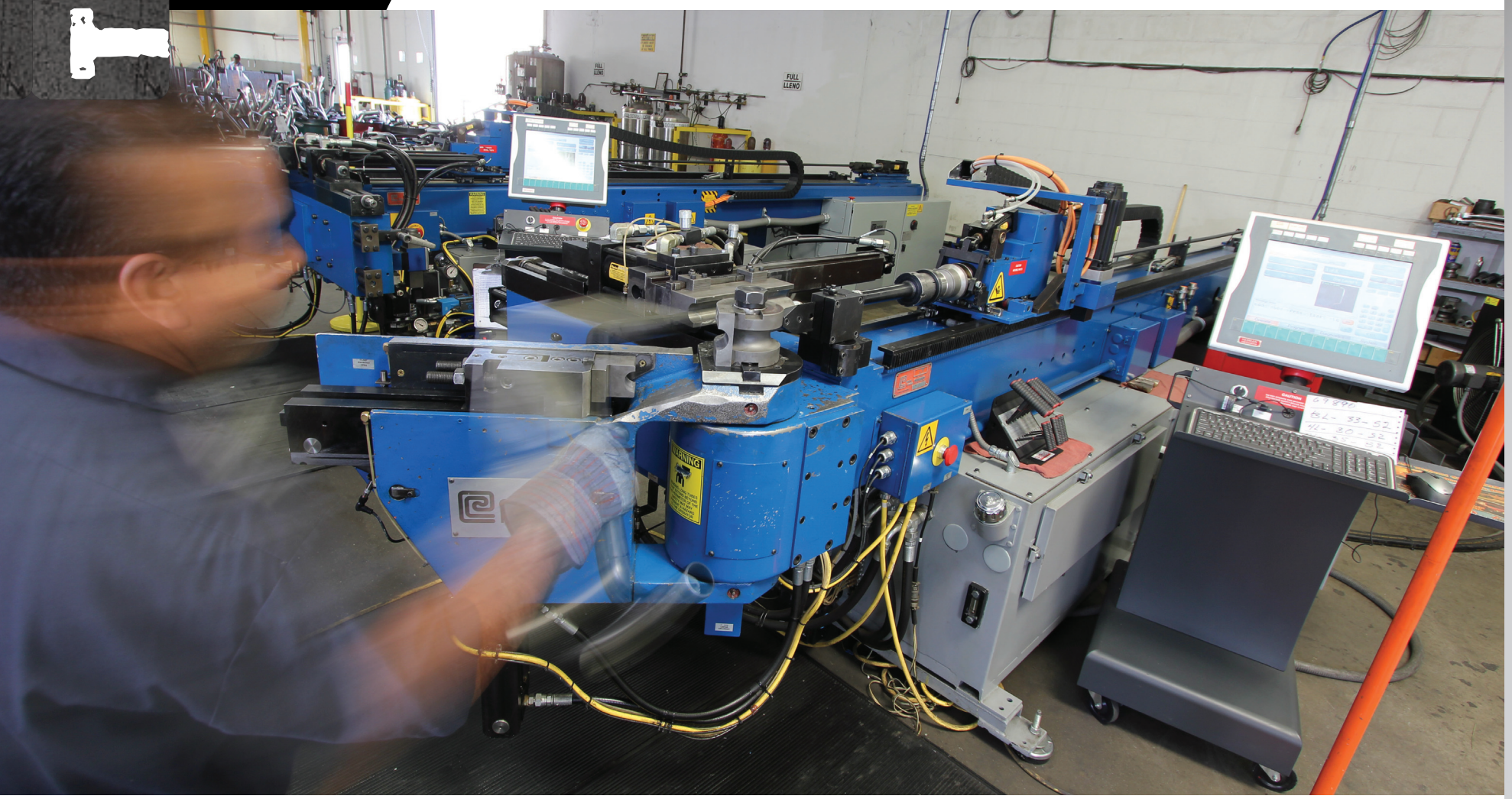
TECH

MORE BARK & BITE!

