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Pontiac's New 2.5 Litre 4 Cylinder Engine

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Pontiac Motor Div.
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Society of Automotive Engineers

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WITH THE ADVENT of the oil embargo in late 1973, General Motors recognized that future American automobiles would be radically different than those previously built. As part of the realignment of General Motors products, Pontiac Motor Division began to examine the potential for producing engines smaller than the 350 In^3 - 400 In^3 - 455 In^3 V-8's then being produced. Engines considered included:

(1) New, smaller V-8's from 250 In^3 to 381 In^3.

(2) A 90° V-6 from one of the existing V-8's.

(3) A 90° V-4 from one of the existing V-8's.

(4) An in-line four (L-4) made from one-half of an existing V-8 in a fashion similar to that of the 1961 Tempest L-4.

(5) A S-4 which had cylinders 1, 4, 6, and 7 from one of the existing V-8's.

(6) A new L-4.

(7) An in-line six version of a new L-4.

After reviewing long-term planning with regard to future energy needs and impending legislation, it was decided that one project would be the new in-line four-cylinder engine, as shown in Figure 1. While it was likely that the least tooling expenditures would have resulted from creating an updated version of the 1961 Tempest L-4, it was felt that this approach would not yield the optimum design in light of the goals for the new engine. These goals, which later became known as the "Formula" used in producing this "Formula Engine", were:

(1) Minimize noise and vibration.
(2) Maximum usable power.
(3) Excellent durability.
(4) Excellent driveability.
(5) Excellent fuel economy.

Note that low mass and low manufacturing cost were not specifically mentioned. Yet, both relatively low mass and low manufacturing cost were achieved. This is partially due to the lack of late fixes being required. Such fixes are often expensive and heavy, but the initial approach taken on quality precluded their need.

As part of the decision to build the new L-4 engine, a review was made of recent General Motors engine designs. This review revealed a 2.5 Litre (151 In^3) L-4 engine was being produced by General Motors do Brasil. This particular engine had started life as a version of the early 1960's Chevrolet II 153 In^3 L-4 which is currently produced by General Motors of Mexico. General Motors do Brasil had reduced the stroke from 3.25" to

ABSTRACT

Pontiac has designed a new 2.5 Litre four-cylinder engine which overcomes many of the current objections to this type of engine. The engine is smooth, quiet, powerful, durable, and fuel efficient. In addition, it has excellent driveability.

The approaches used to achieve this situation included a review of the components which create the vertical secondary shake force in light of the mathematics involved, a unique intake manifold design, and parasitic power consumption control in several engine areas.

