*Design Details of the Mitsubishi Kinsei Engine**

The author says the Japs did an ingenious job of combining proven features of engines of foreign manufacture in this design and rates it a "highly dependable, though not highly developed, piece of equipment.

By W.G. Owens, *Staff Engineer, Wright Aeronautical Corp.*

THE CONDITION of the only physical engine available for study and the data readily available can form the basis for only a very meager report. The study has, however, been an interesting one and the results are recorded for what value they may have. The design comments are, of necessity, of a general nature — much the same as those which would be made on the preliminary layout of a new design. For the convenience of many of us who habitually think in term s of English units, these units are used even though a large portion of the work is apparently based on the metric system. As a result, the numerical data are approximate conversion figures in the hope that these figures will best serve the purposes intended.

The inspection indicates to the writer two possible conclusions which are presented herewith:

1. That the group responsible for the design did a very ingenious job of combining what they apparently believed to be the most desirable features of a number of products of foreign manufacture — proved features all. These features are built into a composite design of the sort that "has to work the first time" — and probably did.

2. That manufacturing methods and equipment of manufacturers whose features were appropriated

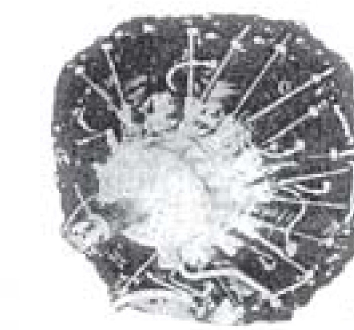
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FIG.1. Left front view of a Mitsubishi Kinsei Engine like the one described in the accompanying article. FIG. 2. Right rear view of engine shown in Fig. 1. FIG. 3. Left rear view of engine shown in Fig. 1. FIG. 4. On the left, front view of eh complete cylinder assembly and on the right a view from the rear. Front and rear bank cylinders are identical except for push rod angle.

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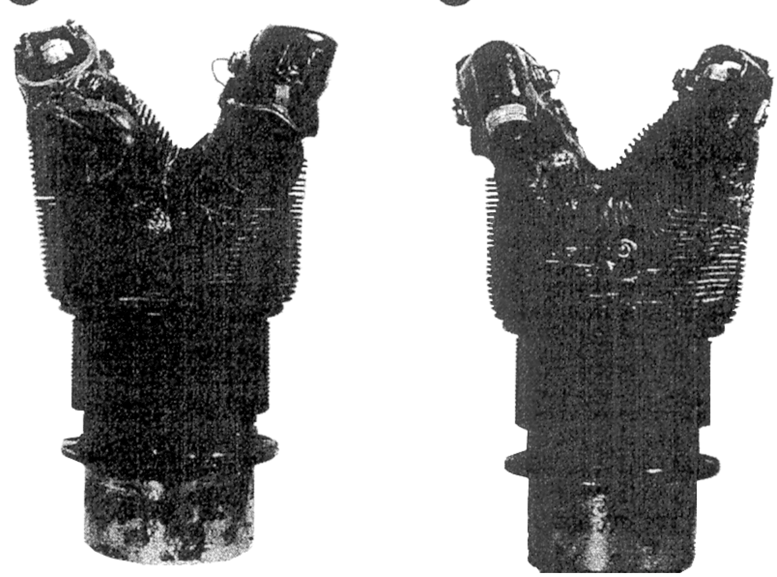


* General description of the engine appeared in "A viation' s" report on the joint meeting of the Society of Automotive Engineering Detroit Section, and the Engineering Society of Detroit, June 8, 1942, in the article War Production of Aircraft, page 104, July, 1942. This additional material is presented through the courtesy of the SAE.

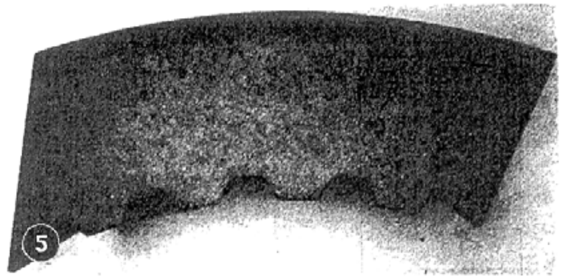
were probably used to produce parts of quality comparable to the originals; and that the available "heavy-industry" equipment probably influenced both the design and finished parts which are peculiar to this engine. In short, I am trying to convey the idea that this is undoubtedly a highly dependable, even though not highly developed, piece of equipment; and that it was probably produced under time and tooling limitations which we would consider nearly impossible.

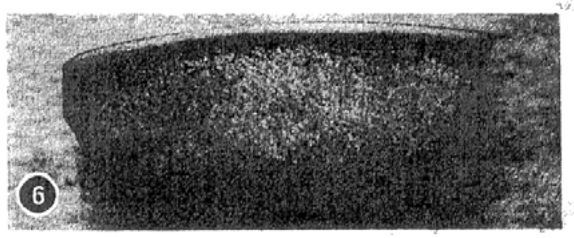
The report is made possible by the graciousness of the Experimental Engineering Section of the Army Air Force Material Center, Wright Field, Ohio, in making the engine available for study. The spirit of cooperation of the personnel of that section in the disclosure of their findings and in the discussion of the subject is also gratefully acknowledged. Much of the detail investigation was carried out with the excellent assistance of the Materials Laboratory and other engineering personnel at the Cincinnati, Ohio, plant of the Wright Aeronautical Corp.

General Data and Discussion

Type — Radial aircooled
Cylinders — 14, 5.5-in. bore x 5.95-in. stroke
Cylinder arrangement — Two radial banks of 7
Engine diameter — 47 in. approximately
Piston area — 332 sq. in.
Displacement — 1970 cu. in.
Compression Ratio — 6.6 : 1
Supercharger — Centrifugal, 9.62-in. diameter impeller
Supercharger drive — 8.48 x crankshaft
Performance *estimates* on 95- to 100- octane fuel based on American standards of service life.
Maximum cruise — 600-650 hp. — 2,000 rpm.
Rated — 850 hp. — 2,250 rpm. to 8,000 ft.
Military rated & Takeoff — 1,050 hp. — 2,500 rpm. to 5,500 ft.

General engine condition (before it crashed) was very good. See Figs. 1, 2, and 3. Evidence would tend to indicate that it had been operated for only a short period since overhaul but that that operation had been satisfactory. Pistons, cylinder barrels, valves, rods, reduction gear, and so on, which are available for inspection are excellent. Parts of the supercharger and accessory drive are mutilated badly enough to make any comments on this section invalid. There is, however, some indication





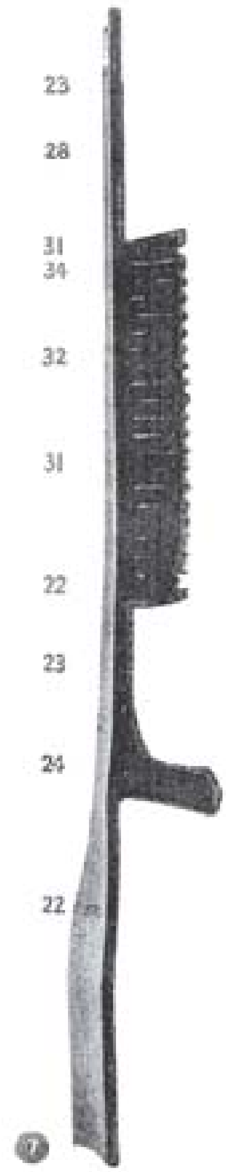
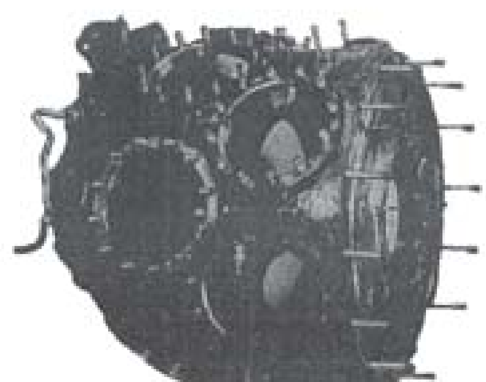


FIG. 5. Section of crankpin showing internal splines and case hardened journal surface. FIG. 6. Section of starter and accessory drive shaft showing case hardened journal surface on material which is hardened throughout when applied to propeller shaft. FIG. 7. Section of cylinder barrel showing variation in core hardness of the only nitrided part found in the engine. FIG. 8. Three-quarter front view of the crankcase main section. FIG. 9. Intermediate crankcase front section and valve gear with a pair of tappets, cam, and cam bearing in place. Detached parts shown are, left to right, push rod and housing, tappet guide, tappet roller, cam retainer, tappet and pin, cam drive gears, front main bearing which supports reduction driving gear, and bearing race lock ring.

