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METALLURGICAL EXAMINATION OF JAPANESE SAKAE-12, ENGINE No. 124676

Originating Agency:

NATIONAL DEFENSE RESEARCH COMMITTEE OF OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT WAR METALLURGY DIVISION

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METALLURGICAL EXAMINATION OF JAPANESE SAKAE-12, ENGINE NO. 124676

Reported by

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J.R. Cady
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Originating Agency

National Defense Research Committee of Office of Scientific Research and Development, War Metallurgy Division.

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE,
32, Bryanston Square, London, W.1.

Metallurgical Examination of
Japanese Sakae-12 Engine. No. 124676

February 12, 1945

From:
BATTELLE MEMORIAL INSTITUTE

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FOREWORD

A Japanese Sakae-12 aircraft radial engine, Serial No. 124676, was received from the Technical Air Intelligence Center at the Naval Air Station, Anacostia, D. C., for metallurgical examination. The designation CEE 20505 was assigned by the Navy and BMI 704 by Battelle Institute. The engine was captured on Saipan in June, 1944. It was mounted on a wooden cradle of Japanese origin, and appeared to have been removed from a repair station rather than a Japanese airplane. The following information was supplied by the Foreign Economic Administration:

Name of Manufacturer: Nakajima Hikoki K.K.

Estimated Date of Manufacture: November or December, 1943.

The information obtained in the examination of this engine has been compared in detail with that obtained from the examination of Sakae-12 Engine No. 121592 and Engine No. 2842 examined by Pratt and Whitney.

The engine examined by Pratt and Whitney was reported to be a Sakae-12, but probably was a Type 99-950 HP Japanese Army engine closely related in design to the Sakae-12 Japanese Navy Engine. Where duplicate data are given, they are recorded under the serial number of the engine tested.

SUMMARY

A study of the Sakae-12 engine examined for this report revealed a number of changes in material and some changes in manufacturing methods over those employed in Sakae engines of earlier manufacture.

The steels used were clean, of electric furnace quality, and nearly all were alloyed. Molybdenum and chromium were the most commonly used alloying materials, and these were found in nearly all of the steels. High nickel contents were found in nearly half of the steels, although

the number of applications where nickel steels were used was reduced by half, in comparison with earlier engines. Nickel in amounts up to 0.5% in the replacement steels appeared to be residual from the use of alloy scrap. The use of large quantities of scrap in making the steel was also indicated by high copper and tin residuals. Tungsten probably was added as an alloying material in the master rods and articulated rods. That vanadium was not found in the structural steels was in line with previous observations on Japanese alloys. Manganese showed a reverse trend from the previously observed low values in those steels where nickel had been reduced; it was definitely added as an alloying element in some of these steels. Silicon appeared to have been the primary deoxidant in the steels, although in some of them aluminum was used as well.

Aluminum alloys for both forging and casting were similar to those used in American practice. The nickel content of the "Y" alloy, commonly used for the cylinder head, was replaced with twice the quantity of silicon. The cylinder head showed excellent casting practice, and did not appear to have softened unduly at engine operating temperatures. Magnesium alloys were used only in the diffuser and the small accessory gear housing. These alloys contained aluminum but no zinc, as is customary in German and American practice.

The main roller and ball bearings were made from steel similar to SAE 52100; they were forged, correctly heat treated, accurately machined, and ground. Sleeve bearings were cast-bronze, leaded-bronze, copper-lead, nickel-bronze, leaded nickel-bronze, wrought duralumin similar to Alcoa 17S, cast aluminum alloy with tin and copper additions, and tin-antimony. This variety of bearing materials showed careful selection and attention to the needs of individual applications. Most of the sleeve bearings, including those made from aluminum-base alloys, were held in place with bronze pins.

The aluminum bearings have high thermal expansion and low yield strength. If a correctly sized bearing is made at room temperature, it is liable to upset at the engine operating temperature with a resulting permanent deformation. Aluminum-tin alloys stand up well at high speed and under a light load where the temperature change is not great.

Fabrication practices did not show any great changes when compared with those used in earlier engines. Excessive machining allowances were still used for some steel forgings with the resulting end grain and poor directional properties where it occurs. Cold-drawn valve springs were substituted for heat-treated springs. Small unimportant parts, such as washers, continued to be made by machining from bar stock.

An examination of the heat treatment employed showed a wide use of case hardening, nitriding, and, in one case, induction hardening. These were usually applied over a fully hardened core structure. The heat treatment was occasionally inconsistent, as some nuts were observed to be quenched and drawn, while the bolts were not. The white layer was not always removed from nitrided parts as in the case of the sun gear, while the core structure was too soft for the hardened nitrided core on the cylinder barrels.

The surface finishes of highly stressed parts continued to be good, although not as much care was taken as with earlier engines. Cadmium plating continued to be used extensively for corrosion protection of steel and brass parts, although it was replaced by zinc for the impeller shaft and omitted entirely from the springs in the spring-loaded gear. Chromium plating was used to prevent wear of the piston compression rings and to prevent galling of the master rod bearing.

ECONOMIC CONSIDERATIONS

The lavish and wasteful use of alloying metals was corrected to some extent in this engine. In many of the more important parts the nickel content of the steel had been reduced, in some cases to the point where only residual nickel was indicated. To compensate for this, the chromium content for most of the parts had been increased, a significant increase in carbon content was noted, and many of the steels carried molybdenum, manganese, and silicon as well. The net result is that Japanese aircraft steels are still more highly alloyed than their American counterparts.

These changes indicate that the Japanese have started making the same changes that the Germans made in 1940 and 1941. They do not go all the way, however, and adopt German practice as of December, 1943. The high alloy content of the Japanese aircraft steels still leaves considerable savings to be made in the conservation of strategic metals without an appreciable sacrifice of performance.

In addition to the nickel savings in steel, nickel was eliminated in the aluminum-alloy cylinder head, and nickel-bronze was replaced with copper-tin and copper-zinc alloys in the valve guides and tappet assembly. Zinc was substituted for cadmium plating, and steel for the aluminum-bronze in the counterweight of earlier engines. These changes are in line with correct conservation practices.

DISCUSSION OF RESULTS

The Sakae Engine No. 124676 is shown as-received in Figure 1. All of the parts were examined for hardness, microstructure, cases, coatings, and fabricating methods. The ferrous parts were spark tested, and selected parts were analyzed for chemical composition. The Japanese markings appearing on the various parts are recorded in Table 11. Detailed information on the individual parts is given under the various engine section headings. Usually this information is in the form of tabulated analytical data, tabulated metallurgical data, and a written discussion covering the important parts.

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February 16, 1945

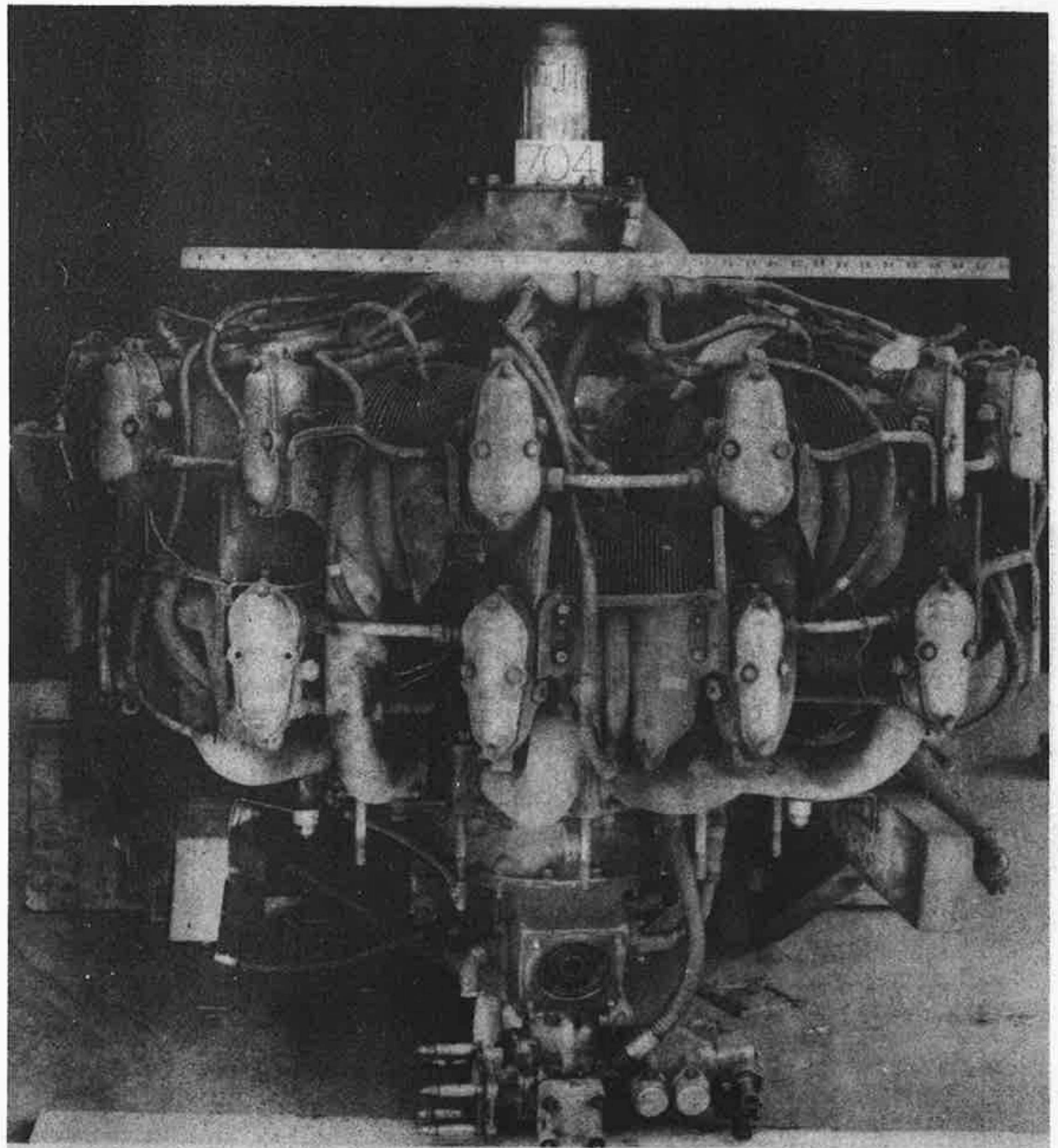


Figure 1. 33048

Japanese Sakae-12 Radial Engine No. 124676 (CEE 20505).
Aircraft Engine Captured on Saipan, June, 1944.

POWER SECTION

By Morse Hill

The power section of this Japanese Sakae-12 was not greatly different from that of an engine of earlier serial number.

The small differences which did exist are discussed under the headings of stationary or crankcase parts, rotating or crankshaft parts, and reciprocation or rod parts. The details of the individual parts and their analyses are shown in Tables 1 and 2.

Crankcase Section

A three-section crankcase was used (Figure 2). Inset backing rings supported the main roller bearings. An aluminum alloy of the Alcoa 17S type was used in the solution heat-treated and aged condition for the crankcase; this practice appeared to be customary for most Japanese engines. The solution treatment, as shown by undissolved microconstituents, was not so complete as in other crankcases previously examined. The flow lines, as usual, for the aluminum forgings conformed well to the contour of the piece and indicated extensive breakdown of the original structure. The backing rings for the main bearings were evenly carburized. The bearings had been evenly and fully hardened.

Attached to the crankcase were two baffles for directing the flow of oil. They were cast from a high (5 to 10%) silicon, aluminum alloy, and had not been heat treated. The cylinder studs which were set into the crankcase were cadmium plated after machining from bar stock. They appeared to have been uniformly heat treated in such a way as to produce a homogeneous microstructure. Hardness was uniform within a range of 5 points on the Rockwell "C" scale.

