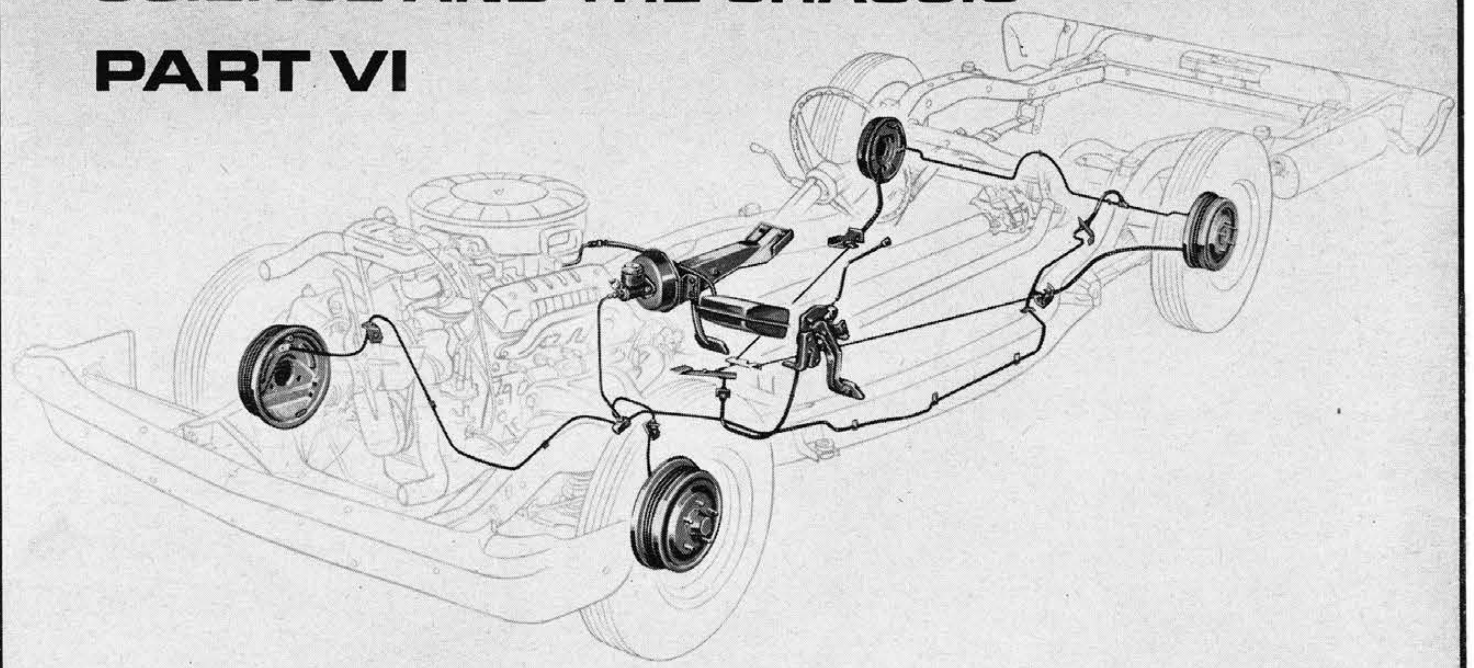
## SCIENCE AND THE CHASSIS

## PART VI



# THE BRAKE SYSTEM

BY ROGER HUNTINGTON

EVERYBODY IS TALKING about "total performance" these days. The idea is that more than just straight-line speed and acceleration is needed to make a real high-performance car. There must be quick steering response, rock-steady stability at speed in a cross wind, high cornering power, near-neutral steer characteristics—and more powerful, stable brakes that don't fade under stress.

### *A Few Fundamentals*

The fundamentals of automotive braking systems have been thoroughly explained in various publications, but a brief review may be in order.

