. NAKAMURA had been a civilian employee of the Navy Ministry for the past 30 years and was associated with the Experimental Station in design and testing most of that time.
>
> Approximately six years ago, according to Mr. H. INOUYE, Plant director, the Mitsubishi Company conducted some experiments along the same line for operation of small diesel engines, but they were unable to operate the engines under tests longer than ten minutes. They gave up their experiments as the desired results could not be obtained.
>
> From all the information which it was possible to gather, it can be stated that the closed cycle system was not used by the Japanese, and that they had little knowledge to contribute on the subject.

ENCLOSURE (A)

LIST OF JAPANESE DOCUMENTS FORWARDED THROUGH
ATIS TO THE WASHINGTON DOCUMENT CENTER

I. EXPERIMENTAL DIESEL ENGINES.

A. ZB 35 Single Cylinder Engine

1. NavTechJap No. ND50-1100.2 .... ATIS No. 3057

BLUEPRINTS

a Assembly Drawing-Side
b. Assembly Drawing-Right
c. Assembly Drawing-Left
d. Assembly Drawing-Rear
e. Assembly Drawing-Top
f. Assembly Drawing-Lateral Cross-Section
g. Assembly Drawing-Front Cross-Section
h. Crankcase Assembly
i. Crankshaft Assembly
j. Piston and Connecting Rod Assembly
k. Cylinder Assembly
l. Distributor System Assembly
m. Drive Gear Assembly
n. Scavenger System Assembly (Drawing #1)
o. Scavenger System Assembly (Drawing #2)
p. External Scavenger System
q. Fuel Injection Equipment
r. Fuel Injection Test Assembly
s. Balancer

2. NavTecJap No. ND50-1100.3 .... ATIS No. 3058

EXPERIMENTAL REPORT

a. Research Report
b. The Relation Between Scavenging Pressure and Scavenging Air Volume
c. Combustion Rate as it is Affected by Reduction of Scavenging Air

ZC 707 Twenty Cylinder Engines

1. NavTechJap No. ND50-1100.1 .... ATIS No. 3056

BLUEPRINTS

a. Assembly - Longitudinal Cross-Section
b. Assembly - Forward End Cross-Section
c. Assembly - Left
d. Assembly - Front
e. Assembly - Top

2. NavTechJap No. ND50-1100.4 .... ATIS No. 3059

PHOTOSTAT OF DETAILED DRAWINGS

ENCLOSURE (A), continued

C. Model No. 61

1. NavTechJap No. ND50-1103 .... ATIS No. 3086

MODEL NO. 61

a. Test Data No. 4
b. Test Data No. 5

D. Model No. 62

1. NavTechJap No. ND50-1105 .... ATIS No. 3072

BLUEPRINTS

a. Profile
b. Lateral Cross-Section
c. Longitudinal Cross-Section

E. Model No. 63

1. NavTechJap No. ND50-1104 .... ATIS No. 3077

BLUEPRINTS

a. YVC 4 Cylinder Cross-Section Blueprint #1
b. YVC 4 Cylinder Cross-Section Blueprint #2
c. YV 16 Cylinder Longitudinal Cross-Section
d. YV 16 Cylinder Lateral Cross-Section
e. No. 63-8 Cylinder Longitudinal Cross-Section
f. YVB-8 Cylinder Lateral Cross-Section
g. YVA-4 Cylinder Test Data No. 2
h. YVA-4 Cylinder Test Data No. 1
i. Model No. 63 Book of Design and Calcuations
j. YV 16 Cylinder Test Data #2
k. Pages from Test Data of YV 16 Cylinder Diesel Engine

F. Miscellaneous Blueprints

1. NavTechJap No. ND50-1107 .... ATIS No. 3062

BLUEPRINTS

a. Model No. 11 Cross-Section
b. Model No. 25 Lateral Cross-Section
c. Model No. 25 Side
d. Model No. 31 Profile
e. Model No. 42 Cross-Section #1
f. Model No. 42 Profile #1
g. Model No. 42 Profile #2
h. Model No. 42 Cross-Section #2

II. OPERATIONAL DIESEL ENGINE

A. Blueprints and Test Data for Model No. 2

1. NavTechJap No. ND50-1130 .... ATIS No. 3084

MODEL NO. 2

a. Vibration Dampener Blueprint
b. Vibration Dampener Blueprint
c. Cross-Section Blueprint

ENCLOSURE (A) continued

d. Top and Side Blueprint
e. Top Oil Injection Valve Comparison and Performance Data
f. Air Pressure Pump Assembly-Side View
g. Tabulation of Vibration for Both Engine and Engine Stand and for Piston Rods
h. Type and Endurance Test Run #4
i. Summary of Damage During Type and Endurance Test Run No. 4
j. No. 3 Test Run Data

B. Miscellaneous Blueprint and Complete Test Data for

1. NavTechJap No. ND50-1109 .... ATIS No. 3073

MODEL NO. 22 ENGINE

a. Assembly Cross-Section Blueprint
b. Side and Top
c. Experimentation on Substitution of Light Metal Alloys in Model No. 22 Engine
d. Results of Experimentation on Supercharging Model No. 22 Engine
e. Test Data #1
f. Test Data #2

C. Model No. 13

1. NavTechJap No. ND50-1106 .... ATIS No. 3064

BLUEPRINTS

a. Assembly Cross-Section
b. Side and Top

D. Model No. 51-6

1. NavTechJap No. ND50-1090.1 .... ATIS No. 3053

DIESEL ENGINE TEST STAND REPORT

E. Model No. 51-10

1. NavTechJap No. ND50-1090.2 .... ATIS No. 3054

MISCELLANEOUS BLUEPRINTS

a. Assembly Drawing No. 1
b. Crankshaft Detail No. 1
c. Crankshaft Detail No. 2
d. Assembly Drawing No. 2
e. Crankshaft Detail
f. Assembly Drawing

F. V-12 Air-Cooled Pre-Combustion Diesel Blueprint

1. NavTechJap No. ND50-1100.5 .... ATIS No. 3044

BLUEPRINT

a. Front View
b. Rear View
c. Right
d. Left
e. Top
f. Longitudinal Cross-Section

g. Lateral Cross-Section
h. Crankshaft

G. <u>V-12 Air-Cooled Diesel Miscellaneous Blueprints</u>

1. NavTechJap No. ND50-1101.2 .... ATIS No. 3042

MISCELLANEOUS BLUEPRINTS

a. Cross-Section
b. Side-View
c. Crankshaft Detail
d. Top
e. Front
f. Piston and Connecting Rod Detail

H. <u>V-12 Water-Cooler Diesel Miscellaneous Blueprints</u>

1. NavTechJap No. ND50-1101.1 .... ATIS No. 3041

MISCELLANEOUS BLUEPRINTS

a. Side
b. Rear
c. Base and Center Frame Detail
d. Valve and Lifter Detail
e. Cylinder and Head Detail
f. Clutch Detail
g. Crankcase Detail
h. Reverse and Reduction Gear Detail Assembly
i. Crankshaft
j. Plan View
k. Side View
l. Reverse Gear Detail

I. <u>V-12 Air-Cooled Direct Injection Diesel Blueprints</u>

1. NavTechJap No. ND50-1100.6 .... ATIS No. 3043

BLUEPRINTS

a. Front
b. Rear
c. Left
d. Longitudinal Cross-Section
e. Lateral Cross-Section
f. Crankshaft

III. <u>COMMERCIAL AND PEACE TIME CONSTRUCTION AND DESIGN</u>

A. <u>Niigata Diesel and Semi-Diesel Engine Catalogue</u>

1. NavTechJap No. ND50-1093 .... ATIS No. 3050

CATALOGUE

B. <u>Ikegai Iron Works Solid Injection Diesel Engine</u>

1. NavTechJap No. ND50-1092 .... ATIS No. 3051

CATALOGUE

ENCLOSURE (A), continued

C. Kobe Engine Works Catalogue of Heavy Oil Marine

1. NavTechJap No. ND50-1094 .... ATIS No. 3023

ENGINES

D. Mitsubishi-Kobe Diesel Catalogues

1. NavTechJap No. ND50-1095 .... ATIS No. 3049

CATALOGUES

a. Four Cycle Engines
b. General

E. Hanshin Iron Works

1. NavTechJap No. ND50-1096 .... ATIS No. 3048

CATALOGUES AND REPORT

a. Marine Diesel Engine Catalogue
b. Solid Fuel Injection Diesel Instruction Manual
c. Diesel Engines for Land Use
d. Report of Capital Structure and Production to Prefectural Governor

F. Diesel Automotive Industrial Company Catalogue

1. NavTechJap No. ND50-1098 .... ATIS No. 3046

CATALOGUE

a. Five Liter Diesel Engine Instruction Manual
b. Model TX40 Truck Instruction Manual
c. Isuzu Commercial Catalogue

G. Kanegafuchi Diesel Industry Catalogue

1. NavTechJap No. ND50-1099 .... ATIS No. 3045

CATALOGUE

IV. MISCELLANEOUS DOCUMENTS

A. Engine Material Specifications

1. NavTechJap No. ND50-1102 .... ATIS No. 3052

a. Substitute Materials for Marine Engine Parts
b. Japanese Engineering Standard Rules

B. Test Report of Electro-Magnetic Type

1. NavTechJap No. ND50-1108 .... ATIS No. 3063

DYNAMIC BEND TESTING DEVICE

C. Sample Marine Trial Run Data

1. NavTechJap No. ND50-1097 .... ATIS No. 3047

ENCLOSURE (B)

LIST OF EQUIPMENT FORWARDED TO THE UNITED STATES

NavTechJap No.	Description
JE50-1235(1-3)	Assorted Dynamometers 1- Dynamometer 2- Hydrophlic Dynamometer 3- Recording Dynamometer
JE50-1272	Recording Dynamometer
JE50-1130(1)	ZB-1 type ZB-35 Single Cylinder Diesel Engine Lubricating Oil Tank Primary Fuel Oil Filter Temporary Fuel Oil Filter Primary Fuel Hand Priming Pump
JE50-1130(2)	ZB-2 Lubrication Oil Cooler for ZB-35-1
JE50-1131(1)	ZC-1 Type ZC-707 2000 Hp Diesel Engine Nine Fuel Oil Pipes Three Steam Pipes One Air Pipe
JE50-1131(2)	ZC-2 Oil Cooler for Type ZC-707 Engine
JE50-1131(3)	ZC-3 Water Cooler for Type ZC-707 Engine One Unit Injector (MO-1) Twenty Starting Air Valves (P101-P105) Two Hundred Piston Rings A-B-C- (C303-C305) One Hundred Oil Rings A-B (C307-308) Four Cylinder Gaskets (113) Ten Non-Return Valves and Seats M107-M108) 290 Needle Rollers (215C) (E114 - E145) Two Special Tools
JE50-1131(4)	ZC-4 Exhaust Gas Manifold, Front and Rear Auxiliary Fuel Tank No. 2 Swirl Chamber Temporary Fuel Pump Breezer Eight Lubricating Oil Pipes Three Fuel Oil Pipes Three Water Pipes
JE50-1131(5)	ZC-5 Main and Auxiliary Oil Filter (J-03) Cranking Handle (S-1) Oil Priming Pump Handle
JE50-1131(6)	ZC Air Starting Bombs (six) Instrument Panel Hand Priming Oil Pump Nine Lubricating Oil Pipes Nine Fuel Oil Pipes Two Cylinder Liners Two Pistons Connecting Rod and Bearing

ENCLOSURE (C)

NS/an

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

9 February 1946

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

Subject: Report on Mitsubishi Tokyo Engineering Company Twenty-Cylinder Marine Diesel Engine ZC 707, Forwarding of.

Reference: (a) NavTechJap Report - "Japanese Navy Diesel Engines", Index No. S-42.

Enclosure: (A) Subject Report.

1. Subject report, Enclosure (A), written by Dr. H. OINOUYE and Mr. K. OKAMURA and translated by Mr. M. YOSHITANI, Mitsubishi Tokyo Engineering Company engineers, is forwarded herewith.

