Top Fuel dragsters are the fastest accelerating machines on land, and the DSR Army car is one of the quickest (Courtesy of the NHRA)

10,156 bhp!

Lawrence Butcher of **Race Engine Technology**, in conjunction with Don Schumacher Racing and AVL Racing, presents exclusive data on exactly how much power is produced by one of these blown nitro monsters

Since the late 1950s, Top Fuel dragsters, running on a heady fuel mix of nitromethane and methanol, have ruled the roost as the fastest racecars in the world. Power levels are astounding, and for decades drag racers have debated just how much horsepower these giants of the dragstrip produce. Unfortunately, there has never been the opportunity to place a full-blooded, blown-nitro engine on the dyno, as a test system capable of handling such power does not exist.

Until now though, because finally, with the cooperation of leading NHRA Top Fuel team Don Schumacher Racing (DSR) and testing specialist AVL, for the first time ever *RET* has been able to obtain genuine power measurements from one of these behemoths of the racing world. Here's how we did it. ►

The key to the power of a Top Fuel engine is nitromethane fuel and an enormous Roots-type supercharger (Photo: Lawrence Butcher)

If racing were held in Jurassic Park then a Top Fuel dragster would be the Tyrannosaurus Rex. Nothing in motorsport comes close to the sheer brutality and violence that is unleashed when a Top Fuel car launches and is propelled down the strip. The performance figures are startling, to say the least – the average run (over 1000 ft) is completed in around 3.8 s, with terminal speeds in excess of 320 mph. At the time of writing, the NHRA record elapsed time (ET) achieved by a Top Fuel dragster stood at a mind-boggling 3.680 s, set by DSR driver Antron Brown in August this year, while his fellow DSR racer Spencer Massey achieved the highest NHRA speed, 332.75 mph, also in August.

Running a supercharged 495 cu in V8 on a fuel blend of 90% nitromethane and 10% methanol, these cars are capable of pulling up to 6 *g* of acceleration. They will consume more than 13 gallons (60 litres) of fuel from the burnout to the end of a run. Nothing else bears comparison, and anyone who has watched one of these beasts actually run can attest to the pure visceral thrill of the experience. However, one question has always been raised: how much power does a Top Fuel engine produce? The answer, until now, has been elusive.

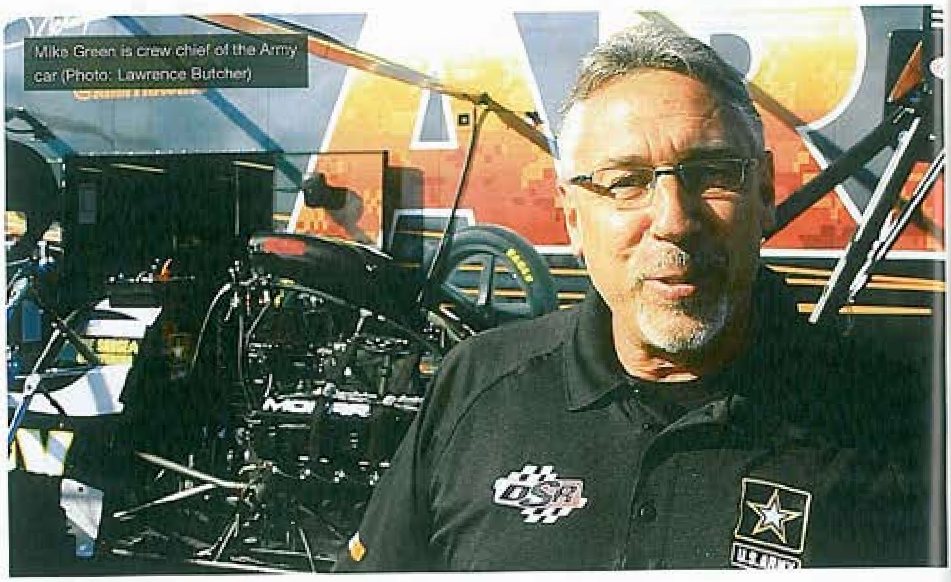
Estimating power

There is not an engine dyno in the world that can restrain the immense power on tap from a blown, nitro-injected Hemi V8. Even the highest capacity dynamometers max out at around 4000 bhp, well short of the previously estimated power of a Top Fuel car. Even if there was a dyno that could measure the power levels in question, the ferocity of the power delivery and lightning-fast response of the engine would probably tear it apart.

