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# **The Turbo/Intercooled Syclone Engine**

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## ABSTRACT:

The turbo/intercooled Syclone engine is the latest variant off the famed GM 90° small block engine platform. Application is specifically to the Syclone short wheelbase all wheel drive pickup truck to be marketed by GMC in 1991. The engine project was a joint venture between General Motors Powertrain Division and PAS TRIAD of Troy, Michigan. Engine manufacture will originate at the GMPD Romulus 4.3L plant with final assembly at the Shreveport vehicle assembly facilities of GMC Truck and Bus and PAS TRIAD.

Features of the engine include:

- High specific performance (1430 KPa BMEP).
- Air to water intercooling with an independent cooling loop.
- Electronically controlled wastegate for boost and knock control.
- High dynamic range multi-port fuel injection.
- Communization with standard 4.3L engine where possible to facilitate manufacturing process and quality management.
- Use of upgraded materials for highly stressed critical components including pistons, cylinder head gaskets, main bearing caps, and exhaust manifolds.

Time for concept to market was held to 18 months via an intensive concept evaluation, design/development program. The early engine feasibility work featured a "probe" durability test where the engine was run successfully at 600 N-m torque, approximately twice the BMEP of the standard 4.3L. Engine validation was done to a jointly developed test plan that was specifically tailored for the vehicle usage expected.

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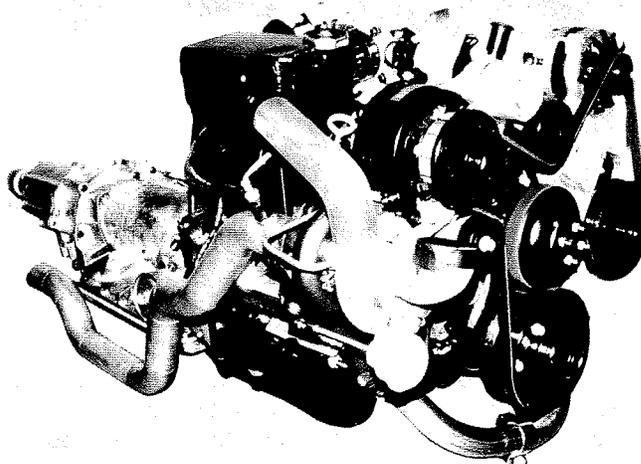
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## INTRODUCTION

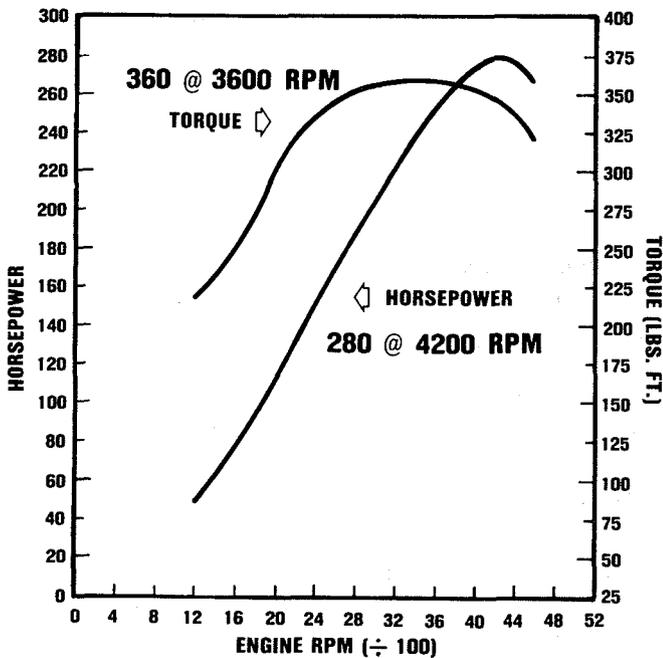
**ENGINE DESCRIPTION** - The Syclone engine bottom end is a modified 4.3L (Vortec) 90° V cylinder case that has the same basic dimensions as the 5.7L GM small block V8. Bore is 101.6mm (4.001") and stroke 88.39mm (3.48") with bank offset 22mm (.88"), left bank forward. Compression ratio is reduced from 9.1:1 for the naturally aspirated version to 8.35:1 for the Syclone via a new piston. Cylinder heads are carryover from the standard 4.3L engine. The major feature of the engine is a totally new induction and fuel system from the intake manifold up.

**FIGURE 1. ENGINE ASSEMBLY**

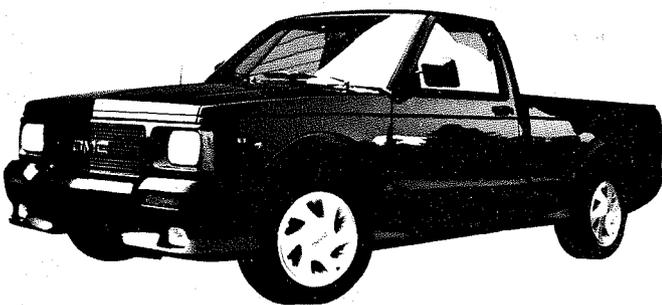


**PERFORMANCE** - The engine control system manages the engine performance level to 209Kw (280 Hp) at 4200 RPM and 488 N-m (360 lb-ft) at 3600 RPM. The torque response is relatively flat as shown by the performance curve. Boost is limited to 97 KPa (14 psi) via an electronically actuated wastegate. The performance system, including a Hydramatic 4L60 (THM 700-R4) 4 speed automatic transmission and full time all wheel drive in the Syclone pickup truck, is capable of five second 0-60 MPH and 13.4 second quarter mile times. The vehicle drivetrain and chassis were designed for stability and comfortable driveability feel, as well as outstanding performance.

