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METALLURGICAL EXAMINATION OF A JAPANESE SAKAE-21 AIRCRAFT ENGINE

Originating Agency:

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

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

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Reported by

L.H. Grenell
J.R. Cady
H.W. Gillett

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.

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JAPANESE SAKAE - 21 AIRCRAFT ENGINE

August 8, 1944

From:

BATTELLE MEMORIAL INSTITUTE

Report Prepared By:

L. H. Grenell
J. R. Cady
Research Engineers

H. W. Gillett
Official Investigator

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FOREWORD

A Japanese Sakae-21 radial engine, Serial No. 21327, from a Hamp, Mark II, fighter aircraft was received from the Naval Air Station, Anacostia, D. C., for metallurgical examination. The designation CEE-2963 was assigned by the Navy, and BMI-533 by Battelle. The engine and plane were captured at Munda, New Georgia, in August, 1943. The following additional information was supplied by the Foreign Economic Administration.

2. SAKAE 21, serial No. 21327
Manufactured by: Nakajima Hikoki K. K.
Date of manufacture: September, 1942

This engine was probably used on Japanese plane type A6M3- Type O, Fighter, Hamp, which is assembled by Mitsubishi. Apparently all Sakae 21 engines have been installed on planes assembled by Mitsubishi; either Type O, S/E Fighter, Hamp, or Type O, S/E Fighter, Zeke, Mark 2.

Photographs of nameplates and their translation, as well as the markings found on this engine, are compiled at the end of this report under Figure 24 and Table 18.

SUMMARY

Material and workmanship used throughout the engine were of excellent quality. No apparent effort was made to conserve either critical materials or man-hours of labor. Alloy steels were used extensively. The amount of alloys employed would be considered lavish by U. S. standards under the present war economy.

The majority of the steels used appeared to be of electric furnace quality. Phosphorus and sulphur contents were low, and the steels

were clean and free from dirt. Practically all contained high residual amounts of copper and tin customarily found in Japanese steel produced largely from scrap. Many of the steels were aluminum-treated for grain-size control, and a majority were highly alloyed with nickel and chromium.

The aluminum alloys used were standard alloys similar to American materials. Aluminum castings were good, and aluminum forgings, particularly in the crankcase and impeller, were excellent. Magnesium castings used in the diffuser, rocker box, and various accessories followed German practice in composition and in the use of the as-cast alloys. These castings were free from excessive porosity and microshrinkage.

Forging was used extensively in obtaining a desirable fibrous structure in many of the steel and aluminum parts. Even small items, where no saving would be made in machine time or metal, were forged to obtain the best physical properties. A number of the steel forgings showed excessive allowance for machining. This practice resulted in the grain structure cutting across instead of around the stressed fillets. This condition was notable in the crankshaft and would not be acceptable in American practice.

Welding was used extensively in fabricating the motor mount and ignition assembly. The quality of the gas welding employed was excellent, but a saving could have been made, particularly in the motor mount, by using fusion-arc welding.

Machining operations and surface finish on practically all parts appeared to be excellent. A lack of understanding of the value of good surface finish was found in the highly polished articulated rods whose surface was marred by deeply stamped numbers, and in the carefully polished crankshaft counterweights where a stressed condition did not exist.

Heat treatment of the steel parts and aluminum forgings was extensive and of good quality, although the aluminum-magnesium castings were not heat treated. The Japanese showed decided preference for case hardening by carburizing and by nitriding. They followed German practice in this treatment, although the Germans apparently are no longer nitriding cylinder barrels. The Japanese have very carefully limited the case-hardened surface to the actual areas subjected to abrasion. The webs, side, and even the tips of the gear teeth were usually not carburized although the gear tooth face would have a deep case.

Numerous bearing alloys were used; the Japanese apparently understood the various service conditions encountered and used satisfactory materials for these applications. SAE-52100 steel was used for ball and roller bearings. Cast tin-bronze, leaded tin-bronze, aluminum bronze, copper-lead alloys, and tin-antimony babbitt were used.

Ingenuity was shown in the solution of some problems by adapting unusual metals to special service conditions. In the tappet roller a hard, heat-treated, nickel-copper bearing was used against a fully hardened SAE-52100 steel shaft. The battering action of the cam in this part appeared to have caused failure in softer, more commonly used metal combinations.

ECONOMIC CONSIDERATIONS

No shortages of material or manufacturing facilities were observed. From a metallurgical standpoint, the standards used by the Japanese for aircraft engine construction were the equivalent of American practice. Good technical control was shown in the selection of materials, the control of steel and nonferrous alloys manufactured, and in accurate heat-treating practices.

Comparison of the materials in this engine with those in the Sakae-12 made in 1941, shows only one change. This was in the crankshaft which for the Sakae-12 was of the same analysis plus 1% tungsten. None of the Sakae-21 parts, excepting valves, showed additions of tungsten. This change is of doubtful significance in view of the lavish use of tungsten in other Japanese equipment.

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August 21, 1944

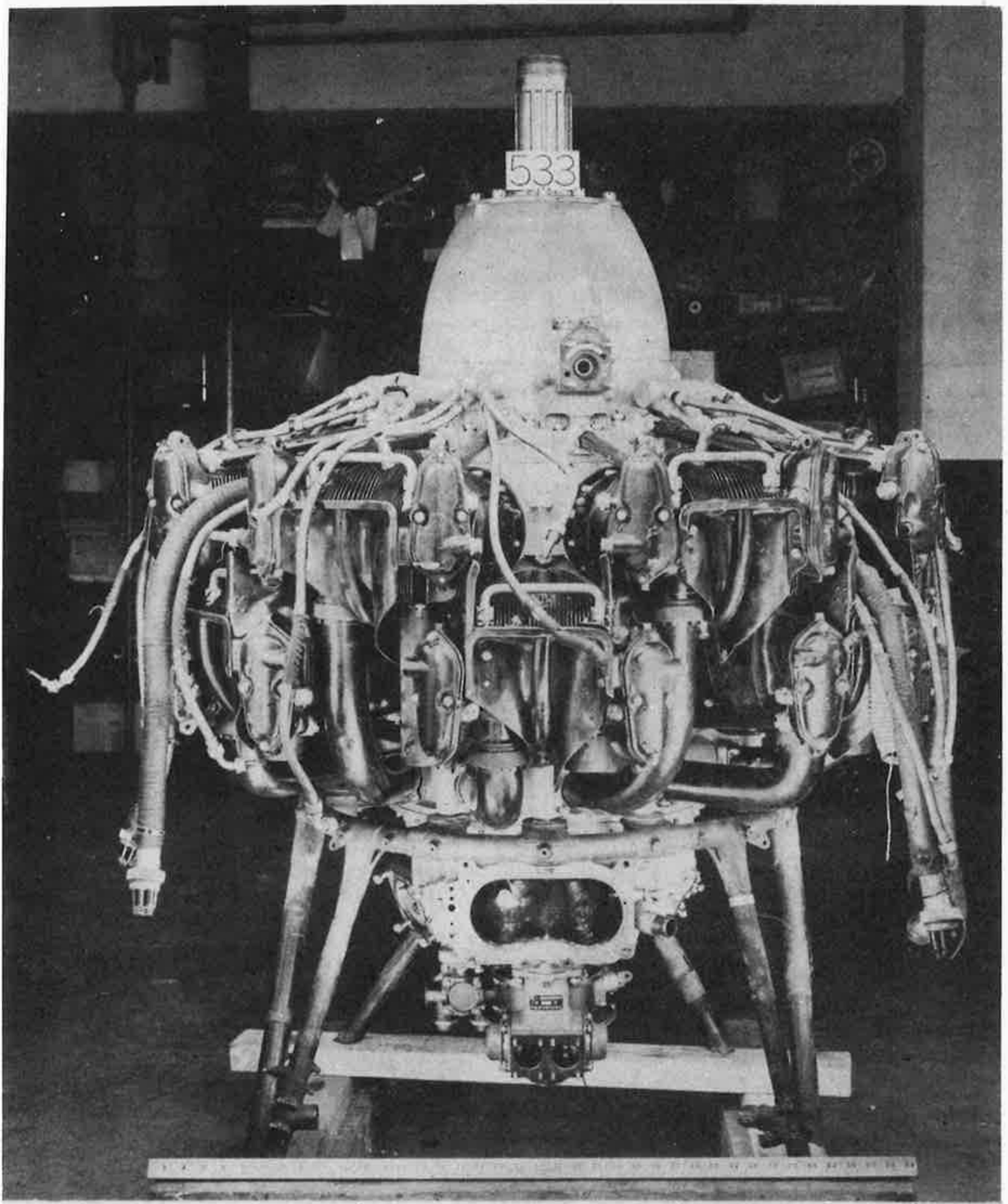


Figure 1. Japanese Sakae-21 Radial Engine From Hamp Mark II "Zero" Fighter Plane Captured at Munda, New Georgia. (CEE-2963) Engine Serial No. 21327. 29567

I - POWER SECTION

by

Morse Hill

Crankshaft

The most important items in the crankshaft section were the three parts of the crankshaft proper. These were held together by solid bolts tightened upon hardened washers. Internal splining of the front and rear sections in the throws held the parts in place relative to each other. The crankshaft counterweights were cast from an alpha-beta aluminum-manganese bronze. The counterweights were riveted to the projections on the crankshaft with steel rivets which were machined from bar stock. An adaptor for the propeller oil tube was screwed into the front part of the crankshaft. There was also a drawn-steel tube to carry oil through the center section between the throw splines. The adaptor for the shaft, which led to the starter and accessory section, was splined, without bushing, into the rear part of the crankshaft.

As may be seen from Table 1, the crankshaft was an .18% carbon steel resembling 3312 but containing .17% Mo in addition. This molybdenum may have been an intentional addition, although "The National Emergency Steels", NE 8000 Series, page 7, indicates that in 2% of the heats melted here this amount may be residual. The 3312 analysis has long been used for those parts where it is desired to have excellent core properties with the possibility of surface hardening. As shown below, the properties of the crankshaft were good:

Ultimate Strength, p.s.i.	Yield Strength, p.s.i.	Elongation in 2 Inches, %	Reduction of Area, %	Vickers Diamond Hardness
186,600	at .1%, 128,000 at .2%, 148,000	16	51	400 - 413

With these properties the case had a hardness of 743 VDH and a depth of .02 inch, the hardening being restricted to the throw and there not extending to the radii. The martensitic needles and the presence of excess carbides in the case suggested the use of one of the complex cyanide baths whose action at high temperatures was primarily carburizing, but was also nitriding.

The base metal had been forged until the dendrites were well broken up and strong flow lines developed. Near several of the fillets the flow lines made an angle of more than 45 degrees with the surface. Such flow lines would probably not be considered acceptable in this country. From their shape, the forging dies must have had slightly greater allowances than is customary in this country. All parts of the crankshaft had been imperfectly homogenized before quenching, as was shown by small amounts of ferritic areas.

The finish of the crankshaft parts was excellent in most of the highly stressed areas, especially on the external surfaces which were ground and polished. However, several of the oil holes in the crankshaft proper appeared to have been cut with a dull or clogged drill and were not further finished, even in stressed areas. The counterweights had been carefully polished, and the adaptor to the starter and accessory section was ground. However, the propeller oil tube adaptor, which was not stressed, was left as finish-machined.

Both adaptors had been machined from bar stock. The starter shaft adaptor may have been a source of service trouble, for it had a composition similar to "Nitralloy" with medium carbon, and showed aluminum, chromium, and molybdenum on qualitative spectrography. Although the adaptor was nitrided all over, the case was left especially thick on the

unsplined bearing surface where it was .02" thick, with a white-etching layer .007" thick. In spite of this case, the surface appeared to have been galled in service. The white layer hardness was 836 VDH, and that of the other surface was 905 VDH. Both this hardness variation and the finish of the oil holes suggested that engineering control of manufacturing may have been somewhat incomplete.

The crankshaft bolts were machined from bar stock and carefully finished. Although the bolts were only about an inch in diameter, the steel composition (Table 1) used about .3% C, 3.0% Ni, 3.0% Cr, and .56% Mo, amounts far in excess of those needed to assure adequate hardenability but comparable to compositions used for such purposes in prewar U. S. practice. The washers under the crankshaft bolts appeared to be of a steel resembling SAE-52100 and were fully hardened, although the structure was dark martensite or, perhaps, bainite rather than the light martensite usually found in bearings. The carbides were small and comparatively few in number. Salt-bath heat treatment seemed probable.

Piston

The piston section consisted of the piston and rings. The piston had been forged from "Y" alloy, similar to Alcoa 142. While in this country this alloy is promoted as a casting alloy, continental practice is to use it for wrought sections as well. Because of its high strength at elevated temperatures, it has been often recommended for such things as pistons. In this motor, however, the alloy was not too successful, for the crown hardness dropped to 70 Brinell, while the skirt hardness remained at 119, a value easily obtained upon heat treating. The microstructure indicated that the softening resulted from growth of the precipitate beyond the effective size. The forging had produced well broken-up constituents and flow lines which conformed reasonably with the contour.

The piston rings were of cast iron and compared favorably with those made in this country. However, the graphite tended to be more of the "octopus" nature. The oil rings had a thin chromium plating on the wearing surface which seemed to adhere well. The microstructure of several rings was examined, but so much variation existed that it is impossible to tell what structure was desired. Analysis of the piston ring iron showed the presence of 0.22% Ni and 0.50% Cr. This is higher than the normal residual range for these metals and indicates a mild alloying treatment to improve the properties of the rings.

Rod Assembly

The rod assembly consisted of the steel piston pins fitted with aluminum plugs and connected to one end of the articulated rods fitted with bronze bearings. At the other end of the rods were the knuckle pins. The master rod carried the bearing which rode upon the crankshaft. Both master and articulated rods were made from the same type of steel, C .25%, Cr 1.25%, Ni 3.50%, Mo .45%. This analysis again illustrates the use of excessive alloy. Since the tensile properties shown were developed by heat treatment, it is possible that there was a desire to achieve high tensile strength with relatively low carbon steel. The microstructure showed the heat treatment to be excellent; the quenching and drawing produced a uniform structure. Material of this alloy content would be almost foolproof in heat treatment.

The finish of all parts of the rod assembly was excellent. The polish on the rods was particularly fine; however, the effect of this finish was greatly diminished by the practice of extensive marking with an electric needle on the stressed exterior surfaces and of stamping other numbers in the metal surface (Figure 4). The assembly as-received was heavily coated with engine varnish.

A tin-bronze was used for the piston pin bearings. The structure of the bearing was dendritic with segregation of tin eutectic somewhat diffused into the matrix. The structure also showed well-dispersed particles of iron-rich constituent. The main rod bearing was of copper-lead, backed with a low carbon, slowly-cooled steel sleeve. The lead was well dispersed. Very small crystals of what was probably a tin compound were visible. Inside, it was coated with about .001" of pure lead.

The aluminum plugs in the piston pins were machined from bar stock and appeared to be of a simple duralumin, not heat treated. The piston pins themselves were of an .11% C, ±.50% Ni, 1.00% Cr steel, carburized on the bearing surface about .02" deep. The molybdenum was .12%, but this was probably residual rather than an intentional addition. The finishing was careful, and a fairly good microstructure had been obtained, although there was some inhomogeneity.

Crankcase Assembly

The crankcase assembly consisted of the front, middle, and rear duralumin forgings to which were attached the cylinder barrels, and within which the crankshaft revolved upon three roller bearings. To prevent oil leakage from around the crankshaft at the front and rear end, an oil seal was used consisting of two aluminum-bronze rings sliding between steel rings within a cast aluminum housing. The seal fitted around the crankshaft and was attached to the crankcase by the housing. Attached to the front section of the crankcase were two aluminum baffles or deflectors to direct the oil flow.

The crankcase parts were made from a duralumin composition conforming to Alcoa 17S, and appeared to have been carefully forged, machined, and heat treated. The physical properties, as shown below, were excellent.

The bearings rested not on the crankcase, internally, but on carburized thin-steel backings which had been forged to shape. The oil baffles were cast from a duralumin-type alloy, and were held in place with quenched-and-drawn bolts. The baffles appeared not to have been heat treated, perhaps because there was little stress on them. The casting which held the oil seal was extremely sound and well made; this casting was heat treated. The moving rings were of aluminum bronze with fairly large amounts of iron and manganese and were not heat treated.

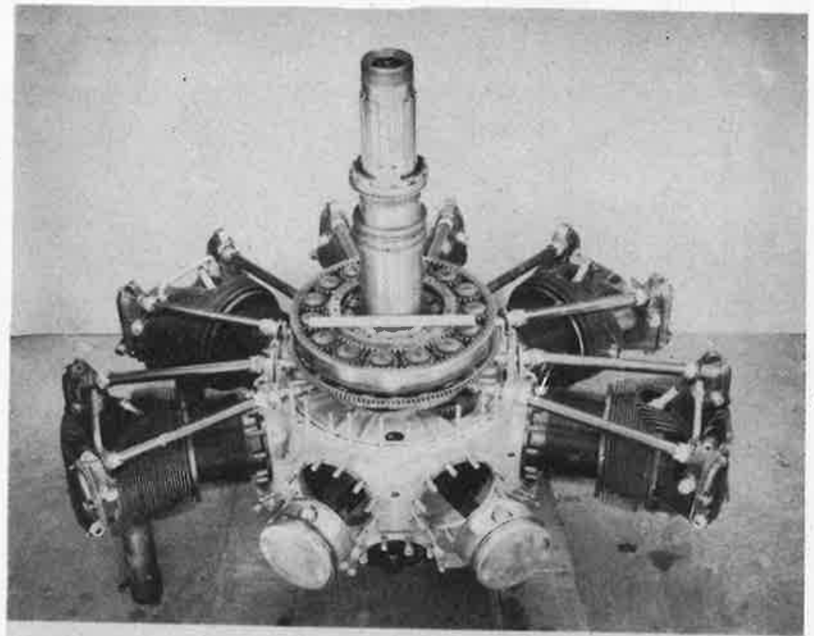


Figure 2. Front Power Section of Twin Bank Radial Engine Showing Reduction on Gear and Propeller Shaft (CEE-2963). 29936

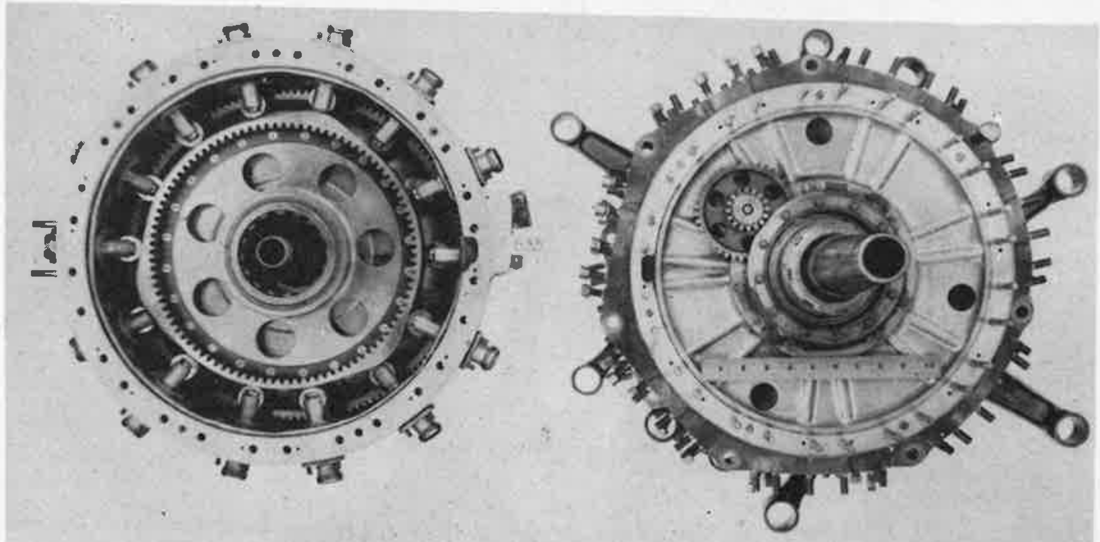


Figure 3. Front Cam, Push Rod Rollers, and Power Section of Sakae-21 Aircraft Engine (CEE-2963). 29935

