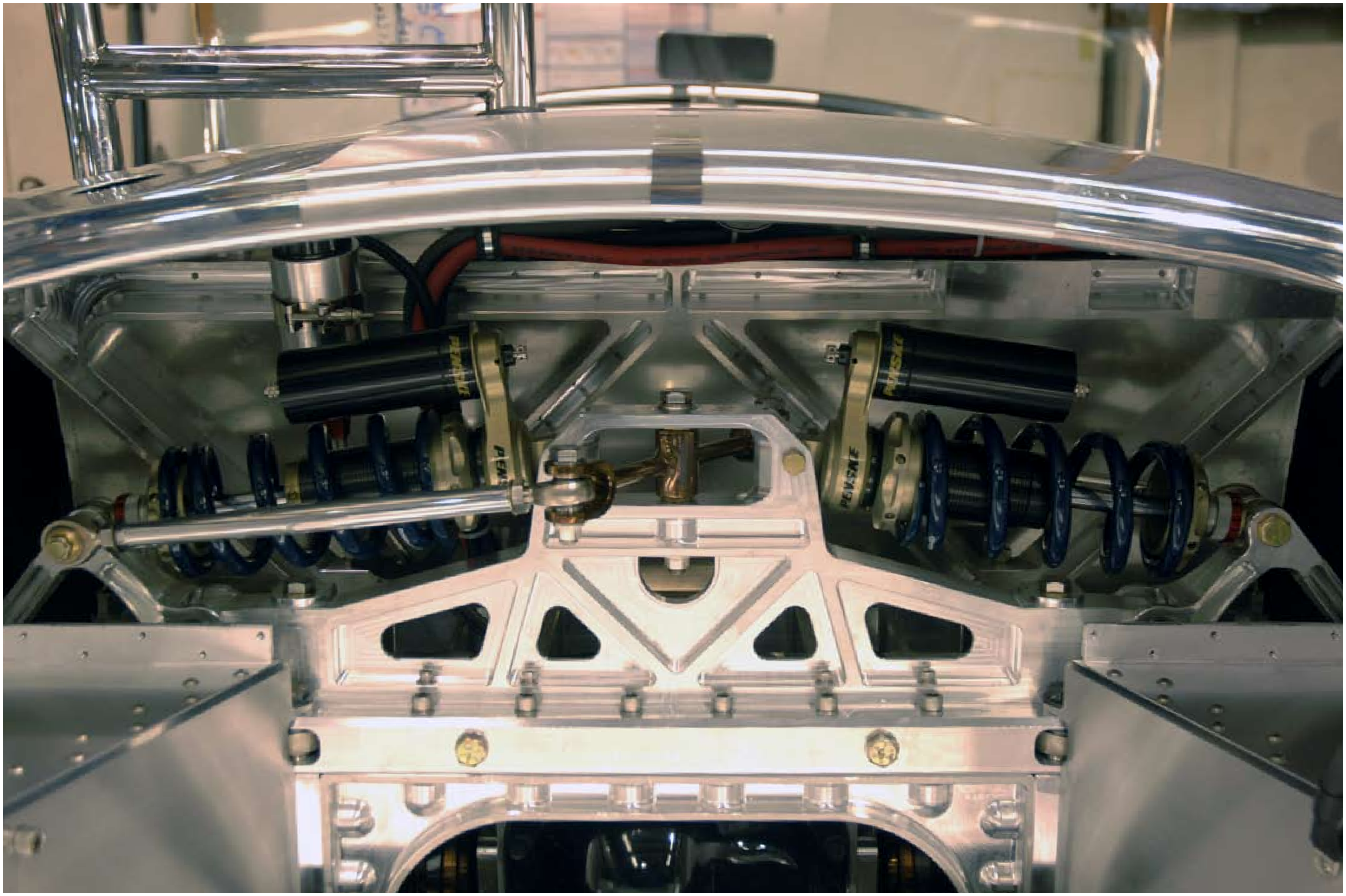
SUSPENSION

A journey of a thousand miles begins with a single step.

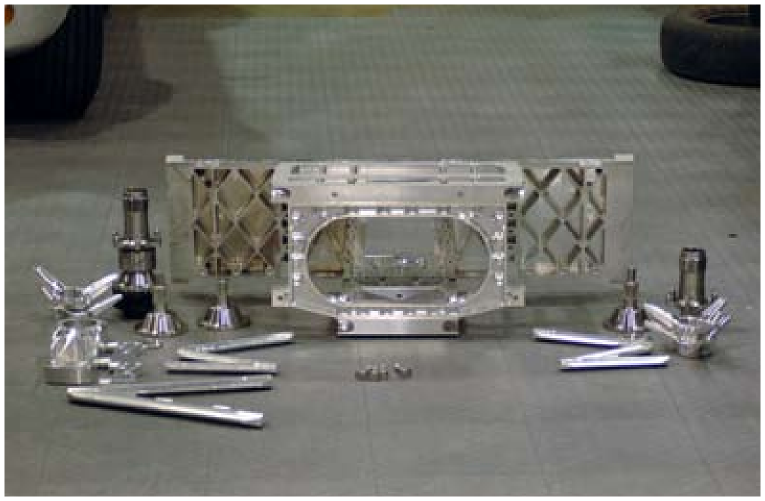
Confucius



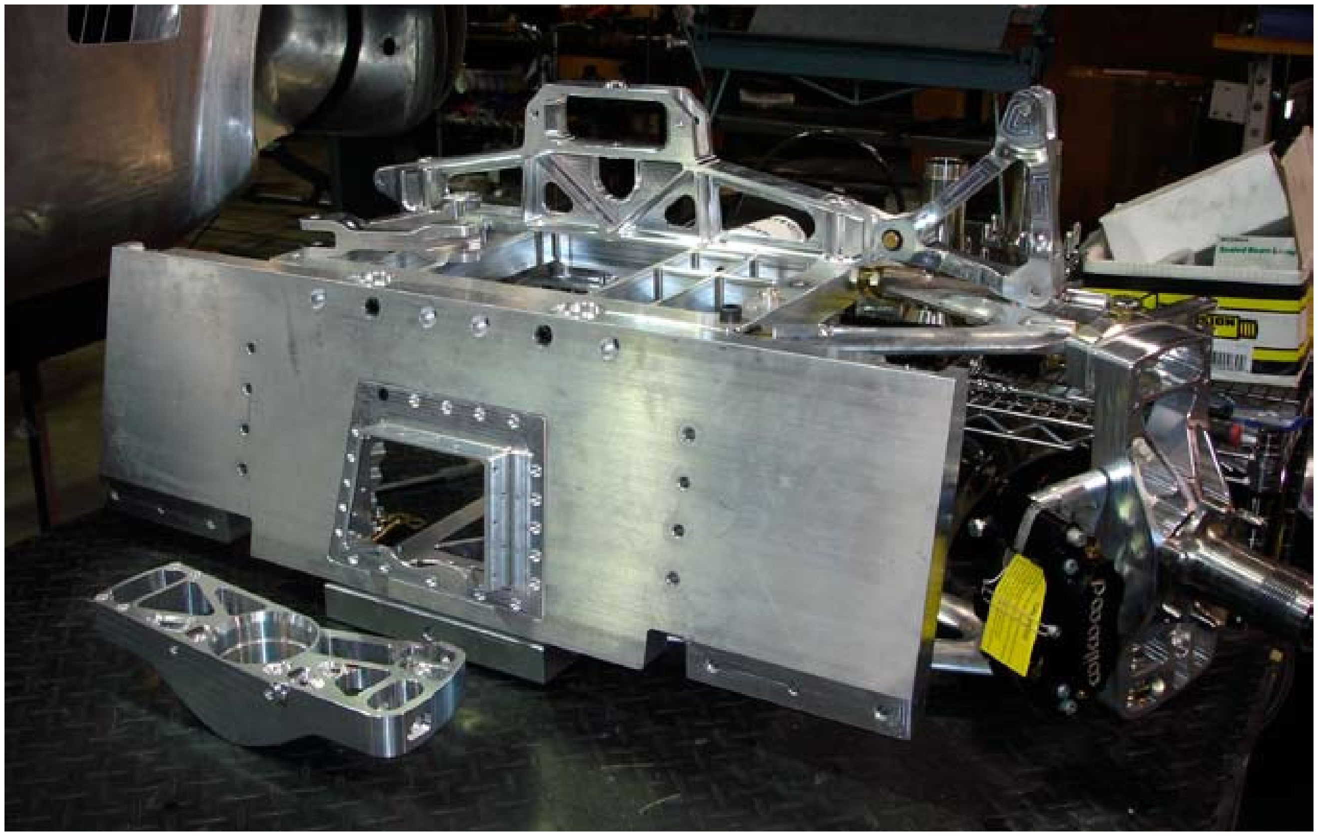
Completed rear push-rod suspension.