**FIGURE 2. ENGINE PERFORMANCE**



**FIGURE 3. SYCLONE VEHICLE**

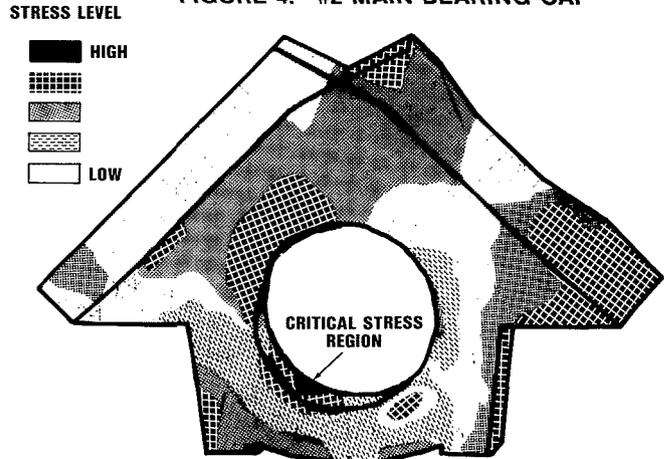


**BASE ENGINE**

**CYLINDER BLOCK** - The 4.3L cylinder block is GM232-M grey iron with heavy duty bulkheads and oil pan rail for added rigidity. Early development work with a "probe" test engine overboosted to 600 N-m (450 lb-ft) of torque, found the cylinder case structure to be adequate. However, teardown inspection found a crack in the number two main bearing cap with the orientation in line with the peak main bearing loads. Analysis found this area of the main bearing cap to be highly stressed as shown in the figure. The problem was solved by

changing the main bearing cap material from grey iron to nodular iron which increased ultimate strength to 550 KPa (80KSI) from 240 KPa (35KSI). Final line boring and finishing of the main bearing bores is done at the Romulus 4.3L Engine Plant with the same processing as the grey iron parts.

**FIGURE 4. #2 MAIN BEARING CAP**



**CRANKSHAFT** - The nodular iron crankshaft has a 30° crankpin splay for even fire and 57.2mm (2.25") diameter crankpins. The fillets are deep rolled to maximize fatigue strength. Optimization of the crankshaft design for strength and bearing performance is described in the reference (1) SAE paper on the original 4.3L engine.

The increased cylinder firing pressures at WOT with the turbocharger increase the crankpin fillet alternating stresses on a Goodman diagram as compared to the naturally aspirated engine. Minimum safety factor was reduced 33%, but is still considered acceptable for the vehicle duty cycle. Analysis was supported by the development/validation vehicle and dynamometer test program with no crankshaft failures attributable to fatigue.

**BALANCE** - The firing event and balance strategy for the Syclone was maintained similar to the naturally aspirated 4.3L, as described in reference (1). The engine employs even firing and has inherently unbalanced primary and secondary couples caused by harmonics of the reciprocating forces. Crankshaft counterweights cancel the crankshaft and connecting rod rotating imbalance plus 80% of the clockwise component of the primary couple. The primary counter-clockwise component is unaffected. This procedure results in the diagram of the resultant combined primary couple being biased in the horizontal plane by a ratio of 7:1 to the vertical. Sensitivity of most vehicles and engine mounting systems to vertical inputs was the reason for the primary balance strategy.

**CONNECTING ROD** - The connecting rod remains carryover from the naturally aspirated engine and is a robust I beam pressed forged design using SAE 1141

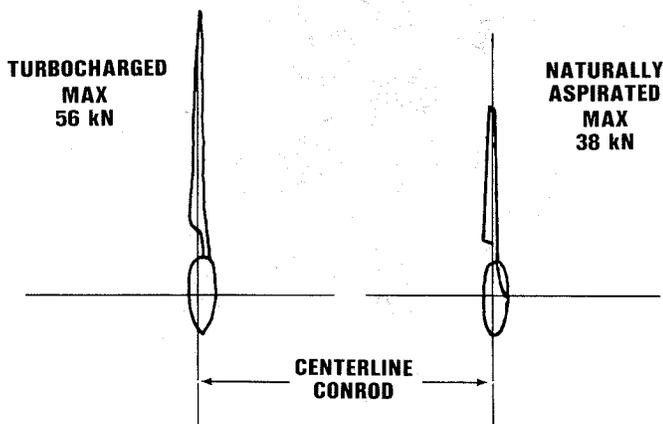
steel for the rod and cap. Extreme cyclic loading on the rod at high RPM is avoided by limiting engine speed to 4800 RPM via fuel shutoff. The maximum connecting rod compressive loading is increased with the turbocharged engine but remains within acceptable limits. Again the testing program was completed without a connecting rod failure.

