HISTORY OF THE McCULLOCH AIRCRAFT ENGINE

(4-Cylinder, 2-Cycle)

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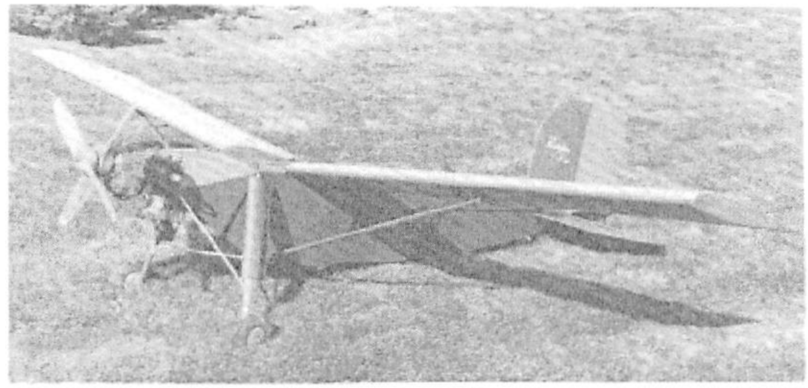
". . . do not purchase a used aircraft with engine or a used engine and attempt to fly same without establishing the condition of the engine."



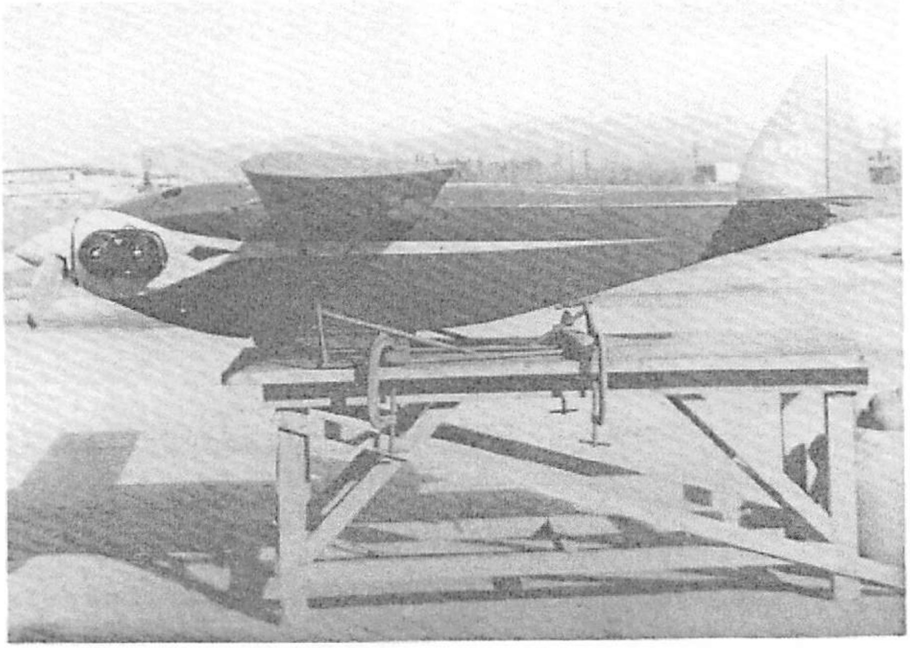
The grand-daddy of aerial target radio-controlled aircraft. The OQ-2, dating to 1939, had a span of 12 ft., fuselage length of 8.6 ft., gross weight of 108 pounds and achieved a speed of 90 mph. The Radioplane Company manufactured the aircraft with a metal frame triangular fuselage and wooden wings which were fabric-covered. Note the concentrically shafted counter-rotating propellers employed to eliminate engine torque effects. Engine was an opposed twin 2-cycle developing 6.5 horsepower manufactured by the Righter Company. (Photo by the author.)

The venerable McCulloch, lovingly called Mac by PRA members, 4-cylinder, 2-cycle, air-cooled military drone engine has a unique place in the history of the homebuilt rotorcraft typified by the Bensen B-8 Gyrocopter. For the Bensen Gyro and other similar aircraft, choosing an engine results in an attitude not unlike the light beer commercial with Coach Madden, formerly of the NFL Oakland Raiders, where he says, "there are lots of others (engines) and you can pick any one you want, but as for me..." and with thousands of other gyro enthusiasts, the pick is the Mac. The fundamental reason for its popularity is its outstanding horsepower-to-weight ratio in excess of one (1), far superior to any other engine currently available for these aircraft. In Dr. Igor B. Bensen's "History of the Gyrocopter, Part IX" (**PRFlying** magazine, December, 1981), the author refers to the 40 year old technology of the Mac engine and laments, "to this day not one single manufacturer has come forward with its modernized equivalent which would match its specific weight of 1.0 pounds per horsepower!"

