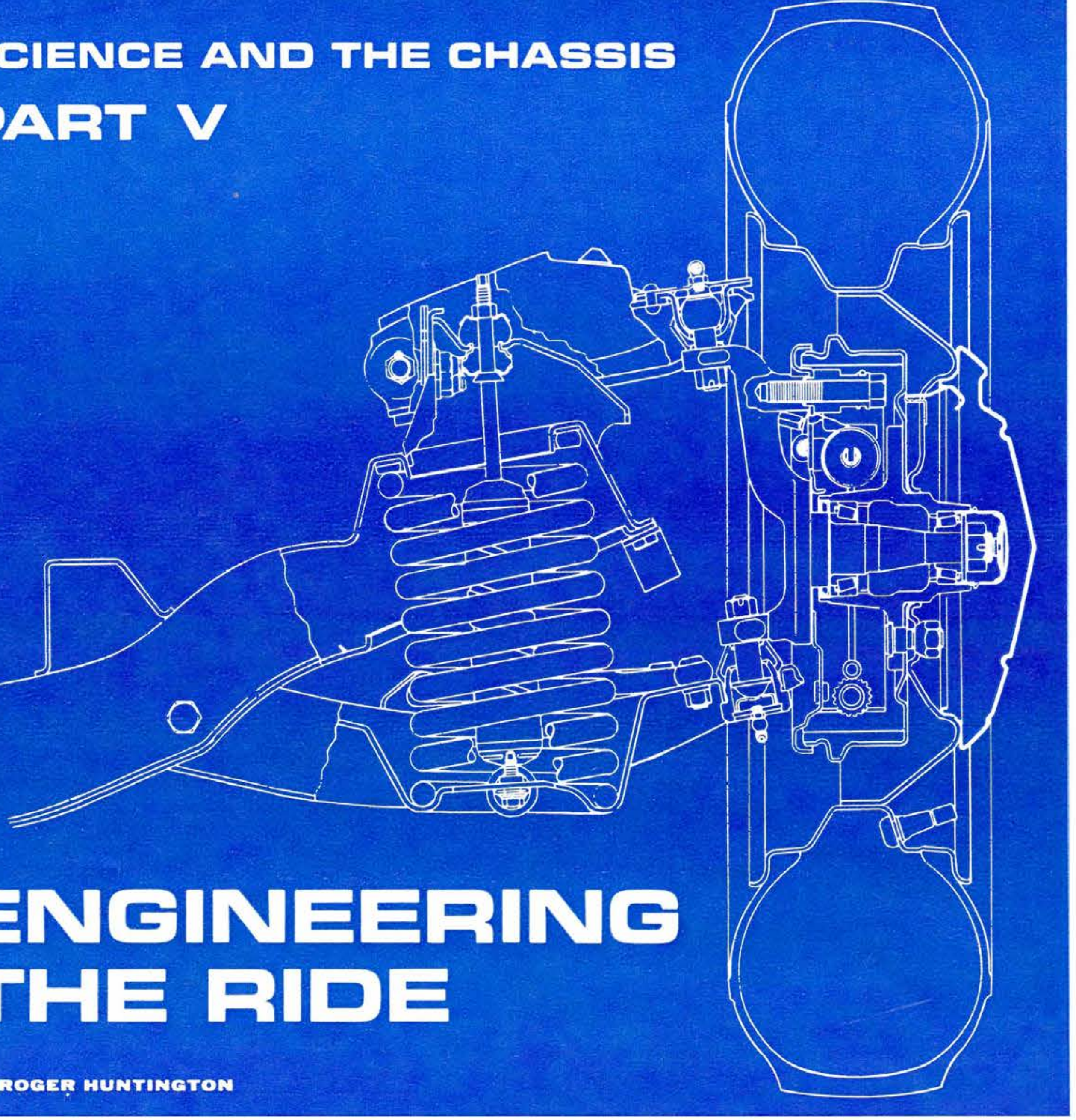
SCIENCE AND THE CHASSIS

PART V



ENGINEERING THE RIDE

BY ROGER HUNTINGTON

THE MODERN i.f.s. gives a leverage that reduces effective spring stiffness at the wheel.