**PISTON AND RINGS** - The piston is a hyper-eutectic aluminum alloy strutless design with a T6 heat treat. Manufacturer is Zollner Corporation. Skirt contour was specifically designed to handle the high thrust forces from the turbocharged firing pressures. A low tension ring package is the same as used in the 4.3L naturally aspirated truck engine. This includes a barrel faced moly filled cast iron upper compression, tapered face cast iron lower compression, and three piece oil control package with chrome plated scraper elements separated by a stainless steel expander.

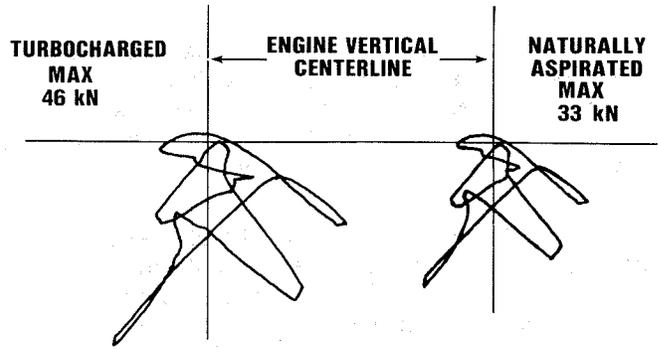
The piston pin is also carryover from the naturally aspirated 4.3L and is a semi-floating design with fixation in the connecting rod by interference fit. A full floating design was not required with the limited RPM range of the engine. Material is low carbon steel with a nitrided or carburized/heat treated surface. A slight amount of horizontal ovality is provided in the piston pin bore to accommodate piston pin distortion under load.

**MAIN AND CONNECTING ROD BEARINGS** - The main and connecting rod bearings are conventional CONNEC shaped inserts with base material aluminum over steel and a thin babbit overplate. The upper mains are the only grooved bearings. All journals, including the main thrust faces, are ground and lapped for improved roundness and surface finish. This, plus the CONNEC bearing shape, serves to increase load carrying capacity over conventional eccentric designs by as much as 30%. Peak loading for the turbocharged engine bearings is increased significantly at WOT as shown in the load diagrams. Due to original design robustness in the bearing system, minimum oil film thickness and maximum oil film pressures remained within established guidelines.

**FIGURE 5. CRANKPIN BEARING LOADS**

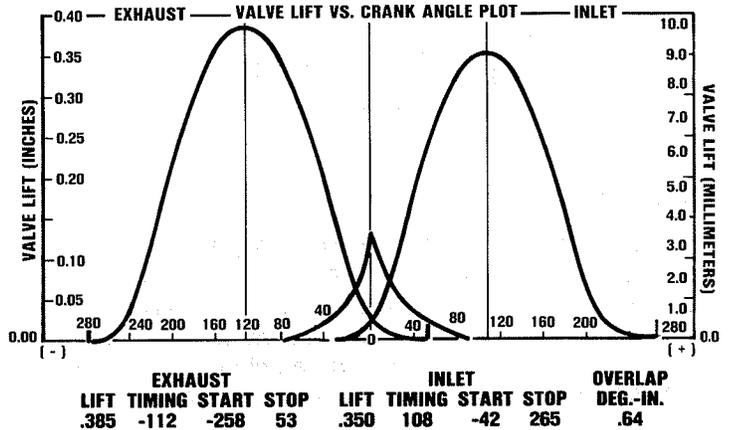


**FIGURE 6. #2 MAIN BEARING LOADS**



**CAMSHAFT/VALVE TRAIN** - The camshaft profile and timing are carryover from the naturally aspirated 4.3L with short events and low overlap desirable for idle stability, strong low end torque, and maximum fuel economy. Valve train limiting speed and contact stress safety margins remained satisfactory with the complicating factors of turbocharger boost and higher cylinder firing pressures. Valve event timing and overlap diagrams are shown in the figure.

**FIGURE 7. VALVE LIFT VS. CRANK ANGLE PLOT**



Roller followers were incorporated into the valve train in 1987 to reduce engine friction and improve cam to follower Hertzian stresses. Camshaft material is heat treated SAE5150 steel. Roller followers are heat treated AISI 52100 bearing quality steel.

**CYLINDER HEAD GASKET** - Special attention was given to design of the cylinder head gasket to insure integrity at the higher firing pressures with the turbocharged engine. Victor Products division of Dana Corporation developed a new graphite composite head gasket incorporating stainless steel flanges and annealed steel fire rings to handle the elevated cylinder pressures. Victor conducted dynamometer deep thermal testing to validate the design.

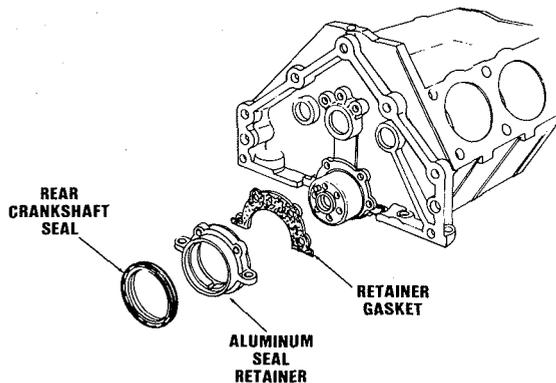
**LUBRICATION SYSTEM** - The lubrication system is a wet sump design using a spur gear pump in the oil pan. The basic system is similar to the description in reference SAE paper (1). The full flow oil filter is remote mounted to clear the forward running propshaft. Oil

cooling is achieved by routing oil from the filter mounting block through a water-to-oil cooler mounted in the radiator side tank.