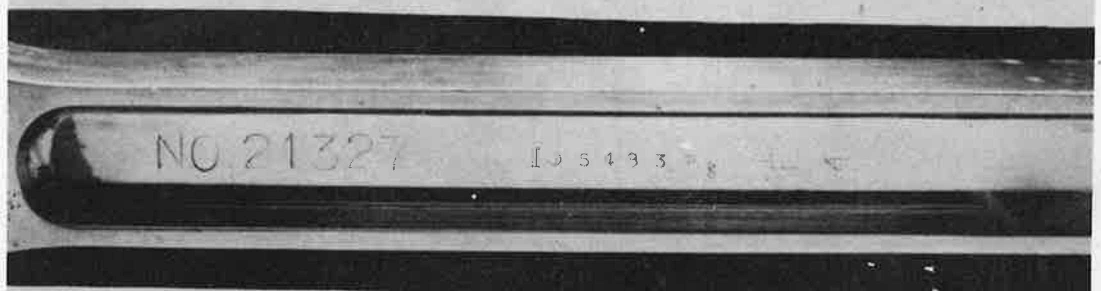


Figure 4. Articulated Rod Showing Numbers Stamped in the Polished Surface (CEE-2963). 30979

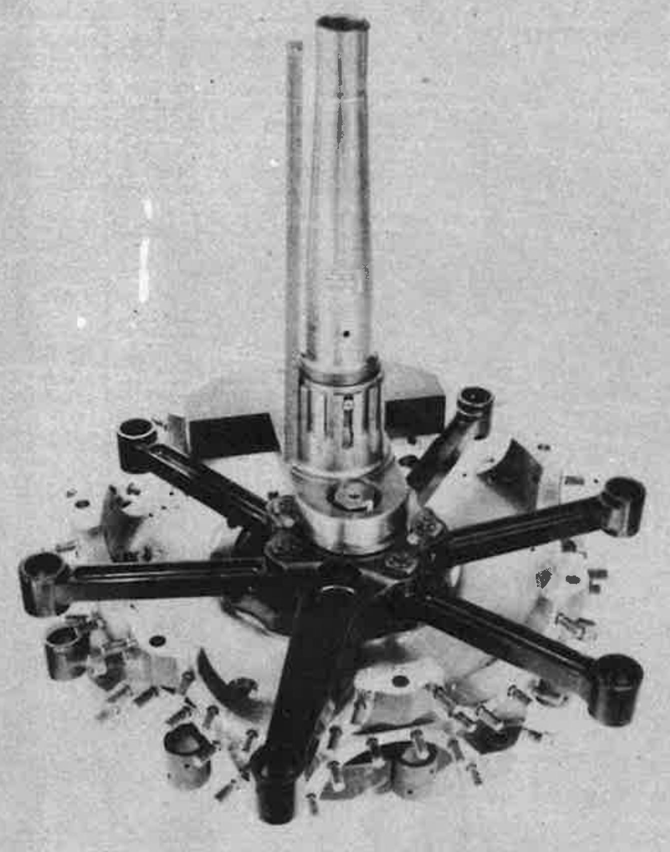


Figure 5. (CEE-2963) 29772

Crankshaft, Crankcase, Master Rod, Articulated Rods, Counterweight, and Front Crankshaft Extension of Sakae-21 Aircraft Engine.

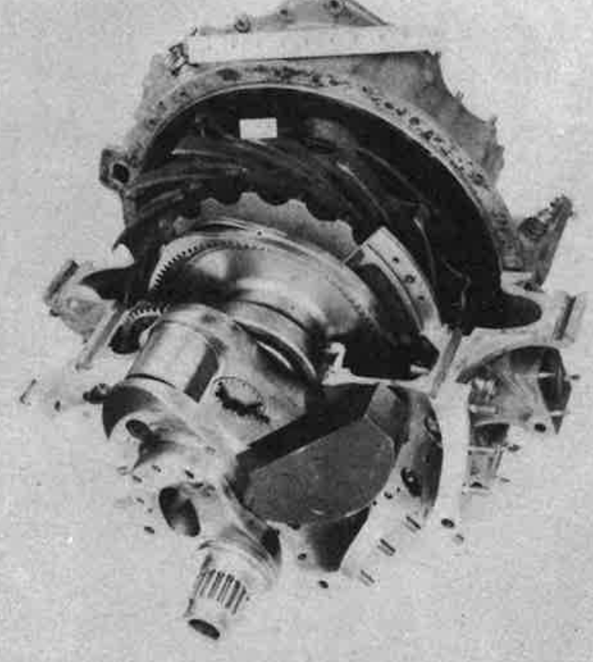


Figure 6. (CEE-2963) 30681

Rear Part of Power Section and Blower Case, Center and Back Section of Crankshaft, Crankshaft Bearing, Cam Plate, Cam, Impeller, Diffuser, Cover Plate, Blower Case; and Air Intake Section of Sakae-21 Engine.

TABLE 1. ANALYSES OF POWER SECTION COMPONENTS - SAKAE 21 (CEE-2963)

Forrous Parts, %

PART	PART NO.	C	P	S	Mn	Si	Ni	Cr	W	V	Mo	Cu	Sn	Al	Ti
Front Crankshaft	533-46	.18	.021	.035	.57	.21	4.15	1.68	<.01	<.02	.17	.34	.048	.030	<.004
Crankshaft Bolt	533-47	.28	.015	.014	.43	.24	2.98	2.96	<.01	<.02	.56	.29	.095	.014	<.004
Piston Pin	533-54	.11	.014	.023	.57	.17	4.50	0.86	<.01	<.02	.12	.19	.044	<.005	<.004
Master Rod	533-55	.24	.014	.016	.58	.19	3.52	1.28	<.01	<.02	.45	.22	.044	.006	<.004
Articulated Rod	533-56	.25	.012	.012	.55	.24	3.38	1.39	<.01	<.02	.40	.26	.066	.007	<.004
Piston Rings	533-60	Cast Iron			--	--	0.22	0.50	--	--	--	--	---	---	---

Nonferrous Parts, %

PART	PART NO.	Mn	Si	Ni	Cu	Fe	Zn	Mg	Pb	Sb	As	Al	Sn	P
Crankcase	533-59	.46	.34	<.01	3.9	.40	--	.34	--	--	--	Bal.	---	--
Piston	533-60	.03	.39	1.34	4.3	.27	--	1.27	--	--	--	Bal.	---	--
Master Rod Bearing	533-65	--	--	--	67.1	--	.05	--	29.7	--	--	--	0.29	<.01
Piston Pin Bearing	533-66	--	--	--	86.1	--	.13	--	Nil	--	--	--	10.1	.52

TABLE 2. FEATURES OF PARTS FROM CRANKCASE SECTION OF JAPANESE SAKAE 21 AIRCRAFT ENGINE (CEE-2963)

Part No.	Name	No. Pieces	Weight, Grams	Hardness*	Surface Treatment	Type of Material**	Structure of Properties
46	Crankshaft						
-1	Front Section	1	12,701	400	Case hardened in throws; VDH 743;.02" deep; all exterior surfaces ground; oil holes very rough.	Steel; C .18, Cr 1.7, Ni 4., Mo .17	185,000 p.s.i. Ultimate S. Appears case hardened from salt bath. Flow lines show dendrites well broken up, but make angles of more than 45° with surface.
-2	Center Section	1	8,221	413			
-3	Rear Section	1	9,014	403			
-4	Counterweight	2	6,207	156 Br.	Excellent machined surface.	Al-Mn bronze	Two-phase structure, indicating lack of heat treatment.
-5	Counterweight Rivets	10	106	277 Br.		Med. C steel	Machined from bar stock.
-6	Front Sleeve Bearing	2 halves	127	70			
	Adaptor to Accessory Drive Shaft	1	363	396	Nitrided all over; 836-905 VDH; .02" deep; galled on seating surface.	Nitralloy G or H	Coarse grained; quenched; white layer not removed.
-7	Propeller Tube Adaptor	1	382	278	Case hardened; VDH 600; Turned from bar stock; fair finish.	Steel; C .35, Cr and perhaps Ni	Quenched after insufficient homogenizing; rather high draw.
-8	Cam Lock	1	10	421	Ground finish.	Steel	Quenched and drawn.
-9	Retainer Nut	1	170	256	Machine finish; Cd plate.	Steel, med. C	Quenched and drawn.
47-1	Crankshaft Bolts	2	454	341 Br.		Steel; C .3, Ni 3., Cr 3., Mo .6	
-2	Crankshaft Bolt Washer	2	14	741-786			
54	Piston Pin	14	400±	355	Carburized .01" deep.	Steel; C .1, Cr .9, Ni 4.5, Mo .1	Machined from bar stock.
-1	Piston Pin End	28	21	100	Engine varnish.	Aluminum	Machined from bar stock.
55	Master Rod	2	4,308	330	Engine varnish; very carefully polished.	Steel; C .3, Cr 1.3, Ni 3.5, Mo .5	Excellently quenched and tempered.
56	Articulated Rod	12	907	329	Same as master rod.	Same as master rod.	Ultimate S., 157,000 p.s.i.; Yield S., 144,000 p.s.i.; Elongation, 12%.
59	Crankcase						
-1	Front Section	1	11,565	73 Br.	Greenish-gray paint over grayish primer. Machine marks removed from gasket surfaces; carefully finished.	Simple duralumin	Solution heat treated and aged. Ultimate S., 42,000; Yield S., 22,000; Elongation, 20%. Forged with good break-up of structure and conforming flow lines.
-2	Center Section	1	14,713	74 Br.			
-3	Rear Section	1	11,069	74 Br.			
-4	Bolts and Nuts	14	178	281	Cd plated.	Steel; similar to 4130	Turned from bar; quenched and tempered.

Table 2. (Continued)

Part No.	Name	No. Pieces	Weight, Grams	Hardness*	Surface Treatment	Type of Material**	Structure of Properties
59	Crankcase						
-5	Oil Baffle	2	77	77 Br.	As forged.	Aluminum, perhaps duralumin.	Cast; not heat treated.
-6	Oil Seal Body	1	992 Assembly	69 Br.		Aluminum, perhaps duralumin.	Cast without porosity.
-7	Oil Seal Movable Rings	2		196	Ground.	Aluminum bronze; Al 9., Mn 4., Fe low.	Not heat treated.
-8	Retainer for Rings	2				Steel, similar to crankshaft bolt.	
-9	Cylinder Studs	168	168	330-348	Cd plated.	Steel; similar to 4130, but lower C; definite Ni.	Twelve studs checked in hardness limits shown.
91-2	Main Bearing Retainer	1	389	393	Carburized; VDH 666.	Steel; similar to crankshaft bolt.	
60	Piston	14	1,210	70-119 Br.	Engine varnish.	"Y" alloy.	Well forged; heat treated but crown softened.
-1	Piston Ring (Seal)	56	27	230-240	Cr on wearing surface.	Cast iron.	Rosette structure comparatively fine with little steadite.
-2	Piston Ring (Oil)	14	30	230-240	.007" carbon deposit.	Cast iron.	Structure well broken up; pearlite coarse.
65	Master Rod Bearing	2	311		Copper lead on annealed low C iron. Cu 67., Pb 30.		Coated inside with Pb, .001" thick. Shows very well-dispersed lead.
66	Articulated Rod Bearing	12				Tin bronze.	Dendritic structure shows eutectic of Cu-Sn compound, also coring.
88	Crankshaft Main Bearing	2			Reported elsewhere.		
92	Crankshaft Center Bearing Wedge	2	454	330 Core	Carburized 642; .025" deep.	Steel; similar to crankshaft bolt, but lower in Ni, higher in C.	Ground on bearing surfaces; flow lines show upsetting.
-2	Wedge Bolt	8	1 ea.	275 Core	Cd plated.	Steel; C .30, plain steel with high residue.	Machined from bar stock.
95	Knuckle Pin	14	212		Carburized .02" deep.	Steel; similar to 2330, perhaps with Mo, C .25-.30.	Ground surface; made from bar stock.
-1	Retainer	4	11	321	Ground surface.	Steel; similar to 2330.	Quenched and drawn,-rolled plate.
-2	Bolts	14	35		Engine varnish; well machined.	Steel; similar to crankshaft bolt, but higher C.	Bar stock.
-3	Nuts	14	14		Same as above.	Same as above.	Bar stock.

* Hardnesses are Vickers Diamond Hardness with 10 kg. load, or Brinell (where marked "Br.") with 500 kg. load.

** The values have been rounded off to indicate approximate composition.

II - CYLINDER ASSEMBLY SECTION

by

A. B. Westerman
C. E. Levoe
H. C. Cross

Cylinder Barrel and Head

The cylinder barrel was forged from an alloy similar to Nitralloy 135-G type steel, but with lower carbon and was quenched and tempered. The bore was nitrided to a depth of .002" - .004". The Vickers hardness of the case averaged 872; of the core, 282. The steel contained a few sulphide and oxide inclusions, but was generally clean. The barrel was finished with fine machining cuts, and all changes of section were generously filleted.

The cylinder head was sand cast with the use of numerous cores from an Alcoa 142 type alloy with low nickel, and was solution heat treated and aged. The Vickers hardness was 82. A macroetched section taken perpendicular to the parting line revealed light porosity. However, the quality and surface finish of this intricate casting were good.

The cylinder head and barrel were covered with an ordinary black paint or enamel containing an iron-oxide pigment. There were no signs of blistering of the coating.

The valve seat inserts were forged from austenitic Ni-Cr-Mn steels, which are not commonly used in the United States for this application. The Vickers hardness of the exhaust insert was 198; of the intake insert, 190. The valve seat contact surface of the exhaust insert was checked, probably from lack of resistance to service conditions.

Push Rods

Each push rod consisted of two ends machined from plain carbon-steel bar stock and press-fitted into a low carbon-steel tube. The push rod ends were carburized to a depth of .045". All parts were quenched and tempered to Vickers hardness of 450 for the tubing and 706 and 221 for the case and core, respectively, of the ends. The tube was coated with a thin layer of cadmium.

Rocker Arm

The rocker arm was forged from Ni-Cr-Mo steel and was heat treated to a Vickers hardness of 383. Macroetching revealed flow lines which were indicative of good forging practice. The rocker arm was coated with a thin layer of cadmium.

The rocker arm bearing was cast from Cu-Sn alloy and had a hardness of 123 Vickers.

Rocker Box Cover

The rocker box cover was cast from a 5% Al-Mg alloy with a Vickers hardness of 69. The cover was in the as-cast condition and was slightly porous. For corrosion protection all surfaces were chemically treated and the outer surface covered with black paint. The inner surface showed numerous checks.

Valve Springs

The valve springs were made from coiled, high carbon-steel wire and had an average Vickers hardness of 449. The springs appeared to be poorly heat treated and showed partial decarburization of approximately .001". The springs were cadmium coated.

Valves

The intake valve was a common type; it was solid and had been forge upset. The stem tip had been hardened locally, probably flame hardened. The exhaust valve was the ordinary hollow-head, sodium-cooled type and was fabricated in the usual manner of forging and drilling the stem. After the stem was drilled, the valve was partially filled with sodium, the end of the stem heated, forged shut, and a piece of hardened tool steel either flash welded or pressure resistance welded to the end of the stem. A stellite type alloy was puddled onto the face of the exhaust valve.

The stem of the exhaust valve had been nitrided to a depth of .002 inch. This type of steel is not usually considered readily nitridable and was nitrided more out of necessity than because a good case was produced. The case was not so hard (500 VDH) as some previously examined from other Japanese aircraft. On the other hand, there are no evidences of corrosion or pits in the case as there were in the extremely hard cases examined. It is possible that the high hardness has been sacrificed for better corrosion resistance, or possibly that these valves have not been in service for a very long time and thus have not had time to become pitted.

The compositions of the valves, and some similar common valve steels, are given in Table 3. The composition of the exhaust valve was exactly that of the commonly used U.S. valve steel. The intake valve was similar to Silcrome No. 1 but had a greater chromium content and somewhat lower silicon. The facing material used on the exhaust valve was similar to Stellite No. 6 in composition. Comparisons of the valve alloys with standard American alloys are shown in the following:

TABLE 3. ANALYSES OF CYLINDER ASSEMBLY COMPONENTS, SAKAE 21 (CEE-2963)

Ferrous Parts, %

PART	PART NO.	C	P	S	Mn	Si	Ni	Cr	W	V	Mo	Cu	Sn	Al	Ti
Cylinder Barrel	533-10	.47	.014	.027	.40	.29	.48	1.43	.01	.008	.20	.25	.067	.90	.004
Push Rod Ends	533-12A	--	.010	.024	.31	.27	.15	.06	.01	.004	.018	.27	.14	.034	.004
Rocker Arms	533-14A	.25	.021	.012	.52	.25	3.20	1.27	.01	.004	.35	.28	.010	.010	.004
Valve Seat Inserts	533-53	.57	---	---	5.50	.42	12.50	3.50	---	---	tr	--	---	---	---
Exhaust Valve	533-20	.48	.014	---	.47	.57	13.7	14.0	2.12	.25Co	.11	--	---	---	---
Intake Valve	533-16	.37	---	---	.42	2.34	.20	10.9	Nil	.10Co	.82	--	---	---	---
Exhaust Valve-Seat Facing	533-20A	.70	---	---	--	2.37	.98	25.4	3.38	62.0Co	--	--	---	---	---
Spring Retainer	533-17A	.30	---	---	.49	.29	3.03	.69	---	---	tr	--	---	---	---

Nonferrous Parts, %

		Mn	Si	Ni	Cu	Fe	Zn	Mg	Al	Sn
Cylinder Head	533-11	.01	.40	.81	4.46	.51	---	1.16	Bal.	---
Baffle	533-15	--	.36	--	3.94	.50	---	.40	Bal.	---
Intake Manifold	533-24	--	.26	--	0.06	.37	---	.05	Bal.	---
Cylinder Head Bushing	533-11B	--	--	--	93.5	.01	.21	--	---	5.81
Rocker Arm Bearing	533-14C	--	--	--	88.5	.01	.30	--	---	9.82
Rocker Box Cover	533-21	--	.30	--	---	.023	--	Bal.	5.0	---

Valve No.	C	P	Mn	Si	Cr	Ni	W	Mo	Co	Fe
Exhaust Valve No. 533-20	.48	.014	.47	.57	14.0	13.7	2.12	.11	.25	Bal
U.S.Valve Steel	.40 to .50	.030 Max	.70 Max	.30 to .80	13.0 to 15.0	13.0 to 15.0	1.75 to 3.00	.50 Max	--	Bal
Intake Valve No. 533-16	.37		.42	2.34	10.9	.20	Nil	.82	--	Bal
Silcrome No. 1	.40 to .50	.020 Max	.20 to .60	3.00 to 3.50	8.0 to 9.0					Bal
533-20 Seat Facing	1.70			2.37	25.4	.98	3.38		62.0	
Stellite No. 6	1.25			2.7	27.0		4.00		65.0	

The stem tip of the intake valve had been hardened locally to a depth of about 3/8 inch to a hardness of 600 VDH. There was little indication of the hardening in the structure. The structure of both the body of the valve and the hardened stem was typical of Silcrome No. 1. There was a large amount of small carbides in a matrix of slightly tempered martensite.