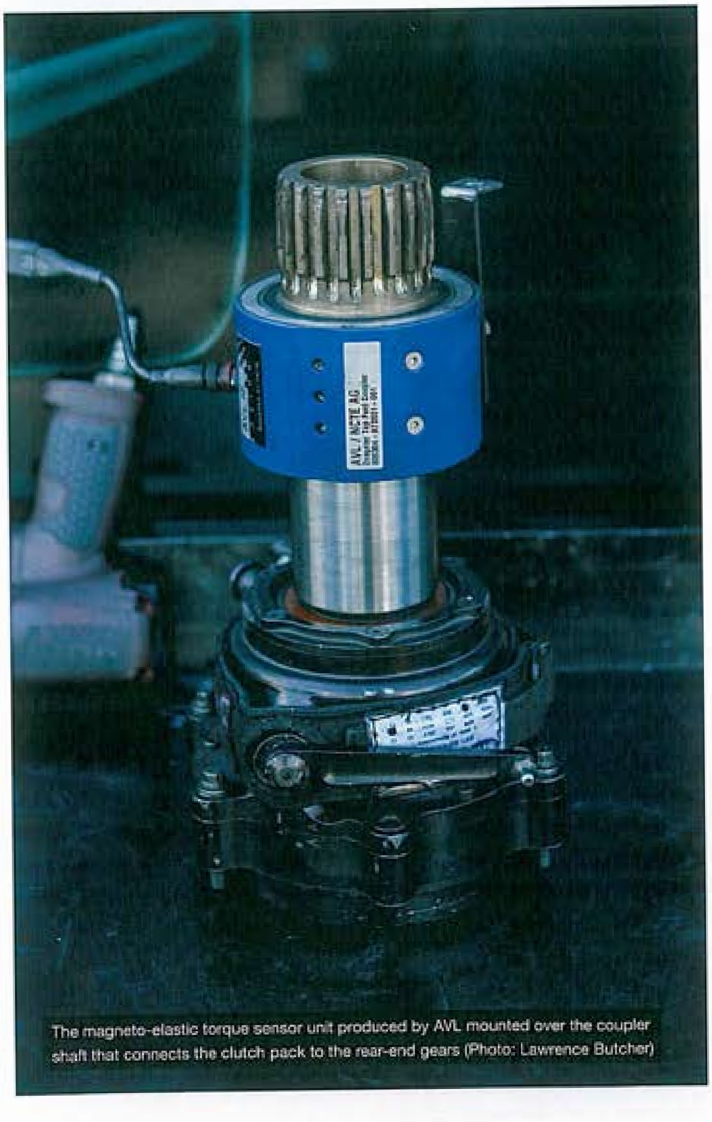
> “Anyone who’s watched one of these beasts actually run can attest to the pure visceral thrill of the experience”

Over the years, there have been many efforts to estimate the power that Top Fuel dragsters develop in order to run the extraordinary times that are seen on the dragstrip. Until now, the only means by which horsepower could be estimated was by using mathematical models, similar to those used throughout racing for performance simulation. To gain an accurate idea of how much power the current generation of cars possess, it has been necessary to consider a number of factors. For example, ET and speed data from various points on the track, vehicle weight, aerodynamic drag, parasitic power losses and inertia all need to be accounted for in order to estimate the power needed for a dragster to run at a specific final ET and speed.

Going back to 1988, it was calculated by engineer Patrick Hale that a record-setting run by racer Eddie Hill of 5.006 s over the quarter-mile required a touch over 4000 bhp. By the turn of the century, performance had climbed inexorably and times had dropped below 4.5 s. Looking at a 4.486 s run by Doug Kalitta in 2003, Hale ascertained that this would need double the horsepower of Hill's run 15 years earlier, putting the figure at around 8000 bhp. With the NHRA switching in 2008 from the quarter-mile to running over 1000 ft (owing to safety concerns relating to top speeds and track lengths), it is not possible to compare runs posted in the past seven years directly with those set previously. However, the same mathematical theory applies, and it would seem that engine power has continued to rise.