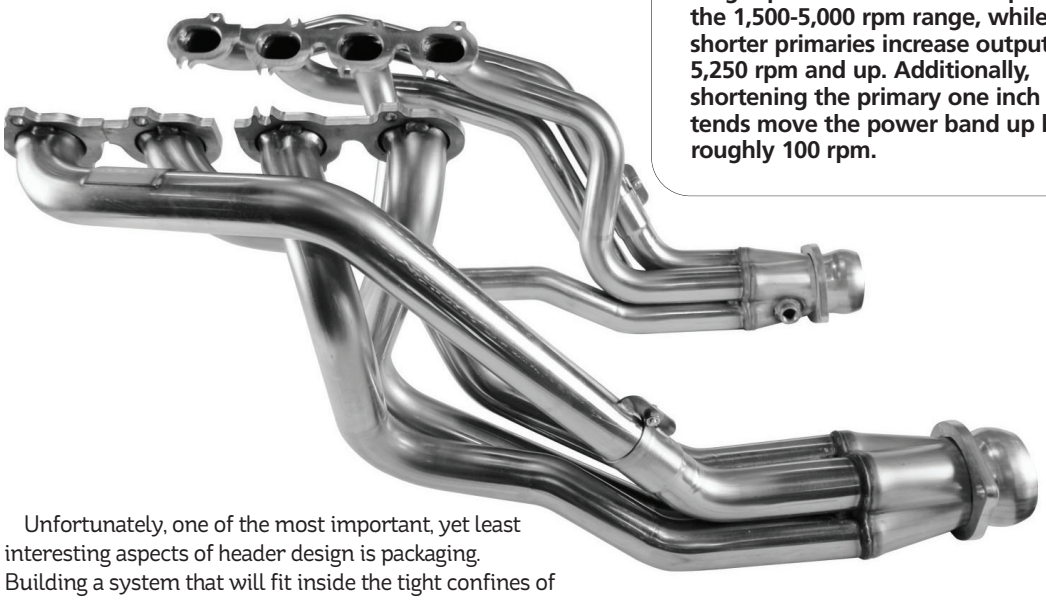
Headers kick out huge bolt-on horsepower. Here's what you need to know before installing a new set of pipes

BY **STEPHEN KIM** PHOTOS **THE AUTHOR AND COURTESY OF THE MANUFACTURERS**

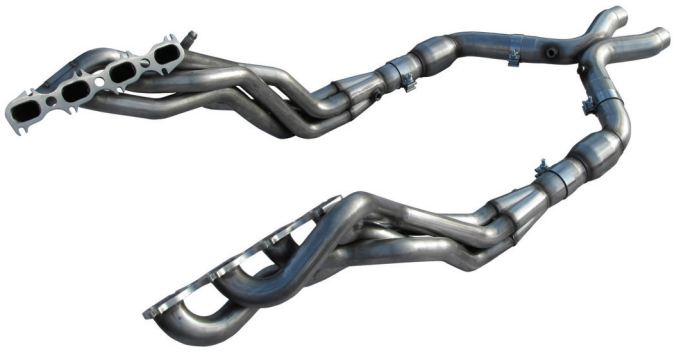


As any seasoned thug will attest, before your head gets dunked in a bathtub by a mobster, it's best to brace yourself by taking a deep breath. Once re-emerging from the water, however, the only way that thug can ingest a fresh gulp of oxygen is by first clearing out room in his lungs by exhaling. Otherwise he chokes. It seems like common sense, but if engines are nothing more than glorified air pumps, the same logic applies, even if you don't hang out with mobsters.