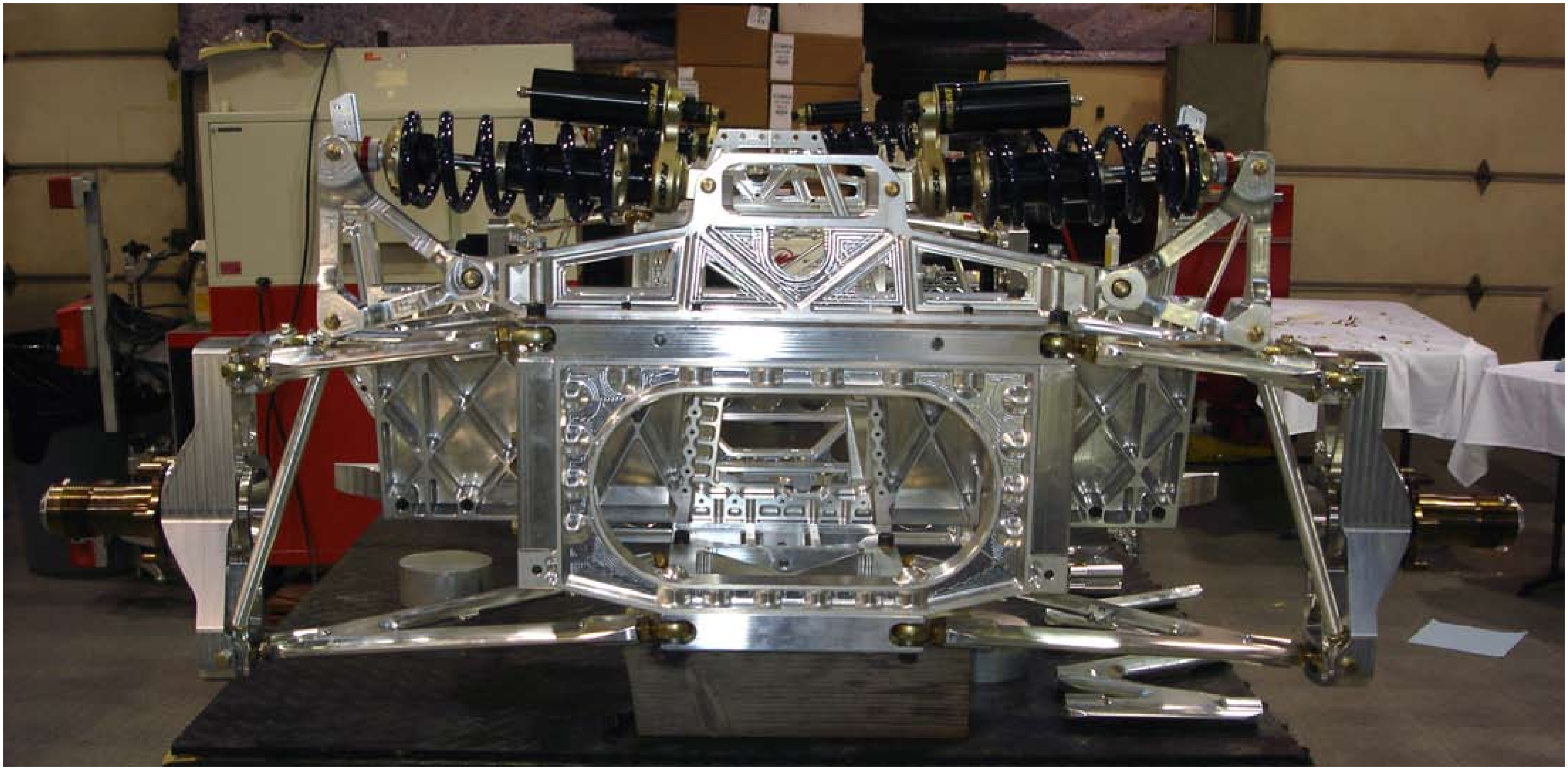
The completed rear push-rod suspension. We chose to use a push-rod suspension so we could adjust the shock travel rate independently of the wheel rate. You want the shock to move as much as possible when the wheel moves. The farther a shock moves, the easier it is to control the wheel because the shock has more "time" for the valving to work. Here you can also clearly see the sway bar we designed. The sway bar is designed such that it works progressively. The harder the car leans into a corner, the more the sway bar acts to "lift" the inside wheel—thus keeping the car flatter on extreme maneuvers.

Front suspension box being assembled.



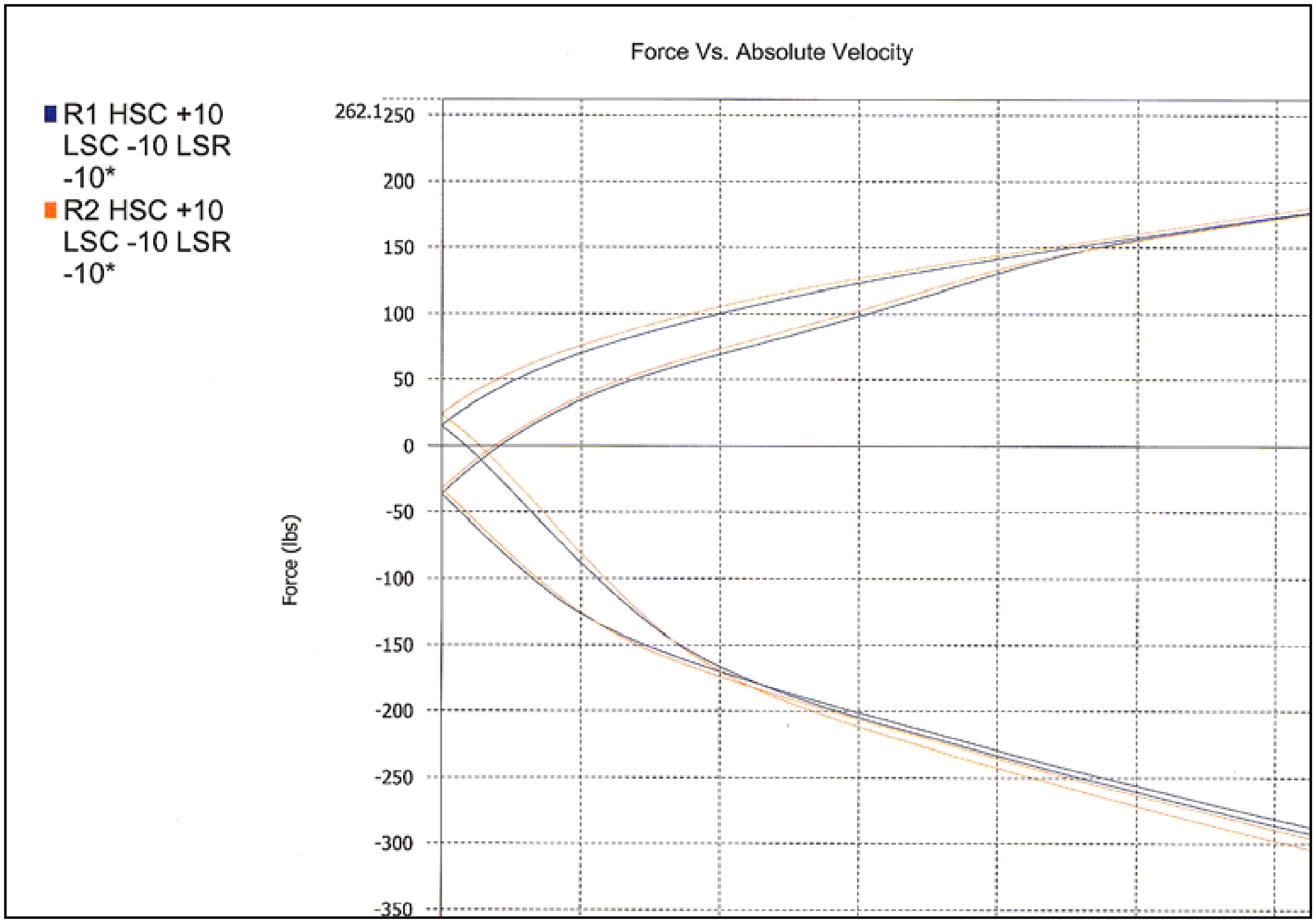
Rear suspension box being assembled.



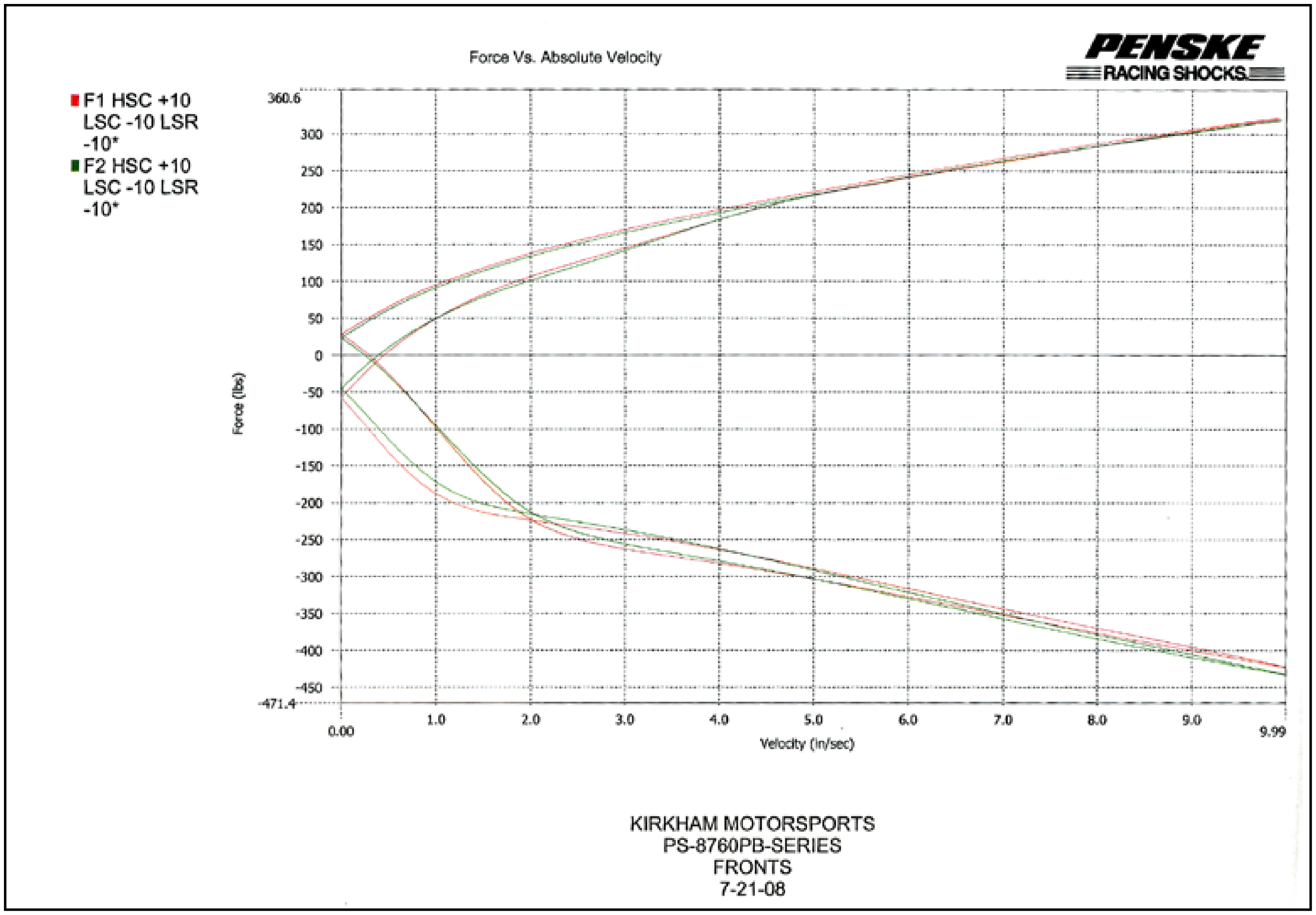


Rear suspension assembly.