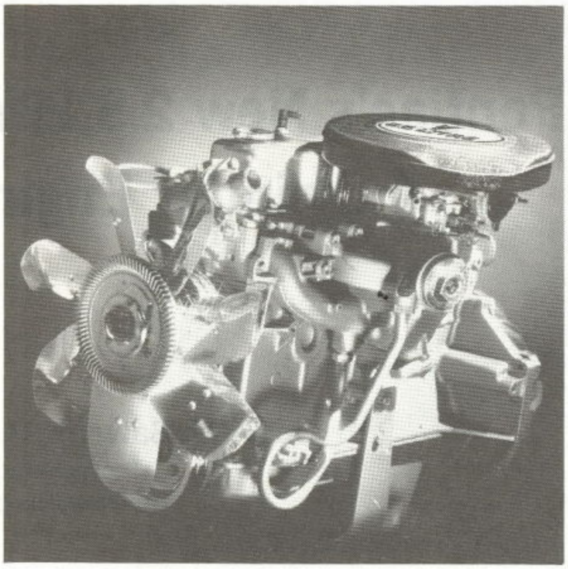


Fig. 1 - 2.5 l engine - left hand side

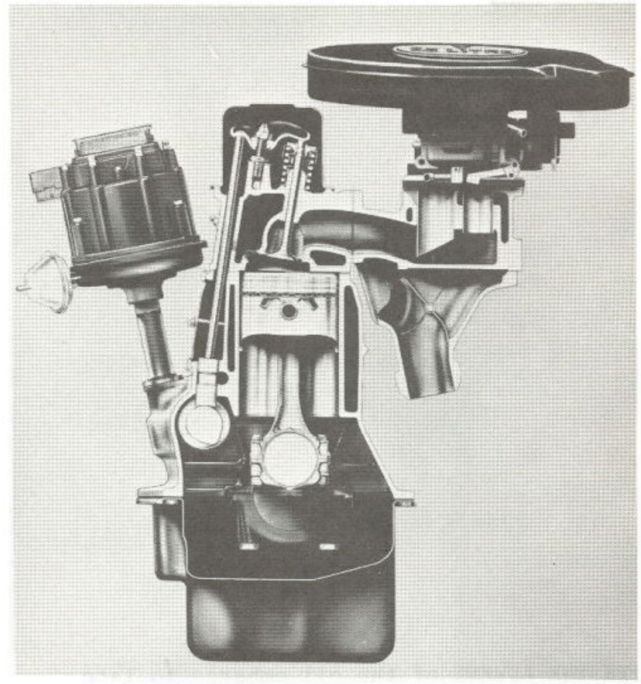


Fig. 2 - 2.5 l engine - cross-section

Fig. 3 - 3000 lb IWC vehicle

3.00" and increased the rod length from 5.70" to 6.00" to reduce the vertical shaking forces inherent in an L-4 without counter-shafts. At the same time, they had increased the bore from 3.88" to 4.00" to maintain the displacement. Pontiac's analysis indicated that this engine had significantly reduced secondary vertical shake versus either the 153 In^3 engine or the aluminum 2.3 Litre (140 In^3) engine then being used in small General Motors vehicles. In addition, since the 2.3 Litre was currently being produced by Chevrolet, the 2.5 Litre, being slightly larger, fit well into Pontiac's marketing plans. It was also felt that lower mass and smaller external size would result from designing a new engine rather than copying the 1961 Tempest engine.

While some features of the General Motors do Brasil engine were retained, such as displacement and bore centers, the majority of the pieces are not interchangeable with the new Pontiac L-4. For example, such basic parts as the intake manifold, the cylinder head, the exhaust manifold, the rocker cover, the oil pan, the connecting rod, and the piston cannot be mixed between the engines. Different bolt patterns and all new tooling are used to build the Pontiac L-4.

GENERAL DESCRIPTION

The new 2.5 Litre L-4 was introduced in the 1977 Sunbird, Phoenix, Astre, and Ventura. The engine is a cast iron, pushrod actuated valve design. The internal construction is shown in the cross-sectional view, Figure 2. For reference with respect to vehicle usage, Figure 3 shows the Sunbird-Astre size (3000 lb. EPA inertia weight class), and Figure 4 shows the Phoenix-Ventura size (3500 lb. EPA inertia weight class).

The engine uses a 4" bore and 3" stroke for a displacement of 2.5 Litres (151 In^3). A cast combustion chamber is used. Compression ratio is 8.25:1. The engine is designed for exclusive operation on 91 RON unleaded fuel. The piston is an all aluminum design without a steel strut. Five main bearings are used with a cylinder bore spacing of 4.400". Intake valves measure 1.72" diameter,

Fig. 4 - 3500 lb IWC vehicle

and exhaust valves are 1.50". A staged two-barrel carburetor is used with a disposable style air cleaner. Total weight of a dressed, Federal system, automatic transmission, car ready engine is 375 lbs.

SHAKE FORCES

An in-line four-cylinder engine without counter-rotating balance shafts experiences a secondary vertical shake force. Mathematical analysis indicates that the length of the stroke, the length of the connecting rod, and the amount of the reciprocating mass are all involved in producing this force. To minimize this force, and, thus, noise and vibration in the 2.5 Litre L-4, the short 3" stroke has been combined with a long (6.05") connecting rod and low reciprocating mass. One of the mass control features is the use of an all aluminum piston without a steel strut. Similar pistons are used in Pontiac V-8 engines. The use of twin rotating countershafts would also have minimized vibration. However, these shafts would have caused mass and cost increases, consumed power, possibly been noisy, and made manufacturing and service more difficult.

The piston and rod assembly is shown in Figure 5.

Fig. 5 - Piston and rod assembly

POWER AND CALIBRATION DEVELOPMENT

One of the chief goals of the new engine was to maximize usable power. Usable power was defined as power that would be available at lower engine speeds. This power assists in standing start accelerations, entering freeways, and when passing. This concept of small engine power differs greatly from that of most small engine manufacturers. Most small engines are tuned for high horsepower output at high rpm. It was felt that the Pontiac philosophy would result in a more pleasing vehicle, particularly in view of the 55 mph (88 kph) speed limit. Benefits would include the ability to use low numerical axle

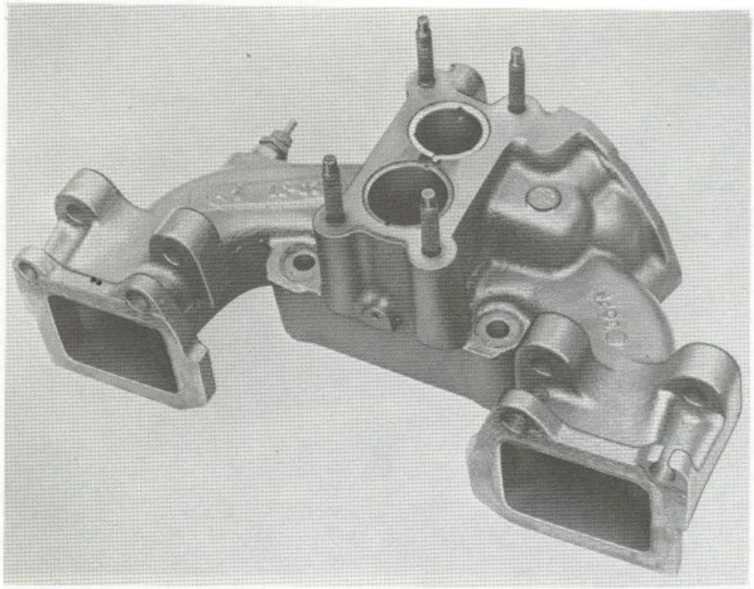


Fig. 6 - Intake manifold assembly

ratios which would result in lower engine speeds and less powertrain noise being generated.