2. The subject engine is being delivered to the Bureau of Ships, Washington, D.C. and is identified by NavTechJap Equipment Numbers JE50-1130 and JE50-1131.

3. Reference (a) contains information regarding the subject engine, which was designed and constructed as a high-speed, motor torpedo boat, marine diesel, by the Tokyo Engineering Co. at Kamata, TOKYO. At the time that information was being gathered for the preparation of reference (a), this company was ordered to complete and test the subject engine and to submit a detailed report thereon to the U.S. Naval Technical Mission to Japan.

4. The tests have been made, and the results thereof are contained in the subject report. However, the results obtained during the tests do not measure up to design performance. In the time allowed, the company was barely able to complete the engine, and failed to eliminate the various defects which developed during the testing. It is believed that only study of the actual engine will yield the information necessary to evaluate it.

5. Since the test data are inconclusive, general dissemination thereof as a part of reference (a) is not desirable. It is believed, however, that this report will be of great interest to the Bureau of Ships, particularly in view of the fact that the engine itself is now being shipped to the Bureau.

C. G. GRIMES
Captain, USN

CC: WDIT, G-2,SCAP (with enclosure).

ENCLOSURE (D)

DATA ON JAPANESE DIESEL ENGINES FURNISHED
BY THE NAVY TECHNICAL DEPARTMENT, TOKYO

1. Brake mean pressure, piston speed, exhaust temperature and fuel consumption for typical diesel engines of Japanese Navy, in use during the war.

Name of Engine	Type of Engine	Cyl. Dia. (in)	Stroke (in)	No. of Cyl.	Rev/min	Normal Full Power (BHP)	Engine Wt. (ton)	Brake m.p. (lbs/in^2)	Piston Speed (ft/sec)	Exhaust Temp. (°F)	Fuel Cons. (lbs/hp/h)	Lub. Oil Cons. (lbs/hp/h)
No. 2	2 cycle double actg. air injection diesel	18 1/2	20 7/8	10	350	7000	ca. 70	70	20.3	740	0.45	ca. 0.024
No. 22	4 cycle single actg. solid inject. diesel	16 15/16	17 3/4	18	510	2250	38	86.5	25.1	800	0.39	ca. 0.015
No. 23	4 cycle single actg. solid inject. diesel	14 9/16	19 11/16	8	360	950	34	81	20.4	ca. 710	ca. 0.38	ca. 0.010
No. 51	4 cycle single actg. solid inject. diesel	5 1/2	7 7/8	10	1500	300	ca. 2.5	83.3	32.8	1050	0.45	ca. 0.020
M-400	4 cycle single actg. solid inject. diesel	11 13/16	13 3/4	6	500	400	11	69	19.6	700	0.38	ca. 0.010

Remarks:
1. Cylinder diameter and stroke of piston are converted from millimeter to inch.
2. Figures with "ca." are written from the writer's memory.

2. Bearing pressure of the crankshaft for typical diesel engines of Japanese Navy.

Engine Name	Max. Combustion Pressure at Full Load (Pmax, lbs/in^2)	Apparent Bearing Pressure of Crankshaft (Papp, lbs/in^2)	Performance Results for Bearing Metal
No. 2	650	770	No defect was found
No. 22	860	1350	Metals were rarely worn out
No. 23	720	850	Quite well
No. 51	880	1300	Metals were rarely worn out
M-400	780	1300	Quite well

Remarks:

1. The apparent bearing pressure is the value, the force upon piston due to the maximum combustion pressure divided by both side bearing projected area.
2. Strict specifications for casting of white metal for both No. 22 and No. 51 engines were applied. These engines have unfavorable crank-arrangement, which caused very severe bearing condition.

ENCLOSURE (D), continued

3. Diesel engine fuel oils and lubricating oil, which were used by the Japanese Navy during the war.

Engine Oils			Lubricating Oils	
Name of Oil	No. 1 Heavy Oil	No. 2 Heavy Oil	Name of Oil	No. 2
Specific gravity at 60°F	0.94	0.915	Specific gravity at 60°F	0.93
Flashing point °F	over 176	over 150	Flashing point °F	380
Freezing point °F	under 14	under 23	Freezing point °F	7
Water content	under 0.1%	under 0.2%	Viscosity by redwood	86°F 580" 212°F 46"
Sulphur content	under 1.0%	under 1.0%		
Ash content	under 0.01%	under 0.05%	Ash content	trace
Maximum calorific value (BTU)	over 39500	over 39500	Carbon	0.02%
Octane number by C.F.R.	over 30	over 38	Oxidation	0.02
Viscosity at 86°F by Redwood	under 120	under 30	Saponification value	1.24
Remarks: Generally used for normal diesel engines. Only for 2-cycle double-acting engines, originally octane 45			Remarks: Generally suitable for all diesel engines.	

4. Torsional vibration properties of typical diesel engines of the Japanese Navy submarines and other ships.

Name of Engine	Type Ship in Which Installed	Displacement Tonnage	Frequency of Two Nodal Torsional Vibration (cycle/min)	Torsional Vibration Damper
No. 2	Submarine	1950	1200	Oil-cushion type
No. 22	Submarine	965	1900	Oil-cushion type
No. 23	Coast defense boats	745	1950	Originally oil cushion type was installed, afterward found not necessary
No. 51	Torpedo boat	25	(ca) 6000	No damper
M-400	Submarine	320	5350	No damper

Remarks:

1. For all diesel engines which were built during the war, critical speeds did not exist if the dampers were in order.
2. The critical range of torsional vibration occurred (as defined by the Japanese Navy) when the additional stress due to vibration exceeded 3600 lbs/in² (250 kgs/cm²) in ordinary mildsteel crankshaft.
3. For No. 51 torpedo boat engine no data was found. Frequency above written is only from writer's memory. We have measured the vibration by Geiger's torsiograph, but could not find any critical vibration, and afterward the endurance was also tested. We believe all ranges safe.

ENCLOSURE (E)

REPORTS ON INSPECTION OF THIRTEEN DIESEL MANUFACTURING PLANTS

* * * * *

PLANT REPORT NO. 1

Plant Inspected: Mitsubishi Heavy Industry Co., NAGASAKI.

Date of Inspection: 24 October 1945.

Parties Interviewed: M. KUSANO, Engine Workshop Manager
M. FUJITA, Diesel Engine Designer
S. TANAKA, Engineering Dept. Manager
S. SENO, Chief Engineer

Models of Engines Produced: Model No. 23
Model No. 51-10
Model No. 51-6

Remarks:

This plant suffered heavy bomb damage from fire bombs. While the atomic bomb did some damage, the plant was out of operation prior to the bombing of the city.

In addition to building the above engines, this company also assembles, casts, and machines some parts of the Model No. 1 (5000 hp 8-cylinder) and Model No. 2 (6800 hp 10-cylinder) engines. These engines, used in the I-Type submarine, are of the two-cycle double-acting type with air injection. Because of transportation difficulties in the latter stages of the war, it became necessary to manufacture some spare parts for keeping in operation submarines in which these engines were installed. It was capable of doing this.

Prior to the war, this company built large engines of the Sulzer design for commercial vessels, but during the war, it built and installed many turbines because coal for fuel presented no problem, whereas a shortage of oil was anticipated. The production of engines of all types did not exceed 18 engines per month.

The compound internal combustion engine of the Mitsubishi type has been under test for some time. The present one is the second of a series, the first of which ended in failure according to Mr. S. TANAKA, manager of the engineering department. It was. however, of a larger type and for the past year, they have concentrated on the smaller size which they hoped to use in fast type patrol craft to replace high speed gasoline engines.

From information given, it was strongly indicated that it was not possible to develop over 150 hp on account of combustion difficulties. A Gray diesel engine captured in Shanghai had had the blower removed, and no doubt a study was being made of the GM blower to discover means of forcing additional air into the low pressure cylinder. The transfer valve was a source of trouble because of the high exhaust temperatures of 1200° to 1300° F. In order to produce the designed horsepower of 210, the fuel injection adjustment was set at a duration of 60°. Injection started at 40°BTC and closed at 20° ATC.

In the opinion of Mr. TANAKA, and Mr. Saburo SENO, chief engineer, within three months they would have completed all work necessary to go into a redesigned engine for production for use in the place of gasoline engines of the high-speed type. The initial production would not have been large, but it indicates the confidence in this type of engine.

The two engines used for experimental purposes have been partially destroyed. Considerable work would be necessary to restore them to operating condition. All drawings with the exception of the cross-section drawing were destroyed by fire. This cross-section drawing, together with a translation of a paper on the working principle of the engine, are the only documents available for inclusion in this report.

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PLANT REPORT NO. 2

Plant Inspected: Fuji-Nagata Zosenjo (Fuji-Nagata Shipyards), OSAKA.

Date of Inspection: 1 November 1945.

Parties Interviewed: Sakae UMEMURA, Managing Director.

Models of Engines Produced: None

Remarks:

This concern built boats for coastal shipping service and also destroyer escorts. It does not manufacture Diesel engines, although one attempt was made to produce an automotive type high speed engine. Arrangements had been made to secure plans from Austria, but the plans never reached Japan. Work was begun, nevertheless, on such an engine, and some parts had been completed, when a bomb attack destroyed them. The experiment was abandoned.

* * * * *

PLANT REPORT NO. 3

Plant Inspected: Hanshin Nainenki (Hanshin Internal Combustion Company), OSAKA-KOBE area.

Date of Inspection: 1 November 1945.

Parties Interviewed: Shigeru KOBAYASHI, Supervisor.

Models of Engines Produced: Fishing boat and cargo boat engines.

Remarks:

This plant made commercial engines for fishing boats and small cargo boats on orders placed by the Navy through the Shipbuilding Control Association or its subsidiary association, the Marine Internal Combustion Engine Control Association. Both two-and four-cycle engines were built; they did not incorporate any new or unique features. The reports and catalogues, obtained from the plant, show production, types of engines, history, and damage assessment.

* * * * *

PLANT REPORT NO. 4

Plant Inspected: Kobe Seiko (Kobe Manufacturing Co.)

Date of Inspection: 1 November 1945.

Parties Interviewed: Mr. S. KIMURA, Director.

Models of Engines Produced: Model No. 22
Model No. 51
15 kilowatt generating set

Remarks:

During the war, this company manufactured Model No. 22 submarine engine which was rated at 2250 hp. The total number of engines produced was sixty. In February 1945, on orders from the Navy Ministry, production of this type engine was discontinued, and the last delivery was made in April. Two engines had completed their tests, and no shipping instructions had been issued prior to the cessation of hostilities. Sufficient material was available to build an additional 20 engines. The Navy Ministry order was issued to enable this plant to concentrate on the production of the Model 51 engine for which it was unsuited. The planned production was 20 engines per month, and while considerable material was in process, no shipments of this model engine had been made. The company also built 15 kilowatt generating sets for coastal vessels.

The plant was bombed on 17 March 1945. Damage exceeded 25 percent.

In addition to diesel engines for the Navy, this plant was also engaged in making shovels, draglines, and deck machinery.

* * * * *

PLANT REPORT NO. 5

Plant Inspected: Osaka Tekkojo (Osaka Steel Works), OSAKA.

Date of Inspection: 2 November 1945.

Parties Interviewed: None

Models of Engines Produced: Not reported (see below).

Remarks:

This concern was reported by U.S. Intelligence to have manufactured diesel engines. However, Japanese Navy Engineers report that only coast defense ships were built here.

A visit to the plant revealed that it was completely destroyed. No personnel were available for interview.

* * * * *

PLANT REPORT NO. 6

Plant Inspected: Kubota Kikai Kojo (KUBOTA Engine Works), SAKAI, OSAKA.

Date of Inspection: 2 November 1945.

Parties Interviewed: N. KUBOTA, Manager.
S. KAWABATA, Engineer.

