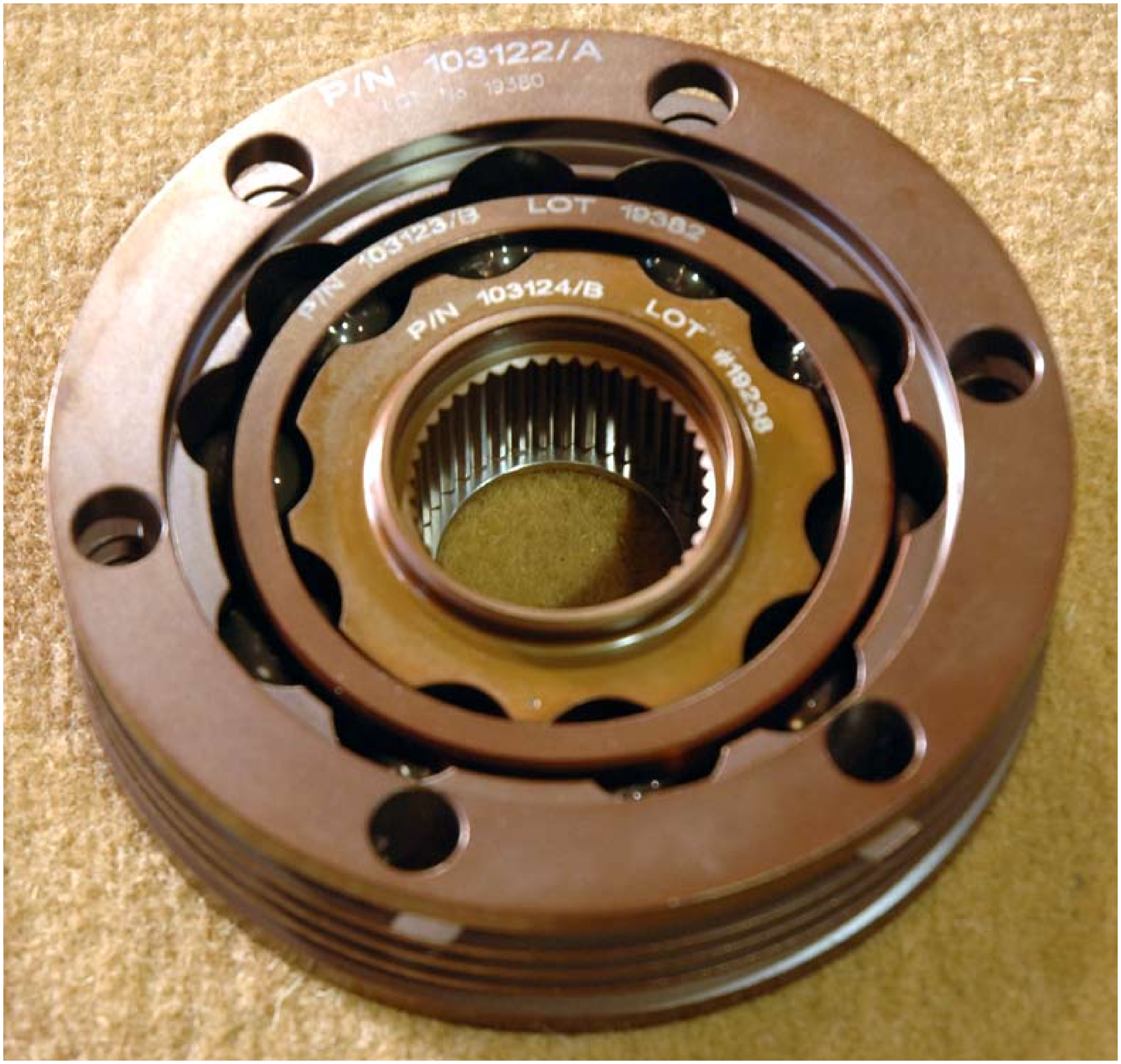
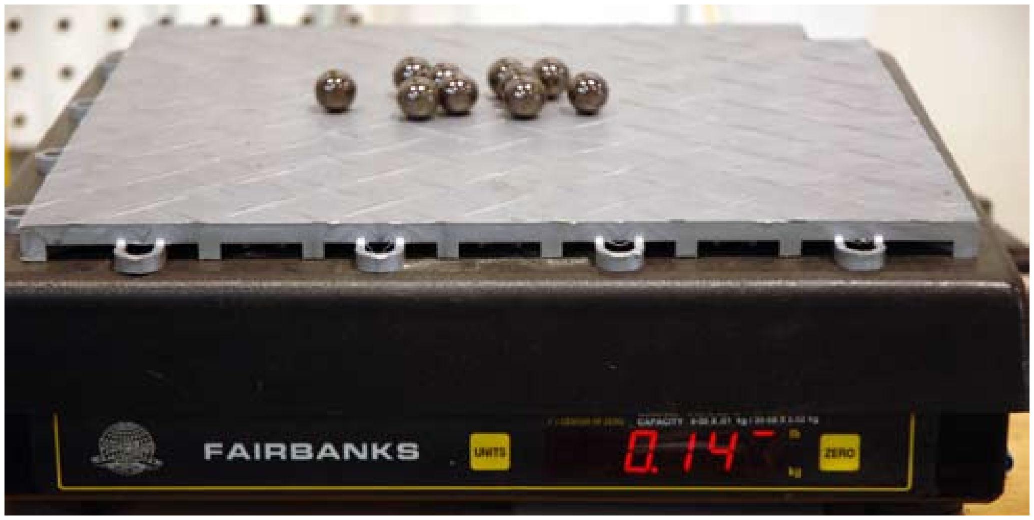
# HALF SHAFTS