Crankshaft

The manufacture of the crankshaft followed the usual practice of forging nearly to shape, machining, and carburizing the throws. The flow lines of the forward section of the shaft (Figures 3 and 4) were the first observed in this part and did not reasonably follow the contour of the part; that is, the flow lines in the web between the main bearing and the throw were all parallel to the lines in the long center portion. The carburized area conformed to the throws well, and it was quite uniform in depth and hardness. Apparently, the bearings functioned well, for there was but little scratching or scoring of the bearing surface of the crankshaft. The analysis was one of the few found in this part which used less than 4% nickel. The crankshaft bolts also showed less nickel than has been frequently found.

Different from some other early Sakae engines, but similar to late Japanese practice, was the use of steel for the counterweights. Probably because stresses are low, the steel had not been heat treated after forming.

Rods

The master articulated rods and retaining pins were similar to those found in other Japanese engines. The materials used were of the same type as those used in other engines. The rods were heavily marked in the web after the Japanese custom, but were smoothly finished on the outside surfaces. Piston pins and knuckle pins were also similar to those reported earlier for this model of engine. Nitriding of knuckle pins is uncommon in most Japanese engines, although several of the Sakae engines have followed this practice. The nitrided case was even and had been ground so that all or the white layer was removed.

Master Rod Bearing

The master rod bearing was a cast copper-lead alloy, approximately .024" thick, with a comparatively coarse dendritic structure and some lead segregation. No lead plating or other surface treatment to prevent corrosion of the copper-lead alloy was observed, although it has been used in other Japanese engines. The plating may have been removed by wear, as some scoring was observed. The copper-lead alloy was cast against a thin steel shell, which in turn was keyed through a side flange to the master rod, a single key being used., Both the steel bushing and the surface of the master rod against which it was placed were ground and highly polished. The care used in finishing these surfaces may have been intended to insure a tight fit and to decrease fretting; however, fretting had occurred on both the master rod and the steel bushing. The fret marks were very uniform on both surfaces and followed a pattern, which may have been caused by chatter marks in grinding or by engine vibration. It is generally necessary to prevent movement between the parts in order to eliminate fretting. Dissimilar materials usually show less fretting, as do surfaces which are intentionally roughened by grit blasting.

Pistons

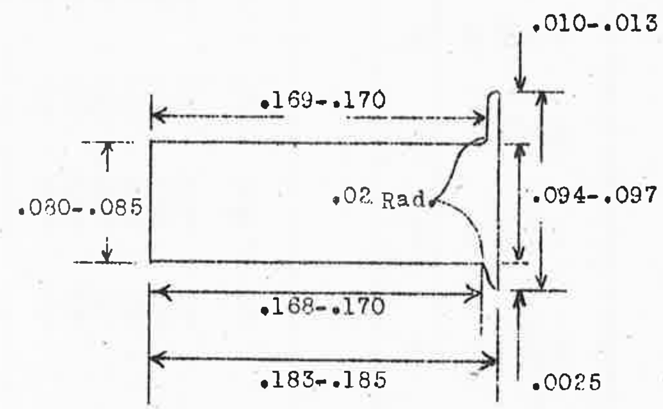
The pistons were but little different from those of other engines, although the heat treatment had been unusually successful in producing high hardness, which was retained in the skirt of the piston. The customary softening was noted in the crown. Examination of pistons from this and several other engines indicated that cast blanks may have been press forg

*Examination made by Rustay of Wyman Gordon Company

to the final shape. Press forging was indicated by the internal smoothness of the piston. Even deep in the waffle pattern, no machining marks were evident. The microstructure indicated the use of cast blanks. The copper constituent was not broken down so much as it would be in rolled billets, but rather retained a suggestion of dendritic forms. Also, the distribution of the copper compound was less even than would be expected in a piece which had been broken down by rolling or extruding.

Piston Rings

The piston rings were the most unusual feature of the whole power section, in that their shape was different from that of other rings examined and that several were found to be broken. The cross-section showing the shape of the piston ring appears as follows:



Dimensions in Inches

The shape suggests that the ring may have worn to this contour, but the measurements obtained on several rings from different places and different pistons indicated that the section shown was intentional, and, since the large rim was uniformly on the skirt side of the ring, it seemed probable that this design was intended as a scraper. Nothing in the metallurgical structure of the broken rings indicated the nature of the material as a cause of failure. The rings fitted rather loosely in the slots. This type of ring was used for the two top rings and for some of the bottom rings.

MH:ic
February 17, 1945

TABLE 1. ANALYSES OF PARTS FROM THE POWER SECTION OF SAKAE-12 AIRCRAFT ENGINE NO. 124676 (CEE 20505)

A - Ferrous Parts

BMI		Chemical, %			Spectrographic, %								
No.	Name	C	P	S	Mn	Si	Ni	Cr	W	Mo	Cu	Sn	Al
46	Crankshaft, No. 124676	.22	.028	.018	.96	.31	2.08	2.01	.06	.42	.33	.082	--
	Crankshaft, No. 121592	.17	.031	.015	.53	.31	3.91	1.57	1.03	.16	.24	.051	.019
	Crankshaft, No. 2842	.26	.026	.041	.49	.29	3.78	1.64	?	-	-	-	-
47	Crankshaft Bolt	.29	.020	.021	.57	.23	.37	2.27	.04	.24	.20	.059	.012
54	Piston Pin	.25	.017	.023	.41	.22	2.15	1.90	.05	.27	.26	.063	.009
55	Master Rod	.29	.019	.016	.54	.23	3.34	1.52	.15/ .25	.40	.27	.046	.005
56	Articulated Rod	.28	.028	.017	.53	.34	3.13	1.35	.15/ .25	.43	.26	.042	.010

B - Nonferrous Parts

		P	Mn	Zn	Si	Ni	Pb	Cu	Sn	Al	Fe	Mg
59	Front Crankcase	-	.47	--	.20	--	--	3.56	--	Bal.	.32	.48
60	Piston	-	02	--	.28	2.12	--	4.38	--	"	.49	1.50
65	Master Rod Bearing	.014	--	-	--	1.26	31.1	65.9	--	.29	.80	--
66	Piston Pin Bearing	.29	--	.23	--	--	--	88.01	11.22	--	--	--

TABLE 2. DETAILS OF PARTS OF POWER SECTION OF JAPANESE SAKAE-12 AIRCRAFT ENGINE NO. 124676 (CEE 20505)

Part No.	Name	Wt., Grams	Pieces, No.	VDH	Type of Material *	Heat Treatment and Remarks
44	Crankshaft Counterweight	6800	2	160	Steel, little alloy.	Annealed; forged slightly: polished surface. Engine No. 121592 had a brass counterweight.
-1	Counterweight Rivets	400	8	155	Ditto	annealed; bar stock; turned surface.
46	Crankshaft					
-2	Front Section	9100	1	Core 383 Case 590 to 650	2% Ni, 2% Cr, .5% Mo.	Quenched & stress relieved after carburizing. Forged, poor flow lines; ground in bearing areas only; Cd plated on exterior surfaces.
-3	Center Section	13600	1	Core 375 Case 590 to 650	Ditto	Quenched & stress relieved after carburizing. Forged, good flow lin(); 185,000 p.s.i. Ult. S., 140,000 p.s.i. Y.S. 47% R.A., and 15% El.; carburized 1/16" in throws.
-4	Rear Section	9100	1	Core 388 Case 590 to 650	Ditto	Ditto
-5	Retainer Nut	78	1	350	Alloy steel, .25 to .3% carbon.	Quenched & drawn; bar stock; Cd plated.
-6	Oil Tube	18	1	298	Low C steel.	Structure from drawing; drawn tubing; swaged in place.
-7	Spline	480	1	375	Alloy steel.	Quenched & drawn; forged.
47	Crankshaft Bolts	460	2	383	2% Cr, .4% Ni, .25% Mo.	Quenched & drawn; bar stock; probably tightened beyond yield strength.
-8	Nuts for Bolts	57	2	372	Similar to bolts.	Quenched & drawn; bar stock.
-9	Locknuts for Bolts	21	2	371	Med. C steel.	Quenched & drawn; bar stock.
54	Piston Pin	360	14	Core 450 Case 770	2% Ni, 2% Cr, .25% Mo.	Quenched & lightly drawn; bar stock; ground surface had picked up bronze from bearing.
-10	Piston Pin Plug	31	28	115	Al with 4% Cu	Bar stock; heat treated and aged.
55	Master Rod	400	2	360	3.5% Ni, 1.5% Cr, .5% Mo.	Quenched & drawn; forged, usual flow lines; markings stamped moderately deep in center section.
56	Articulated Rod	790	12	339	Ditto	Ditto

Table 2. Details of Parts of Power Section of Japanese Sakae-12 Engine No. 124676 (Continued)

BMI No.	Name	Wt., Grams	Pieces, No.	VDH	Type of Material*	Heat Treatment and Remarks
59	Crankcase					
-11	Front Section	15300	1	84	Similar to Alcoa 17S.	Sol'n heat-treated and aged; forged, usual flow lines; painted gray-green outside, hand-scraped gasket surfaces.
-12	Center Section	21900	1	81	Ditto	Usual flow lines conforming to shape quite well; sol'n heat-treated and aged.
-13	Rear Section	15900	1	78	Ditto	Sol'n heat-treated and aged; forged, usual flow lines; heat treatment fair.
-14	Connecting Bolts	51	14	372	Alloy steel, .35% C.	Quenched & drawn; bar stock; clean steel.
-15	Baffles	68	2	99	Similar to Alcoa 195.	Cast; heavily blackened with engine varnish, sol'n heat treated and aged.
-16	Cylinder Studs	14	168	356	Alloy steel.	Quenched & drawn; bar stock; uniform hardness, machined threads.
-17	Bearing Backing Rings	59**	3	Core 356 Case 658	Alloy steel.	Quenched & stress relieved after carburizing; forged rings; carburized .015" deep on inner surface.
60	Piston	1660	14	Crown 100 Skirt 150	Similar to Alcoa 356.	Sol'n heat-treated and aged; forged casting, fair flow lines; crown overaged. Skirts well heat treated.
-18	Seal Rings	30		Core 235 Cr 950	Cast iron.	Cast; various structures; several rings broken. Cr plated on outside .002"; rings worn or cut to peculiar shape.
-19	Oil Rings	27		Core 220 Case 968	Cast iron.	No. 121592 Rings 260 VDH, .001" Cr plate. Ditto
65	Master Rod Bearing	320	2	37	Cu-Pb alloy	Cast with fair Pb dispersion; dendritic structure; somewhat worn; not lined with Pb.
66	Rod Bearings	46	53	124	88% Cu, 11% Sn bronze.	Cast with fine structure.
71	Crankshaft Spigot Bearing	320	1	33	Cu-Pb alloy	Cast.
88	Main Bearing, Front	2240	1	658	Similar to SAE 52100.	Quenched and stress relieved; forged.
90	Main Bearing, Rear	2240	1	647	Ditto	Ditto
91	Main Bearing, Center	4540	1	679	SAE 52100 type.	Quenched & stress relieved; forged, dendritic residues; slight indications of chafing on wedging surface.
92	Main Bearing Wedge	390	2	Core 483 Case 657	High alloy, low C steel.	Quenched & stress relieved after carburizing.

Table 2. Details of Parts of Power Section of Japanese Sakae-12 Engine No. 124676 (Concluded)

Part No.	Name	Wt., Grams	Pieces. No.	VDH	Type of Material *	Heat Treatment and Remarks
92						
-20	Wedge Bolts	12	6	326	Med. C steel.	Quenched and drawn; bar stock.
93	Lifting Eye	43	2	363	Med. C steel.	Quenched and drawn; forged; Cd plated.
95	Knuckle Pin	210	28	Core 322 Case 968	Similar to Nitralloy	Quenched and drawn; Bar stock; nitrided less than .01".
-21	Knuckle Pin Retainer	23	10	321	Med. C steel.	Quenched and drawn; bar stock.
-22	Knuckle Pin Retainer	26	10	312	Med. C steel.	Quenched and drawn; bar stock.
-23	Knuckle Pin Plug	1	28	88	Aluminum alloy	As-rolled; rolled or extruded stock.

