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Boosted Beyond Bolt-Ons: Project White Lightning Gets Even More Power

It must really chap the hides of all those Mustang owners out there that the hottest horse in the Blue Oval stable is a truck. Even the much-heralded SVT Cobra, with its high-revving DOHC four-valve motor, takes a back seat to the mighty Lightning pickup truck. In all fairness to the ‘Stang owners, the Lightning is no ordinary truck. Sharing its SVT origin with the 4.6L Cobra, 2.0L Focus and 351-based haulers of yesteryear, the Lightning more than makes up for those free-flowing, four-valve cylinder heads with displacement and boost. Compared to the bad-boy 4.6L Cobra, the SVT Lightning’s two-valve modular motor seems a trifle unsophisticated. Though valvetrain deficient, the Lightning finds motivation via displacement and boost. At 5.4 liters, the Lightning motor sports 0.8 liters (48 cubic inches for those not metrically inclined) of additional displacement. With that displacement comes something very important, something decidedly lacking in the SVT Cobra motor, namely, torque. Further improving that torque production (and necessary to motivate a truck with a portly 4,500-pound curb weight) is boost provided by an Eaton M112 positive displacement supercharger. The combination of displacement plus boost makes for one impressive hauler, but just because it's good doesn't mean we can't make it even better.

The early Lightnings (such as our '99 model) were equipped with an Eaton-blown 5.4L, pumping out 360 hp and a whopping 440 ft-lb of torque. Though impressive even in stock trim, this supercharged motor is just getting started in terms of potential power production. Unlike the owners of lesser, normally aspirated motors, Lightning owners reap huge rewards when it comes time to modify their motors. Supercharged motors — and, for that matter, all factory forced-induction motors — respond very well to aftermarket modifications. The normal route to...
performance, including exhaust, air-intake, and mass-air-meter modifications, yields big dividends in terms of power, much more so than those seen on normally aspirated V-8 motors. After experimenting with all the usual bolt-ons, Lightning owners can always resort to jacking up the boost via a smaller blower pulley or larger crank pulley. The benefit of additional boost (as we will see shortly) is not just more top-end power, but an increase seen across the board. Increasing the boost on positive-displacement-equipped motors results in a power increase from idle to redline, and a consistent one at that. It is not unusual for Lightning owners to experience gains of 50-80 hp without so much as removing the valve cover.

Most Lightning owners are well aware that their heavy haulers can hit 100 mph in sub-14-second e.t.s right off the showroom floor. Credit the impressive, ultra-flat torque curve offered by the positive-displacement Eaton supercharger. As impressive as the stock performance is, and as easy as the supercharged motor is to modify, there is (as always) a limit to the power offered through external modifications. One of the factors limiting performance may be the supercharger itself. While many enthusiasts mistakenly think that coming up with more power is as simple as cranking up the boost, there is a limit. Unfortunately, no form of forced induction can be cranked up indefinitely. More so than other forms, positive-displacement superchargers are not efficient enough to sustain elevated pressure ratios.

Turbos and even centrifugal superchargers run well at higher boost levels, but positive-displacement superchargers, especially the Roots-style Eaton M112 supercharger used on the Lightning, are generally used on low-boost applications for average to moderate performance gains.

One reason behind the different usage for different superchargers is heat. Most positive-displacement superchargers are nothing more than air pumps, moving air from one side of the blower to the other. They are not true compressors, as no internal compression takes place. Boost (pressure) is created by exceeding the amount of air the engine can ingest between the blower and intake valve. Basically, the positive-displacement blower processes (grabs from one side and moves to the other) more air than the motor can process. The result is boost pressure. Unfortunately, the lack of true internal compression greatly reduces the efficiency of this method of supercharging. The result of this inefficiency is heat. Heat is normally a byproduct of any type of forced induction. Positive-displacement superchargers create more heat per pound of boost than other, more efficient, forms. As this test demonstrated, there are distinct differences between different types of positive-displacement superchargers as well.