***If I have seen farther it is by standing on the shoulders of Giants.***

***Isaac Newton***




Throughout the years we have been fortunate to have many of the world's best car designers, panel beaters, engineers, race car drivers, and others at the peak of the automotive world share their methods and knowledge with us. One of our customers, Kenny Hill of Metalore, makes the constant velocity (CV) joints, hubs, and axles for most of the F1, Indy, and Lemans teams. He also has made many of the critically machined parts on satellites and the space shuttle. There is no finer automotive engineer, designer, or machinist on earth than Kenny Hill. He has shown us his secrets of machining and engineering design on some of the most critical and highly stressed parts on the world's highest performance cars. We used Kenny's CV joints in our 1/2 shafts and employed many of his machining and design secrets during the creation of this car.

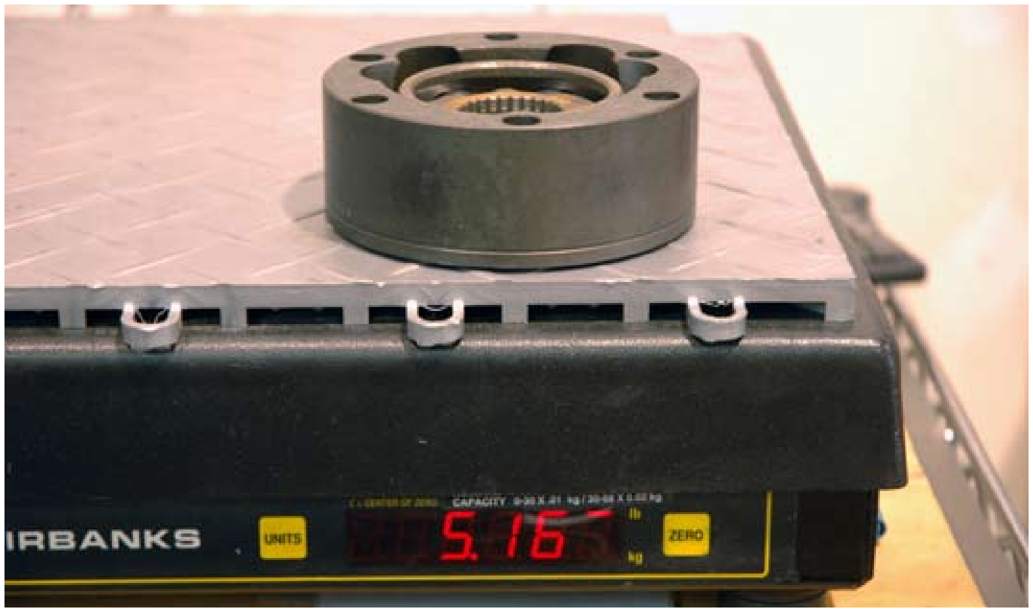


***10 silicon nitride balls weigh 0.14 pounds***

***Porsche 6 steel balls weigh 0.74 pounds***

Among the things that make Metalore's CV's so light (and extraordinarily strong) are the ceramic silicon nitride balls—straight out of aircraft jet turbine engines. There are ten balls in a Metalore CV joint. Metalore uses ten balls because they have a much greater contact area than typical Porsche six ball CV's. Ten balls are able to spread the load around the joint very evenly, as there are ten contact patches instead of six. Silicon nitride balls are exceptionally light—less than 1/5 the weight of Porsche CV balls—and yet the Metalore joint can withstand over 800 horsepower for an entire season of racing. The constant velocity joints take a tremendous beating in any high-performance car. The Porsche CV's probably wouldn't last a single lap in an F1 machine.

***Metalore joint weighs just 2.76 pounds.***



***Porsche production CV weighs 5.16 pounds.***

*Metalore CV caps are made from the same hard material as the actual joint so they will not yield under high stress.*


The Metalore CV is almost 1/2 the weight of the Porsche production CV. There are four CV's per car, so this is a savings of almost 10 pounds of rotational mass and 5 pounds of unsprung mass. The more rotational mass, the more difficult it is to accelerate a car. The more unsprung mass, the more difficult it is to control the contact patch of the tire as the wheel moves up and down. Also, the Metalore CV's were "finned" to reduce the rotational mass to a minimum and to help dissipate heat.