* While many of these material types were determined by analysis as shown in Table 2. others were determined by spark or microscopic appearance.

** Bearing Backing Rings weighed with the Crankcase - Front Section, Center Section, and Rear Section.

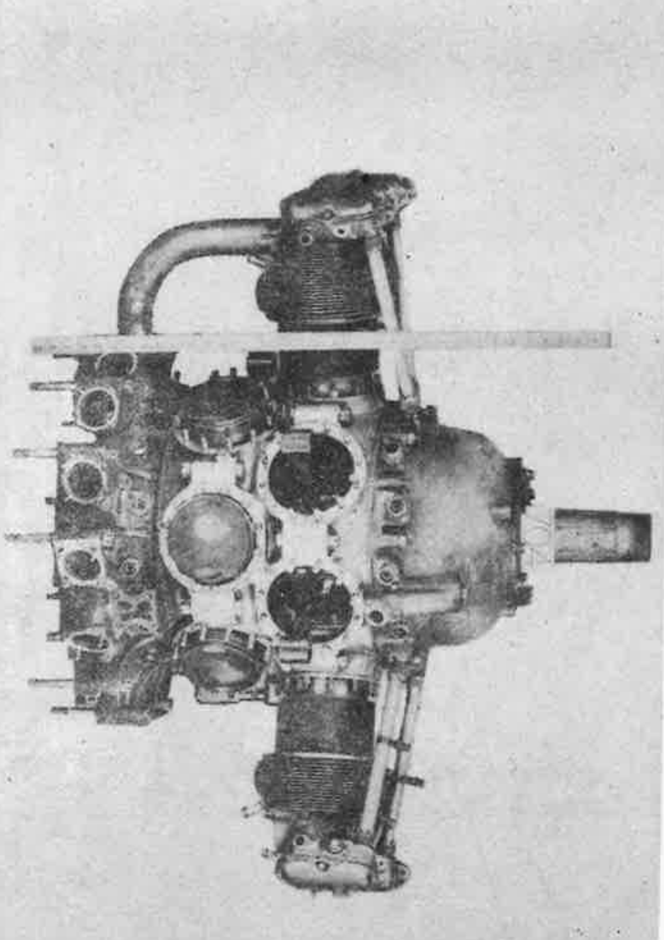


Figure 2. 33176
Partial Disassembly of Sakae-12 Showing Arrangement of Power Section, Blower Case, and Nose Section of Aircraft Engine No. 124676 (CEE 20505).

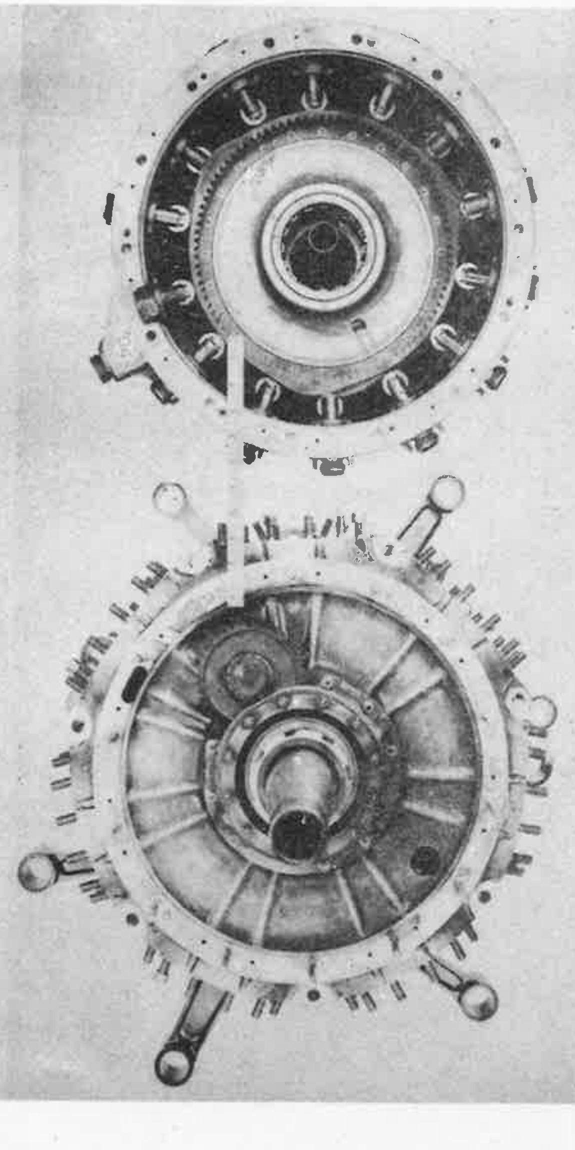


Figure 3. 33228
Front Cam, Push Rod Rollers, and Power Section of Sakae-12 Aircraft Engine No. 124676 (CEE 20505).

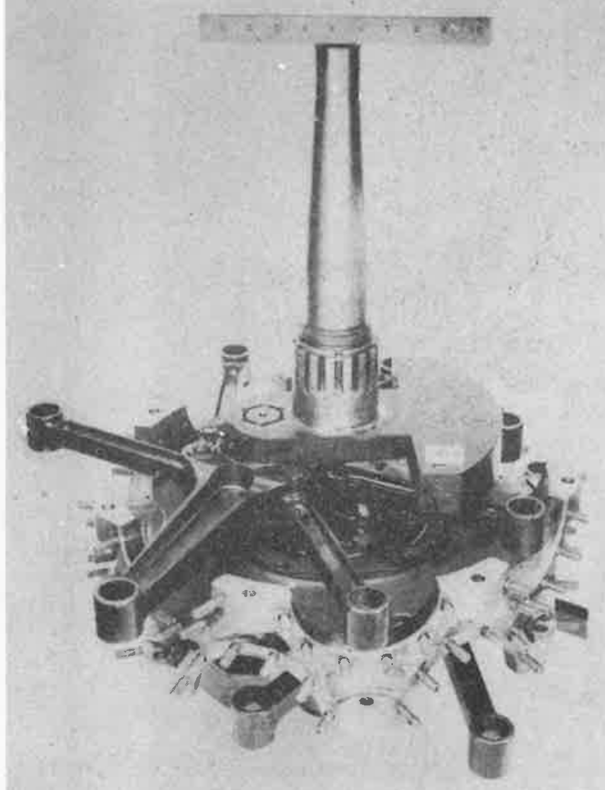


Figure 4. (CEE 20505) 33229
Crankshaft, Crankcase, Master Rod, Articulated Rods, Counterweight, and Main Bearing.

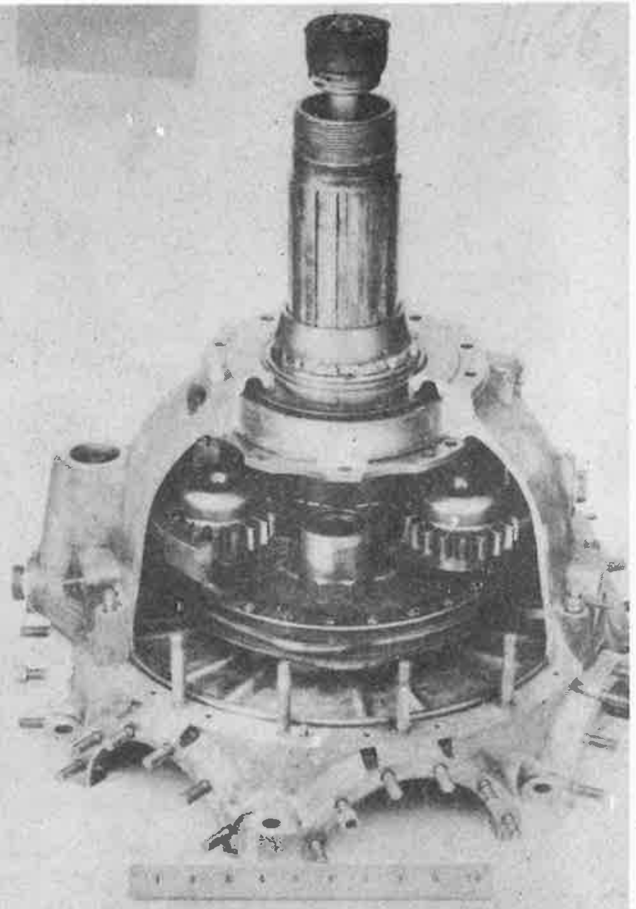


Figure 6. (CEE 20505) 33233
Nose Assembly: Propeller Shaft and Bearing, Reduction Gearing, Cam, and Crankcase.

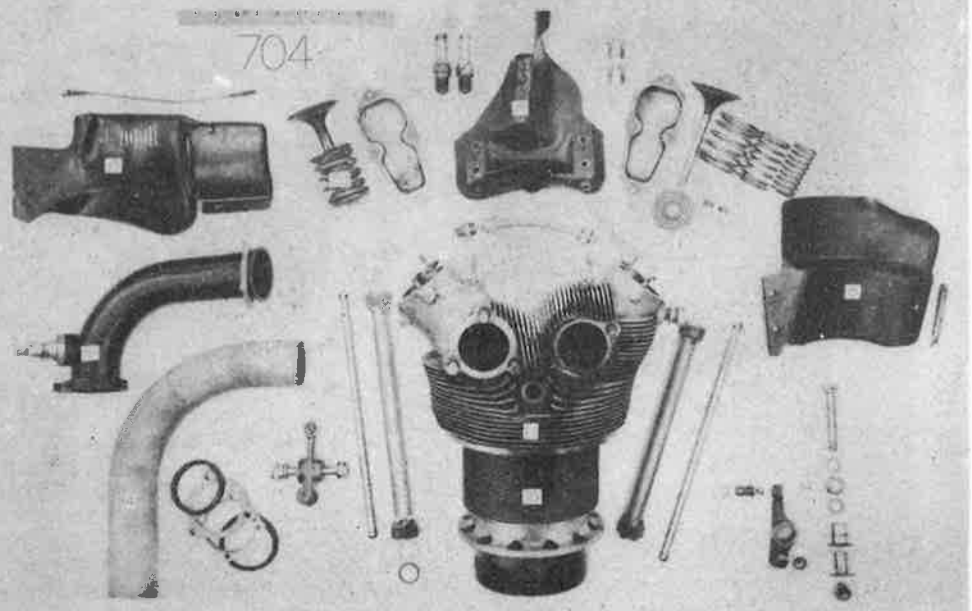


Figure 5. Disassembly of Cylinder Section: Valves, Rocker Arms, Push Rods, Baffles, and Intake Manifold (CEE 20505). 33227

CYLINDER ASSEMBLY

By A. B. Westerman

The disassembled view of the cylinder assembly is shown in Figure 5. Details of the major parts are discussed in the following paragraphs. Analytical data are listed in Table 3, and complete details of construction are given in Table 4.

Cylinder Barrel and Head

The cylinder barrel of the 1943 model was forged from Nitralloy 135 modified steel with low aluminum; that of the 1941 model from Nitralloy 135 Type-G steel. The barrels were quenched and tempered, and the bore surfaces were nitrided to depths of .006/.010". The resulting case and core hardnesses were 995 and 270 Vickers, respectively, for the later model and 942 and 380 Vickers, respectively, for the earlier one. The barrels were fairly well finished and had generous fillets at all changes of sections. The barrels were covered with black paint or enamel with iron-oxide pigment.

The cylinder heads were both sand cast with the use of numerous cores, the 1943 model from a Cu-Si-Mg-aluminum base alloy which is not commonly used in the United States, and the 1941 from the widely used Alcoa 142 alloy. Both cylinder heads were slightly porous; however, in general, the quality and surface finish of these castings were good. Both were solution heat-treated and aged to Vickers hardnesses of 68 and 73 for the 1943 and 1941 models, respectively. No coating was found on the 1943 cylinder head; the earlier one, however, was covered with black paint or enamel with iron-oxide pigment.