Lubrication for the turbocharger bearings is achieved by feeding oil externally from an engine mounted adapter through an orifice and pipe system to the turbo center housing. Oil returns to the pan via gravity feed from the turbocharger.

**OIL SEALING** - Avoidance of oil leakage was a high priority in the original 4.3L in 1985. Significant upgrades were incorporated in seal materials and methods for the rocker covers, oil pan, and crankshaft. The rear crankshaft oil seal was further upgraded in 1986 with the addition of a single piece circumferential viton seal design.

**FIGURE 8. ONE-PIECE REAR CRANKSHAFT SEAL**



**ELECTRONICS**

**IGNITION AND ELECTRONIC SPARK CONTROL SYSTEM** - The engine uses a Delco Remy HEI (High Energy Ignition) system with closed loop electronic spark control (ESC). HEI incorporates a compact distributor design with a high efficiency coil. The ignition system is fully described in reference (1).

ESC is used to optimize engine performance and eliminate detonation via active control of spark advance. The base spark advance table in the engine control computer is set up for best engine performance using premium fuel under ideal operating conditions. Detonation may arise due to variations in fuel octane or weather conditions. The ESC retards spark from the base table values when detonation is detected by a specifically designed knock sensing accelerometer mounted on the engine. The knock sensor is tuned to the detonation fundamental frequency for the engine. Spark retard is proportional to the time interval of detected detonation and is removed in an exponentially decaying manner. Spark retard returns to zero when detonation ceases to be detected.

The engine control computer also ties wastegate operation into the ESC system and reduces boost when full authority spark retard is insufficient to control detonation. When spark retard of more than eight degrees is called for, boost level is reduced in one psi

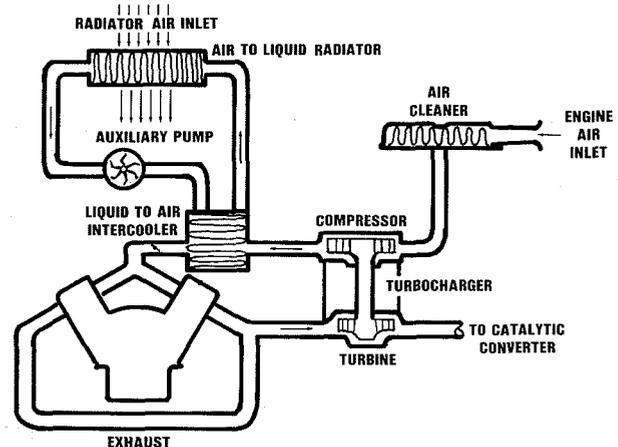
increments by opening the wastegate until spark recovers. When spark retard drops below four degrees, boost is again increased incrementally to calibrated level by closing the wastegate.

**INDUCTION - TURBOCHARGER SYSTEM**

**INDUCTION SYSTEM FLOW PATH** - Induction system flow in the Syclone engine starts at the air cleaner inlet which is attached to the radiator support crossmember. Air passing through the air cleaner is directed across the vehicle through a duct passing over the radiator support. The inlet to the compressor section of the turbocharger from the cross-over duct is a complex laminated elbow constructed from kevlar reinforced silicone.

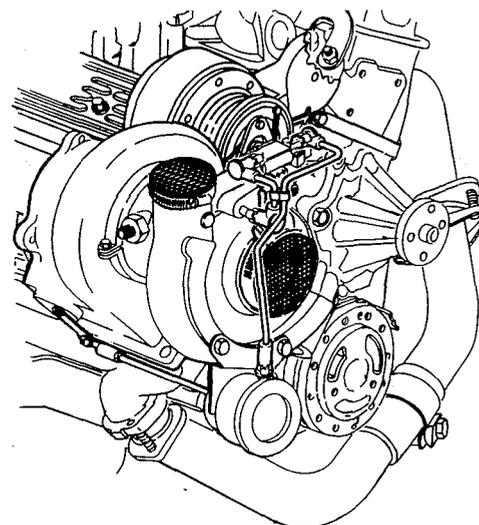
**FIGURE 9.**

**INDUCTION-EXHAUST SYSTEM FLOW SCHEMATIC**



The Turbocharger assembly is mounted to the right hand exhaust manifold with the compressor outlet duct pointing upward. A wire reinforced silicone hose directs the high pressure air to the engine mounted charge air cooler. Air exits the charge cooler directly into the throttle body and the inlet manifold. All components of the compressor inlet system were flow bench developed to minimize the compressor inlet depression.