Above left is the back cup on the Metalore CV. The cup is made from the same hard material as the CV joint so it will not yield under the CV bolts. Production CV cups are notoriously soft and squish out under severe use. If the cup material yields under the constant vibration and loads the CV's are under, the distance the bolt clamps will get smaller and the bolt will lose all preload, vibrate, and eventually back out. As production joint covers are stamped, they have to use a softer, formable steel. Such soft material in a high-performance application will eventually squish out under the extreme loads applied by the axles. The shiny button in the middle of the Metalore cover above is an axle stop to prevent the CV joint from bottoming out on (and damaging) the ceramic balls.

Above right is the CV top cup on the Metalore CV. Again, it is made from the same hard material as the CV joint and the rear cover. The boots are made from silicon for extreme temperature use. If you look closely at the inside of the boot, you can see it has a labyrinth seal to keep the grease from spewing out at the high rpms found on F1 car axles.

*Left: CV joint bolts. The heads are dimpled to reduce weight and drilled for the extremely important safety wire.*

*Below: The area directly under the head of the bolt is highly stressed from the large change in cross-sectional area at that point. This area needs to have a generous radius to prevent three F's on the CV report card—fatigue, fracture, and failure.*

*High-performance bolts require high-performance washers. These washers are chamfered on one side to clear the radius under the head of the bolt. It does no good to use a normal, sharp-edged washer to cut under the head of the bolt and create a stress riser at its most vulnerable point.*

*This is the "spreader washer" used on normal production CV joints. They try to spread out the load of the bolt to prevent the soft stamped seal cups on production CV's from squishing out. They are a very cheap, unreliable band-aid that does not address the root of the problem—the soft cups squishing out and causing bolts to loosen and fail.*

***A standard Porsche axle design is on the right. We patterned our axle after the Metalore axle on the left.***

The Metalore F1 axle is on the left, and the Porsche production type axle is on the right. On the Porsche shaft, notice the raised shoulder on the inboard end of the spline. This shoulder is designed to stop the CV joint as it is pressed onto the axle—bad idea. The highest stress concentration in the axle is exactly in this area with the shoulder.

In a production axle, the minor diameter of the spline is the smallest diameter on the shaft—so it is the weakest spot in the axle. The largest diameter of the axle is that raised shoulder—so it is the strongest spot in the axle. So, in the production axle, the weakest part of the axle twists right next to the strongest part of the axle. Therefore, the point of HIGHEST stress is right at the junction of the weakest part of the axle to the strongest part of the axle because all the forces have to be resolved over an extremely short distance. You might as well write "BREAK HERE" at the shoulder on the Porsche shaft because that is surely where it will break.