The car's suspension was designed to be a push-rod system so we could accurately control the wheel to shock movement. The shocks are Penske triple adjustable—the best shocks money can buy. The shocks can be adjusted in fast jounce, slow jounce, and rebound. By decoupling the fast jounce from the slow jounce, we made the car more easily tuned for the street. The fast jounce is set quite softly—in case the driver hits a pot hole. We set the slow jounce quite firm. This slows down body roll as the car leans into a turn so the chassis isn't upset by quick, jerky movements. Also, from this angle, you can easily see the "short arm, long-arm" design of the suspension. As the wheel moves up and down, the shorter upper control arm moves on a steeper arc than the longer, lower control arm. This "pulls" the top of the wheel in faster than the bottom of the wheel—camber gain. With proper camber gain, the tire stays as flat as possible on the ground as the car rolls in a corner. Our control arms are uncommonly long to minimize geometry changes as the wheel moves up and down. Longer arms move through their respective arcs slower than short arms—thus minimizing any upsetting effect wheel movement can have on the chassis.

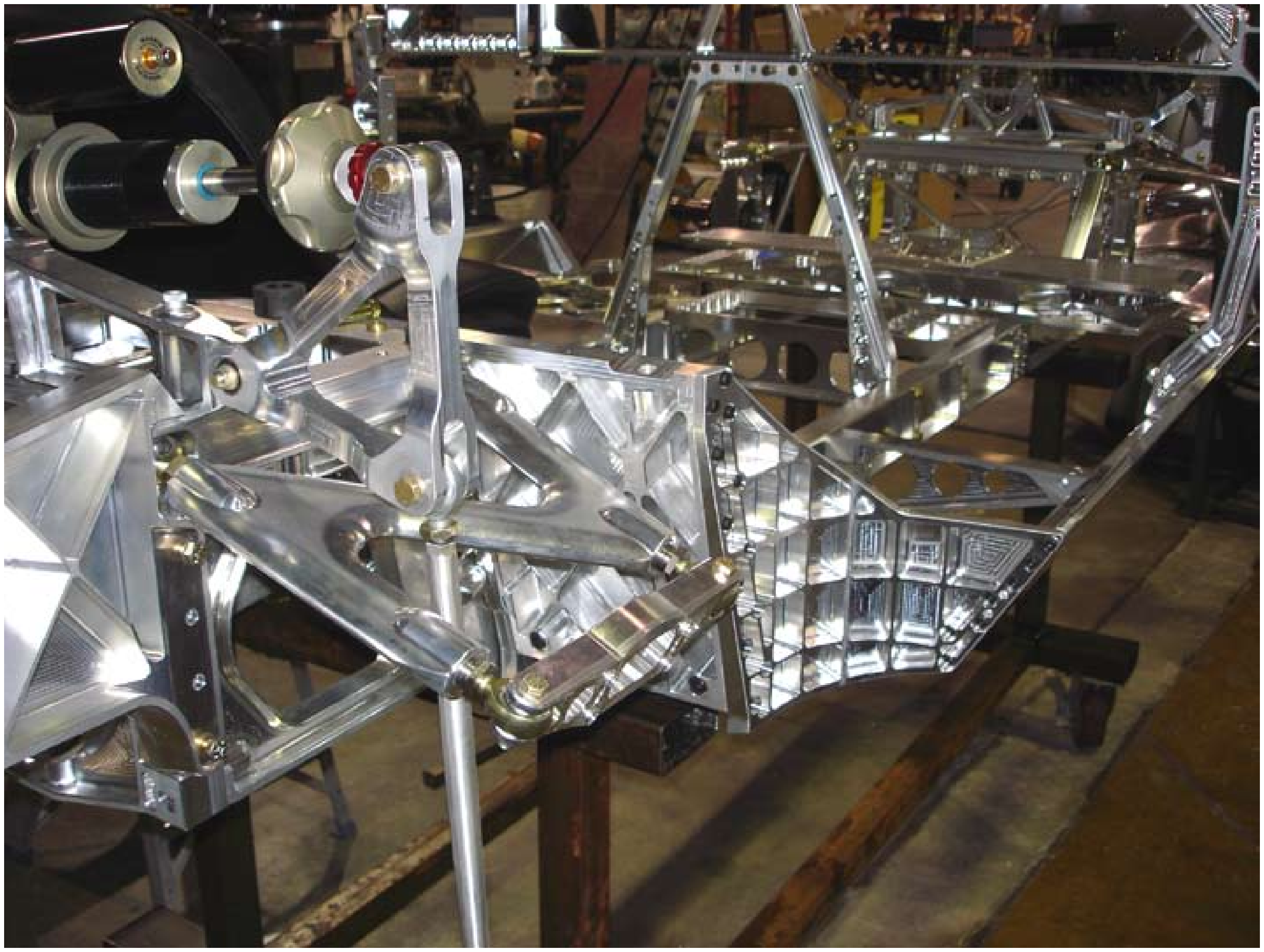


We used Penske triple-adjustable shocks for the car so we could finely tune the suspension.



These graphs depict the characteristics of the shocks as they were tested by Penske on their shock dyno.

The front suspension box on the prototype car. The tunnel is sitting disassembled on top of the frame rails.

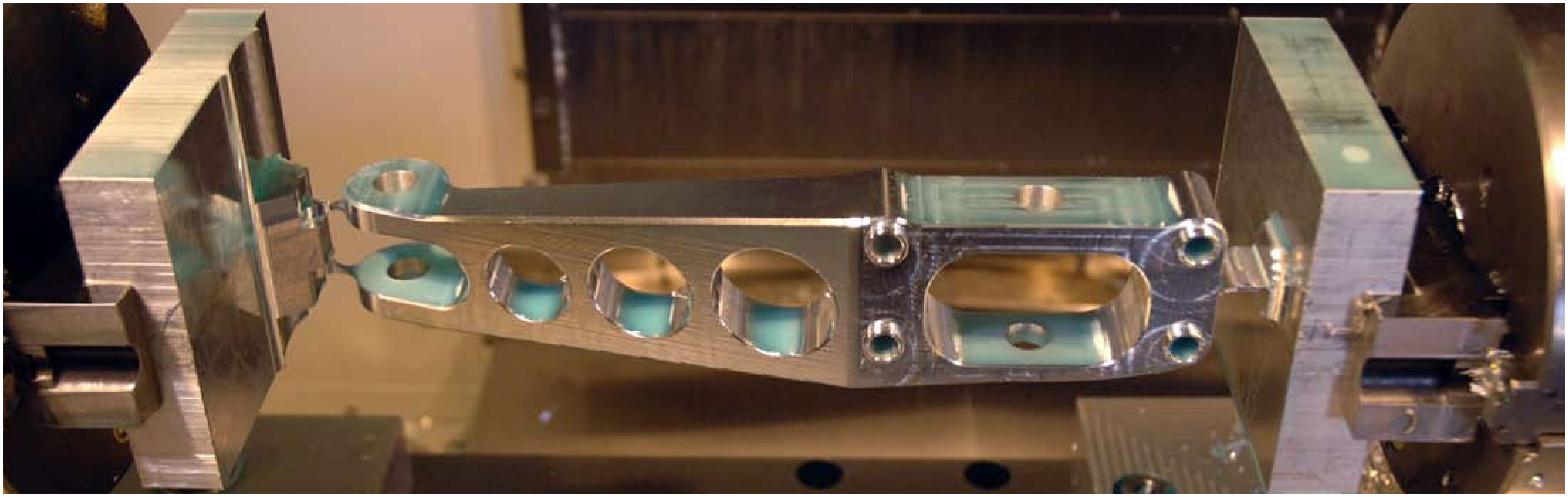


The right rear suspension coming together on the prototype car. This is an earlier version of the rear rocker.

Front suspension box assembled to the main frame rails.