UNTIL NOW in this series we've been concentrating on the handling and cornering of a car. This month we're going to talk about *ride*. It's pretty generally agreed that the handling of a car must be compromised to get the optimum ride. There are certain tricks that the engineer can use to ease this compromise but it's still true that the best-handling cars in the world definitely don't have the softest and easiest ride. And vice versa. The best-riding cars tend to mush and wallow in turns and stiff crosswinds (perhaps we could say any car that acts this way doesn't really have a secure and easy "ride").

We discussed the subject of spring-suspended masses in an earlier chapter (March) on suspension. But let's review it briefly:

Fundamental Relationships

All the parts that are suspended on the chassis springs of a car (body, frame, engine, etc.) combine to form the "sprung mass." The parts that bounce up and down with the road wheels (wheels, tires, axles and brakes) form the unsprung mass. The two masses are connected by the springs, of course, plus some form of damper (shock absorber) to control the bouncing and pitching by dissipating the vertical energy. This is usually done by forcing oil through a restricted orifice, so that the energy is converted to heat in the oil. In bygone days it was done with rubbing friction. Same principle. The main thing to picture is this pattern of masses suspended on springs with dampers connecting them.

Now it is known that any spring-suspended mass will oscillate up and down at some "natural" frequency when the mass is acted upon by an outside force. Note: The frequency of the outside force has no effect on the natural frequency of the oscillating mass. It affects only the amplitude of the oscillation—in other words, the distance through which it moves up and down. If the frequency of the outside force is perfectly matched to the natural frequency of the sprung mass, we have synchronous vibration. This gives tremendous amplitudes and virtually uncontrolled oscillation. Efficient dampers are a must to control this condition. But as the frequency of the outside force varies from the natural frequency, the amplitude gets shorter. If this outside frequency were 1½ times the natural rate the two motions would oppose each other—and the oscillation would stop.

The natural frequency of a sprung mass depends on the stiffness of the spring and the weight of the mass. Or it can be conveniently calculated in terms of the static deflection of the spring when it is supporting the mass and there is no oscillation. This, of course, is a function of the spring stiffness and weight of the mass. We needn't go into the actual mathematical formula for natural frequency here. Essentially, this frequency is inversely proportional to the square root of the static deflection. For instance, let's say there's a load of 800 lb. on a spring that has a stiffness rate of 100 lb./in. of deflection. Thus the static deflection would be 800/100=8 in. And our natural frequency of oscillation here would be 66 cycles/min. (cpm). But if we doubled the stiffness of the spring to 200 lb./in.—so the deflection was reduced to 4 in.—the frequency would only go up to 94 cpm.

This is a car's suspension system: The sprung mass merely oscillates up and down at some more or less fixed frequency when acted upon by road shocks through the unsprung mass. (Shock absorbers only damp this oscillation and don't appreciably affect the amplitude or frequency.) It's the job of the car's designer to select a spring stiffness (and static deflection) which will give a natural frequency that is acceptable to the passengers. This frequency is often called the "ride frequency." This is the actual oscillation frequency at the wheel. It can't be calculated simply from the spring stiffness because of the leverage effect of suspension arms. Generally a given spring will show a slower frequency (and greater deflection) at the wheel than at the spring seat because of this leverage. But, of course, the frequency follows the same inverse square root law.

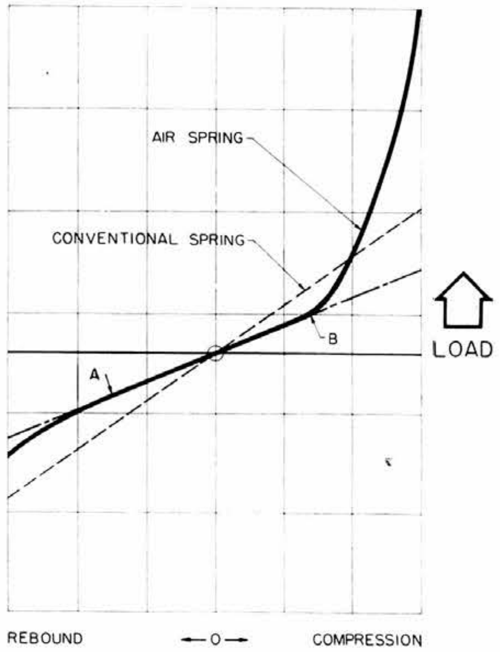
So what natural frequency do we want for our optimum ride? Opinions vary. A number of researchers have checked thousands of people of both sexes and all sizes and ages, using a special vibrating seat, to determine their tolerance for ride oscillations. It soon became obvious that the smaller the amplitude (total vertical movement) of the vibration, the higher the frequency they could tolerate and still feel reasonably comfortable. If the amplitude is not over 0.25 in., humans feel fairly comfortable with oscillation frequencies as high as 180–200 cpm. But when the amplitude is increased to 2.0 in. the maximum ride frequency for comfort is 80–90 cpm. And for a 3–4-in. travel you would have to reduce the frequency to 60–70.