Mike Green is crew chief of the Army car (Photo: Lawrence Butcher)

This rise in power is down to teams such as DSR finding ways of getting ever greater quantities of fuel into the engines on each firing stroke. Generally this has been thanks to them gaining better control over the fuel injection system and a greater understanding of the engine's needs. So for example, the DSR US Army-sponsored car featured here has seen extensive modifications to its fuel system over the past five years. This has included the addition of extra auxiliary injectors to enrich the mixture throughout a run as well as improved control systems to govern the rate at which this fuel is added.


The magneto-elastic torque sensor unit produced by AVL mounted over the coupler shaft that connects the clutch pack to the rear-end gears (Photo: Lawrence Butcher)

"With a multi-thousand horsepower motor, even small percentage gains can equate to considerable horsepower increases"

These changes, combined with ongoing modifications to the rest of the combustion system, such as the chamber and port designs, has netted impressive gains. It should also be remembered that when dealing with a multi-thousand horsepower motor, even small percentage gains equate to considerable horsepower increases. It is also the case that while adding more fuel can generate greater power, this still needs to be harnessed and put down through the tyres, so greater engine performance has had to be matched with more effective chassis tuning to ensure that it can be fully exploited.

The latest calculations by Hale, made in 2014, concluded that a figure of 10,000-plus bhp was needed for cars to turn in the 3.8 s, 320-plus mph times that were being set in drag racing's premier class. However, it was still impossible to substantiate that horsepower figure through direct measurement, the golden rule of any simulation being that it has to be verified against real-world data in order to validate it.

As Mike Green, crew chief on the DSR Army car explains, "A lot of people have done calculations to try to figure out or estimate how much horsepower our engines make. As we have developed the engines over recent years, increasing the amount of fuel we put in and

As can be seen here, the installation of the sensor in the car has a minimal impact on the overall packaging (Photo: Lawrence Butcher)

> “The technology is for use where it is not practical to fit conventional sensors – nothing is more extreme than a Top Fuel car”

theoretically the power output, the figure has gone up from 6000 bhp to 8000 bhp, and the number thrown about a lot now is 10,000 bhp. We were not sure if that is accurate, but with this new venture with AVL we have been able to see how close to that figure we actually are.”

The new way

It had been generally accepted that there was no practical means of directly measuring the power output of a Top Fuel engine; however, in recent years, contactless torque sensors have been developed that are suitable for on-vehicle use, which offered a potential solution. Since power is simply a function of crankshaft speed and torque output, and rpm is straightforward to measure, the contactless torque sensor effectively acts as an on-board dyno.

The technology has now advanced to the stage where *RET* contributor David Wood has been able to use it to enforce a maximum power output regulation in powerboat racing (see *RET* 69, March/April 2013), while series such as the WEC use it to gauge the relative power outputs of competing engines for regulatory purposes. In *RET* 42 (November 2009) we ran an article in which contactless torque sensing was used to establish the power output of Ian King's Top Fuel motorcycle engine, and this raised the question: could the same approach be used on a Top Fuel dragster, producing five or more times as much horsepower?

When we looked for a sensor manufacturer prepared to develop a version that could measure the power of a Top Fuel engine and yet be capable of surviving the pummelling a blown-nitro motor in full swing dishes out, we discovered that AVL already uses the technology in Formula One. Furthermore, DSR was keen to work with AVL on developing such a sensor, recognising the benefits that detailed data on engine power could bring.

As Martin Monschein, racing applications manager for AVL who headed up the project explains, the company's motivation for taking on such a challenge was straightforward. “Part of the motivation behind us undertaking this project was to prove the technology we have developed. We wanted to show that it is suitable for any application. It is intended to be used in areas where it is not practical to fit conventional sensing technology, and there is nothing more extreme than a Top Fuel car.”