Consider the Metalore axle on the left in this picture. The minor diameter of the splines is only 0.025 inches bigger than the major diameter of the rest of the shaft. As such, the "weakest" part of the axle is the full distance between the minor diameter of the splines on either end of the shaft. Therefore, the shaft can resolve all the twisting forces over the entire length of the shaft—greatly enhancing its fatigue life.

***Metalore CV joint axle retaining clips.***

This is the ingenious axle retaining device Metalore uses. In the upper half of the axle hole, you can see a split ring sitting down in a pocket on the inner race of the CV joint. If you look very carefully, you can see a 45-degree chamfer on the inner edge of the ring. This chamfer seats against the 45-degree chamfer on either end of the splines cut into the axle. The split ring is shown with the chamfer up in this picture so you can see it. When the axle is actually installed into the inner race of the CV joint, the chamfer faces down against the 45-degree chamfer on the axle splines.

A spiral lock retaining ring (top of the picture) then slips into a groove (just above the split ring) and locks the entire system together so the axle cannot come out. By not holding on to the splines and by not creating a shoulder for the joint to press against, Metalore has minimized all stress risers in the axle.

***Hub side "Tulip" for the 1/2 shaft—
made from 17-4 PH H900.***

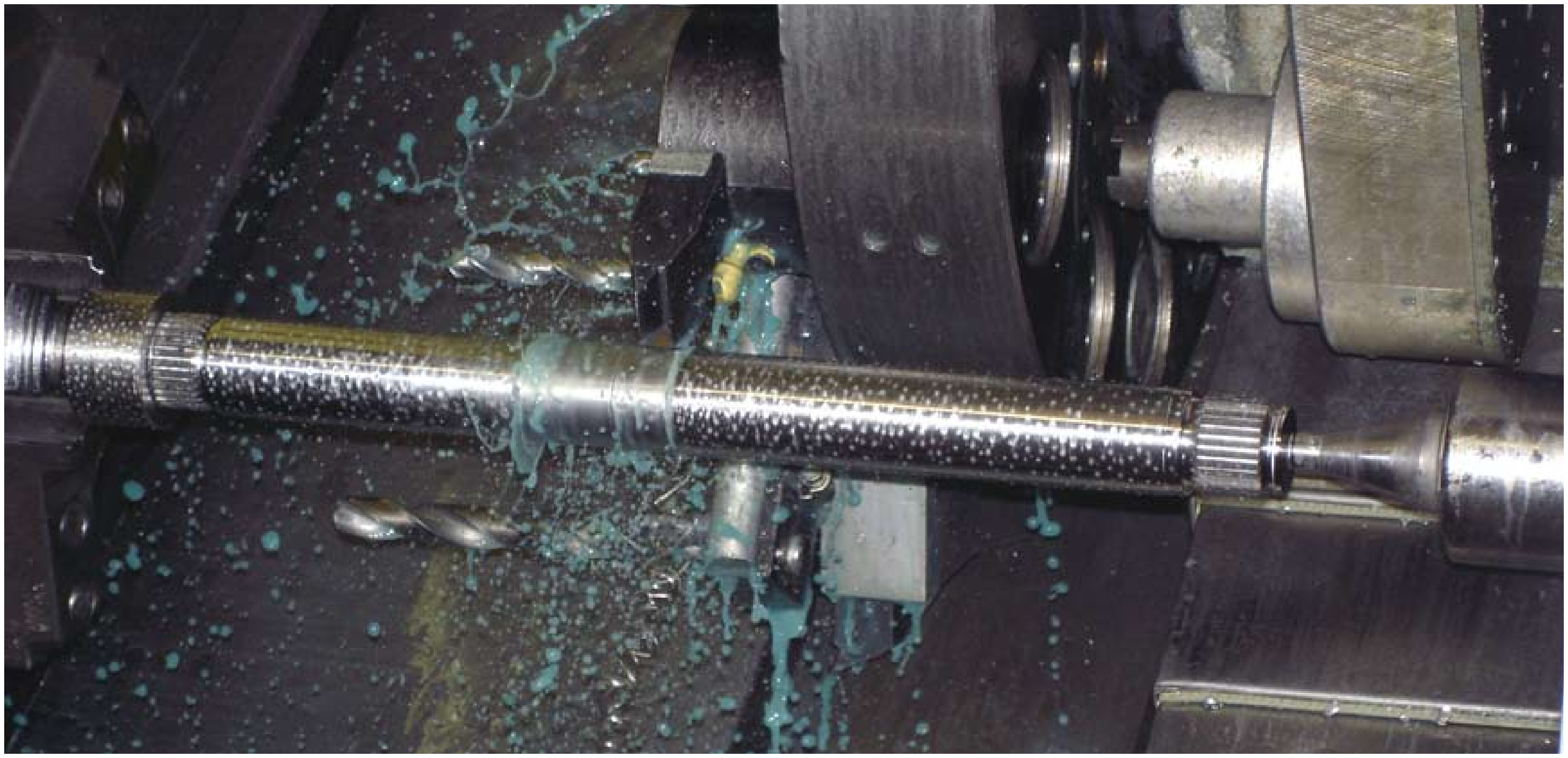
To drive the wheels, the 1/2 shaft needs to be splined at both ends. This is the hub side of the 1/2 shaft. The part is machined from a bar of 17-4 PH stainless steel that weighs 36 pounds. The finished part weighs 2.6 pounds. We use 17-4 PH because it is a precipitation hardening steel that does not require quenching to achieve the required hardness for extremely demanding parts. With 17-4 PH, there is no risk of a micro crack forming during quenching. 17-4 PH has strength comparable to 4340, a nickel-modified, chromoly steel.