The exhaust and intake valve seat inserts of both models were forged from austenitic medium carbon, Ni-Cr-Mn steel, which is not commonly used in this country. The inserts of the 1943 model averaged 191 Vickers hardness; of the 1941 model, 185 Vickers.

Push Rods

The push rod of the 1943 model consisted of two ends machined from SAE 1035 steel, press fitted into low-carbon alloy steel tubing. Each end was carburized to a depth of .04", and was quenched and tempered to Vickers hardnesses of 772 and 204 for the case and core, respectively. The fact that this core hardness was low and that the core was not fully hardened might be attributed to the use of too low a quenching temperature. The tubing was coated with cadmium, and was in the quenched and tempered condition with a Vickers hardness of 414. No push rods from the earlier model were examined.

Rocker Arm

The rocker arm of the 1943 model was forged from SAE 3435 steel and that of the 1941 model from Ni-Cr-Mo steel, and each was quenched and tempered to an average hardness of 344 Vickers. Flow lines representative of good forging practice were revealed by macroetching. Both rocker arms were coated with thin layers of cadmium.

The rocker arm bearings of both models were cast from phosphor-bronze. The Vickers hardness of the 1943 arm was 146; of the 1941 arm, 136.

Valve Springs

The valve springs of both models were fabricated by coiling high-carbon steel wire of circular cross-section. The springs from the later model were in the cold-drawn condition and had hardnesses which ranged from 355 to 457 Vickers, averaging 398. The springs from the earlier

model were quenched and tempered; the hardness were fairly uniform and averaged 532 Vickers.

Structurally, the valves of the Sakae engine were very similar to valves of like function from other Japanese engines which had been examined previously. The intake valve was made from a single piece of steel of the following approximate composition: C .4, Cr 12, Mo 1.2, Si 2.33% (See Table). This steel had been upset from bar stock to form the head. The stem tip had been hardened by heat treatment to 338 VDH. No facing material was used on the valve. It appeared not to have been operated at temperatures which would cause changes in the microstructure.

The exhaust valve was a hollow head, sodium-filled type, formed by forging and machining. A 14% Cr, 14% Ni steel with 4% W, 2% Si, and .35% C similar to AMS 5700 was used for these valves. After the sodium had been inserted, the opening was plugged with a round plug of a material, which appeared to be similar to the intake valve discussed above, and a piece of tool steel attached by welding. The tip had been cut from the end of a bar. The stem had been nitrided, but the hardness was only VDH 520. The seating face of the head was of stellite composition and had been deposited from a welding rod. Its hardness, 495 VDH, was normal for this type of material.

CHEMICAL ANALYSES OF VALVE COMPONENTS

Name	No.	C	Mn	Si	Ni	Cr	V	Mo	Cu	Sn	W		
Intake Valve	16	.41	.42	2.33	.38	11.5	.043	1.22	.17	.008	<.01	Ti	.008
Exhaust Valve	20	.35	.89	2.03	12.5-17.5	14.2	.024	.19	.09	.098	3.60	Al	.041
Exhaust Valve Face	20A	1.53	.18		1.7	22.7					4.96	Co	57.6

Note: Iron is balance in all analyses

CHARACTERISTICS OF VALVES

No.	Name	Hardness, VDH	Type of Material	Remarks
16	Intake Valve	Stem 338	C .41, Cr 11.5, Mo 1.2	Upset from bar; tip of stem hardened.
20	Exhaust Valve	Stem 223	AMS 5700	Stem plugged. Sodium filled, stem nitrided VDH 520, tool steel tipped VDH 519.
20A	Exhaust Seat	495	Stellite 6	Puddled on in even layer.

ABW:MH:rrr
2-21-45

TABLE 3. **ANALYSES OF PARTS FROM CYLINDER ASSEMBLY OF JAPANESE SAKAE-12 ENGINE NO. 124676 (CEE 20505)**

A - Farrous Parts

BMI No.	Name	Chemical, % C	P	S	Spectrographic, % Si	Mn	Ni	Cr	W	V	Mo	Cu	Sn	Al	Ti	Co
704-10	Cylinder Barrel	.40	.032	.057	.40/ .50	.55/ .65	.17/ .23	1.60/ 2.00	<.01	.020/ .035	.27/ .37	.20/ .30	.10/ .20	.60/ .75	<.004	--
704-12A	Push Rod End, No. 124676	.35	.018	.020	.23	.56	.19	.05	<.01	<.02	.03	.28	.037	.015	<.004	--
	Push Rod End, No. 2842	.14	.020	.023	.28	.52	--	.97	--	--	.21	--	--	--	--	--
704-14A	Rocker Arm	.42	.017	.011	.41	.49	2.90	.85	<.01	<.02	.04	.17	.039	.005	.010	--
704-53A	Exhaust Valve Seat Insert	.56	.028	.010	.53	5.4	12.1	3.6	--	--	--	--	--	--	--	Tr.
704-53B	Intake Valve Seat Insert	.63	.029	.011	.38	5.3	12.2	3.5	--	--	--	--	--	--	--	Tr.

B - Nonforrous Parts

BMI No.	Name	Chemical, % Cu	Si	Mg	Mn	Fe	Al	Sn	Pb	Zn	Ni	P
704-11	Cylinder Head, No. 124676	4.0	3.88	1.25	.46	.36	Base	--	--	--	--	--
	Cylinder Head, No. 121592	4.05	.29	1.13	.03	.28	Base	--	--	--	.81	--
	Cylinder Head, No. 2842	3.99	.37	1.42	--	.28	Base	--	--	--	1.63	--
704-67	Rooker Arm Bearing	88.05	--	--	--	--	Nil	11.51	Nil	.13	Nil	.34

TABLE 4. METALLURGICAL DATA ON CYLINDER ASSEMBLY FROM JAPANESE SAKAE-12, ENGINE NO. 124676 (CEE 20505)

BMI No.	Name	Weight (g.)	VDH #124676	VDH #121592	Type of Material	Remarks
704-10	Cylinder Barrel	3300	Case 995 Core 270	942 380	#124676: Nitralloy 135 modified steel with low Al; #121592: Nitralloy 135 type G steel	Forged; quenched and tempered; bore nitrided .006/.010"; covered with black paint
704-11	Cylinder Head #121592;	8200 15,650 for barrel and head	68	73	#124676: Cu-Si-Mg-Al alloy; #121592: Alcoa 142	Sand cast; slightly porous; solution heat treated and aged.
704-11A	Exhaust Valve Guide	121	69	129	#124676: Cu-Sn alloy; #121592: Ni-Pb bronze	Cast and machined.
704-11B	Intake Valve Guide	81	151	115	#124676: Cu-Zn alloy; #121592: Ni-Pb bronze	#124676: Machined from bar stock; #121592: Cast and machined
704-11C	Spark Plug Bushing	35	136	195	#124676: Aluminum bronze, #121592: Cu-Sn alloy	#124676: Machined from bar stock; #121592: Cast and machined
704-11D	Valve Spring Seat	23	164	-	Low C steel	Machined; annealed
702-12	Push Rod Assembly	132				
702-12A	Push Rod Ends	-	Case 772 Core 204	- -	SAE 1035 steel	Machined; carburized .04"; quenched and tempered
704-12B	Push Rod Tube	-	414	-	Low C alloy steel	Tubing; quenched and tempered; Cd coated
704-13	Push Rod Housing	52	110	-	Alcoa 17S type alloy	Tubing; solution heat treated and aged; anodized
704-13A	Push Rod Housing Nuts	17	102	-	Alcoa 24S type alloy	Machined; solution heat treated and aged
704-13B	Push Rod Housing Gasket	-	-	-	Natural rubber	-
704-13C	Push Rod Housing Packing Ring	1	126	-	Alcoa 17S type alloy	Machined; solution heat treated and aged

Table 4. Cylinder Assembly - cont'd

BMI No.	Name	Weight (g.)	VDH #124676	VDH #121592	Type of Material	Remarks
704-14	Rocker Arm Assembly	429	-	-		
704-14A	Rocker Arm #121592	230 288	344	345	#124676: SAE 8435 steel; #121592: Ni-Cr-Mo steel	Forged; quenched and tempered; Cd coated
704-14B	Rocker Arm Shaft Bushing	10	Case 623 Core 308	695 390	Low C alloy steel	Machined; carburized .02/.04" on outer surface; quenched and tempered
704-14C	Tappet Adjusting Screw	20	Case 650 Core 380	695 142	Low C alloy steel	Machined; tappet bearing surface carburized .02/.03" quenched and tempered
704-14D	Tappet	5	743	748	SAE 52100 type steel	Forged; quenched and tempered
704-14E	Rocker Arm Shaft	84	450	-	Low C steel	Machined; quenched and tempered ; head Cd coated
704-14F	Rocker Arm Shaft Nut (Large)	28	210	-	Low C steel and Alcoa 17S type alloy	Nut machined; annealed; Cd plated; plug stamped
704-14G	Tappet Adjusting Screw Nut	8	299	181	Low C Steel	Machined; Cd coated; #124676: quenched and tempered; #121592: annealed structure
704-14H	Rocker Arm Shaft Washer	6	209	-	Low C steel	Machined; annealed
704-14I	Rocker Arm Shaft Nut Washer	5	237	-	Low C steel	Machined; annealed; Cd coated
704-14J	Rocker Arm Shaft Spacer	5	333	-	Low C steel	Machined; quenched and tempered
704-14K	Push Rod Bearing	10	Case 715 Core 297	703 390	Low C alloy steel	Machined; carburized .03/.05"; quenched and tempered
704-15	Baffles	955(for 4)	92	-	Alcoa 17S type alloy	Stamped with low-C steel stamped fittings attached with Alcoa 17S rivets; covered with black paint
704-15A	Baffle Front Studs	20	348	-	Low C steel	Machined; quenched and tempered
704-15B	Baffle Front Nuts	3	175	-	Low C steel	Machined; annealed

Table 4. Cylinde Assembly - Cont'd

BMI No.	Name	Weight (g.)	VDH #124676	VDH #121592	Type of Material	Remarks
704-15C	Baffle Front Washers	1	147	-	Low-C steel	Machined; annealed
704-15D	Baffle Spacer	14	180	-	Low-C steel	Tubing; annealed; Cd plated
704-15E	Baffle Back Clamp	20	193	-	Low-C steel	Machined; annealed; covered with black paint
704-15F	Baffle Back Nuts	4	326	-	Low-C steel	Machined; quenched and tempered
704-15G	Baffle Back Washers	2	140		Low-C steel	Machined; annealed
704-17A	Outer Valve Spring	153 150	383	532	High-C steel	Coiled wire; Cd plated; #124676 cold drawn; #121592 quenched and tempered
704-17B	Inner Valve Spring	66 57	457	525	High-C steel	Coiled wire; Cd plated; #124676 cold drawn: #121592 quenched and tempered
704-17C	Middle Valve Spring	99 93	355	540	High-C steel	Coiled wire; Cd plated; #124676 cold drawn; #121592 quenched and tempered
704-17D	Valve Spring Retainer	70 71	543	483	Low-C alloy steel	Forged; quenched and tempered; Cd plated
704-17E	Valve Clip	2	522	-	High-C steel	Wire; cold drawn
704-18A	Exhaust Valve Retainer Collets	3	519	-	Low-C alloy steel	Machined; quenched and tempered
704-18B	Intake Valve Retainer Collets	3	525	-	Low-C alloy steel	Machined; quenched and tempered
704-21	Rocker Box Cover	95	76	-	Alcoa A108 type alloy	Die cast; as-cast condition; slightly porous
704-21A	Rocker Box Cover Studs	8	331	-	Low-C steel	Machined; quenched and tempered
704-21B	Rocker Box Cover Nuts	3	167	-	Low-C steel	Machined; annealed
704-22	Spark Plug	Similar to spark plug (BMI No. 441) described in OSRD Report No. 4125				