The Mac 4-cylinder drone, or unmanned target aircraft engine, is indeed based on technology more than 40 years old. The McCulloch Company, then of Milwaukee, Wisconsin, was introduced to the world of aircraft two-cycle engines during World War II. The first radio-controlled, aerial target aircraft were developed in the late 1930s by the Army Air Corps and the Radioplane Company of Van Nuys, California. The first ever aerial target unmanned aircraft (drone) became fully operational in the early 1940s. The OQ-2A was manufactured by the Radioplane Company by the thousands and served as the aerial target workhorse throughout the war. These aircraft were powered with a 2-cylinder horizontal opposed 2-cycle engine designed and manufactured by the Righter Company of Los Angeles, California. The first engine, Righter Model 2-GS-17, military designation 0-15-1, was equipped with concentrically shafted counter-rotating propellers (to offset engine torque effects) and developed 6.5 horsepower. In order to expand wartime production capability, the U. S. Government through its War Mobilization Board, assigned selected war production tasks to U. S. companies having an appropriate cability. As a peacetime manufacturer of small engines, the McCulloch Company of Milwaukee was assigned the task to manufacture to print the Righter 0-15-3 engine. This was a second version of the engine which deleted the counter-rotating capability in favor of a single propeller and which developed 8 horsepower. McCulloch qualified its first 0-15-3 engine in a 25 hour run at Wright Field, Dayton, Ohio, on April 3, 1944. By then Radioplane had begun working on its larger, improved radio-controlled drone, the OQ-14, which was to be powered by the new Righter 2-cylinder engine, the 0-45, which developed 25 horsepower. Soon both the Righter Company and the McCulloch Company were running assembly lines on both the 0-15-3 and the 0-45 engines for the war effort.

In the meantime, the military services were asking the Radioplane Company for a larger, faster, unmanned aerial target for more realistic training for our fighter pilots and gunners; a quest that is ongoing today. Accordingly, the Radioplane Company came up with a design that called for a 4-cylinder, 2-cycle engine that would produce in excess of 60 horsepower. In November, 1944, the Radioplane Model RP-15, military designation OQ-6, was test flown and developed speeds in excess of 190 mph. This was the first flight of the Mac 4-cylinder engine as we have come to know it today. It must be said here that Mr. Walter H. Righter, President of the Righter company, had conceived the basic design in the upgrading of his 0-15-3 from 8 to 16 HP. The OQ-6 was similar in design to previous Radioplane aerial targets used during the way and it, too, had fabric covering. Its wingspan was 14 feet long with a fuselage length of 10 feet. Unfortunately, the end of the war closed out the OQ-6 with the cancellation of virtually all military contracts.

It wasn't long, however, before the military was back at Radioplane in Van Nuys, asking for an advanced design aerial target drone to replace the aging OQ-2s, OQ-3s, and OQ-4s used during World War II. For the new design, the Radioplane engineers departed from the traditional fabric-covered, strut-braced designs begun in the

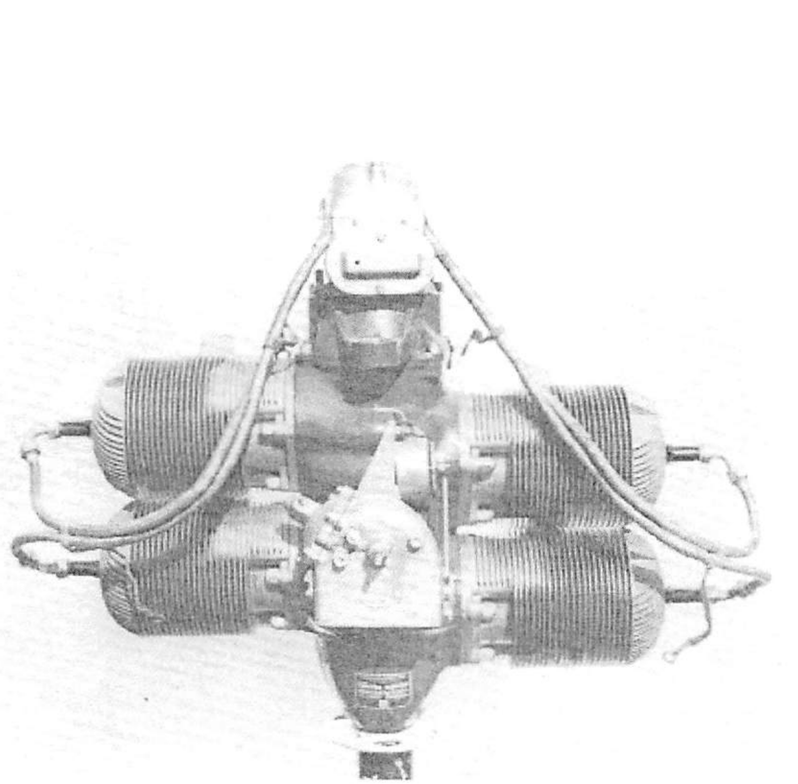


The Radioplane Model RP-15, military designation OQ-6, was produced as a prototype in May, 1943. It was the first drone aircraft to be equipped with a McCulloch 4-cylinder aircraft engine. The OQ-6 was similar to WW II targets with fabric-covered wings and fuselage. The OQ-6, however, incorporated ailerons for the first time. The end of WW II cancelled any production plans. Wing span was 14 ft. with fuselage length 10 ft. and a gross weight of 295 lbs. The Mac 60 powered it to a top speed of 195 mph. (Photo by Radioplane.)