In order to achieve this goal, careful attention to engine calibration must be paid. There cannot be one cylinder which compromises the engine calibration by having higher levels of emissions or spark knock versus the other cylinders. It was felt that the intake manifold was the key to successfully calibrating the engine. This manifold is shown in Figure 6.

The first concern was to determine the proper area and runner type for the engine. Too small a cross-sectional area inhibits power. Too large an area deteriorates response. Calculations were made to determine the theoretically optimum starting point. Steel manifolds, with their interior surfaces sandblasted to simulate castings, were constructed at the theoretical optimum area, as well as larger and smaller areas. Siamesed and split runner designs were both tried. Testing revealed that the originally calculated runner area and the siamesed runner maximized usable power output.

Equalization of the cylinder-to-cylinder air-fuel ratio was next approached. If any one cylinder was either too lean or too rich, the engine calibration would again be compromised. Development work led to several unique features being incorporated in the intake manifold at this point. The first feature is a set of stainless steel "riser tubes" which are pressed into the intake manifold (these tubes are visible in Figures 2 and 7). These tubes aid the vaporization of fuel and improve mixing. They do this by forcing the

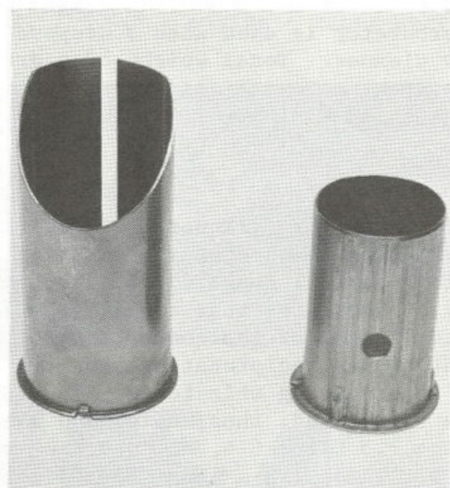


Fig. 7 - Riser tubes

liquid fuel into the air stream, preventing it from running down the metal walls. The tube lengths and shapes had to be developed for this application. The primary tube, which is more centrally located in the runners than is the secondary, was able to be a simple cylinder. The offset secondary bore required a tube with a slanted end for proper air-fuel ratio control.

Exhaust gas recirculation (EGR) is used in current engines to control oxide of nitrogen emissions. Once again, equal cylinder-to-cylinder distribution of EGR is necessary to optimize calibrations. On the 2.5 Litre L-4, exhaust gas is drawn from the front runner of the exhaust manifold, passed through

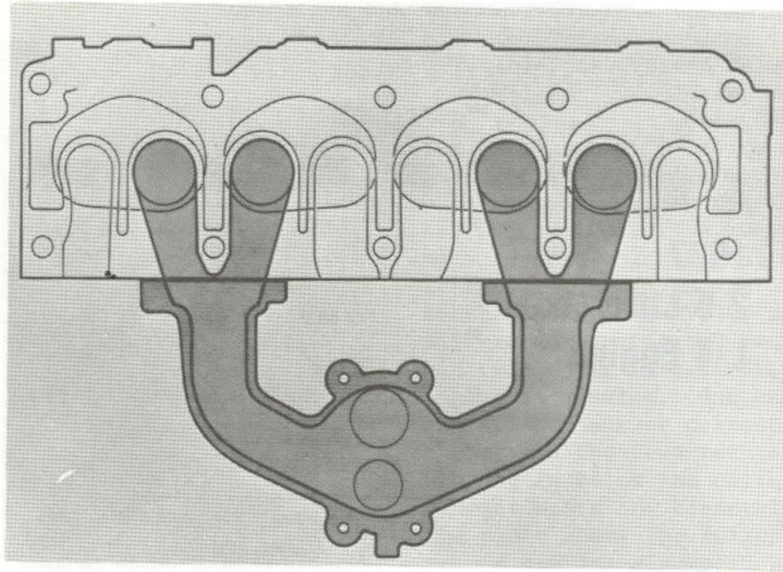


Fig. 8 - Intake manifold offset

a tube, and supplied to the intake manifold. The amount of flow into the engine is regulated by a ported EGR valve on Federal applications and a backpressure EGR valve on California applications. In ported EGR, the amount of exhaust admitted is modulated by a ported carburetor vacuum supply which is controlled by throttle position. In backpressure EGR, the vacuum supply, and, thus, the amount of exhaust admitted, is modulated by exhaust backpressure. It is felt that the more expensive backpressure valve more nearly matches the EGR supply to the engine NO_x output and, therefore, it helps to meet the lower California emission limits while maintaining driveability. After the exhaust gas is metered at the EGR valve, it flows into a cast passage around the primary riser tube. Development of the hole size and location was required to equalize the cylinder-to-cylinder EGR distribution. The exhaust gas flows directly toward the forward hole, while it must take a more difficult path to the rear hole. As a result, the front hole is smaller in size than the rear hole.