With sexy induction hardware like high-flow intake manifolds, superchargers, and nitrous kits everywhere you look, it's easy to overlook the significant role of the exhaust system in the overall internal combustion process. Ideally, any improvements in airflow on the induction side of an engine must be matched with improvements in exhaust flow as well. This clears out the cylinders for yet another fresh charge of oxygen during the next intake stroke. Although factory mufflers perform remarkably well in today's late-model Mustangs, upgrading to a set of long-tube headers can net an extra 20-30 horsepower. While bigger headers can be better, improving exhaust flow involves far more than simply enlarging the size of the pipes. There's real science to the madness, and factors such as primary length, tubing diameter, collector design, and the smoothness of the transitions all play an important role in exhaust flow and velocity, pressure wave tuning, and ultimately horsepower.



Primary length not only influences pressure wave timing, but it can also be used as a tool to fine tune the torque curve. Kooks has found that longer primaries increase torque in the 1,500-5,000 rpm range, while shorter primaries increase output at 5,250 rpm and up. Additionally, shortening the primary one inch tends move the power band up by roughly 100 rpm.



While engine displacement provides a general guideline for target primary diameter, it doesn't tell the entire story. The GT500's 5.4L small-block isn't big by today's standards, but since its factory supercharger moves so much air it requires far larger pipes than its displacement suggests. American Racing offers 1.875-inch headers for GT500s with factory blowers, and 2.000-inch headers for cars equipped with aftermarket superchargers.

Unfortunately, one of the most important, yet least interesting aspects of header design is packaging. Building a system that will fit inside the tight confines of a chassis by snaking around the steering column, shock towers, suspension, oil pan, firewall, starter, and trans tunnel that's also easy to install is a daunting proposition. Furthermore, street cars need headers that have plenty of ground-clearance and corrosion resistance while also keeping under hood temperature in check. So how do you make it all work? In an effort to explore the science behind header theory, and how designers juggle with the reality of conflicting design factors, we consulted with the top header manufacturers in the business. Their insight will make it that much more enjoyable every time you hear a Mustang barking out a set of long-tubes.

EXHAUST FLOW BASICS

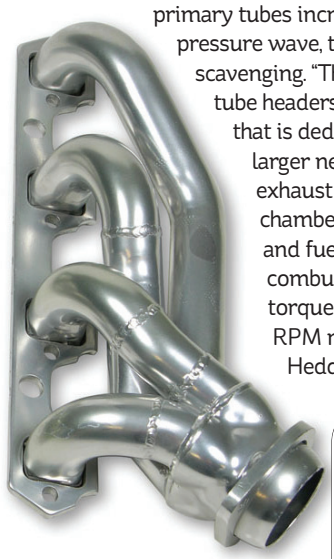
Back in the stone ages, headers were nothing more than a link in the exhaust system that routed exhaust gas from the cylinder heads to the back of the car. However, engine builders quickly realized that subtle variations in header design can substantially impact horsepower and torque output. This is due to the complex interaction between gas particle flow, pressure wave propagation, and valve timing. According to Burns Stainless, as the exhaust valve opens, two distinct events take place in the header pipes. The first is an initial flow of exhaust gases resulting from cylinder pressure created during the power and exhaust stroke, which can reach 350 feet-per-second. Next, a secondary pressure wave travels through the pipes at up to 1,700 feet-per-second, faster than the speed of sound. When the pressure wave reaches the end of the header tubing, a portion of it reflects back toward the exhaust port as a negative pressure wave. If the negative pressure wave can be manipulated to arrive at the cylinder during valve overlap—when both the intake and exhaust valve are open—then it can increase airflow through the intake valve. Consequently, header design involves far more than simply evacuating the cylinders of spent fumes. If done right, a good set of headers actually improves the flow of fresh air into the cylinders as well. Attempting to perfect this effect is the holy grail of modern header tuning.