**FIGURE 10. TURBOCHARGER-EXHAUST CROSSOVER**



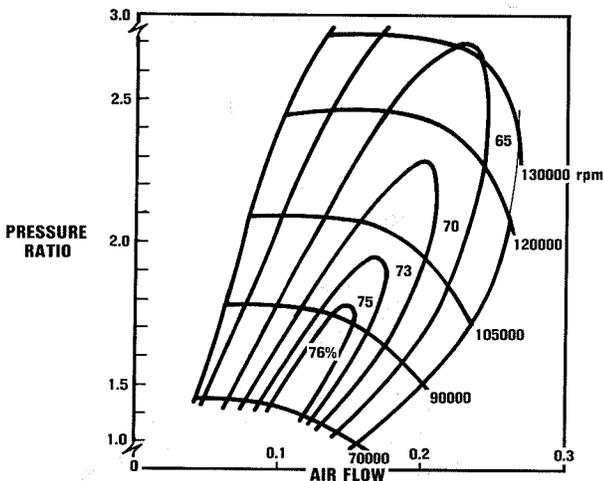
**EXHAUST MANIFOLDING/PIPING AND TURBO MOUNTING** - The packaging of the turbocharger in the engine compartment demanded the development of a completely new exhaust system. Forward positioning of the turbocharger led to the routing of a front, as opposed to the more conventional rear, cross-over pipe. A new left hand exhaust manifold incorporating a long outlet port located at the front of the engine was developed for the front crossover. A two piece stainless cross-over pipe passing below the accessory drive pulley connects to a flange on the forward end of the right hand manifold. The exhaust gas from both banks of the engine are directed to the turbine inlet through individual passages in the right hand inlet manifold casting.

The turbocharger assembly is bolted directly to the right hand manifold. There are no additional braces or brackets associated with the mount. The structural integrity of the mounting scheme was first verified with a detailed finite element analysis which included the effects of heating. The system was subsequently validated with dynamometer and vehicle testing. Both exhaust manifolds are high silicone/molybdenum alloy cast iron.

Exhaust gasses from the turbine outlet housing, which include wastegate flow, are ducted to the catalyst via a 64mm diameter stainless tube. The heated oxygen sensor is located in this pipe 50mm from the mounting flange.

**TURBOCHARGER** - The turbocharger is a Mitsubishi TD06-17C-8cm<sup>2</sup> model specifically matched to the 4.3L engine. The turbocharger features a 360° water cooled center housing to eliminate bearing problems due to heat. Other design particulars are a pressure lubricated brass center bearing, high silicon molybdenum steel turbine housing with integral wastegate, and a pneumatic wastegate actuator. A compressor performance diagram is illustrated.

**FIGURE 11. COMPRESSOR PERFORMANCE DIAGRAM**



**WASTEGATE ACTUATION SYSTEM** - The wastegate controls the amount of exhaust gas applied to the compressor turbine which in turn controls the boost. The wastegate actuation system consists of four main components.

- Wastegate/wastegate actuator
- Wastegate control solenoid
- Manifold air pressure sensor
- ECM

The wastegate actuator is diaphragm driven by boost pressure modified by a bleed. The engine control computer commands duty cycle of an on-off solenoid which sets the bleed rate. The system is under closed loop control to open or close the wastegate to achieve a target boost level based on engine RPM and throttle position. A secondary control loop in the system further modifies boost to control detonation when the ESC has exercised full authority spark retard.

**INTERCOOLER**

**DESIGN CRITERION** - Design criterion for an intercooler for a street driven vehicle are considerably different from those which might be developed for a racing vehicle or a heavy duty truck engine. In the street vehicle, sustained operation at high boost levels, is normally not possible due to society imposed driving limitations. Consequently, the intercooler does not require the capability to stabilize the compressor outlet air temperature at high levels of boost. The primary function is to provide enough system thermal inertia to lower the temperature of the inlet charge in 15 second blasts. Recovery time of the system heat exchanger temperature can be over a period of minutes. These goals established minimum size and heat transfer capacity of the system.

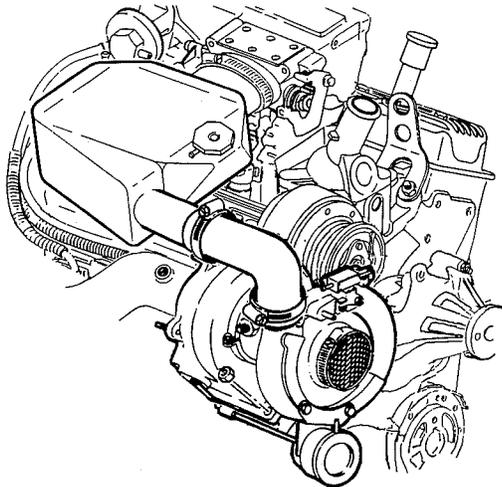
Another major consideration in the selection of an intercooler design is packaging. The primary requirements are to provide a system with access to ambient air for cooling, and to minimize the volume of the charge air side of the flow. As a result of a decision to retain the production water cooling system, including the fan, the only access to external air flow was below the radiator. Routing the high pressure inlet air from the compressor, through an air-to-air intercooler mounted below the radiator proved to be a difficult task with the resulting intercooler volume much larger than desired. This packaging concern was primary in the decision to employ a liquid-to-air system.

**SYSTEM DESCRIPTION** - The liquid-to-air intercooler system consists of three major components; an engine mounted charge air cooler, a frame mounted charge coolant heat exchanger, and a circulation pump.