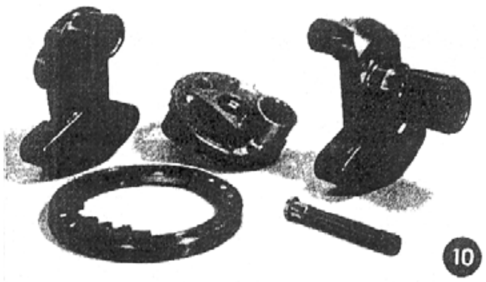


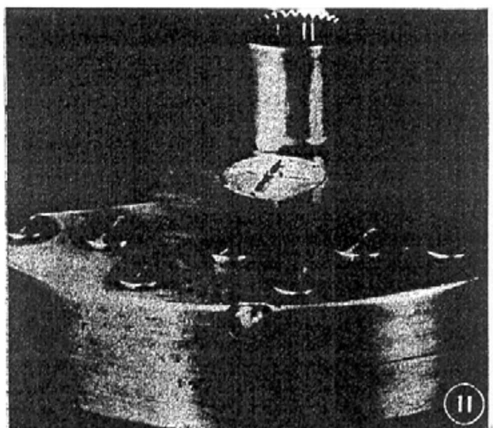
that an impeller thrust bearing failure may have taken place prior to the crash, but that the shaft continued to operate against the spherical face.

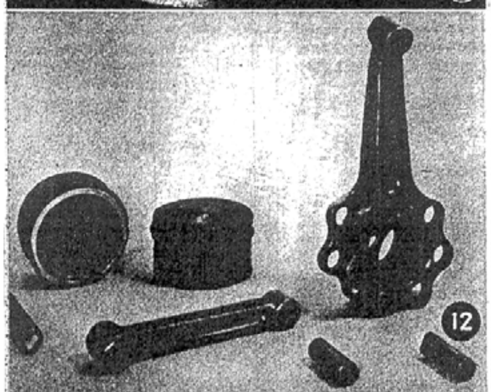
Cooling provision is the only weak spot from a serviceability standpoint, in the writer' sopinion. Potential output is probably limited to approximately 0.5 hp. per cu. in. by this feature. A rather rough estimate places the cooling area per cylinder at somewhat less than 1000 sq. in. Fig. 4 shows the complete cylinder assembly. The baffle pressure drop to keep combustion-chamber temperatures below the detonation point would almost certainly make American aircraft designers very unhappy.

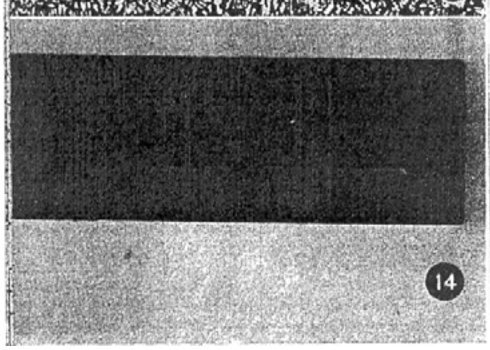
Given the cooling limitations just mentioned, it is believe that the remainder of the engine is very conservatively designed. With these removed it is probable that master-rod bearing lining cracking would soon develop, not because of excessive bearing loading, but because of flexure of the rod hub. The carburized crankpins can be expected to aid bearing performance, and the lubricating means is presumably adequate since it is used by another manufacturer with good results reported.

Some of the materials used in the Kinsei engine are of interest. They indicate that, at least at the time when this engine was built, there were adequate supplies of nickel, cadmium, chromium, cobalt, copper,









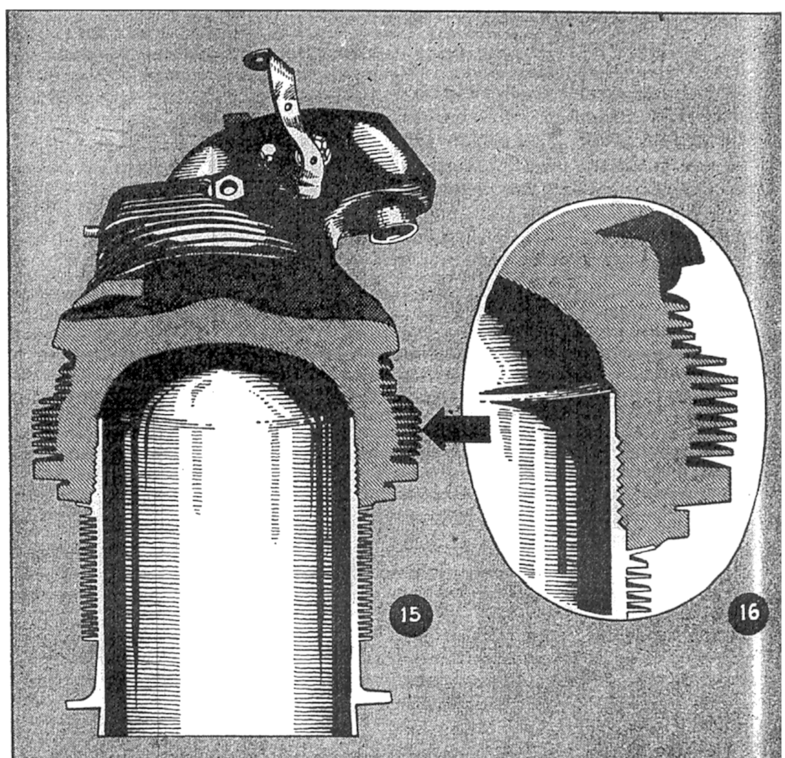
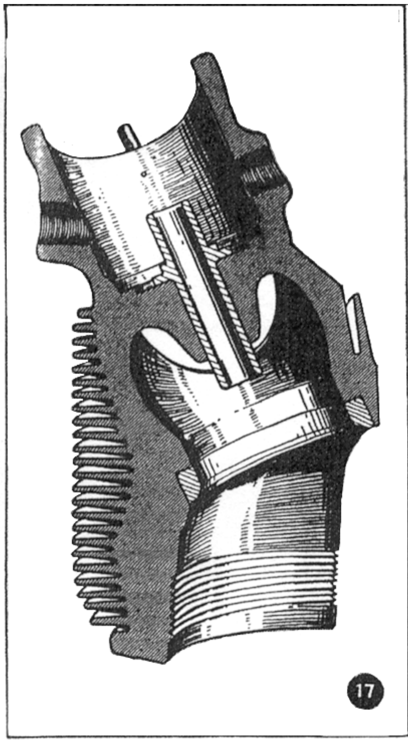


FIG. 10. Crankshaft parts shown are, left to right, rear section, center bearing and retainer, center section, joint bolt, and front section. FIG. 11. Crankshaft rear section showing counterweight and oil jet. These parts are duplicated on the front section. FIG. 12. Pistons and connecting rods. Parts shown are, left to right, piston pin with plugs, articulated rod, knuckle pins, and master rod. FIG. 13. Cross-section of master bearing lining. Note coarse irregular dendritic formation. Shrinkage cracks filled with lead appear at the surface. Lining is lead plated after boring. FIG. 14. Section of knuckle pin showing case hardening, rather rough bores, and sharp corners. Also web which supports against ovalization and confines pressure oil. FIG. 15. Cylinder section showing combustion chamber shape, extreme piston ring position and general structure. FIG. 16. Method of attaching cylinder head to barrel. Note two pilot fits, thread fit and abutment on conical fin.



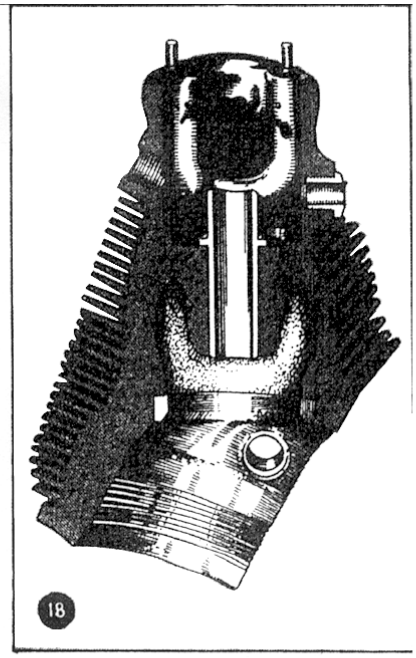


FIG. 17. Section through intake port. FIG. 18. Section through exhaust port.

molybdenum, and tungsten.

