The dream

Engine developer Mike Norman **explains how he and his fellow conspirators that comprise G-Force Engine Development developed Honda's 4-stroke engine into a race-winner, but it's been a bit of a bumpy ride to date**

To me, Grand Prix motorcycle racing has always been the most fascinating form of motorsport. When I started watching GP races, the bikes were 500cc 2-stroke powered and as a result the racing was absolutely nail-biting, edge-of-your-seat racing. From a technical standpoint the rules were fairly unlimited: engineers had a lot of flexibility in their modifications. The machines were so fast that sometimes even the best riders could not hold onto them.

As the 500cc 2-stroke engines became less rider-friendly because of their near instantaneous power delivery, riders started to get hurt more often. At the same time, the irrelevance of the 2-strokes became apparent as manufacturers no longer used them for street bikes. Changes were inevitable in order to improve the safety for the riders and better match the technology of racing to production bikes.

In 2002, the Fédération Internationale de Motocyclisme (FIM) changed the rules for motorcycle grand prix racing to allow 4-stroke engines up to 990cc. As a 4-stroke engine developer, that got my attention. As I learned more about the technology behind the MotoGP 4-strokes, I noticed their mechanical configurations were not too far advanced from the 4-cylinder 4-stroke engines I have developed throughout my career. In particular, there is a tremendous resemblance between the Honda RC211V and the older factory Honda V4 Superbikes such as the HGA Freddie Spencer/Two Brothers RC-30 and some of the ex-Smokin' Joe's RC-45s that I've had the opportunity to work on. For an engine developer, this was very exciting to me. It has always

been my dream to develop a GP engine. Now that they have switched to 4-strokes, that dream is even closer to reality.

Around the same time as the MotoGP switch to 4-strokes, my company, G-Force prepared a Honda NC-30 (VFR400RR) for racing. The customer then took this street-going NC-30 with very little carburetion and suspension modifications and no engine modifications to the track to win against heavily modified Yamaha FZR400 race motorcycles. He credited the chassis as the reason for the excellent performance.

When this same customer purchased another NC-30 that had been modified with a higher degree of engine, chassis and carburetion modifications, the resulting performance at the track and on the dyno really aroused my interest. After riding one I was addicted to the amazing handling. In fact, "the first time I raced one of these bikes on the track was during a 4 hour endurance race. I smiled all the way to the podium to collect the winning trophy." It was amazing fun, it just lacked that top-end rush to make it a complete racing package.

Getting inside the engine and seeing what the Honda engineers had given me to start with was like being given the keys to your dad's Porsche at an open track day. It's time to play! The stock engine of the NC-30 is a V4 with a 90° bank angle. With a 55.0 mm (2.2") bore x 42.0 mm (1.7") stroke the engine capacity comes to 399cc. The crankshaft is a 360° flat-plane design, with both crankpins inline. Each crankpin carries two connecting rods, one for each bank of the V engine. The firing order falls into the "Big-Bang" category with a 90° – 270° – 90° spread as opposed to a traditional 'Screamer' engine with equally timed pulses. This firing order allows the rider to apply power sooner and harder for better drive out of the corners.

The stock pistons are cast aluminum pieces with long, full circumferential skirting. They carry 3-rings: 0.8mm (0.03") thick top and secondary compression rings as well as a 1.5mm (0.06") spring/twin-rail oil control pack. The wrist pins are full length steel pins with an outside diameter of 14.0mm (0.6"). Tying the pistons to the crankshaft are production-grade steel connecting rods, 100.0mm (3.9") from centre to centre, with rod bolt and nut fastening.

The cylinder heads have 4 valves per cylinder, actuated by dual overhead camshafts. Each camshaft lobe rides against individual finger followers acting directly on 7.5mm (0.3") lash shims sitting atop the valves. The valves are steel, controlled by dual progressive-wound steel springs, retained by steel retainers. Valve diameters are 22.5mm (0.8") on each intake and 20.0mm (0.8") on each exhaust. The intake ports are small round ports with a 35° angle of attack on the port throats. The valves are canted away from each other by a 36° included angle. The combustion chambers are a deep pent-roof design, outdated compared to more modern race-engine standards. Centred in each combustion chamber is a special 8 mm (0.3") diameter spark plug to allow for larger valves.

All this was designed to rev to 14,500 rpm with the classic reliability of a street-based Honda. With production quality and lower cost components, there was plenty of room to improve. Knowing this, I was confident I could develop these engines to a level of performance that would do the excellent chassis justice. I thought, "now is my chance to develop an engine with the latest caliber of technology". This was the birth of our project, later dubbed "NC-450V".