Models of Engines Produced: Navy Type medium speed 400 hp.
105 hp tractor engine.
60 hp marine engine.

Remarks:

Both the 400 hp and 105 hp are standard engines, the former having been designed by the Navy and the latter by the Army. Both the 105 hp and 60 hp

ENCLOSURE (E), continued

engines were manufactured at the company's Sakai plant, while the 400 hp was built at their Wakae plant. All engines were four cycle of a conventional design, having no outstanding features except as noted. The specifications for these engines are as follows:

a. Navy type 400 hp

Bore	300mm (11 13/16")
Stroke	350mm (13 3/4")
RPM	430
Cylinders	6
Approximate monthly production	5

b. 105 hp tractor engine

Bore	130mm (5 3/32")
Stroke	160mm (6 3/16")
RPM	1200
Cylinders	6
Approximate monthly production	40

The 105 hp engine is designed with a large capacity crankcase with cooling fins cast on the crankcase. This indicated that some bearing trouble had been experienced and was an approach to the solution.

c. 60 hp marine engine

Bore	110mm (4 4/32")
Stroke	140mm (5 1/2")
RPM	1500
Cylinders	6
Approximate monthly production	100

This engine was so constructed that only one cam was used for the operation of both the inlet and exhaust rockers, and the rocker action was exceptionally smooth. At the request of the officer making the inspection, a short test run was made. The operation of the engine was fairly smooth but combustion was not considered complete, and a grey smoke was present in all power ranges. This was due partly to the type of fuel used and efforts made to adapt the engine to this type fuel.

During wartime, the Wakae plant employed about 1000 persons, the Sakai plant 2600. The latter plant also built kerosene engines for farm purposes. Both plants are intact. The machine tools used are modern, and some attempt is made at line production.

For the purpose of further investigation, one 60 hp marine diesel engine, and one 105 hp tractor engine as well as a small auxiliary air compressor have been forwarded to the Bureau of Ships.

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PLANT REPORT NO. 7

Plant Inspected: Nippon Hatsudoki (Japan Engine Co.), KOBE.

Date of Inspection: 2 November 1945.

Parties Interviewed: Hisashi KOBAYASHI, Consulting Director.

Models of Engines Produced: 80 hp gasoline engine
Navy type 60 hp engine
Medium speed 400 hp engine

ENCLOSURE (E), continued

Remarks:

This concern manufactured two and four-cycle diesels prior to the war and built the 80 hp gasoline engine for landing craft. The maximum rate on the gas engine was 20 per month in 1942. In December 1944, they were ordered to produce 25 Navy type 60 hp diesel engines per month but had only produced a total of 10 engines by the close of the war. Prior to the war, the largest engines built here were 700-800 hp, and these were used in coastal vessels. At the beginning of 1945, it began to build the Navy type 400 hp medium-speed engine but was never able to deliver this. The plant was 80 percent demolished. The first damage was sustained during the raid of 17 March 1945 and the next in June.

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PLANT REPORT NO. 8

Plant Inspected: Kobe Hatsudoki (Kobe Engine Company), KOBE.

Date of Inspection: 2 November 1945.

Parties Interviewed: Shokichi TSUJII, President.

Models of Engines Produced: Navy type 550 hp engines.
380 hp semi-diesel.

Remarks:

This firm built the 550 hp and 380 hp engines during the war. Production consisted of two of the former and one of the latter per month. The 380 hp engine was a semi-diesel for use in coastal vessels and fishing boats. The 550 hp engine was the standard Navy type used in generating sets. Four hundred workers were employed at the Kobe plant to build these engines. In 1943, a textile plant at KYOTO was converted into a branch factory of the Kobe Engine Company. This was in response to Navy orders to produce ten 550 hp engines per month. The first engine under this new contract was completed in October 1944, but production never exceed one per month in spite of the employment of 350 men. This was due, in particular, to the inexperience of the workers and to the lack of proper supervision.

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PLANT REPORT NO. 9

Plant Inspected: Mitsubishi Shipbuilding Yard, KOBE.

Date of Inspection: 2 November 1945.

Parties Interviewed: R. KOKUBO, Superintendent of Engineering Department.

Models of Engines Produced: Model No. 1 - (8 cylinder)
Model No. 2
Model No. 22
Medium speed 400 hp
Model No. 24 - (6 cylinder)
Model No. 51-10
Model No. 51-6

Remarks:

This company has a long record of manufacturing diesel engines for military use. The company began to manufacture submarinesengines of the Vickers type fifteen to twenty years ago; these were 1200 hp engines. Following that, it manufactured three 3000 hp engines.

During the last two years, they concentrated on model No. 22 and the No. 51 in both the 6 and 10 cylinder versions. From 1941 through 1943, it built the Navy Model No. 24 which had the following specifications:

Bore	310mm (12-3/16")
Stroke	380mm (14-15/16")
RPM	550
Horsepower	560

This engine was used for generating sets. It was a four-cycle engine of a type that they had built for some years. Its design characteristics are similar to the MAN engine; it employs solid, jerk jump injection. The engine has no outstanding features.

The tremendous effort to obtain engines of the No. 51 type is again evidenced by the Navy's order to this concern to produce these engines. This order was issued to Mitsubishi Shipbuilding Yard at KOBE in spite of the fact that its experience and machine tool setup were wholly unsuited for producing small engines with any degree of efficiency.

Production at this plant was considerably reduced during the summer of 1945 because of the severe bombing attacks in the area.

* * * * *

PLANT REPORT NO. 10

Plant Inspected: Mitsubishi's Tokyo Engineering Works, Kamata Plant, TOKYO

Date of Inspection: 6 - 10 November 1945.

Parties Interviewed: Hiroshio OINOUYE, Doctor of Engineering, Plant Manager
S. OKAMURA, Engine Designer.
M. YOSHITANI, Head of Planning Department.

Models of Engines Produced: Type 97 tank engine
Type 4 tank engine
Standard Army Type 60 hp engine
Type 100 tank engine

Remarks:

Before the war, this concern chiefly manufactured two engines, a 100 hp engine of the Swiss Saurer type and a 100 hp engine of their own design. The specifications were:

Swiss Saurer Type Truck engine

Bore	110mm (4 9/32")
Stroke	140mm (5 1/2")
Cylinders	6
RPM	2000

This engine was built for the Manchurian Railroad Company for use in its trucks.

ENCLOSURE (E), continued

Mitsubishi 100 hp Automotive Engine

Bore	110mm (4 9/32")
Stroke	150mm (5 15/16")
Cylinders	6
RPM	1800

This engine was a pre-combustion type.

Construction of the above engines was discontinued at the beginning of the war. The company then began to build the following engines:

a. Type 97 tank engine

Bore	120mm (4 11/16")
Stroke	160mm (6 3/16")
Horsepower	170
RPM	1700
Cylinders	V-12
Air cooler	direct injection

b. Type 100 tank engine

Bore	120mm (4 11/16")
Stroke	160mm (6 3/16")
Horsepower	240
RPM	2000
Cylinders	V-12
Pre-combustion chamber	
Air cooler	

The total production for these two engines was approximately sixty to seventy per month.

c. Production for Standard Army Type 60 HP engine for use in landing craft was approximately 100 per month.

Limited production had been begun on a V-12 Type 4 tank engine, and two pilot models were completed. (These were commandeered by the U.S. Army for shipment to the United States for further study.) The specifications are:

Bore	145mm (5 11/16")
Stroke	190mm (7 1/2")
Horsepower	400
RPM	1600
Cylinders	V-12

The engine was built with supercharger and is air-cooled. The boost was 320mm of mercury and produced 500 hp. The engines were to be used in the army's largest tanks, the Type 4.

In April 1944, the company began experiments to meet the necessity for a high output engine to be used in high speed motor torpedo boats. Admiral KONDO collaborated with Mr. OKAMURA in the designing of a 20 cylinder V-type engine with the following specifications:

Bore	150mm (5 15/16")
Stroke	200mm (7 7/8")
RPM	1600 - hp 2000
RPM	1450 - hp 1500
Cylinders	V-20
Dry Weight	10,000 lbs.
Cycles	2

ENCLOSURE (E), continued

Tests of a single cylinder engine of the above type were started in July 1944. Test data for the 20 cylinder engine has been forwarded to the Bureau of Ships (see Enclosure (C)).

A 10 cylinder engine of the same type was also planned. Pilot models were already under construction.

This factory appears to be the most modern diesel plant in Japan with the highest rate of horsepower per man production. The thoroughness of the development and tests of the above experimental engine is indicative of the caliber of its engineers. It is estimated that approximately 2500 persons in this plant were engaged exclusively in building of diesel engines.

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PLANT REPORT NO. 11

Plant Inspected: Kanegafuchi Diesel Industrial Co. (Formerly Nippon Diesel Company), SAITAMA Prefecture.

Date of Inspection: 7 November 1945.

Parties Interviewed: Hisao SHIBATA, Director.
Heizaburo HIRABAYASHI, Chief Engineer.

Models of Engines Produced: Standard Army 60 hp engine
Standard Army 90 hp engine
Standard Army 125 hp engine
Standard Army 165 hp engine

Remarks:

This firm under the name, Nippon Diesel, manufactured small diesels before the war. During the war, it was sold to the Kanegafuchi Company, a large textile interest. Its total output during the war, was contracted for by the Army and its engines were used in trucks, tractors, bulldozers, etc. only. The engines were of the Krupp-Junkers opposed-piston type. The firm manufactured engines and chassis for these units. Of the engines listed above, the first three were built with the same bore and stroke and in two, three and four cylinder models respectively.

Specifications are:

Bore .... 85mm (3 3/8")
Stroke .... 214mm (8 13/32")
RPM 1500

The 165 hp engine was a four cylinder type with the following specifications:

Bore .... 105mm (4 3/32")
Stroke .... 240mm (9 13/32")
RPM 1500

Their total production was about 5000 hp per month. During the war, those persons working on diesel construction exclusively numbered approximately 2000. The plant is entirely intact.

The manufacturing facilities of this plant were not in keeping with the design of engine they were endeavoring to build. Shortly after the first air raid, they started to disperse their equipment in order to save it from destruction. Little of the machinery was in operative condition and those machines remaining were in the process of being shipped. It is further interesting to note that this plant was in an area which had not yet been bombed. In spite of this fact, they went ahead with dispersal as a precautionary measure.

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PLANT REPORT NO. 12

Plant Inspected: Ikegai Tekkojo (IKEGAI Steel Works)

Date of Inspection: 12 November 1945.

Parties Interviewed: K. ISHIKAWA, Plant Director
Mr. KUSAMA, Director of Engine Department
S. KAMAKI, Head of General Affairs Department

Models of Engines Produced: Type 23, 900 hp submarine engine
400 hp medium speed submarine engine
80 hp four cylinder kerosene engine
55 KVA generator engine

Remarks:

This is a very large concern and is one of the principal machine tool manufacturers in Japan. Two of its plants, however, were devoted to the construction of internal combustion engines. The Tamachi plant in TOKYO was chiefly used for the construction of the 80 hp kerosene engine for use in landing craft and for the servicing of Ikegai diesel engines. The Kawasaki plant, on the other hand, was engaged exclusively in the manufacture of diesels. Before the war, a fairly complete line of marine engines for civilian use in fishing boats, etc. was built at this plant. Since the outbreak of the war, the company built exclusively for the Navy. During the last several years at the Kawasaki plant, and prior to the bombing attacks, its production averaged about one 900 hp engine and one 400 hp engine per month. The Tamachi plant averaged about 30 kerosene engines per month. About 1000 workers were employed at the Kawasaki plant which was partially destroyed. Much of the machinery had already been dispersed.

* * * * *

PLANT REPORT NO. 13

Plant Inspected: Hitachi, Ltd, Kameari Works, TOKYO.

Date of Inspection: 13 November 1945.

Parties Interviewed: G. YUASA, Plant Superintendent.
H. SHIBUYA, Designer.
Y. SHIMIZU, Interpreter.