PRIMARY LENGTH

Any manufacturer that offers both shorty and long-tube headers will readily admit that long-tubes produce more horsepower. This explains why many hot rodders are willing to incur the extra expense and installation effort associated with long-tube headers. Simply put, longer primary tubes increase the intensity of the negative pressure wave, thereby increasing exhaust scavenging. "The longer primary length of long-tube headers increases the available tube area that is dedicated to each cylinder, creating a larger negative pressure that evacuates exhaust gases from the combustion chamber better and allows more fresh air and fuel to be shoved into the combustion chamber for increased torque, particularly in the mid- to high-RPM range," Marc Lewis of Hedman Hedders explained

On the other hand, equalizing the length of the primaries from cylinder to cylinder may seem advantageous in theory, but the benefits are questionable in a street application. "Equal-length headers have been shown to provide small gains in extremely modified race engines, where the difference between winning and losing can be mere fractions of a second," Lewis continued. "In some cases, equal-length headers can result in power losses. For the vast majority of street applications, equal-length headers are not worth the additional expense and installation issues typically associated with them."

A merge collectors works off of the same principle as a carburetor venturi. By necking down exhaust gases into a smaller cross-section, a merge collector increases exhaust velocity. For fabricators that prefer building headers from scratch, Burns Stainless and Stainless Works offer a broad selection of merge collectors.



Shorty headers represent a solid compromise between fitment and performance. While they don't offer the ultimate horsepower and torque advantages of long-tubes, shorty's are much easier to install and still outflow restrictive factory exhaust manifolds. Hooker's shorty headers for 351-powered SN95 Mustangs feature 1.625-inch primaries and 3-inch collectors.

Gathering exhaust pulses from four cylinders firing at different intervals into a single collector can result in turbulence, which disrupts flow. Collector spikes help smooth out exhaust flow to reduce turbulence. They also promote scavenging by directing exhaust to the center of the collector.

There's a big difference between a clogged, 20-year-old factory catalytic converter and a high-flow aftermarket unit that supports up to 800 horsepower. Kooks offers its Green cats as optional items on most of its X-pipe assemblies. Available with 2.500- or 3.000 inch outlets, they're EPA certified and can handle temperatures up to 1,500 degrees.

Although the horsepower and torque benefits of an X-pipe are largely dependent upon header efficiency, installing one can't hurt. They improve engine output in most instances, and almost never reduce output. Most aftermarket header manufacturers offer X-pipes as standard or optional equipment.

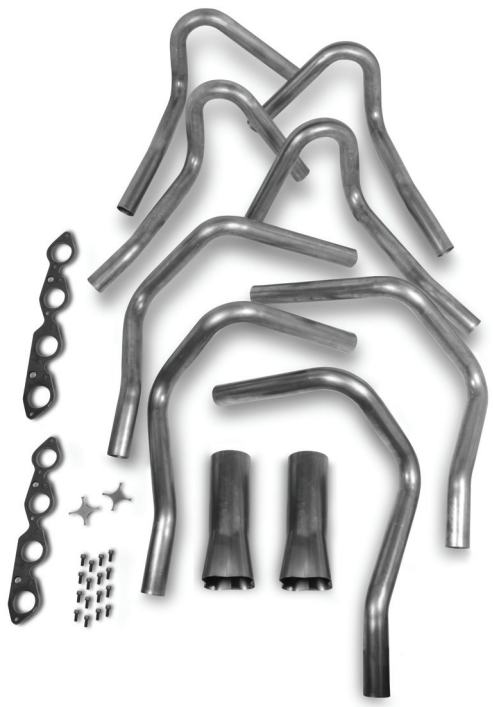
Header theory aside, maximizing and equalizing the length of the primaries often takes a back seat to packaging constraints. "Designing a header is a true blend of science and artistry. On one hand you try to make the tubes as equal as possible to match exhaust velocity so that there is minimal turbulence when the tubes meet at the collector," Jason Bruce of Hooker Headers explains. "However, to make a truly equal-length header sometimes means that you wouldn't be able to install them in the car, so there is a mix of fit and function that header designers are always trying to balance. Shorty headers are designed to be a high-performance alternative to a factory exhaust manifold, which explains why they're popular with many late-model vehicles that must meet strict emissions controls requirements."