The one magnesium alloy found varies somewhat from American standard alloys in that it contains 4.6 percent aluminum, 2.6 percent zinc, and 0.28 percent manganese in addition to magnesium. It will be noted that this alloy is similar to AMS 4424 except that the aluminum content is low.

In the aluminum alloys found, 17S is used for many parts such as main crankcase, tappet guides, piston-pin plugs, and so on. For special purposes such as pistons, cylinder heads, and supercharger front housing, an alloy containing 3.93 percent copper, 1.37 percent magnesium, and 1.67 percent nickel is used either cast or forged.

An all-purpose steel, either case-hardened or hardened throughout, is used for connecting rods, crankshaft, valve rockers, and so on. Fig. 5 shows a section of crankpin. It contains approximately 1.5 percent chromium, 3.5 to 4.5 percent nickel, 0.3 to 0.4 percent molybdenum, 0.35 to 0.5 percent manganese, and varying small quantities of silicon and copper apparently as impurities. Carbon content is varied as required. The same steel with the molybdenum reduced and 0.5 to 0.9 percent tungsten and 0.2 to 0.4 percent cobalt added is used in the propeller shaft and in the starter and accessory driveshaft. The latter part is case hardened as shown in Fig. 6. It is suggested that this may well be a compromise for making the best possible use of the available scrap materials.

Propeller reduction gears, cam, and knuckle pins are carburizing 4.5 percent nickel steel plus approximately 0.8 percent chromium. Reduction-gear pinions vary form this composition in the addition of 0.4 percent molybdenum. Nitriding is used only in the cylinder barrel (fig. 7). The steel conforms very closely to AMS 6470. Nitride depth is 0.010 to 0.020 in. in two barrels cut. Core hardness varied from Rockwell C 22 to 34 in one specimen. Magnetic inspection of all steel parts illustrated showed acceptable material.

Plating is used quite extensively. Cadmium plating appears on the supercharger oil seal rings and most of the propeller shaft in addition to

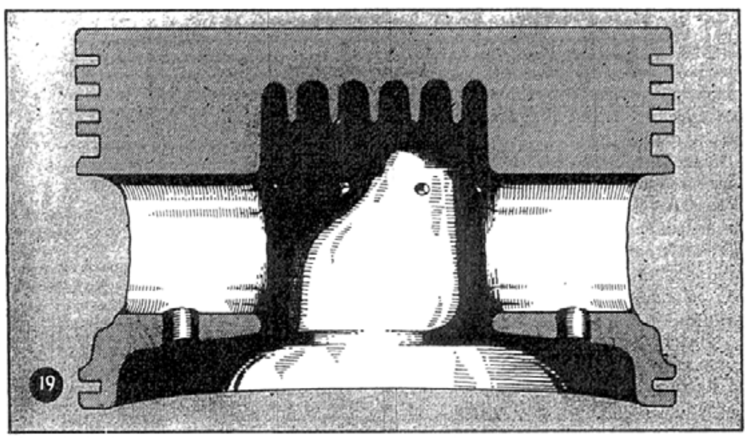
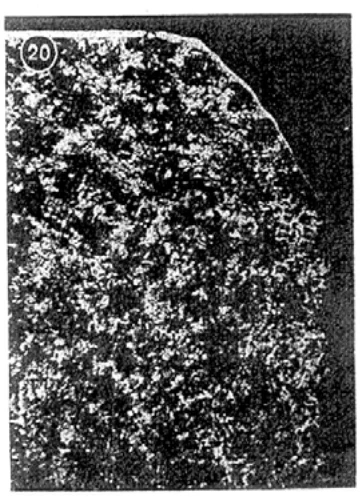


FIG. 19. Section of piston at pin axis.



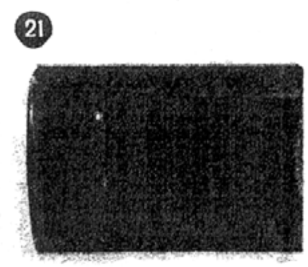
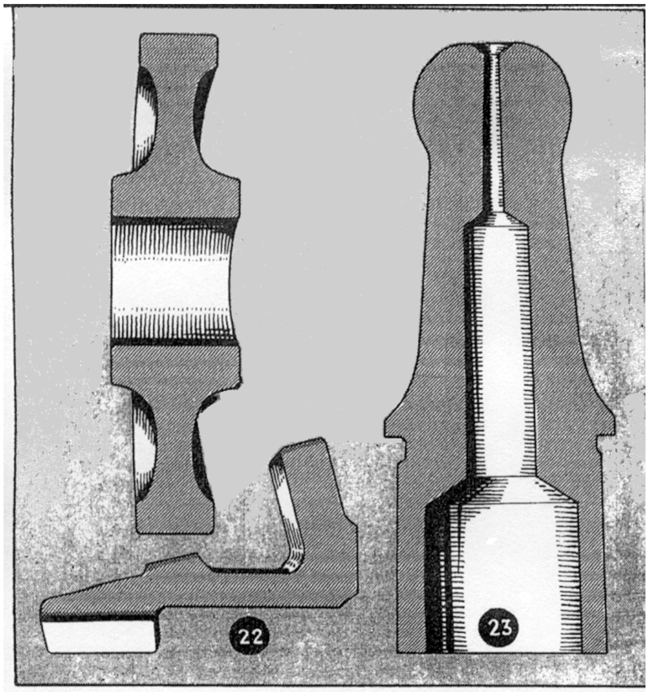


FIG. 20. Section of chromium plated compression ring used in two upper grooves. Note .0007 thick plate tapering to .0000 around .020 approximate radius. Also that structure is exactly that supplied to engine makers in this country. FIG. 21. Section of piston pin end.



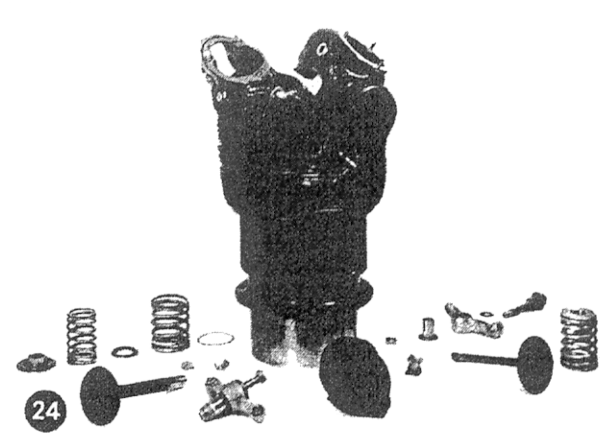


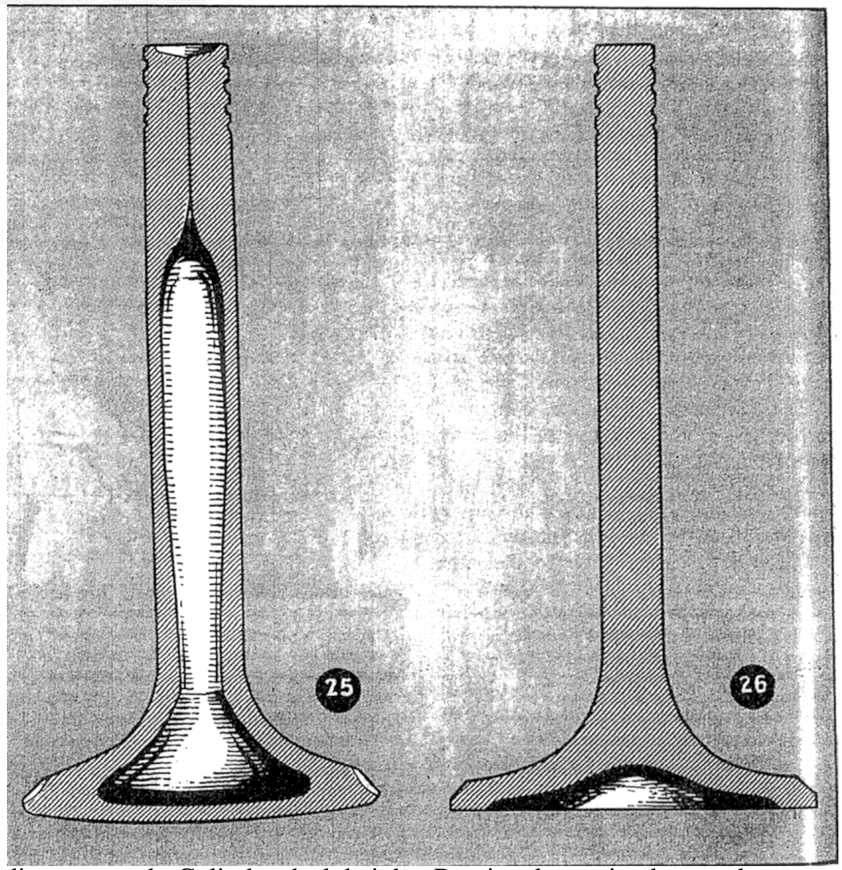
FIG. 24. Cylinder, valve gear parts and exhaust connection.

