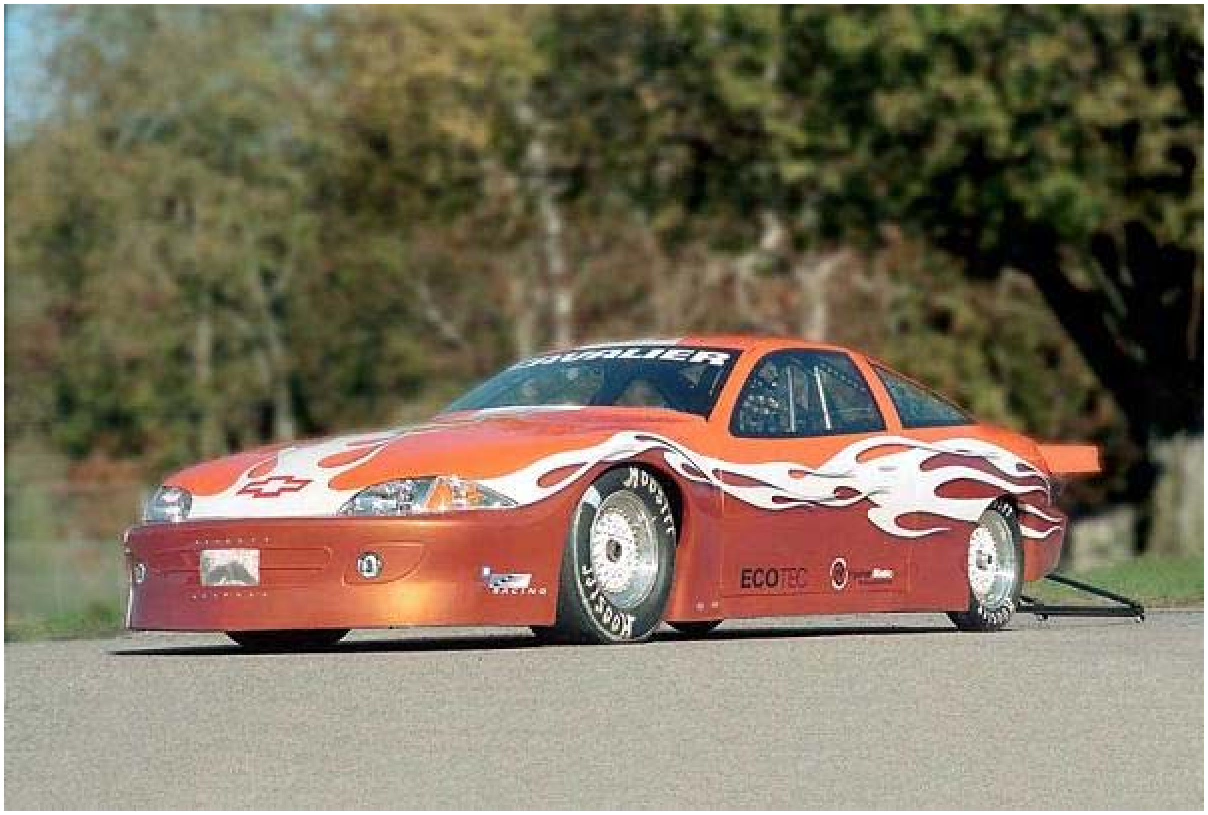
ECOTEC Power from GM

Electronically written by Jesse Schulman

"Birth of the Ultimate Import Fighter?"

GM Racing's 747-horse 2.0L I4 **ECO**TEC Turbo Drag Engine



Genesis

At some point General Motors became aware that there is a thing called "Import Performance," which has positively shaken the entire performance market. GM, for obvious reasons, likes to call this phenomenon "FWD Performance." Eventually, someone at GM realized the company had a new engine called the Ecotec that -- with a few "cheap" tricks -- had the potential to beguile a few folks currently exclusively in love with certain Japanese and European Import Performers. GM scraped together little money and threw it at a small team of experienced racers and engine builders at a skunkworks in Southern California with the goal of ascertaining what a 2.2-liter Ecotec could do if you whipped it good.

"The request was for 800 hp in four months in an engine that would live for 20 - 40 drag runs," says Stephen Bothwell, who came in from the cold to lead GM's Ecotec Drag Engine Project after 2.5 years on the road racing GM's Vortec 4200 in-line six in rally trucks playing the roads and non-roads of places like Baja, Mexico. "The attitude early on in some quarters," says Bothwell, "was people laughed at the idea of a 700-hp Ecotec. But that was then."

Bothwell began by scoping out what sort of power and torque would be required to get people's attention in the "FWD Performance" world, and followed up on that with a crash program to push the envelope of an Ecotec. Hard.