These scientific findings (available in various SAE papers and any number of automotive technical books) have formed the basis for establishment of quite well-defined limits for ride frequency on the world's cars. They won't vary far from the above-mentioned figures of 66 and 94 cpm—equivalent to 8 and 4 in. static deflection at the wheel, respectively. On our "comfort curve" these frequencies would correspond to maximum vertical displacements (amplitude) between about 1.5 and 5 in., which is just about what we get on most roads in a modern passenger or sports car. Larger American cars usually have ride frequencies below 60 cpm. For example, the 1963 Lincoln has a ride rate at the front wheels of 120 lb./in. with a design load of 1370 lb. per wheel. This gives a static deflection figure of 11.4 in. and a calculated ride frequency of 56 cpm. At the rear we find 100 lb./in., 1100 lb. design load, and a rate of 57 cpm. This is typical of the softly-sprung, large American car. (Incidentally, the actual front and rear spring rates here are 375 and 100 lb./in., respectively, illustrating the leverage effect of the front suspension arms.)

Controlling the Pitch

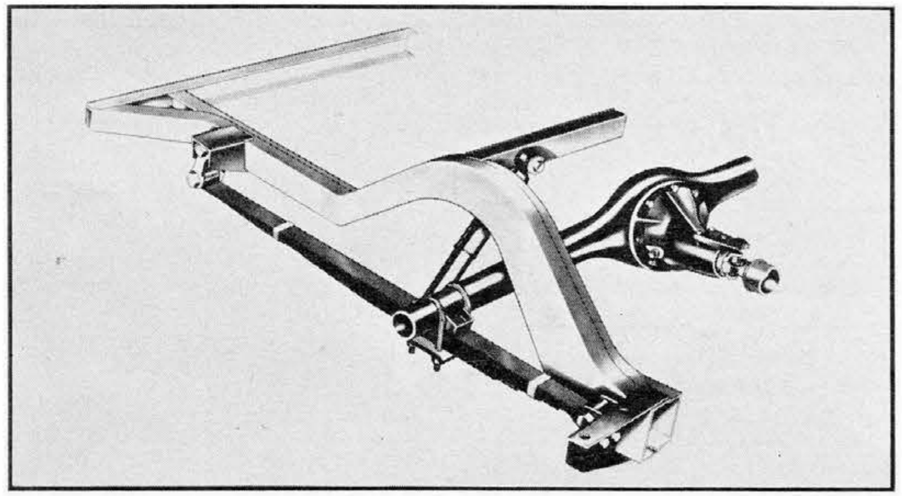
Until now we've been considering our front and rear suspensions as if they worked in unison and as if the body had only strictly vertical motion. Obviously, this is far from the case on the road. The front wheels hit a bump, the body lurches up, then the back wheels hit the bump and the body pitches forward. The front and rear suspensions are working entirely independently. And the body, suspended between them, follows a complex motion determined by the combined characteristics of the two systems.