The sensor

In series such as Formula One and the WEC, the cars nowadays are regularly fitted with torque sensors to measure engine output or the torque experienced by individual driveshafts. Although torque measurement itself is not a new thing, sensors that can survive in the demanding environment of a racecar, and packaged in such a way

AVL was responsible for building the sensor unit, as well as manufacturing a new coupler shaft, which uses a type of magnetic steel that has optimal magnetic properties for sensing applications (Courtesy of AVL)

DSR 'ARMY' TOP FUEL DRAGSTER SUPPLIERS

Block: DSM
Cylinder heads: DSM
Liners: Darton
Oil pan: Williams Oil Pans
Crankshaft: Bryant
Camshaft: Bullet Racing Cams
Timing gear drives: RCD Engineering
Pushrods: Trend
Tappets: Jesel
Rockers: Jesel
Pistons: Venolia
Piston pins: BME
Rings: Mahle
Con rods: DSR
Main bearings: Mahle
Cam bearings: Mahle
Head gasket: Boninfante
Rear main seal: Napa
Fasteners: ARP
Valves: Xceldyne/Manley
Valve seals: CHE
Guide: CHE
Springs: PAC
Injector housing: Aerodine
Intake manifold: AJPE
Ignition: MSD
Plugs: Champion
Barrel valve: Dynamic Machine
Oil pump: System 1
Oil filter: XRP
Supercharger: Chuck Ford/BME
Blower belt: Gates
Fuel pump: Rage

> "Key benefits of these sensors are that they are non-contact and actually use the shaft as part of the sensing element"

that they do not impact on the functionality of the parts they attach to, are a relatively new development. There are different ways to measure torque electronically, but it is the latest developments in the use of magneto-elastic torque sensors that have made it realistic to incorporate such sensors into the data logging systems of a racecar.

Magneto-elastic torque sensors work on the principle that the magnetic properties of a ferromagnetic material will change when stress is applied to it. If these changes in properties can be recorded then a torque figure can be deduced, based on the level of magnetic change compared with the stress placed on the material.

The key benefits of these sensors are that they are non-contact, have no moving parts and actually use the shaft being measured as part of the sensing element. Because they produce signals that are a function of torsional stress, not strain, they can be made much stiffer mechanically than conventional elastic torque sensors; they also offer a far higher frequency response, typically of the order of 2-4 kHz. Measuring surface stress by magneto-elastic methods also provides a non-contacting system for measuring torque in a more compact construction than that required for either the twist angle or surface strain elastic methods, removing the need to incorporate slip rings or other methods of connecting the sensor to the data logging system.

In the case of the system developed by AVL for use on the DSR Top Fuel car, the coupler shaft connecting the clutch to the gears in the rear casing forms the heart of the sensor. AVL took the design of the existing shaft used by DSR and replicated it in a type of steel that provides the best magnetic properties to allow for the changes in magnetic field to be measured. The manufacturing was undertaken in-house by AVL Schrick precision manufacturing, with its advanced machining capabilities actually allowing for some design changes to be made that improved the performance of the coupler in its primary role of transmitting power from the clutch to the rear axle. Notably, AVL re-profiled the splines on the coupler shaft, which resulted in a reduced level of wear.

Given the extreme nature of the environment in a Top Fuel car, the simplicity and inherently rugged design of a magneto-elastic sensor made it the only viable option. Also, the sensor not only had to be able to survive the punishment of a run down the track, but also the subsequent engine strip-down. With limited time between runs, Top Fuel pit crews will tear down and rebuild an engine in well under an hour, so having to remove a delicate sensor would add further complication to an already fraught process and greatly increase the chances of damaging the sensor. In the case of the AVL sensor, the coupler shaft can be fitted and removed in exactly the same way as the non-instrumented coupler, with the only additional operation being the removal of a single ruggedised wiring connector.

The sensor housing, as shown on page 12, contains the sensor element that detects the variations in the shaft's magnetic field as torque is applied. Although the sensing technology is contactless in nature, in order to help the sensor operate reliably in a Top Fuel car, AVL chose to encase the sensor in a bearing housing that slides over the coupler shaft. "The technology is intended for use as a non-contact unit, but for this application, since vibrations are so high, the movement of the sensor relative to the shaft would have been too much," Monschein explains. "There was also the problem of debris from the clutch getting between the sensor and shaft to account for. So with this installation we opted to use a bearing housing incorporating the sensor."