FIG. 22. Sections of cam and valve tappet roller.

FIG. 23. Section of push rod ball end.

FIG. 25. Section of exhaust valve.

FIG. 26. Section of intake valve.



the more common points such as valve springs, valve rockers, push rods, and impeller shaft. Chromium plate is use don the under side of the inlet valve head and on upper piston compression ring outside diameters. Lead is used in the master-rod bearing bore.

A minor design feature almost universally used is threaded pins to locate busings. The bushing and part in which it is installed are tapped after assembly, the pin screwed into place and then machined flush inside and out. This is even found in the piston pin eye of the connecting rods. The resulting sharp corners would, of course, worry us greatly.

Cylinders are numbered by banks in the direction of engine rotation. Thus, number 1F is at the bottom of the front bank between 4R and 5R, and number 1R is at the top of the rear bank.

Design Details

CRANKCASE — The crankcase (Fig. 8) is a typical three-section 17S aluminum-alloy case split on the centerline of the cylinder banks and held together by means of one 0.475-in. diameter through bolt between each cylinder. Cylinder decks are approximately 0.88 in. thick at the bore and incorporate twelve equally spaced studs for cylinder attachment. These studs are approximately 3/8-20 at the nut end, 7/16-17 in the crankcase and have a 0.36-in. diameter neck. Cylinder-deck height is 9.8 in. approximately from the crankshaft axis. The three main crankshaft bearings fit bearing retainer rings shrunk and pinned into the crankcase diaphragm hubs. Bearing bores in the crankcase are: front, 6.56 in., center 11.13 in., and rear 6.3 in. Bearing fits at this point appear to be in accordance with conventional American practice. The front bearing retaining ring only is

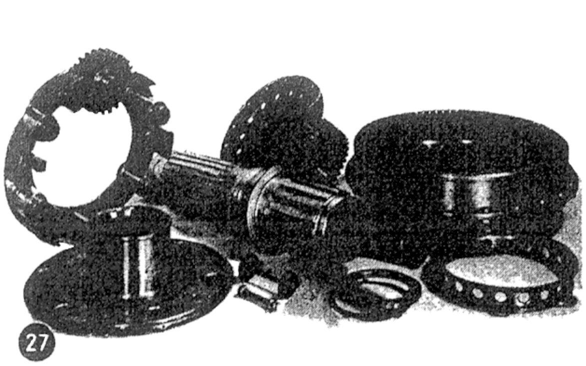
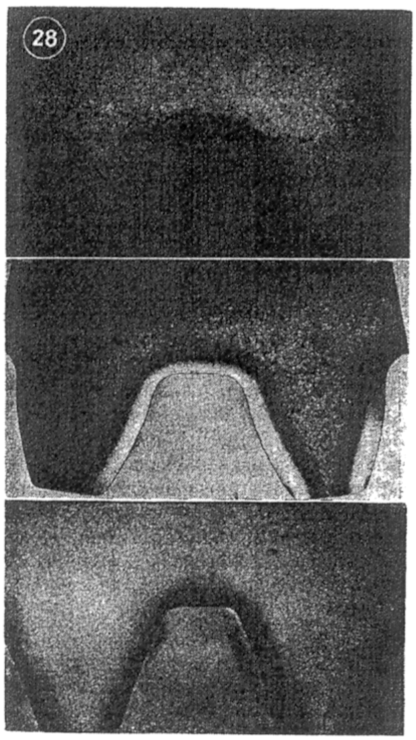


FIG. 27. Propeller reduction gear parts, left to right, pinion, cage hub, propeller shaft, trunnion and cage bolts, stationary reduction gear, cage nut and lock, reduction driving gear, and accessory driving gear.



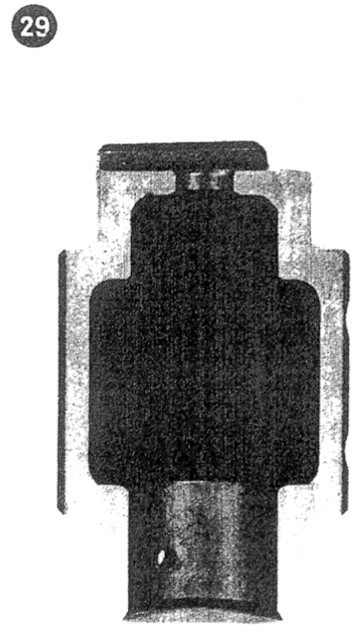


FIG. 28. Sections through reduction gear teeth driving gear, pinion and sun gear.
FIG. 29. Section of reduction gear pinion trunnion.

flanged so that the crankshaft end float is limited through the front main bearing between this flange and a steel ring attached to the aluminum-alloy cam oil transfer bracket bolted to the diaphragm. Studded to the main crankcase is a cast magnesium-alloy section which mounts the valve tappet assembly and in which a fourth main bearing is supported by a diaphragm. This intermediate casting, together with the main crankcase, forms a housing for the valve gear. See Fig. 9.

Unfortunately, the complete crankcase front section which had housed the reduction gear is not available for inspection. This nose section had been of conventional structure as shown in the front view of the engine.

CRANKSHAFT — The engine crankshaft is a three-piece steel shaft mounted on four main bearings as just mentioned. Fig. 10 shows crankshaft parts. Crankpins are 3 in. in diameter by 3-3/8 in. between cheek faces. The installation of the one-piece master rod is accomplished by splitting the shaft near the center of the crankpin. Crankpin diameters and abutting surfaces are carburized to Rockwell C 60 to a depth of 0.044 in. Core hardness is Rockwell C 44. A splined joint typical of certain American practice is used. Thirty-six involute splines with approximately 2.3 in. OD are used for location. The male splines in each case are on the forward half of the split and form a tight fit with the female splines on the rear half. The entire joint is held

FIG. 30. This view of supercharger rear housing shows diffuser plate, thrust bearing and retaining parts, impeller shaft, and impeller. Note that the two sleeves carrying four piston type oil sealing rings each are not shown.

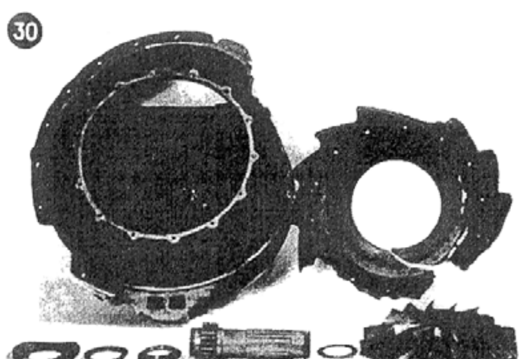
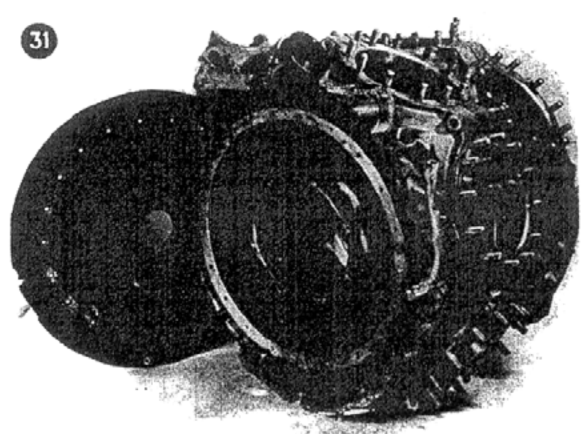
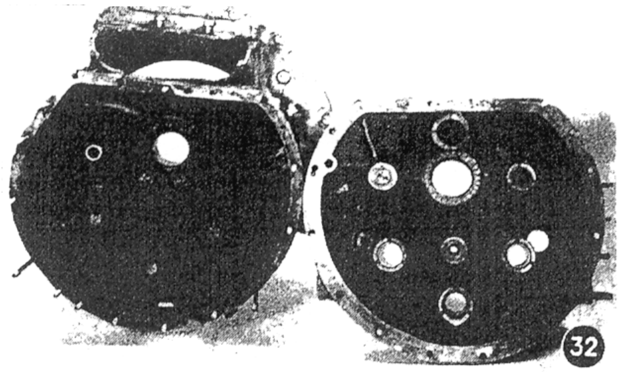


FIG. 31. Left to right: oil baffle plate, remnants of supercharger front housing and main crankcase, which is a typical three-section aluminum alloy case.