As giant air pumps that lack true compression, positive-displacement superchargers improve the power output of a motor by force-feeding air (combined with an appropriate amount of fuel) that the
motor could not otherwise process. The amount of additional airflow supplied by the supercharger is dependent on two variables: the size or displacement of the supercharger and the speed relative to the motor. An example would work well here. The designation M112 given to the Eaton supercharger on our 5.4L Lightning refers to the displacement in cubic inches offered by one revolution. One-hundred-twelve cubic inches equals 1.84 liters of displacement per revolution. All that is needed to calculate the potential boost offered by our (or any) supercharger is to use the following formula:

\[
\text{Blower displacement} \times \text{Drive ratio} \times 14.7 - 14.7 \div \text{Engine displacement} \div 2
\]

Plugging in our 1.84L blower, our drive ratio using the stock 7.5-inch crank pulley, and 3-inch blower pulley, and engine displacement of 5.4 liters, we get the following formula:

\[
\frac{1.84 \times (7.5 \div 3.0)}{5.4} \div 2 \times 14.7 - 14.7
\]

\[
\text{Potential Boost} = \frac{4.6}{2.7} \times 14.7 - 14.7 \div 10.34 \text{ psi of potential boost}
\]

Our testing would indicate that this was about 1 psi high, as the stock setup produced 9.3 psi. The difference can be attributed to inlet restrictions that reduce the flow potential and therefore reduce pressure in the motor. This equation can be used for any type of positive-displacement supercharger, including the Autotorq from Kenne Bell, a Whipple Charger, a MagnaCharger, and even an old GMC Roots-style 6-71 blower.

As indicated previously, there is a limit to how far you can go with boost and airflow. Where was that limit on our supercharged 5.4L Lightning? We aimed not only to find the limit of the Eaton M112 supercharger, but to exceed it by replacing it with a more efficient twin-screw Autotorq design offered as an upgrade for Lightnings by Kenne Bell. Rather than simply install the Kenne Bell supercharger upgrade and be done with it, we decided to show Lightning owners how far you could take your existing combination before upgrading becomes necessary. After all, not all of us want more than 500 hp at the wheels and 600 lb-ft of torque. Who are we kidding, what Lightning owner wouldn't jump at the chance to drive around with the baddest Lightning on the block? Along the way, we decided to monitor every possible parameter to ensure we had plenty of data should our readers have any questions. To that end, we monitored charge temperatures before and after the intercooler, boost pressures before and after the intercooler, and vacuum present at various positions along the inlet tract. This allowed us to isolate the

12. Since we planned to crank up the boost during our blower comparison, we installed a set of Denso Iridium spark plugs. Even with the stock ignition, the Denso plugs allowed us to exceed 20 psi without a single misfire.

13. Vacuum fittings were installed at various points in the inlet system. This vacuum fitting was used in order to determine whether the factory airbox was a restriction.

14. We also installed vacuum fittings to test the mass air meter.

15. A third fitting was installed in the front of the inlet manifold to test the throttle body.

16. We tapped into one of the factory fittings to test for restrictions in the manifold itself.

17. The opening in the inner fenderwell was previously modified to improve airflow to the factory airbox.

18. Data logging equipment was used to monitor changes in boost pressure and air and water temperature before and after the intercooler. Shown is a thermocouple for testing the water temperature used in the air-to-water intercooler.

19. The factory 42-ponds-per-hour fuel injectors allowed us to easily exceed 500 hp at the wheels.

20. All of the testing was done through the factory catalytic converters.
21. Kenne Bell was serious about its data logging. The cab of the Lightning was stuffed with all types of equipment to provide accurate data during the dyno testing.

22. First up was the Eaton M112. In baseline trim (7.5-inch crank pulley and 3-inch blower pulley), the 5.4L Lightning produced 348 hp at 9,3 psi of boost.

23. Johnny Lightning supplied several different aluminum crank pulleys that allowed us to increase the blower speed to improve the power output. The largest measured a full 9 inches.

24. Swapping the blower pulley on the Eaton M112 was easier said than done. We resorted to swapping out the entire nose drive assembly.

25. Equipped with the 2.75-inch blower pulley, 3-inch crank pulley and a modified inlet tract (throttle body and cone filter), the 5.4L pumped out 415 hp at the wheels.

26. After the Eaton M112 was maxed out, the Autotor was installed in place of the stock supercharger.

27. It was necessary to grind the upper inlet manifold before mounting it on the Autotor supercharger. Use of the factory intake hardware ensured that any power gains would be the result of the supercharger itself.