A car in motion possesses a certain amount of "kinetic energy" due to its mass and speed. This energy is directly proportional to the weight of the car and to the square of speed. When the car slows down this energy must be dissipated — actually, converted into some other form of energy. If the car coasts to a stop the kinetic energy is dissipated in wind resistance and chassis friction. If it is stopped with the brakes the energy is converted into heat in the linings, shoes and drums because of the rubbing friction. In fact, the energy is converted to heat in both cases; in a coasting stop the heat is produced by wind turbulence, bearing and gear friction. The brakes merely generate heat much faster, and thus stop faster.

It should also be kept well in mind how this kinetic energy increases with car mass and speed. A 4000-lb. car would possess 33% more energy at a given speed than a 3000-lb. car. But the energy would be doubled by increasing the speed from only, say, 60 mph to 85 mph. This is why speed is a much more critical factor to the brake problem than car weight. The trend to slightly lighter cars is being more than offset by steadily-rising highway speeds. Brakes have far more work to do today than 10 years ago.

The brake system, then, is merely a mechanism to convert the car's kinetic energy into heat—and do it with a minimum of pedal pressure, without squealing, rapid wear, pulling to one side, or "fading" under hard conditions (which will be discussed later). The big problem, of course, is handling the heat and the brake engineer can approach this problem from one or more of three general directions: He can 1) design his brakes to dissipate heat rapidly to the surrounding air, 2) design them to absorb a great deal of heat without an excessive temperature rise, or 3) design the brakes to operate efficiently at very high working temperatures. All these approaches are interlocking, of course. A brake system that operates efficiently at high temperatures will also dissipate heat well, simply because the rate of heat transfer increases very rapidly with the temperature differential between brake and ambient air. However, these three approaches are separate enough to permit a brief analysis of brake design in each category.

### *Dissipating Heat*

Heat can be transferred from one medium to another by three general processes—conduction, radiation and convection. Heat transfer by conduction is through actual physical contact of the two mediums, such as air rubbing along the surface of the brake drum. Or heat is transferred through the brake drum by conduction, through contact of the internal molecules.

Heat radiation is an electromagnetic phenomenon that does not require the presence of a transferring medium. Whenever one body is at a higher temperature than an adjacent body (like a brake drum and the air mass) it sends out heat waves. Radiant heat transfer depends on the surface and color of the body as well as the temperature differential. A dull black body radiates heat most efficiently, which means that black-painted brake drums might run a shade cooler than shiny aluminum drums.

Convection refers to the transfer of heat by the circulation of air (or other fluids). Heated air rises and circulates because of the difference of density, thus transferring heat by its motion. Some degree of brake cooling is due to this factor. The problem is to design brakes to take advantage of these various forms of heat transfer.

The major tricks are well known. Heat transfer is a function of the surface area of the brake components. Therefore, the engineers can merely increase this area. This can be done most efficiently by putting fins on the drum (and possibly, shoes), to greatly increase the surface area without greatly increasing physical size. Or improvements can be made merely by increasing the physical size of the components. Conductive and convective heat transfer can be increased by arranging to ventilate the brake with air slots and scoops. Auxiliary motor-driven air blowers have been used to cool the rear brakes on some racing cars (like the old Pan American Lincolns of the early '50s). Or wheels can be designed to act as turbine blowers to actually draw air across the brakes. A few years ago Bendix experimented with water-cooled brakes (and oil-cooled brakes are now used in the earth-moving industry). The shoes were designed to have water circulate through them, and the heat was dissipated in a special radiator. Cunningham once tried these brakes on his Le Mans cars.

### *Absorbing Heat*

It goes without saying that no brake could possibly come anywhere near dissipating heat as fast as it pours in during a hard stop from high speed. Literally hundreds of BTUs are generated in a matter of a few seconds and automotive brake layouts just can't eliminate heat that fast. So the brake inevitably heats up. This heat is absorbed in the brake components; that is, heat that isn't transferred is retained within the body, and raises its temperature.