4340, however, is extremely prone to corrosion and thus not at all suitable for a street-driven car (unless you like rusty parts). F1 teams don't mind using 4340 as they inspect and change parts frequently, long before rust can form.

***1/2 shaft bolts are notorious for backing out. We safety wired all the bolts to eliminate any chance of their backing out. Notice the reflection of the safety wire in the main axle shaft. The axle was polished to a mirror finish to minimize stress risers. The CV boots are made of high-temperature silicon to resist deterioration over time, as the differential can get quite hot under racing conditions. The boot is also very small. Normal, larger, bellows-type boots tend to balloon at high speed. If the balloon gets large enough, it will be cut by anything it rubs against (exhaust, frame, and suspension members) and fling the CV grease away, destroying the joint.***

***The differential side of the 1/2 shaft is made like a modern 1/2 shaft with a spring clip on the inboard side (small groove at the top of the spline). This allows the removal of the axles out of the differential without taking it completely apart. This "tulip" is also made from 17-4 PH. It is golden colored because it has been heat treated to the H900 condition. H900 is the highest strength condition 17-4 PH can achieve—an astounding ultimate tensile strength of 200,000 psi with a yield of 180,000 psi. For comparison sake, Titanium alloy 6AL-4V (used extensively in the F-22) has an ultimate tensile of 135,000 psi and a yield of 125,000 psi.***

***Above: The completed 1/2 shaft. We made the axle as long as possible to minimize the angularity the CV's will endure as the suspension moves up and down. The shorter the axle shaft, the more angle the CV joints have to resolve. Under extreme angles, the joints are weak and wear out quickly. You can clearly see in this picture the "finning" of the CV joints to enhance cooling and to reduce unsprung weight.***