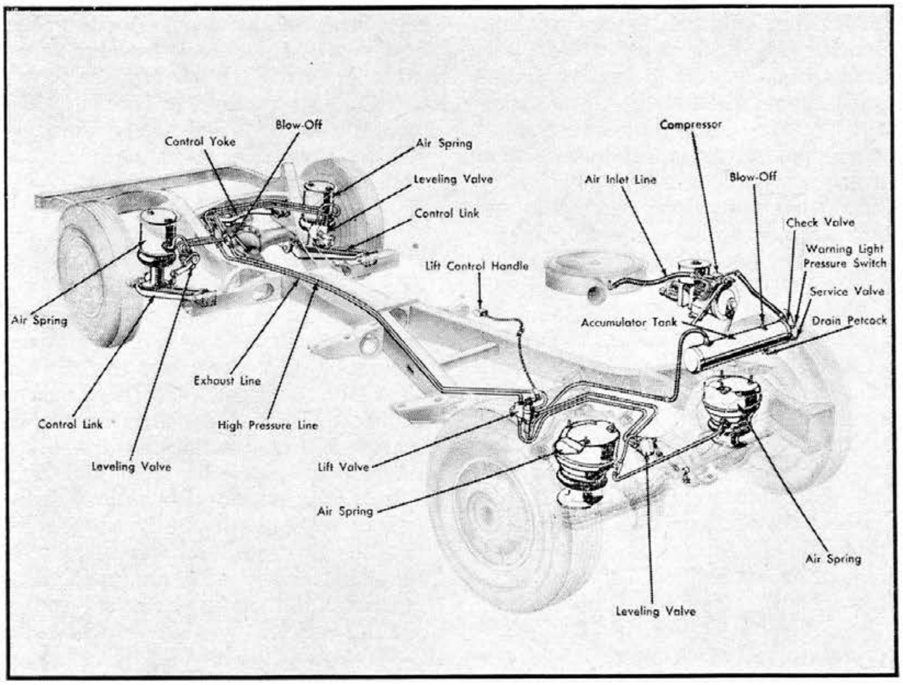
Look at it this way: A vertical force on the sprung mass at one end of the car (like a road bump) will cause the sprung mass to pivot about an axis near the opposite end of the car. This is called "pitch" when the front end pivots about a rear axis, and "bounce" when the rear end pivots about the front end. The important thing here is that the frequency of this pitching and bouncing motion bears no direct relationship to the natural vertical frequency of the suspension. When you're dealing with a rotating motion the moment of inertia, or flywheel effect, of the mass comes into the picture. This moment of inertia of the sprung mass can be understood by imagining the car rotating about its center of gravity, then ▶



DEFLECTION of air vs. conventional springs.

REAR SUSPENSION usually has long leaf springs for maximum flexibility and ride.





CADILLAC air suspension of 1958 gave beautiful ride but the car tended to wallow.

ENGINEERING THE RIDE

picturing a radius out from the c.g. where we can consider all the mass of the body to be concentrated. This is called the "radius of gyration" of the sprung mass.

Obviously, this radius of gyration would have to be located right over the front and rear wheels in order for the pitch and bounce frequencies to equal the natural vertical suspension frequency. Also, the frequencies, or static deflections, of front and rear suspensions would need to be equal, otherwise the pitch and bounce axes would not be located near the rear and front axles, respectively. (With a stiffer front end, the bounce axis would be well ahead of the front of the car and the pitch axis would be ahead of the rear axle.) Automotive engineers generally agree today that optimum ride is obtained when front and rear ride rates are nearly equal and when the radius of gyration of the sprung mass is equal to about half the wheelbase (so the radius reaches to the front and rear wheels).