1930s, and produced a clean all-metal 8.5 feet long fuselage with a cantilevered wing with a span of 9.5 feet. The result was the Radioplane Model RP-18, military designation OQ-17, which was equipped with a 2-cylinder engine developing 35 horsepower and which proved in testing to have severe reliability problems. These difficulties with the engine caused Radioplane to look back to the OQ-6 program for the McCulloch 60 horsepower engine. The larger Mac caused a re-design of the aircraft. The innovative design of the OQ-17 was retained, but the airframe had to be scaled up to accommodate the larger and heavier 4-cylinder Mac. The all-metal fuselage grew to 10.5 feet and the wooden wing to 11.5 feet, causing gross weight to grow from 137 pounds to 234 pounds. This configuration became the RP-19, military designation OQ-19. Production was begun in late 1945 and the first run of 750 OQ-19 aircraft was equipped with the McCulloch Model 4300, military designation 0-90-1, engine. The first 150 OQ-19As had the wooden wing which was replaced by the all-metal design on ship number 151. In 1971 when DOD changed the aircraft designation system, the OQ-19 became the MQM-33 (Army) and MQM-36 (Navy), and production continues today by Northrop Corporation in what has become the longest serialized aircraft production run in the world. The Army National Guard and several foreign countries employ versions of the OQ-19/MQM-33 in their aerial target training operations.

As one can see from the photo, the 0-90/Model 4300 engine at first glance looks for all the world just like the current-day Mac that powers the Bensen. Close inspection, however, reveals significant differences. The 90 carburetor has a throttle plate in the inlet operated by a two-position solenoid, the magneto is rough cast and almost breadboard in appearance, and the nose of the crankcase does not have the top and bottom pipe plugs found on the Model 4318 Mac engines. Inside the 4300 is quite different; the cylinders have three (3) inch bore fitted with an aluminum piston, and resulting in an 88 cubic inch displacement. The cylinders also were dyecast aluminum but were fitted with a cast iron sleeve. (Bill Parsons thought he'd invented something until I showed him a 60 HP cylinder made in 1945.) The crankshaft is of the same physical dimensions as today's engine, but the crankcase is vastly different inside. The nose of the case is machined for a 223020 (Bantam) bearing and the nose spacer for the front roller bearing was machined instead of cast. Also, the

The MQM-33, formerly designated OQ-19, is the world's longest production run for an aircraft with more than 76,000 units produced. This aircraft uses the Mac 4-cylinder Model 4318F, military designation 0-100-3. The wing span is 11.5 ft. with a fuselage length of 12 ft. Gross weight is 322 lbs. with a top speed of 200 mph +. The MQM-33 is in current production for the U.S. Army National Guard and is sold as the KD2R-5 by the Northrop Corporation to the military forces of several foreign countries. (Photo courtesy of the Northrop Corporation.)



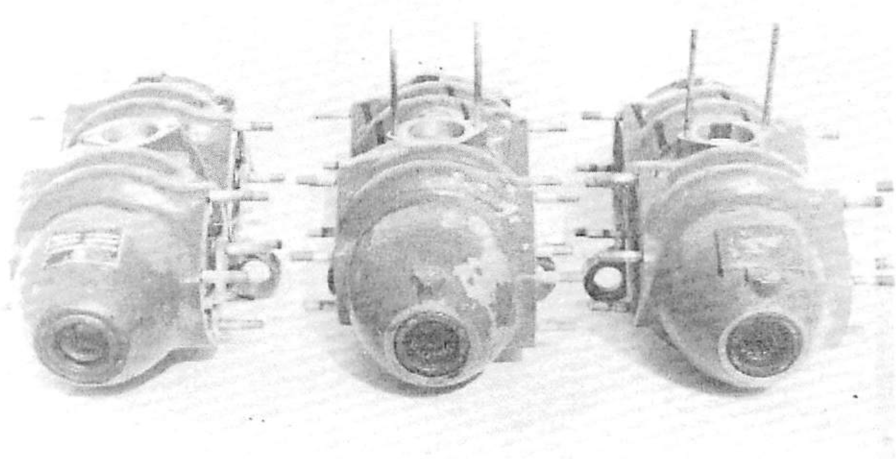
The McCulloch 4300, 0-90 Mac 4 engine. Note the different looking magneto and carburetor with throttleable inlet. This design first entered production in June, 1945, for installation on the Radioplane OQ-19A radio-controlled aerial target. (Photo by the author.)

center main bearing carrier was not die-cast and earliest versions incorporated a babbited center main bearing. This was later changed to incorporate an improved split 223020 bearing with rollers. The connecting rods employed small end rollers and large end caged bearings with two 180° cages per rod. Cage segments used three rollers per segment.