Models of Engines Produced: V-12 air-cooled tank engine
V-12 water-cooled marine engine
60 hp water-cooled tractor engine

Remarks:

This concern, a heavy industries company, began work in diesel construction and design in 1937. At the outbreak of the war with China, the company began manufacturing for the army exclusively. According to Mr. YUASA, the plant superintendent, qualified diesel engineers were very scarce at that time. As a result, the company did practically no experimental work of its own but rather accepted the plans drawn by the army. Outside of certain modifications on the above mentioned engines which were made to facilitate

ENCLOSURE (E), continued

production, no original work has been done by this company, and all of the above engines are standard and of conventional design.

During the first part of the war, the company concentrated on the standard army V-12 air-cooled diesel engine for use in tanks. Their average production reached 12 engines per month. At that time, they began construction of the 60 hp water-cooled engine for tractors. In 1943 they went to work on a water-cooled V-12 engine of the same specifications as the tank engine. This latter engine was for marine use and was contracted for the army. They continued to build one or two 60 hp engines per month, but their main effort was centered in the water-cooled V-12. Production reached about 20 engines per month.

It was estimated by Mr. YUASA that of the total workers employed at the Kameari plant, about 1500 worked exclusively on diesel engine construction. With production occasionally as high as 5000 hp per month, the rate of horsepower per man per month was approximately 3-1/3. From American standards of production, this is extremely low production; from the Japanese standpoint, however, HITACHI is one of the most efficient plants in Japan.

At the time of inspection, the plant was intact, but production was practically shut down on account of the dispersal of machinery which had started early in the year. Operations had not yet begun in the new location.

ENCLOSURE (F)

REPORT ON INTERROGATION OF DIESEL DESIGN PERSONNEL OF THE NAVY TECHNICAL DEPARTMENT.

* * * * *

Agency Interviewed: Navy Technical Department, Navy Ministry.

Date of Interrogation: 10 November 1945.

Parties Interviewed: Rear Admiral KONDO, Chief of Design and Engine Construction.
Commander KONDO, Diesel Engine Production Head.
Mr. NAGANO, Chief Designer, Tokyo Office.

Remarks:

This interrogation was for the purpose of gathering information on design developments and operation of diesel engines in the Japanese Navy. Pertinent facts brought out during the interrogation are as follows:

In answer to a question relative to the reason for the stopping of production of Model No. 2 engine, Admiral KONDO stated that the continued full load operation of the engine developed weaknesses that peacetime operation did not uncover. The cracking of the cylinder head covers and the inability to cool the pistons and piston rods properly were the chief factors. He also stated that inexperienced engineroom crews were a contributing factor.

When asked what was done to replace these engines in submarines, Admiral KONDO stated that the Model Nos. 22 and 23 which were simpler in design and easier to manufacture were substituted. It was also true that both of these engines were easier to operate and easier to maintain.

When questioned about the consequent sacrifice in speed, he stated that it was necessary to accept this loss in speed in order to gain the advantages of continued operation.

In answer to a question concerning the use of synthetic oils, he stated that oils made from pine roots and soya beans were used. The pine root oil had a tendency to gum the injection system, but when soya bean oil was used, no such troubles were experienced.

Regarding the use of aluminum or other light materials by the Japanese Navy for engine construction, he stated that the aircraft industry had first call, and no effort was made to reduce the weight of engines by the use of this material.

Admiral KONDO was questioned on the amount of research on diesel engines undertaken by the Japanese Navy. He stated that practically all experimental work during the war was carried out by private concerns with such help as the Navy could supply. He further stated that the experimental station was chiefly concerned with the testing of synthetic oils for use in diesel engines.

When questioned in respect to the compound diesel engine developed by the Mitsubishi Company at NAGASAKI, he replied that this matter was brought to their attention and upon going into the matter thoroughly, he did not feel its chances of sucess warranted Navy participation but gave them permission to proceed with the understanding that the findings were to be submitted to the Navy Technical Department.

The Type ZC Mitsubishi 20 cylinder experimental engine was discussed. He stated that he had collaborated with Mr. OKAMURA, the Mitsubishi designer, *ENCLOSURE (F), continued*

on this engine.

The question of experimental work on diesel engine operation on a closed cycle with supply of oxygen was put to him. He stated that these experiments had started seven years ago and had not reached a succesful conclusion. No attempt had been made to install this system of operation in any of the submarines. According to him, research on this problem was abandoned during the war. At that time a serious explosion had taken place, resulting in injuries to personnel, and the experiment was abandoned.

When questioned concerning the installation of Model No. 11 in the seaplane tenders, TAIGEI and CHITOSE, he answered that these ships would not develop the desired speed. No further attempts were made to install diesels in large combatant ships.

When asked about the use of gasoline engines in some of the smaller craft, he stated that this was necessary because of the lack of an acceptable diesel engine of the horsepower required.

Upon being questioned about the three man submarine, he said, "I guess you would call them suicide subs!" During the interrogation, Admiral KONDO was at all times cooperative, and wherever possible, all information required was furnished.

ENCLOSURE (G)

Table I(G)
FUEL COMPARISON TEST ON TYPE ZB-35 SINGLE CYLINDER DIESEL ENGINES
(Data in English units)

Kinds of Fuel Oils

	Octane No.	Sp. Gravity (15°C)
Sanga-Sanga gas oil	53	0.8002
U.S. Navy		0.8404
Japanese Navy heavy oil	c.a. 40	0.8910
Japanese Army gas oil (for tanks)	c.a. 40	0.862

Injection duration in partial load running varies as follows:

Injection timing lever is fixed at 16° B.T.C. as shown in data. (This means that the beginning of injection is 16° B.T.C. at middle rack position.)

Load	Inj. begins (before T.C.)	Inj. ends (before T.C.)
2/10	14°	10.5°
4/10	14.5	9.5
6/10	15	8.4
8/10	15.6	7.2
10/10	16.2	6.3
12/10	17.0	5.3
13.3/10	18.0	4.0

Combustion chamber .... Direct injection
Cooling .... Water cooled
Scavenging .... Overhead exhaust valves
Uniflow scavenging, 2 cycle
Bore .... 5.91 in
Stroke .... 7.88 in
Displacement volume .... 216 in^3
Actual compression ratio 13.5
No. of exhaust valves 4
Diameter of exhaust port .... 1.69 in
Scav. ports .... 3 rows of 0.334 in dia. ports
Injection pump - plunger .... 0.434 in
orifice .... 0.0142" x 4 x 140°
Scavenging blower .... Roots-blower driven by electric motor
Timing - scav. open & close .... 49.5° B.B.C. & A.B.C.
exhaust - open .... 86° B.B.C.
close .... 46° A.B.C.
injection .... 16° B.T.C. at output 10/10
Lubricating oil .... Raffinate heavy (S.A.E. No. 40)
(Chosen Sekiyu K.K.)

Rating	Engine RPM	Kinds of Fuel Oils	Brake Mean Effective Press. Pme lbs/in^2	Brake H.P.	Fuel Oil: Injection Timing Lever Before T.C. deg.	Fuel Oil: Consumption Be lbs/hp-hr	Fuel Oil: Feed Press. lbs/in^2	Fuel Oil: Temp. °F
2/10	850	1 Sanga-Sanga	31.9	15.1	16°	0.615	18	84
		2 U.S. Navy	31.7	15.0	16°	0.643	19.9	97
		3 J. Navy heavy oil	32.3	15.3	16°	0.694		92
		4 U.S. Navy	30.65	14.5	16°	0.654	23	95
		5 J. Army gas oil	31.5	14.9	16°	0.651	23	91
4/10	1070	1 Sanga-Sanga	54.0	32	16°	0.458	29	86
		2 U.S. Navy	53.8	31.9	16°	0.481	31	99
		3 J. Navy heavy oil	54.2	32.1	16°	0.520	38	93
		4 U.S. Navy	54.2	32.1	16°	0.491	33	97
		5 J. Army gas oil	54.2	32.1	16°	0.509	34	92
6/10	1220	1 Sanga-Sanga	72.2	48.8	16°	0.416	34	88
		2 U.S. Navy	72.2	48.8	16°	0.438	37	100
		3 J. Navy heavy oil	72.2	48.8	16°	0.459	48.5	95
		4 U.S. Navy	71.4	48.2	16°	0.429	41	97
		5 J. Army gas oil	72.2	48.8	16°	0.428	40	93
8/10	1350	1 Sanga-Sanga	89.5	66.8	16°	0.392	42	88
		2 U.S. Navy	89.5	66.8	16°	0.437	43	106
		3 J. Navy heavy oil	89.5	66.8	16°	0.425	53	97
		4 U.S. Navy	89.6	67.0	16°	0.410	46	99
		5 J. Army gas oil	89.6	67.0	16°	0.412	45.5	95
10/10	1450	1 Sanga-Sanga	105	85.3	16°	0.382	46	93
		2 U.S. Navy	105.1	85.4	16°	0.406	49	106
		3 J. Navy heavy oil	105.8	85.8	16°	0.424	60	98.5
		4 U.S. Navy	103.9	84.4	16°	0.398	52.5	100
		5 J. Army gas oil	103.9	84.4	16°	0.402	56	97.5
12/10	1540	1 Sanga-Sanga	120	102.5	16°	0.384	49	97
		2 U.S. Navy	121.7	104	16°	0.397	54	106
		3 J. Navy heavy oil	120.6	103	16°	0.400	64	100
		4 U.S. Navy	120	102.5	16°	0.378	60	102
		5 J. Army gas oil	119.4	102	16°	0.389	53	102
13.3/10	1600	1 Sanga-Sanga	128.0	118	16°	0.390	50	110
		2 U.S. Navy	127.0	117	16°	0.379	56	108
		3 J. Navy heavy oil	124.7	115	16°	0.405	67	102
		4 U.S. Navy	124.7	115	16°	0.376	60	104
		5 J. Army gas oil	124.7	115	16°	0.385	56	105
Injection Timing Test	1450	U.S. Navy	99.2	80.6	20°	0.410	54	100
		U.S. Navy	101.7	82.6	18°	0.394	54	97
		U.S. Navy	103.9	84	16°	0.382	54	93
		U.S. Navy	103.3	83.9	14°	0.405	53	105
		U.S. Navy	102.7	83.4	12°	0.410	51	106