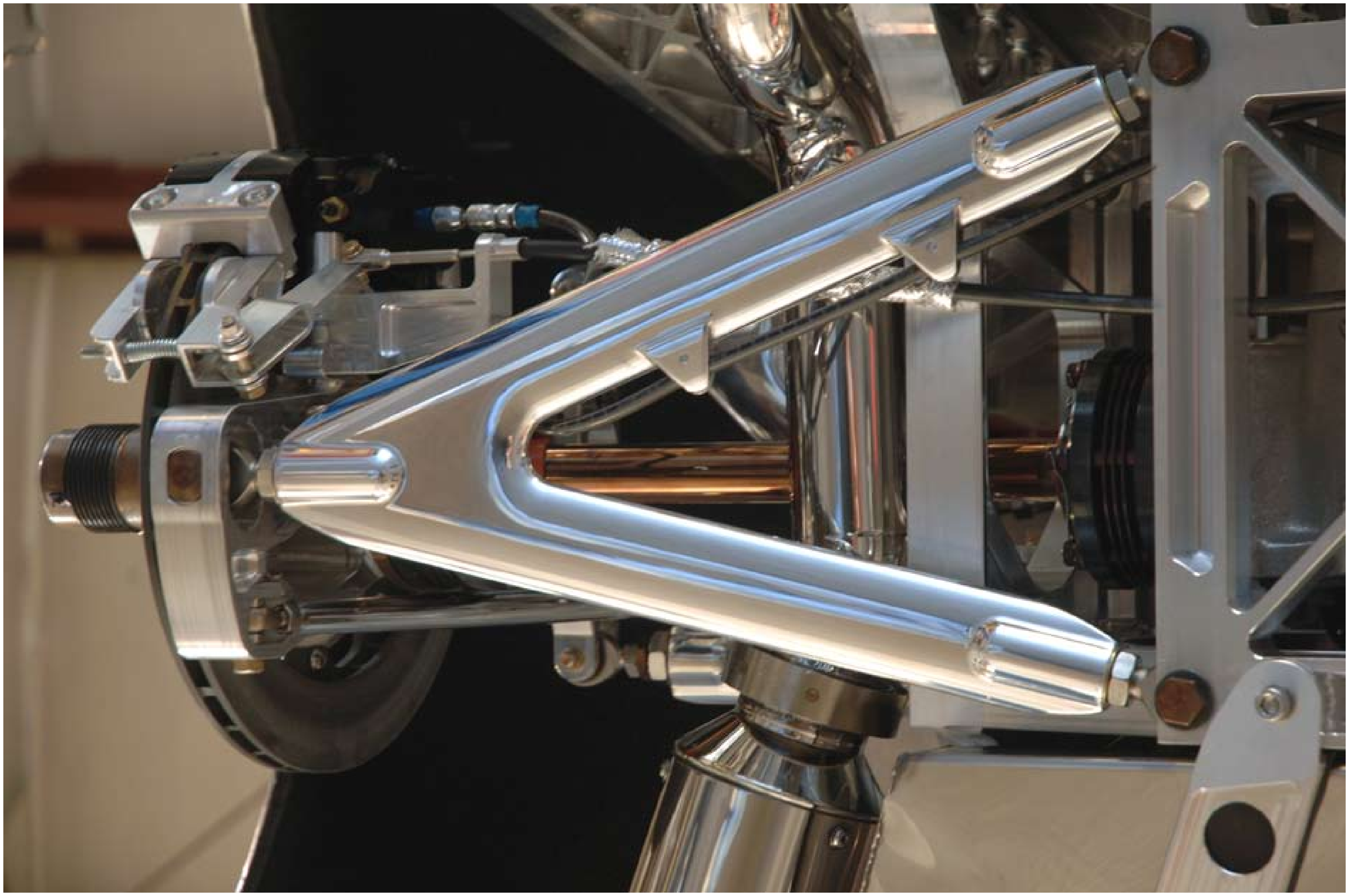
***The 1/2 shaft axle for the prototype car being machined on our 3-axis CNC lathe from 17-4 PH. Notice the special driver so we wouldn't damage the splines.***

*Left: The drive pins were machined directly into the hubs. This is the lightest possible way to make the hub as it removes all fasteners. F1 began making their hubs this way at the same time we did. It is an extremely difficult machining operation because the tools are quite slender and long.*

*Right: If you look carefully at 12:00, 4:00, and 8:00 you can see there is a little ledge machined into the hub (also visible in the photo at left). The ledge prevents the rotor from falling behind the hub. The rotor is driven by the outside diameter of the hub, just like an F1 car. The internal splines in the axle drive the hub.*