Basically, the 0-90 Model 4300 design was the time-set for the current day Model 4318 engine we have come to know as the Mac. Both are a crankcase scavenged flat four-cylinder, 2-cycle, air-cooled aircraft engine with simultaneously firing opposite cylinders; 1 and 2, then 3 and 4. This arrangement is a weight saver over the traditional 90° approach for cylinder firing. Hence the Mac enjoys a superior horsepower to weight advantage. The simultaneous firing of opposite cylinders also promotes a balanced engine with shaking couples and secondaries balanced out without the need for heavy crankshaft counterweights, again saving weight. The precision dye-cast cylinders are arranged separately, enabling loop scavenging; another weight saving measure because older cross flow designs required that a deflector be cast into the piston, while the Mac piston was clean domed and hence lighter. The crankcase is a permanent mold one-piece aluminum alloy casting. The center main bearing carrier is mounted on the crankshaft, which serves as a valve through openings on the crankshaft flanges at the center main. While adding to the weight-saving design, this arrangement more importantly permits a superior mass flow through the engine than would otherwise be permitted with a reed valve setup.

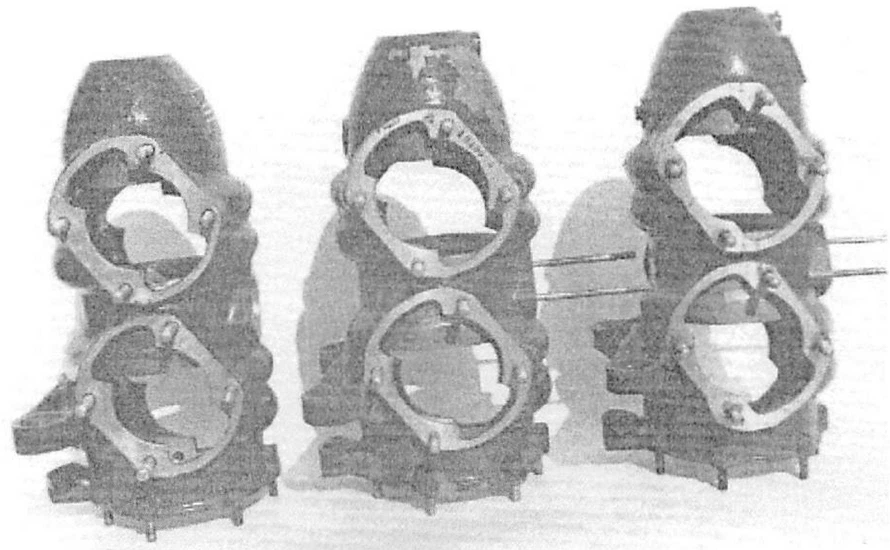
By the late 1940s, the USAF was calling for a drone with improved performance over that which was possible with the OQ-19A and its 60 HP engine. Under the auspices of Wright Field in Dayton, and the Radioplane Company, McCulloch began an improvement program to uprate the engine. McCulloch engineers met the increased horsepower requirements by re-designing the Model 4300/0-90 engine. The cast iron sleeve was removed and the aluminum bore at 3 & 1/16 inches was serrated and chrome plated, resulting in an increase to a total engine displacement of 100 cubic inches. Horsepower was raised from 60 to 72, resulting in the famous Mac 72. Both the carburetor and magneto were redesigned to the current precision cast configurations and the crankcase cylinder mount pads were modified (relieved) to permit better mass flow through the engine. The new crankcase incorporated the now familiar NPT plugs on the top and bottom of the nose section of the case, and the design was modified to accept an improved roller bearing, GR-22 (McGill) for the forward and center main bearing. Identified as P/N 10089, this case became the standard for the Mac 72, McCulloch Model 4318A, military designation 0-100-1, which was introduced with the roll-out of the OQ-19B in 1949. The resulting

Three crankcases used in the history of the Mac 4. Left to right, the Model 4300/0-90-3 (note the absence of NPT plugs on the nose of the 0-90 case), the 4318A/0-100-1 center, and Model 4318F/0-100-3 type case. (Photo by the author.)



0-100/OQ-19 combination provided the answer to the basic training target needs of the Army and Navy and several foreign countries for many years.