continued

	Lubricating Oil				Cooling Water Temp. (°F)		Scavenging Air				Exhaust Gas	
	Pressure (lbs/in²)		Temperature (°F)				Pressure in. of Hg	Temperature (primary surge tank) °F	Quantity		Back Press. (before muffler) in. of Hg column	Temp. °F
	Main Bearing Piston	Cam Shaft etc.	Inlet of Press. Pump	Outlet of Scav. Pump	Inlet	Outlet			lbs/sec	G_a lbs/cycle		
	34	24	147	151	122	129	7.4	140	0.206	0.01451	0.4	369
	23	14.3	158	160	163	167	7.7	142	0.214	0.01515	0.4	379
	24	14	154	156	164	165	8.3	138	0.218	0.01525	0.6	385
	26	15.7	153	154	162	163	7.7	147	0.218	0.01525	0.41	370
	25.5	17.1	149	151	156	156	7.6	133	0.209	0.01303	0.31	362
	40	26	134	135	128	133	12.7	138	0.264	0.0148	0.80	455
	28	17.1	158	160	165	168	13.3	145	0.274	0.01534	0.55	480
	28	17.1	155	157	164	166	13.1	142	0.268	0.0150	0.6	492
	30	18.5	153	155	163.5	165	12.3	145	0.266	0.015	0.47	492
	31	18.5	152	154	158	158	11.7	136	0.268	0.0150	0.47	478
	40	26	140	141	133	138	15.0	142	0.300	0.0150	0.9	542
	28	18.5	160	162	162	167	14.6	151	0.302	0.0150	0.8	572
	31	18.5	166	168	162	167	15.8	147	0.302	0.0150	0.85	552
	31	18.5	156	158	164	167	15.0	147	0.302	0.0150	0.71	548
	31	21	154	156	160	161.5	13.4	141	0.302	0.0150	0.59	552
	41	25	144	145	138	145	17.3	153	0.344	0.01555	1.1	615
	31	18.5	156	164	160	169	19.2	158	0.336	0.0152	0.9	665
	31	18.5	160	162	160	167	19.2	154	0.334	0.0151	0.9	650
	31	18.5	156	158	164	167	18.4	155	0.334	0.0151	0.95	636
	31	18.5	155	158	163.5	167	17.7	147	0.334	0.0151	0.70	636
	33	22	149	150	146	153	24.2	173	0.370	0.0155	1.3	722
	31	18.5	153	164	156	166	22.3	171	0.358	0.0151	1.1	755
.5	28.5	18.5	154	164	158	167	23.2	169	0.361	0.01515	1.1	748
	31	18.5	150.5	162	158	167	21.8	169	0.361	0.01515	1.1	725
.5	30	18.5	159	161	160	167	21.8	165	0.361	0.01515	1.03	718
7	32	19	154	155	153	162	25.4	188	0.380	0.0150	1.38	807
6	31	19.9	151	163	154	165	26.6	185	0.392	0.01528	1.4	829
0	31	17.1	151	164	151	167	26.3	189	0.388	0.0153	1.4	825
2	31	18.5	148	161	156	165	25.6	185	0.388	0.0153	1.18	778
2	31	18.5	150.5	161.5	156	165	25.4	187	0.388	0.0153	1.26	780
0	32	22	151	162	169	171	27.8	198	0.388	0.0148	1.39	909
8	31	19.9	150	163	153	165	27.0	194	0.394	0.01495	1.6	902
2	31	17.1	149	163	153	167	29.7	203	0.405	0.0154	1.5	875
4	31	18.5	148	160.5	154	165	28.2	196.5	0.405	0.0154	1.42	840
5	31	17.1	150	161.5	155	165	28.3	201	0.416	0.0158	1.5	822
0	30	17.1	158	166	149	158	22.2	183	0.366	0.01515	1.0	698
7	31	18.5					21.9	176	0.361	0.0150	1.0	716
3	33	23	143	145	153	165	21.9	164.5	0.364	0.01505	1.0	716
5	31	18.5	149	162	156	165	22.7	198	0.368	0.0152	1.1	755
6	31	18.5	149	162	158	167	22.4	198	0.368	0.0152	1.1	761

ENCLOSURE (G), continued

Table II(G)
FUEL COMPARISON TEST ON TYPE ZB-35 SINGLE CYLINDER DIESEL ENGINE
(Data as Recorded in Metric Units)

Test No.	Date	Kinds of Fuel Oil	Octane No.	Sp. Gravity		Atm. Press. & Temp.	
				15°C	35°C	Press. mmHg	Temp. °C
1	16 Nov.	Sanga-Sanga gas oil	53	0.8002	0.7863	765	14.5
2	16 Nov.	U.S. Navy		0.8404	0.8275	754.6	16.0
3	16 Nov.	Japanese Navy heavy oil	c.a. 40	0.8910	0.8766	754.6	16.0
4*	17 Nov.	U.S. Navy		0.8404	0.8275	758	15.5
5	17 Nov.	Japanese Army gas oil for tanks	c.a. 40	0.8620	0.8488	758	15.5

*Performed after timing test

Lubricating oil .... Raffinate Heavy (S.A.E. No. 40)
(Chosen Sekiyu K.K.)
Scavenging blower .... Roots-blower driven by electric motor
Timing - Scav. open & close .... 49.5° B.B.C. & A.B.C.
Exhaust - open .... 86° B.B.C.
close .... 46° A.B.C.
Injection at output - 10/10 .... 16° B.T.C.
13 3/10 .... 18° B.T.C.

Combustion chamber .... Direct injection
Cooling .... Water cooled
Scavenging .... Overhead exhaust valves
Uniflow scavenging, 2 cycle
Bore 150mm
Stroke 200mm
Displacement volume .... 3.534 lit

Actual compression ratio 13.5
No. of exhaust valves 4
Diameter of exhaust port 43mm
Scav. ports .... 3 rows of 8.5mm dia. ports
Injection pump - plunger .... 11mm ⌀
orifice .... 0.36mm x 4

RESTRICTED

Rating	Engine R.P.M.	Kinds of Fuel Oils	Torque (m-kg)	Brake (hp)	Fuel Oil						
					Injection Timing Lever (B.T.C.)	Rack Position (mm)	Consumption			Injection Per Cycle
							sec/0.1 ltrs	Q ltrs/hr	Be gr/BH/hr	
2/10	850	Sanga-Sanga	12.7	15.1	16	9	68	5.3	279	104.0
		U.S. Navy	12.68	15.0	16		68	5.3	292	104.0
		Japan N. heavy oil	12.85	15.3	16	8.7	66.8	5.39	315.5	105.6
		U.S. Navy	12.17	14.5	16	9	68.8	5.22	297	102.5
		J.A. gas oil	12.55	14.9	16	9	69.1	5.2	296	102
4/10	1070	Sanga-Sanga	21.4	32	16	10.5	42.6	8.45	208	131.5
		U.S. Navy	21.35	31.9	16		42.6	8.45	218.5	131.5
		J.N. heavy oil	21.48	32.1	16	10.3	41.4	8.7	237.5	134.1
		U.S. Navy	21.48	32.1	16	10.6	41.65	8.65	228	134.5
		J.A. gas oil	21.48	32.1	16	10.5	41.15	8.75	231	136.5
6/10	1220	Sanga-Sanga	28.6	48.8	16	12.4	30.9	11.7	189	159.5
		U.S. Navy	28.68	48.8	16		30.6	11.75	199	161.0
		J.N. heavy oil	28.68	48.8	16	11.6	31.0	11.62	208.8	158.7
		U.S. Navy	28.3	48.2	16	12	31.6	11.4	194.5	156
		J.A. gas oil	28.68	48.8	16	12	32.15	11.2	194.5	153
8/10	1350	Sanga-Sanga	35.4	66.8	16	14	23.8	15.1	178	186.5
		U.S. Navy	35.4	66.8	16		23.3	15.45	190.5	191
		J.N. heavy oil	35.45	66.8	16	13.3	24.1	14.9	195.5	184
		U.S. Navy	35.51	67	16	13.8	23.9	15.05	186	186.0
		J.A. gas oil	35.55	67	16	13.5	24.3	14.8	187.5	182.5
10/10	1450	Sanga-Sanga	42.1	85.3	16	15.4	19.0	18.9	174	217
		U.S. Navy	42.1	85.4	16		18.9	19.1	184.5	220
		J.N. heavy oil	42.11	85.8	16	16	19.2	18.75	192.3	215.5
		U.S. Navy	41.7	84.4	16	15.2	19.6	18.35	180.5	211
		J.A. gas oil	41.73	84.4	16	15	19.8	18.2	183.0	209.5
12/10	1540	Sanga-Sanga	47.8	102.5	16	17.1	16.2	22.8	174.5	247
		U.S. Navy	48.3	104	16		15.8	22.8	180.5	247
		J.N. heavy oil	47.8	103	16	16.3	16.8	21.4	182.0	232
		U.S. Navy	47.7	102.5	16	16.5	16.85	21.38	172	231
		J.A. gas oil	47.5	102	16	16	16.85	21.38	177	231
13.3/10	1600	Sanga-Sanga	52.6	118	16	19	13.4	26.8	177	277
		U.S. Navy	52.4	117	16		13.8	25.5	172.5	266
		J.N. heavy oil	51.6	115	16	17.3	14.9	24.2	184	252
		U.S. Navy	51.6	115	16	17.5	15.1	23.85	171	248
		J.A. gas oil	51.45	115	16	17	15.2	23.7	175	247
Timing Test	1450	U.S. Navy	39.9	80.6	20	15	19.8	18.2	186	125.5
		U.S. Navy	40.8	82.6	18	15	20.1	17.7	179	123.4
		U.S. Navy	41.7	84.4	16	15	20.3	17.7	173.5	122.1
		U.S. Navy	41.4	83.9	14	15	19.23	18.7	184	129.0
		U.S. Navy	41.2	83.4	12	15	19.1	18.85	186	130.0

Table II(G), continued

r					Lubricating Oil					Cooling Water Temp. (°C)		
	Feed Pressure (kg/cm²)				Pressure (kg/cm²)		Temperature (°C)					
	Injection Vol Per Cycle mm³	1kg Pump	2kg Pump	Temperature (°C)	Main Bearing	Cam Shaft Etc.	Inlet of Pressure Pump	Outlet of Scavenger Pump	Weight of Tank (kg)	Inlet	Outlet	Pressure (mmHg)
	104.0	0.6	1.2	29	2.4	1.6	65.8	66	70.4	51	53	189
	104.0	0.6	1.4	36	1.6	1.0	70	71	68.5	73	75	195
	105.6			33	1.7	1.0	68	69	67.2	73	74	210
	102.5	0.6	1.6	35	1.8	1.1	67	68	61.7	72	72.5	196
	102	0.6	1.6	33	1.8	1.2	65.5	66	67.2	69	69	192
	131.5	0.6	2.0	30	2.8	1.8	57	57.5	70.0	53	56	324
	131.5	0.6	2.2	37	2.0	1.2	70	71	69.8	74	75.5	336
	134.1	0.7	2.7	34	2.0	1.2	68.5	69.5	68.7	73	74.5	332
	134.5	0.8	2.3	36	2.1	1.3	67.5	68.5	64.8	73	74	312
	136.5	0.7	2.4	33.5	2.2	1.3	67	68	68.4	70	70	295
	159.5	0.6	2.4	31	2.8	1.8	60	60.5	69.7	56	59	381
	161.0	0.6	2.6	38	2.0	1.3	71	72	69.8	72	75	370
	158.7	0.75	3.4	35	2.2	1.3	69	70	68.9	72	75	402
	156	0.8	2.9	36	2.2	1.3	69	70	65.7	73.5	75	380
	153	0.7	2.8	34	2.2	1.5	68	69	68.7	71	72	340
	186.5	0.6	2.9	32	2.7	1.7	62	62.5	69.8	59	62.5	440
	191	0.7	3.1	39	2.2	1.8	69	73	66.4	71	75.5	487
	184	0.75	3.7	36	2.2	1.3	71	72	65.1	71	75	490
	186.0	0.8	3.2	37	2.2	1.2	70.5	72	66.3	72	75	467
	182.5	0.8	3.2	35	2.2	1.3	68.5	70	64.7	73	75	449
	217	0.65	3.2	34	2.3	1.5	65	65.5	66.6	63	67	616
	220	0.7	3.4	41	2.2	1.3	67	73	67.1	69	74.5	565
	215.5	0.8	4.2	37	2.0	1.3	68	73	65.9	70	75	589
	211	0.8	3.7	38	2.2	1.3	66	72.5	67.0	70	75	556
	209.5	0.8	3.5	36.5	2.1	1.3	70.5	72	65.4	71	75	557
	247	0.65	3.4	36	2.2	1.3	67.5	68	67.7	67	72	645
	247	0.7	3.8	41	2.0	1.4	66	72.5	66.5	68	74	672
	232	0.8	4.5	38	2.2	1.1	66	73	67.4	69	75	668
	231	0.8	4.2	39	2.2	1.3	64.5	71.8	67.6	69	74	651
	231	0.8	3.8	39	2.2	1.3	60	72.5	68.2	69	76	643
	277	0.65	3.5	43	2.2	1.3	66	72	67.9	70	77	707
	266	0.7	3.9	42	2.2	1.4	65.5	72.5	66.9	67	74	685
	252	0.8	4.7	39	2.2	1.3	65	72.5	67.8	68	75	751
	248	0.8	4.2	40	2.2	1.3	64.5	71.5	67.5	68	74	715
	247	0.8	4.1	40.5	2.0	1.2	65.5	72.5	64.2	68	74	718
	125.5	0.7	3.8	38	2.1	1.2	70	71	64.2	65	70	564
	123.4	0.7	3.8	36	2.2	1.3			64.2			558
	122.1	0.7	3.8	34	2.3	1.6	62	63	64.2	67	74	556
	129.0	0.7	3.7	40.5	2.2	1.3	65	72	62.7	69	74	576
	130.0	0.7	3.6	41	2.2	1.3	65	72	62.4	70	75	568