450cc engine configuration

The goal of this project was to compete against the Suzuki SV-650s in several different sanctioned organisations. Our initial power goal was 85 hp at the rear wheel. We figured we could use the NC's excellent chassis to make up any deficit in power.

The rules made it clear that the average engine capacity for the platform of the motorcycle was 450cc. OK, that was easy. Now we had to determine the best bore and stroke combination. This brought us up against ring-pack availability, current bore spacing, height limitations for increasing stroke, and so on. Since there were no adequate ring-packs for a 58mm (2.28") bore available from any of the piston manufacturers and a 59mm (2.32") bore would require considerable re-machining and custom sleeves, we opted to run a 57mm (2.24") bore.

Looking at the stock crankshaft, we discovered that, unlike most production motorcycles, Honda had already engineered the crankshafts with little "over-engineering" on the original crankshafts. The webs were already very thin and the amount of overlap of the crankpin to the main journal was very shallow. Even at the approximate 2.5mm (0.1") increase in stroke -1.25mm (0.05") crankpin offset – we were concerned that the overlap might be reduced too much.

With our limited options, we had to settle for a final engine configuration of 57mm (2.24") bore x 44.5mm (1.75") stroke for a total capacity of 454cc. Most of the racing sanctions we race with, or planned to race with, allow a +1mm (0.04")

Mark Elrod (926) launches his G-Force built Honda against a pack of SV560s

"I was confident I could develop these engines to a level of performance that would do the excellent chassis justice"

The stock piston was heavy and had full skirting contributing to extra friction in the motors. Our primary goal with the bespoke pistons was to reduce this as much as possible overbore from the capacity stated. With this we were actually undersized given the allowable total displacement.

The next item was the cylinder head. From preliminary testing the Honda head was already quite well designed. It has finger-follower rockers with small lash shims and at 4.5mm (0.18") the valve stems were already quite thin. The ports flowed well for a 399cc production motorcycle with the exhaust ports actually flowing a little too well in most areas. Preliminary decisions were to develop the bottom-end of the engine first then come back to the cylinder head and valve train once the bottom end was completely developed.

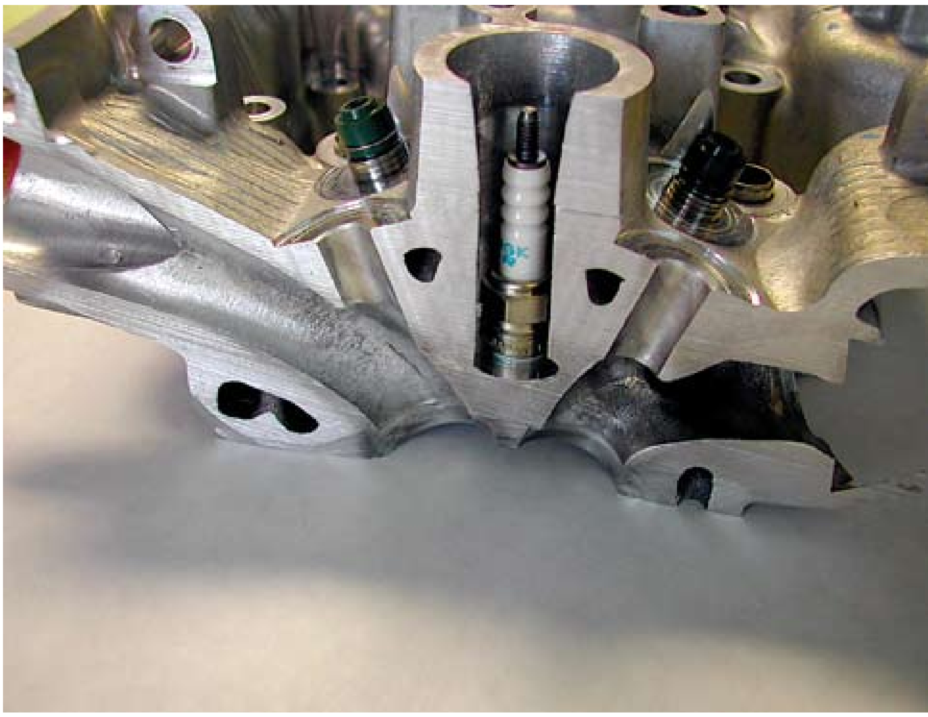
Cams and valve train had been discussed, contemplated and kicked-about for some time by the team. The stock components were designed for street use so they were durable, producing power over a broad range of rpm. Although we initially thought we would need to attend to this we have been able to achieve power numbers close to our initial goals without changing anything. All of our development to date has been with the stock valve train components.