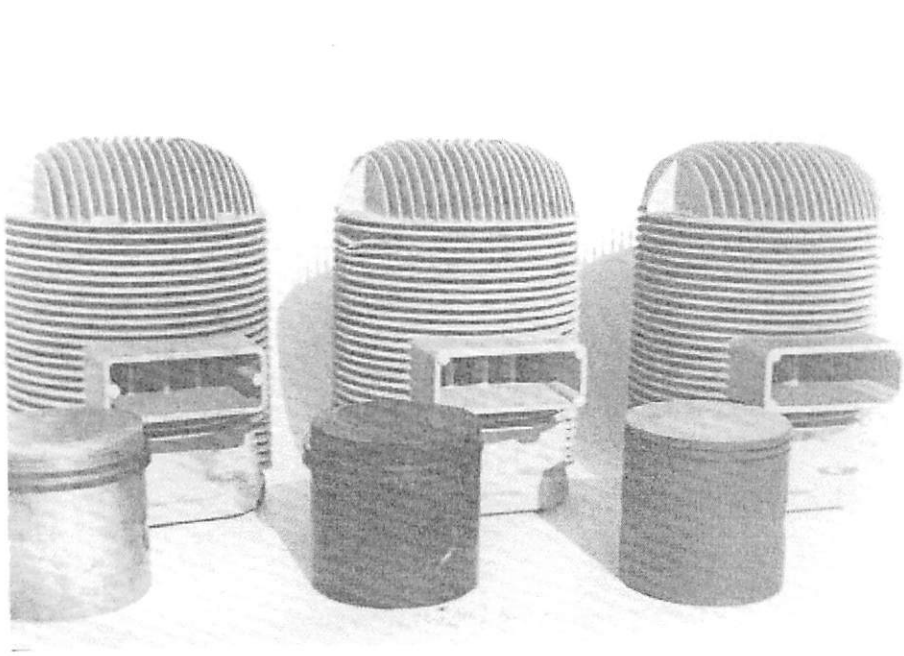
By 1962 it was apparent that the military wanted more horsepower for better aerial target performance, and once again an effort was mounted to draw even more horsepower from the engine. Begun under the sponsorship of an Army product improvement contract, the cylinder was redesigned with larger intake ports and two of the three vertical bars in the exhaust port were removed. The cylinder mount pads were modified to the current configuration. All of these changes were made to increase the aspiration or breathing efficiency of the engine, which increased the horsepower from 72 to 90 HP. Bore and stroke were unchanged, leaving the happy circumstance for civilian users of the engine a utilitarian interchangeability of parts between the 72 and 90 HP versions of the engine. The enlarged exhaust port area necessitated re-design of the piston to pin the ring segments to keep the rings from rotating and expanding into the exhaust port area. The false rings near the dome of the piston employed in the 72 HP version were eliminated and the 1/16 inch 90 HP rings were moved near the top of the piston to better contain combustion heat. Other changes included a new connecting rod, P/N 54169, with uncaged bearings on the large end. This rod is centered on the journal by using thrust washers on the wrist pin line between the interior piston boss and the faced surface of the connecting rod at the small end. The crankcase was changed to incorporate a raised data plate location. Both the free roller bearing and the data plate crankcase, P/N 10489A were introduced late in the 72 HP production run. The 90 HP version of the engine, McCulloch Model 4318F and military designation 0-100-3, continues in production today.



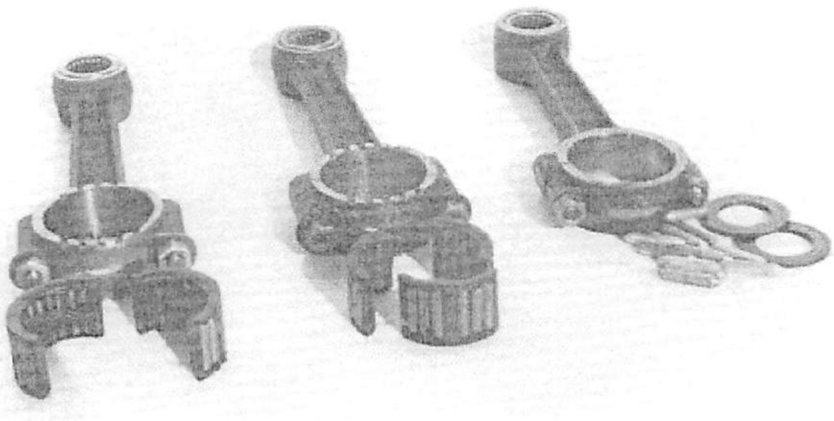
The three Mac cases in profile view. Note the evolution of the changes in the cylinder mount inlet areas which have been progressively relieved in the steps from 60 HP on the left to 72 HP center, and 90 HP right. (Photo by the author)

It should be here noted that there have been several attempts to upgrade the 72 HP cylinder to a 90 HP configuration by eliminating two of the vertical bars in the exhaust port of a 72 cylinder. Beware of this practice; this modification does not a 90 HP cylinder make and the balance of flow is upset by this change. Incidentally, Bill Parsons, in a letter to **PRFlying**, indicated that he measured output horsepower on the dynomometer at 54 HP for the 72 and 62 HP for the 90 version of the engine. For the gyro application, the decision between 72 and 90 versions should be based upon crew weight. The 175 pound pilot should be pleased with the performance of the Mac 72; while the 200 pound pilot should probably employ the 90 HP version. Any 72 HP engine can be upgraded to the 90 HP configuration with a kit using 90 HP cylinders, pistons, and rings.