The structure of the body of the exhaust valve was that of an age hardening alloy, with carbides evenly distributed throughout a matrix of austenite. The grain boundaries were a network of very fine carbides. No analysis was made of the steel used on the stem tip of the exhaust valve, but the structure indicated it was a high-carbon, highly alloyed tool steel, possibly 18-4-1. The welding of the tool steel to the stem of the exhaust valve was poorly done. A considerable amount of metal was melted and left at the interface and there was some porosity. On the other hand, a very good job of puddling was done on the face of the valve. Here there was a narrow band of metal which had been molten and the weld contact was good.

Both valves were in good condition and were well made. A small amount of the high alloy facings and stem-tip materials was used, but the amount appeared to be sufficient for the purpose.

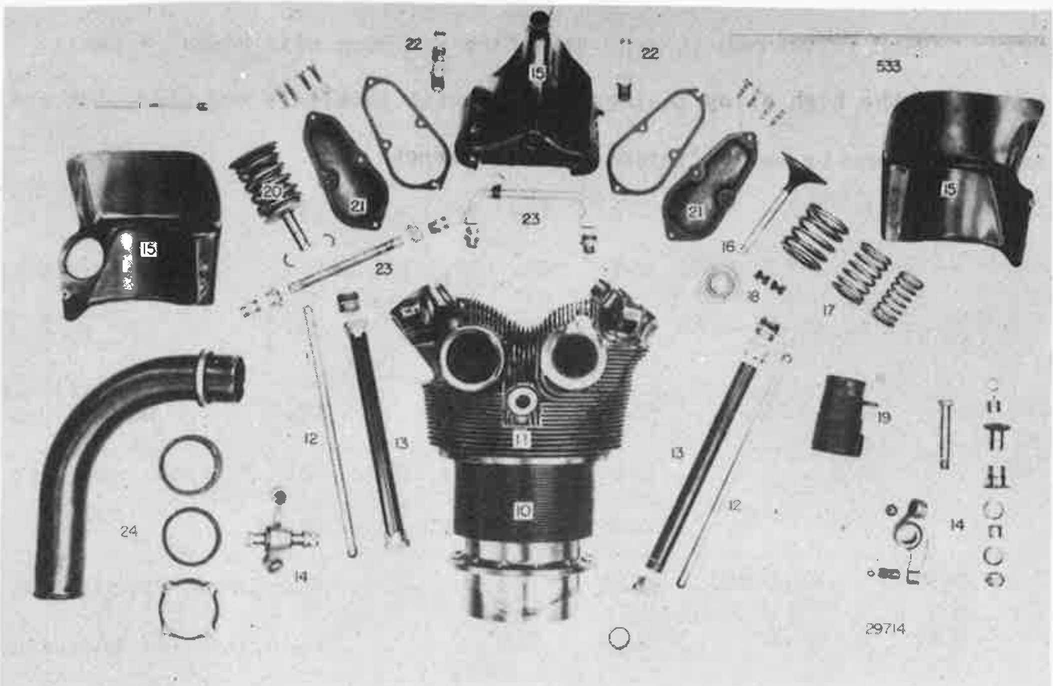


Figure 7. Disassembly of Valves and Rocker Arms from Cylinder Head and Barrel of Sakae-21 Aircraft Engine (CEE-2963). 30386

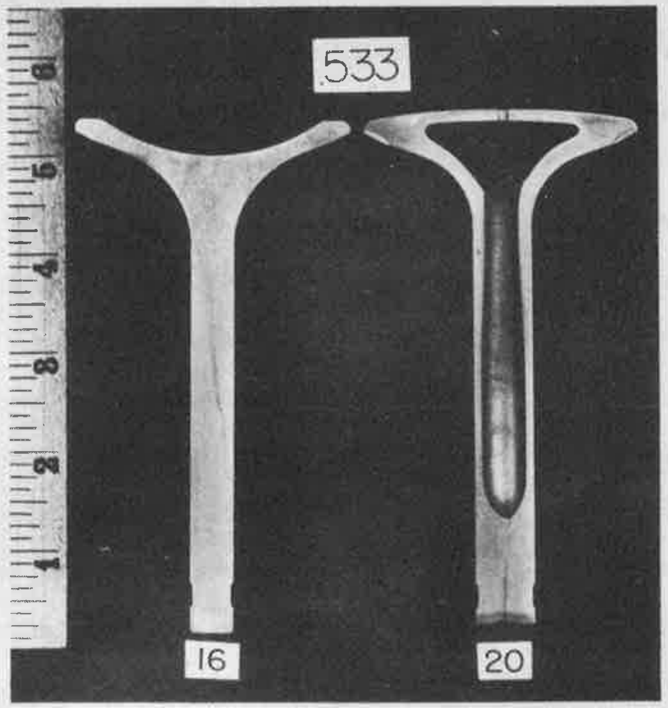


Figure 8. Macroetched Sections of Intake and Exhaust Valves (CEE-2963). 30137

TABLE 4. METALLURGICAL DATA ON CYLINDER ASSEMBLY FROM JAPANESE SAKAE-21 ENGINE (CEE-2963)

BMI Part No.	Name	Weight, Grams	Vickers Hardness Case	Vickers Hardness Core	Type of Material	Remarks
533-10	Cylinder Barrel	7,400	872	282	Nitralloy 135 G type steel	Forged; bore nitrided irregularly from .001" to .004"; after quenched and tempered; covered with black paint or enamel with iron-oxide pigment.
533-11	Cylinder Head	6,900		82	Alcoa 142 type alloy	Sand casting; solution heat treated and aged; slightly porous; covered with black paint or enamel with iron-oxide pigment.
533-11A	Exhaust and Intake Valve Guides			163	Cu-Sn alloy	Machined; press fitted into cylinder head.
533-11B	Spark Plug Bushing			169	Cu-Sn alloy	Machined; fastened into cylinder head with bronze pin.
533-12	Push Rod Assembly	197				
533-12A	Push Rod End		706	221	Plain C steel	Machined; carburized .045"; quenched and tempered.
533-12B	Push Rod Tubing			450	Low C steel	Tubing; quenched and tempered; Cd plated.
533-13	Push Rod Housing	157		123	Alcoa 24ST	Tubing; solution heat treated and aged; covered with black paint.
533-13A	Push Rod Housing Packing Nuts			233	Medium C steel	Machined; Cd coated; as-rolled condition.
533-13B	Push Rod Housing Couplings			206	Medium C steel	Machined; Cd coated; as-rolled condition.
533-13C	Push Rod Housing Gland	7		126	Alcoa 24ST	Tubing; solution heat treated and aged.
533-14	Rocker Arm Assembly	454				
533-14A	Rocker Arm			383	Ni-Cr-Mo steel	Forged; quenched and tempered; Cd coated.
533-14B	Cylinder Head Bushing			128	Cu-Sn alloy	Cast.
533-14C	Rocker Arm Bearing			123	Cu-Sn alloy	Cast.
533-14D	Rocker Shaft Bushing		704	439	Alloy steel	Machined; carburized on bearing surface .020"; quenched and tempered.
533-14E	Tappet Adjusting Screw		678	462	Alloy steel	Machined; carburized .025" at tappet bearing surface; quenched and tempered.

BMI Part No.	Name	Weight, Grams	Vickers Hardness Case	Core	Type of Material	Remarks
533-14F	Tappet			771	SAE 52100 steel	Forged; quenched and tempered.
533-14G	Rocker Arm Shaft			388	Alloy steel	Machined; quenched and tempered.
533-14H	Rocker Arm Shaft Nut			210	Low C steel and Alcoa 24ST	Nut machined; in as-rolled condition; plug; stamping, solution heat treate. and aged, assembly; Cd plated.
533-14I	Push Rod Bearing		678	284	Low C steel	Machined; carburized .025" at bearing surface; quenched and tempered.
533-14J	Tappet Adjusting Screw Nut			330	Alloy steel	Machined; quenched and tempered; Cd coated.
533-14K1	Cylinder Head Bushing Spacer			206	Low C steel	Machined; in as-rolled condition; Cd coated.
533-14K2	Cylinder Head Bushing Spacer			326	Alloy steel	Machined; quenched and tempered; Cd coated.
533-14K3	Cylinder Head Bushing Spacer			206	Low C steel	Machined; in as-rolled condition; Cd coated.
533-15	Baffles	197		85	Alcoa 17ST type alloy	Sheet stamping, solution heat treated and aged, with low C sheet stampings attached with duralumin rivets; covered with black paint.
533-15A	Baffle Studs	14		322	Medium C steel	Machined; quenched and tempered.
533-15B	Baffle Bolts	10		313	Medium C steel	Machined; quenched and tempered.
533-17A	Valve Spring Retainer	210		554	Ni-Cr steel	Forged; quenched and tempered; Cd coated.
533-17B	Inner Valve Spring	170		457	High C steel	Coiled wire; normalized; .001" decarburization; Cd coated.
533-17C	Middle Valve Spring	226		453	High C steel	Coiled wire; normalized; .001" decarburization; Cd coated.
533-17D	Outer Valve Spring	297		436	High C steel	Coiled wire; normalized; .001" decarburization; Cd coated.
533-18A	Intake Valve Retainer Clips	49		203	Al bronze	Cast.
533-18B	Exhaust Valve Retainer Clips	49		563	Alloy steel	Machined; quenched and tempered.
533-19	Exhaust Stack	197		192	Austenitic Ni-Cr steel	Consists of two tubular pieces fitting together, and formed by bending sheet to shape and welding; medium C steel stamped lug welded to one piece.

Table 4. (Continued)

BMI Part No.	Name	Weight, Grams	Vickers Hardness Case	Core	Type of Material	Remarks
533-21	Rocker Box Cover	198		69	5% Al-Mg alloy	Cast; inner surface cracked; surface chemically treated and covered with black paint; in as-cast condition; slight porosity.
533-21A	Rocker Box Cover Studs	14		181	Low C steel	Machined; annealed.
533-21B	Rocker Box Cover Bolts	16		201	Low C steel	Machined; annealed.
533-21C	Rocker Box Cover Gaskets	7			Leatherette	
533-22A	Rocker Arm Oil Lines	227		198	Low C steel	Tubing with fittings Cu brazed; Cd coated.
533-22B	Rocker Arm Oil Line Couplings	45		232	Medium C steel.	Machined; annealed; Cd plated.
533-22C1	Rocker Arm Oil Line Nuts	25		197	Low C steel	Machined; annealed; Cd plated.
533-22C2	Rocker Arm Oil Line Nut	25		130	60-40 Cu-Zn alloy	Machined; Cd plated.
533-24	Intake Manifold	363		38	Alcoa 2S	Two stampings welded together; covered with black paint.
533-24A	Intake Manifold Nut	90		352	Medium C steel	Machined; quenched and tempered; black gun metal finish.
533-24B	Intake Manifold Ring			136	Armco iron	Sheet stamping with rubber ring.
533-24C	Intake Manifold Gland	35		124	Alcoa 24ST	Forged; solution heat treated, and aged; partially covered with black paint.
533-53A	Exhaust Valve Seat Insert	90		198	Austenitic Ni-Cr-Mn steel	Forged; cracks on valve seat bearing surface.
533-53B	Intake Valve Seat Insert	80		190	Austenitic Ni-Cr-Mn steel	Forged.

III - NOSE SECTION

by

F. M. Stephens

Propeller Shaft

This part was forged from nickel-chromium-molybdenum steel with the usual Japanese high residual copper and tin. The propeller shaft was heat treated to a VDH of 336. Workmanship and materials were good throughout. The steel used in this shaft was similar to British Standard Aircraft 2S 28. No similar steel is in standard use in the United States.

Bell Gear

The bell gear was forged from a steel similar to Nitralloy G and was nitrided on the gear teeth and cam bearing race to a depth of 0.01". The core had a VDH of 351 and the nitrided case was VDH 905. The use of a nitrided case on this gear was rather unusual; the steel used could probably be replaced by a standard case-hardening steel. The relatively deep notches indicating degrees on the perimeter of the gear probably had the effect of stress raisers.

Spur Gear

The spur gear was forged from nickel-chromium-molybdenum steel somewhat similar to British Standard Aircraft steel 2S 28. The teeth were carburized to VDH 666. Workmanship was good throughout.

Sun Gear

The sun gear was forged from nickel-chromium-molybdenum steel similar to British Standard Aircraft steel 2S 28. The residual copper was very high, even for a Japanese steel. The teeth were carburized to a VDH of 609. The gear was of good quality.

Front Cam

The front cam was forged from nickel-chromium-molybdenum steel similar to British Standard Aircraft steel 3S 11. The gear teeth and cam faces were carburized to a VDH of 655. Quality of workmanship was good in this piece.

Nose Casting

This casting was made from an aluminum alloy containing 4% copper and 4.4% silicon similar to Alcoa 85. The casting was in good condition throughout.

Tappet

The bearing assembly of the tappet roller was of unusual design. The low C steel roller was case hardened over-all and had a relatively high hardness (VDH 322). A nickel-copper bushing was inserted, as a bearing surface, through the center of the roller. This bushing ran on a 52100-type steel pin hardened to VDH of 700. The sliding action in the tappet was furnished by low C steel tube which moved inside a slightly larger tube. The sliding surfaces of the tubes were carburized to a hardness of VDH 620 to 630. The quality of the tappet assembly was good throughout.

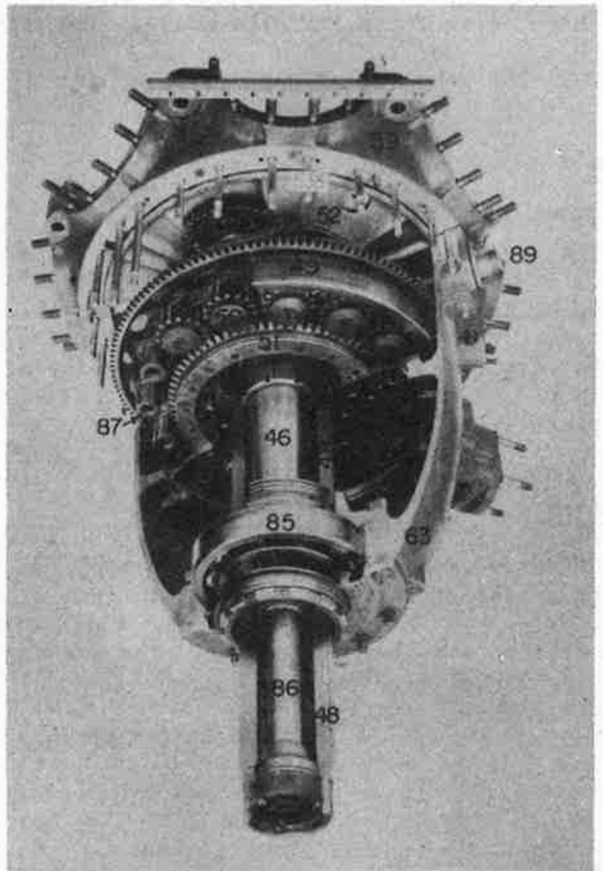


Figure 9. Nose Assembly of Sakae-21 Aircraft Engine (CEE-2963). 30141

46-Crankshaft
48-Propeller Shaft
49-Bell Gear
50-Planet Gear
51-Sun Gear
52-Cam
59-Crankcase
63-Nose Casting
85-Propeller Shaft Bearing

TABLE 5. ANALYSES OF NOSE SECTION COMPONENTS - SAKAE 21 (CEE-2963)

Ferrous Parts, %

PART	PART NO.	C	P	S	Mn	Si	Ni	Cr	W	V	Mo	Cu	Sn	Al	Ti
Propeller Shaft	533-48	.22	.013	.012	.47	.20	3.36	1.23	<.01	<.02	.52	.13	.035	.023	<.004
Bell Gear	533-49	.44	.020	.026	.48	.23	0.34	1.56	<.01	<.02	.22	.20	.069	.95	<.004
Planet Gear	533-50	.18	.018	.014	.50	.26	4.12	1.17	<.01	<.02	.42	.32	.059	.008	<.004
Sun Gear	533-51	.14	.018	.032	.59	.28	4.60	1.20	<.01	<.02	.20	.46	.041	.008	<.004
Front Cam	533-52	.20	.013	---	.69	.19	4.60	0.48	<.01	<.02	.15	.35	.066	.010	<.004

Nonferrous Parts, %

PART	PART NO.	Mn	Si	Ni	Cu	Fe	Mg	Al	Zn	Sn	Pb	P	Sb	As
Nose Casting	533-63	<.01	4.4	<.01	4.0	.49	<.01	Bal.	---	---	---	--	---	---
Planet Gear Bushing	533-50	--	---	--	73.6	--	---	---	.02	5.45	19.0	.17	---	---
Front Cam Bearing	533-69	--	---	--	2.38	.19	---	---	---	92.1	Nil	---	5.28	.016

TABLE 6. METALLURGICAL DATA ON NOSE SECTION OF A JAPANESE SAKAE-21 AIRCRAFT ENGINE (CEE-2963)

Number	Name	No. Pieces	Weight, Grams	Vickers Hardness Core	Vickers Hardness Case	Type of Material	Heat Treatment	Remarks
48	Propeller Shaft	1	16,300	336		Ni-Cr-Mo- Steel	Quenched and Tempered	Forged & machined. Y.S. 138,000 p.s.i., Tensile S. 150,500.
49	Bell Gear	1	8,170	351	905	Nitralloy G	Quenched and Tempered	Teeth and cam bearing surface nitrided to depth of 0.01". Forged.
50A	Planet Gear	15	170	449	660	Ni-Cr-Mo Steel	Quenched and Tempered	Teeth case-hardened 0.03" deep. Forged.
50B	Planet Gear Bolt	15	60	404	726	Medium C steel	Quenched and Tempered	Upset forged. Bearing surface case 0.03".
50C	Planet Gear Nut	15	10	320		Low C steel	Quenched and Tempered	Machined from bar stock. Cd plated.
50D	Planet Gear Bushing	15	65	65		Bronze		Cu-Sn bushing. Cast.
51A	Sun Gear	1	1,810	439	608	Ni-Cr-Mo steel	Quenched and Tempered	Forged. Case 0.015" thick.
51B	Sun Gear Mount Ring	1	2,270	374		Low C steel	Quenched and Tempered	Machined.
51C	Sun Gear Nuts & Bolts	18	16	Bolt 292 Nut 218		Low C steel	Quenched and Tempered	Machined bar stock.
52A	Cam	1	1,590	516	655	Ni-Cr-Mo steel	Quenched and Tempered	Forged. Case 0.004" on gear teeth and cam face.
52B	Cam Drive Gear	1	350	415	695	Medium C steel	Quenched and Tempered	Forged. Case 0.015" Thick on teeth.
52C	Cam Spur Gear Bolts	5	10	320		Low C steel	Quenched and Tempered	Machined bar stock. Cd plated.
52D 1	Cam Spur Gear	1	880	422	660	Low C steel	Quenched and Tempered	Teeth cased 0.015" thick. Forged.
52D 2	Cam Spur Gear Shaft	1	250	444	650	Low C steel	Quenched and Tempered	Shaft cased 0.04" deep. Forged.
52E	Cam Mount Ring Gear	1	2,820	350		Alloy steel 30C	Quenched and Tempered	Forged.