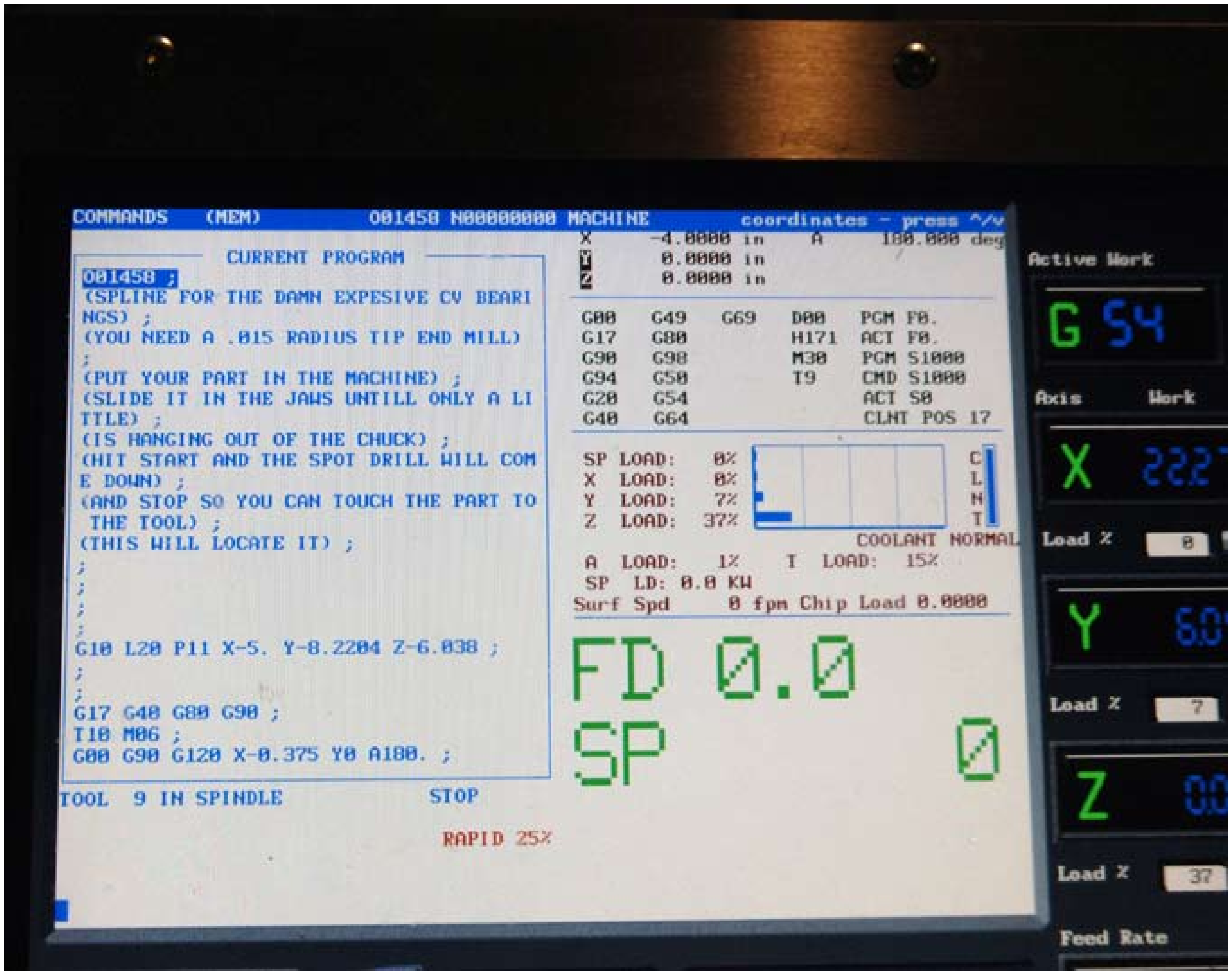
*The drive pins are oblong shaped because the top and bottom of the pin cannot contribute to accelerating the wheel. Anything that didn't make the car lighter or go faster was machined off.*


*Axle and hub assembly. The bearing has the ID and OD ground to make trial fitting of the assembly easier. It is marked "BAD" so it is not used in production.*