g Water (°C)	Scavenging Air							Exhaust Gas	
			Air Flow Meter						
Outlet	Pressure (ps) (mmHg)	Temperature (t_s) (°C)	Pressure Before Orifice ($-P_1$) (mmAg)	Pressure Difference (P_2-P_1) (mmAg)	Intake Temperature (°C)	Quantity (kg/sec)	Quantity Per Cycle (gr/cycle)	Back Pressure (mmHg)	Temperature (°C)
53	189	60	42	85	17	0.0935	6.6	11	187
75	195	61	42	95	20	0.097	6.88	10	193
74	210	59	52	92	19	0.099	6.97	12	198
72.5	196	64	56	92	18	0.099	6.97	11	188
69	192	56	60	91	18	0.095	6.83	8	184
56	324	59	70	140	17	0.120	6.73	21	237
75.5	336	63	80	151	20	0.1245	6.98	14	248
74.5	332	61	60	148	19	0.122	6.82	15	250
74	312	63	85	147	18	0.121	7.11	12	250
70	298	58	87	148	18	0.122	6.82	12	244
59	381	61	90	185	17	0.136	6.80	22	284
75	370	66		188	20	0.137	6.82	20	300
75	402	64	102	188	19	0.137	6.83	22	290
75	380	64	106	188	18	0.137	6.83	18	288
72	340	60.5	105	188	18	0.137	6.83	15	290
62.5	440	67	120	244	17	0.156	7.06	28	325
75.5	487	70	118	233	20	0.1525	6.90	24	353
75	490	68	120	233	19	0.152	6.87	23	343
75	467	68.5	136	233	18	0.152	6.87	24	336
75	449	64	140	233	19	0.152	6.87	23	336
67	616	78	130	284	18	0.168	7.05	33	384
74.5	568	77	132	270	21	0.163	6.85	28	402
75	589	76	140	270	19	0.164	6.89	28	398
75	556	76	159	270	18	0.164	6.89	28	385
75	557	74	170	270	19	0.164	6.89	26	381
72	645	86	110	290	19	0.173	6.83	35	430
74.	672	85	155	310	21	0.1783	6.94	36	444
75	668	87	160	310	20	0.176	6.95	36	442
74	651	85	185	310	18	0.176	6.95	30	415
76	643	86	200	310	20	0.176	6.95	32	417
77	707	92	145	310	20	0.176	6.72	35	487
74	685	90	160	320	21	0.179	6.81	40	484
75	751	95	175	340	20	0.184	7.00	39	470
74	715	91.5	202	340	19	0.184	7.00	36	450
74	718	94	220	350	20	0.189	7.20	38	440
70	564	84	45	269	19	0.166	6.87	25	370
	558	80	43	270	18	0.164	6.89	25	380
74	556	73.5	43	266	18	0.165	6.84	25	380
74	576	92	151	269	21	0.166	6.87	28	402
75	568	92	152	269	21	0.166	6.87	28	406

ENCLOSURE (H)

REPORT ON EXPERIMENTAL COMPOUND DIESEL ENGINE*

I. Abstract.

The compound internal combustion engine of the Mitsubishi type works in two stages of pressure, i.e. both of compression and expansion process.

These processes are divided into two stages of the different cylinder such as high-pressure and low-pressure cylinders.

The cylinder element of the engine consists of one two-cycle low pressure cylinder and two four-cycle high-pressure cylinders and achieves remarkable working by making a special cycle.

II. Explanation of the Working Process.

The working process is shown in Figure 2(H).

III. Remarkable Features.

At this time, the gas transfer valves on both high-pressure cylinders are as shown in Figure 2(H)II, open at the dead center of the L.P. piston; that is to say, at the end of suction of one high-pressure cylinder and the beginning of exhaustion of another high pressure cylinder, and all the fresh air that remains in the gas transfer ports is poured into the high pressure cylinder on the suction side.

This engine will produce remarkable features that increase output more by taking advantage of this gas effectively for its combustion and working.

IV. Experiment.

The particulars for the experimental engine are:

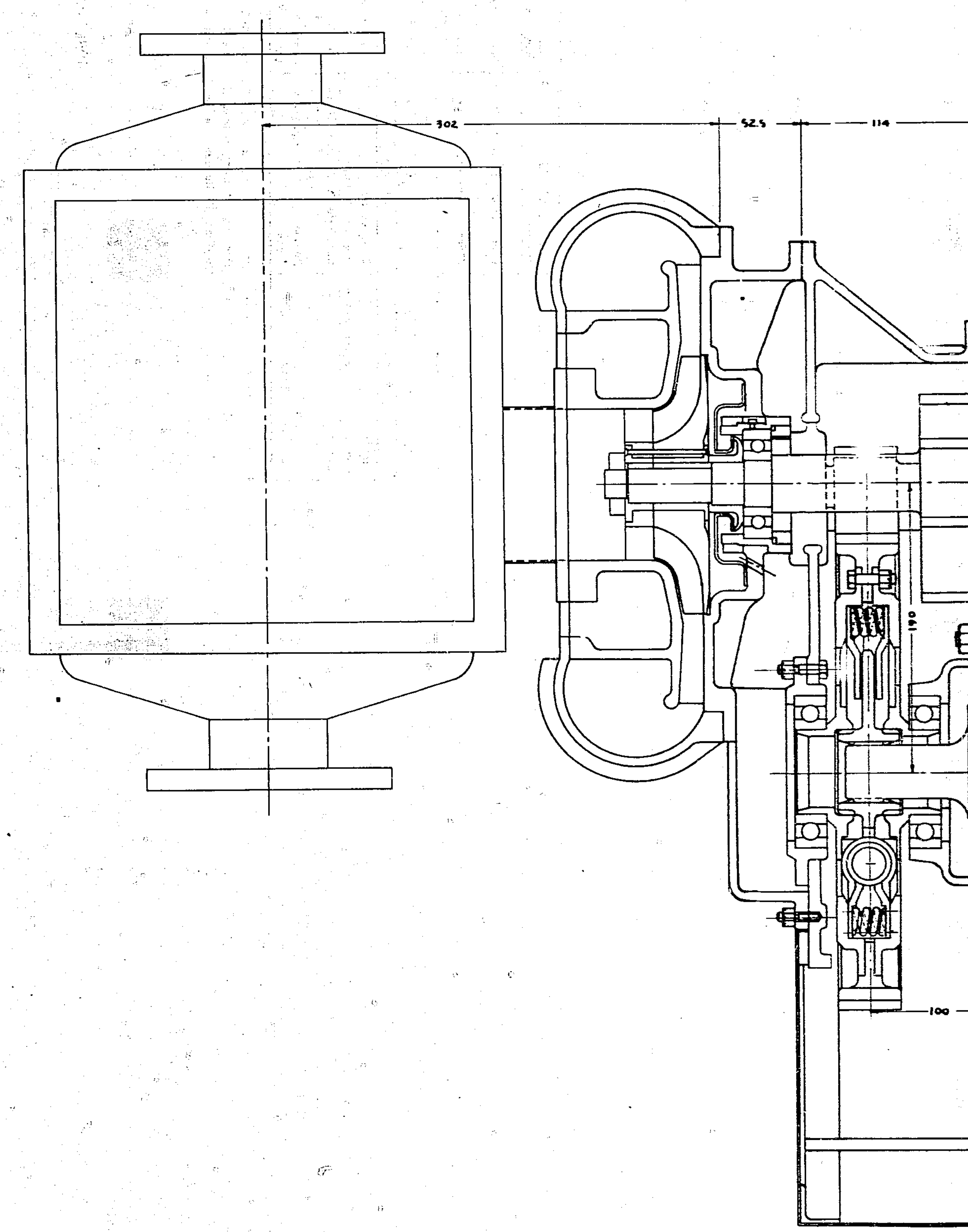
$$\text{Type} \quad 1\ C\ \frac{100}{200} \times \frac{200}{250}$$

High Pressure Cylinder.

Diameter of cylinder D	100mm
Stroke of piston S	200mm
No. of set	1
Revolutions per minute n	1500
Mean effective pressure Pme	8
Brake horse power BHP	210
Weight W ton	0.6 ton
Length of engine L	600mm
Height of engine H (from crank center)	920mm
Breadth of engine B	580mm
Overall height	1,150mm

Note: Data for Low Pressure Cylinder same as above except for cylinder diameter of 200mm and piston stroke of 250mm.

*Prepared by Mitsubishi Heavy Industry Co., Nagasaki.