Table 4. Cylinder Assembly - Cont'd

BMI No.	Name	Weight (g.)	VDH #124676	VDH #121592	Type of Material	Remarks
704-23	Rocker Box Oil Line	48	133	-	Low-C steel	Tubing with machined fitting brazed on one end; annealed; Cd plated
704-23A	Rocker Box Oil Line Nut	21	258	-	Low-C steel	Machined; quenched and tempered; Cd plated
704-23B	Rocker Box Oil Line Fitting	22	131	-	Cu-Zn alloy	Machined; Cd plated
704-23C	Rocker Box Oil Line Gasket	-	-	-	Natural rubber	-
704-24A	Intake Manifold (Long)	370	115	-	Alcoa 17S type alloy	Sheet bent into tubing and gas welded along seam; weld on outer surface of seam ground; ring, formed by gas welding two Alcoa 17S stampings, gas welded to one end of tubing; other end of tubing crimped; damaged spot on tubing repaired by welding
704-24B	Intake Manifold (Short)	490	133	-	Low-C steel	Sheet bent into tubing and gas welded along seam; weld on outer surface of seam ground; fitting, machined from low-C steel, brazed to tubing; one end of tubing crimped; covered with black paint
704-24C	Intake Manifold(Short) Collar	24	124	-	Alcoa 24S type alloy	Machined; solution heat treated and aged
704-24D	Intake Manifold(Short) Gasket	-	-	-	Natural rubber	-
704-24E	Manifold(Long) Gland.	20	119	-	Alcoa 24S type alloy	Forged; solution heat treated and aged
704-24F	Manifold(Short) Gage Housing	40	107	-	Alcoa 142 type alloy	Cast and machined; slight porosity; solution heat treated and aged

Table 4. Cylinder Assembly - Cont'd

BMI No.	Name	Weight (g.)	#124676	#121592	Type of Material	Remarks
704-24G	Intake Manifold (short) Gage Piston	16	266	-	Low-C steel and Cu-Sn alloy	Machined rod with machined sleeve held in place at one end with bronze pin; normalized
704-24H	Manifold (Short) Gage Hose Connection	13	265	-	Low-C steel	Machined; normalized
704-24J	Intake Manifold (Short) Gage Piston Spring	1	-	-	High-C steel	Coiled wire
704-24K	Intake Manifold (Short) Gage Housing Nut	6	111	-	Alcoa 17S type alloy	Machined; solution heat treated and aged
704-24L	Intake Manifold (Short) Gage Housing Screw	2	187	-	Low-C steel	Machined; annealed
704-24M	Intake Manifold (Short) Gage Housing Washer	1	190	-	Low-C steel	Machined; annealed
704-53A	Exhaust Valve Seat Inserts	120	198	190	Austenitic Ni-Cr-Mn steel	Forged; quenched and tempered
704-53B	Intake Valve Seat Inserts	110	183	179	Austenitic Ni-Cr-Mn Steel	Forged; quenched and tempered
704-67	Rocker Arm Bearing	36	146	136	Phosphor bronze	Cast

NOSE SECTION

By F. M. Stephens, Jr.

The nose section assembly, containing the propeller shaft, reduction gears, and front cam assembly, is shown in Figure 6. Analyses of the major components in this section are given in Table 5, while complete details of heat treatment, method of fabrication, weights, and hardness are given in Table 6.

Significant differences in composition were noted between the components of this engine and those examined in the Sakae-12 Engine No. 121592

Bell Gear and Sun Gear

The bell gear and sun gear were forged from steel similar to Nitralloy G. The gear teeth and bearing surfaces were nitrided to a depth of approximately .01 inch. Microstructures (Figure 7) showed that the nitrided white layer had been removed from the bell gear, but still remained in places on the sun gear. The case hardnesses were 824 VDH for the bell gear and 927 VDH for the sun gear. Macroetched sections revealed flow lines indicative of good forging practice.

Propeller Shaft

The propeller shaft was forged from steel similar to NE 8630. The use of this steel was a definite departure from former practice where high alloy steels were used. The resulting product showed a VDH of 330 and a tensile strength of 147 000 p.s.i. The physical properties compared favorably with those of the higher alloy steel previously used. Macroetched sections showed excellent forging practice.

Front Cam

The front cam was forged from steel similar to British Standard Aircraft Steel 2S-28. The cam surface and gear teeth were carburized .03" deep, and showed a VDH of 805. The piece showed good workmanship.

Planetary Spur Gear

The planetary spur gear was forged from a steel not commonly used in this country. The steel contained 2.25% chromium, .55% nickel, and .24% molybdenum. The teeth were carburized to a depth of .02" and a VDH of 358. Workmanship was of good quality. Forging flow lines and the carburized core are shown in the macroetched section (Figure 8).

Nose Casting

The nose housing was cast from an aluminum alloy similar to Alcoa A 108, and was in the as-cast condition with a VDH of 77. The casting was somewhat porous.

Cam Bearing

A tin-base babbitt was used for the cam bearing, and was cast on a steel backing plate. The VDH of the babbitt was 26.

FMS:ic
February 17, 1945

TABLE 5. CHEMICAL ANALYSES OF SELECTED NOSE SECTION PARTS FROM SAKAE-12 AIRCRAFT ENGINE NO. 124676 (CEE 20505)

A - Ferrous Parts

BMI No.	Name	Chemical, % C	P	S	Spectrographic, % Mn	Si	Ni	Cr	W	V	Mo	Cu	Sn	Al	Ti
48	Propeller Shaft, #124676	.31	.026	.029	.64	.38	.51	.22	<.01	<.02	.16	.27	.038	.016	<.004
	Propeller Shaft #21327	.22	.013	.012	.47	.20	3.36	1.23	<.01	<.02	.52	.13	.035	.023	<.004
49	Bell Gear	.45	.017	.027	.55	.36	.43	1.72	<.01	<.02	.21	.25	.083	1.15	<.004
50	Planet Gear, #124676	.20	.020	.011	.87	.29	.55	2.25	<.01	<.02	.24	.25	.055	.008	<.004
	Planet Gear, #121592	.18	.018	.014	.61	.22	4.42	.46	<.01	<.02	.17	.25	.095	.012	.006
51	Sun Gear	.37	.033	.028	.46	.29	.26	1.53	<.01	<.02	.21	.25	.056	1.06	<.004
52	Cam	.23	.007	.016	.57	.29	4.08	.97	<.01	<.02	.33	.17	.050	.008	<.004

B - Nonferrous Parts

		Chemical, % Cu	Si	Mg	Mn	Fe	Sn	Zn	Sb	Pb	Al	P	Ni
63	Nose Casting	4.00	4.42	.01	<.01	.44	--	--	--	--	--	--	Nil
59	Cam Bearing*	4.20	--	--	--	--	89.9	.08	5.9	Tr.	Nil	Nil	Nil

* Sn by difference.

TABLE 6. DETAILED DATA ON NOSE SECTION SAKAE-12 ENGINE NO. 124676 (CEE 20505)

Part No.	Name	Wt. (g.)	VDH	Type of Material	Heat Treatment	Remarks
38	Planet Gear Bolt and Shaft	89	312	Low-C steel	Quenched and tempered	Machined from bar stock
42	Propeller Bearing Retainer	650	85	Aluminum ALLOY	Solution heat treated and aged	Cast
43A	Propeller Shaft, Front Oil Seal	670	Core 342 Case 673	Alloy steel	Quenched and tempered Carburized on wearing surface .03" deep	Forged and cadmium plated
43B	Front Oil Seal Rings	16	241	Cast iron	As cast	Cast
43C	Propeller Shaft, Rear Oil Seal	440	342	Alloy steel	Quenched and slightly tempered	Forged
43D	Rear Oil Seal Rings	16	250	Cast iron	As cast	Cast
48A	Propeller Shaft	15,000	330	Ni-Cr-Mo steel	Quenched and tempered	Forged-Yield strength 131,000 psi Tensile " 147,000 psi
48B	Propeller Shaft, Oil Seal Bearing Ring	490	Core 370 Case 600	Alloy steel	Quenched and tempered Bearing surface carburized .03" deep	Forged
48C	Propeller Shaft, Bearing Washer	90	165	Med.-C steel	Annealed	Stamped from sheet
49	Bell Gear	7,700	Core 333 Case 824	Nitralloy G Nitrided	Quenched and tempered. wearing surfaces .01" deep	Forged (#121592 also Nitralloy Case 900 VDH, Core 345 VDH. #2842, Case 584 VDH, Core 327 VDH.)
50	Planet Gear	970	Core 358 Case 585	Cr-Ni-Mo steel	Quenched and tempered Carburized.02" deep over-all	Forged
51	Sun Gear	4,100	Core 344 Case 974	Nitralloy G	Quenched and tempered Nitrided wearing surfaces .01" deep	Forged
52A	Cam	2,275	Core 390 Case 805	Ni-Cr-Mo steel	Quenched and tempered Wearing surfaces carburized .03" deep	Forged (#121592, Case 691 VDH, Core 415 VDH

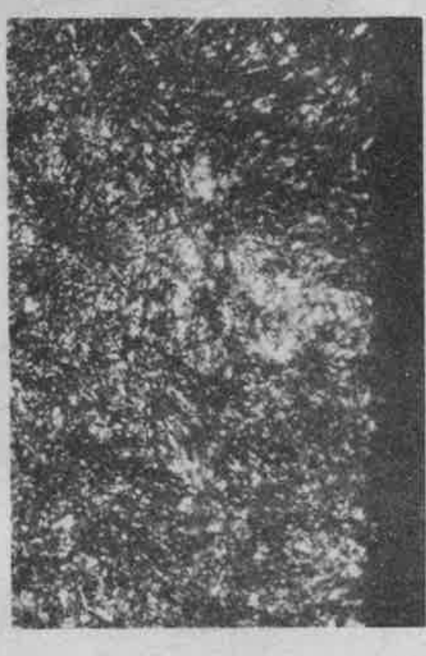
Table 6. Nose Section Sakae-12 Engine - Cont'd

Part No.	Name	Wt. (g.)	VDH	Type of Material	Heat Treatment	Remarks
52B	Cam Nut & Bolt	7	Nut 278 Bolt 346	Low-C. steel	Quenched and tempered	Machined from bar stock
52C	Cam Backing Plate	1,410	100	Aluminum alloy Similar to 17S	Solution heat treated and aged	Forged (#121592, 123 VDH #2842, 112 VDH)
52D	Cam Drive Gear and Shaft	940	Core 420 Case 743	Alloy steel	Quenched and tempered. Teeth carburized .03" deep	Forged
52E	Cam Spur Gear	565	Core 450 Case 641	Alloy steel	Quenched and tempered. Teeth carburized .02" deep	Forged
52F	Cam Spur Gear Bushing	39	74	Copper-Tin	As cast	Cast
52G	Cam Drive Gear Upper Plate	160	709	52100 type steel	Quenched and tempered	Forged
52H	Cam Drive Gear Lower Plate	140	454	Alloy steel	Quenched and tempered	Forged
63	Nose Casting	10,900	77	Aluminumalloy Similar to Alcoa A108	As cast	Cast
69A	Cam Bearing	195	26	Tin base babbit	As cast	Cast on steel backing plate
69B	Cam Drive Bear Bracket Nut & Bolt	10	Nut 227 Bolt 357	Medium-C steel	Quenched and tempered bolt. Nut annealed	Machined from bar stock
69C	Cam Drive Bracket	520	85	Aluminum Similar Alcoa 108	As cast	Cast
69D	Cam Oil Seal Ring	68	204	Aluminum Bronze	As cast	Cast
70	Planet Gear Bushing	180	28	Copper-Lead	As cast	Cast on steel backing plate
85A	Propeller Shaft Bearing	3,650	717	52100 type steel	Quenched and tempered	Forged
85B	Propeller Shaft Bushing	220	22	Copper-Lead	As cast	Cast on steel backing plate