TABLE 6. (Continued)

Number	Name	No. Pieces	Weight, Grams	Vickers Hardness Core	Vickers Hardness Case	Type of Material	Heat Treatment	Remarks
52F	Cam Nuts and Bolts	24	5	254		Low C steel	Quenched and Tempered	Machined bar stock. Cd plated.
63	Nose Casting	1	19,200	97		Similar Alcoa 85 Aluminum	Solution heat treated and aged	Cast.
69	Cam Bearing	1	350	21		Sn-Sb-Cu Babbitt		Sn-Sb-Cu cast on Cu-Sn cast bronze backing.
85A	Propeller Shaft Bearing	1	2,630	700		52100		
85B	Propeller Shaft Bearing Front Retainer	1	560	76		Similar Alcoa 17ST Aluminum	Solution heat treated and aged.	Forged.
85C	Propeller Shaft Bearing Front Oil Gland	1	940	409	677	High carbon alloy	Quenched and Tempered	Forged. Cd plate on ring surfaces, cased 0.03" deep.
85C 1	Front Oil Gland Rings	3	23	262		Cast iron	As cast	High phosphorus iron casting.
85D	Propeller Shaft Bearing Back Retainer	1	1,660	78		Similar Alcoa 17ST Aluminum	Solution heat treated and aged	Forged.
85E	Propeller Shaft Bearing Back Oil Gland	1	567	356	906	High carbon alloy	Quenched and Tempered	Forged. Cd plated. Ring surfaces nitrided 0.01" deep.
85E 1	Back Oil Gland Rings	7	23	270		Cast iron	As cast	High phosphorus iron casting.
85F	Propeller Shaft Bearing Sleeve	1	603	415	644	Low C steel	Quenched and Tempered	Forged. Case 0.01" to 0.03" deep on inside only.
85G	Propeller Shaft Bearing Nuts & Bolts	10	87	320		Low C steel	Quenched and Tempered	Machined from bar stock. Cd plated.
85H	Propeller Shaft Bearing Back Retainer Ring	1	72	356	908	Alloy steel	Quenched and Tempered	Sheet stock. Nitrided case 0.015" thick on all surfaces.

TABLE 6. (Continued)

Number	Name	No. Pieces	Weight, Grams	Vickers Hardness Core	Vickers Hardness Case	Type of Material	Heat Treatment	Remarks
86A	Propeller Oil Tube	1	998	264		Low C steel	Quenched and Tempered	Bearing rings of cast Cu-Sn are brazed to steel tube with Zn-Cu-Ag-Cd brazing alloy similar to "Easy Flo".
86B	Propeller Oil Tube Nut	1	136	232		Low C steel	Quenched and Tempered	Machined bar stock or tubing.
87A	Planet Gear Cage	1	8,050	312	675	Alloy steel	Quenched and Tempered	Shafts cased 0.03" deep. Forged.
87B	Planet Gear Cage Nuts & Bolts	15	58	320		Low C steel	Quenched and Tempered	Bar stock.
89A	Tappet Roller	28		415	720	Low C steel	Quenched and Tempered	Bar stock. Case 0.03" deep
89B	Tappet Shaft	28		381	630	Low C steel	Quenched and Tempered	Tubing. Case 0.03" deep.
89C	Tappet Tube	28	226	398	618	Low C steel	Quenched and Tempered	Tubing. Case 0.03" deep.
89D	Tappet Rod	28		369	704	Low C steel	Quenched and Tempered	Bar stock. Case 0.03" deep.
89E	Tappet Bearing	28		322		Al-Cu bearing Ni-Cu bearing		Cast Al-Cu bushing, cast Ni-Cu bushing. Two types of bushing used at random in this assembly.
	Tappet Bearing Pin	28		700		52100 steel	Quenched and Tempered	
90A	Propeller Governor Shaft & Gear	1	110	438	598	Low C steel	Quenched and Tempered	Bar stock. Gear teeth cased 0.03".
90B	Propellor Governor Bevel Gear	1	137	415	660	Low C steel	Quenched and Tempered	Forged. Case 0.03" deep.
90C	Propeller Governor Spur Gear	1	47	426	655	Low C steel	Quenched and Tempered	Forged. Case 0.03" deep.

IV - BLOWER SECTION

by

D. O. Leeser

The blower case, impeller, rear cam cover plate, impeller cover plate, and the air intake section were made from aluminum alloys. Of these the rear cam cover plate and the impeller were forged and heat treated, while the blower case, impeller cover plate, and the air intake section were sand cast, but not heat treated. The diffuser was an unheat-treated magnesium sand casting made of an alloy similar to the German A-10. Casting technique in all pieces was good, porosity was at a minimum, and grain size was uniform. The aluminum forgings were anodized and the magnesium casting was chemically treated. The aluminum castings were protected only by paint.

The three steel parts of the rear cam were forged. The cam itself and the oil seal seat were made from alloy steel, while the inside bearing was forged from plain carbon steel and lined with babbitt. The wearing surface of the rear cam was carburized .04 inch with a case hardness of R_C 56 and a core hardness of R_C 31.

Impeller Shaft

This piece was forged from a high nickel (4.65%), low chromium (.43%) steel containing only .13% carbon. This analysis is similar to one of the Krupp steels no longer used in this country. The teeth were carburized to a depth of .035 inch, and the spline was cadmium plated .00075 inch. Microstructure of both the case and core showed a quenched and tempered condition. The hardness of the core was R_C 40 and of the case R_C 60.

Impeller Drive Gear

The same type of steel used in the manufacture of the impeller shaft was used in forging the impeller drive gear. The teeth were carburized to a depth of .04 inch with a hardness of R_C 59. The core had a hardness of R_C 40. Microstructure showed a quenched and tempered condition.

Impeller Hub

The hub consisted of two pieces, which were fastened together as well as into the impeller with steel pins, and was splined. The hub was machined from bar-stock steel of a composition similar to our SAE 51335 (12.6% chromium). Hardness value was Vickers 325 (R_C 32). Microstructure showed a spheroidized condition resulting from quenching and tempering.

TABLE 7. ANALYSES OF BLOWER SECTION COMPONENTS - SAKAE 21 (CEE-2963)

Ferrous Parts, %

PART	PART NO.	C	P	S	Mn	Si	Ni	Cr	W	V	Mo	Cu	Sn	Al	Ti
Impeller Shaft	533-57	.13	.013	.023	.54	.19	4.65	0.43	<.01	<.02	.08	.20	.033	.028	<.004
Impeller Drive Gear	533-58	.13	.018	.020	.50	.26	4.65	0.43	<.01	<.02	.15	.39	.067	.011	<.004
Impeller Hub	533-62B	.20	--	--	--	--	0.59	12.57	--	--	.06	--	--	--	--

Nonferrous Parts, %

PART	PART NO.	Mn	Si	Ni	Cu	Fe	Mg	Al	Zn	Sn	P	Pb
Blower Case	533-61	.01	4.5	<.01	4.1	.34	<.01	Bal.	----	----	----	----
Impeller	533-62	.44	.36	<.01	4.1	.35	.34	Bal.	----	----	----	----
Diffuser	533-64	.16	.12	Nil	0.15	.05	Bal.	10.1	Nil	----	----	----
Impeller Shaft Bearing	533-68	---	---	---	83.6	---	---	---	.03	5.72	.09	9.4

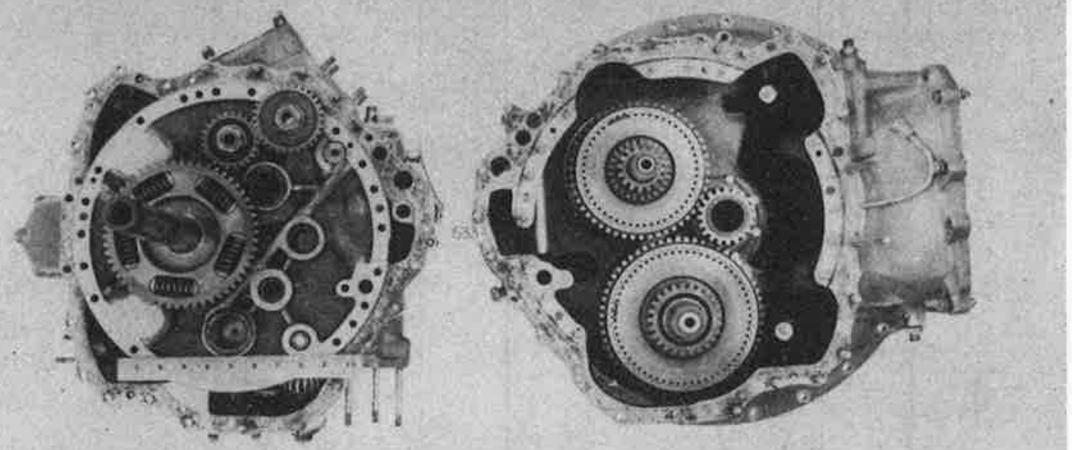


Figure 10. Supercharger Gearing and Clutch of Japanese Sakae-21 Aircraft Engine (CEE-2963). 29934

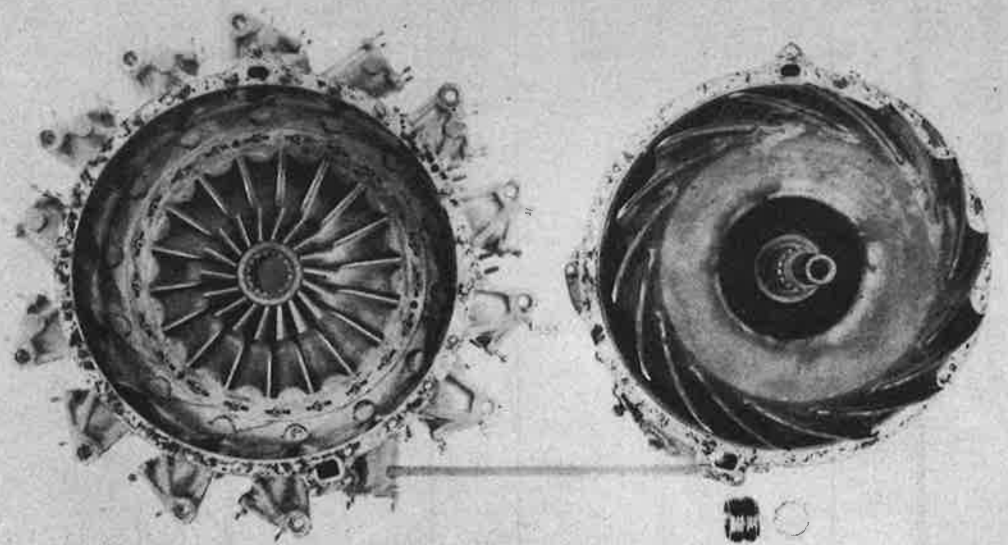


Figure 11. Blower Case, Impeller, and Diffuser (CEE-2963). 29814
The impeller shaft and crankshaft exterior are shown in the diffuser case. The oil gland for the crankshaft exterior is shown below the diffuser case.

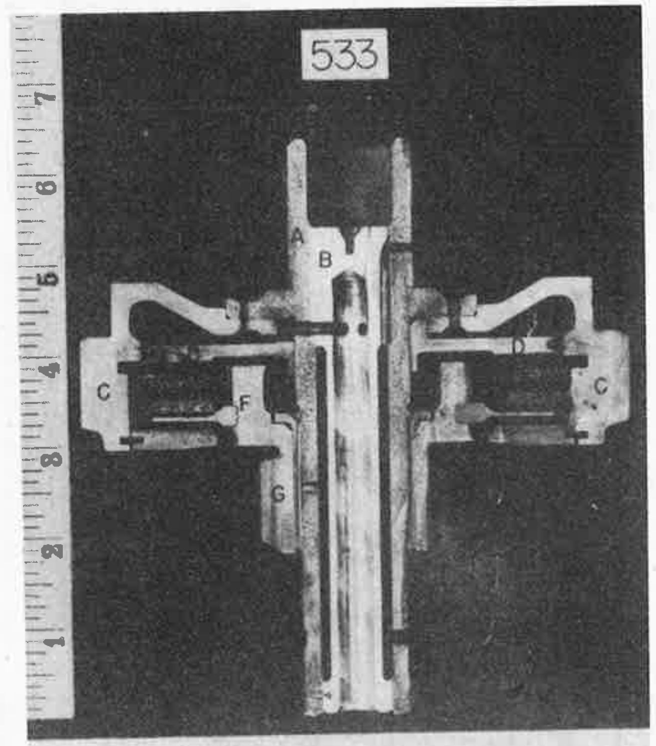


Figure 12. 30062

Section of Impeller Drive Gear and Clutch (CEE-2963).

A-Shaft

B-Oil Spindle

C-Gear

D-Pressure Plate

E-Clutch Disc

F-Spline and Speed Drive Gear

G-Bearing

TABLE 8. METALLURGICAL DATA ON SUPERCHARGER ASSEMBLY AND BLOWER SECTION OF JAPANESE SAKAE-21 AIRCRAFT ENGINE (CEE-2963)

Part No.	Name	Weight, Grams	Hardness Rockwell	Hardness Vickers	Remarks	Microstructure & Heat Treatment
57-A	Impeller Shaft	1,360	C 40*core C 60*case	395 782	Forged from alloy steel. Carburized teeth .035". Cd plated .00075" on spline.	Quenched and tempered in core and case.
57-B	Impeller Shaft Oil Seat (Bronze)	306 (57-B both)	B 83	158*	Bronze bearing seated on steel seat. Machined from bar stock or tubing.	Annealed structure.
57-B	Impeller Shaft Oil Seat (Steel)		C 34	337*	Alloy steel seat. Machined from bar stock or tubing.	Quenched and tempered showing undissolved carbides.
57-C	Impeller Shaft Thrust Bearing	290	B 44*	88	Machined from bronze.	Cast copper-tin bronze.
58	Impeller Drive Clutch					
58-A	Shaft	616	C 50	550*	Forged from alloy steel.	Quenched and tempered showing undissolved carbides.
58-B	Oil Spindle	54	B 75	136*	Machined from heat-treated duralumin bar stock.	Similar to Alcoa 17ST.
58-C	Gear	1,886	C 40 core C 59*case	393* 770	Forged from alloy steel. Carburized teeth .04".	Quenched and tempered showing MnS inclusions in core and case.
58-D	Pressure Plate, Upper	306	C 28	275*	Forged from medium carbon steel.	Quenched and tempered showing MnS inclusions
58-E	Clutch Disc	200	C 29	280*	Forged from medium carbon steel.	Quenched and tempered.
58-F	Spline and Speed Drive Gear	426	C 37 core C 59*case	368* 765	Forged from alloy steel. Carburized teeth .04".	Quenched and tempered in core and case.
58-G	Bearing (Case)	98 (58-G both)	C 33*	320	Machined from alloy steel bar stock or tubing.	Quenched and tempered.
58-G	Bearing (Surface)			25	Machined from lead bronze.	Cast structure.
58-H	Clutch Plate	110	B 100	243*	Machined from medium carbon steel bar stock or tubing. Mounted on phenolic resin impregnated asbestos cloth.	Fine-grained pearlite with ferrite.
58-I	Ball Bearing	300	C 60	785*	Alloy steel.	
58-J	Large Centering Ring	242	C 40	389*	Forged from alloy steel.	Quenched and tempered.
61	Blower Case	17,230	B 21	70*	Sand cast aluminum alloy.	Shows silicon and copper constituents - not heat treated.

TABLE 8. (Continued)

Part No.	Name	Weight, Grams	Hardness Rockwell	Hardness Vickers	Remarks	Microstructure and Heat Treatment
62-A	Impeller	2,840 (62-A and 62-B)	B 57	98*	Forged aluminum alloy.	Heat treated duralumin 17 ST.
62-B	Impeller Hub		C 32*	325	Machined from high alloy steel bar stock. In two pieces held together with pins.	Spheroidized carbides.
64	Diffuser	1,815	B 32	77*	Magnesium sand casting. Alloy similar to German A 10 "Sand Cast".	No solution heat treatment given.
68	Impeller Shaft Bearing	113	F 67	65*	Cast bronze.	Cast tin-phosphorus bronze.
83-A	Spring Loaded Gear	1,135	C 40 core C 60*case	390* 789	Forged from alloy steel. Teeth carburized .04".	Core and case show tempered martensite with few undissolved carbides.
83-B	Gear Springs (5)	50	C 40*	393	Drawn from high carbon steel wire.	Quenched and tempered. Shows disectional properties.
83-C	Gear Springs Guides (10)	21	C 58*	730	Machined from alloy steel.	Quenched and slightly tempered. Shows MnS inclusions.
83-D	Gear Springs Cover	105	C 30	290*	Cut from medium carbon steel sheet.	Quenched and tempered.
84-A	Impeller Control Valve Piston	90	C 37 core C 58*case	370* 735	Machined from alloy steel bar stock. Carburized on wearing surface .04".	Quenched and tempered in both core and case
84-B	Impeller Control Valve Cylinder	112	C 30	289*	Machined from medium carbon steel bar stock.	Quenched and tempered.
84-C	Impeller Control Valve Spring	2			High carbon steel wire coiled spring.	
84-D	Impeller Control Valve Nut	3.	C 30	289*	Machined from mild carbon steel bar stock.	
84-E	Impeller Control Valve Washer	1	B 91	188*	Stamped from low carbon steel sheet.	
84-F	Impeller Control Valve Pin	3	B 100	245*	Machined from medium carbon steel.	
84-G	Impeller Control Valve Bracket	41	C 24	248*	Machined from medium carbon steel bar stock.	Quenched and highly tempered.
93-A	Rear Cam Plate	1,200	B 64	108*	Forged aluminum alloy.	Heat-treated duralumin 17ST or 24ST.
93-B	Rear Cam	1,660	C 31 core C 56*case	298* 673	Forged from alloy steel. Carburized .04".	Quenched and tempered in core and case.
93-C	Rear Cam Bearing, Inside	200	B 50*steel - babbitt	94 29	Forged from low carbon steel. Inside surface lined with babbitt.	Free ferrite with small amounts of fine pearlite.
93-D	Rear Cam Oil Seal Seat	85	C 50*	550	Forged from alloy steel.	Quenched and slightly tempered. Shows undissolved carbides.
94	Impeller Cover Plate	2,900	B 30	296*	Aluminum sand casting.	Shows silicon and copper constituents similar to Blower Case (Part # 61)
96	Air Intake Section	14,900	B 31	297*	Aluminum sand casting.	Shows silicon and copper constituents similar to Blower Case (Part # 61)
99	Tail Shaft	2,270	C 34 core C 60*case	329* 770	Forged from alloy steel. Carburized wearing surface. (Sprockets and sides)	Case and core show quenched and tempered structure with few undissolved carbides.

*Converted Values.

V - ACCESSORY SECTION

by

D. O. Leeser
J. G. Dunleavy
David Adams
Earl Ganslein
C. A. Reichelderfer

Accessory Gear Case

The gear case and mounting plate, shown in Figure 13, were cut from an aluminum alloy similar to Alcoa 85 (4% Cu, 5% Si). They were not heat treated or anodized. Bearing surfaces for heat-treated steel shafts running in these castings were leaded tin-bronze casting inserts. The small gears driving various auxiliaries were Ni-Cr Krupp alloy steel forgings carburized on the wearing surfaces.

Gear Oil Pump

The housing consisted of five magnesium castings, two of which served as spacers. Microstructures revealed a magnesium alloy similar to the German A-10, with porosity. Contrary to standard American practice, the rough interior surfaces were not cleaned to remove sand particles which might work their way into the oil. All surfaces of the castings had been chemically treated, probably by a dichromate pickle. The exterior surfaces were painted with a gray enamel.

Of the remaining nonferrous parts, two bushings and a coiled wire spring were made of brass, five bearings and a bushing were made of bronze, and four small check valve parts were of wrought aluminum.

Spark tests indicated that the only alloy steels (probably Ni-Cr) were the nine gears and the three shafts. The shafts were carburized to a depth of .04 inch. The remaining thirty-three steel parts were plain carbon steels.

All parts except the magnesium housing assembly, which was cast, were machined from bar stock.