HI

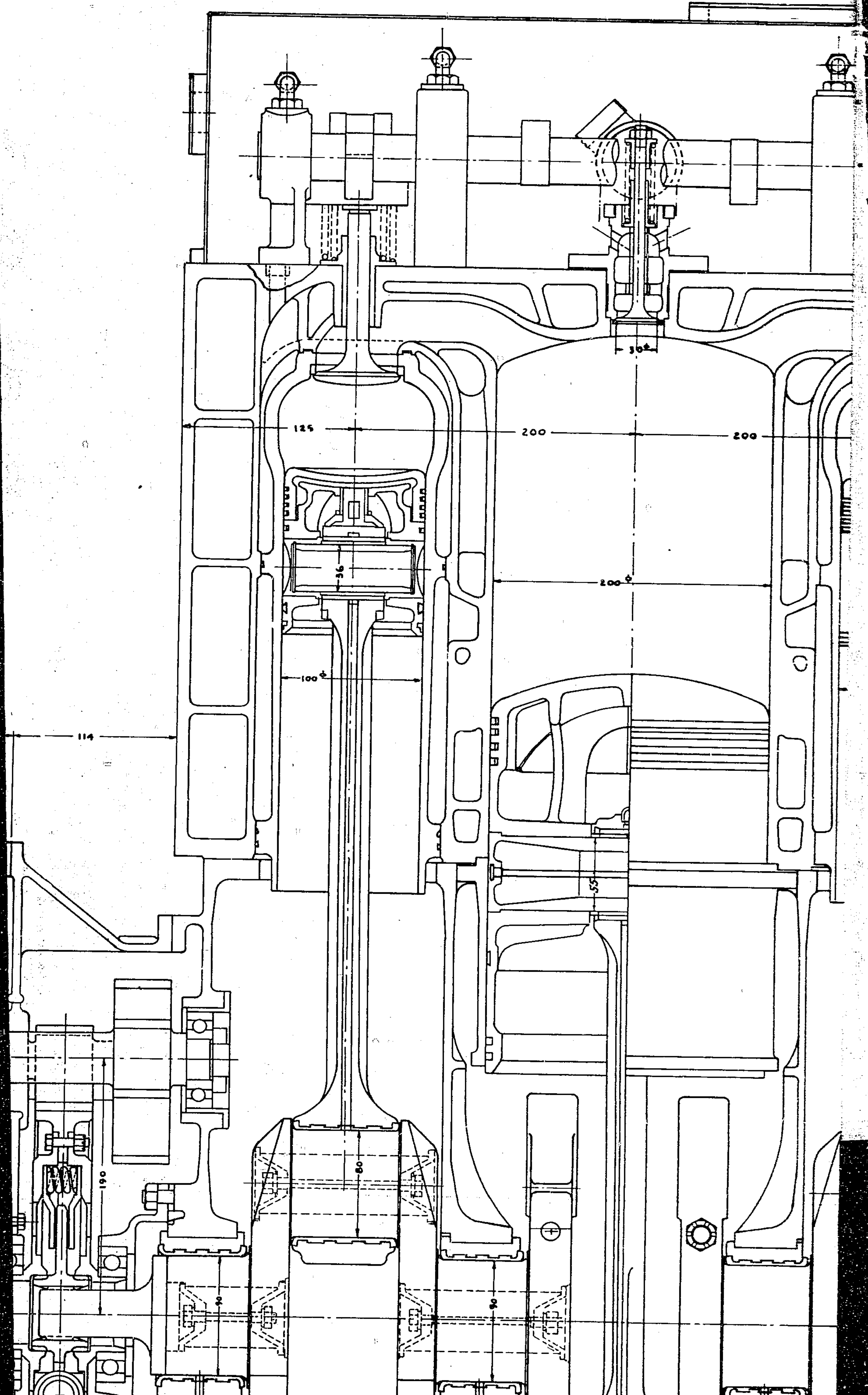
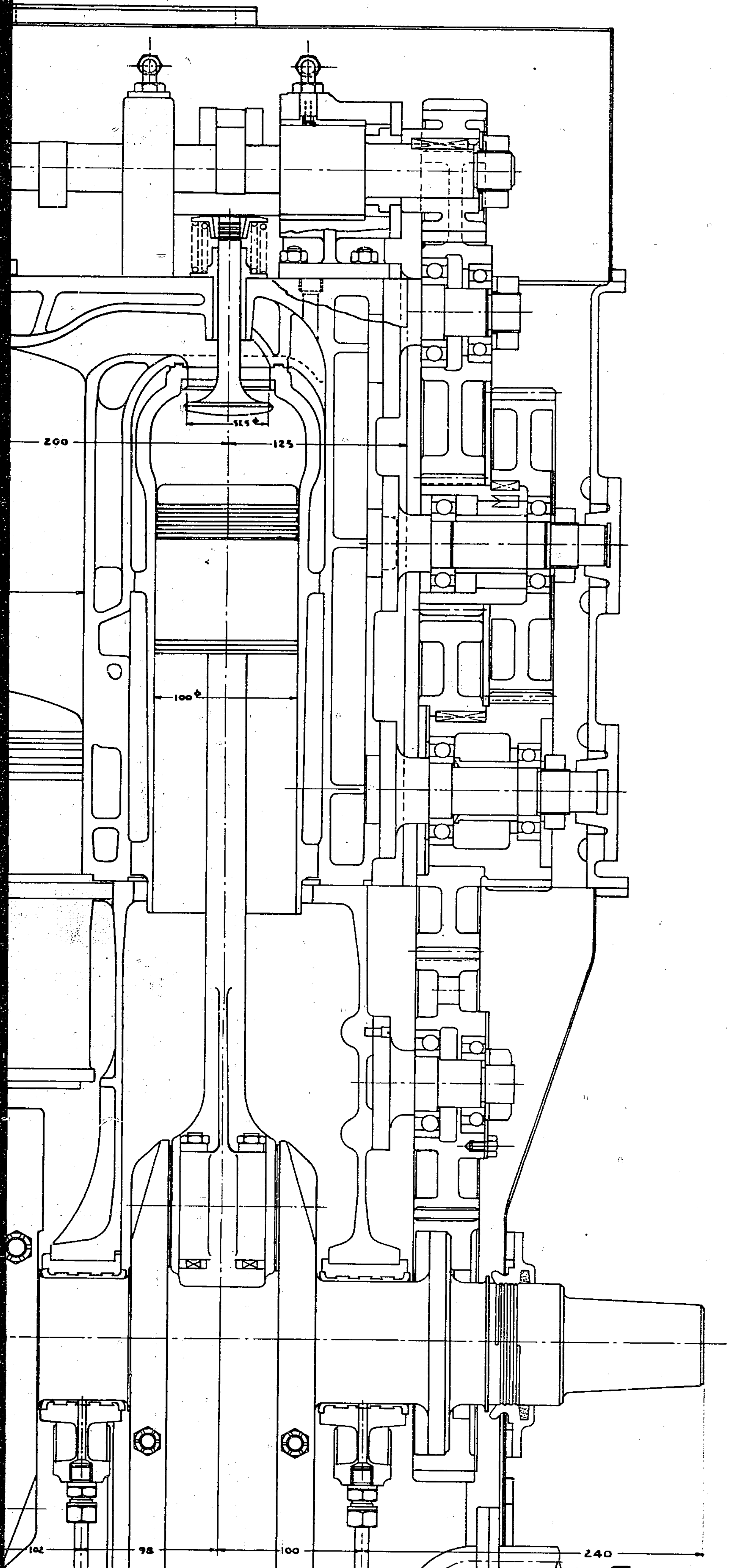
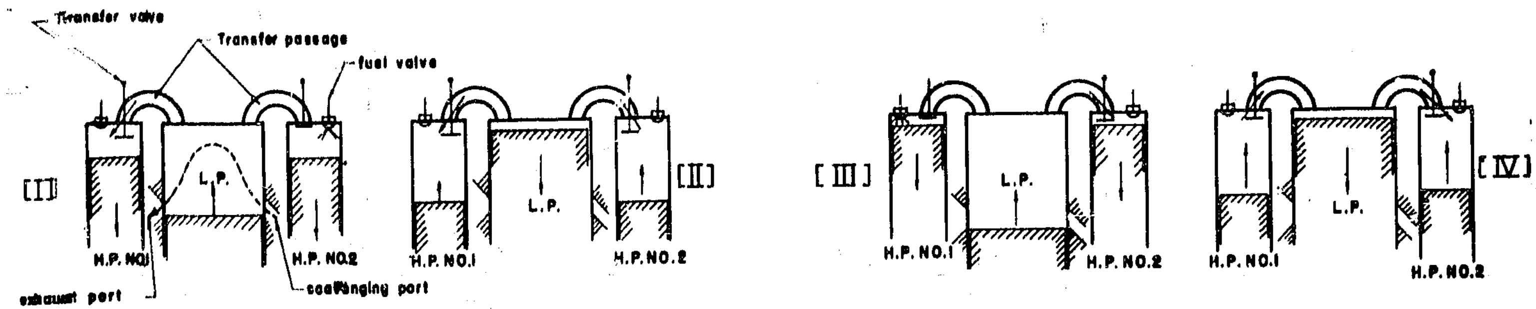


Figure 1(H)
HIGH SPEED SUPERCHARGED COMPOUND EXPERIMENTAL ENGINE


200
125
100
102
98
100
240



CONDITIONS SHOWN IN [I]

CYLINDER	H.P. No. 1	L.P.	H.P. No. 2
Stroke	Suction	Compression	Expansion
Position of Transfer Valve	Open		Closed
Events	Condition of Exhaust Stroke and Start of Suction Stroke	Scavenging Stroke and Beginning of Compression Forcing Air into High Pressure Cylinder No.1	Combustion and Start of Power Stroke

CONDITIONS SHOWN IN [II]

CYLINDER	H.P. NO. 1	L.P.	H.P. NO. 2
Stroke	~~Compression~~	Expansion	Exhaust
Position of Transfer Valve	Opened Slightly		Opened Slighty
Events	Completion of Suction Stroke and Beginning of Compression Stroke	Completion of Compression Stroke and Power Stroke is Begun by Means of Exhaust Gas of No.2 High Pressure Cylinder	Completion of Power Stroke and Start of Exhaust Stroke

Note 1. The Gas Remaining in High Pressure Cylinder No. 2 in Forced Through The Transfer Valve into High Pressure Cylinder No. 1 by The Scavenging Air of High Pressure Cylinder No. 2
2. (III) and (IV) illustrate the conditions existing after the initiation of a Power Stroke in High Pressure Cylinder No. 1.

Figure 2(H)

WORKING PROCESS

ENCLOSURE (I)

TEST DATA ON ZB 35 SINGLE CYLINDER ENGINE
FOR TESTS CONDUCTED ON 1 JULY 1944 AND
COMPUTED VALUES FOR ZC 707 20-CYLINDER ENGINE

(Table of equivalent load characteristics of ZB-35 reduced on ZC-707)

1. Propeller load characteristics of ZC-707 (20-cyl. Engine).

Output	RPM	B.H.P.	
2/10	850	300	Partial load
4/10	1070	600	Partial load
6/10	1220	900	Partial load
8/10	1350	1200	Partial load
10/10	1450	1500	Continuous running allowed
12/10	1540	1800	1 hr. (in type-test 3 hr.)
13.3/10	1600	2000	15 min. (in type-test 1 hr.)

2. Mean effective pressure in ZC-707:

$$Pmi = Pme + Pmb + Pmf$$

Where Pm = Indicated mean effective pressure
Pme = Brake mean effective pressure
Pmb = Mean effective pressure required to drive scavenging blowers (measured in experiment).
Pmf = Friction mean effective pressure (by presumption).
$= 1.5\ kg/cm^2 = 21.3\ lbs/in^2$

Output	RPM	B.H.P.	Pme		Pmb	Pmi	
			Kg/cm^2	lbs/in^2	Kg/cm^2	Kg/cm^2	lbs/in^2
2/10	850	300	2.25	32	0.85	4.60	65.4
4/10	1070	600	3.56	50.6	1.11	6.17	87.7
6/10	1220	900	4.68	66.5	1.34	7.52	107
8/10	1350	1200	5.66	80.5	1.58	8.74	124
10/10	1450	1500	6.58	93.5	1.74	9.82	139.5
12/10	1540	1800	7.45	106	1.89	10.84	154
13.3/10	1600	2000	7.96	113	2.08	11.44	162.4

3. ZB-35 should be tested under the condition that Pmi (indicated mean effective press) is the same as ZC-707.

Friction mean effective pressure of ZB-35 measured by experiment is $2.4\ Kg/cm^2$ ($34\ lbs/in^2$). This is fairly high because ZB-35 is a single cylinder engine and has many accessories such as a balancing weight chamber, feeding pumps for fuel oil, two gear pumps for lube oil, cooling water pump etc. When the scavenging blower is driven by electric motor, the output of ZB-35 will be determined as follows:

Output	RPM	ZC Pmi = ZB Pmi		ZB Pme		ZB-BHP	ZC-BHP
		Kg/cm^2	lbs/in^2	Kg/cm^2	lbs/in^2		
2/10	850	4.60	65.4	2.20	31.3	15	300
4/10	1070	6.17	87.7	3.77	53.6	32	600
6/10	1220	7.52	107	5.12	73	49	900
8/10	1350	8.74	124	6.34	90	67	1200
10/10	1450	9.82	139.5	7.42	105.5	84.5	1500
12/10	1540	10.84	154	8.44	120	102	1800
13.3/10	1600	11.44	162.4	9.04	128.4	113.5	2000