The GM Racing team set about to find the outer limits of an Ecotec the old fashioned way -- by progressively blowing more nitrous through it on an engine dyno until something broke. Then repairing the engine with stronger parts (sending any damaged ports to a lab for forensic analysis), and pushing on until the next weakest link died and went to Hell. And so on.

Quest for Failure: Nitrous

With this in mind, GM Racing bolted a factory-stock Ecotec to an engine dyno and wired up a DFI/Accel programmable engine management system to control it via a data link connected to a laptop computer with Windows-based graphical user interface.

The team then constructed a custom three-stage nitrous system designed to spray a cold fog of nitrous into the Ecotec at a single point near the throttle body, delivering additional fuel to match the oxygen-enriched air via increased pulsewidth from the stock electronic fuel injectors. {that's a dry nitrous system for anyone that wants to know}

GM Racing began the tuning process on a Heinen-Freud water-brake dyno using the stock intake and exhaust manifolds and a modified stock downpipe plumbed without muffler directly into the dyno cell's exhaust removal system. It turns out a well-tuned stock 10:1 2.2-liter Ecotec in the above configuration actually develops 168 crankshaft hp (which is above the factory rating of 140-150 as installed in various vehicles in the United States and Europe).

At this point, the team began to pump up the volume in a rigorous series of tests while a crew stood by with fire extinguishers. Testing at a given power level concluded when the engine could survive a series of 8-10 full-power dyno "Sprints" from peak torque through maximum power in 50 rpm steps, concluding with at least six seconds at full power, for a total of at least 20 very hard seconds. GM Racing successively verified the Ecotec survived happily at 200, 225 and 250 hp over numerous dyno pulls.

However, as the Ecotec pushed through 283 hp at 4400 rpm, all four connecting rods simultaneously failed catastrophically and smashed through the side of the block. Laboratory analysis subsequently revealed a mid-beam compression fracture on all four stock powder-metal rods. All other components checked out fine. GM Racing installed a package of components you'd certainly install if you were taking the trouble to open an engine to upgrade the connecting rods: Super-duty forged Crower X-beam rods -- plus 10:1 JE forged pistons with thicker top ring lands and Hastings moly ring packs. The GM Racing team installed larger fuel injectors, and continued lean on the engine. Power quickly advanced to 350 hp, at which point the engine ran out of breathing room on the exhaust side. The ratio of Reactants (exhaust) to Products (inlet charge) is very high on a nitrous motor. GM Racing found the stock Ecotec exhaust manifold became sufficiently restrictive above 350-hp that injudiciously adding more nitrous could actually make less horsepower -- due to dramatically decreased efficiencies in scavenging exhaust gases from the combustion chamber clearance volume. "We finally made 370-375 hp on nitrous," says Bothwell, "but the engine was really pissed off."

Building the Turbo Ecotec

At this point, GM Racing abandoned nitrous, built an efficient turbo Ecotec, and pushed on with the business of making power. The strategy was, make it efficient from Day One, then turn up the revs and boost. Bothwell's goal: 10,000 rpm and 800 hp.

"We knew the stock crank would need replacing by 500 hp," says Bothwell. "Since we were going to need the rev capability, breathing and rod-stroke ratio of a square bore-stroke engine, we had Crower build a de-stroked forged billet 2.0-liter crankshaft and used it immediately from 350-hp." New, larger 4143 7/16-inch main studs replaced the head bolts to hold the new crank firmly in place.

The GM Team designed a tube-type stainless header fabricated to optimize the collection of exhaust pulses in the correct order to minimize collisions. With plenty of boost, the GM team knew the stock scroll-type plastic intake manifold could flow sufficient air for 500 hp. Since the goal was way beyond 500 hp, they fabricated an aluminum, straight-port dry intake manifold with high-volume plenum for the turbo Ecotec. To regulate big air flow, GM Racing pilfered the throttle body from an LS1 V8.

GM Racing designed the turbo system around an advanced Innovative Turbo turbocharger with plenty of parts to upgrade and tweak performance as required, plus a huge waste-gate and pulse-modulated electronic controller. The GM team fabricated a gigantic custom air-water intercooler that could be cooled continuously on the dyno with tap water or with a dry-ice heat sink at the track.

GM Racing subcontractor Shaver Specialties dramatically upgraded the Ecotec head with significant porting and maximum size lightweight stainless-steel valves. Current SS flow-bench data shows the ported head capable of flowing 272 cfm of air at 0.450 lift and 175-207 cfm exhaust.

With valve seals removed to prevent high-lift collisions with the retainers, Crower cams provide total lift and duration of .46482 inches and 221.4 degrees of duration, total exhaust lift and duration of .46737 inches and 221.3 degrees. Shaver employed a proprietary GM Racing solution to forestall valve float problems at high-rpm and boost (with an eventual goal of 10,000 rpm redline, GM Racing decided to delete the Ecotec balance shafts).