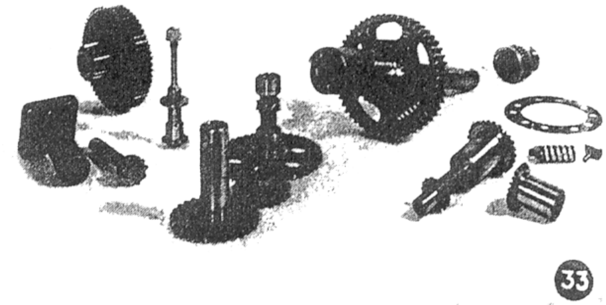
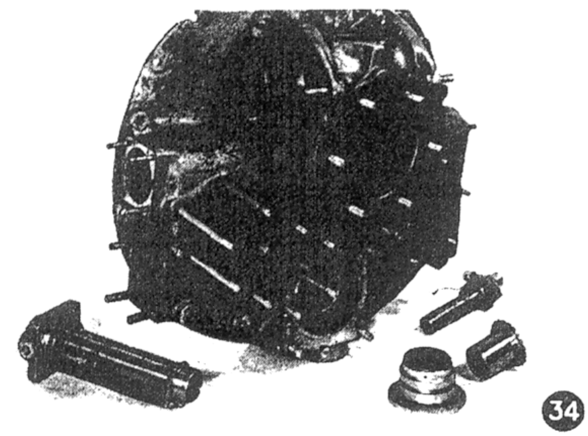
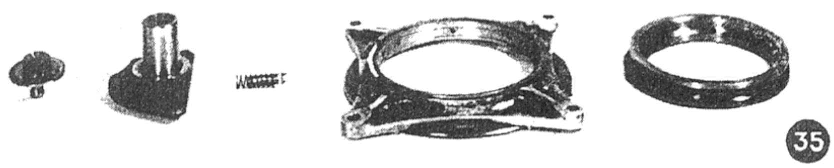


FIG. 32. Supercharger rear housing and cover which together form the housing for the accessory drives. FIG. 33. Left to right: fuel pump drive support and shaft, intermediate supercharger drive gear, idler shaft, oil pump drive gear, idler with bushing partially removed, generator drive gear, accessory drive and starter shaft, magneto drive shaft, magneto drive gear, crankshaft coupling, accessory gear retainer, and spring and buttons. FIG. 34. Supercharger rear cover mounting accommodates fuel pump, oil strainer, oil pump, generator, starter, breather, propeller controls valve, accessory drive box and magnetos. Detached parts are: left to right, oil strainer, magneto shaft mounting and shaft, and propeller control valve. FIG. 35. Oil transfer parts supplying valve gear from crankshaft supply, left to right, cam drive gear, bracket and retaining nut, tube, oil transfer bracket and ring, front main bearing locating ring, crankshaft oil seal, and ring carrier.





together by a necked capscrew. Threads on this capscrew are 1in.-17 by 1.06 in. long. The neck is 0.9-in. diameter by 4.25 in. long. Locking is by means of a pin through the crankcheek and threaded end of the capscrew.

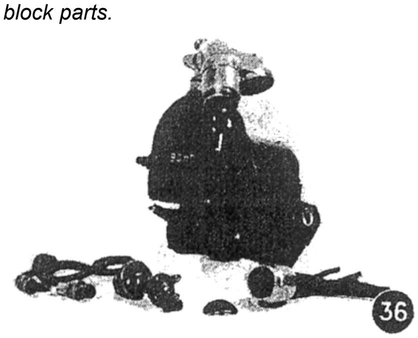
Steel counterweights attached by means of rivets are used. It will be noted that no vibration damping provisions are made.

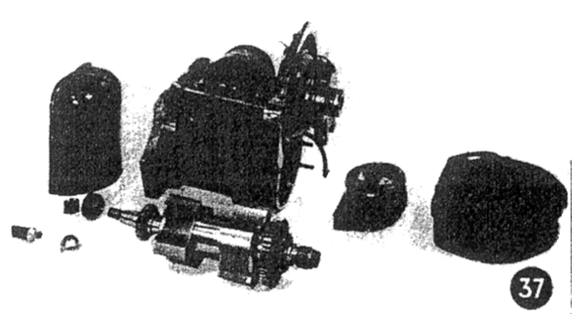
Main bearings of NSK manufacturer are used as follows: rear, sixteen 18x18-mm. rollers, 3.54 in. ID by 6.3 in. OD by 1.14 in. wide; center, 23 balls, 8.5 in. ID by 11.1 in. OD by 0.94 in. wide, symbol 8075GA; front, 19 17x17-mm. rollers, 3.9 in. ID by 6.7 in. OD by 1.06 in. wide outer race and 1.18 in. wide inner race, symbol 8692HA. Inner races of both front and rear bearings are conventional two piece construction. The fourth main bearing is the same size as the rear bearing except that the inner race is integral with the hub of the reduction driving gear. The outer race is positioned by the bearing ring flange and a steel snap ring. This bearing carries symbol 8708HA. Unfortunately, the symbol on the rear bearing was partially destroyed by fracture of the bearing race. Center main bearing mounting on the crankshaft is accomplished by means of a split T-section ring. The halves of this ring are attached from

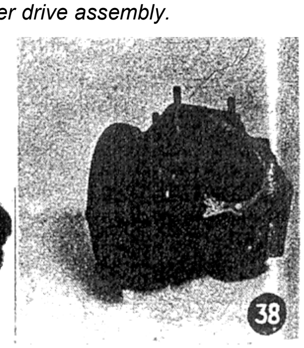
FIG. 36. Japanese 14-cylinder magneto assembled, showing spark plug lead, portion of spark plug, and high tension junction block parts.

FIG. 37. Japanese 14-cylinder magneto disassembled.

FIG. 38. Accessory and tachometer drive assembly.







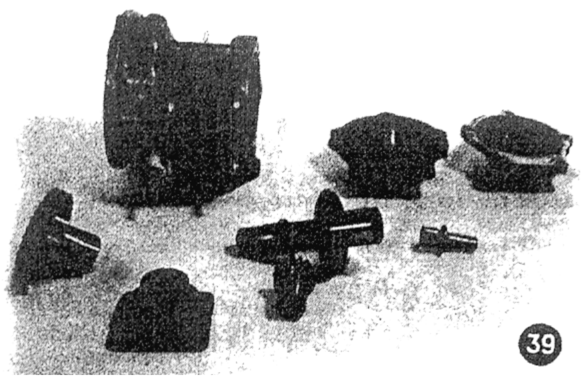


FIG. 39. Accessory and tachometer drive parts.

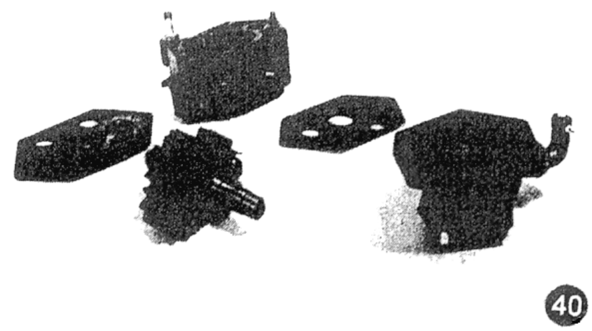


FIG. 40. Oil pump parts (viewing these from left to right) front end plate, gears and shaft, portion of main oil pump body, central plate and valve gear scavenge body.

opposite directions to the crankshaft by means of seven capscrews each. The flange for this attachment is extended radially outward to form a sidewise locating flange for the bearing. A 0.156-in. thick tongue extends into the space provided by the difference in crankshaft bearing journal OD and bearing race ID; thus the radial load is carried on this lip. This method of mounting differs only in detail from that used on certain American engines for a similar application.

The front extension of the crankshaft front section incorporates, in addition to the front main bearing journal, 3.54-in. OD square splines for mounting the reduction driving gear. There are 14 splines spaced on the basis of fifteen with one omitted. The designers apparently found it desirable to index the driving gear. The gear is retained by a large nut per conventional practice. The inside of the extension is bored out to receive a 2.12-in. ID copper-lead-lined heavy steel backed bushing for supporting the rear propeller shaft journal. The rear extension of the crankshaft rear section mounts the rear main bearing with conventional retaining nut and is splined internally to receive a coupling for connection with the starter and accessory drive shaft.

