The Mark Ortiz Automotive

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WELCOME

Mark Ortiz Automotive is a chassis consulting service primarily serving oval track and road racers. This newsletter is a free service intended to benefit racers and enthusiasts by offering useful insights into chassis engineering and answers to questions. Readers may mail questions to: 155 Wankel Dr., Kannapolis, NC 28083-8200; submit questions by phone at 704-933-8876; or submit questions by e-mail to: markortiz@vnet.net. Readers are invited to subscribe to this newsletter by e-mail. Just e-mail me and request to be added to the list.

REAR PERCENTAGE OR POLAR MOMENT?

I am wondering about the relative merits of Front / Rear Weight Distribution versus Polar Moment of Inertia. I road-race a Mustang in a class that allows extensive engine and suspension modifications to late-model muscle cars, but the rules are strict enough to prevent extensive body, floorpan, and frame modifications. As a result of the rules, and the large V8s, the cars are inherently heavy in the front end – usually to the tune of 51-55%, depending on platform, fuel load, etc. So when deciding on the placement of heavy components (such as batteries, fuel cells, ballast, etc.) I'm wondering what the ideal position is. Obviously lower is always better, but how far back is ideal? You could place the masses as far back as possible to improve F/R balance, but at the expense of Polar Moment. You could put the mass in the center of the car, minimizing polar moment but failing to take advantage of an opportunity to improve the car's balance. Or you could put it somewhere in between.

Instinctively, my engineering training tells me that the two things have different functions. F/R distribution should make the car generally behave in a more balanced fashion, and certainly more weight on the back tires will help corner exit traction – which is a key in this type of car. Keeping polar moment low should help keep the car rotationally responsive, and more willing to respond to corrections if the tail steps out.

Several years ago I ran a simple analysis, and found that the average cornering speed of the car seemed to be a determining factor between these two trade-offs. This was not an in-depth analysis. Basically I broke cornering down into the energy it took to rotate the car (start it rotating and stop it rotating) and the energy it took to redirect the velocity vector, and compared the two. It seemed to me that the faster the mid-corner speed, the more the velocity vector change became the dominant force requirement, and therefore we might assume the F/R balance would be more important. My analysis said that, in the kind of racing I do, F/R distribution would be far more important, but I'm surprised at the number of competitors, in amateur and pro competition, who seem to disagree. Of course, my analysis was simplified to a great extent, with numerous assumptions being made that are not necessarily always valid.

So I ask – how far back should I place that ballast, or those movable components? On an average road course, where mid-corner speeds probably average from 40mph to about 100mph or so, which would you deem more important? Would you place that ballast in the back bumper, or under the floorpan or inside the inside frame rail?

And as a secondary question – what would you consider the ideal weight distribution for a car of this type. Obviously, if I can achieve whatever I decide is "ideal", then I want to work to reduce polar moment, but what is that "ideal" number – in your estimation of this type of race car? I've heard arguments for 50/50 and arguments for as much as about 58% rear weight. I tend to think the answer is closer to 55%, but I'm very curious as to your input on this matter as well.

Taking the last part first, the ideal rear percentage, or the desirable range, depends on your tire rules and the nature of the course. To a lesser extent, it is also influenced by the level of available grip, and by aerodynamics.

Suppose we have no tire rules, ample power, lots of freedom with our wings and other aero devices, and a track with serious straights and tight turns. Suppose also that the rules require rear wheel drive. In such a case, we might want as much as 65% rear, or even a bit more, and rear tires about twice the size of the fronts. We would want more than 2/3 of the downforce at the rear. We would want ample area in rear wing sideplates and/or tail fins, for yaw stability.

The reasoning here is that the car will spend a lot of its time accelerating longitudinally: accelerating forward out of the turns and down the straights, and accelerating rearward (braking) at the end of the straights. Propulsion comes only from the rear wheels, so we want as much of our weight on the rear as possible to maximize forward acceleration. Braking is shared by all four wheels, and if the car has ample braking capability, the fronts will do more than half of the braking even if they only carry a third of the car's weight at rest. This is due to the large amount of dynamic load transfer forward during hard braking. So for both forward and rearward acceleration, we want as much rear percentage as possible, at least within practical limits for a road racing car.