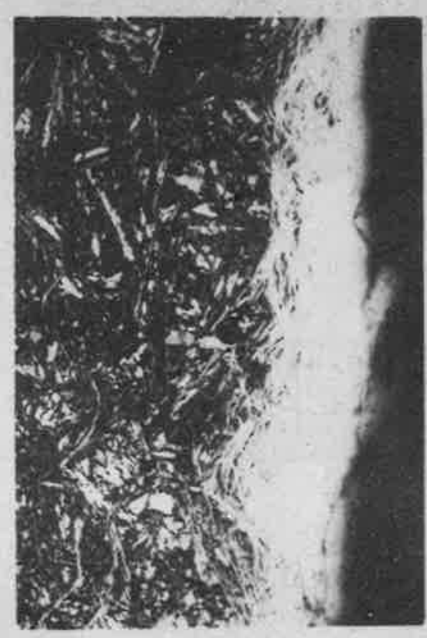
Table 6. Nose Section Sakae-12 Engine - Cont'd

Part No.	Name	Wt. (g.)	VDH	Type of Material	Heat Treatment	Remarks
85C	Propeller Shaft Bearing Ring	660	Core 405 Case 585	Alloy steel Similar to SAE 52100	Quenched and tempered Wearing surface carburized .02" deep.	Forged
86A	Propeller Shaft Oil Tube	775	268	Low C steel	Normalized	Seamless tubing with bronze bearings brazed to tube.
86B	Propeller Shaft Oil Nut		294	Low C steel	Quenched and tempered	Machined from bar stock
86C	Propeller Shaft Oil Plug	135	189	Low C steel	Annealed	Machined from bar stock
86D	Propeller Shaft Oil Screen		126	60-40 Brass	Annealed	Wire stock
87	Propeller Shaft Centering Cone	435	256	Aluminum Bronze	As cast	Cast
89A	Tappet Housing	98	Core 437 Case 706	Alloy steel	Quenched and tempered. Wearing surface carburized .01" deep	Forged. Cadmium plated
89B	Tappet Roller	25	Core 387 Case 673 Bushing 260	Alloy steel Nickel bronze	Quenched and tempered. Carburized .02" deep	Machined from bar stock. (Bearing No. 121592 Cu-Sn alloy)
89C	Tappet Shaft	16	Core 437 Case 724	Alloy steel	Quenched and tempered. Wearing surfaces carburized .04" deep	Machined from bar stock
89D	Tappet Tube	67	Core 410 Case 880	Alloy steel	Quenched and tempered. Wearing surface carburized .03" deep	Machined from bar stock.
89E	Tappet Bearing Pin	7	Core 309 Case 1002	Alloy steel	Quenched and tempered. Nitrided .005" deep	Machined from bar stock. (#121592 carburized .025", Case 699 VDH, Core 437 VDH)

Bell Gear 500X 35378
Nitrided Case .01" deep; 824 VDH
2% Nital etch



Planet Gear 500X 35379
Carburized Case .02" deep; 585 VDH
2% Nital etch



Sun Gear 500X 35380
Nitrided Case and white layer; 974 VDH
2% Nital etch

Figure 7. Case Hardened Structure in Reduction Gears

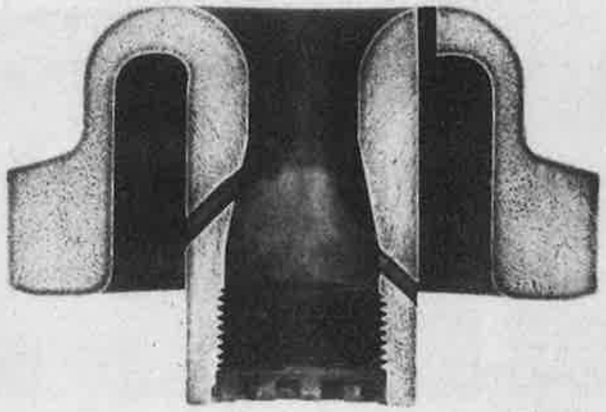


Figure 8. (CEE 20505) 34539
1X

Planet Gear Sakae Engine No. 124676;
Forging Flow Lines and Case Hardened Surface.
Etch 1:1 HCl H_2O

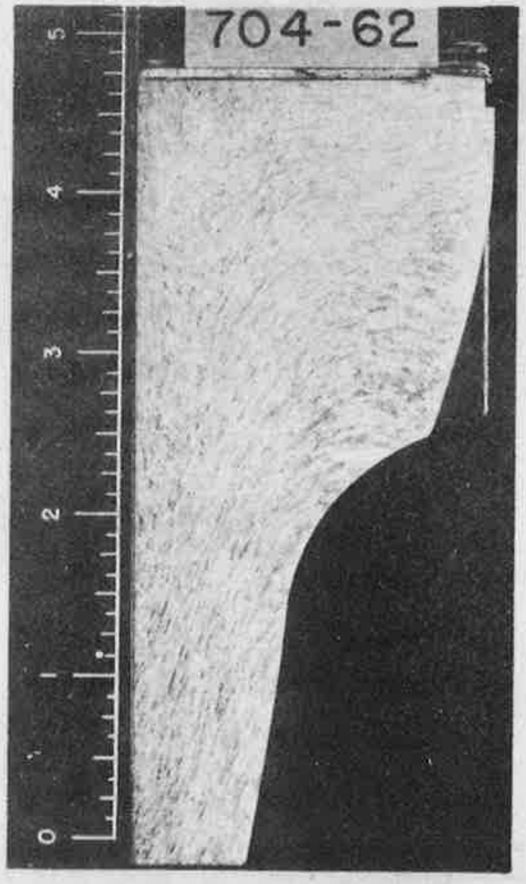


Figure 9 (CEE 20505) 34964
Impeller - Sectioned Through Hub at Top;
Forging Flow Lines and Grain Size.
Etch Flick's Reagent

BLOWER SECTION

By D. O. Leeser

Impeller Shaft

The impeller shaft with integral spur gear (57A) was forged from SAE 4130 steel modified with increased amounts of Cr and Mn. The gear teeth and outer bearing surfaces were carburized about .035 inch, and then given a quench and temper heat treatment. Nonwearing surfaces were zinc plated about .00065 inch.

Impeller shaft bearings (68) were cast of an aluminum alloy containing tin, copper, and magnesium as recorded in Table 1. This is the first high-speed aluminum bearing found in Japanese engines.

Impeller Drive Gear

The impeller drive gear (58A), Figure 11, was forged from a Ni-Cr-Mo steel as tabulated in Table 7. Heat treatment was similar to that of the impeller shaft described above, but the teeth were carburized only .02 inch. There was no coating on the drive gear, but the shaft (38B) on which it fits was cadmium plated approximately .0003 inch.

Impeller

The impeller (62) was forged from Alcoa 17S type aluminum alloy, and heat treated and aged. It was given an anodizing treatment similar to other Japanese impellers examined. Hub splines, machined into the aluminum, made it unnecessary to use a dissimilar metal for the hub. Forging practice is shown in Figure 9.

Upper surfaces of the impeller vanes and the inner surface of the diffuser were severely worn and scratched, and indicated that one or both were not properly seated and had rubbed against each other in operation.

Impeller Cover Plate

The impeller cover plate (94A) was forged, heat treated, and aged from an aluminum alloy similar to Alcoa 25S. It was anodized.

Blower Case

The blower case (61), Figure 10, was sand cast from aluminum alloy equivalent to Alcoa 85 (4% Si - 4% Cu). Casting technique was good and porosity was at a minimum. Hardness values averaged VDH 80.

Diffuser

The diffuser (64), Figure 10, was cast from a magnesium alloy similar to Dowmetal "R". It was not solution heat treated, but was pickled to give a protective oxide coating.

DOL:rrr
February 19, 1945

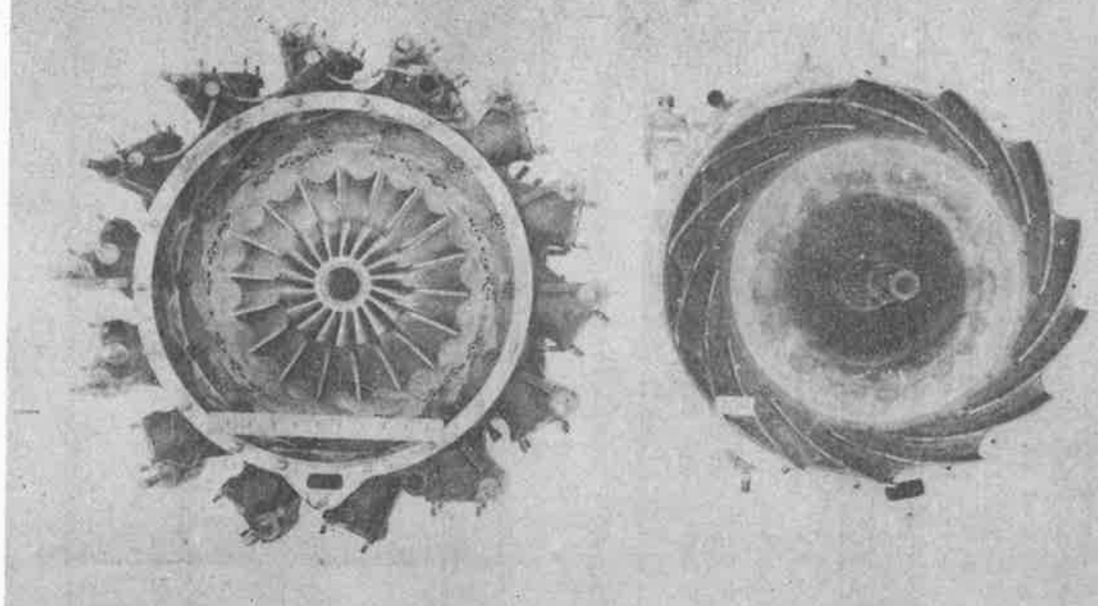


Figure 10. (CEE 20505) 33230
Blower Case, Impeller, and Diffuser.
The impeller shaft and crankshaft extension are shown in the diffuser case and air intake section.

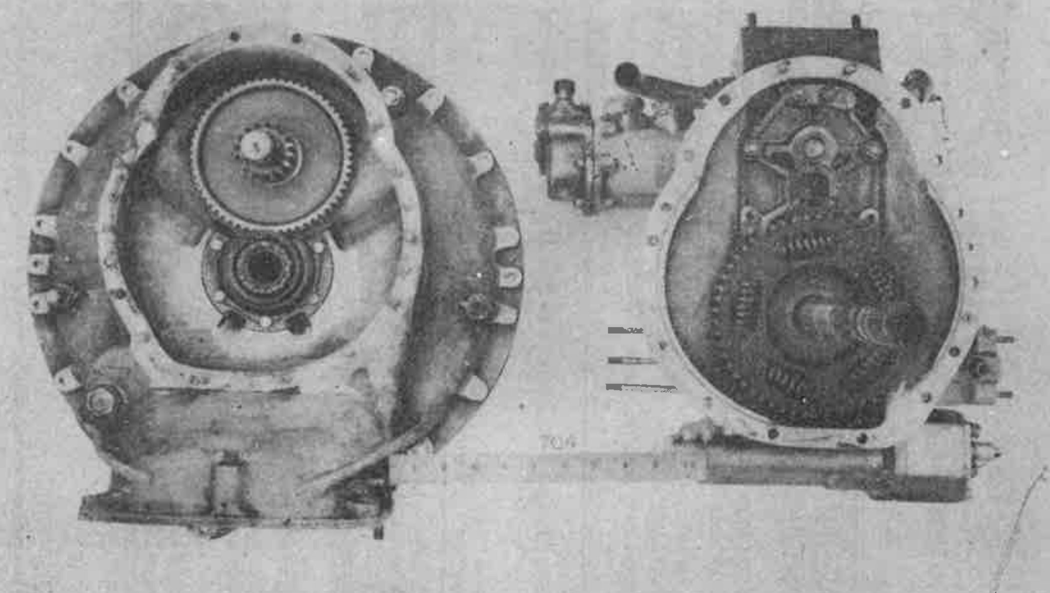


Figure 11. (CEE 20505) 33232
Air Intake Section and Gear Case Showing Supercharger Gearing and Gear Mounting Plate.