The ability of a body to absorb heat depends on just two factors—its mass or weight, and the "specific heat" of the material of which it is composed. Specific heat refers to the number of BTUs required to raise one pound of the material 1° F. Materials vary widely in their specific heats. Aluminum has just about twice the value of iron and steel, 0.22 BTU/lb./degree F., as compared with 0.11. This is why it is an ideal material for brake drums. Not only does it have a high specific heat so its temperature rises that much less for a given heat input, but it also conducts heat four times as fast as iron. Heat can readily get through the drum to the cooling air. No other material has these features for brakes.

But if the effect of specific heat is ignored, there's still the factor of mass. Big, heavy brake drums and shoes will absorb that much more heat within a given temperature rise. There's really no good substitute for mass in a brake. This is a major criticism of disc brakes. The light, thin discs and light caliper assemblies have comparatively little brute mass. A sudden energy load on a hard, high-speed stop generates a tremendous amount of heat in them. They dissipate it rapidly from the open disc, but sometimes not fast enough. Peak temperatures skyrocket and the discs glow red hot—actually visible in a night race like Sebring. These high working temperatures cause fast wear of the friction material. While usually not serious on racing cars, it's something to consider on heavy passenger cars.

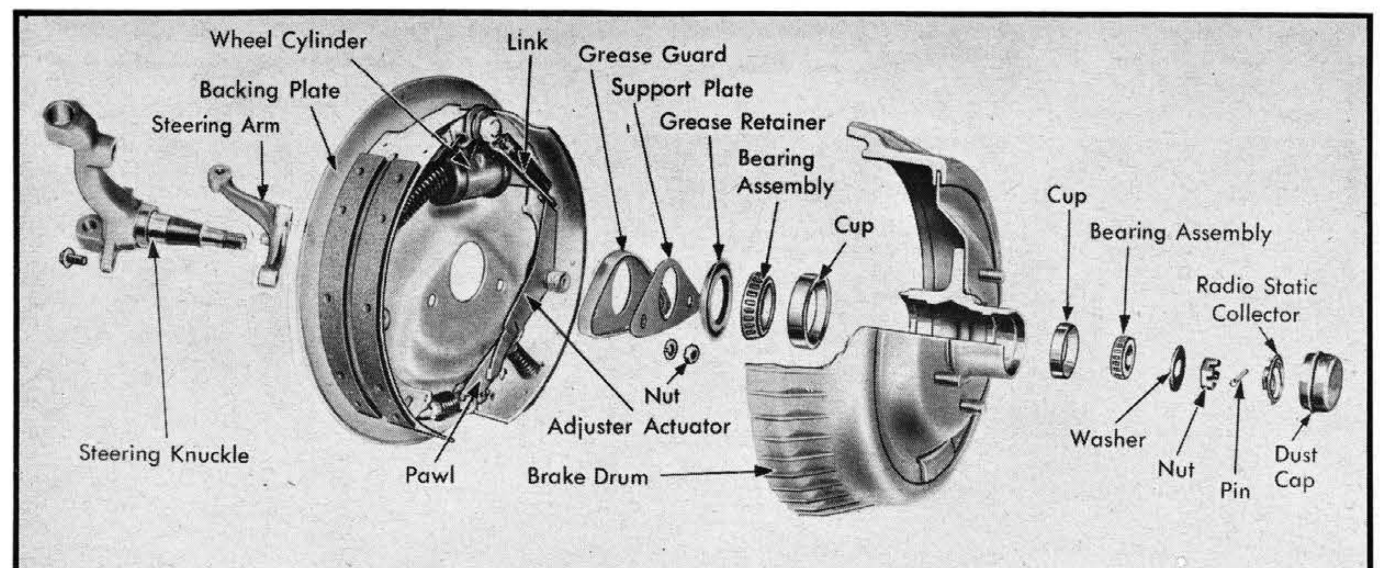
FINNED IRON drum for racing Corvette.

### *Working Hot*

If all else fails, brakes can be designed to work efficiently at fantastic temperature levels. It's easier said than done, but it is possible.

For instance, this is the function of "hard" heavy-duty brake lining. Where standard "soft" lining materials begin to lose friction and "fade" when the temperatures reach 300° F. or so, ▶

EXPLODED VIEW of Cadillac brake shows parts, grooved lining to provide better cooling.