The charge cooler is mounted directly to the engine in line between the compressor outlet and the throttle body. This location provides the minimum volume of air on the compressor side of the turbocharger, minimizing

turbo lag. The liquid side flow path is in a U configuration with the inlet and the outlet located at the rear of the engine. The air side is single pass straight through. The charge cooler is constructed of four aluminum castings, two liquid side, and two water side, welded to the aluminum tube and fin heat exchanger. The forward water side casting incorporates the coolant filler cap which includes an 89 KPa (13 psi) relief valve.

**FIGURE 12. TURBOCHARGER - INTERCOOLER - THROTTLE BODY ARRANGEMENT**



The charge coolant heat exchanger is another aluminum tube and fin assembly capped with injection molded tanks. It is mounted to the vehicle frame directly below the engine coolant radiator. Cooling air is directed from below the front fascia with some encouragement from a short spoiler extending downward from the heat exchanger.

Coolant is circulated through the system by a small centrifugal pump driven by an electric motor. The motor and pump assembly is mounted directly to the heat exchanger bracket. Coolant transfer pipes extending upward along the left side of the engine deliver the fluid to and through the engine mounted charge air cooler.

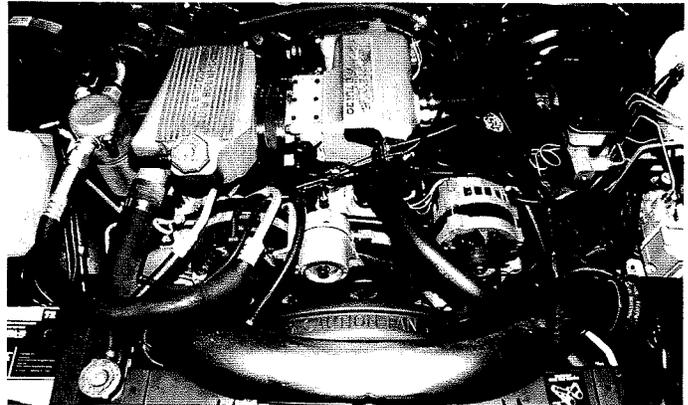
Overflow and coolant recovery is accomplished through a priority sharing arrangement in the engine coolant recovery bottle, with both systems sharing common fluid.

**INLET MANIFOLD AND THROTTLE BODY**

**GENERAL PACKAGING AND DESIGN** - Many considerations influenced the design of the inlet manifold for the Syclone engine. These included:

- Identical port to port runner width
- Fuel injector mounting
- Exhaust gas recirculation system design
- Intercooler packaging
- Throttle and transmission TV linkage
- High inlet manifold pressures
- Engine assembly and hot test requirements
- Manufacturing processing

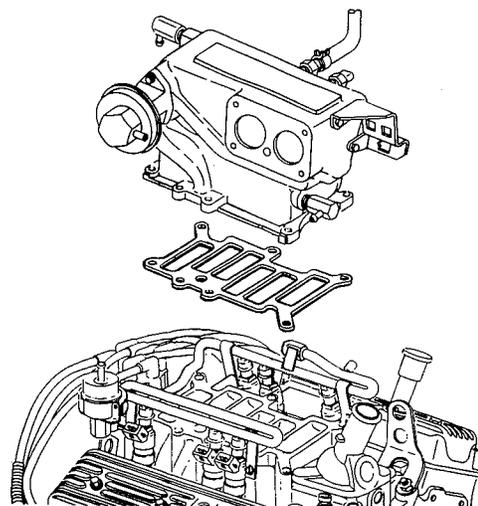
**FIGURE 13. ENGINE COMPARTMENT**



The basic layout of the Syclone inlet manifold consists of six, short individual runners of identical length, feeding air to the cylinders from an enlarged plenum chamber. Plenum chamber volume was based upon the size necessary to provide equal cylinder to cylinder flow with the asymmetrical placement of the throttle body. Relatively short runners were used to avoid low speed torque peaks, since the torque output was governed by driveline considerations; torque being limited by boost control throughout the speed range. The manifold was designed specifically for the turbo-charged application, without consideration for use as normally aspirated.

The inlet manifold is a two piece casting with the lower half providing the water cross-over, the distributor mounting, and the fuel injector bores. The lower also serves to seal the crankcase through unique aluminum/composite gaskets with silicone port seals at the cylinder heads. These gaskets are capable of handling up to 1.5 atmospheres of inlet manifold pressure. Engine assembly considerations dictated the location of the split line between the upper and lower casting. This placement allowed common engine plant processing with the standard 4.3L engine for the water outlet attachment, distributor installation, crankcase and water jacket pressure testing, and final hot testing.

**FIGURE 14. INTAKE MANIFOLD ASSEMBLY**



The upper half of the manifold provides the mounting for the throttle body, the throttle linkage, and the EGR valve. The EGR system plumbing is integral with the manifold casting requiring no external piping. A stainless steel bead encircles the exhaust passage as it pierces the joint between the lower and upper castings. Manifold pressure and temperature transducers are also installed in the upper plenum housing. The throttle body, including twin 52mm throttles, is mounted to the upper inlet manifold forward of the engine center line to accommodate the packaging of the charge air cooler. Bosses for fuel injector hold-down are cast integrally in the lower manifold.

The manifold halves are cast in 319F aluminum alloy with the lower half painted black at engine assembly and the upper section epoxy coated in an argent color.