By this time, the Turbo Ecotec powerplant had grown significantly in width. The GM Team decided to rotate it forward by 33 degrees. This would help deal with multi-G effects on oil drain and dramatically reduce the difficulty of packing it in a racecar.

GM Racing converted the Ecotec to a multi-stage dry-sump oil system designed to reduce crankcase windage and thus increase power by scavenging oil and crankcase gases directly from the cylinder head and oil pan into a high-volume external tank. From the tank, a separate pump would provide superior low-temperature, high-pressure lubrication with reduced aeration directly to the short block, head and turbocharger.

The GM team built a narrow, low-volume, forward biased V-shaped oil pan that funneled return oil to dual dry-sump scavenge pickups. They opened up windows in the girdle of the "Slant-Four" to prevent oil from puddling at a relocated low point and killing horsepower by interfering with the crank at high rpm.

Quest for Failure: Boost

The new turbo Ecotec immediately cranked out 350 hp at 7000 rpm on 2 psi boost, and rapidly closed in on 450 hp with no failures. "Our tuning strategy," says Bothwell. "Was to start rich with a computer generated air-fuel map and sneak up on rich-best torque."

The new turbo Ecotec was defiantly responsive: GM Racing set idle at 1800 rpm, and if you punched it quick, the unloaded engine would blow completely through the 10K rev-limiter in less than a tenth of a second. The team expected an Ecotec-powered drag car to launch at 8000 rpm and run all the way through the gears in the quarter mile, so they cared mainly about the 5-10K rpm range. In this range, GM Racing wanted the turbocharger to achieve any level of "full boost" nearly 100-percent of the time.

As testing continued, GM Racing monitored EGT and exhaust gas oxygen on all four cylinders. Full-power target EGT was 1,230-degrees F, and would never exceed 1,350-degrees. The team continuously logged all sensor data throughout the power quest. The routine was, run the dyno manually at an array of "break points" of speed, loading and boost, holding the engine steady at each point to tweak various parameters that define optimal rich/best torque -- using EGT and wide-range O2 data, fuel-rail pressure, torque and power readouts, a remote-control electronic boost controller and a laptop computer to recalibrate injection pulsewidth and spark advance.

Throughout turbo Ecotec dyno testing, GM Racing chilled the air-water intercooler with fresh tap water. At high levels of boost, pressurized air would enter the cooler at 200 degrees, leave at 105-110 degrees, with some creep due to packaging compromises and negligible pressure-drop. At the track, a dry ice heat-sink would reduce the intake air exiting the cooler to 60-70 degrees.

At 450 hp and 8 psi boost, the GM team began blowing head gaskets. One theory was that core-shifting in the block was causing the gasket to fail (because some Honda motors have this problem). "I didn't buy it," says Bothwell. "But we tried converting the Ecotec block to a solid deck. This, unfortunately, just wasted time and destroyed some blocks, probably due to thermal-expansion issues."

The GM team decided the head was flexing. Returning to a stock-deck Ecotec block, they switched to high-strength H11 head studs. This restricted the head gasket leakage and failure exclusively to outboard sections of the fire ring at either end of the head on cylinders one and four. The GM team solved this problem by reinforcing the two problem areas with twin studs that threaded through bored machined into the upper structure of the head and jammed against the outboard fire-ring areas of the head next to cylinders one and four.

The engine now happily made 500 hp -- and ran smack into the outer limits of stock coil-on-plug performance. Integral microprocessors will not allow the stock coils to energize and fire in the presence of excessive voltage. Short-term solution: GMR converted to a cam driven distributor ignition with industrial-strength super coil.

Unfortunately, as power climbed toward 600, the entire block-head interface began leaking from extreme compression pressures. The Gm team pressed stainless O-rings into machined grooved in the head, machined receiver grooves in the block and installed a soft copper head gasket. Problem solved.

At 600 hp, the extreme power and engine speeds began distorting and flexing the aftermarket super-duty 4350 wrist pins. Left unattended, this would eventually tear out the pin towers below the wrist pins. In this same power range, the Ecotec's ring packs began failing. GM Racing opened the wrist pin bores in the pistons by .003-inch and installed thicker H11 wrist pins with thicker walls. The team simultaneously migrated from the 1.0- x 1.0- x 3.0-inch aftermarket rings to Total Seal 1.5- x 1.5- x 4.0-inch ring packs.

The Ecotec was finally reliable to 650 hp at 19 psi of boost -- a relatively low level of boost, indicating outstanding volumetric efficiency. The GM team verified acceptable stress on all parts and lowered oil pressure to 85 psi after concluding that higher pump settings simply robbed horsepower and excessively aerated the oil.