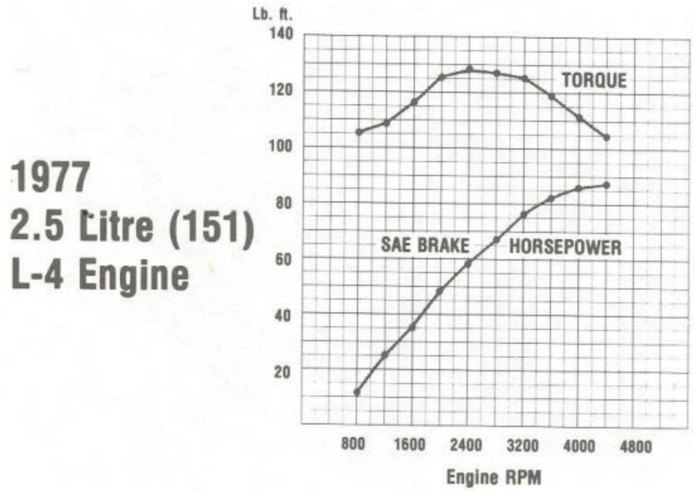
With the area, air-fuel ratio, and EGR distribution equalized between each cylinder, attention was directed to the relative output of each cylinder. Contrary to popular opinion, each cylinder in a multi-cylinder engine does not do equal work. It is very likely that the hardest working cylinder compromises the engine calibration. Study revealed that the end cylinders (1 and 4) produced more power than the center cylinders (2 and 3). The apparent explanation for this condition is the strong manifold flow reversals present in this type of engine. With the 1, 3, 4, 2 firing order, the center cylinders had to do the work of turning the mixture toward their runner from the opposite runner. The end cylinders had the advantage of the mixture already being headed in their direction and, consequently, were filled better. To offset this effect, the intake runners were offset with respect to the ports as shown in Figure 8. With this feature, the flow path favored the center cylinders. As a result, the power output of each cylinder was equalized. The overall engine power was not affected.

Reduction of parasitic engine drag was also given attention. This feature contributes to power, durability, and fuel economy. To aid in this regard, smooth cylinder bores (7 to 15 micro) and rod journals (10 micro maximum) are used. Water pump impeller development resulted in the pump being designed for minimum power consumption with flow capacity matched to the engine's requirement. Oil pump flow and pressure were likewise suited to the engine's needs, with the result that a smaller oil pump (1.000" gears) than originally intended (1.200" gears) was able to be used. Piston ring tension, an important contributor to engine friction, was reduced as far as possible without compromising the oil economy.

The final engine output is shown in the power and torque curve, Graph 1. Note that the low end torque rises quickly and stays "flat" from 2000 to 3200 rpm. This is the normal driving range for this engine.

The comparison of the 1977 2.5 Litre pushrod design with the 1976 2.3 Litre overhead cam design is shown in Table 1.

Graph 1 - Net BHP and net torque



DURABILITY FEATURES

Durability of the new engine was of prime concern. To prove the endurance of the engine, approximately 300 experimental test engines were run. Tests included dynamometer tests for 100 hours at 4500 rpm at full throttle, 200 hour dynamometer cycling tests, manifold durability cycling tests, and road tests. The 200 hour test is a standard General Motors durability test and consists of cycling at wide open throttle from the torque peak to the HP peak. This test approximates 150,000 miles of very hard driving. Engines which complete the 200 hours are normally considered to have fulfilled their function. One of the new four-cylinder engines went over 850 hours on this same test. In addition, the four-cylinder engines used for these tests were able to be reassembled for reuse due to their low wear. The manifold durability cycling test was used to provide the equivalent of approximately 10,000 road test miles in two days. This test was aimed at insuring intake and exhaust manifold integrity.

The engine combines cast iron block, head, and manifolds in a very durable package. The total 2.5 Litre engine assembly weighs only about 20 pounds more than the aluminum block 2.3 Litre.

The cylinder block, as previously mentioned, is a five main bearing design. It is shown in Figure 9.