### PCV/EGR/EVAP SYSTEMS

**PCV** - The PCV system for the Cyclone engine purges crankcase vapors from the crankcase to the turbocharger compressor inlet. Fresh air is routed from the clean side of the air cleaner to a stand-off tube on the left hand rocker cover. Crankcase vapors are extracted from the right hand rocker cover to the compressor. The pressure difference between the air cleaner inlet and turbocharger compressor inlet is sufficient at all engine speeds and loads to create a positive flow from the air cleaner, through the engine, to compressor inlet. A PCV valve is installed in the hose to the compressor inlet to regulate flow.

**EGR** - The exhaust gas recirculation system provides a means to direct exhaust gases from the exhaust port to the intake manifold for Nox emission control. This is accomplished using a vacuum diaphragm valve and an electronic vacuum regulator valve. Ported engine vacuum is directed to the regulator which controls the amount of vacuum signal to be applied to the vacuum diaphragm valve. The EGR valve position is determined by the duty cycle schedule in the ECM, and is a function of coolant temperature, engine speed, manifold absolute pressure and throttle position.

**EVAP SYSTEM** - The evaporative emission control system consists of three major components:

- Fuel tank vent valve
- Activated carbon canister
- Canister purge line

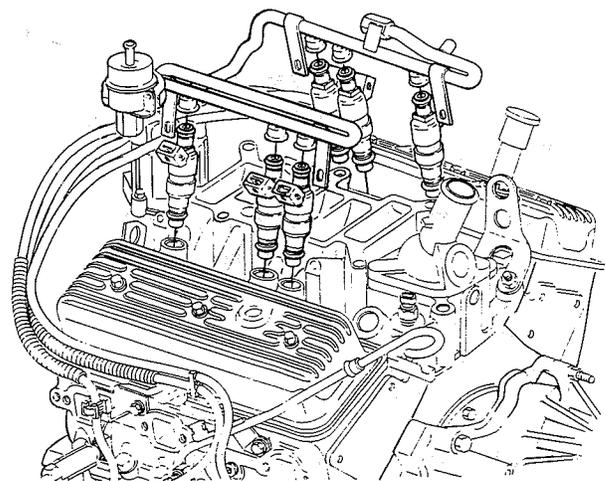
Fuel vapors produced in the fuel tank are piped to the carbon canister for storage. During engine operation, the carbon canister is purged by fresh air routed into the canister, through the activated carbon, and into the engine via a port in the throttle body. A check valve is installed in the purge line to prevent air flow from the throttle body to the canister during boost operation.

### FUEL RAIL AND INJECTORS

The fuel distribution rail is a tubular fabrication with fuel feed and return fittings at the rear of the engine. This arrangement was to increase commonality with the normally aspirated engine fuel lines and results in a "folded back" arrangement. A four bar (60 psi) roller vane fuel pump, mounted in the tank, supplies fuel through steel lines to the rail. The fuel filter is frame mounted away from engine compartment heat to preclude vapor lock problems.

A Bosch fuel pressure regulator and bracket, plus tabs for mounting the rail to the inlet manifold, are integral parts of the rail assembly. The fuel rail assembly is completed with the addition of six Bosch pintle type top feed fuel injectors. System maximum pressure is 414 KPa (60 psi) with 91 Kg/hr (200 lb/hr) fuel flow.

**FIGURE 15.**  
**FUEL RAIL - PRESSURE REGULATOR -**  
**INJECTOR ASSEMBLY**



### ENGINE CONTROL SYSTEM

**SYSTEM DESCRIPTION** - The GM Delco Electronics engine control module or ECM is the computer that serves as the data acquisition, logic processor, and controller of the engine and active emission system devices. "Speed density" based fuel delivery logic is managed by the controller. Major inputs to the ECM, for calculation of air flow and fuel required, are intake manifold absolute pressure, coolant temperature, throttle position, oxygen sensor voltage, and distributor reference pulses. The intake manifold absolute pressure sensor also acts as a barometric sensor at high throttle openings and initial key on. Coolant temperature is used to approximate inlet charge temperature. The distributor reference pulses are used to calculate exact engine speed and synchronize fuel injector timing. Volumetric efficiency tables are programmed into the computer as a function of manifold absolute pressure and engine RPM for the normal exhaust and induction systems in the vehicle. Using the operating parameter inputs and volumetric efficiency tables, mass airflow through the engine and fuel delivery required per combustion event, are calculated.

The term "speed density" is used to describe the calculation procedure.

The ECM turns on the injectors for the precise amount of time to deliver the calculated required fuel. All injectors fire simultaneously with the injection event broken into halves, one per engine revolution. The term simultaneous double fire is used to describe the injection event.

Corrections are applied to the fuel delivery calculations to compensate for EGR, operating temperature, and power enrichment or fuel shutoff requirements. The electrically heated oxygen sensor in the exhaust stream provides an input signal to the ECM logic to trim fuel delivery to exact stoichiometric combustion during warmed up part throttle conditions.

Components and descriptions of the control system are described in the appendix.