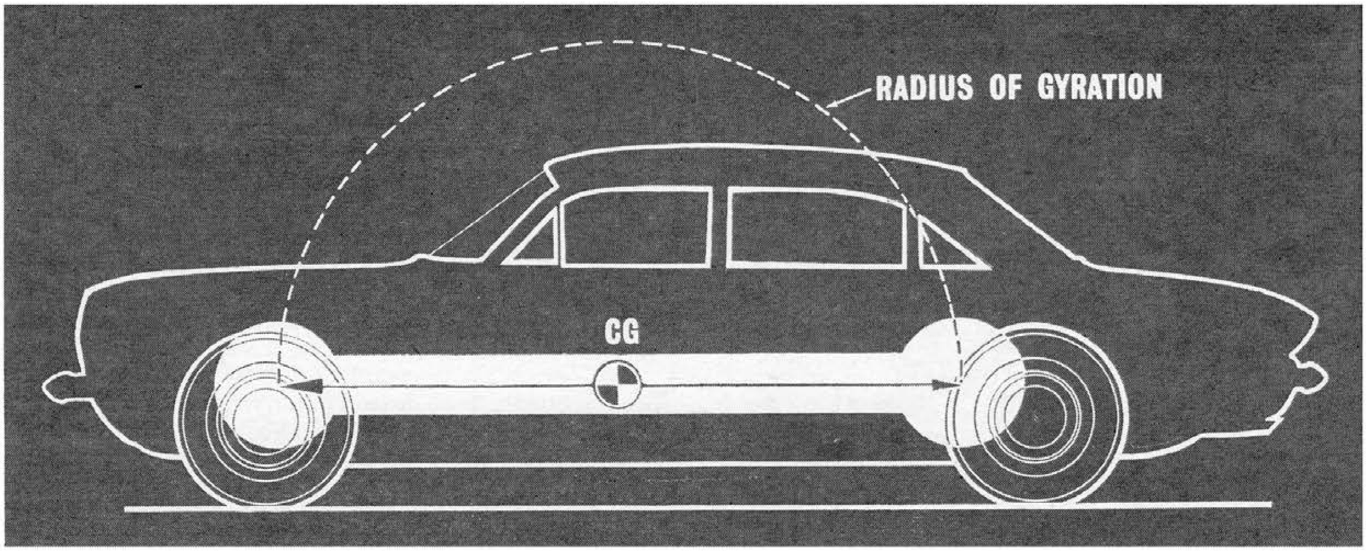
This is not always so easy to arrange on a given car design. The engine mass must be placed far forward, but lots of rear overhang is needed to get the long radius of gyration. A long wheelbase helps. On cars 30–40 years old, and a few more modern sports cars, the rearward engine location shortened the radius to maybe 0.60 of the half-wheelbase length. Furthermore, the early cars needed very stiff front springs to control shimmy and tramp with the solid beam front axles. It was impossible to achieve a good ride. On the other hand, look at the modern American passenger car: Engine over the front wheels, the driver sitting near the center of the wheelbase and a lot of rear overhang. The radius of gyration here is nearly over the wheels. Also, front and rear ride rates tend to be nearly equal, made possible by independent front suspension. This gives nearly parallel pitching and bouncing motion, with a frequency near that of the natural suspension rate. This is just about ideal.

Sprung vs. Unsprung Weight

Think back to high school physics for a moment. Remember that the acceleration imparted to a body by a given force is inversely proportional to the mass of the body. Therefore an upward impact of 200 lb. at an acceleration of one g, acting on a sprung mass of 2000 lb., would cause an upward acceleration of the sprung mass of only 0.1 g. The spring merely transmits the force, but doesn't absorb it.

In an automobile all the sprung mass sees of road bumps would be the up or down acceleration of the unsprung masses—as they move up and down with the road wheels. Thus the relative vertical accelerations of the sprung and unsprung masses would be in inverse proportion to their numerical ratios. That is, if the sprung mass were, say, seven times the unsprung mass, the vertical acceleration of the sprung part would be only 1/7th of that of the unsprung mass. When the road wheels go up over a bump there is a certain upward acceleration of all the unsprung masses that move with the wheels. This builds up a momentum that is transmitted through the suspension spring

OPTIMUM RIDE is obtained when radius of gyration of sprung mass (amount of dumbbell effect) falls near wheel centers.



to the sprung mass. But if this momentum is acting on 6–7 times the original unsprung mass, it's going to produce only 1/6th or 1/7th of the original acceleration.

This is the whole principle of the sprung-unsprung weight relationship in an automobile. It's the ratio that counts. So, we want the highest possible sprung/unsprung weight ratio for optimum ride. This ratio will run 5.5–6.5:1 on cars with independent front suspension and solid rear axles. On cars with independent rear suspension (so the heavy differential is carried on the frame as sprung weight) this sprung/unsprung weight ratio is around 7:1 or more. For example, switching to independent rear suspension on the 1963 Corvette raised the rear ratio from 5.27 to 7.98:1. The ratio is around 7.5:1 on the front. This is also why we can improve the ride of a car by adding weight to the body—we're improving the sprung/unsprung weight ratio, by adding to the sprung side, even though the unsprung mass remains the same. Theoretically, with an infinitely high sprung/unsprung weight ratio, we would get a perfectly smooth ride, even though the road wheels might be bouncing around like a basketball.