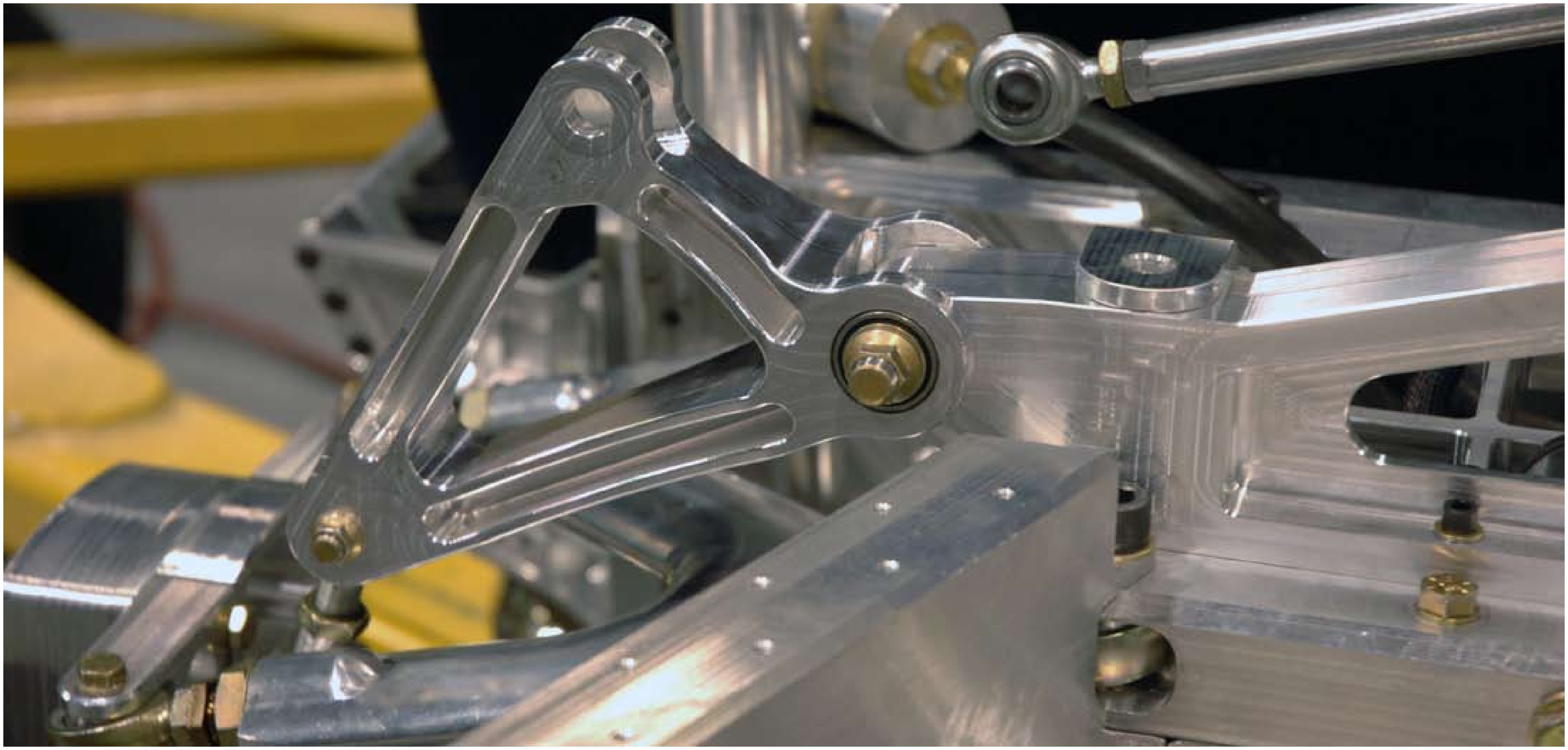
Rear suspension box assembled to the main frame rails.

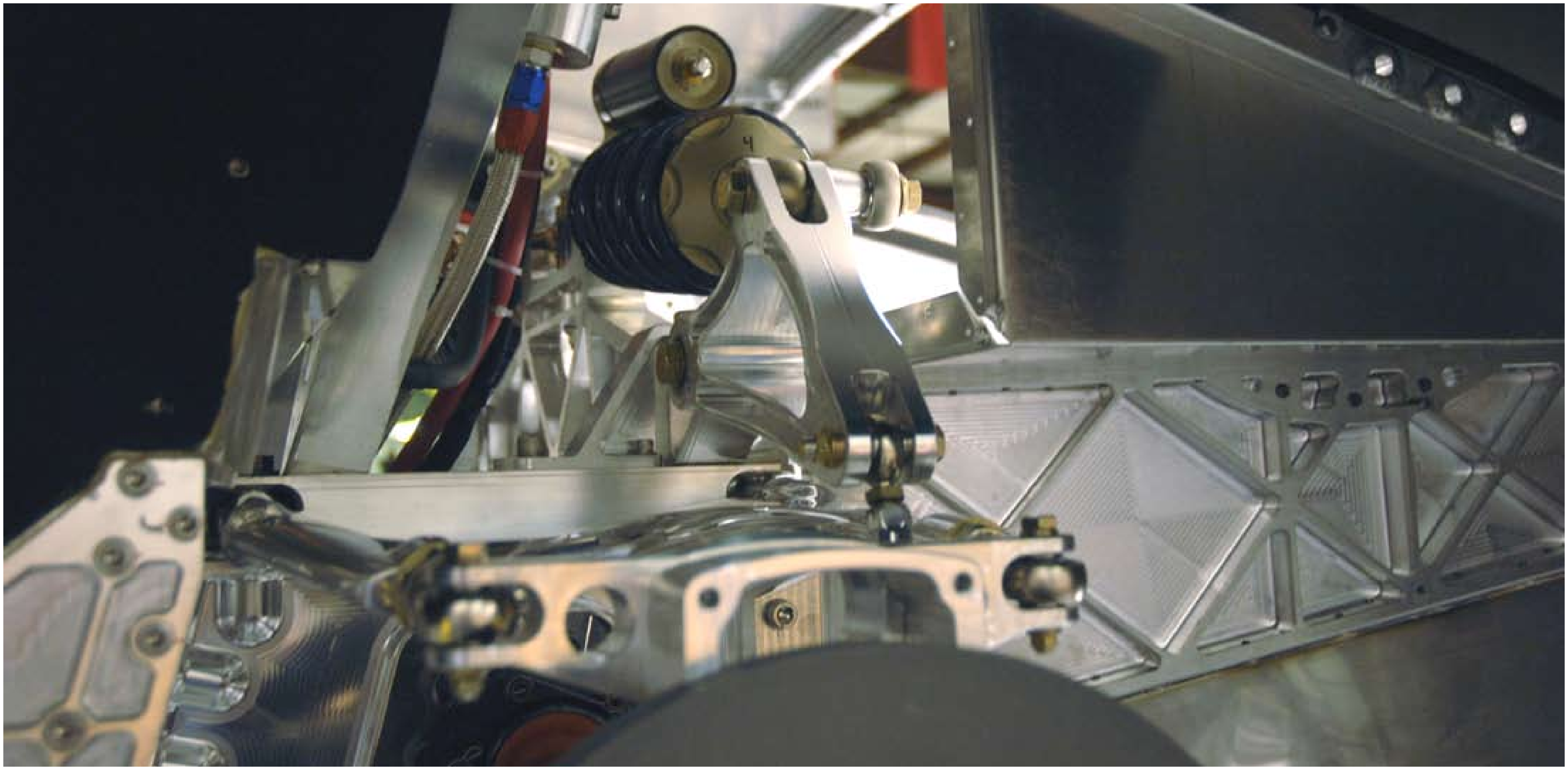
Note the size of the original block. Most parts had over 90% of the aluminum removed during machining.



Front shock tower being machined from a solid plate of aluminum.

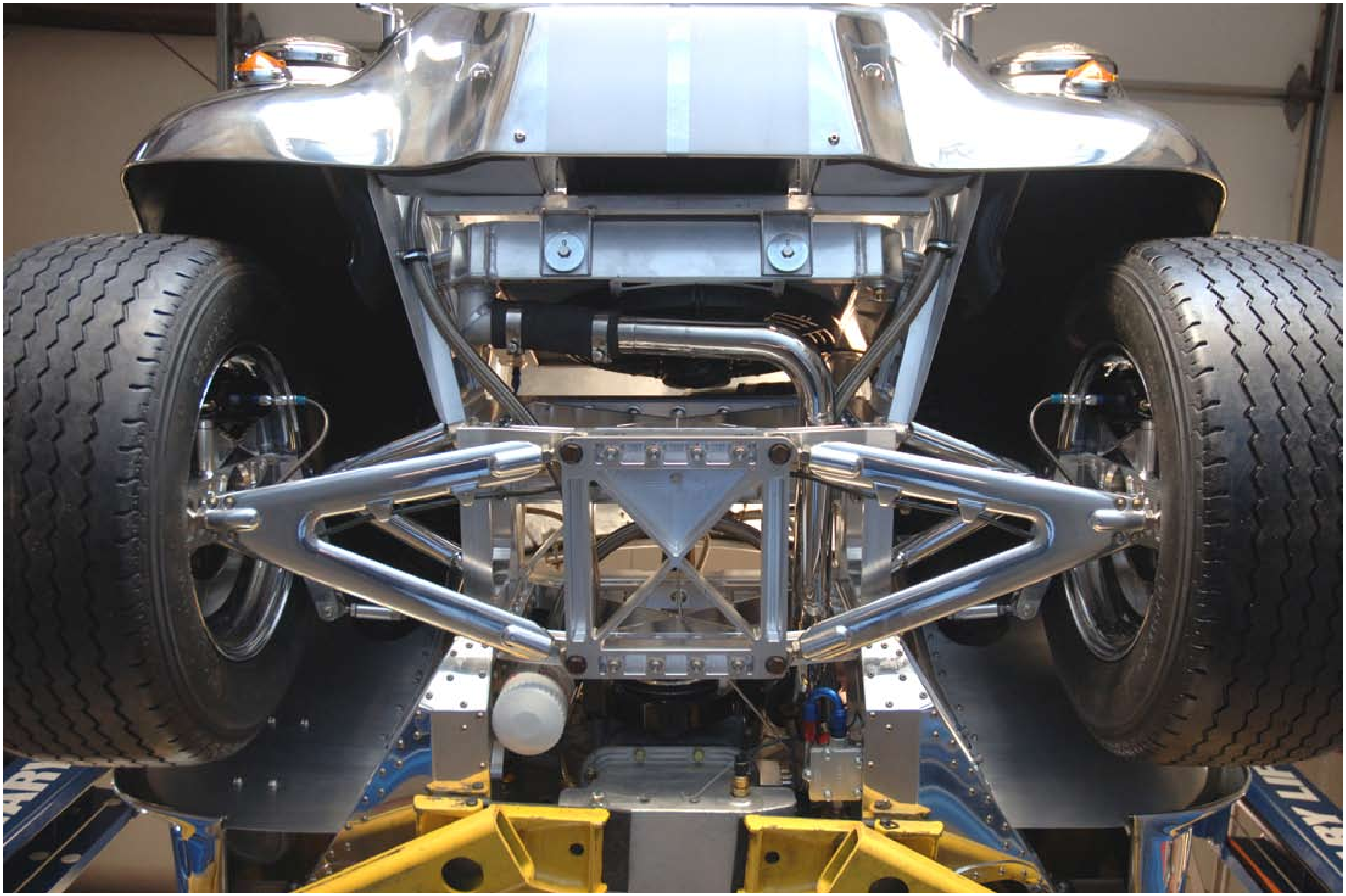
Closeup of a rear suspension rocker. If you look closely at the pivot bolt on the rocker, you can see the washer under the nut does not contact the aluminum rocker. The bolt clamps through the race of the bearing onto special hardened thrust washers that separate the rocker from the shock tower, thereby preventing the soft aluminum from being "point loaded" and ultimately failing due to creep.