Analyses of Gear Oil Pump Components

Part	Part No.	Mn	Si	Al	Fe	Mg	Zn
Gear Pump Housing	25	.14	.13	10.3	.042	Bal.	<.02
Gear Pump Spacer, Front	25	.16	.13	9.6	.018	"	<.02
Gear Pump Spacer, Back	25	.13	.51	8.5	.051	"	<.02

Starter

The examination of the inertia starter showed very little use of alloy steels, or heat treatment for additional physical properties; plain carbon steels were used wherever possible. Workmanship was good. Heat treatments were uniform, and in some cases showed very close control. An example of good heat treatment was the clutch housing cast from "Y" alloy or Alcoa 142, the precipitation aging of which showed close temperature and time control.

An interesting comparison may be made between a German engine starter, previously examined, and the Japanese starter. Evidently the same design was used for both starters with very few alterations in the Japanese piece. The German starter showed better workmanship, but the Japanese starter should fulfill its intended purpose. Several changes which would facilitate manufacture were made by the Japanese.

The parts subjected to wear or requiring high strength were made from approximately the same type of alloys. One of the major alloy changes was the absence of magnesium in the Japanese starter. All of the housings were cast aluminum, while the German starter used a sand-cast magnesium alloy and one aluminum forging of the 17S type. The Japanese substituted an aluminum casting of the "Y" alloy type for this forged part and an aluminum-silicon sand casting alloy, similar to Alcoa 47, for the magnesium parts.

Fuel Pump

The fuel pump was a duplex unit consisting of a vane rotor pump mounted on a gear pump. The two units may have served independent functions. A wide variety of metals was used including plain and alloy steel, wrought and cast aluminum, copper, bronze, brass, and cadmium. The extensive casting, forging, machining, and heat-treating operations must have required many man-hours. The single use of a free-machining steel screw stock represents one of the few attempts by the Japanese to reduce machining time.

Oil Sump and Check Valve

The oil sump and check valve shown in Figure 19 contains no unusual materials, and standard procedures seem to have been followed in manufacturing them.

The steel adaptors and plugs (see Table 16) contained much more carbon than would normally be expected in unstressed parts, but this higher carbon would not be objectionabl The normalizing treatment would give sufficient machinability.

The cadmium plating noted on several parts was thin, being at the most a few tenths of a thousandth inch in thickness.

The body of the sump had a structure resembling Dowmetal C. Primary beta (Mg-Al-Zn) constituent was prevalent and small amounts of Mg_2Si and manganese constituents were observed. The matrix was that of a solution-treated and aged alloy.

Rocker Box Oil Sump

The sump assembly consisted of a 6-8% Al-Mg sand-cast body with several hose connections composed of brass nuts and steel tubing. Connections either had brass nuts or steel nuts with brass inserts in the magnesium casting.

No critical materials or heat-treated parts were used. All exposed ferrous and nonferrous parts were cadmium plated.

Cuno Parts

A sand-cast aluminum housing enclosed the Cuno drive mechanism and strainer parts. Spark tests revealed that only two pieces were made of alloy steels (the ratchet and the drive gear and shaft); the rest were manufactured from plain carbon steels. Cast tin-phosphorus bronze bearings were used.

Macroetching showed that only one piece, the piston arm, was forged, and that the rest were machined from rolled or cast stock.

Machine Gun Synchronizer

The synchronizer parts (Figure 16) were in good condition and well protected against corrosion. Most of the steel parts were cadmium plated, and many of the uncoated parts were made of alloy steel. Spark tests indicated that the alloying elements were chromium and nickel, although some indication of tungsten was seen. All gear teeth and bearing surfaces were case carburized.

Two tin-bronze bearings and one brass fitting were used. The housing was a solution-treated and aged magnesium sand casting.

Although some of the parts were rough machined, all bearing surfaces were well finished. In general, workmanship was good.

A summary of the examination reveals the following:

Cast	3
Forged	3
Machined from bar stock. . .	11
Stamped.	5
Formed from wire	1
Machined from tubing	1
Duplicates not examined. . . .	6

A summary of heat-treating data for the steel parts gave the following results:

Quenched and tempered . . .	13
Not treated	6
Duplicates not examined . .	6

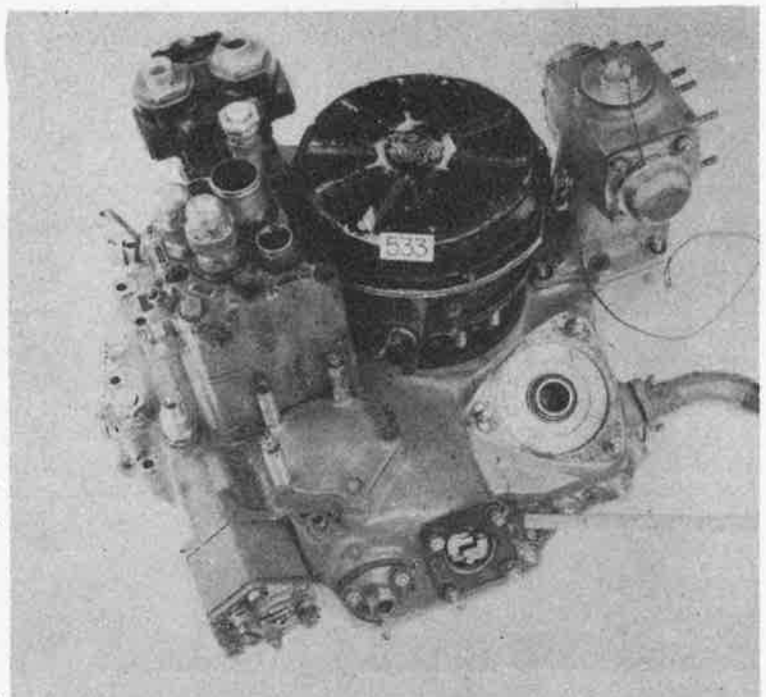


Figure 13. Gear Case and Accessories; Starter, Fuel Pump, Oil Pump, and Cam Drive. (CEE-2963) 29716

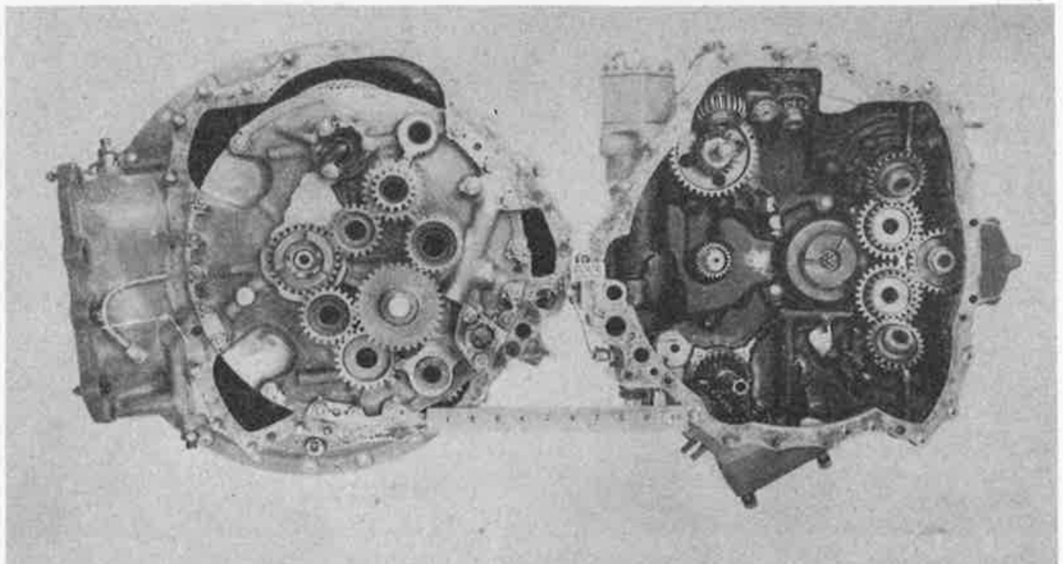


Figure 14. Gear Case Opened - Accessories (Right), Supercharger Clutch Plate, Closed (Left). (CEE-2963) 29715

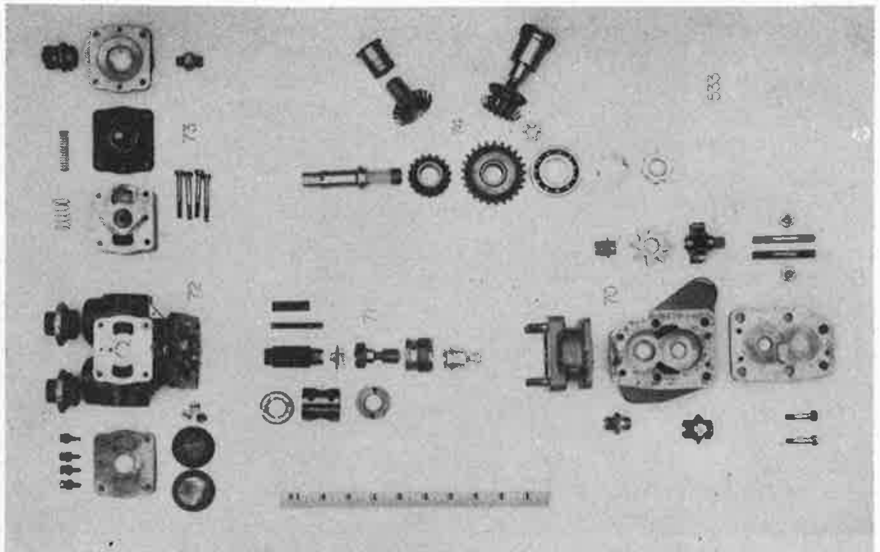


Figure 15. Fuel Pump Disassembly (CEF-2963). 29998

-70 Gear Pump
-71 Fuel Pump Assembly
-72 Fuel Pump Case
-73 Diaphragm Assembly
-74 Driving Gear Assembly

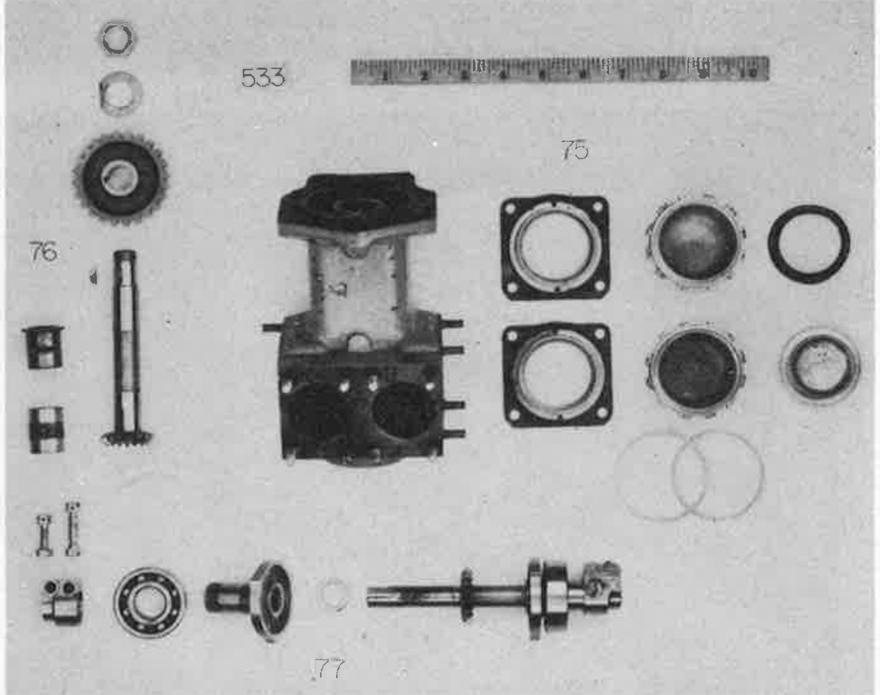


Figure 16. Machine Gun Synchronizer (CEF-2963). 30029

-75 Machine Gun Cam Case
-76 Cam Drive Shaft and Gear
-77 Cam Assembly

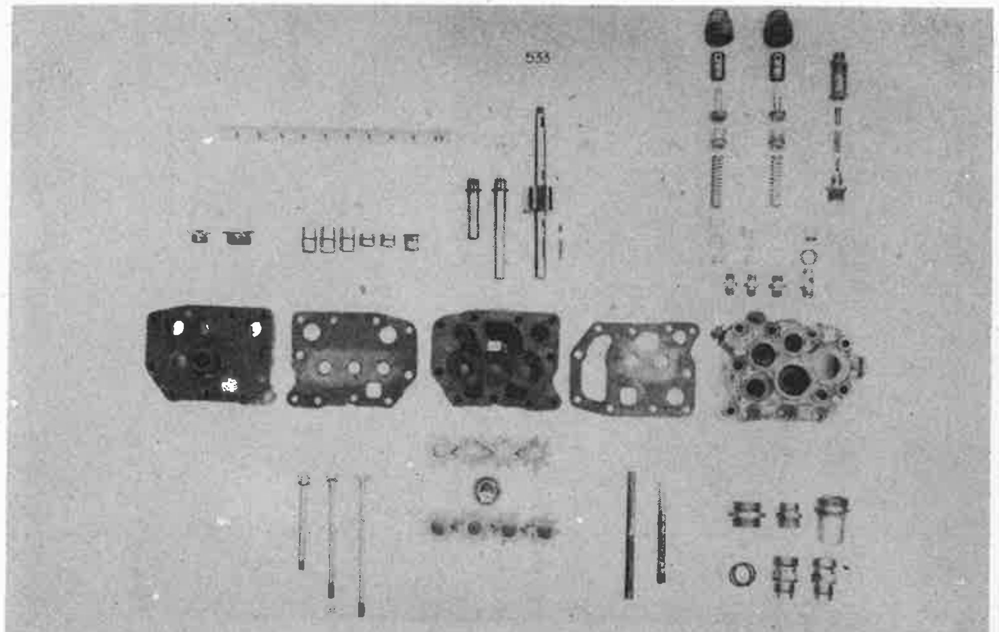


Figure 17. Gear Oil Pump Disassembly. (CEF-2963) 29880

-25 Housing Assembly (5)
-26 Gears (9)
-27 Shafts (3)
-28 Large Check Valves (2)
-29 Med. Check Valves (3)
-30 Small Check Valves (3)
-31 Connecting Couplings (5)
-32 Assembly Tubes (2)
-33 Assembly Bolts (3)
-34 Bushings (2)
-35 Bearings (6)

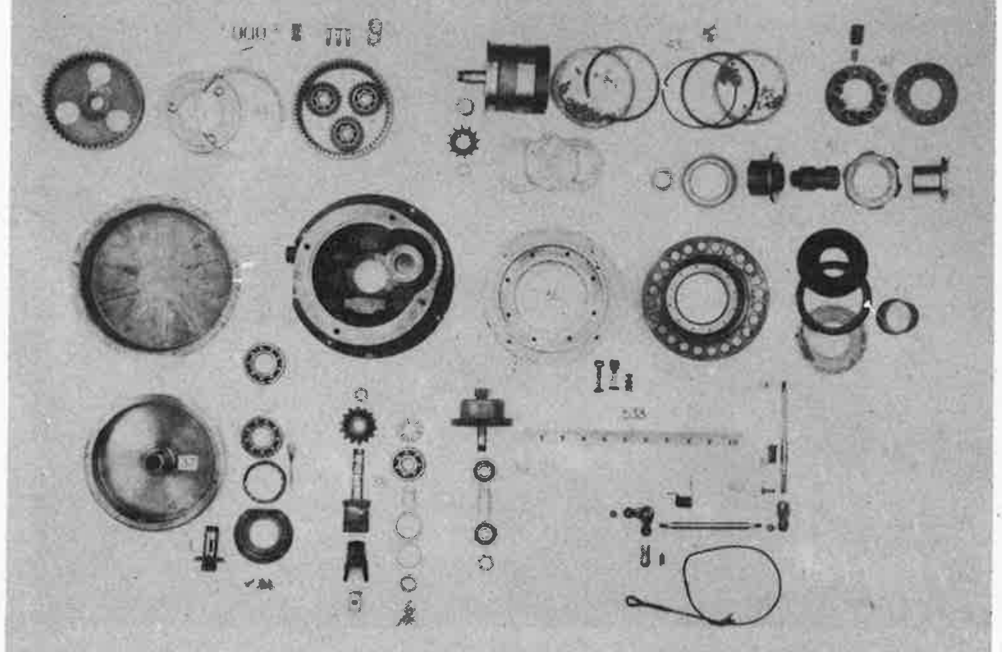
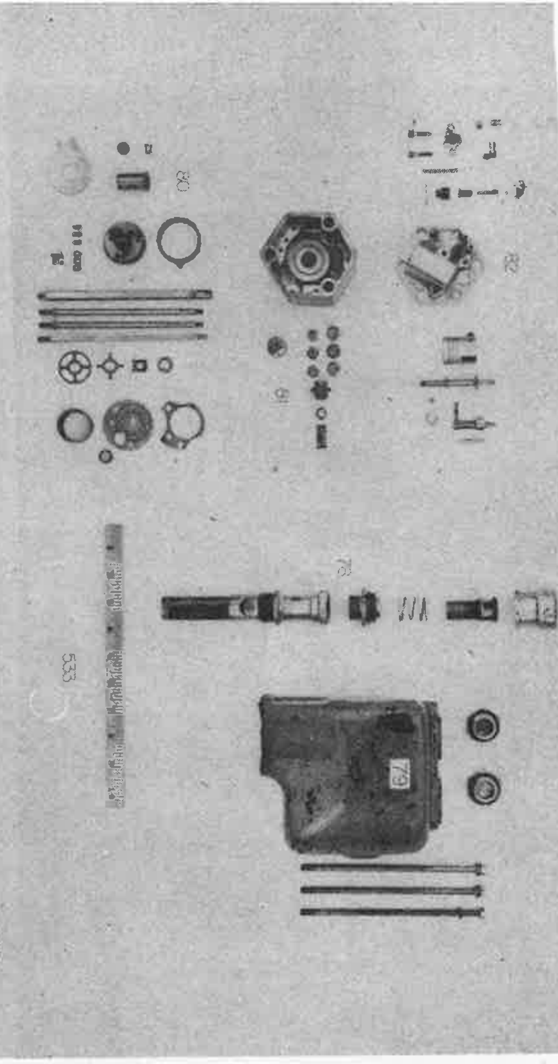


Figure 18. Inertia Starter Disassembly (CEF-2963). 29937

-36 Starter Housing
-37 Flywheel Assembly
-38 Crank Assembly
-39 Auxiliary Gear Assembly
-40 Retchet Linkage
-41 Ratchet Assembly
-42 Clutch Springs, etc.
-43 Clutch Housing, Bearings and Plates
-44 Clutch Gears, etc.



30028 30028

Figure 19. Cuno Oil Strainer Parts.

-80 Cuno Drive Ratchet and Strainer Parts
-81 Cuno Drive Case
-82 Cuno Drive Mechanism

Crankcase Oil Sump Parts.