The crankshaft is drilled for lubrication of connecting-rod bearings and all parts forward. The oil passage through the center cheek is of some interest in that a large axial hole serves as a point to start diagonal drilled oil holes to each crankpin. These oil holes are offset to allow th drilling spindle to miss the crankpin. The large hole is then plugged by means of a 17S aluminum-alloy spool pressed in and not otherwise retained. Lubrication to the master connecting-rod bearings is by means of five holes in each crankpin. Four of these holes are located (two on each side) in a plane normal to the plane of the crank throws. The fifth hole is close to the center of the pin, a few degrees in advance of the plane of the crank throws on the side unloaded by rod inertia. Oil jets for piston lubrication are provided by drilled holes through the counterweights to the main journal bores (see Fig. 11).

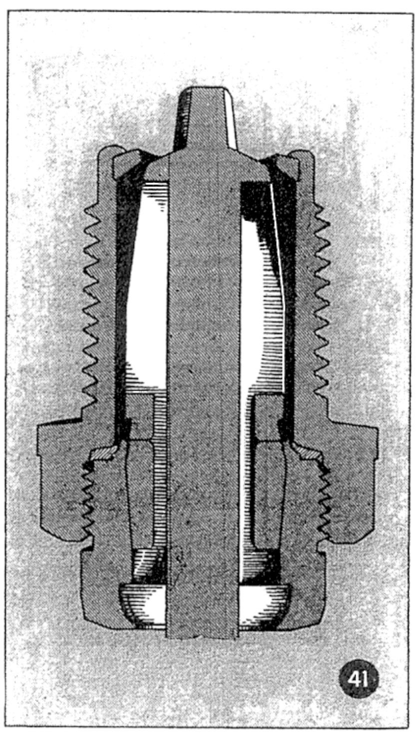


FIG. 41. Section of cylinder end of spark plug.

CONNECTING RODS — The connecting-rod system in each bank is of the conventional master articulated type. The master-rod length is 11.25 in. from crankpin to the piston-pin center. It is of I-section construction with the typical carving required for transfer from hub to shank sections. See Fig. 12. The hub section has the appearance of being rather small compared with the rest of the rod, with flanges scalloped quite closely around the knuckle-pin bores. Material is the all-purpose steel mentioned in the "Ge neral Discussion," hardened to Rockwell C 40. Master rod bearing is a heavy-steel-backed, copper-lead-lined, shrunk-in bearing with a flange at one end. Steel is soft, 0.094 in. thick. Lining analysis corresponds to American practice with a small amount of tin and 1 percent silver. The lining structure is good for medium loading. Bond and fracture examination were good, ductility — good, X-ray — good. Micro examination shows good distribution but coarse structure with irregular dendrites in the cross-section and shrinkage in the surface structure. See Fig. 13. Lining is 0.020 in. thick. The flange is cut away at two points to mate with keys milled into the rod hub to prevent rotation. As mentioned previously, the crankpins are 3 by 3-3/8 in. The bearing shell is chamfered and cut off to provide 2.87 in. bearing length. Bearing clearance used is approximately 0.005 in.

Articulated rods are 8.7 in. long between knuckle-pin and piston-pin centers. They are the conventional I-section rods and appear very similar to some used in this country. Articulated rods are tin-bronze bushed at each end. These are very good quality castings. The material is uniform and unusually free from foreign inclusions. Hardness is Rockwell B 70. The knuckle-pin bushing is 1.03 in. in diameter by 1.57 in. long. Piston-pin bushings on both master and articulated rods are 1.24 in. in diameter and 1.81 in. long.

Knuckle pins (Fig. 14) are flanged at one end and locked in the master rod by lock plates screwed to the rod flange in the conventional manner. Pins are drilled from both ends leaving a web at the center. The end opposite the flange is plugged for bushing lubrication passage. As noted previously, the all-purpose steel is used. The specimen examined showed 0.040 in. case depth, Rockwell C 57 hardness on the case and 43 on the core.

Rod weights are etched on each end of each rod and are approximately 0.93 lb. for the knuckle-pin end and 1.72 lb for the piston-pin end of the master rod. Equivalent rotating master weight used is 37.6 lb. Apparently no correction is made for knuckle-pin displacement or for crankpin oil. Master rods are installed in 3F and 3R cylinders.

CYLINDERS — Cylinder construction is of nitrided steel barrel, aluminum-alloy head type, similar to American practice. See Fig. 15. Barrel cooling fins 0.45-in. deep are machined on the steel barrel. There are 21 fins covering a longitudinal length of 2.75 in., that is a spacing of 0.131 in. which is quite close. Attaching flanges are also turned onto the barrel and spotfaced for flat washers at the cylinder attaching nuts. A skirt length o f2.95 in. allows approximately a 2 in. projection into the crankcase interior.

Cylinder heads are characterized by quite closely spaced (5 per in.) fins which average 0.9 in. in depth. This design would appear to give relatively small cooling area for the output which could be expected from engine of this size. Relatively small angle between valves (56 deg. approximately) further hinders the application of fins at the top of the combustion-chamber dome.

Attachment of the head to the barrel (fig. 16) is by means of a screw joint using threads of 3-mm. pitch (8.5 threads per in.). The thread form is believed to be the International Screw Thread standard 60-deg. thread with radius tips and roots. A shrink-fit pilot is provided both above and below the threaded section of the joint. The joint is completed by screwing the tapered loser face of the head against the upper side of an angularly machined fin. Presumably, the parts are machined with a differential angle so that the tip of this angular fin bears first during assembly. The cylinder-barrel threads run out into a relief. Head threads are milled and no relief is provided. It will be noted that there is a relatively ling heavy barrel section within the vicinity of the angular fin which is broken up by the thread relief above and the normal fin root below. Excessive stress concentrations would be expected at the thin wall sections adjacent to the heavy section.

The cylinder head is cast of the aluminum alloy described previously. It shows a Brinnel hardness number of 60.

Two spark-plug inserts are screwed into the head. The left-hand threaded joint is tapered. No other locking means is provided. The inserts, of aluminum bronze, are located at the front and rear slightly off-center, and are approximately radial to the internal dome contour. Valve-seat inserts are shrunk into the bores in the cylinder head per conventional practice. The steel exhaust insert is alloyed with nickel, chromium, and quite high manganese, with a Rockwell hardness of 87 B. Intake insert is aluminum bronze. See Fig. 17. Tin-bronze valve guides are used in both intake and exhaust. Valve rocker boxes are cast integral with the head and are very similar inform to those of one American manufacturer. The box is completely enclosed except for a small cover plate over the valve end for installation of the rocker and valve clearance adjustment. Evaluation of valve ports is impossible by inspection but they appear to be well worked out. Port diameters are as follows: intake at valve end 2.24 in., at connection end 2.16 in.; exhaust at valve end 2.18 in., at connection end 2.26 in. Connection with the intake pipe is accomplished by means of a shrunk and pinned sleeve, the outer end of which is recessed inside and threaded outside to provide a packing gland type joint with the pipe. The exhaust connection int the head (see Fig. 18) is protected by a steel sleeve of the above ID approximately 0.07 in. thick by 0.94 long shrunk into the exhaust-port bore. Connection to the exhaust system is accomplished by means of a slip joint tube held in place by a lug and one stud. The exhaust connector used with the installation extends approximately 3 in. to a ball joint.

PISTONS — Pistons in this engine (Fig. 19) are aluminum-alloy forgings very similar to current American practice. A Brinell hardness of 100 is quite uniform. Pin bosses are drilled for splash lubrication. Heads are flat with no valve-clearance cut-outs. The underside of the head is ribbed at right angles to the piston-pin bore. The piston is fitted with six 0.09-in. wide piston rings in five grooves. The two upper rungs are flat-faced compression reins chromium plated on the outside diameter to a depth of 0.0007 in. (See Fig. 20) The third ring is a tapered-face compression ring installed with the scraping edge down. There are two scalloped oil-control rings in the fourth groove. These rings are conventional in that, in addition to the scallop0ed lower side face, the outer face is radiused at the upper side and stepped to form oil drainage spade below th scraping edge. The fifth ring, which is below the piston pin is a typical 45-deg. oil scraper. A relatively narrow land (0.23 in.) is provided above the upper compression ring. The next two lands are 0.17 and 0.14 in. respectively. Ring side clearance is approximately in accordance with American practice. Scraper rings are fitted closely (0.00 in. in fifth groove, and 0.003 in. in fourth groove) with progressively increasing clearances toward the piston head (0.006 in. in the third groove and 0.008 in. in grooves one and two). All rings have parallel side faces and approximately 0.2 in. radial depth. The piston pin (Fig. 21) is a low-alloy steel hardened throughout to Rockwell C 42. It is not case-hardened. The piston pin is retained by means of 17S aluminum-alloy plugs pressed into the pin. The heads of these plugs are relatively thick and the spherical contacting area is decreased by a large chamfer. Two angular holes through this chamfer serve the dual purpose of venting the pin and providing cooling means.