TUBING DIAMETER

While primary length and pressure wave tuning go hand in hand, primary diameter affects where in the RPM range an engine produces the bulk of its torque. It's all about velocity. "Smaller primaries will increase exhaust velocity at low rpm. However, they can also become a restriction at high rpm, and in extreme conditions they result in increased cylinder temperature, detonation, and power loss," George Kook, Jr. of Kooks Custom Headers explains. "Larger primaries decrease exhaust velocity and interior header pressure. As a result, an engine will perform better at higher rpm when static pressure inside the header is sustained. The same applies to collector diameter, which can dramatically affect power output. That said, the old adage that bigger is better is not always the case. While it's true that primaries and collectors that are too small can hurt horsepower at high rpm, tubing that's too big can hurt 60- and 330-foot times at the track, thus slowing your car down."

CNC tubing benders and laser cutters can speed up the production process, but header manufacturing is still a very hands-on, labor intensive process. Although Hedman utilizes some automated equipment, it feels that computerized welders and assembly equipment do not lend themselves well to the header manufacturing process. Considering Hedman backs its headers with a lifetime warranty, they're extremely confident in their human craftsman.

As no surprise, 1.500- and 1.625-inch primaries are common in smaller-displacement motors that can benefit from a bump in low-end torque, whereas 1.75-inch and larger primaries are often used in larger stroker small-blocks that need additional exhaust flow at high rpm. Even so, the ideal solution isn't always so clear cut. "The craze back in day was to run 1.625-inch diameter primaries on Four-Valve Cobra motors because they seemed like the right size on paper for a 4.6L motor," Nick Filippides of American Racing Headers recalls. "However, the Cobra exhaust ports are gigantic, and there is no clean way to funnel them into a 1.625-inch primary and then immediately dump them into a tight bend in the chassis. Eventually, we said enough of this nonsense. We started using 1.750-inch primaries, picked up power, and never looked back.



Choosing the thickness of both the header tubing and flanges is a balancing act between weight savings and durability. For truck and extreme duty applications that require greater vibration and shock resistance, Hooker opts for 3/8-inch header flanges and 16-gauge tubing. For most passenger car applications, Hooker prefers 5/16-inch flanges and 18-guage tubing to reduce weight.

Ceramic metallic coatings act as a thermal barrier by retaining heat inside the header tubing. This not only decreases under hood temps, but it also increases exhaust velocity, since higher exhaust temperatures increase flow. In addition to silver ceramic coatings, Hooker also offers its Darkside (black) and Titanium (gray) coatings as options. Regardless of color, Hooker ceramic coatings can sustain temperatures up to 1,700 degrees.

Header theory often takes a back seat to packaging limitations. For example, shoehorning a 460 big-block into a Fox Mustang doesn't leave much space for header pipes, which makes both header design and installation a challenge. Kudos to Hooker for developing an off-the-shelf solution that works.

COLLECTOR DESIGN

Since it wouldn't be practical to route eight primary pipes all the way back to the mufflers, each bank of primaries merge into a common collector pipe, which usally measures between 2.500- and 3.500 inches in a typical small-block application. As with the primary tubing, smaller-diameter collectors increase low-end torque at the expense of high-RPM horsepower, while larger collectors increase top-end power at the expense of low-RPM torque. That said, the true function of the collectors go far beyond harvesting exhaust gas from the primaries. "A collector helps broaden the powerband of an engine by spreading the strength of the exhaust scavenge wave over a broader RPM range," Vince Roman of Burns Stainless explained. "When an engine is operating in the tuned RPM window determined by the primary length—or on the pipe—the scavenging effects of the header system are optimized. However, when the engine is off the pipe, the collectors help attenuate the effects of the mis-timed scavenge waves, effectively broadening the powerband."