The relatively available McCulloch drone engines came along at just the right time for the Bensen gyrocopter which had been struggling with a 40 HP Nelsen engine. The marriage between the Mac and the Bensen seemed



Cylinders and pistons in the Mac 4 evolution. Left 60 HP, cylinder P/N 10097; center 72 HP, cylinder P/N 10491; and right 90 HP, cylinder P/N 54668. Note the 90 HP piston with ring grooves (1/16") moved to the top of the piston and false rings eliminated. (Photo by the author)



Connecting rods and bearings for the Mac 4 evolution. Left 60 HP, rod P/N 10060 with 2-piece cages; center 72 HP "A" rod P/N 10061A with 3-piece cages; and right 90 HP "E" rod P/N 54179 with no cages (note the large brass washers, P/N 10699, used to center the cageless rod). (Photo by the author.)

made in heaven; performance of the machine was greatly improved, providing a greater performance margin for safer operation. There is, however, great hazard and potential economic loss in the procurement of an engine suitable for use on the gyro. The purpose of this article is to acquaint the reader with the background and history of the engine and to help current and potential Mac users to correctly identify what they have and what must be done to an engine for correct application to the gyro.

Since the Mac engines have been around for nearly 40 years, one cannot be sure that what resides inside the engine is applicable to the data plate if there is one. Unless the complete history of the engine is known, a complete disassembly and inspection of the engine is required prior to placing the engine in flight service on a gyro or other experimental aircraft application.

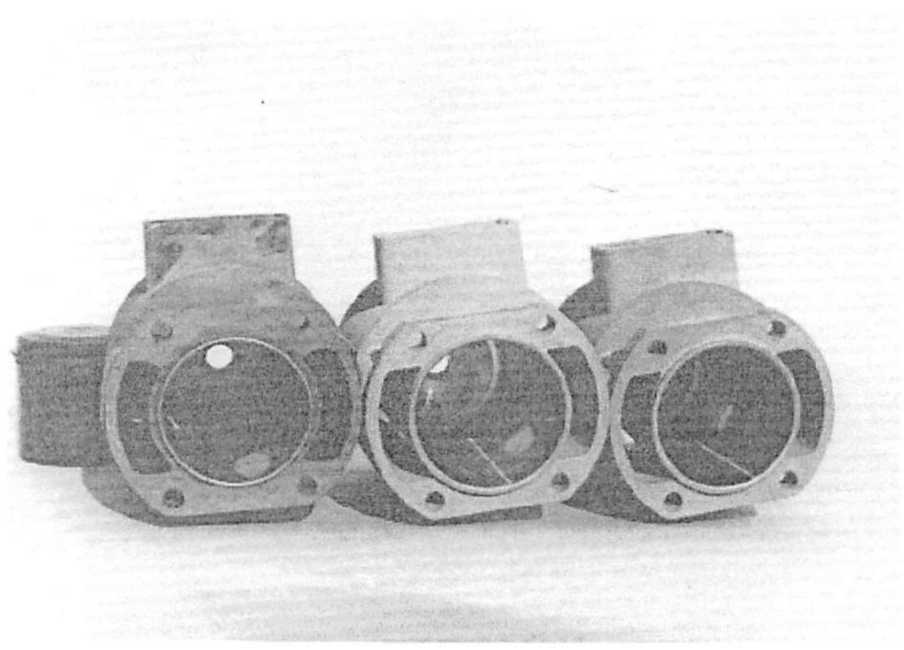
The following should be accomplished before placing a Mac engine in service on a GYRO or other homebuilt aircraft . . .

DISASSEMBLY: The engine should be completely disassembled. The maintenance manual should be followed to avoid damage to the engine during this effort.

INSPECTION: Carefully inspect the aluminum crankcase, P/N 10489(A) and the rear crankcase cover, P/N 10012D, which contain integrally cast engine mount lugs. If unsure, take the parts to an inspection station approved by FAA and ask for NDI (nondestructive inspection) service. Any parts passing this inspection can be reasonably expected to have structural integrity. Inspect the crankshaft for alignment and condition. Pistons should be inspected for cracks, indications of overheat and/or seizure and foreign object damage. The cylinders should have a complete chrome shine with no excessive wear and/or chrome flaking. All bearings should be inspected for condition. Section VI of the Maintenance Manual should be followed for this effort. Condition decisions should be based upon Section XII of the Manual.