As such, the bearing housing ensures that the sensor element is kept a set distance from the shaft, helping to ensure that reliable readings are obtained. The bearings used are ceramic ball bearing units, so they

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HEART OF THE BEAST

Powering the Don Schumacher Racing 'Army' Top Fuel dragster is a 495 cu in (8120 cc) engine based around the Chrysler Hemi architecture. This is a classic 90° V8, with pushrod actuation of two valves per cylinder, with the valves arranged in a hemispherical combustion chamber, the inlet valves canted inward and the exhaust valves sloping outwards, creating a 56° included angle, the same as the original Hemi.

Although referred to as a 'Hemi', beyond basic dimensions, a modern Top Fuel engine has very little in common with its production-based forebear. For one thing, the heads and block are machined from aluminium billet, and feature no water jackets for cooling, allowing for a very strong structure to be created, which is necessary owing to the extreme combustion pressures when running. The block encases a billet steel crankshaft, with a 4.5 in (114 mm) stroke running in five plain bearings, which drives aluminium con rods topped with three-ring alloy pistons.

The prodigious power of the engine is down to the fuel and induction system. Running on a nitromethane-methanol mix means that, compared with gasoline, about eight times the amount of fuel can be crammed into each cylinder per stroke. The oxygen atoms in nitromethane (CH_3NO_2) mean that when combusted, it breaks down into gaseous products that create large amounts of heat and pressure, without the need for adding further oxygen to the mix; this is referred to as anaerobic combustion.

It is this characteristic of the fuel that means the route to more power with a nitro engine is to keep adding fuel. It should be noted though that being able to add eight times more fuel to the cylinder does not equate to eight times the power compared with a similar gasoline engine, as nitromethane has a lower thermal energy; it does, however, effectively double the power output.

Combustion is initiated via spark ignition, but typically only half of the fuel in the cylinder is burnt before the charge air-fuel mixture is spent. After this point, the remaining fuel, which has been heated by the initial combustion, continues to combust anaerobically, and this occurs for much of the duration of the combustion stroke.

The nitromethane mixture is injected into the inlet air stream (which is forced into the engine by a Roots-type supercharger) via no fewer than 37 injectors, located in the injector hat (which extends above the supercharger) and in the supercharger itself, the inlet runners and the heads. Unsurprisingly, the fuel pump used to supply the nitro is as outlandish as the rest of the engine, with the mechanical gear pump capable of delivering more than 100 gallons per minute. The fuel line from the tank to the pump has a diameter similar to the coolant hoses found on more mundane machinery.

Although the Roots-type blower is by no means the most efficient type of supercharger, the use of more effective high-helix or centrifugal blowers is not permitted by the regulations. Roots blowers work most efficiently at relatively low pressure ratios, and the impact on charge pressure of the volume of fuel in the inlet is considerable. On launch, manifold pressure will be at about 4.0 bar absolute, but by the end of the run the increased volume of fuel in the manifold will cause this to exceed 5.0 bar.

While the sight of a Top Fuel dragster launching may appear to be little short of an explosion, it is in fact a carefully controlled event, with the crew chief being responsible for finely balancing a host of tuning parameters. This involves increasing or decreasing fuel delivery, increasing or decreasing ignition timing, and clutch operation, to put exactly the right amount of power to the rear wheels to match the track conditions at the time of the run. Fuel delivery and ignition timing are controlled through a combination of electronic timers and analogue valves in the fuel system (closed-loop control is not permitted), and the clutch (there is no conventional gearbox) is a six-plate unit with a combination of a pneumatic release bearing and weighted 'fingers' to govern lock-up.

As the car launches down the track, the pneumatic release bearing, which is also controlled by a timer, begins to lock the clutch up. Once the bearing is fully released, the initial clutch pressure is controlled by a number of primary clutch arms, which are weighted levers that increase the clamping pressure of the clutch as engine rpm rises. After the first second or so of a run, a second set of levers comes into play, further increasing the clamping load on the clutch pack unit until engine rpm reaches a point where the clutch is fully locked up.