-78 Oil Sump Check Valve
-79 Oil Sump

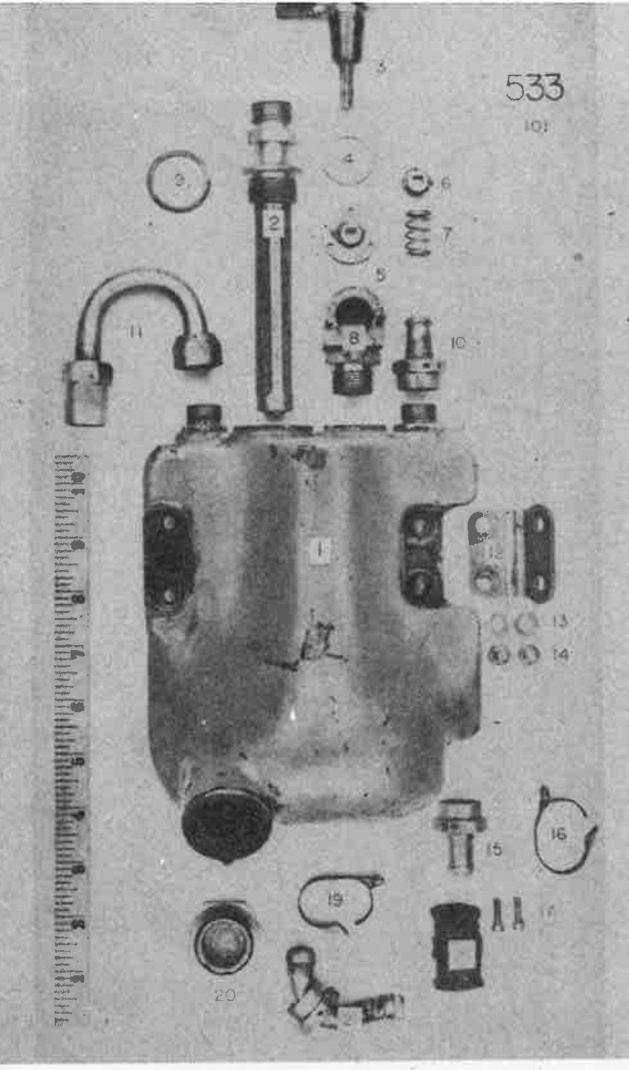


Figure 20. Rocker Box Oil Sump Parts (CEE-2963). 30641

TABLE 9. BREAKDOWN OF PARTS OF JAPANESE MACHINE GUN SYNCHRONIZER FROM SAKAE-21 ENGINE (CEE-2963)

Part No.	Name	Hardness V.D.H.	Material & Microstructure	Method of Manufacturing	Remarks
75-1	Synchronizer Housing	40	Magnesium, containing Al, Zn, Mn, similar to Dowmetal G.	Sand casting, Solution heat treated and aged.	Covered with black coating then gray paint which had blistered.
75-2	Housing Flange		Same as Part # 75-3.		
75-3	Housing Flange	332-595	Martensite, Sorbite, differentially hardened.	Forged & machined, Cd plated.*	Threads & inner flange hardened.
75-4	Flange Cap		Same as Part # 75-5.		
75-5	Flange Cap	208	Ferrite & pearlite (.30 C).	Drawn & machined, Cd plated.*	
75-6	Cap Washer	225	Ferrite & pearlite (.70 C).	Cut from stock, Cd plated. *	
75-7	Cap Washer		Same as # 6.		
75-8	Housing Bushing	117	Brass (65 Cu, 35 Zn).	Machined from tubing.	
75-9	Housing Cap	200	Ferrite & pearlite (.65 C).	Bar stock, Cd plated.*	Roughly machined.
75-10	Housing Cap Washer		Fiber.	Cut from stock.	Red color.
76-1	Drive Shaft Nut	327	Sorbite, free carbides.	Bar stock, Cd plated.*	
76-2	Drive Shaft Washer	104	Ingot iron, ferrite.	Cut from stock, Cd plated.*	
76-3	Drive Shaft Gear	696-415	Martensite, tempered. Cr-Ni steel teeth case hardened .01" case.	Bar stock.	Rough outside machining, teeth scored.
76-4	Drive Shaft Key	201	Sorbite.	Cut from stock.	
76-5	Drive Shaft	701 418 709	Teeth - martensite, case hardened .01" case. Shaft - tempered martensite, case hardened .005" case. Bearing surfaces - martensite, case hardened - highalloy steel.	Bar stock.	
76-6	Drive Shaft Sleeve	126	15% tin bronze. Typical alpha delta structure.	Cast and machined.	
76-7	Drive Shaft Sleeve (large)	142	15% tin bronze. Typical alpha delta structure.	Cast and machined.	
77-1	Cam Shaft Bolt and Nut	143	Partially spheroidized cementite.	Bar stock, Cd plated.*	
77-2	Cam Shaft Fastening	139	Partially spheroidized cementite.	Bar stock, Cd plated.*	
77-3	Cam Shaft Lug (left)	296	Sorbite.	Bar stock.	Very roughly machined, few rust spots.

TABLE 10. METALLURGICAL DATA ON GEAR OIL PUMP FROM JAPANESE SAKAE-21 AIRCRAFT ENGINE (CEE-2963)

Part No.	Name		Weight, Grams	Hardness, Rockwell	Type of Material	Remarks
25	Gear Oil Pump Housing Assembly:					
	Large	(1)	756	B 30	Magnesium	Stabilized - coarse grained. High aluminum alloy (German A 10)
	Medium	(1)	627	B 30	Magnesium	Stabilized - coarse grained. High aluminum alloy (German A 10)
	Small	(1)	406	B 30	Magnesium	Same as above but higher aluminum.
	Spacer	(2)	151	B 45	Magnesium	Same as Large and Medium, but one had excess Si (.35% - too high). All were castings, showed porosity. The rough interior surfaces had not been cleaned to remove the sand. All had oxidized coatings and paint.
26	Gear Oil Pump Gears:					
	Large	(2)	161	C 36	Alloy Steel	Machined from bar stock.
	Medium	(2)	134	C 35	Alloy Steel	Machined from bar stock.
	Small	(4)	75	C 36	Alloy Steel	Machined from bar stock. Quenched & tempered.
	Drive	(1)	71	C 30	Alloy Steel	Machined from bar stock.
27	Gear Oil Pump Shafts:					
	Large w/Gear	(1)	410	case C 59 core C 36	Alloy Steel	Machined from bar stock. Carburized to depth of .04" Low carbon martensite with excess ferrite.
	Medium	(1)	122	case C 61 core C 35	Alloy Steel	Machined from bar stock. Carburized to depth of .04". Low carbon martensite with excess ferrite.
	Small	(1)	83	case C 61 core C 38	Alloy Steel	Machined from bar stock. Carburized to depth of .04". Low carbon marteniste with excess ferrite.
	Key, Small	(3)	1	C 28	Low C steel	Machined from bar stock. Quenched and tempered.
	Key, Large	(1)	3	C 33	Low C steel	Machined from bar stock. Quenched and tempered.
	Nut	(1)	8	B 87	Mild C steel	Machined from bar stock. Quenched and tempered.
	Washer	(1)	2	B 87	Mild C steel	Machined from bar stock. Quenched and tempered.
28	Gear Oil Pump Large Check Valves:					
	Cover	(2)	56	B 90	Mild C steel	Machined from bar stock.
	Cap	(2)	20	C 31	High C steel	Machined from bar stock. Quenched and tempered.
	Piston	(2)	24	B 86	Medium C steel	Machined from bar stock. Quenched and tempered.
	Nut	(2)	22	B 88	Medium C steel	Machined from bar stock. Quenched and tempered.
	Spring	(2)	14		High C steel	Coiled wire spring.
29	Gear Oil Pump Medium Check Valves:					
	Cover	(1)	57	C 30	Medium C steel	Machined from bar stock.
	Cap & Cylinder	(1)	40	B 95	Mild C steel	Machined from bar stock.
	Piston	(1)	4	C 28	Medium C steel	Machined from bar stock. Cold rolled steel.
	Spring	(1)	1		Brass	Coiled wire spring

TABLE 10. (Continued)

Part No.	Name		Weight, Grams	Hardness, Rockwell	Type of Material	Remarks
30	Gear Oil Pump Small Check Valves:					
	Union, Small	(2)	18	B 85	Low C steel	Machined from stock. Normalized.
	Union, Medium	(1)	24	B 88	Medium C steel	Machined from stock. Normalized.
	Union, Large	(1)	26	B 89	Mild C steel	Machined from stock. Normalized.
	Ball, Small	(1)	2	B 69	Aluminum	Machined from stock. Normalized.
	Ball, Large	(1)	5	B 70	Aluminum	Machined from stock. Normalized.
	Cap, Small	(1)	4	B 66	Aluminum	Machined from stock. Normalized.
	Cap, Medium	(1)	11	B 91	Medium C steel	Machined from stock. Normalized.
	Cap, Large	(1)	7	B 66	Aluminum	Machined from stock. Normalized.
31	Gear Oil Pump Connecting Couplings:					
	Small, Long	(1)	81	B 91	High C steel	Machined from bar stock.
	Small, Short	(1)	58	B 90	High C steel	Machined from bar stock.
	Large, Long	(1)	121	B 92	Medium C steel	Machined from bar stock.
	Large, Short	(1)	106	B 89	Medium C steel	Machined from bar stock.
32	Gear Oil Pump Assembly Tubes:					
	Long	(1)	26		Low C steel	Probably seamless tubing.
	Short	(1)	18		Low C steel	Probably seamless tubing.
33	Gear Oil Pump Assembly Bolts:					
	Long	(1)	50	C 25	Medium C steel	Machined from bar stock.
	Short	(1)	50	C 24	Medium C steel	Machined from bar stock.
	Medium	(1)	46	C 20	Medium C steel	Machined from bar stock.
34	Gear Oil Pump Bushings:					
	Small, threaded	(1)	22	B 58	Brass	Machined from bar stock.
	Small, unthreaded	(1.)	15		Bronze	Machined from bar stock.
	Large, threaded	(1)	42	B 55	Brass	Machined from bar stock.
35	Gear Oil Pump Bearings:					
	Small	(2)	9		Bronze	Machined from tubing.
	Large	(2)	19		Bronze	Machined from tubing.

TABLE 11. METALLURGICAL DATA ON GEAR CASE ASSEMBLY OF JAPANESE SAKAE 21 AIRCRAFT ENGINE (CEE-2963)

Part No.	Name	Weight, Grams	Vickers Hardness	Material	Remarks
97	Gear Case	11,400	75.3	Aluminum.	Cast - machined and painted grey-green color.
97-a	Gear Case Bushings		133	Tin bronzes.	Cast.
98	Gear Mounting Plate	4,788	78.0	Aluminum.	Cast - machined.
99	Crank Shaft Rear Extension Bushing	363	61.8	Leaded tin bronze.	Cast.
103	Crank Extension Starter Rachet	485	Gear case 641, core 379 Rachet case 569 Shaft 359	Low carbon alloy steel. Low carbon alloy steel.	Case hardened on rachet surface and on edges of gear teeth - forged. No case hardening; bar stock.
104	Gear Case Drain Pipe	71	85.3	Magnesium.	Cast.
105	Impeller Control Assembly	271	310-315	All parts low carbon steel-Cd plated.	All parts with exception of the straight connecting rod and bolts which were turned from bar stock, were drop forged. The support arm was ground down by hand.
106-a	Magneto Drive Gears (2)	613	Gear case 610, core 418 Shaft case 847, core 334 Nut 280	Low carbon alloy steel. Low carbon alloy steel. Low carbon steel.	Case hardened on edges of gear teeth and on wearing surface of side of gear - bar stock nitrided case on surfaces of ring slots - bar stock. Nut - bar stock.
106-b	Magneto Seat Plate	57	389	Low carbon steel.	Forged.
106-c	Machine Gun Synchronizing Gear	257	Gear case 649, core 415 Shaft case 564, core 415	Low carbon alloy steel.	Case hardened on edges of gear teeth - forged. Case hardened on edges of shaft teeth and on wearing surfaces of shaft - bar stock.
106-d	Accessory Drive Gears for Synchronizing Gear (2)	485	Gear case 679, core 406 Shaft Gear case 550, core 429	Low carbon alloy steel.	Case hardened on edges of gear teeth - forged - and riveted together.

TABLE 12. METALLURGICAL DATA ON FUEL PUMP FROM JAPANESE SAKAE-21 AIRCRAFT ENGINE (CEE-2963)

Part No.	Name	Weight, Grams	Vickers Hardness	Type of Material	Remarks
70-1	Gear Pump Case	327	80.5	Aluminum.	Sand cast - machined - painted grey-green color.
70-2	Gear Pump Case Lid	121	78.2	Aluminum.	Forged and machined - painted grey-green color.
70-3	Gear With Shaft	100	394	Low carbon - low alloy steel.	Machined from bar stock.
70-4	Gear	64	336	Low carbon - low alloy steel.	Machined from bar stock.
70-5	Bronze Shaft	35	100	Bronze	Machined from bar stock.
70-6	Inlet and Outlet Nipples	70	192	1020 steel.	Machined from bar stock.
70-7	Fuel Pump Support Stand Assembly	285	100	Aluminum.	Sand cast - machined - painted grey-green color.
70-8	Stand Assembly Bolts (4)	84	307	Low carbon screw stock.	Machined from screw bar stock - Cd plated.
71-1	Drive Shaft	49	case 476, core 381	High carbon steel.	Machined from bar - case hardened on outer surface.
71-2	Shaft Coupling	22	case 588, core 438	High carbon steel	Machined from bar - case hardened on outer surface.
71-3	Retainer Plug	100	179	1025 steel.	Machined from bar.
71-4	Front Rotor Bushing	86	64.1	Tin bronze.	Cast.
71-5	Rotor	65	case 575, core 336	Low carbon - alloy steel.	Machined from bar stock - case hardened on inner and outer surfaces.
71-6	Rotor Veins	28	case 469, core 305	Low carbon - alloy steel.	Bar stock - case hardened on all surfaces.
71-7	Rear Rotor Bushing	42	64.2	Tin bronze.	Cast.
71-8	Rotor Shell	70	case 661, core 288	Low carbon - alloy steel.	Machined from bar stock - case hardened on inner surface.
71-9	Accessory Drive Shaft	42	339	Low carbon steel.	Machined from bar stock and Cd plated.
72-1	Fuel Pump Case	798	76.9	Aluminum with brass threaded seatings.	Sand cast - machined and painted black.
72-2	Socket Plugs (2)	91	170	1020 steel.	Machined from bar - Cd plated - badly corroded.
72-3	Inlet and Outlet Plugs (2)	70	95	Aluminum.	Machined from bar - had a bronze color coating.
72-4	Fuel Pump Case Plate With Outlet for Pressure Gauge	70	76.2	Aluminum.	Cast - painted black.

TABLE 12. (Continued)

TABLE 12. (Continued)

Part No.	Name	Weight, Grams	Vickers Hardness	Type of Material	Remarks
72-5	Fuel Pump Case Plate Screws (4)	14	232	Low carbon screw stock.	Machined from screw stock.
73-1	Diaphragm Case	142	83.9	Aluminum.	Sand cast and machined - painted black.
73-2	Diaphragm Case Lid	71	78.2	Aluminum.	Cast and painted black.
73-3	Diaphragm Tension Control Plug	71	283	1020 steel.	Machined from bar stock.
73-4	High Tension Spring		396	High carbon spring wire.	Cold drawn from wire.
73-5	Low Tension Spring			Copper, tin, zinc alloy with some iron.	Wire.
73-6	Diaphragm Assembly	42	214	Low alloy steel - and a brass bushing.	Machined from bar stock.
73-7	Diaphragm Case Screws (4)	28	234	1020 steel.	Machined from screw stock - Cd plated.
73-8	Diaphragm			Rubberized cloth.	
74-1	Slip Ring Shaft and Bevel Gear	256	case 719, core 368 case 690, core 400	Shaft - low carbon alloy steel. Gear - low carbon steel.	Machined from bar - case hardened on outer surface. Machined from bar - case hardened on sides & tip of gear teeth only.
74-2	Bevel Gear Shaft with Brass Bushing	142	case Shaft 524 case Gear 633, core 386	Low carbon steel.	Machined from bar stock - case hardened on outer surface of shaft - on sides & tip of gear teeth.
74-3	Shaft with Small and Large Bevel Gear	349	364 case 605, core 393 case 741, core 419	Shaft - low carbon alloy steel. Small Gear - low carbon steel. Large Gear - low carbon steel.	Machined from bar stock. Machined from bar stock. Case hardened on tips and sides of gear teeth. Large gear - forged and case hardened on sides and tip of gear teeth.
74-4	Ball Bearing	79		High carbon alloy steel.	(sent out for analysis)

TABLE 13. METALLURGICAL DATA ON INERTIA STARTER OF JAPANESE SAKAE-21 AIRCRAFT ENGINE (CEE-2963)

Part No.	Name	Weight, Grams	V.D.H.	Type of Material	Remarks
36	Starter Housing Assembly				
	Temporary Ratchet Cover	123	96	Similar to Alcoa 17S	Stamping
	Gear Housing	1536		Similar to Alcoa 47	Sand Casting
	Clutch Assembly Housing	815		Similar to Y alloy	Casting - heat-treated and aged
	Clutch Assembly Cap	155	140	Low carbon steel	Stamping
	Rubber Gasket	10		Rubber	Pressed
	Gasket Cover	24	127	Low carbon steel	Stamping - annealed
	Gasket Cover	39	123	Low carbon steel	Stamping - annealed
	Ratchet Cover	34	131	Low carbon steel	Stamping - annealed
	Assembly Bolt	10		Low carbon steel	Forged and machined - annealed
	Assembly Washer	1		Low carbon steel	Stamping - annealed
	Assembly Nut	4	235	Low carbon steel	Forged and machined - sulphur screw stock - quenched and tempered
37	Fly Wheel Assembly				
	Fly Wheel	1717	343	Low carbon steel	Machined - quenched and tempered - bar stock
	Gear	103	480	Low carbon steel	Machined - quenched and tempered - bar stock
	Key	2	297	Low carbon steel	Machined - quenched and tempered - bar stock
	Bearing			Similar to SAE 52100	Races machined - balls forged - quenched and tempered
	Washer	5	97	Aluminum	Stamping
	Packing Ring	5		Brass and felt	Machined bar stock - annealed
	Cover	36	115	Low carbon steel	Stamping - annealed
	Screw	2		Low carbon steel	Machined bar stock - annealed
	Oiler	9		Brass	Machined bar stock - annealed
38	Crank Assembly				
	Cranksocket	206	171	Low carbon steel	Machined bar stock - annealed
	Swivel	70	215	Low carbon steel	Machined bar stock - normalized
	Spur Gear	89	446	About .40% alloy	Machined bar stock - quenched and tempered
	Swivel Plug	16	103	Aluminum	Machined bar stock
	Small Nut	7	237	Low carbon steel	Machined bar stock - normalized
	Large Nut	20	241	Low carbon steel	Machined bar stock - normalized
	Bearing			Similar to SAE 52100	Races machined - balls forged - quenched and tempered
	Spacer	8	108	Aluminum	Machined
	Spring Clip	1		High carbon steel	Wire - quenched and tempered
39	Auxiliary Gear Assembly				
	Auxiliary Gear	269	446	Med. carbon alloy	Machined - bar stock - quenched and tempered
	Bearing			Similar to SAE 52100	Races machined - balls forged - quenched and tempered
	Spacer	11	105	Aluminum	Machined - bar stock
	Nut	6	212	Low carbon steel	Machined - normalized
40	Ratchet Linkage Assembly				
	Ratchet Control Rod	31	236	Low carbon steel	Machined - bar stock - normalized
	Ratchet Control Shaft	53	265	Low carbon steel	Machined - bar stock - normalized
	Ratchet Control Lever	11	388	Low carbon steel	Machined - bar stock - quenched and tempered
	Ratchet Control Outer Lever	26	153	Low carbon steel	Machined - bar stock - annealed

TABLE 13. (Continued)