# THE BRAKE SYSTEM

these special friction materials will hold on up through 500 to 600°. Of course there is a penalty. At low speeds in normal driving the brakes will require much more pedal pressure for a given braking force. They don't start working properly until they get hot. Unless driving requirements are quite severe, heavy-duty linings may be of questionable value. There are many brands and grades, however, and nearly any compromise desired is available.

Then there are the new metallic brake linings. These will continue to give good holding power (friction) up to over 1000°, when drums get red hot (some have been tested at nearly white-hot temperatures). Metallic lining development is still in its infancy. It shows much promise for the future. But certainly when a brake is designed to work at these temperatures it has to do much more than include special lining. The drum surfaces must be very hard to assure long life. The compatibility of the lining and drum materials must be just right to prevent grabbing when cold. And, most important, drum distortion becomes a terrible problem at high working temperatures. The thing gets so jacked out of shape (mostly bell-mouthing) that the friction material can't get a bite on it. Careful design of drums to prevent this distortion is a must on good high-performance brakes.

### *Designing Good Drum Brakes*

There's a lot more to designing good drum brakes than getting efficient heat dissipation and stable linings. One of the big areas of development down through the years has been to get minimum pedal pressure for a given braking torque. A soft lining material helps a lot in this direction, but this is only a small part of the problem. More can be done with shoe layout.

Conventional brake shoes are formed as segments of a circle, and they have various means of pivoting against the drum. The simplest method would be to pivot both shoes at one end, and to install a single hydraulic cylinder with dual pistons at the other end—pushing the tips of the shoes in opposite directions against the drum. It will be obvious that the shoe that is being pushed in the same direction the drum is turning will have a certain "self-energizing" effect. In other words, the friction of the lining generates a torque about the pivot that tends to pull the shoe harder against the drum. This is called a "leading" shoe. Naturally the other shoe is a "trailing" shoe. Its friction would tend to pull it away from the drum, so the net benefit would be zero. The "shoe factor," in other words, would be 1. (The shoe factor is the drag on the drum divided by the piston force pushing the shoe against the drum.)

Use of separate cylinders for each shoe and pivoting them at opposite ends results in 2-leading-shoe brakes —and the shoe factor jumps to around 2. That is, the drum drag would be about twice the piston force on each shoe. These 2LS brakes were used for many years on Chrysler products. But they're expensive because of the necessity of twin cylinders. A still more efficient arrangement is known as the Bendix "duo-servo" system. Here there is only one hydraulic cylinder, pushing both shoes. But instead of pivoting the shoes at the bottom, they have a link that transfers its force to the opposite shoe and the secondary shoe is pivoted at the top, next to the cylinder. The self-energizing effect of the leading shoe is actually transferred across to the secondary shoe. The shoe factor is nearly 3 with this layout. It gives the minimum possible pedal pressure for a given braking torque. It's simple, inexpensive (with only a single cylinder required), and is well adapted to the new self-adjusting cross links. All late American passenger cars use these Bendix-type brakes. (Chrysler completed the switch this year.)