Don't Forget the Shocks

We mentioned before that the prime function of the shock absorbers is to damp out the vertical oscillations of both the sprung and unsprung masses. By certain arrangements of the valves and orifices in a hydraulic shock, the engineer can get any type of resistance-vs.-velocity curve he wants. Space doesn't permit a detailed discussion, but damper calibration can have a huge effect on ride and handling.

But it's still true that the reaction to any resistance given by the damper will be transmitted directly to the sprung mass. The shock can't theoretically give a better ride. But here's a subtle angle: Any shock absorber converts some of the vertical energy of the sprung and unsprung masses into heat. This energy is not available to bounce around the car. In other words, though we've heard for years that the term "shock absorber" is a misnomer (they are actually dampers), it is true that these things do absorb some road shock, although it probably is a pretty small fraction of the total vertical energy.

But what of the future? The trend today is toward much larger shock diameters and lengths, with larger volumes of oil in action. More oil means more possible heat absorption and dissipation without foaming or boiling. Where could this lead? The day may come when U.S. cars will have hydraulic suspension systems (like that of the MG-1100 sports sedan) which will actually absorb and dissipate a substantial proportion of the total vertical energy of the sprung and unsprung masses.

And now the Tires

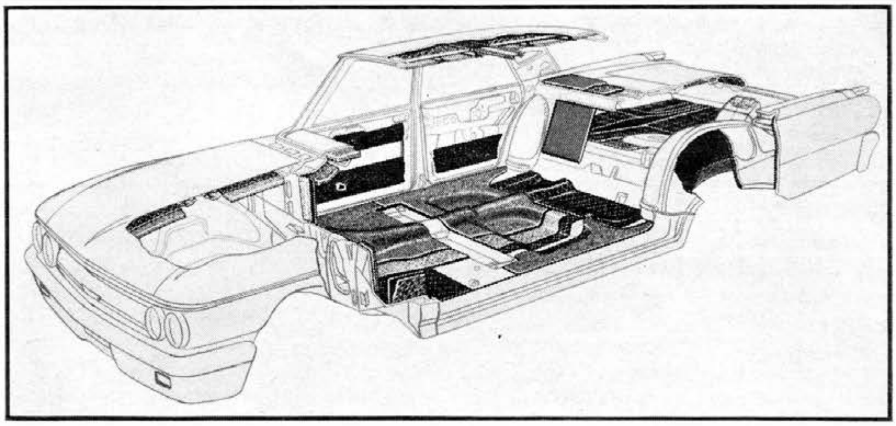
Up to now we've been analyzing the suspension in terms of one basic spring system connecting the sprung and unsprung masses. Actually we've got another spring system between the unsprung mass and the road in the tire itself. This spring system has a stiffness of about 800 lb./in. and a natural frequency of maybe 160–180 cpm. It works in series with the chassis springs. Furthermore, the flexing of the tire casing and tread layer gives a substantial amount of inherent damping and energy absorption in the link between road and unsprung mass. Your tires have a tremendous effect on ride.

And they have only scratched the surface in improving the ride through tire technology. Lower inflation pressure is only one trick. The late development of high-hysteresis rubber compounds could be important. These compounds are less resilient than conventional rubbers (they have less bounce) and thus tend to absorb vertical energy and convert it into heat, rather than return virtually 100% of the input force. They can do about anything they want with these synthetics. The problem is to get the best compromise between ride, traction, wear rate and heat build-up in the casing at high speed. Any time energy is absorbed it has to be dissipated somehow. Heating will always be a problem, so perhaps the answer is to develop a tire which will run comfortably at 300–400° F.!

There is much yet to be done with the tire casing. Right now they have to compromise vertical flexibility to get good lateral stability and cornering power. The most promising development on the horizon is the "belted cord" tire—with casing ply cord running straight across the carcass, and one or more high-strength plies (some using wire cord) under the tread to give high cornering power at low slip angles. These tires definitely give a softer ride in relation to handling than conventional American tires with 30–40° cord angle. Look at the Michelin X, Dunlop Duraband, Pirelli Cinturato—these could be the tires of tomorrow.

There's a long way yet to go on ride. Next month: Brakes. ■

INSULATION and padding on this Mercury help inhibit part of "ride" problem.



LINCOLN ISOLATES rear suspension in rubber to produce quieter, softer ride.