Part No.	Name	Weight, Grams	V.D.H.	Type of Material	Remarks
40	Ratchet Clevice	8	146	Low carbon steel	Machined - bar stock - annealed
	Large Ratchet Control Rod Spring	7		High carbon steel	Wire - quenched and tempered
	Small Ratchet Control Rod Spring	4		High carbon steel	Wire - quenched and tempered
	Clevice Pin	3		Low carbon steel	Machined - bar stock - normalized
	Ratchet Control Cable	6		High carbon steel	Wire - quenched and tempered
	Small Pin	2		Low carbon steel	Machined - bar stock - annealed
	Large Nut	5	260	Low carbon steel	Machined - bar stock - normalized
	Small Nut	2	256	Low carbon steel	Machined - bar stock - normalized
41	Ratchet Assembly				
	Ratchet	233	528	Low C, Mo or W and Cr alloy steel	Machined - bar stock - quenched and tempered
	Clutch Drive Shaft	199	485	.40-.50 C, Cr-Mo or W alloy steel	Machined - bar stock - quenched and tempered
	Clutch Pressure Spline	215	446	Low C, Mo or W and Cr alloy steel	Machined - bar stock - quenched and tempered
	Clutch Bearing	74	74	Brass	Machined - bar stock - annealed
	Clutch Bearing	41	63	Brass	Stamping - annealed
	Nut	28	151	Low carbon steel	Machined - bar stock - annealed
42	Clutch Springs, etc.				
	Clutch Spring	16		High carbon steel	Wire - quenched and tempered
	Clutch Spring Guide	2	108	Aluminum	Machined - bar stock
	Clutch Spring Holder	39	279	High carbon steel	Machined - bar stock - quenched and tempered
	Clutch Spring Tension Plate	111	264	Low carbon steel	Machined - bar stock - normalized
43	Clutch Housing Bearings and Plates				
	Clutch Housing	887	257	Med. carbon steel	Machined - bar stock - normalized
	Clutch Bearing			Similar to SAE 52100	Races machined - balls forged - quenched and tempered
	Clutch Bushing	8		Leaded Brass	Extruded - annealed
	Spur Gear	50	498	.40% C alloy steel	Machined - bar stock - quenched and tempered
	Nut	6	230	Low carbon steel	Machined - bar stock - normalized
	Initial Plate	51	271	.25 -.30% C alloy steel	Machined - bar stock - normalized
	Brass Clutch Plate	17	210	Mn bronze	Stamping - annealed
	Steel Clutch Plate	15	238	High carbon steel	Stamping - quenched and tempered
	Clutch Lock	1	198	High carbon steel	Stamping - normalized
	Spring Clip	9		High carbon steel	Wire - quenched and tempered
	Retainer Ring	79	163	Low carbon steel	Machined - bar stock - normalized
	Screw	1		Low carbon steel	Machined - bar stock - normalized
44	Clutch Gear, etc.				
	Clutch Drive Gear	362	260	.40% C Cr W or Mo steel	Machined - bar stock - normalized
	Differential Drive Plate	194	251	.25% C alloy steel	Machined - bar stock - normalized
	Oil or Grease Ring	67		Brass	Machined - bar stock - annealed
	Differential Ring Gear	29	435	.45% C Cr W or Mo steel	Machined - bar stock - quenched and tempered
	Differential Gear	78	Gear 458 Races 695	Gear: low C alloy steel Races: SAE 52100 Balls: SAE 52100	Gear machined - balls forged - quenched and tempered
	Washer	1	206	Low carbon steel	Stamping - normalized
	Screw	5		Low carbon steel	Machined - bar stock - normalized
	Stud	2		Low carbon steel	Machined- bar stock - normalized
	Spacer	9	240	Low carbon steel	Machined - bar stock - normalized

TABLE 14. METALLURGICAL DATA ON CUNO PARTS FROM A JAPANESE SAKAE-21 AIRCRAFT ENGINE (EE-2963)

Part No.	Name	Weight, Grams	Hardness, Rockwell	Type of Material	Heat Treatment and Remarks
80	Cuno Drive Ratchet - Strainer Parts				
80-A	Steel Bushing	1		Low carbon steel	Machined from bar stock
80-B	Bronze Bushing	3		Bronze	Extruded Machined from bar stock
80-C	Cover Plate	12	B 89	High carbon steel	Spheroidized carbides Stamped from sheet
80-D	Bronze Bearing	12	B 58	Cast bronze	Cast tin-phosphorus bronze
80-E	Ratchet Ring	28	C 31	Medium carbon steel	Quenched and tempered Machined from tubing or bar stock
80-F	Ratchet	84	C 38	Low alloy steel	Hot-rolled and normalized Fine-grained pearlite with ferrite
80-G	Ratchet Pawls	1	B 94	Mild carbon steel	Machined from bar stock
80-H	Pawl Pins	1	C 43	Mild carbon steel	Machined from bar stock
80-J	Pawl Springs			High carbon steel	Coiled wire spring
80-K	Filter Core Stud	70	C 38	Mild carbon steel	Tempered martensite Machined from bar stock
80-L	Filter Stud	31	C 21	Mild carbon steel	Machined from bar stock
80-M	Filter Stud	30	C 32	Mild carbon steel	Machined from bar stock
80-N	Strainer Leaf	1		High carbon steel	Spheroidized carbides Stamped from sheet
80-O	Strainer Leaf Spacer			High carbon steel	Stamped from sheet
80-P	Strainer Leaf Washer			High carbon steel	Stamped from sheet
80-Q	Strainer Leaf Washer	2	C 20	High carbon steel	Stamped from sheet
80-R	Ratchet Driver Lever Plug	11	B 92	High carbon steel	Stamped from sheet
80-S	Ratchet Driver Lever Spacer	37	B 94	Med. carbon steel	Machined from bar stock
80-T	Ratchet Drive Lever	2		Mild carbon steel	Machined from bar stock
80-U	Ratchet Drive Lever Insert	13	B 87	Mild carbon steel	Machined from tubing
81	Cuno Drive Case				
81-A	Cuno Drive Housing	346	B 83	Aluminum	Al-Si alloy Sand casting
81-B	Check Valve Case	15	B 82	Med. carbon steel	Machined from bar stock
81-C	Bushing, Large Mouth	3		Mild carbon steel	Machined from bar stock
81-D	Bushing, Small Mouth	2		Mild carbon steel	Machined from bar stock

TABLE 14. (Continued)

Part No.	Name	Weight, Grams	Hardness, Rockwell	Type of Material	Heat Treatment and Remarks
81-E	Check Valve Coupling	20	B 70	Bronze	Cast P, Sn bronze Machined from bar stock
81-F	Check Valve Ball	6		High carbon steel	Ball bearing stock
81-G	Check Valve Spring	2		High carbon steel	Coiled wire spring
82	Cuno Drive Mechanism				
82-A	Pin	1		Low carbon steel	Machined from bar stock
82-B	Pin	1	C 35	Mild carbon steel	Machined from bar stock
82-D	Machine Bolt	3	C 24	Mild carbon steel	
82-E	Rocker	6		High carbon steel	
82-F	Rocker Arm	5	C 29	Med. carbon steel	Machined from bar stock
82-G	Rocker Arm Clip	3	B 92	High carbon steel	Stamped from sheet
82-H	Rocker Arm Clip Rivet			Mild carbon steel	Cut from wire
82-J	Injection Pin	2	B 70	Brass	Extruded 60-40 brass Machined from bar stock
82-K	Injection Bushing	1		Brass	Machined from bar stock
82-L	Injection Bushing Cover	2		Brass	Machined from bar stock
82-M	Injection Pin			Med. carbon steel	Cut from wire
82-N	Injection Spring			High carbon steel	Coiled wire spring
82-O	Housing Cover	132	B 89	Aluminum	Al-Si alloy Sand casting
82-P	Piston	29	B 65	Aluminum with high carbon steel insert	17ST wrought aluminum Machined from bar stock
82-Q	Drive Gear and Shaft	17	C 25	Low alloy steel	Machined from bar stock
82-R	Drive Gear Washer	1	C 24	Low carbon steel	Cut from sheet
82-S	Piston Pin Washer	1	B 96	High carbon steel	Cut from sheet
82-T	Piston Arm	21	C 35	Med. carbon steel	
82-U	Piston Assembly Pin	3	C 30	Mild carbon steel	Cut from rod

TABLE 15. METALLURGICAL DATA ON ROCKER BOX SUMP FROM JAPANESE SAKAE-21 AIRCRAFT ENGINE (CEE-2963)

Part No.	Name	Weight, Grams	V.D.H.	Type of Material	Remarks
101-1	Sump Casting	835	71	6-8% Al-Mg alloy.	Sand Cast.
101-2	Screen	99	75	Copper screen.	
101-3	Valve Lever	49	206	About SAE 1030.	Normalized bar stock.
101-4	Valve Washer	3	210	Low C steel.	Annealed - stamping.
101-5	Valve Guide	10	210	Low C steel.	Annealed - bar stock.
101-6	Valve Guide	3	234	Low C steel.	Annealed - bar stock.
101-7	Valve Spring	2		High C steel.	Wire.
101-8	Valve Body	137.5	93	Brass.	60 - 40 brass bar stock.
101-9	Washer	2		Copper.	Stamping.
101-10	Hose Coupling	33	brass 111	Brass and low C steel tubing.	60 - 40 brass bar stock.
101-11	Oil Connection	59	brass 116	Brass and low C steel tubing	60 - 40 brass bar stock.
101-12	Bracket	38	130	Low C steel.	Forging or stamping.
101-13	Bracket Washers	1		Low C steel.	Stamping.
101-14	Bracket Screws	5	160	Low C steel.	Machined screw stock.
101-15	Hose Coupling	33	brass 119	Brass and low C steel tubing.	60 - 40 brass bar stock.
101-16	Hose Clamp	5		Low C steel.	Sheet.
101-17	Hose Clamp Screws	1.5	147	Low C steel.	Machined - screw stock.
101-18	Hose	13		Rubber.	
101-19	Hose Clamp	5		Low C steel.	Sheet.
101-20	Plug	54	185	Low C steel.	Machined - bar stock.
101-21	Oil Line	45	brass 112	Brass and low C steel tubing.	60 - 40 brass bar stock.
					All parts, both ferrous and non-ferrous, were cadmium plated.

TABLE 16. METALLURGICAL DATA ON OIL SUMP AND CHECK VALVE FROM JAPANESE SAKAE-21 AIRCRAFT ENGINE (CEE-2963)

Name	Weight, Grams	V.D.H.	Method of Manufacture	Macrostructure	Microstructure
Check Valve - Part #78					
Valve Seat	86.5	103[3]	Machined all over from hot-rolled brass bar stock. Cd plated.	Structure - lines parallel to axis.[2]	High zinc brass - Tobin or Naval brass type.[4]
Plunger	39.5	100	Machined all over from hot-rolled brass bar stock, wearing surface not plated, remainder Cd plated.		High zinc brass - Tobin or Naval type. Similar to 60 Cu, 39 Zn, 1 Sn.
Spring	8.5	94	Formed from phosphor bronze wire stock and Cd plated.		Structure of phosphor bronze alloy. Probably 6 Sn, .6 P, balance Cu.
Bushing	61.0	232	Machined all over from steel bar stock.	Flow lines parallel to axis.[6]	Near eutectoid normalized steel. .60-.70 % carbon.
Screen Adapter	174.0[1]	218	Machined all over from steel bar stock.	Flow lines parallel to axis.	Near eutectoid normalized steel. .60-.70 % carbon.
Screen and Frame		52	Screen formed and soldered to frame, then soldered to adapter.		Nearly pure copper.
Oil Sump - Part #79					
Top Plug	38.8	197	Machined all over from steel bar stock and Cd plated.	Flow lines parallel to axis.	Near eutectoid normalized steel. .60-.70% carbon.
Side Plug	38.4	209	Machined all over from steel bar stock and Cd.plated.	Flow lines parallel to axis.	Near eutectoid normalized steel. .60-.70% carbon.
Body	950.0	84	Magnesium sand casting.	Cast.	Cast structure, high Al[5] content, Mg_2 Si present.
Bushings (2)	70.0 ea.	102	Machined all over from hot rolled brass bar stock.	Lines parallel to axis.	High zinc brass - Tobin or Naval type. Similar to 60 Cu, 39 Zn, 1 Sn.

1 Screen and adapter were weighed together.
2 Brass macroetched with standard dichromate etch.
3 Vickers Diamond Hardness - 10 Kg. load.
4 Brass microetched with $NH_4OH+H_2O_2$; stain removed with Grards solution.
5 Magnesium microetched with 2% aqueous oxalic acid.
6 Steel macroetched with 30% HCl.

VI - IGNITION SYSTEM

by

A. B. Westerman

The ignition system consisted of two conduits, 14 pairs of connectors, three cables, and numerous fittings, unions, and conductors. The conduits were made by bending Alcoa 2S type tubing into semicircular shapes and welding plugs, stamped from sheets of the same material, to one end of each conduit and fittings, machined from Alcoa 24ST, 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 position. Fourteen pairs of small nipples and three large nipples were welded to the conduits at intervals. Each nipple was made by welding a threaded fitting machined from Alcoa 24ST type tubing to a tube formed by bending Alcoa 2S type sheet and welding along the seam. The two conduits were joined by a union.

The same materials and methods were used in manufacturing the connectors and the cables. Two flexible tubes, the outer one manufactured by braiding Cu wire and the inner one by spiralling 60-40 Cu-Zn type strip, were soldered at each end to fittings. One end of each connector and cable was joined to a conduit nipple by means of a union. The other end of each connector was attached to a cast 60-40 Cu-Zn type elbow with a 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 consisted of several strands of

Cu wire covered with rubber-like insulating material. 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 means of 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 forming the inner tubes of the connectors and cables, were coated with Sn. The outer surface of the conduits were coated with gray paint. Leatherette coverings were laced over the cables. The fittings and unions were machined from 60-40 Cu-Zn type bars or tubing.

VII - EXHAUST SYSTEM

by

C. E. Levoe
H. C. Cross

The parts as they were received are shown in Figure 21. The corrosion on the inside and outside indicated the parts had seen service. The manufacture appeared to be conventional with the exception of the heat treatment. These pieces were, as far as could be determined, identical in method of manufacture and analysis to the collector ring and exhaust stack examined and reported in BIOS/JAP/PR. 1490

The fabrication consisted of cutting and stamping half sections from hot-rolled sheet and gas welding the halves together with a low carbon 18-8 rod. On the ends of each of the stack parts of the collector rings, a piece of the same material, flanged slightly at one end, was lap welded. This piece was bent to form a circle, welded together, and the inside machined smooth before being lap welded on the collector ring. The reason for this machining is that the exhaust stacks fit inside this piece and must fit tightly.

Small angle fastenings were welded on the ends of all the stack parts of the collector rings and near the ends of all the exhaust stacks. The exhaust stacks fitted into the stack part of the collector ring and they were bolted together through the fastenings. The other end of the exhaust stack fitted into the exhaust port in the engine and was fastened the same way. The collector rings were fastened together with a sheet metal clamp, hinged on one side and bolted together on the other side. There was a raised groove on the two sides near the connection on all collector rings; the clamp was grooved and the grooves fitted into one another and made a nearly air-tight joint.

The main part of the collector ring was fastened to the engine for added stability. Fastenings were welded to small sheets of the same material as the collector rings; these sheets were then bent in a circle and tack welded to the collector rings.

The sheet used in the manufacture of these parts was approximately 21 U. S. Standard Plate Gauge (.036"). It was an ordinary low carbon 18% chromium, 8% nickel stainless steel with a small amount of titanium added. The following is the chemical analysis of a representative sample of the collector rings and the connector (533-19).

	C	Cr	Ni	Mn	Si	Ti	Cb	Mo
533-9	0.09	18.5	8.4	0.47	0.67	0.19	Nil	0.04
533-19	.12	20.0	8.7	--	.69	--	-	Nil

The titanium content of this steel was much too low to stabilize the steel. Five times the amount of carbon is usually considered the amount of titanium needed. Although the weld metal was not analyzed, metallographic examination indicated it was low carbon 18-8 without titanium. There were titanium inclusions in the steel but none in the weld metal.

The structure of the sheet was that of a cold-worked 18-8 steel. The strain lines indicated that the material was not annealed after stamping and welding. Parts such as these would have been annealed after welding in this country.

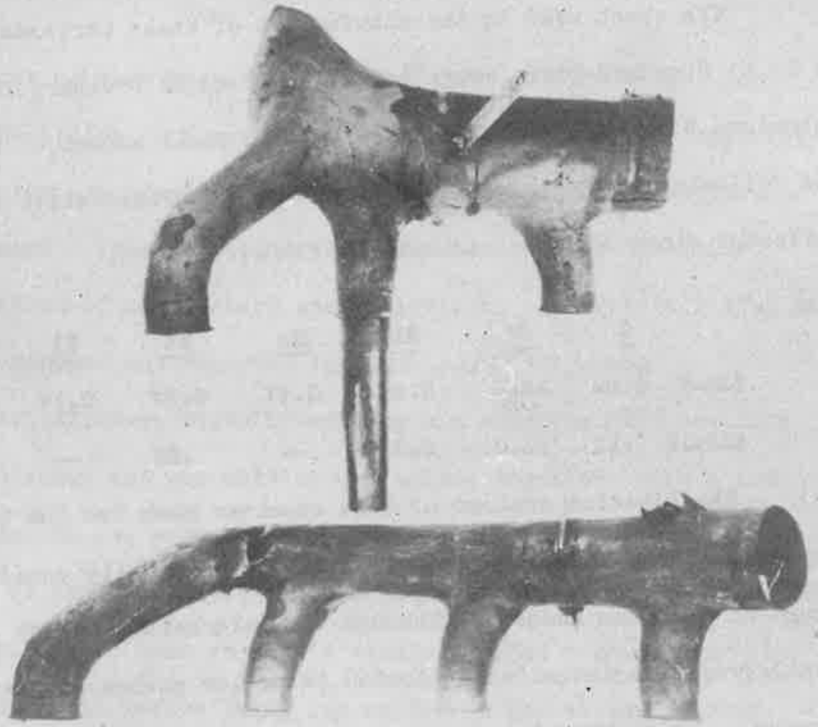


Figure 21. Exhaust Collector Rings - Sakae-21 Aircraft Engine (CEE-2963). 30138

VIII - MOTOR MOUNT

by

D. O. Leeser

The mount consisted of a seamless 1-1/2" diameter X4130 tubing hoop onto which attachment forgings and 1-1/4" and 1-1/2" seamless support tubes, reinforced at the base with gussets, were welded. Gas welding was used throughout. The welds had neat appearances, but magnaflux tests showed four instances of incorrect fusion as illustrated in Figure 23.

The forgings consisted of two equal halves which were deeply cut on the welded edge and the entire cut filled with weld material.

Natural rubber shock absorbers fitted into the forgings and were held in place by aluminum washers machined from bar stock and coated with oxidized films, probably by anodizing. Assembly studs, cadmium plated for corrosion resistance, fastened the mount to the motor housing. The studs had a hardness of RC 27 indicating a tensile strength of about 126,000 p.s.i.

Hardness and microstructures indicated that the tubes and forgings were normalized and that there was no heat treatment given the frame after assembly. Hardness of the weld material averaged Vickers 136 (R_B 76). Tension tests were made on the support tubes with results shown in Table 17. SAE-X4130 steel was used in the seamless tubes, showing the following analysis:

C	.32	W	.01
P	.014	V	.02
S	.021	Mo	.25-.35
Mn	.60-.70	Cu	.18-.25
Si	.40-.50	Sn	.010-.070
Ni	.08-.12	Al	.005-.010
Cr	1.0-1.2	Ti	<.004

A viscous and partially gelled oil was found inside the motor mount. It had the following properties:

Density	1.050
Refractive Index	1.4886
Saponification Number	215
Acid Number	59

The material had the characteristic odor of tung oil. The non-gelled portion dried rapidly on exposure to air to give a rubbery gel, which is also characteristic of tung oil.

The data above also support the conclusion that the material was tung oil since they would be characteristic of a bodied or oxidized tung oil or a tung oil varnish.