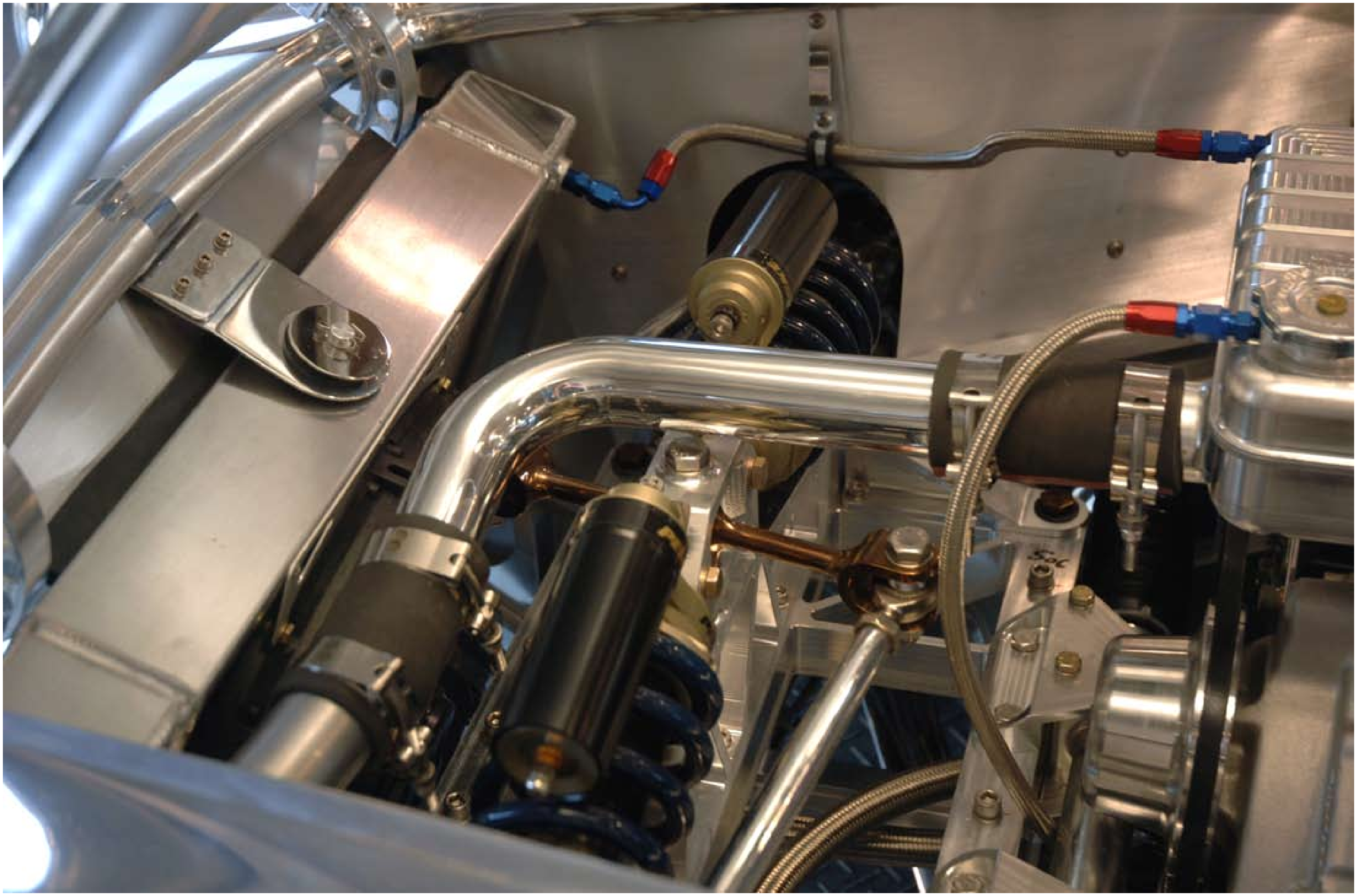


A closeup of the rear suspension rocker. Notice how the rod ends on the rocker and the upper control arm were designed to be mounted in double shear. Double shear minimizes bending loads on the parts.

Finished front push rod and rocker assembly. The rocker pivots on roller bearings at all three points for an extremely smooth shock action. The rear rocker assembly is set up to pivot on roller bearings as well.



Finished front suspension. We mounted the oil filter low on the chassis to make changing the oil easy.

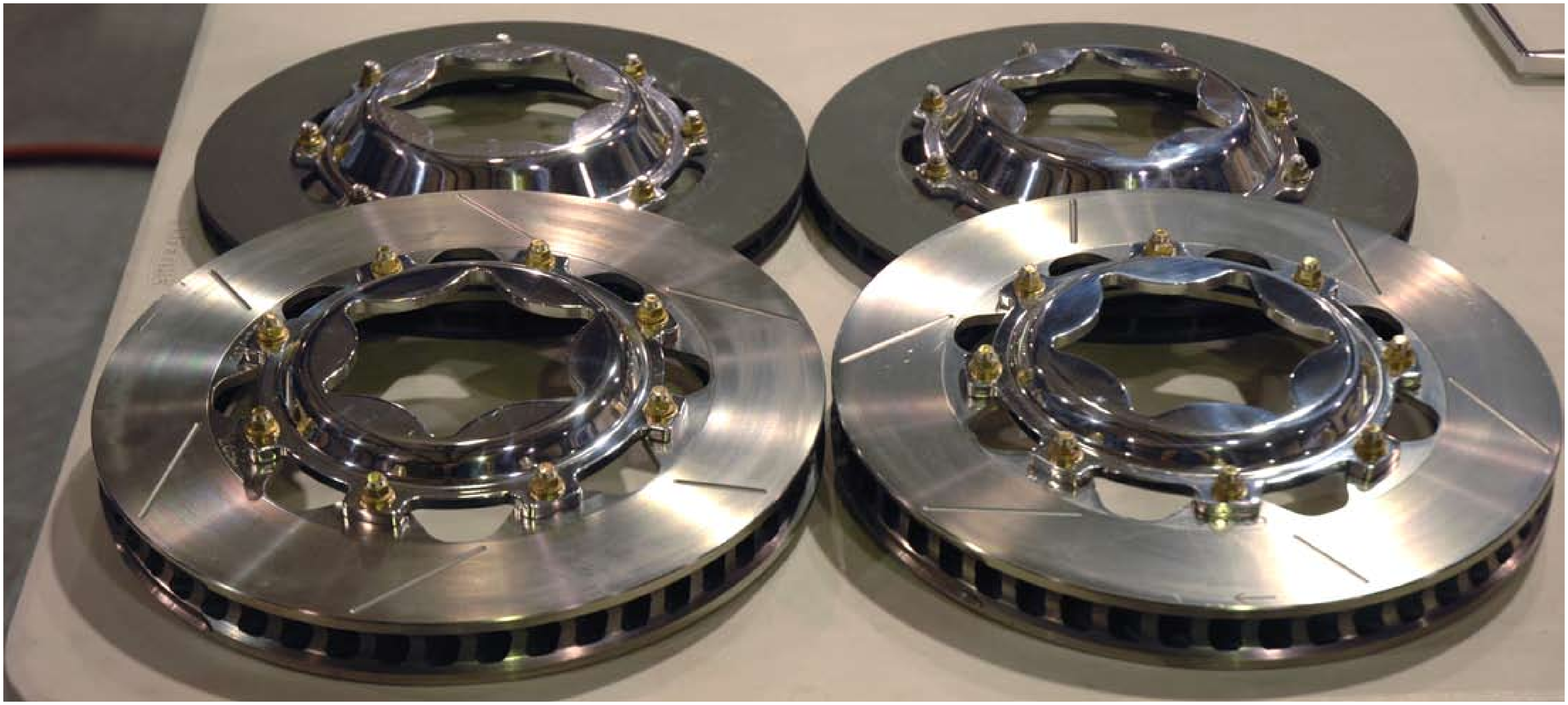


The operation of the sway bar is easy to see in this picture. The design of the sway bar is inherently progressive. The sway bar was machined from a 2-inch bar of 17-4 PH and then precipitation hardened in our shop.