28. Replacing the Eaton M112 with the twin-screw Autotor resulted in a gain of 55 hp at the wheels using identical crank and blower pulleys.

The culprit robbing our airflow. Naturally, the ever-important air/fuel ratio was part of the data-logging equation, as was spark timing, engine speed and mass air voltage. In fact, nearly every variable available on the scanner was available for viewing after each run. In short, we had access to every last bit of information to ensure differences in power could be attributed to the test component at hand.

We mentioned charge temperature as one of the variables employed in the data logging. Since heat is a natural byproduct of compression, a supercharger producing boost will always raise the inlet air temperature above ambient. Hot air is the enemy of a motor, as hotter air is much more likely to cause detonation. Obviously understanding a great deal about both the nature of positive-displacement superchargers running near 10 psi and the need to suppress detonation, Ford (SVT) installed an intercooler in the system to lower the charge temperature. The factory SVT intercooler was an air-to-water design, offering impressive capabilities. Once we got the boost cranked up to a whopping 21 psi, the charge temperature of air exiting the supercharger exceeded 300 degrees Fahrenheit. The air-to-water intercooler dropped this elevated charge temperature down to a tad more than 100 degrees, knocking out 200 degrees in the process. Though no additional power was produced by this reduction in charge temperature, the result was a dramatic change in the detonation threshold.

The idea behind the testing was to first take our Project White '99 Lightning motor and upgrade it to current 2001 specs. The change included a new airbox, mass air meter, supercharger, intake manifold, intercooler, and processor provided by Ford SVT. Oddly enough, these components did not create any more power than the stock components did. We even tried running a test on just the new intake manifold and intercooler, thinking the longer runners in the 2001 intake might offer some additional ram effect. The dyno results showed the 3-5 inches of additional runner length had little to no effect on the power curve. Generally speaking, longer runners produce better low- to midrange power, while shorter runners increase power closer to redline. The runner length must be tuned to the specifics of the motor (i.e. cam timing, exhaust primary tubing, and head flow). The early intake offered no runner length, just a common plenum open to the head port. Adding 3-5 inches had little effect on the operating range of the supercharged engine. The installation of the late-model components did provide the benefit of a larger 90mm mass air meter, which allowed us to exceed 500 hp at the wheels before topping out the electronics in the meter. The same could not be said of our original 80mm meter.

Equipped with the 2001 components and a modified after-cat exhaust (but factory cat pipe), the supercharged 5.4L Lightning produced 348 hp at the wheels and 439 lb-ft of torque. As a testament to the torque production capabilities of a...
positive-displacement supercharger; the torque curve exceeded 400 lb-ft at the wheels from 3,000 rpm (our lowest load speed) to 4,800 rpm. The Eaton-supercharged 5.4L also exceeded 300 hp at the wheels from 3,700 rpm all the way to redline. These are power numbers a four-valve Cobra can only dream of. The 5.4L was equipped with all of the stock components, including a 7-1/2-inch crank pulley, a 3-inch blower pulley, and all of the factory inlet system. The Eaton supercharger produced a maximum boost reading (taken at 5,000 rpm) of 9.3 psi. According to the data logging equipment set up by Kenne Bell, the charge temperature exiting the blower measured 207 degrees Fahrenheit before being cooled to just 85 degrees by the ultra-efficient air-to-water intercooler. Ford SVT obviously programmed the processors to produce a safe air/fuel mixture, as the Kenne Bell-supplied Horsa real-time air/fuel monitor indicated the ratio hovered at a safely rich 10.32:1.

Testing was run on the Eaton using four different crank-pulley sizes ranging from the stock 7.5-inch pulley to a 9-inch pulley supplied by Johnny Lightning. We also employed two different blower pulleys, the standard 3-inch and a smaller 2.75-inch. The physical size of the Eaton blower snout prohibited installing anything smaller than the 2.75-inch blower pulley without machining the snout down to accept the inside diameter of the pulley. Removal of the stock crank pulley took some doing, but installation of either the 8.5-, 8.75-, or 9-inch pulleys was quite easy once the factory pulley was out of the way. Each step up in pulley ratio (down in blower pulley or up in crank pulley) brought about a linear change in power and boost. The power gains were roughly equivalent to 10 psi per pound of boost. This was not surprising, since a change in pulley ratio increased the speed of the supercharger relative to the engine at every rpm. The result was a gain in power across the board.