The art of the crew chief is in finding the right rate at which to lock the clutch up, while deploying the maximum amount of power possible without uncontrolled tyre slip occurring (a Top Fuel tyre is in a constant state of controlled slip during a run).

have very low friction and thus a minimal impact on the rotation of the shaft. By being able to seal the sensor element in this housing, it could also be effectively isolated from outside pollutants.

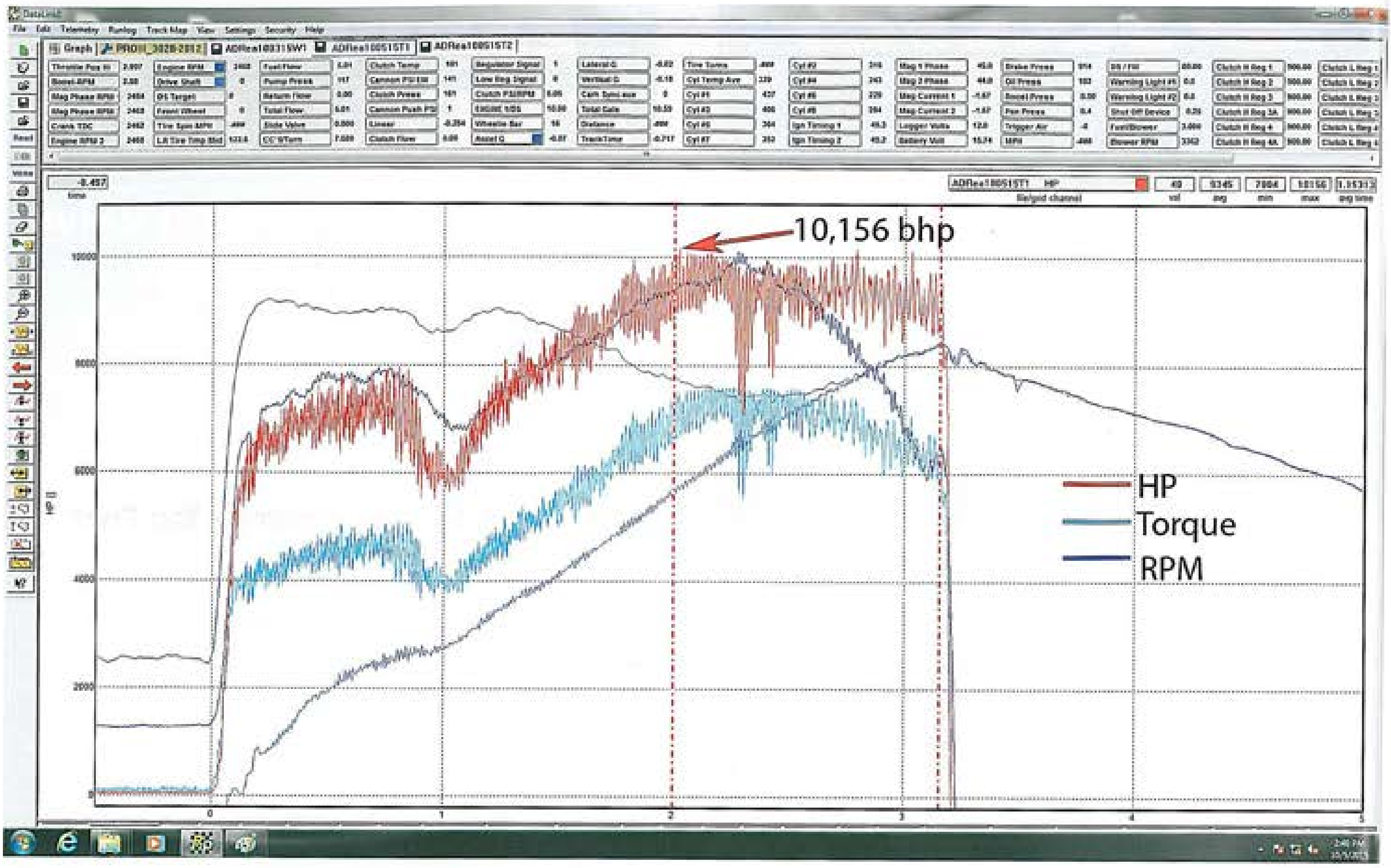
Monschein notes, "In applications where we have run these sensors before, the sensor is simply mounted on a ring around the shaft being measured, or on a bracket above the shaft. But for this installation, the dust coming out of the clutch meant we would have to clean it between every run or it could start failing during a run. So that was our main concern." The mounting of the sensor/bearing unit is straightforward, using a simple yet rigid bracket to attach it to the chassis.