The Push for 800 Horsepower

Consider this: 800 hp is a lot. On a 122 cubic inch motor with 750 hp -- three-quarters of a thousand -- you're basically dealing with 6.14 hp per cubic inch. Pressures and stresses of all kinds -- thermal and mechanical loading across the board -- escalate to extreme levels. A Chevrolet 5.7-liter LS1 V8 with this much specific power (horsepower per cubic inch) would be making 2,137 hp.

The super-modified Ecotec was able to achieve a reliable 750 hp on 24 psi of boost at 9000 rpm with 10:1 compression and an unspecified fuel with extremely high octane and excellent heat of vaporization characteristics. But as Bothwell's team pushed beyond the 750-plus range, GM Racing began to encounter such extreme cylinder pressures and thermal expansion that the thin-wall stock cylinder sleeves and support structure began to warp and go out of round, split. Cylinder piston became a problem.

As of this writing, the team has has developed a promising new "Super-Turbo" Ecotec, built in a process where GMR machinist entirely removes the stock sleeves and aluminum cylinder support structure/core, pressing thick, custom-built bottom-flanged steel sleeves into receiver bores machined directly into the floor of the water jacket. GMR reinforces the new extra-thick full-floating sleeves with a pool of epoxy that effectively raises the floor of the water jacket to surround the base of the cylinders, GM Racing increased the cylinder bore clearance in the Super-Turbo engine by 0.001-inch, and shot-peened the piston skirts to help retain oil.

Analysis

It's amazing that any components whatsoever designed for a stock 140 hp 2.2-liter Ecotec would survive on an extreme power plant making more than six times its power. However the stock Ecotec block and main/girdle structure did survive to 750 hp, as did the stock sleeves. The stock main bearings survived. The stock stamped roller finger-followers were effective to at least 9700 rpm, as were the hydraulic lifters. The oil passages remained stock to 800 hp. The stock chains, guides, tensioners and water pump worked all the way to heaven. The stock head survived with minor strengthening and massive breathing modifications. Many other components were good for two to four times stock power (see chart). GM Powertrain engineers designed a base engine with many stock components that were above and beyond what was needed for stock performance. "The crank support structure of the Ecotec is unbelievably strong," says Bothwell. "We detected no core shifting under the most extreme conditions."

The engine-fuel combination turned out to be extremely knock-resistant. The Ecotec combustion chamber is efficient, with an excellent tumble and high flame speed, and the engine was able to run 10:1 compression without knock at boost pressures as high as 36 psi at 21 degrees spark advance. In a vehicle, the on-board computer is aware of which gear is in use and varies maximum boost accordingly to avoid detonation and traction control problems.

From the excellent power-boost ratio of 750 hp at 24 psi, one can infer that careful turbo selection, camshaft selection and timing, good intercooling and carefully considered turbo system geometry result in a happy situation in which inlet manifold pressure exceeds backpressure in a happy phenomenon called crossover, where horsepower really skyrockets.

Turbo configuration and size would change three times during the tuning process. The highest-flow turbo is currently capable of delivering 40 psi boost at very high power levels. The largest Innovative wastegate is unable to divert enough exhaust to keep boost from creeping to a minimum of 15 psi when heavily loaded on the dyno, though this is not a problem on the track.

What is the Ecotec's final frontier? So far, unknown; but we'll be looking to the track in 2002 for the answers to that question.

HP	250	300	350	400	450	500	550	600	650	750	1000
Block	*Stock									*Sleeves	
Girdle	*Stock										
Rods	*Stock	*Crower Forged Rods (283 hp)									
Pistons	*Stock	*JE Forged (283 hp)									
Wrist Pins	*Stock	*JE 4350 Pins (283 hp)						*H11 Custom Pins			
Rings	*Stock	*Hastings Moly (283 hp)									
Crank	*Stock					*Crower Custom Billet Steel					
Crank Fasteners	*Stock										
Head	*Stock								*GM Racing Reinforcement		
Head Gasket	*Stock							*Annealed Copper with O-rings			
Head Fasteners	*Stock		*7/16 Studs			*H22 Studs					
Camshaft(s)	*Stock		*Crower Custom High-lift and Duration								
Valves	*Stock			*5.5mm Stainless							
Valve Springs	*Stock		*NA								
Intake Ports	*Stock		*Shaver Specialties								
Exhaust Ports	*Stock		*Shaver Specialties								
Turbocharger	*Stock		*Innovative								
Boost	*Stock		*2psi		*8psi				*19psi	*24psi	
Lubrication	*Stock		*Three-Stage Dry Sump								