TABLE 7. ANALYSES OF BLOWER SECTION PARTS OF SAKAE-12 AIRCRAFT ENGINE NO. 124676 (CEE 20505)

A - Ferrous Parts

BMI No.	Name	Chemical, % C	P	S	Spectrographic, % Mn	Si	Ni	Cr	Mo	Cu	Sn	Al
57-A	Impeller Shaft, #124676	.24	.017	.016	.85	.25	.33	1.25	.25	.25	.076	.006
	Impeller Shaft, #21327	.13	.013	.023	.54	.19	4.65	.43	.08	.20	.033	.028
58-A	Impeller Drive Gear, #124676	.21	.012	.021	.44	.29	1.98	1.82	.24	.23	.055	.017
	Impeller Drive Gear, #21327	.13	.018	.020	.50	.26	4.65	.43	.15	.39	.067	.011

Note: W less than .01; V less than .02; Ti less than .004 on all ferrous parts listed.

B - Nonferrous Parts

		Chemical, % Al	Si	Fe	Cu	Mn	Mg	Sn	Zn
61	Blower Case (Alcoa 85)	Base	4.2	.33	4.0	<.05	<.01	--	--
62	Impeller (Alcoa 17S)	Base	.24	.29	3.7	.43	.32	--	--
64	Diffuser	9.5	.13	.04	.04	.13	Base	--	<.1
68	Impeller Shaft Bearing, #124676	Base	.30	.24	3.84	--	1.90	2.35	--
	Impeller Shaft Bearing, #21327	--	--	--	83.6	--	--	5.72	--

TABLE 8. METALLURGICAL DATA ON SUPERCHARGERAND BLOWER SECTION OF SAKAE-12 AIRCRAFT ENGINE (No. 124676 - CEE 20505)

Part No.	Name	Wt. (g	VDH	Type of Material	Heat Treatment and Remarks
57A	Impeller Shaft	1050	485 Core 734 Case	Ni-Cr-Mo steel	Forged, carburized on teeth .035". Quenched and tempered. Zinc plated .00065" on splines and neck.
57B	Impeller-Shaft Thrust Bearing Seat	310	63	Leaded phosphor-bronze	Cast
57C	Impeller-Shaft Thrust Bearing	38	200 34	Low carbon steel and copper-lead alloy	Machined from bar stock or tubing. Quenched and tempered. Bearing cast on flat side.
57D	Impeller-Shaft Oil Seals	475	400 Core 724 Case 173 Rings	Alloy steel hub with bronze rings	Machined from bar stock or tubing. Carburized .01" in grooves. Rings cold worked bronze.
58A	Impeller Drive-Gear	1400	470 Core 762 Case	Ni-Cr-Mo steel	Forged, teeth carburized .02". Quenched and tempered.
58B	Impeller Drive-Gear Shaft	380	325	Alloy steel	Forged. Quenched and tempered.
61	Blower Case	19,750	80	Alcoa 85 or Alcoa 108 aluminum alloy	As-cast. No heat treatment, or surface finish.
62	Impeller	8,200	100	Alcoa 17S duralumin	Forged, heat treated and aged. Anodized. Splines machined into aluminum.
64	Diffuser	2,275	80	Dowmetal "R" magnesium alloy	Cast. No solution heat treatment. Pickled for corrosion prevention, no selenium.
68	Impeller Shaft Bearing	35	123	Aluminum alloy with Cu-Mg-Sn	Cast. Aluminum-tin alloy.
83A	Spring-Loaded Gear	1,100	380 Core 570 Case	Alloy steel	Forged, quenched and tempered. Teeth and sprockets induction hardened .04".
83B	Spring-Loaded Gear Springs (5)	56	410	High carbon steel	Wrapped from cold drawn wire and highly stress relieved. No Cd plating.
83C	Spring-Loaded Gear Spring Guides (10)	21	330 Core 681 Case	Low carbon alloy steel	Machined from bar stock, carburized .03" on all surfaces except flange, then quenched and tempered

Table 8. Supercharger & Blower Section - Cont'd

Part No.	Name	Wt. (g.)	VDH	Type of Material	Heat Treatment and Remarks
83D	Spring-Loaded Gear Cover	103	333	High carbon steel	Stamped from sheet, then quenched and tempered.
94A	Impeller Cover Plate	3,100	125	Alcoa 25S	Forged, heat treated, and aged.
94B	Impeller Cover Plate Bearing	88	381 Core 1,050 Case	Nitralloy steel	Machined from tubing. Nitrided .005", quenched and tempered.
96	Air Intake Section	10,400	100	Alcoa 85 aluminum alloy	As-cast, not modified or heat treated.
99A	Tail shaft	2,550	446 Core 707 Case	Alloy steel	Forged, carburized .02" on sprockets and wearing surfaces, then quenched and tempered.
99B	Starter Ratchet	150	400 Core 690 Case	Alloy steel	Forged, carburized .025" on ratchet and gear teeth, then quenched and tempered.

ACCESSORY SECTION

By D. E. Adams
J. G. Dunleavy

Gear Case and Mounting Plate

The gear case and mounting plate, shown in Figure 11, were cast from an aluminum alloy similar to Alcoa 355 (1.3% Cu, 5% Si , 0.5% Mg with .3% Fe). In comparison with previously examined cases, this is a reduction in copper of approximately 3%. Another reduction in use of copper was noted in use of only one cast tin-bronze bushing of the ten accessory bushings. The starter shaft bushing was cast from an aluminum alloy of approximately .35% Si, 3.5% Cu, .20% Fe, .40% Mg, and 7.7% Sn. The remaining eight accessory gear bushings were machined from wrought aluminum alloy similar to Alcoa 17S (4.0% Cu, 0.5% Mg , 0.5% Mn). The starter shaft bushing was threaded and pinned into place. The small auxiliary drive gears were low-carbon alloy steel forgings carburized on wearing surfaces of shafts and gear teeth.

Cuno Oil Strainer

Spark testing and visual examination showed the automatic Cuno oil strainer on this engine to be identical to the one found on the Japanese Sakae 21 "Hamp", Mark II, "Zero" fighter plane (CEE 2963). Photograph of disassembly and metallurgical data can be found respectively on Pages 44 and 50 of BIOS/JAP/PR 1467.

Magneto Drive Gears

The magneto drive gears were forged from low-carbon alloy steels, case hardened on wearing surface of shaft and gear teeth. The bushings were machined from a wrought aluminum alloy similar to Alcoa 17S.

Machine Gun Synchronizer

The synchronizer was housed in a magnesium alloy casting. The cams were machined from a low-carbon alloy steel which had been quenched from below the critical as evidenced by the large amount of ferrite in the core. The wearing surface of the cam was case carburized. The two cams were serrated, soldered, and locked in their relative firing positions. The camshaft was machined from a low-carbon alloy steel, and the drive shaft was forged from a low-carbon alloy steel, case carburized on wearing surface of gear teeth and shaft. A low-carbon alley steel, quenched and tempered to a hardness slightly under that of the shaft, was machined for the camshaft lock nut.

Oil Sumps

The main oil sump and the rocker box sump were aluminum-alloy sand castings, covered with a coat of black paint to prevent corrosion. The design of the main oil sump was changed slightly over the sumps used in other engines to allow a larger volume in the sump chamber. The principal change was from a magnesium to an aluminum alloy.

DEA:JCD:rrr
February 19, 1945

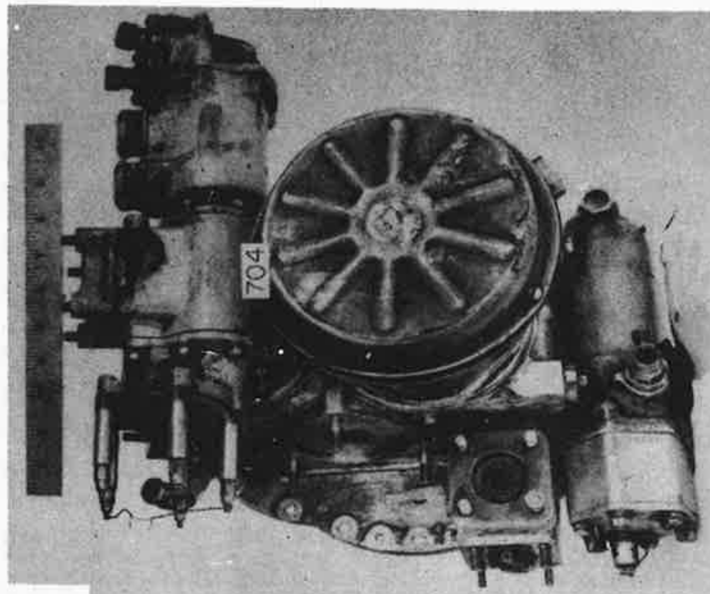


Fig. 12 (CEE 20505)
Gear Case and
Accessories

33231

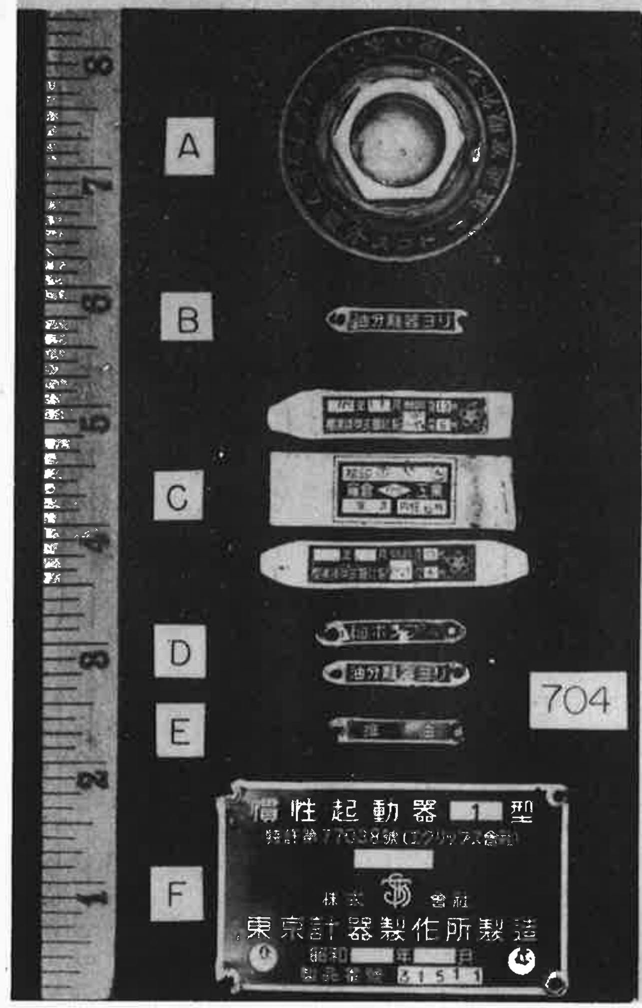


Fig. 13 (CEE 20505)
Name Plates From
the Japanese Sakae-12
Aircraft Engine
#124676

33340

TABLE 9. METALLURGICAL DATA ON ACCESSORY SECTION OF SAKAE-12 ENGINE NO. 124676 (CEE 20505)

Part No.	Name	Wt. (g	VDH	Type of Material	Remarks
97A	Gear Case	6300	87	Aluminum similar to Alcoa 355	Sand cast
97B	Auxiliary Drive-Gear	68	769 Case 468 Core	Low carbon alloy steel	Forged, quenched and tempered, case carburized on wearing surface of gear teeth and shaft
97C	Auxiliary Drive Gear Bushing (Al)	42	108	Al similar to Alcoa 17S	Wrought aluminum; machined, sol'n heat treated and aged.
97D	Auxiliary Drive-Gear Bushing (Cu alloy)	53	89	Tin bronze	Cast
98A	Gear Plate	675	89	Al similar to Alcoa 355	Cast
98B	Starter Shaft Bushing	87	41	Al (.35 Si, 3.5 Cu, .40 Mg,. 20 Fe, 7.7 Sn)	Cast aluminum-tin alloy
102A	Magneto Drive-Gear	190	758 Case 402 Core	Low carbon alloy steel	Forged, quenched and tempered, case carburized wearing surface of gear teeth and shaft
102B	Magneto Drive Gear Bushing	41	102	Al similar to Alcoa 17S	Wrought aluminum; machined; sol'n heat treated and aged.
105A	Machine Gun Synchronizer Housing	550	88	Magnesium	Cast, painted grey green color. (#2842 - cast aluminum similar to Alcoa 108)
105B	Machine Gun Synchronizer Housing Cap	41	82	Magnesium with Al insert	Cast, painted grey green color.
105C	Right Cam	155	849 Case 204 Core	Low carbon alloy steel	Machined from bar stock, case carburized cam surface, quenched below the critical, free ferrite in core
105D	Left Cam	155	-	Low carbon alloy steel	Machined from bar stock, case carburized cam surface, quenched below the critical, free ferrite in core.