VALVE GEAR — The cam is a double track ring running on a tin-bronze cast bushing of very good quality which, in turn, is a push fit on a ledge of the crankcase intermediate front-section diaphragm. The cam is case-hardened to Rockwell C 60. Core hardness is Rockwell C 32. The drive is through a pair of spur gears from the crankshaft to the intermediate cam drive. This intermediate cam drive is mounted on a stub shaft on the crankshaft front main diaphragm and is made as a cluster gear incorporating a pinion which drives the internal gear integral with the cam. A bronze bushing in the cluster gear completes the assembly. It is interesting to note that no lock is provided on the screw which retains this gear, rotation being such that the right-hand thread is expected to tighten during engine operation. This gear train provides for cam rotation at on-sixth crankshaft speed and in a direction opposite the crankshaft rotation. Three lobes on each cam track provide for operation of all fourteen exhaust and all fourteen intake valves. As was noted previously, cam lobes and tappets are tilted at an angle of 14 deg.-30 min. to provide more nearly straight-line action of the push rods and tappets. Thrust resulting from this angle is taken through th flange of the cam bearing ring to the intermediate front section diaphragm. As a result, the designers have found it permissible to retain the cam by three short retaining pieces each held by two studs which also pass through holes in a second flange on the cam bearing ring. Clearance for the internal cam gear is provided underneath the retainers.

The cam is designed with constant-velocity pick-up and seating sectors for a running clearance of 0.045 in. ± 0.025. At 2,000 rpm., pick-up and seating velocity of both intake and exhaust valves is 1.95 fps. The cam design gives 50-deg. overlap, 264 deg. of inlet opening, 290 deg. of exhaust opening. Timing is approximately as follows, although an accurate check was not made: inlet opens 20 deg. early, closes 64 deg. late; exhaust opens 80 deg. early, closes 30 deg. late. Valve lift is 0.54 in.

Tappets are arranged in pairs in 14 17S aluminum-alloy tappet guides (one per cylinder). A great deal of machining was done to cut these guides out of what must have been extremely simple forgings. They are bored and slotted elaborately for various reasons including oil feed and drainage. Tappets are Rockwell C 61 throughout, although the photomicrographs show a change in structure near the surface. They are 0.62-in. diameter and are fitted with pressed-in ball sockets for push-rod actuation. Tappet rollers, 1.25-in. diameter (Fig. 22), are Rockwell C 61 throughout and are mounted on 0.31 in. diameter case-hardened (Rockwell C 61 case, 30 core) floating pins. Push rods are low chrome-alloy steel tubing with pressed-in ball ends of low-alloy steel heat-treated to a hardness of Rockwell C 30, except at the tip which is quenched to obtain a hardness of Rockwell C 60. Fig. 23 shows a section of the push-rod ball end. Push-rod housings are aluminum alloy attached by means of a packing gland type joint to the cylinder rocker box. There were no lower push-rod housing connections available when the engine was inspected, but photographs of a similar engine indicate a single piece which forms attachment for two push-rod housings and is, in turn, attached to the crankcase by the three studs which also retain the tappet guide block.

Valve rockers are cadmium-plated steel forgings of the alloy described previously. See Fig. 24.) They oscillate on pressure-lubricated plain tin-bronze bushings pressed and pinned into a bore in the arm. These ride on a flanged steel journal supported by a stepped rocker bearing bolt. Rocker thrust is taken by the bushing flange against a shoulder on the journal. The push-rod ball socket is permanently installed in one end of the rocker. Adjustment is at the valve end by means of a screw threaded into the arm and locked by means of a jam nut. A flatted ball bears on the valve stem and is seated in the adjusting screw, providing a familiar type of construction.

Hollow-head and -stem exhaust valves (Fig. 25) and the familiar “tulip” head solid-stem intake valves (Fig. 26) are used. The exhaust valve steel is the high-chromium, high-nickel plus tungsten and cobalt alloy generally used in this application. It is forged and machined in one piece with welded Stellite tip and face. Face and tip hardness is Rockwell C 56; stem Rockwell B 96. and head, Rockwell B 93. Metallic sodium is used as a coolant. The inlet valve is a familiar material with 13.2 percent tungsten, 3.2 percent chromium, 0.8 percent nickel, 0.1 percent cobalt, 0.4 percent manganese, 0.4 silicon, and 0.5 percent carbon. Rockwell C 35 to 45 with the tip hardened to 55.

Major valve dimensions are as follows: exhaust, 2.53-in. diameter head, 45-deg. face, 0.62-in. diameter stem; intake, 2.67-in. diameter head, 45-deg. face, 0.46-in. diameter stem. Valves seat on inserts in the cylinder head as mentioned previously. The bronze intake insert is 2.75-in. OD by 2.24-in. ID; the steel exhaust insert is 2.67-in. OD by 2.18-in. ID. Valve-spring upper washers are retained by a split lock incorporating a tapered OD and a corrugated ID which fits three circumferential semi-circular grooves in the valve stem. Two springs are used per valve — the inner seating on a washer on the guide flange and the outer on a loose steel washer in the cylinder. Springs are cadmium-plated carbon steel with a hardness of Rockwell C 40. Quality is very good.

REDUCTION GEAR — the 0.7:1 propeller reduction gear is of the planetary type; parts are shown in Fig. 27. A large internal gear with 84 teeth is splined to the crankshaft front extension as described previously. This gear is of two-piece construction, being made up of a flange integral with the splined hub. The internal ring gear is attached to the OD of this flange by means of a large number of small diameter trough bolts. The roots and flanks are Rockwell C 62. Core hardness (including tips) is C 26. The 36-tooth sun gear of this planet set is attached to the crankcase front section by through bolts in the conventional manner. Roots and flanks of this gear are Rockwell C 60. Core hardness (including tips) is C 38. (See Fig.

28.) Unfortunately, as mentioned previously, this section is not available for inspection. Six 24-tooth planet pinions are mounted on trunnions pressed into a machined-out split cage. Pinion roots and flanks are Rockwell C 59. Core hardness (including tips) is C 41. Case depth is 0.045 in. Trunnions (Fig. 29) are low-alloy steel carburized on the journal surface only to give Rockwell C 59 on the case, 42 on the core, and a case depth of 0.035 in. Pinions run on pressed-in steel-backed copper-lead lined bushings. The lining is 0.020 in. thick, of coarse structure but otherwise of very good quality and satisfactory for its purpose. The pinion cage is splined to th propeller shaft and retained in place by a large nut. The propeller shaft is the steel mentioned previously as being similar to AMS 6254. It is hardened throughout to Rockwell C 59. The propeller attachment is not common to American standards. Splines are involute type — 22 single and one wide spline cut on the basis of 24 splines. Outside diameter is 3.725 in. and spline depth 0.135 in. Cone seat diameters are 3.735 in. for the large cone, and 3.228 in. for the small. A 1-in. wide undercut is machined between the latter and the spline ends. Propeller nut threads are 2.5-mm. pitch x 80-mm. diameter. A small gear is bolted to the pinion cage to provide some type of drive on the crankcase front section. This gear forms the basis for the supposition mentioned under discussion of this section.

SUPERCHARGER AND DRIVE — A gear-driven centrifugal supercharger turning at 8.48 x crankshaft speed is incorporated in the engine. The drive is accomplished in a manner very similar to that used on an American engine. The main accessory drive and starter shaft, driven through a splined coupling from the rear main bearing journal and running in a bronze bushing in the supercharger rear cover, serves a number of purposes. (See Fig.30.) The hub for a spring-loaded supercharger drive gear is integral with this shaft. The impeller shaft rides on two steel-backed, copper-lead lined bushings on journals of this shaft. The shaft itself is of the material described previously having a core hardness of Rockwell C 40 and a case of 55 at wear points. The single-speed supercharger drive is completed by a case-hardened cluster gear and pinion mounted on a shaft fixed in the supercharger rear housing and piloted in a bushed bore in the supercharger rear cover. This intermediate drive cluster incorporates a coper-lead lined, steel-backed bushing. The 17S aluminum-alloy impeller is mounted on square splines on the impeller shaft just mentioned. A steel bushing is incorporated in the impeller. Impeller diameter is 9.62 in. Impeller design is conventional with 12 vanes apparently machined and bent per American practice. A 14-vane supercharger diffuser plate of magnesium alloy (Fig. 30) is mounted by means of 14 screws to a supercharger rear housing flange. Fourteen intake pipes are taken tangentially from the annulus formed between the supercharger front and rear housings, the oil baffle plate and the diffuser plate. The supercharger entrance passage from the carburetor is conventional but appears to be slightly small for an engine of this size. Axial clearance in the entrance is low.