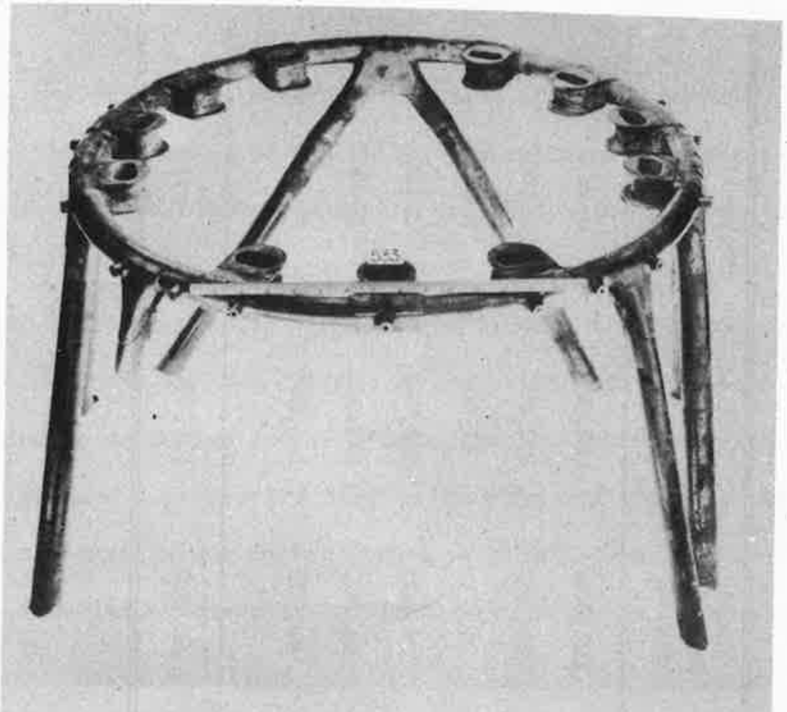


Figure 22. Motor Mount For Sakae-21 Aircraft Engine (CSB-2963). 29776

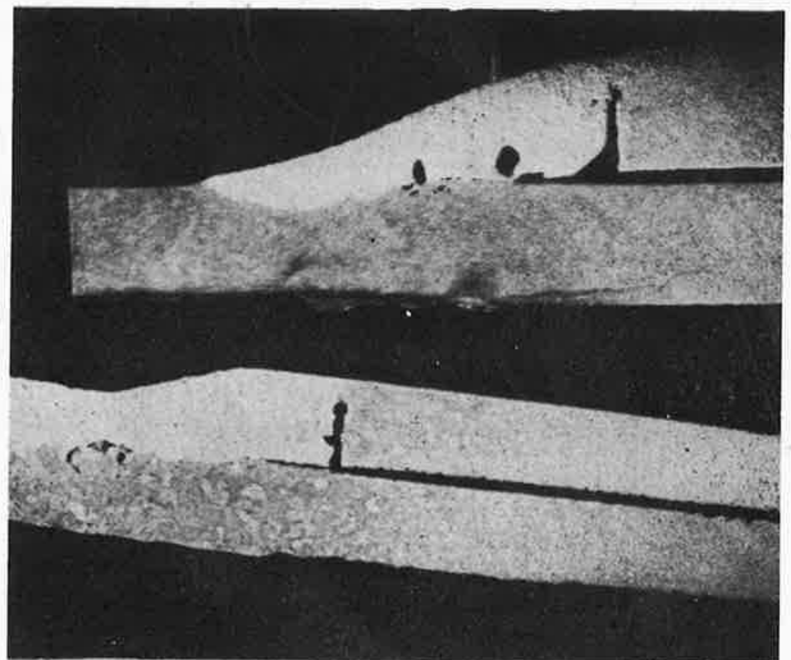


Figure 23. Gas Fusion Welds on Motor Mount Showing Porosity and Lack of Fusion (CSB-2963). 30203 10X Vilella's Etch

TABLE 17. MOTOR MOUNT (533-45) PHYSICAL TEST DATA - JAPANESE SAKAE 21 AIRCRAFT ENGINE (CEE-2963)

TEST NO.	Outside Diameter, Inches	Wall Thickness, Inches	Elongation in 2 Inches, %	Elongation of Tube	Yield Strength, p.s.i.	Tensile Strength, p.s.i.	Rockwell Hardness
1	1.179	.051	*	*	102,000	119,000	B-98
2	1.418	.064	*	11.7% (8")	83,000	100,000	B-100
3	1.575	.061	23.5	8.6% (8")	93,000	99,000	B-99
4	1.425	.055	12.5	8.7% (8")	102,500	128,500	B-100
5	1.432	.057	24	12.4% (8")	84,000	109,000	B-99
6	1.565	.057	21	10.1% (6")	89,000	125,000	B-98
Average			20.2	10.3%	92,500	113,000	

* Break occurred on gage markings.

IX - PROTECTIVE COATINGS

By E. E. McSweeney

Magnesium Castings Suitable protective treatment of magnesium alloy castings was provided. This consisted of a pickling pretreatment in order to secure good paint adherence, followed in most cases by an application of gray alkyd-resin enamel.

The magnesium diffuser casting was given an unusual treatment, both in respect to the pickling bath and the surface coating. Selenium was used, probably as selenium-dioxide or sodium selenite in an aqueous solution with orthophosphoric acid to produce a protective film by the selenite process. Following this treatment the casting was coated with a very thin layer of an oily wax containing a flake material which resembled graphite. No paint or other coating was applied.

Gear Plate The friction material molded on the gear plate was woven asbestos cloth impregnated with phenolic resin.

Aluminum Housings The gray enamels on the aluminum housings were very good coatings. It was insoluble in the common organic solvents and had excellent hardness, flexibility, and adhesion. It was a baked enamel containing no phenolic or alkyd (phthalic) resins. The vehicle used was probably a tung oil-natural resin varnish. The pigment was principally ZnO with some inert fillers.

Cylinder Barrel and Head The exterior and cooling fins of the cylinder barrel and head were covered with black coatings which had blistered considerably and had very poor adhesion. Ignition of the coating showed the presence of a large amount of gray inorganic residue, indicating a high concentration of inert fillers in the coatings. The vehicle was probably an oil or varnish, but apparently contained no alkyd or phenolic resins, although it was so far decomposed as to make any conclusions as to its original composition very indefinite.

The interior of the cylinder head had a black coating which appeared to be largely carbon resulting from carbonization of the oil.

Cylinder Gasket This was a wire mesh impregnated with rubber or synthetic.

Engine Varnish Connecting rods, pistons, and related parts of the power assembly were heavily coated with an engine varnish which had accumulated from the breakdown of the lubricating oil. Magnagauge measurement showed this layer to be .00008 to .0003 inch thick.

American radial aircraft engines run under conditions most favorable to the formation of engine varnish have acquired coatings .0005 inch thick in 250 hours of operation.

HWG:LHG:JRC/sm:vc:ic
September 8, 1944

TRANSLATIONS OF MARKINGS ON SELECTED PLATES FROM JAPANESE
SAKAE-21 ENGINE #21327

A. Oil Pump Plates

Oil Outlet	Oil Outlet	Mouth
Before starting.	Speed-adjusting pressure valve.	Main oil pressure gauge.

B. Fuel Pump Plates

Pump Outlet

Place this on the side in assembling.

Outlet Direction of rotation Outlet

C. Oil Strainer Plate

Inspection Stamps

Automatic oil filter, Model 11

Number ? 8188
May, ?
? ? Kaisha

D. Oil Sump Plate

Oil Outlet

E. Clutch Control Plate

Speed I ←——→ Speed II

F. Gear Case Plates

Oil Inlet Oil Outlet

G. Gun Synchronizer Plate

SAKAE Type-21 Machine Gun Transmission System.

Number 73

Nakajima Hikoki K. K.

H. Gear Case Accessory Plate

Intake Pressure Gauge Handle

I. Oil Pump

Input

Output (Note: The plate with the character for "output" is upside down in the photograph.)

The interior of the cy

to be largely carbon resi

Cylinder Gaske

synthetic.

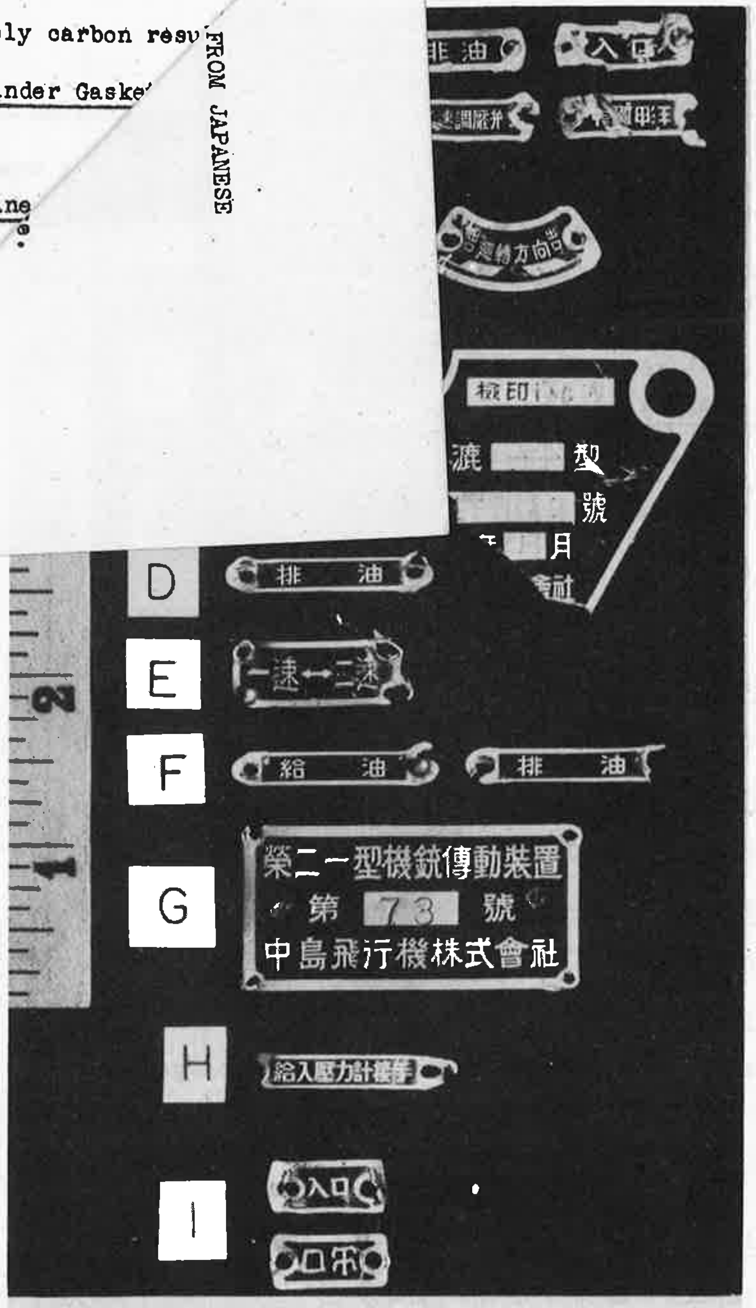
Engine

power ass

lated

sh

FROM JAPANESE



BMI-533 - CEE-2963) 30210

Figure 24. Name plates from the Japanese Sakae-21 aircraft engine, Serial No. 21327.

TABLE 18. SAKAE-21 AIRCRAFT ENGINE (CEE-2963)
WEIGHTS AND MARKINGS

Part No.	Name	Markings	Weight, Grams
10	Cylinder Barrel	No. 21327 (02) 1268 [illegible]	7400
11	Cylinder Head	Chris 17 3F 522 中 (02) 1066 1	6900
12	Push Rod (Valve)	End - RS6, RE6	197
13	Push Rod Tube Assembly (Pach-Nuts)?		204
14	Rocker Arm Assembly	RE6 中 , RS6 中 (大)	454
15	Baffles and Bolts (3)		221
16	Valve, Intake		267
17	Valve, Spring Assembly	中 [illegible]	903
18	Valve, Washer Locks		98
19	Exhaust Stock	[illegible] (+ロ) ロ 人	197
20	Valve, Exhaust		379
21	Rocker Box, Gasket, Studs, and Bolts	Cover: 中 U 77 [illegible] 6 TR 6 U T_7 (Y) 129 T	198
22	Spark Plugs	Y I H 2 A 6 (Y)	89
23	Rocker Arm Oil Lines and Connection		40
24	Intake Manifold Assembly		488
25	Gear Oil Pump Housing Assembly (5 parts)	Spacers: (1) 17AF 937 - 367 (2) 367 Large: No. 21327 - 367 Medium: [illegible] 17AF1411 - 367 中 (H) [illegible] Small: [illegible] 16AF4874 - 367	1940

Table 18. (Continued)

Part No.	Name	Markings	Weight, Grams
26	Gear Oil Pump Gears (9)	中 appeared on all steel parts.	441
27	Gear Oil Pump Shafts (3)	Ditto	629
28	Gear Oil Pump Large Check Valves (2)	"	136
29	Gear Oil Pump Med. Check Valves (1)	"	112
30	Gear Oil Pump Small Check Valves (3)	"	97
31	Gear Oil Pump Connecting Couplings (5)	"	366
32	Gear Oil Pump Assembly Tubes (2)	"	44
33	Gear Oil Pump Assembly Bolts (3)	"	146
34	Gear Oil Pump Bushings (2)	"	979
35	Gear Oil Pump Bearings (6)	"	28
36	Starter Houd ng		2751
37	Starter Fly-wheel and Bearings	2-8166 (Also 2-8148 M) NTN KS025 25	1879
38	Starter Crank Assembly and Bearing	6302 IT II NSK	423
39	Starter Auxiliary Gear Assembly	3201- NSK JT II 887	286
40	Starter Ratchet Linkage Assembly		158
41	Starter Ratchet Assembly		790
42	Starter Clutch Springs, Etc.		167
43	Starter Clutch Housing, Bearings and Plates	2-3901 NTN M KS-083 83-7 (Also 2-4014 and 2-4006)	1122
44	Starter Clutch Gears, Etc.	6201 NSK JT II	1006

Table 18. (Continued)

Part No.	Name	Markings	Weight, Grams
45	Motor Mount	♣03 - 7 (5 3190	14,930
46	Crankshaft (3 Sections)	F 387 No. 21327 II (02)	29,940
	2 Plug	No. 21327	
	Front Crankshaft Section	No. 21327 (02) 100 中 F 387	
47	Crankshaft Bolt and Washer		468
48	Propeller Shaft	II (02) 155 中 No. 21327	16,300
49	Bell Gear	No. 21327	8,170
50	Planet Spur Gear	No. 21327	305
51	Sun Gear	中 (41) 67	4,096
52	Cam	II 41 884 中	5,905
53	Valve Inserts - Intake - Exhaust		80 90
54	Piston Pin and Ends		400±
55	Master Rod	No. 21327 (02) 484 F3 7, 6, 5, 4, II (02) 484 中 Chris F3	4,308
56	Articulated Rod	(1) No. 21327 II (41) 5483 中 F 4 (2) No. 21327 II (41) 5292 中 F 1 3 (3) No. 21327 II (41) 5497 中 F 7	907
57	Impeller Shaft " " Bearing	中 No. 21327 NTN 2-126 6008 PB 40 NTN No. 21327	1,956
58	Impeller Dhive Gear	中 No. 21327	4,638
59	Crankdase (3 Sections)	Stamps on Cylinders R_4, F_1, R_5, F_7 On Inside: R R_3	37,350
	Oil Buff F No. 21327	F II (41) 776 426 中 Chris Other Side: S 15 426 II 7	
60	Piston	1.21 OKG F 前 3 (41) 4694 中 6 Chris	1,210

Table 18. (Continued)

Part No.	Name	Markings	Weight, Grams
61	Blower Case	No. 21327 I (02) 65 中 17AF54 (ℓ)	17,230
62	Impeller	I (02) 28 [illegible] 中 0 No. 21327 S	2,840
63	Nose Casting	Chris 17AF1257 II (02) 352 中 Name Plate torn off.	19,200
64	Diffuser	⊕ (ℓ) 4245 [illegible]	1,815
65	Master Rod Bearing	中 2-1680 中	311
66	Articulated Rod Bearing		50
67	Rocker Shaft Bearing		45
68	Impeller Bearing	No. 21327 中	113
69	Front Cam Bearing		350
70	Fuel Pump	Case: 394 No. 21327 中 [illegible] 16 AF 4850 Lid; 394 Shaft: 中 Nipples: 中 中	1,086
71	Fuel Pump Assembly,	Plug: ◇	592
72	Fuel Pump Case	Case: [illegible] VII 299 Plugs: 22246 ○ (4ℓ (ℓ) (25 Gauge: 299	245
73	Diaphragm Assembly	Case: オフフ°ヱB 7貝ニナルナロフ市 合セルコr Lid: 299 U 17 ◇ 52 田 ± (r)	354
74	Driving Gear Assembly Slip Ring Shaft: Bevel Gear Shaft: Small & Large Bevel Gear: Ball Bearing:	 No. 21327 中 No. 21327 中 No. 21327 中 6005 NSK J A No. 21327 中	826

Table 18. (Continued)

Part No.	Name	Marking	Weight, Grams
75	Machine Gun Cam Case	Washer: 中	
76	Cam Drive Shaft & Gear	Gear: 中 NTN ㇇ - ゲ φ o Bearing: KA 20 NTN	2,458 Total
77	Cam Assembly	Cam: 十 Shaft: 中 Bearing: RT. NTN KA20 NTN Cam: 42 Lug: RT. 中 ㄓ+ 2	
78	Oil Sump Check Valve	Seat: 中 Plunger: 卄 Bushing: 中 ☮ Adaptor: 玕	37
79	Oil Sump	Body: (H) No. 21327 77 AF 273	1,098
80	Cuno Drive Ratchet & Strainer Parts		329
81	Cuno Drive Case		384
82	Cuno Drive Mechanism		229
83	Ring Gear (Shock Absorber)	中 No. 21327	1,311
84	Impeller Drive Control	No. 21327	252
85	Propeller Shaft Bearing	NTN No. 21327 NTN 2-456 C Ka 95	4,751
86	Propeller Oil Tube		1,134
87	Planet Gear Cage		8,108
88	Crank Main Bearing	Front: NTN No. 21327 F KR 299 2-2211 C 2 W NTN 2-2211 No. 21327 F	2,250
		Center: NSK 8745 1A No. 21327	3,820

Table 18. (Continued)

Part No.	Name	Markings	Weight, Grams
88	Crank Main Bearing Rear:	NTN No. 21327 * K KR 299 2-1779 MC C NTN 2-1779 KR 299	2,250
89	Push Rod Roller		226
90	Propeller Governor Shaft and Gear		294
91	Crank Center Main Bearing Retainer		389
92	Center Bearing Crank Wedge	• 85	454
93	Rear Cam Plate	No. 21327	3,145
94	Impeller Cover Plate	17 AF 740 No. 21327	2,900
95	Knuckle Pins	F 2 [illegible] 1102 484	212
96	Intake Section	No. 21327 I (08) 355 (B) (71) 17 NF 1665	14,900
97	Gear Case	No. 21327 17AF247 [illegible] II (02) 780 中 (H) I R	11,400
98	Gear Mounting Plate	No.21327 (H) II [illegible] 17AF572 中 65 テ	4,788
99	Tail Shaft	中 No. 21327	2,270
100	Ignition System		14,000
101	Rocker Box Oil Sump		1,415
102	Lifting Eye		60
103	Crank Extension Starter Rachet	No. 21327 F717 T102 中 (★)	485
104	Gear Case Drain Pipe		71
105	Impeller Control Assembly	No. 21327 中 Y (t)	271
106	Magneto Drive Gear	No. 21327 中	822
59-10	Oil Seal Retainer	17 A E 115	