Ancillary components

The exhaust system was the next area of debate. Honda no longer made this bike and very few third party components existed. We were limited by what remained. Fortunately, we had a steady stream of these bikes going through G-Force, so we were able to test various available exhaust systems, recording the lengths, diameters and merge points to determine what worked best.

The exhaust system chosen was a dual two-into-one system made by RLR Motorsports out of Shropshire, England. The individual systems ran the two front cylinders down to the right of the bike and the rear cylinders ran out the back of the bike and to the left. The titanium mufflers ran one each side of the tail of the motorcycle (side-by-side "shotgun" style). These systems have 34.9mm (1.375") primary head pipes that are 825.5mm (32.5") long, merging into a 38.1mm (1.5") secondary that is 457.2mm (18") long. The song is muffled by a 47.6mm (1.875") core muffler that is 482.6mm (19") long. With the 360° flat-plane crankshaft's "Big-Bang" firing order, the dual two-into-one system has a unique growl to it that is unmistakable at the track.

Induction system upgrades for motorcycles are not very prominent. The factories deliver motorcycles with carburetion or fuel injection and there are almost no third party manufacturers worldwide. In addition, the number of V4 racked carburetors is next to nil. Our motorcycles all came with carburetion by Keihin. During their peak in the mid '90s, HRC (Honda) made racing upgrade kits available. These kits contained some different jetting components and sometimes different velocity stacks for tuning the intake length. Otherwise, the engine tuners were on their own – unless you were in the right place at the right time and knew how to acquire a set of special Keihin FCR flat-slide racing carburettors. Those carburettors were made in very limited production for the factory race teams and in an extremely short run after that. So our ability to get hold of any has



been very difficult. Thus far, the induction system on our project motorcycles has been based on the stock carburettors that came with the production motorcycles.

The ignition system is a sealed ECU with no ability to make adjustments although HRC did provide a replacement ECU for the later RVF version that accompanied their racing kits. These ECUs had an ignition curve better suited to racing with an elevated rev limiter for extended top-end tuning. Currently all of our motorcycles have this ECU. For additional adjustability, we have slotted the mounting holes in the ignition trigger to advance or retard timing by approximately 10° in each direction. Unfortunately, this only allows us to shift the entire ignition curve one way or another. While not the ideal way to tune an ignition, we have been able to obtain better combustion in the 9,000 rpm to 14,750 rpm range we run in with minor drawbacks.

Putting it all together

The first engine configuration contained bespoke billet pistons made by REC, the former Cosworth motorcycle piston importer in the USA. These pistons were designed with reduced weight, reduced friction and increased durability. The piston height was reduced to a minimum, including moving the wrist pin up as high as possible. The skirt area was reduced to just what was necessary to keep the pistons stable in the bores. The wrist pins bridges were brought inboard and an extremely short pin was used. The result was a final piston package that was nearly 8 grammes lighter than the stock piston package, while increasing the bore by 2mm (0.08") and raising the compression from 11.3:1 to 12.4:1.

The pistons were tied to the crankshaft by bespoke billet titanium connecting rods made by Design-It Prototype, a local race fabrication shop in northern California. These rods were designed with a narrow beam for reduced windage at high rpm. The goal was to reduce reciprocating mass for better longevity of the connecting rod bearings and crankshaft. As a secondary result, we reduced rotating mass and the mass of the crankshaft to match for better acceleration.

For years G-Force has been using weld-up, offset ground crankshafts to increase the stroke in engines although for this engine we were concerned about the lack of overlap of the main journal and crankpin for strength. For our early configuration engines, we used weld-up crankshafts by CCR, a small crankshaft welding/repair shop in northern California, with increased radii at the mains and the crankpins for additional strength. These crankshafts were then rebalanced for the lighter rods and pistons and deep-nitrided for even more strength and surface hardness.

With the concerns of thinning the cast-in iron cylinder liners, we opted to have Millennium Technologies in Plymouth, Wisconsin bore out the liners and replace them with aluminium sleeves plated with nickel silicone carbide. Our goals were to have a stable sleeve that would resist distortion and transfer heat better while also reducing friction. The crankcases were otherwise unmodified. The rest of the lower-end of the engine was also left alone. Everything from the transmission to the clutch and oil delivery system is completely stock.