Custom control arm bolts made from 17-4 PH H900.

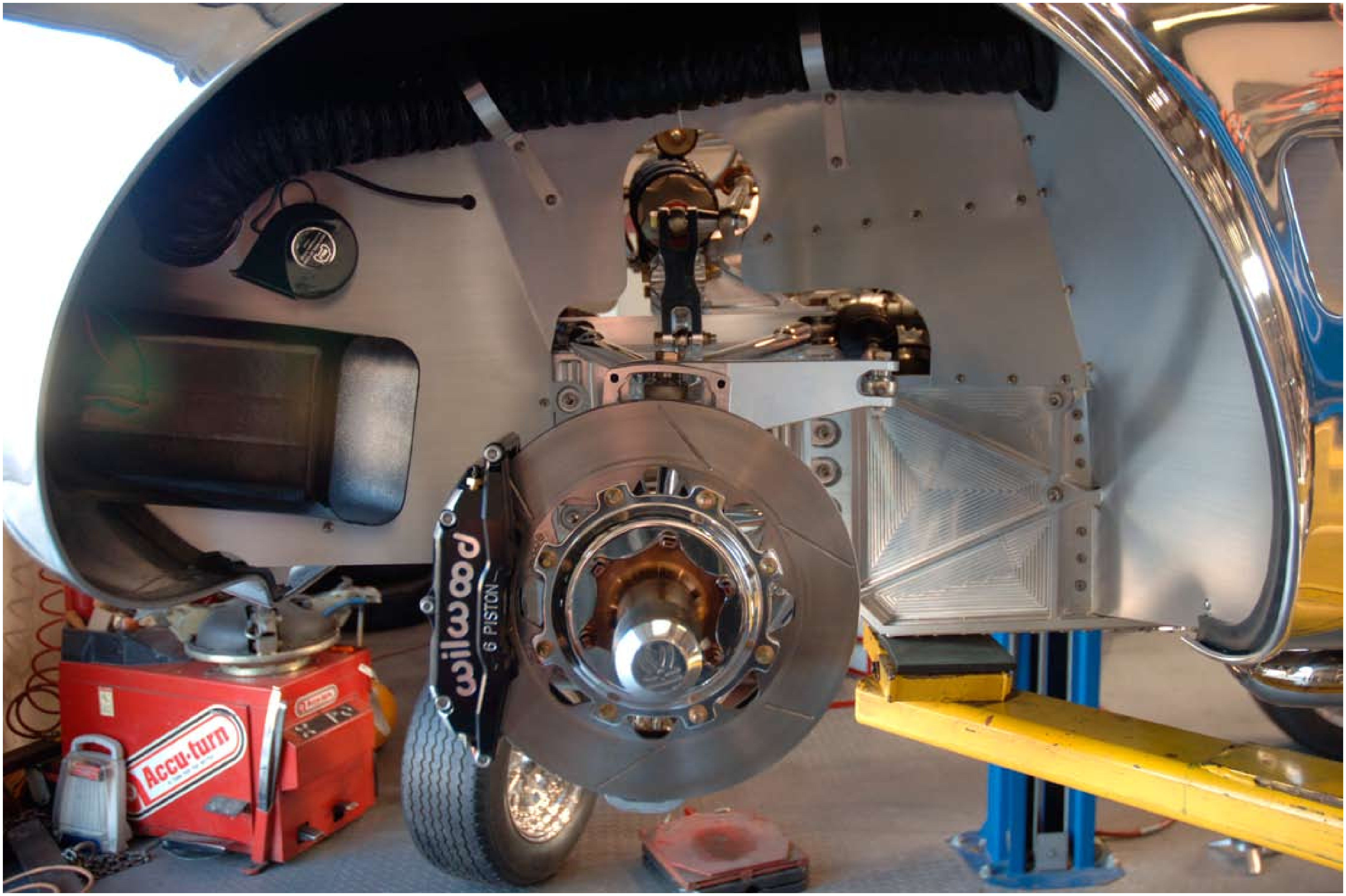
We custom made the suspension bolts. The greatest stress concentration on a bolt is at the root of the thread where it tapers out onto the shank. We relieved the end of the threads to remove that stress riser. The shank of the bolt is exactly 0.500 inches in diameter until it gets about 1/4 of an inch from the head of the bolt. There, if you look closely, you can see a faint line where the shank gets 0.005" larger in diameter. The holes in the chassis must be slightly oversized (by 0.002") so the bolt can slip in. This minor slop in the hole, however, allows the shank of the bolt to rock in the hole on the chassis when the suspension is heavily loaded. This will slightly upset the alignment and kinematics of the suspension. To prevent this unwanted motion, the enlarged area on the shank "presses" itself into the chassis hole as it is screwed in, for a very tight fit.

The brake line brackets were machined directly into the control arm to save weight. We routed the brake lines behind the leading arm of the control arm to protect the lines from road debris. The long, sweeping curve of the control arm has a large radius to minimize stress where the arms blend together.



Brake hats and rotors.

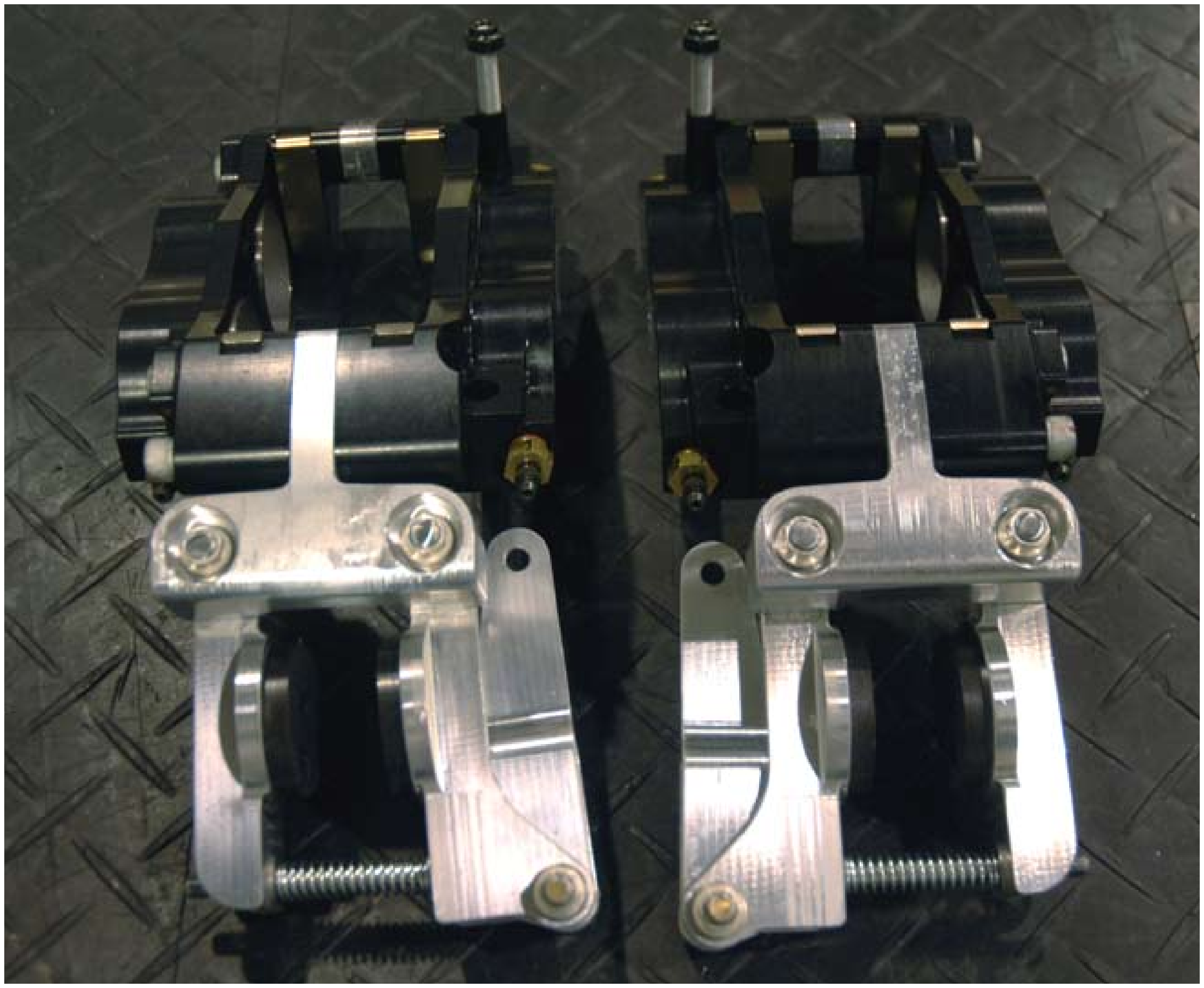
The internal “tulip-shaped” ID of the rotor hats slips over the OD of the hubs. Little ridges machined into the hub prevent the rotor from falling behind the hub on the inboard side. On the outboard side the wheel keeps the rotor in place. The thickness of the rotor hat is 0.005 inches thinner than the space between the wheel and the ridge in the hub so the rotor can float axially (to leave room for thermal expansion of the rotor and hat). The rotor changes size as it heats and cools, but because the hat is driven by only the OD of the hub, it is completely free from the hub in all three axes—thus minimizing any brake shudder from being transmitted to the wheel. The rotor hats won’t rattle but are safely clamped in place between the wheel and the ridges machined into the hub. Nevertheless, the rim never actually touches the rotor hat. Temperature changes in the rotor will not distort the hub—or transfer braking heat to the wheel hubs. Distortion is one of many problems that lead to the dreaded brake shudder. One of the big challenges with race cars is keeping all the tolerances on the parts in the micron range to keep brake shudder away as parts are stacked on top of each other. Instead of stacking a bunch of parts on top of each other, we just eliminated most of the causes of brake shudder by simply decoupling the brake rotor hat completely from the hub and wheel assembly. I have never seen anyone else do it this way—probably because this procedure requires a lot of very tight tolerance machining. We did, however, use the Ducati brake system as inspiration (more standing on the shoulders of giants to see a little bit farther). The rotor hats were completely polished to remove any stress risers from the machining process. The slots in the rotors wipe the boundary layer of gas and dust off the pads for enhanced braking.