Supercharger oil sealing is accomplished by four cadmium-plated cast-iron piston rings in impeller shaft spacer grooves at either end of the impeller. The rings seal against steel sleeves tightly fitted into the supercharger rear housing and the crankcase oil baffle plate. (See Figs. 31 and 32.) It is interesting to note that a boss for venting the supercharger oil seal is cast into the supercharger rear housing but left undrilled.

ACCESSORY DRIVES — The 50-tooth spring-loaded accessory drive gear mentioned previously also drives all of the accessories except the magnetos through a centrally located 19-tooth idler gear to: (1) a 29-tooth generator drive gear and shaft; (2) a 40-tooth oil-pump drive gear and shaft; (3) a 40-tooth accessory gear box drive gear and shaft. An 8-tooth spiral gear is machined into the oil-pump drive shaft and mates with a 9-tooth spiral gear on the fuel-pump drive on the left side of the engine at 1.11 engine speed. The square shaft and square pad, formerly standard on American engines, are used for the fuel-pump mounting.

Magneto drive (Fig. 33) is accomplished from a 30-tooth spur gear integral with the crankshaft extension through an intermediate magneto driveshaft which runs in two bronze bushings in the supercharger rear cover. Machined integral with this shaft are a 24-tooth spur gear and a 14-tooth bevel gear. The bevel gear mates with two 20-tooth bevel geared magneto shafts mounted laterally in bronze-bushed support housings which are, in turn, mounted in the supercharger rear cover. (See Fig. 34.) No oil seals are provided. Three-stud flange mounted magnetos are mounted on either side of the rear housing and are driven through a splined coupling engaging the female splines in the magneto gear shafts.

LUBRICATION SYSTEM — A three-section oil pump comprising a pressure pump and two scavenge pumps is mounted on the rear cover. Oil from the pressure pump is taken through passages in the supercharger rear housing and a disc-type oil strainer to the large bronze bushing in which the anti-propeller end of the crankshaft extension runs. Oil transfer to the drilled crankshaft extension is accomplished through slots in the bushing and drilled holes in the shaft journal. All forward engine lubrication is taken through this journal and on through the drilled passages in the crankshaft. Master connecting-rod bearing lubrication was mentioned previously. Knuckle-pin oil is bled from the master-rod bearing clearance through holes drilled near one end of the bearing. These holes in the shell connect holes drilled in the rod flange and thence to corresponding holes in the hollow knuckle pin. Piston-pin lubrication is by splash. Holes for this purpose are drilled in the articulated rod eye near the shank and in the bottom of each pin boss in the piston.

Propeller reduction-gear oil is taken from the hollow front crankshaft journal and propeller shaft through holes in the splined mount for the pinion cage and on through drilled passages to the hollow pinion trunnions.

Valve-gear lubrication is through a ring-sealed sleeve and a spring-loaded tube to the intermediate cam drive gear bracket, thence through a slip joint to the crankcase front intermediate section diaphragm and drilled passages therein to the cam ring and valve tappets. (See Fig. 35.) Pressure oil is metered to all plain rocker bearings through passages in the tappets, push rods, and valve rockers.

Accessory drives are lubricated through drilled passages in the supercharger rear cover leading from the main oil annulus around the crankshaft extension bushing.

This source also supplies a two-position propeller control valve in the right side of the rear cover. Oil from this valve is led through drilled passages in the supercharger housings and crankcase front sections and through tubes in the crankcase main sections to a journal-type seal on the propeller shaft. This seal is mounted within the stationary reduction gear. A spun tube in this gear completes the two-position hydraulic propeller control system. A diaphragm in the propeller shaft separates propeller oil in the forward part from the engine oil in the after part.

Scavenging of the main portion of the engine is accomplished by drainage to an oil sump mounted at the bottom of the supercharger front housing. The main scavenge section of the oil pump draws oil from this sump and discharges it to the external system in the conventional manner. The third section of the oil pump takes rocker box scavenge oil from a small oil sump mounted on No. 1 front cylinder at the extreme bottom of the engine. Oil from the rocker boxes on Cylinders 1, 2, 3, 6, and 7 front and 3, 4, 5, and 6 rear drains from box to box into this sump. Upper cylinder boxes drain through push-rod housings and tappet guides directly into the valve gear drive compartment.

ACCESSORIES AND MISCELLANEOUS — Information on accessories for this engine is very meager.

An electric inertia starter is mounted on the conventional six-bolt starter pad and engages a three-jaw end of the crankshaft extension.

The magneto photographs, Figs. 36 and 37, presented herewith are believed to be from a magneto similar but not that used with this engine. The remainder of the ignition system is radio-shielded in a manner very similar to American engines, including spark-plug elbows and spring contactors in the spark-plug well. Illustrated with the complete magneto is an interesting quick-disconnect fitting which makes it possible to remove the radio shielding from the magneto without disturbing the blocks and wire attachment. Seven wires pass through each of the blocks; however, as mentioned before, this equipment is not from the engine on which this report is based, but represents one system which is in use.

No carburetion data on this engine are available to the writer.

An accessory drive gear box, Fig. 38, is mounted on the right-hand side of the rear cover. This box forms the drive for a single tachometer and two accessories, the nature of which is not known. This drive involves a small spur gear (probably twelve teeth), which is not available, splined into the right-hand accessory drive-gear shaft. Fig. 39 shows drive parts. It meshes with a 30-tooth gear mounted in the accessory drive housing, and splined to a shaft mounting a bevel gear. Tachometer drive is through a splined coupling directly from this shaft. It is 0.5 crankshaft speed (if th missing gear mentioned above is twelve-tooth.) A square-pad drive similar to the air-pump drive on American engines and a triangular-pad drive are accomplished through two bevel gears each mating with the gear on the main shaft.

The nature of the drive used on the crankcase front section is not know, but it is believed that a combination gun synchronizing impulse generator and constant-speed propeller governor drive is made available at this point on later engines.

The oil pump is mounted at the left-rear of the engine, taking its drive through a spline in the oil pump and fuel-pump drive shaft mentioned previously. Parts are shown in Fig. 40. A magnesium-alloy housing is cored for oil passages and mounts the gears and shafts directly. The 1.12 in. wide nine-tooth scavenge gears splined to the engine shaft and drives the main oil pump shaft on which three eleven-tooth gears are mounted. The 0.88 in. wide oil pressure pump consists of a gear keyed to this main shaft driving a nine-tooth idler. Both of these pumps are in the main pump housing. A thin plate separates the pressure pump from the valve gear scavenge pump which is a duplicate of the pressure pump except that the teeth are only 0.47 in. wide. The main oil pump shaft is also fitted with a floating member to provide a tongue drive for a square pad accessory on the rear of the valve gear scavenge pump housing. A quill drive for this accessory is formed by a 0.27-in. diameter by 3-in. long neck between the splines which fit into the forward end of the main shaft and the slotted journal. All oil-pump gears are carburized low-alloy steel.

The remains of a spark plug is sectioned and shown in Fig. 41. It is a mica-insulated plug of quite conventional construction.

Engine mounting is accomplished by means of seven longitudinal bolts in bosses cast at alternate intake pipe connections in the supercharger front housing. Breathing appears to be through a flange at the top of the magneto drive shaft housing in the supercharger rear cover.

Editor’s Note:

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It was reconstructed from microfilm by J.L. McClellan. The microfilm was taken from a tightly bound volume, so that there is some distortion of the images, especially near the binding. It has not been practical to remove or compensate for all the distortions, so none of the illustrations in this reconstruction should be considered reliable sources as to fine details of shape, proportion or spatial relationship. The distortions are, in general, small, and should not detract from a general appreciation of arrangement and relationship. Mr. McClellan has attempted to represent the original layout of the article, but there are some exceptions. Limitations in the compositing tools cause a difference in the text flow relative to the illustrations, compared to the original, so that some changes have been made, to compensate partially for that effect, and the tabular data have been removed from the flow of text and brought together on a single page after the text, partly to make them more accessible, and partly to sidestep problems with page layout.