Eventually, we installed the big-daddy 9-inch crank pulley and ran the motor with the standard 3-inch blower pulley. The combination resulted in a blower speed three times that of the engines' with a drive ratio of 3:1, the supercharged motor cranked out 13.4 psi of boost and 396 hp. The change in pulley ratio increased boost pressure by 4 psi and increased peak power output by nearly 50 hp over the baseline run with the stock pulleys. Since we had such luck with the change in pulley ratio, we continued our hunt and installed the smaller 2.75-inch blower pulley, upping the drive ratio to 3.27:1. The results were less than dramatic, as the peak boost (always taken at 5,000 rpm) measured 14.1 psi, but the peak power changed only slightly to 398 hp. There were power gains evident at the beginning of the run, but not near the top. One thing we noticed was that the vacuum present in the inlet tract was sizable at more than 2-1/2 inches. This type of vacuum represented a restriction, meaning that our motor was struggling to breathe. Swapping out the stock airbox and throttle body for a cone filter and a prototype billet throttle body from AccuFab resulted in a jump in power to 415 hp. The boost rose slightly to 14.7 psi, indicating the reduction in the inlet restriction indeed provided more airflow.

Realistically, we had reached the limit of the Eaton supercharger, both in terms of flow and rpm potential. The limited power gain offered by the increase in pulley ratio (3-inch down to 2.75-inch) indicated that the blower was nearly maxed out in terms of power production. An outlet temperature of 284 degrees indicated that the blower was certainly heating the air in its effort to supply the motor. Luckily, the intercooler kept things cool at just 103 degrees. As we said before, this intercooler kicked some serious butt. According to our handy-dandy calculator, our 9-inch crank pulley and 2.75-inch blower pulley produced a maximum rotor speed of 17,672 rpm at an engine
speed of 5,400 rpm. This represented a gain of 4,172 rpm over the stock setup. We were now running the M112 well above the maximum rpm recommended by Eaton or Ford. Why do you think they made the pulleys so hard to change? They didn’t want enthusiasts popping on a pulley and damaging the bearings in the supercharger. We had run out of available blower pulleys, run out of available crank pulleys, and flat-out run out of blower. It was time for a change.

In an effort to keep the comparison between the two positive-displacement blowers even, Kenne Bell made a custom adapter to mount the Autorotor twin-screw supercharger to the stock Lightning lower manifold. The twin-screw supercharger was further modified to accept the stock inlet manifold. These modifications allowed the Autorotor to be installed in place of the Eaton, using all of the factory inlet hardware. In doing so, any differences in power could be attributed solely to the differences in the two superchargers.

Once bolted in place, the 5.4L was run first with a pulley ratio identical to the stock Eaton tests. In order to compare it to the baseline runs with the Eaton, we installed a 7.5-inch crank pulley and a 3-inch blower pulley. The results were impressive. Using an identical pulley ratio, the Autorotor pumped out 403 hp, besting the Eaton by a whopping 55 hp. Simply swapping the blowers resulted in that much gain. The gains were not surprising, since the boost gauge indicated a full 13.2 psi. You will remember the Eaton only managed to put out 9.3 psi using the same pulley ratios. Given the similarities in displacement between the two blowers, the difference in boost production and power output was significant.

Since the more efficient Autorotor produced a higher boost reading, we wanted to see what happened if we penalized the twin-screw and altered the pulley ratio to reduce the boost to 9.3 psi to match the Eaton. The results once again favored the Autorotor, as the KB blower produced 364 hp to the Eaton’s 348 hp at an identical 9.3 psi. Credit the greater airflow and less parasitic loss associated with the twin-screw for the difference in power between the two blowers. As further testament to the efficiency of the Autorotor, the charge temperature exiting the blower was some 42 degrees lower than the Eaton at the same boost pressure (the two had near-identical charge temperatures exiting the intercooler). In fact, the charge temperatures exiting the Autorotor at 13.2 psi were slightly lower than those exiting the Eaton at just 9.3 psi. Less parasitic loss, more flow, and lower charge temperatures all combine to make the twin-screw Autorotor a seemingly more efficient supercharger. As we were to see, the Autorotor was just getting started in terms of power production.