While companies like Stainless Works make off-the-shelf headers for most popular applications, certain unique combinations—say a Coyote in a Torino—may require fabricating custom headers. To make the job easier, Stainless Works offers custom header kits that come with the flanges of your choosing, collectors, and 10 J-bends.

For stainless steel header applications that will be exposed to extremely high temperature, double-slip collectors provide some much-needed flexibility in the tubing. After welding slip joint collars on the ends of the primaries, they slide inside the collector to accommodate for the high thermal expansion rate of stainless steel. This explains why they're so popular in turbo combos.

Not all collectors are created equal, and various collector designs influence exhaust flow in different ways. While a standard collector has a uniform diameter throughout its length, a merge collector necks down in diameter before opening back up. "Merge collectors increase exhaust velocity and increase low- and mid-range torque, but depending on an engine's intake manifold design and camshaft overlap, they can also restrict exhaust flow and decrease horsepower in certain applications," says George Kook, Jr. "Merge collectors are not a magic go-fast component that works 100-percent of the time since every application is different. We usually recommend merge collectors in naturally aspirated engines, and standard collectors in forced induction applications."

X-PIPES

Many header systems for late-model Mustangs come with either standard or optional X-pipes. Plumbing an X-pipe into the exhaust system behind the collectors allows the exhaust pulse from both banks of cylinders to interact with each other. The performance advantages of an X-pipe are largely dependent on the efficiency of the headers themselves. "An X-pipe is basically a scavenging device that works with the exhaust signals. When one bank of cylinders fires on an engine, an X-pipe allows that exhaust pulse to enter the opposite bank of cylinders to assist in the scavenging process," Nick Filippides explains. "This improves throttle-response and mid-range torque. Interestingly, in certain racing applications that have very efficient header designs, an X-pipe won't help much at all. When you see substantial gains in horsepower and torque by adding an X-pipe, it's usually due to an inefficient header design."

CATALYTIC CONVERTERS

Gutting out the factory catalytic converters is one of the oldest free mods in the book. So if an aftermarket manufacturer offers an X-pipe with your choice of off-road pipes or high-flow cats, the off-road pipe will make more power, right? Not always. "Depending on the application, we have seen high-flow cats that make within two horsepower of an off-road pipe, but also make two additional pound-feet of torque," George Kook, Jr. explained. "We have dyno tested our high-flow cats on an 850 hp Shelby GT500 without seeing any appreciable difference in hp. So the old adage that cats steal horsepower, in most cases, is not true."

TRI-Y

While most long-tube headers on the market feature a four-into-one layout, a four-into-two-into-one design—also known as a Tri-Y header—offer certain theoretical advantages. "On a 90-degree V-8 engine, a 4-2-1 header has a higher scavenging efficiency than a 4-1 design. This means that they can theoretically make more power and

Compared to a typical street/strip passenger car, tube chassis racecars have very simple header designs. With tons of room for header designers to work with, creating gradual bends and optimizing primary lengths and diameters isn't a problem.

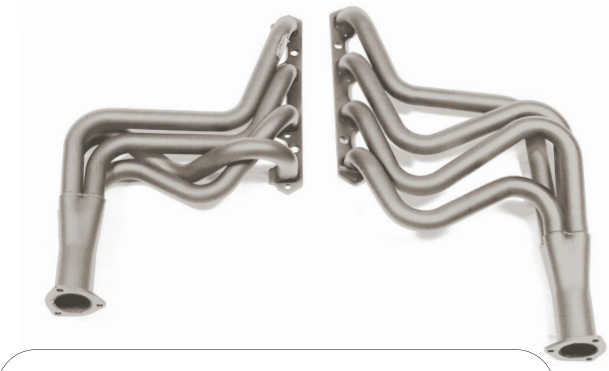
torque," Vince Roman of Burns Stainless explains. "Additionally, Tri-Y headers are usually lighter in weight and easier to package than a similarly performing 4-1 header since they have smaller collectors. Despite these benefits, Tri-Y headers can be more difficult to tune, and require different cam duration and timing to take advantage of their higher scavenging efficiency. Tri-Y headers are also very sensitive to changes in an engine's firing order. Likewise, they are difficult to build in high-rpm applications such as Pro Stock since their optimum primary lengths are so short."