Table 9. Accessory Section - Cont'd

Part No.	Name	Wt. (g.)	VDH	Type of Material	Remarks
105E	Cam Shaft	170	311	Low-carbon alloy steel	Machined from bar stock, quenched and tempered.
105F	Machine Gun Synchronizer Drive Shaft	520	608 Case 369 Core	Low-carbon alloy steel	Forged, quenched and tempered, case carburized on wearing surfaces of gear teeth and shaft.
105G	Cam Shaft Lock Nut	23	339	Low-carbon alloy steel	Machined from bar stock, quenched and tempered.
74	Oil Sump	1900	79	Aluminum alloy Similar to 108	Sand cast, painted black. #2842 Magnesium alloy similar to AMS 4454
	Oil-Sump Screen			Steel support with brass wire screen	Steel Cd plated
78	Rocker Box Sump		73	Aluminum alloy similar to 108	Sand cast, painted black.

IGNITION SYSTEM

By A. B. Westerman

The ignition system of the 1943 model weighed 31 pounds and consisted of two conduits, 14 pairs of connectors, two cables, and numerous fittings, unions, and conductors. The ignition system is shown in Figure 14. The conduits were manufactured by bending Alcoa 2S-type tubing into semicircular shapes and welding plugs (stamped from the same material) to one end of each conduit, and fittings, machined from Alcoa 24S-type alloy, to the other end. Four bands cut from Alcoa 2S type sheet were bent around and welded to the conduits; lugs stamped from low-C steel sheet were attached to the bands with Cu rivets. These lugs fitted over the studs joining the nose section to the crankcase and helped to hold the ignition system in place. Fourteen pairs of small nipples and two large nipples were welded to the conduits at intervals. Each nipple was made by welding a threaded fitting machined from Alcoa 24S-type bar to a tube formed by bending Alcoa 2S type sheet and welding along the seam. The two conduits were joined by a union machined from Alcoa 17S-type alloy.

The connectors were manufactured by the same methods and from the same materials as used for the cables. Two flexible tubes, the outer one made by braiding Sn coated Cu wire and the inner one by spiralling Zn coated low C steel strip, were soldered to machined 60-40 Cu-Zn type fittings; one end of each connector and cable was joined to a conduit nipple by a machined 60-40 Cu-Zn type union. The other end of each connector was attached to a cast 60-40 Cu-Zn type elbow with a 60-40 Cu-Zn type union.

Conductors ran through the conduits and branched off into the cables and connectors, seven into each of the former, and one conductor into

each of the latter. Each conductor was composed of a core of 37 individual Sn-coated Cu wires, each 0.010 inches in diameter. An 1/8-inch thick layer of rubber covered the core. Cotton fabric was braided over the rubber and was covered with an external black, glossy coating which was probably a cellulose ester lacquer. The conductors coming through each cable passed through a rubber insulator and a plastic spacer, which were adjacent to the fitting on the cable end farthest from the conduit. A plastic sleeve fitted over each conductor end, and a brass sleeve was forced between the plastic part and the conductor. High C-coiled wire springs were fastened to the connector ends by screws, which fitted into the brass sleeves. The ends of the cables were joined to the distributor caps and the ends of the connectors to the spark plugs with unions.

All of the brass parts, with the exception of the spiralled strip tubing, were coated with Cd. Coverings consisting of alternate layers of paper and cotton fiber with a phenolic-resin varnish bond were laced over the cables with braided cotton cord impregnated with a pitch composition. The general workmanship was good.

The ignition system of the 1941 model was not received for examination.

ABW:rrr
February 21, 1945

TABLE 10. COMPARISON OF PHYSICAL PROPERTIES SAKAE-12 ENGINE NO. 124676 (CEE 20505)

Part Name	Engine No.	Tensile Strength P.S.I.	Yield Strength* P.S.I.	Elongation, %	Reduction In Area, %
Crankshaft	2842	190,000	104,000	16.0	50.0
		191,000	121,000	14.5	46.5
	124676	185,000	140,000	15.0	47.0
Articulated Rod	2842	160,000	147,000	19.5	65.0
		160,000	150,000	20.0	65.0
	124676	167,000	156,000	10.5	xx
Propeller Shaft	124676	148,000	133,000	19.0	41.0
		146,000	130,000	21.0	42.5
Crankcase	2842	45,000	-	20.0	xx
		44,400	-	20.0	xx
Crankcase - Front Section	124676	41,000	19,000	16.0	xx
Crankcase - Center Section		43,000	24,000	14.0	xx

* Yield strength at 0.1% offset

xx Flat specimen

TABLE 11. WEIGHTS AND MARKINGS OF SAKAE-12 AIRCRAFT ENGINE #124676 (CEE 20505)

Part No.	Name	Weight, Grams	Markings
10	Cylinder Barrel	12258	(K) (03) 8734 [symbol] [symbol] [symbol] 7 301 #124676
11	Cylinder Head		Lid- [- - 602] (KDC) 9 1 [symbol] (03) [symbol]
12	Push Rod	131	FS7
14	Rocker Arm Assembly	428	FS7 [symbol] † [symbol]
16	Intake Valve	248	[symbol] Fl (K) D
17	Valve Seat	71	(T †) [symbol]
	Valve Spring	317	III † k
18	Valve Retainer Collets		
	Exhaust	5	3
	Intake	4	7
20	Exhaust Valve	233	2 ER (+) Fl
22	Spark Plug	89	U.S.A. [symbol] TIB 8 P (W)
23	Rocker Box Oil Line	89	[symbol] [symbol]
24	Intake Manifold	481	(Steel) (03) [symbol] 100 + (H)
		364	(Aluminum) (H) [symbol]
36	Starter	10896	H 5610 (03) [symbol] 462 [symbol] † 502 [illegible] [symbol]
			(F) 1862 X1 (AK)

Table 11. Weights and Markings - Sakae-12 Aircraft Engine #124676

Part No.	Name	Weight Grams	Markings
37	Cam Drive Gear	604	R No. 124676 (T)
	Cam Drive Gear Shaft	336	-R (T) (中)
44	Crankshaft Counterweight	6810	7034 (中) R
46	Crankshaft (3 Sections)		
	Center	9080	(03) 2883 7034 No. 124676 (中)
	Rear	9080	7034 F. R. (03) 2825 (中) ✿ No. 124676
	Front	20430*	F7034 (03) 3949 (中) No. 124676
47	Crankshaft Bolts	459	No. 124676 F 7054
48	Propeller Shaft & Planet Gear Spider	14982	(中) (03) 2141 No. 124676
49	Bell Gear	7718	⁜ (中) (03) 1293 124676
50	Planet Gear		
	Gear	978	(中) No. 124676 4
	Retainer Nut	91	(中) 77_1 E
51	Sun Gear	4086	(中) (03) 1233 No. 124676
52	Cam	2270	3484 (03) (中)
	Cam Plate	1414	F No. 124676 (中)
53	Valve Inserts	110	(中)
54	Piston Pins	360	None
55	Master Rods	4994	No. 124676 (03) 7245 (中) ✿ F3

* Counterweight attached.

Table 11. Weights and Markings - Sakae-12 Aircraft Engine #124676

Part No.	Name	Weight, Grams	Markings
56	Articulated Rods	791 ea.	No. 124676 M X (中)
57	Impeller Shaft	1050	No. 124676 栄一二型
	Large Oil Seal	257	(中) No. 124676
	Small Oil Seal	216	No. 124676
58a	Impeller Drive Gear	1386	(中) No. 124676 8 (中) 栄一二型 FIO
58b	Impeller Drive Gear Shaft	381	(中) 一
59	Crankcase (Front)	15890	F 1986 (03) D857 (中) 7 F No. 124676 F4
	Crankcase (Rear)		R (03) 4254 D857 (中) 7 ✿
60	Piston Assembly	1660	R 前 4 (03) ES (中) ✿
61	Blower Case	35829*	No. 124676 (中) (03) 11127 (中) (T) ✿
62	Impeller Inductor	3178	O No. 124676 S. ✿ (03) 1984. (中)
63	Nose Casting	10896	(中) (03) 704907 ✿ (中) 124676
64	Diffuser	2270	(03) 7384 (中)
68	Impeller Shaft Thrust Bearing	35	None
	Retainer and Seat	315	No. 124676 (中)
77	Main Oil Sump	3178	85 (Y) (中) 甲:非 ト (中) (03) 8612 No. 124676

* Blower and Rear Crankcase.

Table 11. Weights and Markings - Sakae-12 Aircraft Engine No. 124676

Part No.	Name	Weight, Grams	Markings
78	Rocker Box Sump	2270	No. 124676 (Ta) (M) S
85	Propeller Shaft Bearing	3632	KA-95 NTN No. 124676 M 3 1593
	Retainer	660	No. 124676 (中) (中)
86	Propeller Shaft Washer & Nut	650	None
	Propeller Shaft Oil Tube	775	(中) No. 124676
87	Propeller Shaft Centering Cone	432	上 105572 ✿ [illegible] (不) D1-4-85
88	Crank Main Bearing (Front)	2243	NSK 8761 KE III No. 124676 F 687 JF III
89	Tappet Assembly	195	FE 61 (中)
90	Crank Main Bearing (Rear)	2238	KE III 8761 No. 124676 R 1063 NSK
91	Crank Center Bearing	4540	NTN- 130 KR 130 124676
92	Center Main Bearing Wedges (2)	388 ea.	S 28 (中) (中)
93	Lifting Eyes	43	(E) F 4
94	Impeller Cover Plate	3178	No. 124676 (中) S
95	Knuckle Pins	212	F1 (中)
96	Air Intake Section	10442	⊕ (03) 534802 ✿ (H) (中)
97	Gear Case	7264	26 ⊕ (03) (H) 9081 (中) ✿ No. 124676
98	Gear Plate	1171	No. 124676 9122 ⊕ (03) (H) (中) ✿ (K)
99	Tail Shaft Assembly	4994	(No.) 124676 (中)
100	Ignition System,	15890	None

Table 11. Weights and Markings - Sakae-12 Aircraft Engine No. 124676

Part No.	Name	Weight, Grams	Markings
101	Cuno Oil Strainer	3632	NAKA 119843 ‡ ⩓ (20) 8971 ✿ 1752 (S K) 349 中 124676
102	Magneto Drive Gears	186 ea.	(中)