The results

As the AVL sensor had not at the time of this initial deployment been approved for competition by the NHRA, the only time it could be run was during track testing, when teams can run non-approved parts. The test chosen for the sensor's debut was set for the day after the NHRA's Keystone Nationals at the Maple Grove Raceway in Pennsylvania, a round of the NHRA's championship drag racing series.

The race weekend itself was a successful one for DSR, with the Army-sponsored car to which the sensor would be fitted making it to the final before driver Tony Schumacher was beaten by fellow DSR racer Antron Brown. This was despite the event almost becoming a washout, with torrential rain lashing the US eastern seaboard and preventing any serious running until Saturday afternoon. The delayed schedule had a knock-on effect on the planned test running on the Monday, with the sportsman classes needing to complete their finals on the Monday morning.

As it was, DSR was able to lay down only one definitive pass during the late-morning test session, before the NHRA Safety Safari team left with its track prep equipment, negating the benefit of any further passes. To explain, the track is prepped using a machine that rolls rubber onto the surface, with the NHRA's and track owner's machines using different rubber compounds. Tony Schumacher attempted a second run but shook the tyres off the line, meaning no meaningful power numbers could be recorded. Fortunately though, one run was all that was needed to validate the sensor installation and prove it was working correctly.



The evidence! The data here shows the power (red) and torque (light blue) curves of the engine during the run. The blue line that runs almost in sync with the power curve is the acceleration of the vehicle, while the topmost line is engine rpm. The steadily rising blue line at the bottom of the chart is driveshaft rpm. Peak and average power values are shown in the top right corner (Courtesy of DSR)

Once the car was back in the pits and the data downloaded, it was immediately clear that the test had been successful.

Neal Strausbaugh, assistant crew chief on the Army car, was the first to look at the data. "We have done a lot of sensing of various things over the years, and I will admit that we were sceptical about whether the sensor from AVL would work, simply because we were not familiar with the technology," he says. "We have tried things in the past with high-speed monitoring of sensors and we have failed a lot of sensors. But the guys from AVL were always on top of it and they had done their homework when they showed up with their technology.

"Now that I've seen the data, I'm very pleased with what we have got. We just didn't know what the power would look like, we don't spend a single second on an engine dyno in our world, but from doing some maths on the peak loads during a run, we had thought it could be around 10,000 bhp. But to be honest, I am shocked that the power is there!"

The headline figure of over 10,150 bhp is impressive enough in its own right, but the figures produced by the engine across the entire run bring home just how powerful a Top Fuel engine is. Looking at the data trace shown in the figure above, the average power output across the run deserves closer attention. From just under 0.2 s into the run to the point where Schumacher backs out of the throttle (at around the 850 ft mark) the engine is producing well over 7000 bhp, only dropping below this number as the clutch pulls the revs down just before the 1 s mark. It can also be seen that, from just under 1.5 s into the run until the end, power is continually over 8000 bhp.

"From our end it is great that the data we have collected is of such high quality – I am actually ecstatic with the results!"

With one of the great unanswered questions of drag racing now solved, Strausbaugh sums up his feelings about the feat that's been achieved here, even with only one run's worth of data to study. "Looking at the averages across the run and seeing those at well over 9000 bhp, with the peak at over 10,000, that is very impressive for us," he says. "From our end it is great that we are actually up there and that the data we have collected is of such a high quality – I am actually ecstatic with the results! This could have been a test where we were just presented with a bunch of squiggly lines that didn't correlate with anything – a lot of the time you have to work very hard to pick the information out of the data – but what we can see here is very smooth data and we are very excited to have it."