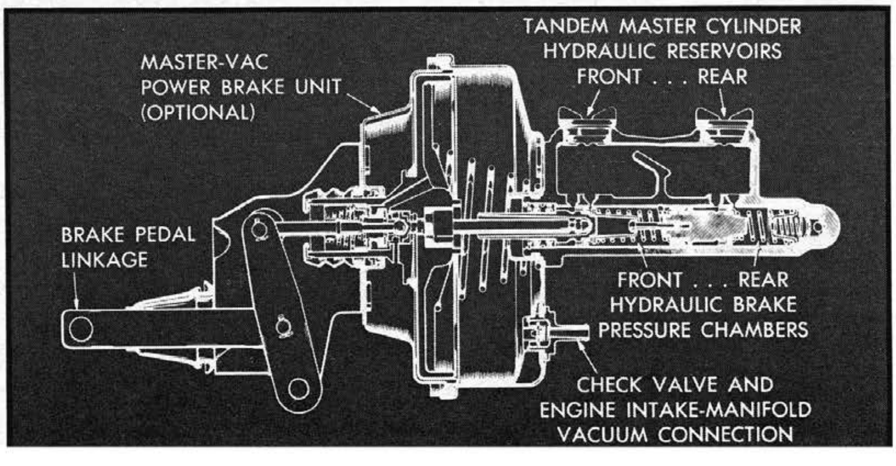
The biggest disadvantage of brakes with a high shoe factor is that their stopping power is highly dependent on the coefficient of friction between lining and drum (because actually the friction is doing almost as much work in applying the shoes as cylinder force). And, in turn, braking power falls off rapidly as the linings heat up and lose their friction. The Bendix brakes are very bad from this standpoint. This has led to the development of two-trailing-shoe brakes for some heavy, high-performance cars. These have a shoe factor of about 0.8, and require a lot of power assist to get hard braking. But they're very little affected by loss of lining friction. They'll keep on stopping until the linings char to a cinder.

### *Disc Brakes*

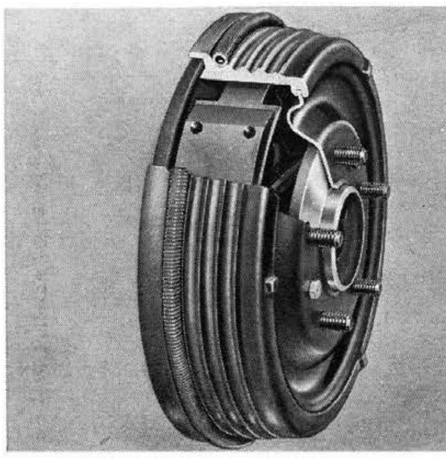
Drum brakes are presently used on the overwhelming majority of the world's passenger cars, but the trend is to disc brakes. Studebaker's Avanti has just introduced them to the American scene (after false starts by Chrysler and Crosley over 10 years ago), and there probably will be two or three 1964 models using them as standard or optional equipment.

The big advantage of the disc brake is obvious: the rubbing surfaces and caliper housings are right out in the open air for optimum cooling. An important secondary advantage is that

DIAGRAM OF dual master cylinders on Rambler power brake.

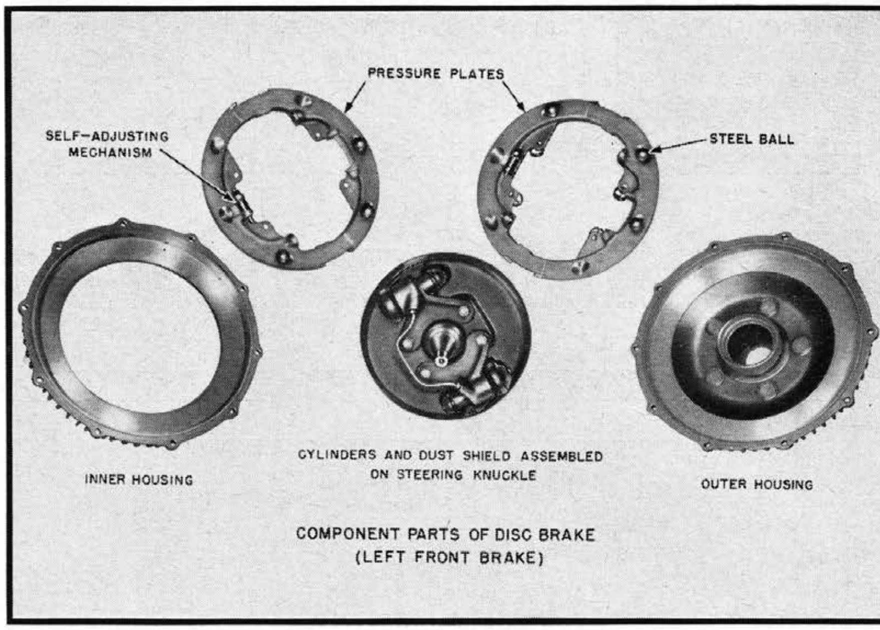



CUTAWAY SHOWS squeal-stopping coil spring.



the disc expands toward the friction pad under high heat loads, so there is not the problem of thermal distortion there is with drum brakes. Otherwise, it's doubtful that there are any other really important advantages to the discs. They seem to be inherently more expensive. They don't save as much unsprung weight as once thought. Mileage between lining replacements tends to be shorter. But they do give very stable braking under tough conditions of heat input.