The cylinder head is also a cast iron. It features paired intake ports separated by a central divider for each pair, cast combustion chambers, a paired center exhaust port, and individual end exhaust ports. The exhaust valve seats are induction hardened, and the valve stems are chrome-plated. Screw-in rocker arm studs are used. These studs offer

Table 1 - Power Comparison 1977 2.5 litre 2 barrel versus 1976 2.3 litre 2 barrel

Engine	HP	Torque
1977 2.5 Litre	87 @ 4400	128 @ 2400
1976 2.3 Litre	84 @ 4400	113 @ 3200

(Note - Emissions limits lowered from 1976 to 1977).

improved durability performance over pressed-in studs. In addition, they retain steel pushrod guide plates. These plates guide the pushrod without the manufacturing expense and difficulty associated with broaching guidance slots in the head. Other advantages versus the more conventional pressed-in studs are less critical assembly, the need for less service, and easier servicing. The head assembly is shown in Figure 10.

Bearings and rings also received durability performance attention. Both main and rod bearings are of M-400 material, the General Motors premium bearing material. The top compression ring is barrel-faced and moly-filled. The second ring is taper-faced and tin-plated. The oil ring expander is stainless steel, and the oil ring rails are chrome-plated.

Durability of the exhaust manifold has historically been a problem on in-line engines. This situation has been addressed on the 2.5 Litre L-4 with special metallurgy, special fasteners, gasketing, and an innovative clamping arrangement. The annealed exhaust manifold assembly is attached to the intake manifold with four bolts and a metal-asbestos gasket. The intake manifold is then held to the cylinder head and manifold gasket with

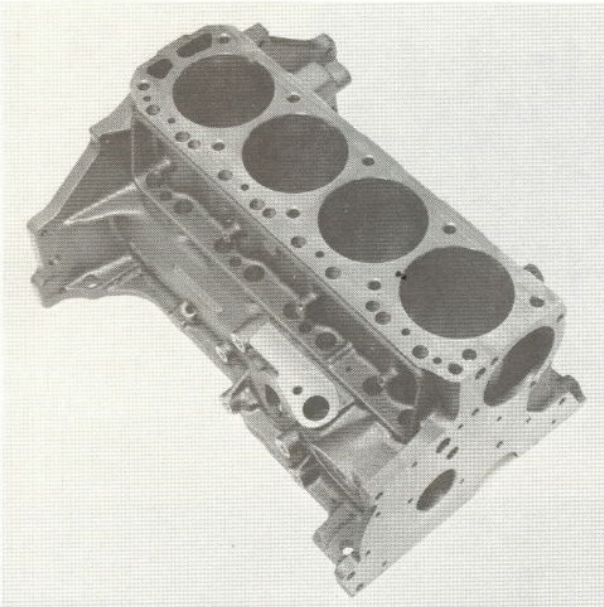


Fig. 9 - Cylinder block assembly

bolts. In four places, clamps are used which bear on both the intake and exhaust manifold. These clamps have bolts through their center. The majority of the bolts used in this assembly have special conical head recesses. These recesses allow several thousandths additional stretch at a given torque level versus a standard bolt. This helps maintain gasket loading if any relaxation takes place. The net result of this system is that the exhaust manifold is free to move, restrained only by limit pins at its ends. This movement prevents the cracking, warping, and leaking often experienced with a rigidly attached manifold.

DRIVEABILITY

A primary requirement for the 2.5 Litre L-4 was the ability to have excellent driveability whether hot, cold, or in between. This area is one of the strongest consumer concerns and required concentrated development.

The carburetor on the 2.5 Litre is a staged two-barrel design as shown in Figure 11. Included is a primary bore and progressively opening secondary bore. Similar carburetors have been used on other small American engines. However, several modifications were made to improve both hot and cold driveability. These features will be addressed as the different operating conditions are discussed.

To enhance cold driveability, the following features are included in the engine:

(1) Staged electric choke.
(2) Internal vacuum break delay.
(3) External vacuum break delay.
(4) Thermal control valves.
(5) Spark retard delay valve (SRD).
(6) Early fuel evaporation (EFE).

The staged electric choke senses engine temperature and provides more or less choke, depending upon whether the engine is cold or hot, respectively. A two-element heater is used to heat the bi-metal choke coil causing it to relax and open the choke valve. Current to the choke assembly is supplied through an oil pressure activated switch so that the electric choke is activated only when the engine is running. One heating element is in operation whenever current is supplied to the choke, and the temperature inside the choke housing is below the calibration value. This element heats the bi-metal coil and also heats the plate above the switch pocket for the second heating element. When the switch pocket reaches the calibration value or above, a bi-metal switch then supplies current to the second heater connecting it in parallel with the first heater. This switching function causes the choke to come off at a faster rate with two heaters engaged than with one heater engaged. The vacuum break delays retard the pull-off of the choke to enhance the cold start and initial cold driveaway. One thermal control valve switches the EGR off and early fuel evaporation (EFE) on when coolant temperature is below a specified value, again to improve cold driveability. The early fuel evaporation valve is a "door" in the exhaust manifold, shown in Figure 12, which either supplies heat to the intake manifold floor or shuts it off. The other thermal control valve switches the distributor vacuum from its normal warm engine supply to full manifold vacuum through the spark retard delay valve. The SRD valve "traps" vacuum in the distributor advance can when manifold vacuum decreases with a cold engine. A slow bleed down to actual manifold vacuum is incorporated.