As in our previous efforts with the Eaton M112, we increased the boost on the Autorotor in an effort to find the limit of the supercharger. Naturally, the motor was run with 100-octane fuel to keep detonation from rearing its ugly head, but credit a (safe) rich air/fuel ratio and one heck of an intercooler for keeping the motor alive during all the testing. We eventually installed the 9-inch crank pulley and equipped the Autorotor with the same size 3-inch pulley used in the previous Eaton test. Equipped with the 3-inch blower pulley and the 9-inch crank pulley, the motor produced 396 hp with the Eaton supercharger. Equipped with an identical drive ratio, the Autorotor spun the rollers to the tune of 449 hp at the wheels. The Autorotor topped out at 15.8 psi, but there was a great deal of vacuum present in the inlet system. Before going on to a smaller pulley, we opted to make some inlet changes. Obviously the stock inlet tract was not designed to flow enough air to support 449 hp at the wheels.

The next test was run with the 9-inch crank pulley, the 2.75-inch blower pulley, and the AccuFab throttle body and cone filter. This test was identical to the earlier tests made with the Eaton. Incidentally, later tests were run on the effectiveness of the AccuFab throttle body and we were quite impressed to find that the larger prototype throttle body improved power by 17-20 hp. Equipped (as the previous Eaton test) with the 9-inch crank pulley, the 2.75-inch blower pulley, and a free-flowing inlet tract, the Kenne Bell supercharged 5.4L Lightning motor topped out an amazing 20.6 psi and 511 hp at the wheels. At such an elevated boost level, we have come to expect an elevated charge temperature. The data logging equipment indicated a blower exiting temperature of 307 degrees, but the intercooler was obviously still on the job, yanking out a full 200 degrees to give us a finished charge.

Graph 1: Kenne Bell Bolt-On Blower Upgrade
This graph illustrates what happened when we bolted on the Kenne Bell Autorotor supercharger upgrade on the ’99 Lightning. Using identical crank and blower pulleys as well as a factory inlet system, the Autorotor supercharger improved the peak power output by 55 hp. Effectively, the only change made during these tests was the design of the supercharger itself (Roots vs. twin-screw). Obviously the twin-screw Autorotor demonstrated its superiority by producing more boost (13.2 psi vs. 9.3 psi), more power (403 hp vs. 348 hp), and a lower charge temperature (204 degrees vs. 207 degrees). It is important to note that the charge temperature was lower exiting the Autorotor, despite the much higher boost pressure.

Graph 2: Eaton vs. Autorotor (Both at 9 psi)
This test was run to demonstrate what happened when we reduced the boost on the Autorotor to match the Eaton. We installed a much larger supercharger pulley on the Autorotor to slow it down relative to the motor, reducing the boost from 13.2 psi to 9.1 psi. Even penalizing the Autorotor by slowing it down, it still outpowered the Eaton 384 hp to 349 hp. The charge temperature had dropped on the Autorotor to just 165 degrees (compared to 207 degrees for the Eaton). Out near 5,300 rpm, the difference between the two blowers was a considerable 28 hp. Credit the better flow rate and lower parasitic loss of the more efficient Autorotor for the power gains.

Graph 3: Maximum Power (9-Inch Crank and 2.75-Inch Blower Pulley)
After running both blowers with a variety of crank and blower pulleys, we eventually installed the largest crank pulley – the 9-inch — and the smallest (for the Eaton) blower pulley – the 2.75-inch. The tests were run with inlet modifications consisting of a larger AccuFab throttle body and cone filter on the factory 90mm mass air meter. The superchargers were run in identical trim. Equipped with the Eaton supercharger, the 5.4L motor pumped out an impressive 415 hp. Once we installed the Autorotor from Kenne Bell, the power jumped to 511 hp. The only change was the supercharger. Running an identical pulley ratio, the Autorotor pumped out 6 additional psi of boost (20.6 psi vs. 14.7 psi) and nearly 100 more horses. The smaller differences in power at lower engine speeds indicated by the graph were a function of how we rolled into the throttle during each test.
The data logging also indicated that we were nearing the 5-volt ceiling on the factory 90mm mass air meter, but we felt there was sufficient safety for one more change. We installed a 2.57-inch blower pulley in place of the 2.75-inch pulley used in the previous test. The result was yet another gain to 522 hp and a whopping 600 lb-ft at the wheels. Boost peaked at 21.6 psi for this final run.

