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TECHNICAL WHITEPAPER:

MONOBLOC vs. Two Piece Calipers

The automotive brake caliper has a basic problem. The thing is necessarily shaped like the letter "C" with the force of the pistons exerted on the top and bottom of the letter. This force spreads the caliper apart like opening a book. The result is that some of the force generated by the foot pedal and master cylinder(s) is used up (wasted, actually) in spreading the caliper. The inevitable results are increased pedal travel and tapered pad wear. Caliper designers spend a lot of time trying to minimize this deflection. The problem is that there isn't much room for the bridge that connects the inboard and outboard halves of the caliper – just about like a clamshell. We will not address the single piston or sliding caliper, which I consider to be a crime against nature.

Some advertising is hyping the "monobloc" (i.e. machined from billet, cast, squeeze or semisolid forging or conventionally forged from one piece rather than two halves bolted together) as the final answer to braking problems. Maybe, maybe not – but first lets look at some history.

The monobloc today is a product of the age of CAD/CAM manufacturing, Finite Element Analysis (FEA) and very effective marketing.

Opposed piston calipers made from cast iron, in which we have little if any interest here, have always been two-piece assemblies. The material itself is stiff enough that, always assuming a basically competent mechanical design, caliper flex is usually not a problem.

The first lightweight Aluminum racing calipers were made by Girling – the two-piston AR, BR and CR series introduced in the early 1960s. They were machined from a single casting with the piston bores machined clear through one side from the back and up to the piston length into the other. The through holes in the back were closed with screw in plugs and seals. The bridge section was relatively thin. Due to the low coefficient of friction between the pads and the rotors, the line pressures of the day were pretty high and the calipers flexed giving a less than optimum pedal feel and tapered pad wear. We lived with it because we had to – and that may be when the myth that a long brake pedal aids modulation began.

Over the next twenty years or so both Girling and Automotive Products (AP) developed improved one-piece light alloy calipers with more pistons and stiffer bridges. They were adequate until aerodynamic download took a quantum leap with the development of ground effects in the late 1970s. While the coefficient of friction between the pads and the discs did not materially increase, the coefficient between the tire and the track did. Braking distances shortened dramatically.

The same amount of heat that had caused problems before ground effects was now generated in a much shorter time. The need for increased heat sink mass and radiant surface area made it imperative to maximize disc diameter - which reduced the space available for caliper bridges inside of wheels. Caliper deflection became a serious problem. The solution was the two-piece caliper with steel bolts in close fitting holes to stiffen the assembly. The location of the bolts is also critical to the overall stiffness of the unit. Locating them lower near to the piston centerline results in less deflection.

As a point of academic interest there is no advantage to using an extremely high tensile bolt in this application – again, we are looking for stiffness, not strength. Stiffness is a function of the material's modulus of elasticity and all steels have the same elastic modulus (about 207 gigapascals per cubic millimeter or Gpa. The use of metric units will make sense below when we get to rule making in racing). There is also no advantage to using a nut on the threaded end of the bolt. Assuming sufficient thread engagement (and good threads) a bolt screwed into the threaded caliper half with optimum pre load is just as good as a nut and bolt system.

The coefficient of friction between pad and rotor was dramatically increased by the development of the “carbon metallic” brake pad for cast iron rotors and the almost simultaneous development of the carbon-carbon braking system with about the same coefficient but a fraction of the mass. Multi piston (up to six) calipers with staggered piston diameters were quickly developed. Multiple calipers on the same disc also made a short-lived appearance in racing. This strategy in another form is now only seen in a few street caliper types with multiple pad sets and up to eight pistons in a single assembly. In this case the original multiple caliper layout was better because the long unsupported flanks of multiple pad set caliper designs accentuate the caliper flex problem. Six pistons is a practical limit for a stiff assembly and a well designed four piston calipers will always flex less for a given piston area than a six piston similarly well designed for the same wheel clearance.

Aluminum forgings are significantly stronger than castings but not necessarily stiffer and there were few customers who wanted to ultimately pay for the complex dies necessary to produce different caliper sizes and configurations as forgings of exotic alloys. Then with the advent of the multi-axis CNC milling machine, it became possible to produce monobloc calipers from solid billets of Aluminum by machining the piston bores from the center window, eliminating the necessity for forging dies (and for the troublesome screwed in plugs).

About the same time Finite Element Analysis software became generally available. While FEA is still a work in progress and every program requires some amount of calibration to suit the individual application, the technique allows very accurate modeling of a prospective design under the expected operating conditions of stress and temperature. The model identifies areas of high and low stress allowing the designer to iteratively reduce mass by carving away the areas of low stress and to simultaneously add design stiffness by modifying the shape or the cross section of the highly stressed areas. FEA must be validated by physical testing, but used properly, the programs can generate very efficient designs in term of mass to stiffness and mass to strength ratios. However, the modulus of elasticity of Aluminum is only about 71 Gpa. Equal to 10.3 x 10 6 psi and it is very difficult to arrive at a bridge design that is sufficiently stiff while leaving room for a large diameter rotor.