Hot driveability required major development work. Initial test results indicated that the fuel was being overheated in the carburetor during hot soaks. One source of the heat was the EGR passage from the exhaust to intake manifold. This passage was originally cast integrally in the manifolds. Initial development work resulted in the cast passage between the manifolds being replaced by a short tube. This reduced manifold thermal mass and provided a cooling effect. Later development resulted in the short tube being used on the Phoenix and Ventura where there is substantial engine compartment space around the engine. The Sunbird and Astre, which have more crowded engine compartments, required a longer tube for the same cooling effect. This long tube is visible in Figure 1. A thicker carburetor insulator was used to increase

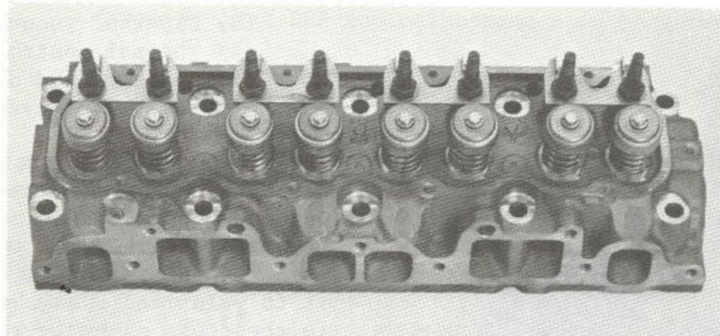


Fig. 10 - Cylinder head assembly

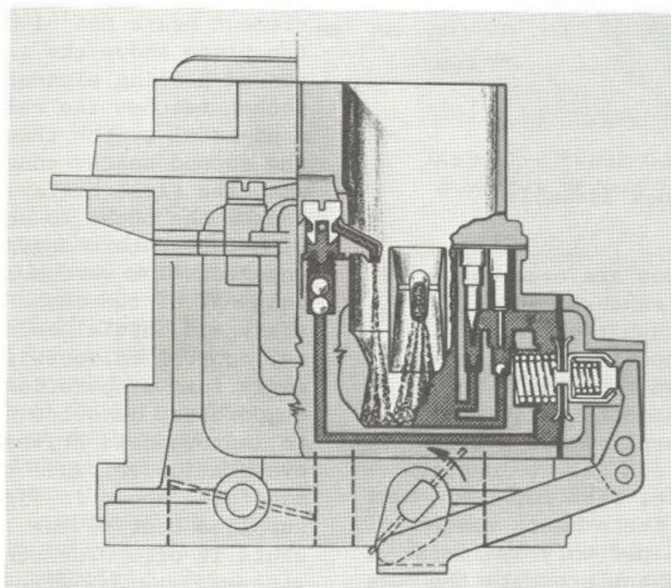


Fig. 11 - Staged carburetor

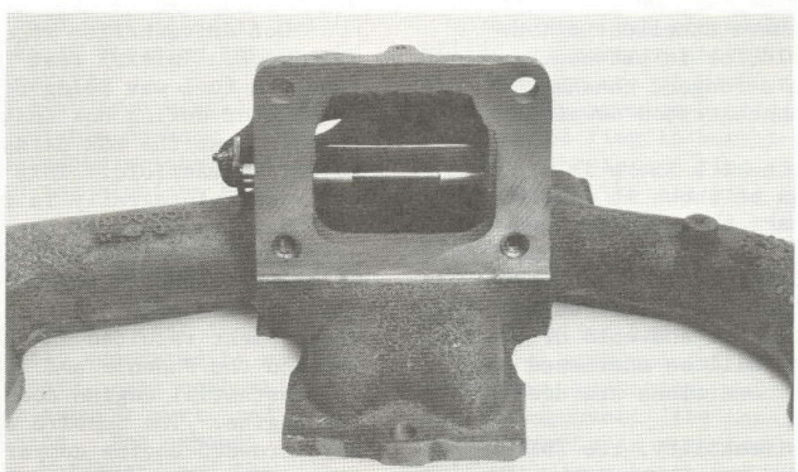


Fig. 12 - Early fuel evaporation system

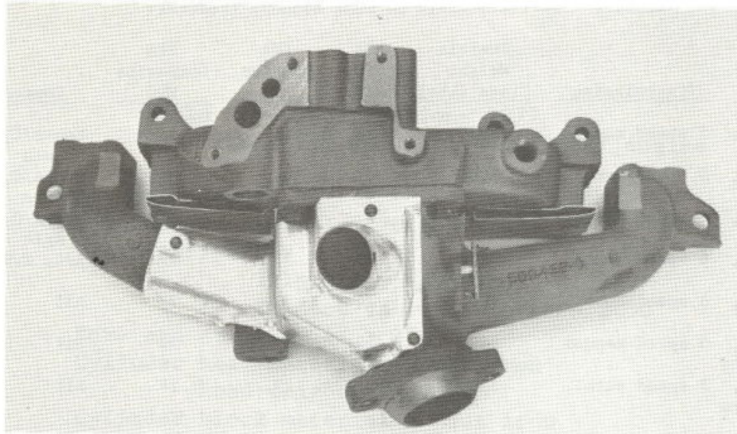


Fig. 13 - Manifold heat shield

the temperature drop across this part, thereby reducing heat conducted to the carburetor.

Two heat shields were incorporated into the engine. One single layer steel shield is positioned directly under the carburetor to deflect radiated and convected heat during hot soaks. The second shield is a double layer of steel positioned between the intake and exhaust manifolds as shown in Figure 13. This prevents radiated and convected heat from the exhaust manifold from being transferred to the intake manifold and ultimately to the carburetor.

Internal carburetor revisions to prevent the fuel from being overheated were also made. These involved channel, orifice, and pullover revisions.

An electric-vacuum bowl vent was installed. This device insures that fuel vapors are routed to the evaporative emissions canister during soaks. It also insures positive shutoff of the vent when the ignition is on, so that the carburetor calibration is not affected. This latter feature is especially noticeable during altitude operation.

A review of commercially available small cars indicated that many of them experienced impaired hot driveability when equipped with air conditioning (A/C). As a result, several specific features are included on A/C-equipped cars. These include:

(1) Wide open throttle cut-off switch.
(2) A/C speed-up solenoid.
(3) A/C "clutch grabber".
(4) A/C start delay.