EXOTIC ALLOYS

The two most commonly used metal alloys in off-the-shelf headers are mild steel and stainless steel. Mild steel costs roughly half as much as stainless steel, but offers no corrosion resistance whatsoever. Stainless steel, on the other hand, costs twice as much as mild steel, but virtually eliminates any and all corrosion concerns. While this is hardly ground-breaking information for savvy hot rodders, far less is known about more exotic alloys such as T-321 stainless steel and Inconel. Furthermore, there can be quite a bit of variation from one batch of T-304 stainless steel to the next. "As the least expensive austenitic alloy, T-304 is the workhorse of stainless steel tubing and it is great for most exhaust applications," says Vince Roman of Burns Stainless. "For improved high-temperature durability, T-321 stainless steel is alloyed with titanium or columbium, making it suitable for extreme applications where exhaust gas temperature can exceed 1,400-degrees Fahrenheit. The downside is that T-321 stainless costs approximately twice as much as T-304 stainless."

In extreme temperature applications where cost is no object, Inconel 625 alloy tubing is the ultimate solution. "Inconel can be considered a 'super stainless' alloy that has a higher percentage of nickel content. This enables it to withstand temperatures in excess of 1,800 degrees while also offering half the coefficient of thermal expansion compared to stainless steel. This explains why Inconel is widely used in endurance applications that run for several hours at a time at high-RPM. The downside is that Inconel 625 costs approximately three times more than T-321 stainless steel. It is also a more difficult to fabricate with, so it will usually incur higher fabrication costs as well."

Not all T-304 stainless steel is created equal. Chinese stainless steel is often alloyed with nickel pig-iron instead of the pure nickel that's used in U.S. manufactured stainless steel. Though the concentration of the nickel content may meet SAE alloy standards, many fabricators have noticed that imported materials do not weld as well as U.S. manufactured material. When exposed to heat, offshore tubing will sometimes turn black instead of a golden brown color.



Small headers may seem wimpy, but the key in choosing the correct header is to accurately assess how a vehicle will be used. These Hooker long-tubes for 302-powered '95 F150 trucks feature 1.500-inch primaries that measure 32 inches in length, and are matched with 2.500-inch collectors. They're clearly designed to bump up low-end torque, which is precisely what you want in a tow rig.

WORKING WITH STAINLESS

In scenarios where an off-the-shelf header is not available for your specific engine and chassis combo, fabricating custom headers may be the only alternative. While mild steel is rather straight forward to work with, stainless steel requires a more methodical approach. "When cutting stainless steel tubing, we recommend using a fiber blade. With a chop saw, mount the tubing secure in a vise because if you pinch the blade, it will disintegrate," George Rumore of Stainless Works explained. "After making the cuts, sand the ends flush using a belt sander and belts that are 80-grit or coarser. If MIG welding, use stainless wire and gas designed specifically for welding stainless steel. If TIG welding, use 308 rod. It's always advisable to first tack weld everything together on the car, then finish weld the pipes on a bench to ensure good weld coverage around the circumference of the pipes."

Cutting and welding aside, accounting for the high thermal expansion of stainless steel requires careful planning as well. Not only does red-hot header tubing look wicked, it moves around an awful lot. Different alloys have different thermal expansion coefficients, which must be taken into consideration when designing a header system. Stainless steel expands 25 percent more than mild steel, and almost twice as much as Inconel. "When working with stainless steel, use slip joints to alleviate the thermal stress caused by expansion," Vince Roman of Burns Stainless advised. "It's also important to design the tube pack with sections that can expand and contract without creating stress. Clearances between the tubes and the chassis should be more generous as well." ■

SOURCES

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