With the results of the flow tests, I applied very mild port clean-up work on the intake side of the cylinder heads. The goal was to increase the flow in the low-lift portion of the flow curve, with max-lift gains as a secondary target. The exhaust ports were flowing between 83% to over 105% of the intake in some areas. Rather than decrease the flow in the exhaust, I chose to leave the exhaust ports alone and would later revisit the intake ports for better flow.

Inset: Three versions of the bespoke Carrillo rods: Left is the standard steel H-Beam, centre is the titanium H-Beam and right is the low profile steel A-Beam. The steel A-Beam had the lightest pin end while titanium had the lightest big end
Top: With the first crankshaft failure, the engine went from 10,000rpm to zero in less than 20 degrees. Most rods would have snapped, but the Carrillo rods held together preventing much worse engine damage
Left: Cut-away view of the cylinder head arrangement. Note the 8mm spark plug and wide included valve angle

ABOUT G-FORCE

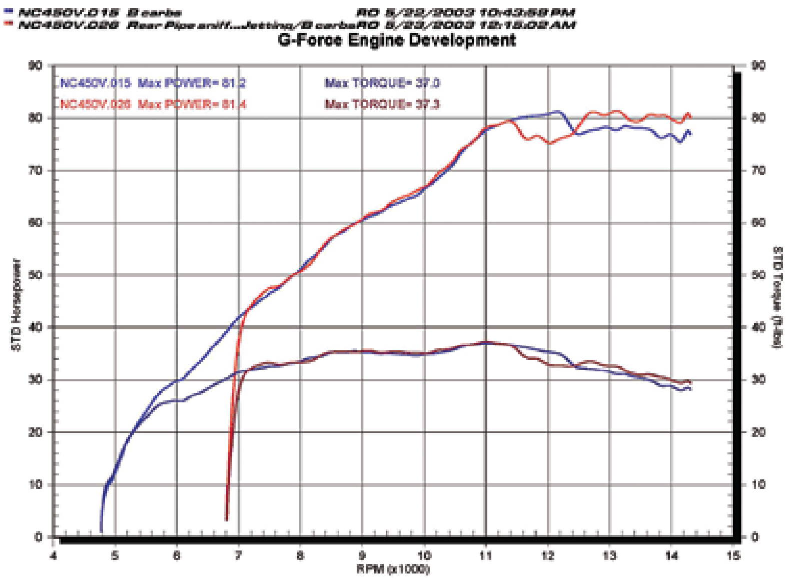
Mike Norman started tuning bikes in his garage in Sacramento, California in the mid 1980s. The garage became busy enough that he opened a retail performance shop in 1994: G-Force Performance Center. As that business grew, Norman met Mike Sampognaro who later invested in G-Force as a financial and working partner in 2000. Norman and Sampognaro met Mike Lohmeyer in 2002 as a customer of G-Force who purchased the first NC-30 from G-Force and became the initiator of the project. Lohmeyer then met Mark Elrod and convinced him to join the team. Eventually G-Force, the retail shop, closed but in its place the informal, non-retail group, G-Force Engine Development was created.

G-Force Engine Development is a group of enthusiasts that gather on the weekends and evenings to develop road racing motorcycles. Everyone on the team has other jobs and are not sponsored or financially supported by any outside interests. The motorcycles described in this article have been privately financed by the individuals.

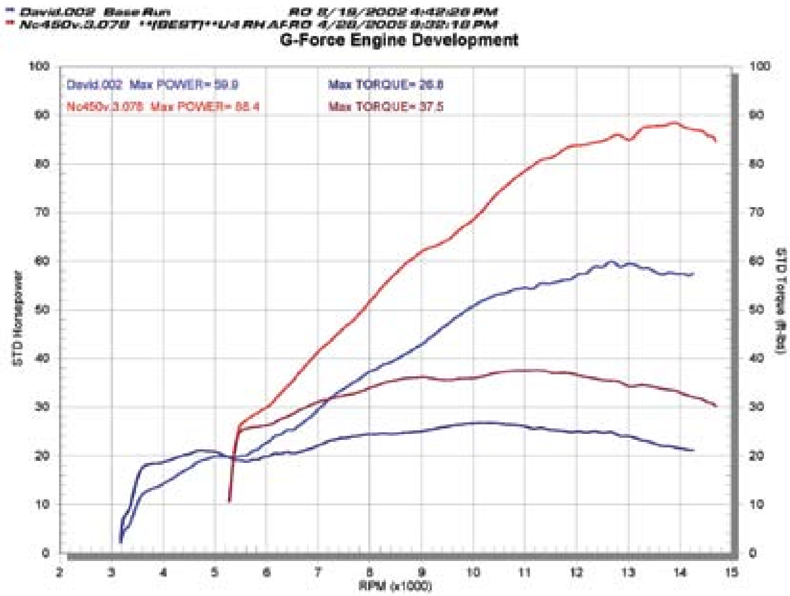
There are four key people in G-Force Engine Development: Mike Norman, Mike Lohmeyer, Mike Sampognaro and Mark Elrod (Three Mikes and a Mark – it can get confusing). In addition, several other friends assist with the project whenever they can.