The wide open throttle cut-off switch shuts off the A/C compressor during heavy throttle operation. This provides additional power for such things as passing or entering a freeway. Engines without A/C are equipped with a normal idle stop solenoid. When de-energized, this controls the anti-diesel idle. When energized, it controls the curb idle. On A/C-equipped cars the same solenoid is used, but it is set so that when de-energized it controls curb idle. When energized by turning the A/C on, it controls the idle with the A/C load. Due to the use of a cycling clutch A/C system for improved fuel economy, this speed does vary to some degree. Note that the solenoid used is not powerful enough to open the throttle by itself. To control the anti-diesel function on A/C-equipped cars, a "clutch grabber" was added. This feature engages the A/C compressor clutch when the engine is switched off. This increased load prevents the engine from running-on. To assist the hot startability on A/C-equipped cars, a twelve second delay is incorporated in the compressor circuit. The compressor is kept off during cranking and for twelve seconds after the engine starts. This allows the engine to stabilize before attempting to carry the A/C load.

MISCELLANEOUS FEATURES

A high energy ignition capable of 35KV output is used on the 2.5 Litre L-4. This device features a breakerless distributor with an integrally mounted coil. The distributor centrifugal advance mechanism includes the following features to prevent the wear often seen on unbalanced engines:

(1) M3630 high density nylon weight bushings.
(2) Chrome-plated cam (.0005" min.).
(3) .015"-.025" weight case depth (R_c 55 min.).
(4) Chrome-plated weights (.0005" min.).

To insure accuracy of the important initial timing setting, the actual top dead center point of #1 cylinder of each engine is sensed in production. A probe analyzes each short block assembly to determine this position. The timing pointer is then welded on in its correct location for each particular engine with manufacturing tolerances minimized.

Table 2 - 1977 2.5 Litre L4 fuel economy (Federal)

Car	Transmission	Inertia Weight Class (Lbs)	EPA City MPG	EPA Highway MPG	EPA Composite MPG	Comments
Sunbird, Astre	5 speed manual	3000	28	41	33	Non-A/C, 2.73 Axle
Sunbird, Astre	5 speed manual	3000	27	40	31	Non-A/C, 2.93 Axle
Sunbird, Astre	4 speed manual	3000	27	38	31	Non-A/C, 2.73 Axle
Sunbird, Astre	4 speed manual	3000	25	37	29	A/C, 2.93 Axle
Sunbird, Astre	3 speed auto.	3000	24	32	27	All
Phoenix, Ventura	5 speed manual	3500	22	34	26	All
Phoenix, Ventura	3 speed auto.	3500	21	29	24	All

The resistor style AC spark plugs used have .060" gap.

The strong flow reversals in four-cylinder engine manifolds have already been discussed. The California version of the engine uses the exhaust manifold flow to inject air at the exhaust ports ahead of the standard catalytic converter. It does this through the use of a Pulsair assembly. This assembly consists of four tubes and check valves (one per cylinder), with the check valves mounted in a common body. The valves sense periods of negative pressure in the exhaust port and allow air to flow in from the clean air supply at the air cleaner. Backflow to the air cleaner is prevented by the valves also.