This would be so even if we are constrained to equal size tires front and rear. If our event is, say, a zero to 100 to zero competition (accelerate from a standstill to 100mph, then brake to a standstill, all in a straight line), we'd want to build the car so it just barely picks the front wheels off the ground at launch, or almost does so. Note that the rear percentage needed for this varies dramatically depending on the wheelbase, the c.g. height, and the amount of grip available. With a production-based car – relatively short wheelbase and high c.g. – and good drag slicks, the ideal rear percentage may be less than 50%. The grip of modern drag tires is so good that a 50/50 car can actually be limited by wheelstand rather than wheelspin. With a high c.g. and a short wheelbase, the ideal rear percentage varies dramatically with the grip level.

If we have more chassis design freedom, we'd rather have a dragster than a pro stock: long wheelbase, low c.g., lots of static rear percentage. With such a layout, rearward load transfer is less, and consequently dynamic rear percentage varies less with grip level. A single layout and setup will therefore be more nearly optimal over a wider range of conditions. With street tires or road racing tires, the ideal rear percentage will be considerably over 50%. As long as the car doesn't have to turn, we'd want to build it like a dragster, even if the front and rear tires have to be the same size.

Of course, the questioner here doesn't have such design freedom, nor is he running on a track with no turns. I'm just examining extreme cases, to illustrate some points.

The opposite extreme case would be a skidpad competition: the car just has to corner at the highest possible constant speed. Accelerations now are almost purely lateral. We might suppose that the ideal design here would have equal-size front and rear tires, and 50% static rear weight. That is indeed close to correct, although if we can use unequal tire sizes, we can get as good cornering from a tail-heavy car as from a 50/50 one. If there are no limits on tire size, two practical considerations will limit us: camber control and steering geometry. We can control camber about equally well at both ends of the car, but there is a case for using smaller tires on the front from the standpoint of steering dynamics. If we do that, we want the car tail-heavy, roughly in proportion to tire size.

Oddly enough, the radius of the skidpad affects the optimum rear percentage. This is a bit counter-intuitive, but it's true. Really small skidpads (or really tight turns) call for a more tail-heavy car than the tire sizes would suggest, and really big skidpads (or really big turns) call for a more nose-heavy car. The reasons for this are of different natures for the two cases.

On a really small skidpad, such as the 50-foot diameter one used in Formula SAE competition, the front wheels track noticeably outside the rears, even when the tires are sliding. Consequently, the drag forces of the front tires, especially the heavily loaded outside front, act at a larger radius than the radius the c.g. is following, and the propulsion forces from the rear tires act at a smaller radius than the c.g. is following. This creates a yaw moment out of the turn, and tightens the car (adds understeer). Additionally, in some cases there may be effects from a limited-slip differential or a locked rear that create understeer in small-radius turns.

When the turn radius is really large, the car will need to transmit substantial amounts of power through the rear tires just to maintain constant speed. On really fast turns, the car may actually be near full power, and not gaining any speed at all. The rear tires are transmitting hundreds of horsepower, just to overcome aerodynamic drag and the induced drag from the front tires as they run at a slip angle.

This means that the rear tires are using a substantial portion of their performance envelope, or traction circle, to propel the car, so they have less of their capability available to generate lateral force. The car is consequently subject to power oversteer. The best way to counter this is to have a disproportionate amount of aerodynamic downforce at the rear of the car. However, in many classes, including stock cars running on high-speed ovals, the rules may not allow the aerodynamic devices needed to achieve this. It then becomes desirable to make the car a bit nose-heavy to add understeer and counter the power oversteer.

I am not trying to confuse the issue. I am merely pointing out that, as the questioner has already come to appreciate, we cannot state categorically that a particular rear percentage is ideal. It depends on other factors.

That said, the questioner appears to be correct that in his class, more rear percentage is better, within the limits imposed by the rules, without going above minimum legal weight. And there is indeed a tradeoff in such a situation between getting good rear percentage and reducing yaw inertia (polar moment of inertia in yaw, commonly "polar moment" for short). I agree with the questioner's tentative conclusion that it is better to go after rear percentage and forget yaw inertia, for road course applications.

It is interesting to consider what it might take to make us go the other way, and put the ballast closer to the middle. I think we might do that if we were autocrossing, particularly if a large part of the course was made up of a long, constant-speed slalom, and if the course had no significant straights, so that the car was continually cornering and continually changing direction, and never had to spend a lot of time accelerating longitudinally – in other words, if there was a lot of yaw acceleration and relatively little longitudinal acceleration.

But no road course is like that. Almost all of them have serious straightaways, and few really abrupt transitions. A car with large yaw inertia will tend to understeer into the slower turns and oversteer coming out, but to some extent the driver can overcome the entry understeer with trailbraking, and the exit oversteer by using an "out fast" line and judicious throttle management.