Here are a couple of important things to remember about this adventure. This testing clearly demonstrated the superiority of the twin-screw design over the Roots-type M112 manufactured by Eaton. It also demonstrated how efficient the factory Lightning intercooler was at pulling away the elevated charge temperature. Our recommendation would be not to change a thing about the intercooler — it works great. These are a few other important things to ponder, namely the fact all that of this power was made without so much as lifting a valve cover. You read that right: this Lightning motor had no internal modifications whatsoever. All of the power runs, including the many exceeding 500 hp, were done through the factory cat pipe with the stock injectors, fuel pump(s), and mass air meter. Given the responsiveness of the Lightning motor to these modifications, we feel certain that dropping the stock cat pipe and manifolds in favor of headers and an off-road pipe combined with a larger MAF and a smaller blower pulley might yield as much as 575-600 hp at the wheels — all without touching the motor. However, most of these modifications would render our truck smog illegal in the wonderful state of California where it lives. For now, we'll be happy with bolting on an extra 55-100 hp.

**Graph 4: Boost Curves**
The data logging provided a wealth of information, including this pair of boost curves generated during runs with the Eaton and Autorotor. The curves were generated during the runs illustrated in the graph titled Kenne Bell Bolt-On Blower Upgrade. The graphs were generated using identical crank and blower pulleys. Note that the two positive-displacement superchargers produced near-identical boost curves. Though equipped with identical pulley ratios, the Autorotor produced 3 psi more boost.

**Graph 5: A Lesson in Efficiency**
This graph helps illustrate one measure of the efficiency of the two superchargers, namely the charge temperature. To produce this graph, we ran the two superchargers at identical boost levels. Remember, boost is a measurement of pressure, and pressure creates heat. The greater the pressure, the greater the heat. Obviously, pressure is not the only thing that creates heat; the two superchargers produced decidedly different temperatures curves during the respective runs. Running from approximately 6 psi to 9 psi, the temperature of the air exiting each blower increased with pressure. The air exiting the Eaton at 9 psi reached 207 degrees, while the maximum temperature from the Autorotor was only 165 degrees. The twin-screw design is simply more efficient at pumping air than the Roots.

**Graph 6: Intercooler Efficiency**
Even before pumping up the boost on the Lightning motor, we realized that the stock (late-model) intercooler was pretty efficient. After installing the Autorotor and cranking up the boost beyond 20 psi, we found out just how impressive it really was. Running 21.6 psi and thumping out 522 hp and 600 lb-ft of torque, the charge temperature exiting the supercharger measured 320 degrees. Not a problem, as the stock intercooler dropped it down to a hair more than 100 degrees without working up a sweat. The intercooler was responsible for yanking out 200 degrees. The data logging allowed us to view the two temperatures curves exiting the blower and intercooler. Note that even as the charge temperature out of the blower increases dramatically, the intercooler just creeps up slowly. This intercooler system really worked.

**Graph 7: AccuFab Throttle Body**
Check out the power gains offered by the new AccuFab throttle body. While we had the truck on the dyno, we decided to test the merits of the individual components. Our vacuum ports told us that there were indeed restrictions in the inlet. Adding the larger AccuFab throttle body resulted in 17-20 additional horsepower over the factory piece.

**Sources**
- **AccuFab**
  Dept. TR
  1514 B. E. Francis
  Ontario, CA 91761
  (909) 930-1754
- **Ford Motorsport SVT**
  Dept. TR
  14555 Rotunda
  Dearborn, MI 48120-1273
  (313) 845-2273
- **Johnny Lightning**
  Dept. TR
  25 Archery Rd.
  New Providence, PA 17560
  (717) 786-4670
- **Kenne Bell**
  Dept. TR
  10743 Bell Ct.
  Rancho Cucamonga, CA 91730
  (909) 941-6646

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