The Controlled Combustion System (CCS) is used on both the Federal and California versions of the engine. This system controls the emissions output of the engine through the engine calibrations and internal features.

To extend the quality approach to even the appearance of the engine, several styling features were included. These were:

(1) Chrome rocker cover.

(2) Chrome oil filler cap.

(3) Stylized air cleaner cover with identifying multi-color decal.

While the reduction in shake forces in the basic 2.5 Litre L-4 are significant versus the 2.3 Litre L-4, credit must also be given to two additional vehicle areas. Chassis development work on mounts and dampers and body development work with acoustical materials have both contributed to the quiet, smooth sensation with the 2.5 Litre L-4.

FUEL ECONOMY

Fuel economy with the 2.5 Litre L-4 was a prime objective. The preceding details on calibration, power output, and friction reduction give the explanations of where effort was expended to meet this goal. The results are shown in Table 2. These figures indicate fuel economies which are as good or better than cars with considerably smaller engines and/or less mass.

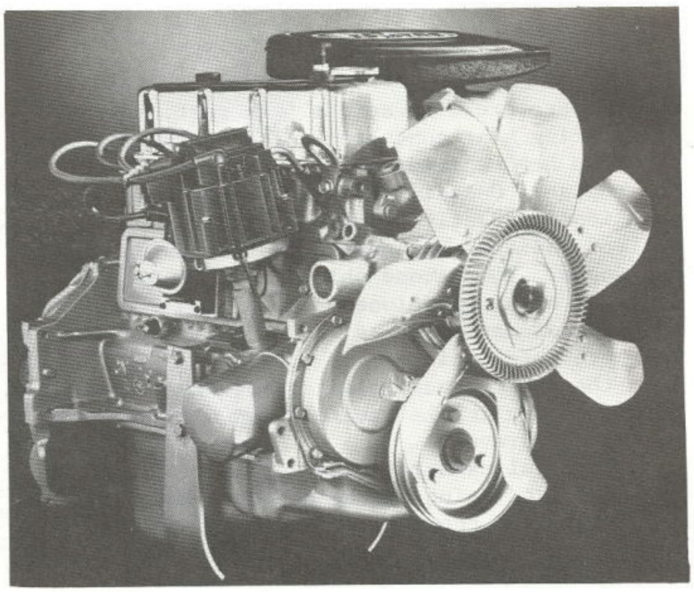


Fig. 14 - 2.5 l engine - right hand side

CONCLUSION

All of the original goals for the new 2.5 Litre Formula L-4 engine shown in Figure 14 have been achieved by the Pontiac team. The engine is smooth and quiet, has a feeling of power, is durable, has excellent driveability, and fuel economy.

These features make this powerplant extremely desirable in light of current and future energy needs. It is felt that this engine will continue as one of General Motors' future primary engines.

Specifications are listed in Table 3.

Table 3 - Specifications 1977
2.5 litre (151 cu. in.) 4 cylinder engine

No. cylinders - 4
Compression ratio - 8.25:1
Valve arr. - OHV
Inlet valve diameter - 1.72"
Exhaust valve diameter - 1.50"
Bore and stroke - 4" x 3"
Cylinder head material - Cast iron
head weight - 38.25#
Cylinder block material - Cast iron
block weight - 96.5#
Piston material - Aluminum, tin-plated
Piston description - Cam ground slippper type
Piston weight - 585 g
Piston ring material- Top cast iron moly filled
2nd cast iron tin plated
Oil ring-stainless steel expander, chrome plated steel rails
Piston pin material - Forged steel
Conn. rod material - Armasteel (pearlitic malleable iron)
Crankshaft material - Nodular iron
Crankshaft weight - 36.8#
Main bearing journal diameter - 2.30"
Rod bearing journal diameter - 2.00"
Camshaft material - Hardened alloy cast iron
Camshaft weight - 7.8#
Camshaft timing (based on top of ramp points)
- Inlet opens BTC - 33°
Inlet closes ABC - 81°
Inlet duration - 294°
Exhaust opens BBC - 76°
Exhaust closes ATC - 38°
Exhaust duration - 294°
Overlap - 71°
Lift - .406"
Rocker arm ratio - 1.75
Tappets - Hydraulic
Intake manifold material - Cast iron
Exhaust manifold material - Annealed cast iron
Carburetor make - Holley staged 2 bbl.
Carburetor barrel size - Primary 1.033"
Secondary 1.417"
Cooling system type - Closed with recovery bottle
Exhaust emission control type
- Federal-CCS;Calif. - CCS + Pulsair
All EGR, underfloor catalytic converter
SAE net BHP - 87 @ 4400 RPM
SAE net torque (lb.-ft.) - 128 @ 2400 RPM