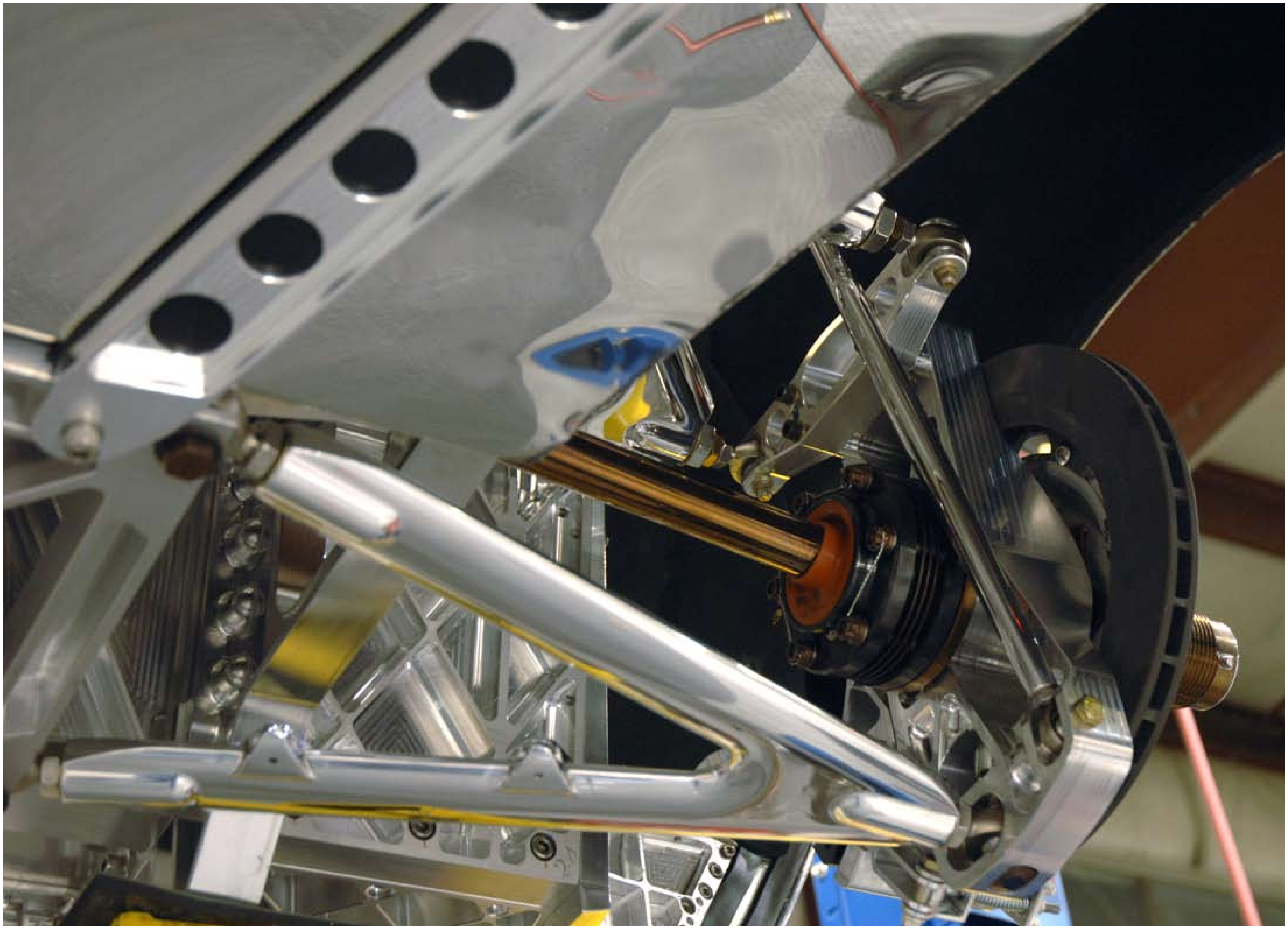
***Installed 1/2 shaft. The exhaust has to hug the chassis to not interfere with suspension movements.***

***The axles were splined on one of our 4-axis mills.***




*A little comic relief while we were working with extremely expensive parts. The first line of code says, "SPLINE FOR THE DAMN EXPENSIVE CV BEARINGS."*

*Using a micrometer to make sure the hub side of the 1/2 shaft has the correct minor diameter.*



Here you can see the hub side of the installed 1/2 shaft. Of particular interest is the push rod. We made push rod widest in the center, tapering toward the ends. As push rods “push” on the shocks, they want to buckle in the center (think of standing on a soda can—it fails in the center). By making the push rods wider in the middle, we were able to even out the stresses along the part and reduce its over all weight.