IDENTIFICATION: If your engine has a three-inch bore and a cast iron sleeve, it is a 60 HP engine. If the cylinder has a 3 & 1/16 inch bore and the exhaust port has three vertical bars, it is a 72 HP engine. **WARNING:** Inspect the exhaust port with one bar very carefully to see if a 72 port has been modified to look like a 90. One sure way to tell is to compare your intake ports with those of a known 90 HP cylinder. The 90 ports are much larger than those of a 72 and are discernable to the eye. Since the 72 and 90 versions have the same bore and stroke, either 72 or 90 piston can be used in either 72 or 90 cylinder. One catch here, though, the 72 HP piston must be modified for use in the 90 HP cylinder by pinning the compression rings so they cannot rotate and break off at the ring segment joint

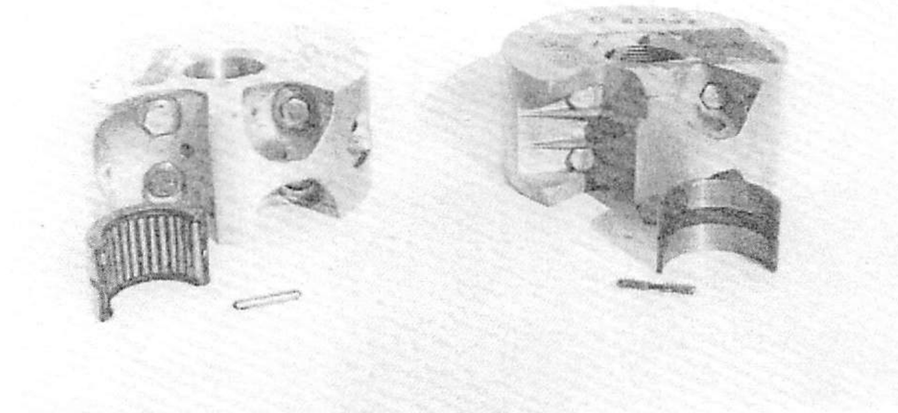
Cylinders in the Mac 4 from the bottom. Left 60 HP with cast iron liner; center 72 HP, and right 90 HP with enlarged intake port. (Photo by the author.)



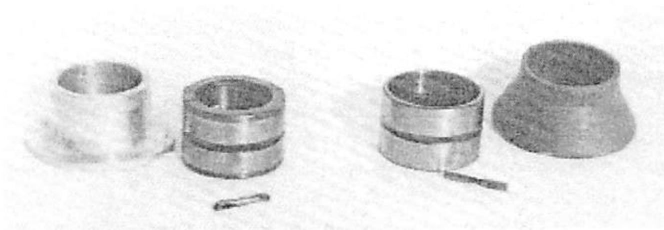
in the exhaust port.

If the connecting rods have lubrication cuts on the large end and incorporate three brass colored cages per rod (120° each), you have an "A" rod (P/N 10061A). The bearings and cages should be discarded and replaced with the aftermarket AX bearings which incorporate two steel cages (180°) and a separate segment for each roller bearing. If the connecting rods have free rollers (without cages) on the large end and are centered with a brass thrust washer between the rod and the piston at the small end, you have the "E" rod for the 4318E configuration once manufactured for the Bensen application. Inspect the free large end rollers for color of the tapered tip: black tipped ends should be discarded and replaced with P/N 54183 which are silver plated and have shiny ends. **WARNING:** Do not use the AX bearings with the "E" rod (P/N 54179), and do not use the thrust washer (P/N 10699) with AX bearings.