## VALIDATION/DEVELOPMENT

The test and validation schedule shown in the appendix was mutually established as a program requirement between GM and PAS at the beginning of the joint venture. The required testing was designed to validate the brand new hardware and revalidate the existing production componentry from the naturally aspirated 4.3L engine. The fact that the base 4.3L engine was designed and developed as a truck engine to a rigorous duty cycle facilitated the success of the turbo conversion. In addition to the standard development tests, multiple durability tests were run on the engine under demanding operating schedules in vehicles and on dynamometer. The test program was monitored via joint PAS/GMPD management ride trips during cold (KapusKasing) and hot (Phoenix) weather. The success of the test program was an absolute requirement to ensure the high level of reliability expected in today's marketplace.

## APPENDIX 1

### ECM SENSORS AND INPUT SIGNALS

#### A/C COMPRESSOR ENGAGEMENT

Supplies signal to ECM when A/C compressor is engaged

Used to adjust engine idle air control to compensate for addition of A/C compressor loads

#### COOLANT TEMPERATURE SENSOR

Indicated temperature of engine coolant

Used for various ECM controlled functions and fuel correction calculations

#### ENGINE CRANKING SENSOR

Provides signal to ECM when engine is being cranked

Used to calculate appropriate fuel required for desired A/F ratio while engine is being cranked

#### ENGINE DETONATION SENSOR (ESC)

Provides signal to ECM when an engine knock condition exists

Used to retard spark timing to eliminate knock condition

#### HEATED EXHAUST OXYGEN SENSOR

Provides signal to ECM which varies with the oxygen content in the exhaust gas

Used to trim fuel delivery to provide stoichiometric A/F ratio

#### MANIFOLD ABSOLUTE PRESSURE SENSOR

Provides signal to ECM to indicate intake manifold absolute pressure

Used for various ECM controlled functions and air flow calculations

#### PARK/NEUTRAL SWITCH

Indicated when transmission gear selector is in park, neutral, or a drive gear

Used to adjust spark timing and engine idle speed

#### THROTTLE POSITION SENSOR

Indicates position of throttle blade

Used for control of fuel injection A/F ratio, idle speed, transmission converter clutch, and EGR

#### TRANSMISSION GEAR SENSOR

Indicates transmission gear selected

Used to adjust idle speed and to control converter clutch engagement

#### VEHICLE SPEED SENSOR

Indicates vehicle speed

Used to control transmission converter clutch engagement, idle speed

**APPENDIX 2**  
**ECM CONTROLLED SYSTEMS**

**CHARGE AIR COOLER PUMP CONTROL**

Used to operate the charge air cooler liquid circulation pump

ECM monitors signals from engine coolant to determine when to circulate air charge cooler coolant

**ELECTRONIC SPARK CONTROL**

Used to optimize spark timing for control of exhaust emissions and fuel economy, and to identify engine detonation

ECM monitors signals from coolant temperature sensor, engine load, and engine detonation sensor and supplies signals to distributor for spark timing control

**EXHAUST GAS RECIRCULATION**

Used to control Nox emissions by recycling exhaust through the intake/ combustion process

ECM monitors signals from coolant temperature sensor, throttle position sensor, and manifold absolute pressure sensor to determine when exhaust gases can be recycled

**IDLE AIR CONTROL**

Used to control engine idle speed

ECM monitors signals from coolant temperature sensor, throttle position sensor, manifold absolute pressure sensor, vehicle speed sensor, A/C compressor engagement, and engine cranking sensor to adjust IAC airflow for the desired engine idle speed

**PORT FUEL INJECTOR CONTROL**

Used to control the amount of fuel to yield the desired A/F ratio for each particular operating condition

ECM monitors signals from coolant temperature sensor, engine load, exhaust oxygen sensor, throttle position sensor and engine cranking sensor and signals the fuel injector to release the required amount of fuel

**TRANSMISSION CONVERTER CLUTCH CONTROL**

Engages and disengages converter clutch during various driving modes

ECM monitors signals from coolant temperature sensor, throttle position sensor, vehicle speed sensor, transmission gear sensor, to determine if converter clutch should be engaged or disengaged

**WASTEGATE SOLENOID CONTROL**

Used to control the wastegate to achieve the desired boost level

ECM monitors signal from coolant temperature sensor, throttle position sensor, RPM and manifold absolute pressure and supplies signal to wastegate control solenoid to manage boost

**APPENDIX 3**  
**4.3 LITER ENGINE VALIDATION TESTS**

- Fuel Calibration
- Spark plug heat range - pre-ignition
- Engine coolant visual flow
- Heat rejection (Dynamometer)
- Engine cooling (hot tunnel)
- Engine crankcase oil pullover
- Engine crankcase blowby
- GM test 1 - as installed power
- GM test 2 - exhaust system restrictions
- GM test 4 - MBT and LBT
- Corporation engine durability - 300 hours
- CD-9WOT cycling - 300 hours
- Gasket durability - thermal shock
- Piston and pin scuffing
- Hot starting
- Cold starting
- Vehicle cold start and drive away
- Vapor lock
- Full Federal test cycle
- S.H.E.D. (emission test)
- Federal mass cycle
- AMA (4,000 miles)
- Proving ground (complete vehicle)
- R-15-6 (20,000 miles)
- R-15-27 (50,000 miles)

## BIBLIOGRAPHY

1. Walker, J.W.; Wiltse, R.F.; Harhaus, V.W.; The GM 4.3 Liter V-6 Gasoline Engine; SAE Paper 841225; presented to the Passenger Car Meeting, October 1-4, 1984