ENCLOSURE (I), continued

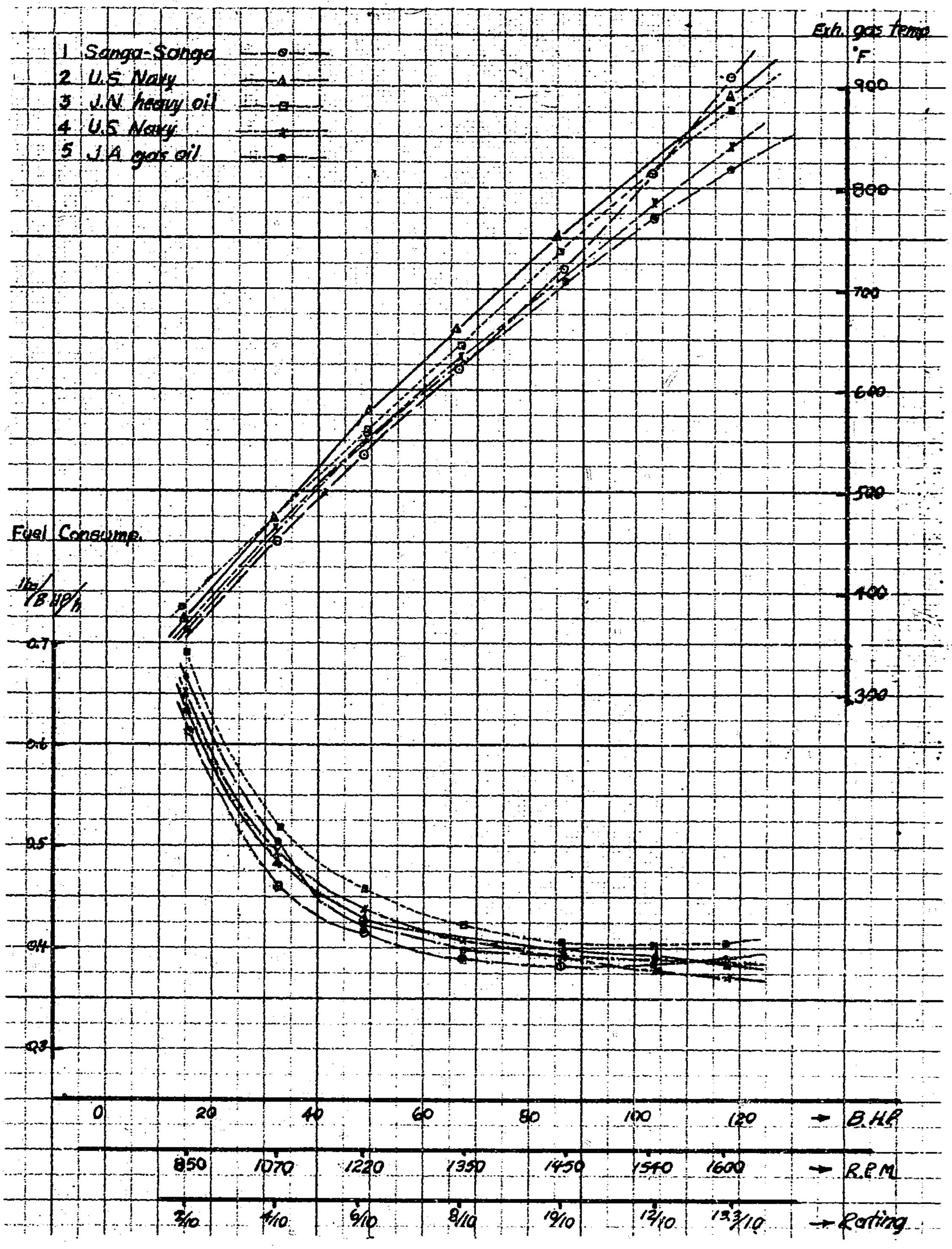


Figure 1(1)

ZB35 SINGLE CYLINDER DIESEL FUEL CONSUMPTION AND EXHAUST GAS TEMPERATURE

	Time	RPM	Integral Counter	Inj. Timing deg. before T.S.C. / lever position in inch	Load W in lbs	Torque M in lbs-ft	Output Ne in hp	Brake Mean Eff. Pr. Pme in lb/in²	Estimated Indicated Mean Eff. Pr. Pme in lb/in²	Fuel sec/0.02642 gallon	Fuel
Saturday 1 July 1944 Atm. press. 298 in. Hg. Room temp. 86°F Start-1610	1618	1200	7141/454.4	0.493	89.5	210	48	73.5	112	30.5	3.
	1625	1400	7151/465.0	0.511	88.4	207	55.2	72.5	111	26.3	3.
	1630	1600	7162/475.5	0.519	88.4	207	63	72.5	111	22.5	4.
	1634	1600	7171/455.0	0.55	110	259	79	90.6	129	19.2	4.
	1637	1600	7179/493.0	0.649	132	310	94.5	109	147.5	16.6	5.
	1640	1600	7185/499.5	0.708	143	336	102.5	118	156.5	15.2	6.
	1643	1600	7193/507.1	0.747	154	362	110.5	127	165.5	14.0	6.
	1645	1600	7195/512.9	0.787	165	388	118.5	136	174.5	13.0	7.
	1650	stop	7207/520.6								
Sunday 2 July 1944 Atm. Press. 298 in. Hg Room temp. 82.6°F Start-1400	1410	850	7308/622.1	0.354	37.5	91.5	14.8	32.1	70.5	65.8	1.
	1415	1070	7318/631.8	0.405	66.2	155	31.5	54.5	93.0	41.0	2.
	1422	1220	7330/643.6	0.491	88.4	207	48.3	72.5	111	29.3	3.
	1427	1350	7341/654.3	0.550	109.5	257	66	90.1	128.5	23.0	4.
	1430	1450	7351/168.5	0.621	128.5	302	83.3	105.9	144	18.4	5.
	1435	1540	7367/680.6	0.700	146	342	100.5	120	159	15.3	6
	1440	1600	7379/683.2	0.789	157	367	112	129	167	13.4	7
	1444	stop	7387/701.2								

Bore .... 5.9 in
Stroke .... 7.88 in
Total volume . 216 in³

TEST DATA OF ZB-35 SINGLE CYLINDER ENGINE

Fuel Consumption				Injected Quantity of Fuel per Cycle q in^3/cycle	Fuel Press.		Fuel Temp. After Prim. Filt. t_{f1} in °F	Lub Oil				Weight of lub. oil tank in lb.	Water Temp. (°F)		Sc Ai
								Press. (lb/in^2)		Temp. (°F)					
sec/0.02642 gallon	Q gallon/hr	Net Fuel Consump. Rate Be in lb/hp hr	Est. Indicated Fuel Consump. Rate Bi in lb/hp hr		After Primary Filt. Pt_1 in lb/in^2	Before Secondary Filt. Pt_2 in lb/in^2		High Pe_1	Low Pe_2	Before charging pump tl_1	After discharging pump tl_2		Before circulating pump tw	Outlet of eng. tw2	Pressure P_a in in. Hg
30.5	3.14	0.459	0.299	0.0101	14.22	28.5	110.4	49.9	28.5	150	153.5	291	154.3	156	16.5
26.3	3.60	0.450	0.299	0.00995	14.22	34.6	125.6	49.9	28.5	160.6	158	292	158	165	21.5
22.5	4.22	0.467	0.306	0.0102	14.22	39.9	129.3	49.9	28.5	161.5	151	286	167	167	26.4
19.2	4.95	0.435	0.306	0.0119	14.22	39.9	133.0	49.9	28.5	161.5	151	286	170.5	170.5	27.1
16.6	5.72	0.420	0.310	0.0128	14.22	39.9	136.5	48.5	27.0	162.5	151	286	172.2	172.2	27.8
15.2	6.25	0.421	0.317	0.0151	14.22	39.9	136.5	48.5	27.0	164.2	150	286	172.2	172.2	27.8
14.0	6.78	0.426	0.326	0.0163	14.22	39.9	138.2	48.5	27.0	166	150	286	167	169	27.7
13.0	7.32	0.429	0.335	0.0176	14.22	39.9	138.2	48.5	27.0	166.8	150	286	163.5	169	27.8
65.8	1.44	0.681	0.308	0.00655	12.82	17.1	124.9	49.9	21.4	160	160.6	299.5	161.5	161.5	10.4
41.0	2.32	0.514	0.299	0.00835	12.82	25.6	124.9	45.6	25.6	156	166	299.5	163.5	164	16.3
29.3	3.24	0.466	0.306	0.00840	14.22	28.5	128.4	48.5	27.0	158	167	299.5	169	169	17.4
23.0	4.14	0.435	0.304	0.0118	14.22	31.4	132.0	48.5	27.0	159	170.5	301.5	172.2	172.2	19.8
18.4	5.16	0.431	0.313	0.0138	14.22	32.1	134.9	48.5	27.0	152.5	171.5	301	169	170.5	23.3
15.3	6.20	0.429	0.326	0.0155	14.22	32.1	136.4	56.3	28.5	148	150	301	167	167	26.9
13.4	7.09	0.440	0.339	0.0171	14.22	37.0	138.1	56.3	28.5	148	150	300.5	170.5	172.2	28.7

Nozzle
0.01495" x 4 x 140'
(edge removed)
pump No. 3

* Slightl
** Slightl
*** Slightl

INLER ENGINE

Water Temp. (°F)		Scav. Air (°F)		Exhaust Gas			Flow Meter				
Before circulating pump tW	Outlet of eng. tW2	Pressure P_s in in. Hg	Temperature ts	Pressure P_e in in. Hg	Temp. te in °F	Color	Pressure at inlet $P - P_1$ in in. Hg	Pressure diff. $P_1 - P_2$ in in. Hg.	Temp. at inlet t in °F	Flow G in lb/sec	Rev. of roots blower Ne in RPM
154.3	156	16.5	124	1.3	568		1.93	7.45	88.7	0.298	355
158	165	21.5	133	1.69	607	*	2.60	10.15	88.7	0.347	410
167	167	26.4	147	2.01	658	*	3.27	12.68	88.7	0.384	450
170.5	170.5	27.1	161.5	2.09	764	**	3.27	12.68	88.7	0.384	455
172.2	172.2	27.8	174	2.16	857		3.23	12.5	88.7	0.382	445
172.2	172.2	27.8	180	2.12	907		3.31	12.75	89.6	0.387	450
167	169	27.7	184	2.12	965		3.31	12.9	91.5	0.387	450
163.5	169	27.8	188	2.08	1017		3.31	12.95	92.4	0.399	450
61.5	161.5	10.45	125.5	0.98	329	*	1.1	3.74	86	0.212	253
63.5	164	16.3	127.5	1.14	374	*	1.57	5.40	86	0.254	315
69	169	17.4	134.5	1.3	446	*	2.09	7.65	87	0.315	260
72.2	172.2	19.8	143.5	1.77	564	*	2.52	9.35	87.8	0.334	390
69	170.5	23.3	161.5	2.08	653	***	2.95	11.0	89.6	0.360	420
67	167	26.9	179.5	2.36	717	*	3.34	12.5	91.5	0.380	445
70.5	172.2	28.7	196	2.48	798	*	3.58	13.0	93.3	0.386	455

* Slightly grey blue
** Slightly blue
*** Slightly grey

…eter		Rev. of roots blower Ne in RPM	Theoretically required air quantity Gn in lb/cycle	Flow per cycle Gs in lb/cycle	Residual fresh charge A in lb/cycle	Apparent excess air ratio	True excess air ratio	Charging air ratio K	Room Temp. (°F)	
Temp. at inlet t in °F	Flow G in lb/sec								Dry bulb	Wet bulb
88.7	0.298	355	0.00435	0.0149	0.00946	3.42	2.17	1.65	100.5	18.4
88.7	0.347	410	0.00426	0.01482	0.00783	3.48	2.30	1.65		
88.7	0.384	450	0.00437	0.0144	0.00785	3.27	2.25	1.60		
88.7	0.384	455	0.0051	0.0144	0.00985	2.82	1.93	1.60		
88.7	0.382	445	0.0059	0.0143	0.00976	2.42	1.65	1.59		
89.6	0.387	450	0.00645	0.0145	0.00970	2.24	1.50	1.61		
91.5	0.387	450	0.0070	0.0145	0.0098	2.06	1.39	1.61		
92.4	0.399	450	0.00735	0.01456	0.00975	1.93	1.29	1.62		
86	0.212	253	0.0028	0.01495	0.00872	5.33	3.18	1.65	96.0	83.4
86	0.254	315	0.0036	0.0142	0.00925	3.95	2.57	1.57		
87	0.315	260	0.0044	0.01486	0.0095	3.38	2.16	1.64	97.6	84.2
87.8	0.334	390	0.00506	0.01482	0.00961	2.93	1.87	1.63		
89.6	0.360	420	0.00588	0.01488	0.0098	2.53	1.66	1.64	104.0	86.0
91.5	0.380	445	0.00665	0.01479	0.00986	2.22	1.48	1.63		
93.3	0.386	455	0.0073	0.0145	0.00975	1.98	1.33	1.58	105.9	87.9

$$\lambda = \frac{G_s}{G_n} \qquad \lambda = \frac{A}{G_n}$$

$$K = \frac{G_s}{\text{Wt. of atm. air with vol. of piston displ.}}$$