Wilwood 6 piston, differential bore calipers

The front calipers are 6-piston Wilwood units. The leading bore of the caliper is smaller than the trailing bore to give a slightly higher clamping force on the trailing piston. As the rotor sweeps through the caliper, the trailing edge of the pad is hotter and so the coefficient of friction is slightly lower—hence the trailing piston needs to clamp with a slightly higher force to keep the pad square to the rotor under extreme braking conditions.

Polished rear upper control arm.



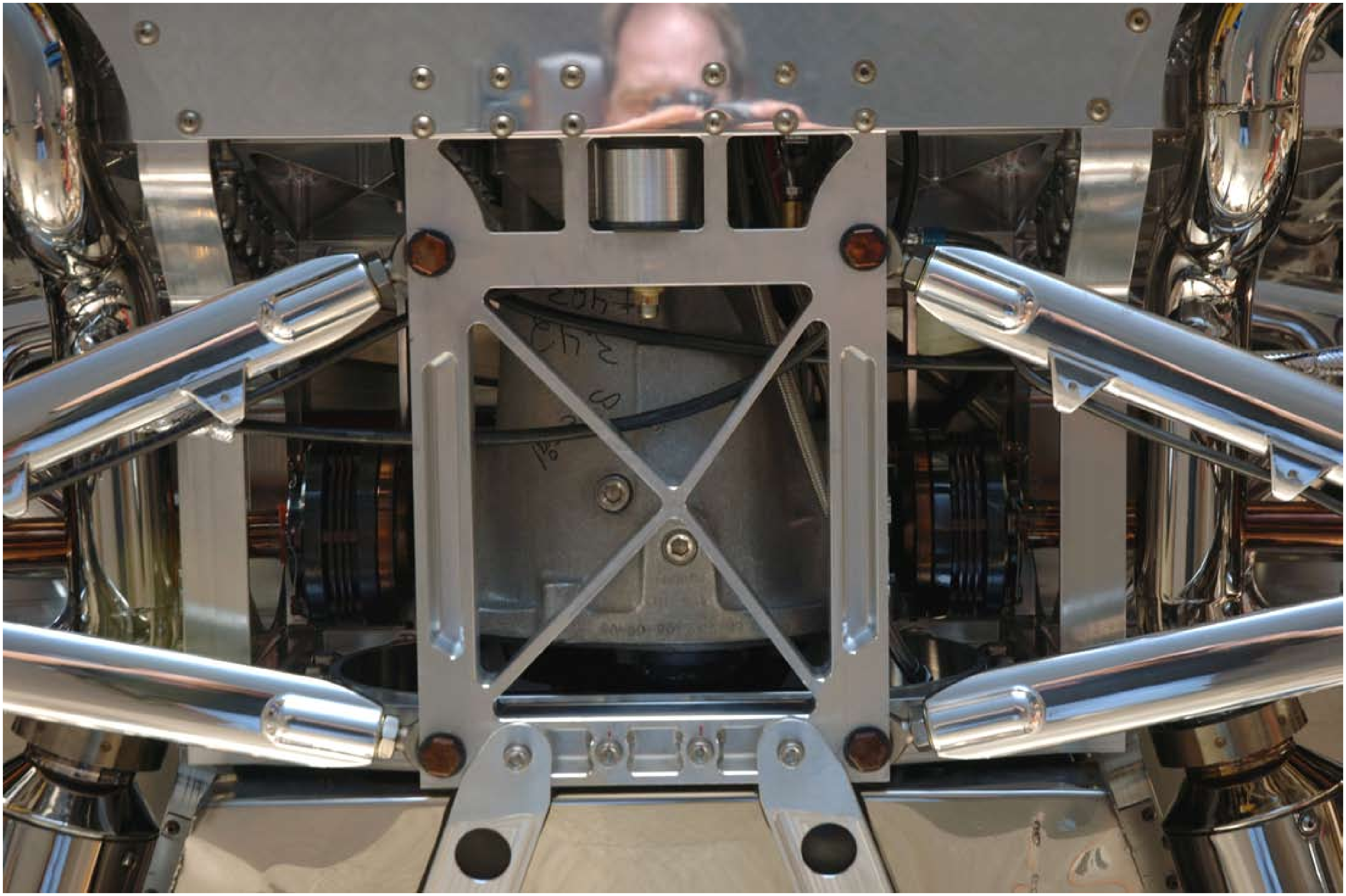
We designed our own aluminum E-brake calipers to be as lightweight and compact as possible. We used a 12.2" OD rotor in a 15-inch rim, leaving very little space to work with.

We mounted the push-rod as far out board on the front lower control arm as possible to minimize any bending loads. Also, notice the upper and lower ball joints are held in double shear for maximum strength.

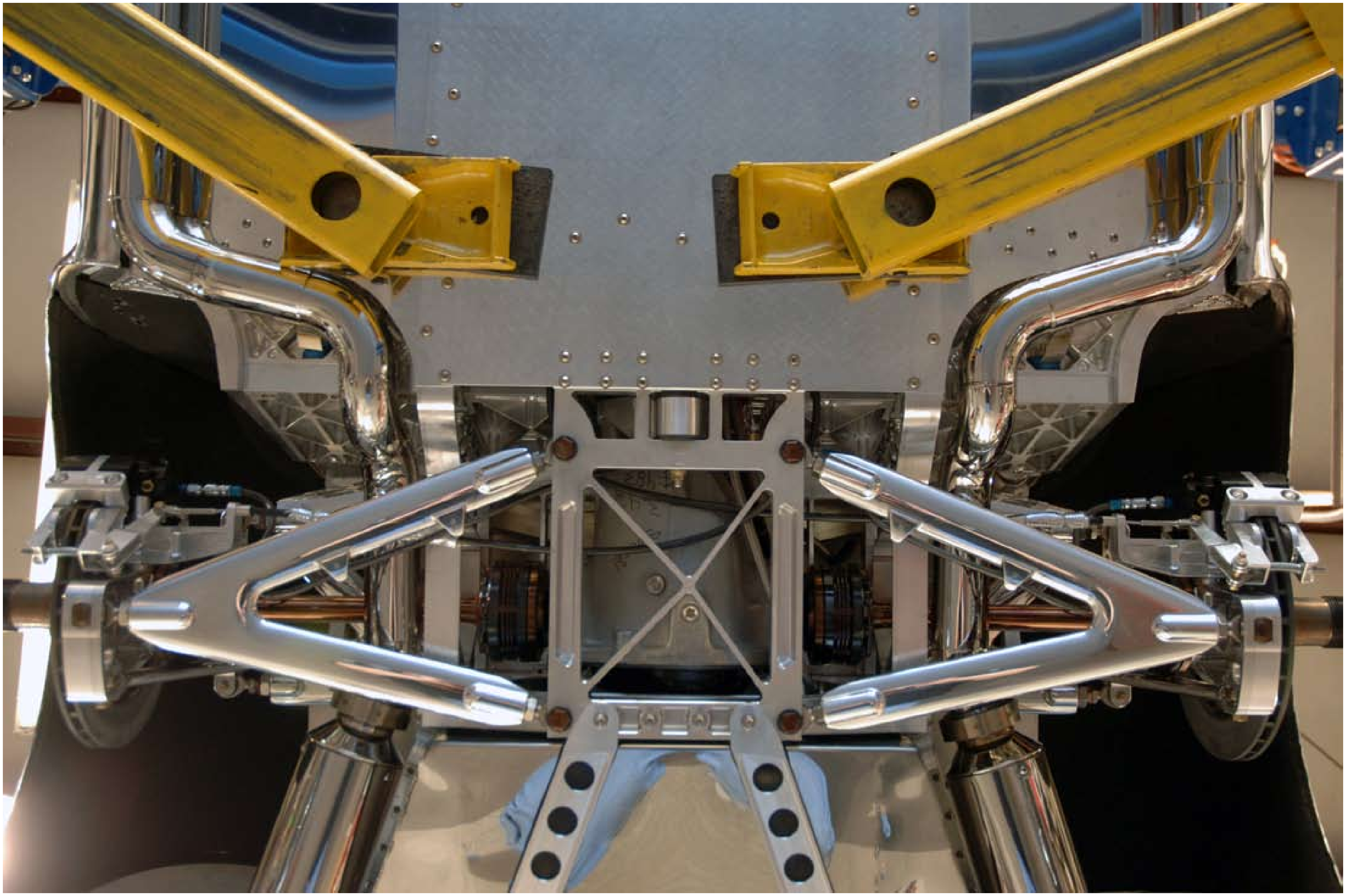
Nickel plated 4340 chromoly rod ends.

We designed the ends of the rear upper control arms with an ingenious adjustment system we saw on Lemans GTP cars. The rod end has a 1/2 inch left-hand thread that screws into the bronze colored adjustment sleeve we made. The bronze-colored sleeve (made from hardened 17-4 PH) has 1/2 inch left-hand threads on its inside diameter and a 3/4 right-hand thread on its outside diameter. The larger threads on the OD have a large surface area to help prevent the threads on the aluminum control arms from creeping under prolonged loading. Because of the opposing left-hand and right-hand threaded setup of the adjuster sleeve, simply turning the sleeve provides for infinite adjustment of the length of the control arm. When all adjustments are finalized, simply tightening the jam nuts on both the top and bottom of the sleeve locks it in place.