A big step was the development of Metal Matrix Aluminum (MMC) composite materials with a modulus of about 135Gpa - twice the stiffness of Aluminum. Aluminum Beryllium alloys with a modulus of 192 Gpa are stiffer yet - three times the stiffness of Aluminum and nearly the same as steel. Both of these aluminum alloys retain a high degree of their original strength at elevated temperatures – which is a lot more than can be said about Aluminum. A whole new generation of very stiff, very strong, very light, and very expensive calipers arrived in Formula One and World Sports Cars – the only players who could afford them. The so-far fruitless efforts to reduce the cost of racing at the top have now outlawed Aluminum Beryllium and most of the Aluminum metal matrix composites simply by specifying a maximum modulus of elasticity of 80Gpa – (there's the tie-in. Still a very significant 13% greater than that of Aluminum). In Formula One extensive iterative FEA work has recovered about 30% of the stiffness through design. Since the measuring techniques for determining the modulus don't repeat very well there are also all sorts of fun and games going on between the manufacturers and the FIA - but that doesn't concern us here.

What has happened is that the FEA techniques pioneered in the old cost-no-object days of Formula One have been applied to some aftermarket and production calipers. In the case of monobloc designs made from billet, once the machine tools have been paid for, monobloc calipers may actually be cheaper to produce than two-piece units. Then there are newly developed high volume production methods where monobloc calipers are made from near net shaped squeeze or semi-solid forgings, again finished by machining the piston bores from the center window. As in the case of billet, in the case of designs made from squeeze or semi-solid forgings, once the foundry tooling and machine tools have been paid for, monobloc calipers are definitely cheaper to produce. The current generation of Monobloc after market calipers from the reputable manufacturers are at best only about as stiff as conventional two piece units – at ambient temperature.

There is a rub. Brake calipers, especially those attached to hard driven high performance vehicles, do not operate at ambient temperature. Caliper operating temperatures can and do often exceed 300 degrees F on high performance street vehicles. – at which point the Aluminum bridge of the monobloc has lost more than half of its strength while the steel bolts in a two piece unit are unfazed. In fact, steel is essentially unaffected until around 200 degrees F where it begins to gain in strength. Steel gains 25 to 32 percent in strength when it peaks at about 400 degrees F. We are also seeing designs for production like another old Girling design called the four piece caliper (early ‘70's – terrible flexing problems) returning where the bridges are made of steel and incorporated into the mounting bracket instead of Aluminum for just this reason. In this design the pistons are carried in two Aluminum bodies bolted on each side of the bridges. This type, with all four pieces in Aluminum but heavily ribbed for cooling was also the design of the first Porsche Turbo caliper (mid to late ‘70's).

The mechanical properties of some aluminum alloys used in caliper production at different temperature are shown in table 1 thru 3.

Table 1

Data for permanent mold castings made from Aluminum A356.0 – T61 (72 Gpa)

Test Temperature (°F)	**Ultimate Strength** (ksi)	**Yield Strength** (ksi)	**Elongation** (typical, %)
75	41	30	10
212	32	27	12
300	21	17	15-30
400	12	9	18-40

Table 2

Data for parts made by squeeze molding or semi-solid forging using Aluminum A356.2 – T6 (72 Gpa)

Test Temperature (°F)	**Ultimate Strength** (ksi)	**Yield Strength** (ksi)	**Elongation** (typical, %)
75	45	33	12
212	33	30	14
300	23	19	18-35
400	13	10	20-45

Table 3

Data for parts made from forgings or from billet Aluminum 7075 – T73 (71Gpa)

Test Temperature (°F)	**Ultimate Strength** (ksi)	**Yield Strength** (ksi)	**Elongation** (typical, %)
75	70	60	13
212	63	58	15
300	31	27	20-30
400	16	13	22-55

So what does it all mean???? Caliper performance characteristics depend on material strength and a combination of design and material stiffness. The monobloc caliper architecture designed to be made from a very strong and very stiff material will not deliver the same level of performance when made from more common production materials.

It means that aftermarket monoblocs have significantly less strength and stiffness than the current Formula One units – let alone the unobtanium ones of days gone by. It means, if you want to spend a lot more money for a good monobloc racing caliper, if it happens to be available with piston areas that suit your car, you can have a trick monobloc caliper that will almost certainly flex more than an optimum two piece unit and is a few ounces lighter. It also means, if you are able to use a monobloc caliper designed for a production application made either by squeeze or semi-solid forging, cost might be comparable but any claim of them being intrinsically better than a well designed two piece caliper with bolts is simply not true. It is pure marketing hype when a commercially available monbloc caliper, where the manufacturing strategy was aimed at reducing costs to produce a fixed multi piston design, is represented as better than every other design in the aftermarket.

To further make the point, if there were no qualifiers like cost or some sanctioning body rule, the optimum caliper arrangement arguably would be a monobloc design but with steel bridge bolts installed and a re-enforced window. Me? I'd rather use the best designed two piece units, made from squeeze or semi-solid forgings correctly sized for my application, have the firmest brake pedal that I can get and spend the extra money on something to make my car handle better – like shocks.

by Carroll Smith, Consulting Engineer at StopTech

STOPTECH

Stoptech is the performance engineering and manufacturing division of Centric Parts. It is the leader in Balanced Brake Upgrades for production cars and has three patents in basic brake technology and one other pending. With a worldwide network of resellers, StopTech's product line includes Balanced Brake Upgrades for approximately 450 applications featuring StopTech's own six-, four- and two-piston calipers, two-piece AeroRotor Direct Replacement Kits, braided stainless steel brake lines and slotted and drilled original-dimension rotors. StopTech also stocks a wide range of performance brake pads. The company's website, www.stoptech.com, is a clearinghouse of performance brake information, and provides details on StopTech products.

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