Norman is a mechanical designer and has been developing racing engines for over 20 years. He is currently a technical representative for Ducati North America. Sampognaro is a maintenance officer for the USAF-ANG. Lohmeyer is an eectronics engineer, specialising in PCB and circuitry design. Elrod is a computer coder (programmer) and business entrepreneur. Each has a great amount of input and experience in various technical capacities to offer, which has helped drive the development of these motorcycles to a new level. All members of the team also race these motorcycles.

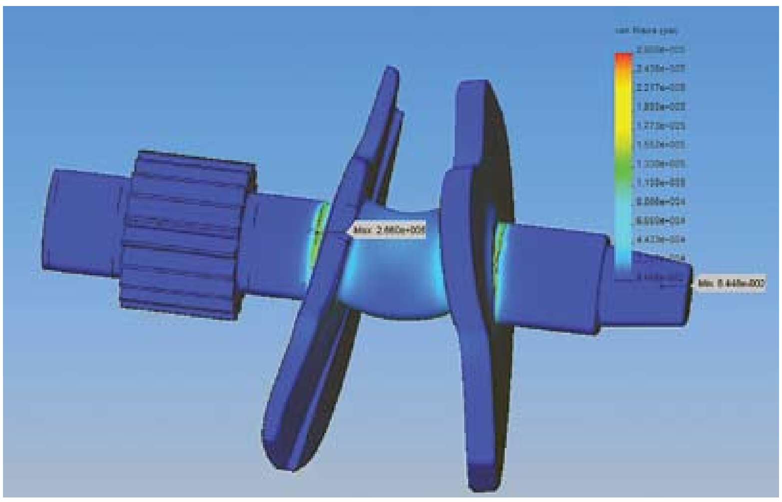
People always ask why we would invest so much personal time and money into this project. Lohmeyer summed it up nicely saying, "I could just go out and buy a modern 600, but where would be the fun in that."



This graph shows the inconsistent power drop-off that we were trying to diagnose



This graph shows the comparison of a stock motor (blue) and our 450cc motor as April 2005



FEA diagram of the weld-up stock crankshaft depicting the predicted failure point of the crankshafts. This is exactly where the crankshafts failed in the actual race engines

Plans are also in the works to increase the intake valve size to match the increased engine capacity.

The cleaned up cylinder heads were installed using stock head gaskets that were modified on the mill to match the larger bore. The press-on cam gears were replaced with modified pieces enabling us to adjust the cam timing with the stock cam gear drive. Cam timing was set, based on flow numbers, for increased top-end power delivery. Valves and valve train components were left completely stock and the valve lash was set within the factory recommended clearances.

The engines were fed by the stock 32mm (1.3") CV carburettors. However, with a couple of our motorcycles running this engine, we opted to try different carburettor configurations on each bike. Our primary bike had an original, very hard to obtain, HRC F-III carburettor kit. This included extremely short bell mouths that reduced the intake tract length by 43mm (1.7"), as well as different slides and internal carburetion components. This set-up was also designed to run without an airbox, leaving the carburetors open to the atmosphere right at the bell mouths. On the other bikes, we opted for a more conservative route, leaving the stock airbox and air filter in place to try and protect the engine from track debris and dirt in the event of a get-off.

Initial results

The stock motorcycles produced approximately 60 hp at the rear wheel. Well-tuned motors with the HRC racing kit components produced around 70 hp and our target was 85 hp. Our first true dyno run revealed 81.2 hp @ 12,200 rpm (approximately a 35% power increase over stock). With some tuning we eventually saw 84.6 hp @ 13,150 rpm (a 41% increase over stock), practically achieving our initial goals. "Hell, if 85 hp is so simple, let's aim for 90 hp", I thought! Oops, 90hp proved to have opened Pandora's Box.