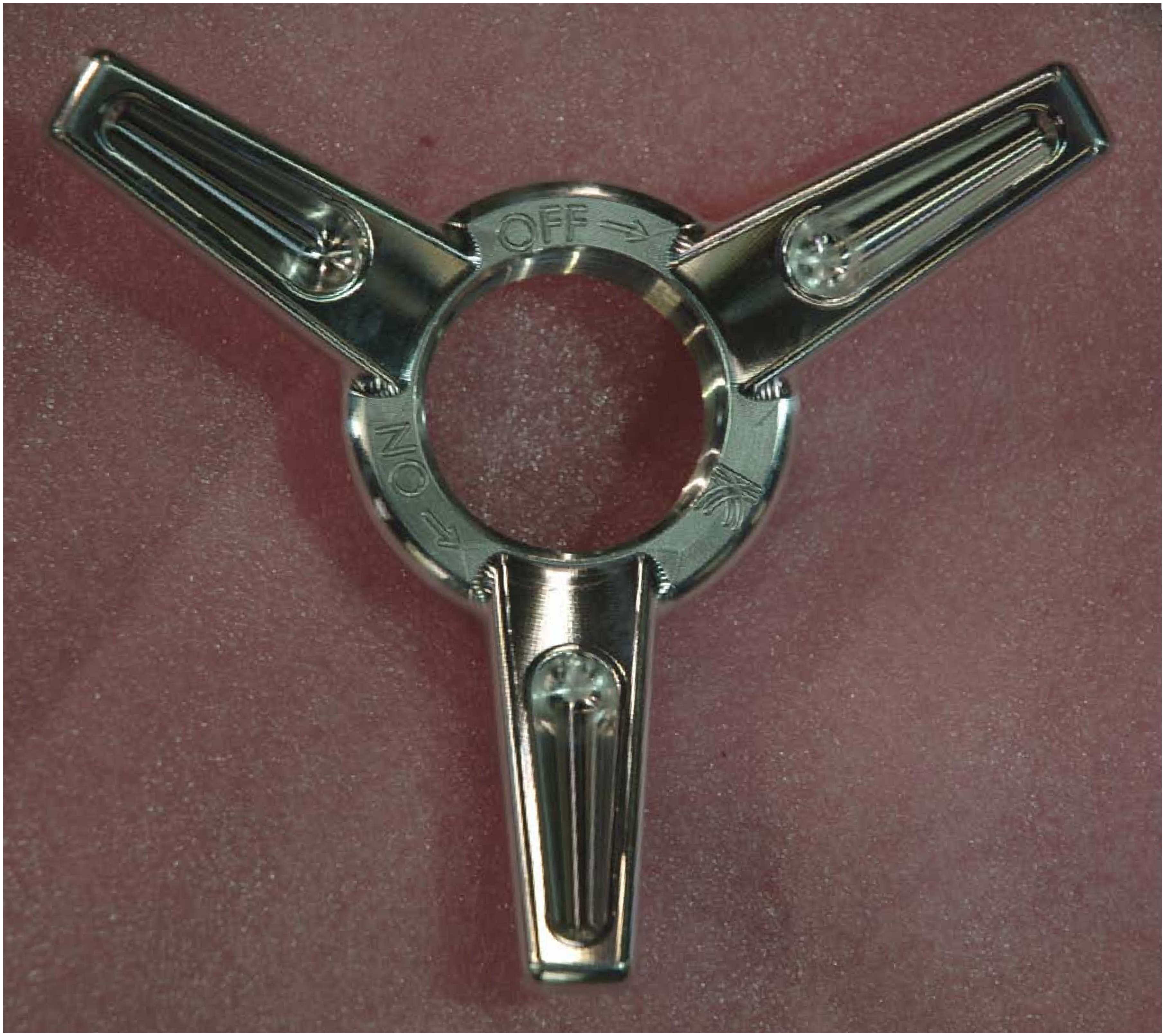
In this close-up view, you can see the high-quality rod ends we used throughout the car. The rod ends are made from heat-treated 4340 (a nickel-molybdenum based chromoly) for superior strength and fatigue resistance. Polishing the rod ends to remove all stress risers further improved the fatigue life of these highly stressed parts. Finally, the rod ends were electroless nickel plated to eliminate the possibility of hydrogen embrittlement from standard plating practices. If you look closely, you can see the Teflon lined outer race (a thin brown line between the inner and outer races of the rod end). All rod ends we used in the car were Teflon lined, so no grease is necessary to lube them. Grease attracts dust and grime and prematurely wears rod ends out. As a final touch, the jam nuts are made from stainless steel to prevent corrosion.



Looking straight up at the differential on the finished car. Notice all the stainless steel bolts. Here you can see the inboard side of the 1/2 shafts. The differential is marked with a 3.42 in magic marker—indicating it has a 3.42:1 gear ratio.

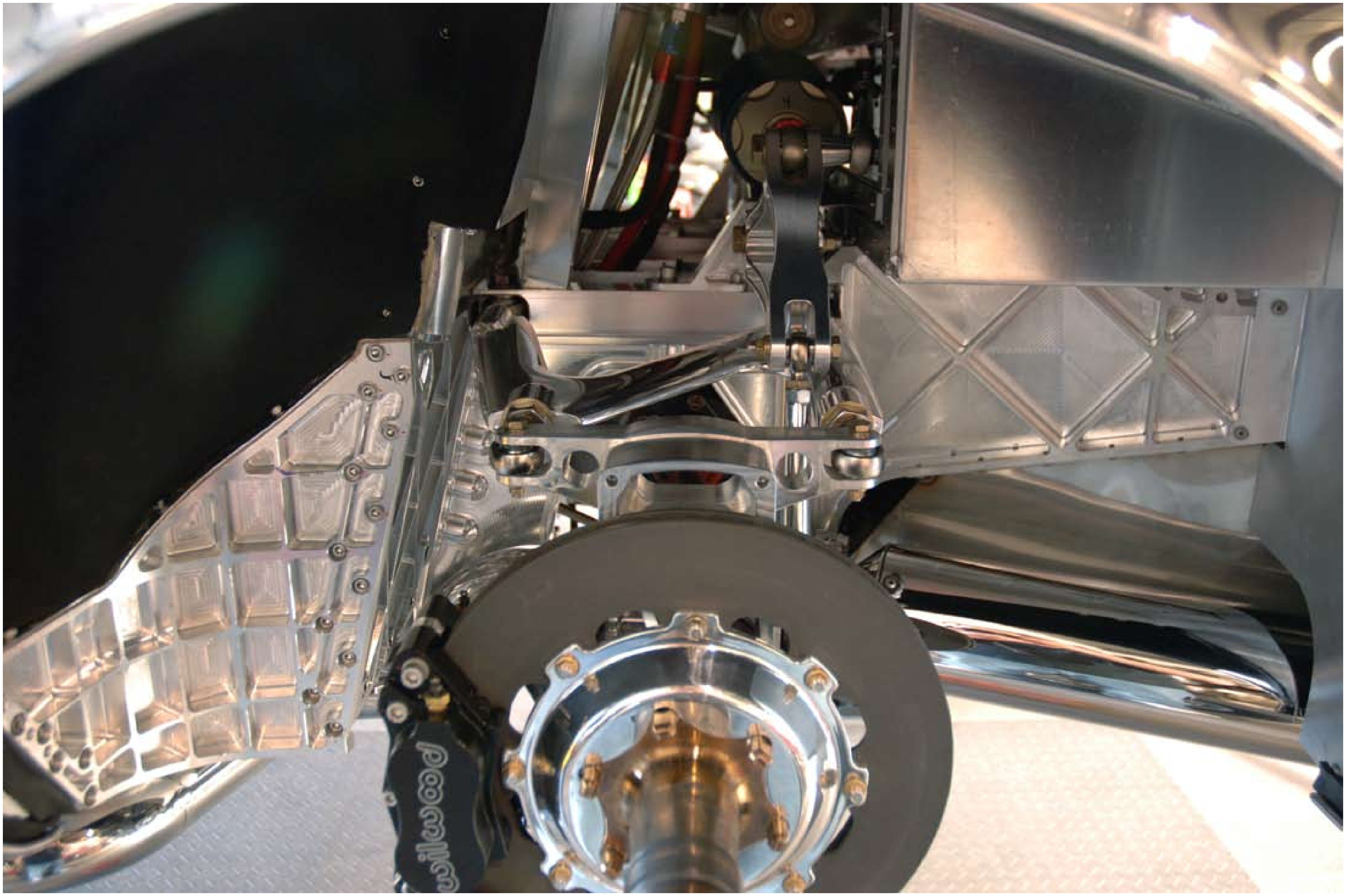


This shot is zoomed out a bit so you can see how everything was very carefully packaged together to fit in an extremely small area.



Billet aluminum knock off.

The hub knock offs were machined from a solid billet of aluminum. Following years of racing tradition on all high-performance race cars, the hubs on the left side of the car are machined with right-hand threads, and the hubs on the right side of the car are machined with left-hand threads. If you look closely at the center of the wing nut, you can see “OFF” with an arrow engraved in the clockwise direction. This indicates this knock off is for the right side of the car. We machined the knock offs with a thicker base so they don’t bend as easily as the originals.



There is very little room, so the push-rod has to thread between the arms of the rear upper control arm. You can also easily see how the rod ends on the rear upper control arm are captured in double shear. Camber and toe adjustments are done on the upper control arm with sleeve nuts.

All the control arms were designed with maximum radii to minimize any stress risers in the parts. Additionally, the control arms were polished to a mirror finish to absolutely minimize any stress risers. Here you can also see the brake flex line brackets that were machined directly into the control arms.