Right now it looks as if Budd Automotive's new disc design might be the answer for heavy American cars. It features a massive disc of cast iron, formed like a "sandwich" of two plates with fins between them. Not only is there a large mass to absorb heat, but the fins between the two rubbing surfaces are very effective in dissipating heat. The design also uses very large friction pad area and four pistons instead of the usual two. It's a brake designed for heavy cars. Budd claims pad life nearly equal to current drum brakes, a 10 to 15% saving in brake weight, and prices competitive with current drum designs (in mass volumes). Improved lining life is probably the most important development. This has been a major criticism of the Bendix-Dunlop design on the Avanti. Designed basically for lighter foreign cars, it has been hard put to handle big U.S. cars weighing over 3500 lb. Incidentally, in years past much excessive pad wear was caused by dust and grit from the road rubbing between the pad and disc. Early designers didn't think it was necessary to provide special protection from this road dirt, but carefully-designed dust shields (usually a stamped steel plate) are now used adjacent to the disc—and these multiply pad life by two or three times in some cases.



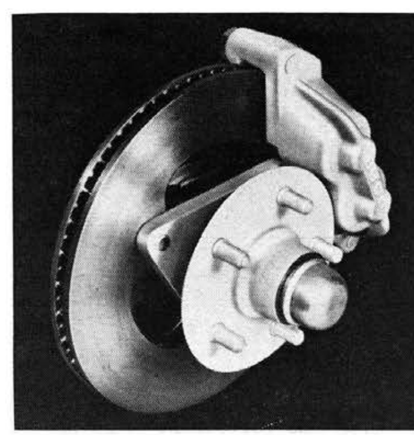

**ILL-FATED** clutch-type brakes tried by Chrysler in early '50s.

It should also be mentioned here that disc brakes have no inherent self-energizing action. They need a lot of power assist on heavy cars, but this is being overcome also. Dunlop recently announced a new self-servo disc brake. It uses triangular pads, with the power piston pushing the pad against an angular reaction surface, thus giving a wedging action against the disc. The "servo factor" (equivalent to shoe factor) is about 2 and pedal pressure is reduced about 30% for a given stopping "G." This self-energizing feature could make discs a lot more attractive around Detroit, since American drivers have used Bendix duo-servos so long that they expect ridiculously low pedal pressures.

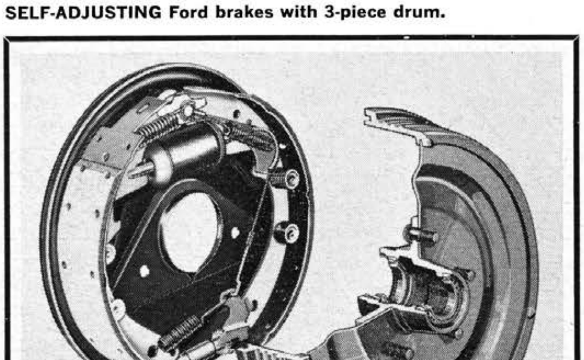
And after all that—designing a brake that's stable, will handle the heat, won't distort, will give low pedal pressures—then it's necessary to start thinking about problems like cost, space, squeal and chassis adaptability.

Next month, the car structure—frames and unit bodies—will be discussed. ■

**BUDD DISCS** have ventilated plate.



**SELF-ADJUSTING** Ford brakes with 3-piece drum.



**AVANTI DISC** brake pads pinch against plate.