Obstacles

The main obstacle we encountered while building these motors was the delivery of components. Vendors could not deliver anywhere near the date promised. Our pistons took nearly six months for the first batch and eight for the second. The original titanium connecting rods took nearly a year. The weld-up crankshafts took more than six months and even these dates required us to be continually interacting with our vendors, not always pleasantly. In several cases, even when the parts arrived, they were incorrect and had to be sent back for re-work. We were not having fun.

Once the motors were together, we still encountered issues. Initial testing proved that the power was unstable above 12,000 rpm. Power would drop off at varying rpm and inconsistent times. We tested the crankcase pressure during the runs and discovered that the power drops were accompanied by large pressure spikes, indicating ring sealing issues. We chased many theories of cylinder wall distortion and ring flutter and then, during our attempts to determine the ring sealing issues, we ran into another obstacle.

During one of the power runs, a titanium connecting rod let go, turning the insides of our engine to pure shrapnel. We had the remnants of the broken connecting rod inspected by Jack Sparks of Carrillo Industries in San Clemente, California. He discovered that the rods, although a decent design, were manufactured with a disastrous defect causing a stress-riser right at the weakest point of the rod cap. This defect caused us to pull all the remaining rods from every motor we built using these rods, and discard them all. Unfortunately, we were too late with one other motor, again causing catastrophic damage.

Jack had mentioned that the new parent company to Carrillo, the PMI Group, wanted Carrillo to produce titanium rods and asked whether we would be interested in working with him. Yes! We jumped at the chance. The only unfortunate by-product was yet more delays – Jack told us he wouldn't be able to provide us with titanium rods in a timely fashion, so we asked him to make us steel rods while we awaited the titanium pieces. He even made two different variants of the steel rods for us to sample; the traditional "H" Beam and their sleeker "A" Beam rod.

Once we received the steel rods, we were able to piece together another engine and get back to determining the cause of the ring sealing issues. As it was the peak of the racing season and we were chasing the championship, trying to find time to cure the ring sealing issues proved difficult. Before we could fully address the issue we were unexpectedly hit with the next disaster.

During a race in the Formula-IV class, while our team member Mike Lohmeyer was in the lead and about to wrap up enough points to win the F-IV championship (against the SV-650s), the crankshaft snapped, causing the engine to lock-up and spit Lohmeyer over the top of the bike. He was okay but walked away dusty, bruised and in disbelief.

Careful FE analyses of the crankshaft revealed that we were right at the edge of strength for the stock crankshaft design and material. We discussed the possible solutions with several people in the industry. Through FEA, we optimised the radii of the main journal and crankpin fillets and had them shot-peened for additional strength on the next batch of weld-up crankshafts. Even with these modifications, the FEA results were much better than before, but only time would tell.

During the rebuild with the newly modified crankshafts, we finally discovered the piston ring grooves were cut incorrectly and the rings were sticking in the fully compressed state. We had the grooves carefully re-cut and finished and the rings were now floating as they should. About the same time the engines were ready to go back together, we received the titanium rods from Carrillo. The motors were carefully balanced, reassembled and installed for testing.

Feeling comfortable we had found the cause of the power instability and that we had a durable motor with the Carrillo titanium rods and shot-peened crankshafts, we opted to test some big-valve heads in the quest for 90 hp. Unfortunately, I opened the ports too much, losing valuable port velocity and the motors would not even pull for the first dyno run. We had to do a quick swap back to the original heads. Success! The motors pulled stronger than ever on the very first run. The evening tests ended with 88.4 hp @ 13,800 rpm (approximately a 48% power increase over stock). "After so many false starts and much frustration, seeing the dyno chart that night made it all worth it. Finally a new step forward!", expressed Lohmeyer.

We were close enough to meeting our power goals of 90 hp to know we could get there – and we hadn't even begun to optimise the cylinder head, valve train, induction or exhaust systems. When you reach your goal, what else is there to do but set a new one? Our new goal: why 100 hp only seemed appropriate. mt

Left clockwise: Mark Elrod (926) leading an SV650 in the Formula-IV class
Pieces of the failed Design-it Prototype titanium rod after it came apart during a dyno run
Close inspection of the failed Design-it prototype Ti rod revealed a fatal flaw in the manufacturing