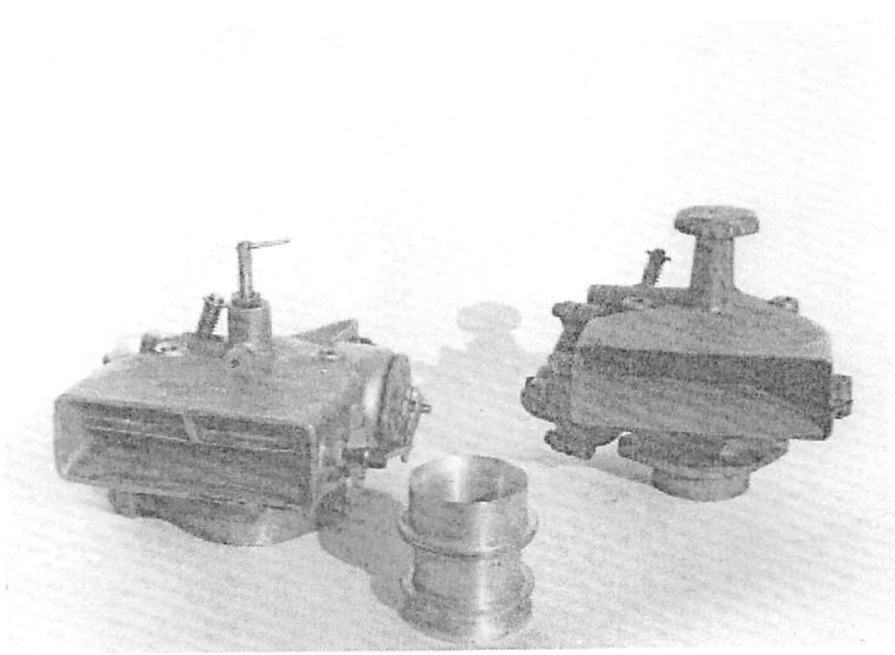
MODIFICATION: Several changes must be made to the disassembled engine to make it applicable to the gyro. The carburetor stud holes used to mount the carburetor to the engine must be enlarged from the original 5/16" size to 3/8" to accept the 3/8" carb mounting studs. A clue to the engine's past may be found if the original 5/16" carb studs have been broken off; this indicates that the engine was probably subjected to a high "G" military recovery and that the engine is probably in the original military configuration. If this is the case for your engine, the above inspection procedures should be strictly followed with diligence. A throttleable carburetor must be modified for application to the gyro and fitted to the engine. The new dual-float Holley is recommended, along with an adapted plate under the carb. This arrangement has been dynomometer tested to produce 10% more horsepower than the old side-bowl Holley with its troublesome float arm. The pistons must be cam ground to promote more even expansion of the piston under heat load, reducing the probability of seizure. AX bearings should be used with the "A" rod (P/N 10061), and "E" rods must use free rollers and the brass thrust washers. Do not mix AX bearings with "E" rods and free rollers with "A" rods. The crankcase or the rear



Center main bearing carriers from the Mac 4 engines. Left 60 HP with Bantam bearing (earliest versions had babbited bronze bearing); right, precision cast unit employed in 72 and 90 HP versions. Early 72 engines had Bantam bearings like the 60, which should be discarded in favor of the McGill bearing shown here on the right and used exclusively in late 72 and all 90 HP versions. (Photo by the author.)



Nose bearing cone. Left 60HP machined with Bantam bearing; right, 72 and 90 HP with cast cone and McGill bearing. (Photo by the author.)

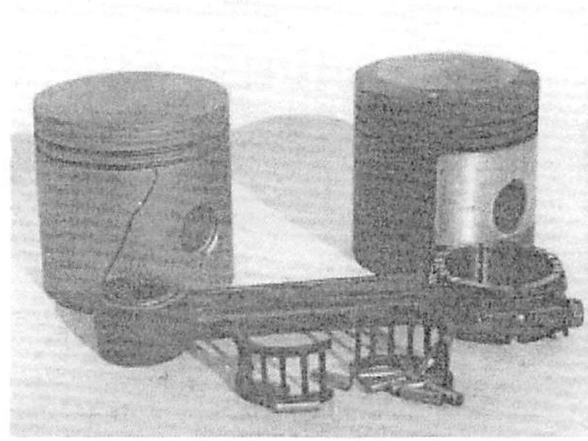


Carburetors for the Mac 4 cyliner. Left the 60 HP carb with a two-position solenoid controlled throttle (one piece casting with a removeable machine venturi); and right, 72 and 90 HP two-piece casting and unthrottleable. (Photo by the author.)

case cover should be drilled and tapped to 1/8'' NPT at an appropriate place for fitting the marine style 2-cycle pulse pump. Lastly, the magneto should be overhauled and fitted with a good quality silicon insulated copper wire for the high voltage leads.

ASSEMBLY: Follow the instructions of the Maintenance Manual in Section IX;, and condition the engine after installation using the airframe manufacturer's engine conditioning instructions. For safe and reliable operation, your engine must be equipped with a CHT (cylinder head temperature gage) and a tachometer. **WARNING:** do not attempt powered flight in your aircraft until sufficient ground operation of your overhauled Mac has established power check, stabilization of cylinder head temperature and reliable ground operation.

One last caution — do not, repeat, do not purchase a used aircraft with engine or a used engine and attempt to fly same without establishing the condition of the engine. Unless you are absolutely certain of the condition of the equipment, do not attempt to fly it. Find out from someone who knows how to help you, if you do not know what to do. The local chapter of the Popular Rotorcraft Association (PRA) can be invaluable to you. Contact any PRA chapter; they will be more than happy to help you with information and sources, or contact the professionals — I don't know anyone in the business who won't take a few moments and help. REMEMBER, *all* single engine aircraft are subject to single engine failure and the inevitable engine-out landing that follows engine failure as sure as day follows night. By knowing your machine, including the guts of the engine, you can reduce the risk of engine failure.



Piston modification is required to even expansion under heat load. Left 72 HP piston with cam grinding outlined in grease pencil (machine used is Van Norman). Right, piston is three-ring with grinding accomplished by milling machine. In the foreground is set of AX bearings — note the 180° cages with one-cage segment for each bearing. (Photo by the author.)

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