October 2002

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.

MOVE THE REAR WHEELS BACK TO IMPROVE TRACTION?

Regular readers will be aware that this newsletter is used as the basis of a column in *Racecar Engineering* called "The Consultant". In the October 2002 issue, Simon McBeath has an article about the DJ Firehawk hillclimb car, in which he remarks: *Creating that slightly longer wheelbase was achieved by sweeping back the rear wishbones, which also had the benefit of minimising chassis overhang, effectively shifting some weight forward and keeping the major masses well within the wheelbase. The result is almost exactly 40:60 weight distribution front to rear. The swept-back rear suspension has, apparently, also been found to be an aid to traction in US buggy racing. Perhaps this is one for The Consultant's column?*

First, I agree that 40/60 weight distribution is a good general-purpose target for a car where the rear tires can be larger than the front ones. I also agree that moving the differential forward of the axle line a bit is advantageous in terms of yaw inertia, although there is a penalty in halfshaft joint longevity and frictional losses.

I don't work much with off-road cars, but I can speak to the physics of traction. In any rear-wheel-drive vehicle, more rear percentage – static or dynamic – translates to more traction, in straight-line forward acceleration or hill climbing. From this standpoint, moving the rear wheels aft (or the front ones) hurts traction, since it reduces both static and dynamic rear percentage. So the simple answer is that moving the rear wheels aft for better traction is wrong. For better traction, you need to move them forward, or move major masses back.

However, in the real world we are not always dealing with pure forward acceleration, and forward acceleration is not always limited by the rear wheels' capability to generate forward force.

In the real world, we not only have to put power down – we also need to steer. We also have to avoid flipping the vehicle over backwards. These considerations may lead us not to go for maximum static rear percentage in all cases.

The first case I can recall of somebody moving the rear wheels back on an existing vehicle occurred in the 1970's when Porsche moved the rear wheels on the 911 back a couple of inches. This was not done to improve forward traction. It was done to make the car a little less tail-heavy and thereby reduce limit oversteer without making the rear tires drastically larger than the fronts.

It is commonplace in hillclimb and drag racing motorcycles to fit a long rear swingarm and move the rear wheel aft as much as a foot. Why is this done? Because the vehicle is wheelstand-limited rather than traction-limited. The center of gravity is high. The wheelbase is short. When grip is good or the grade is steep, the rider is limited by the need to keep the bike from flipping rearward on top of him, rather than wheelspin.

Drag cars, especially ones that are required to resemble road cars, can be wheelstand-limited up to surprisingly high static front percentages, because of the extraordinary grip of modern drag tires. When drag slicks were less evolved, everybody tried to move the weight back as far as possible and raise the CG as far as possible. This is the way to go, up to the point where the front wheels come off the ground. Once that point is reached, we are faced with a delicate balancing act: we must maximize rear wheel loading but still be able to steer with the fronts, within the range of forward accelerations we can anticipate. It turns out that the best design is one with a very long wheelbase, a low CG, and ample static rear percentage – a rear-engined dragster. But a funny car, with a much shorter wheelbase and much greater static front percentage, can turn nearly as good a time – provided that the traction characteristics of the track and tires are what we normally expect. Pit the same cars against each other on a slippery surface, or on street tires, and the funny car has no chance.

When we are dealing with forward acceleration while cornering, things get even more complex. The front tires not only have to afford us some measure of directional control, they also have to provide sufficient cornering force to keep the car from developing a power push.

For a given track and tire, limiting lateral acceleration at the front or rear of the car depends on the relationship between the dynamic normal (vertical) force on the tires and the centrifugal force they are required to resist, plus the fact that a tire's ability to generate lateral force diminishes when we ask it to generate longitudinal force at the same time.

When we have a car at its limit in lateral acceleration, and we then ask it to accelerate forward as well, we know that the car will have to reduce its lateral acceleration and widen its arc. Whether it gets looser or tighter depends on the balance between two conflicting effects. The first effect is rearward load transfer. The normal force on the rear tires increases, and the normal force on the fronts decreases, while the proportion of centrifugal force at each end of the car remains essentially unchanged since its constituent masses do not shift significantly. This tends to tighten the car (increase understeer). The other effect is that with rear wheel drive the rear tires must give up some lateral force capability in order to make forward force, while the front tires are not required to do this. This effect tends to loosen the car (increase oversteer).

Many factors other than wheelbase and CG location influence cornering balance under power, including differential type, toe settings, tire design and inflation, and suspension design and settings. In oval track cars, we have additional effects from suspension asymmetries, tire stagger, and static left percentage. But let's consider the influence of wheelbase, CG height, and front/rear CG position, assuming other factors are held constant.

Almost any rear-drive car will be tightened by very moderate power application, and loosened if we apply enough power to create obvious wheelspin. In between these extremes, the car has a range of throttle position where power tightens the car compared to steady-state, and at some point a transition to power oversteer. If that transition to power oversteer occurs only with obvious wheelspin, and the car just gets tighter with power up to that point, we say it has power understeer, or a power push. If anything more than minimal power application loosens the car, we say it's loose on power or prone to power oversteer.

Desirable behavior lies somewhere between these extremes. For best exit speed, we would like the car to remain reasonably balanced as power is added, and just use up more road as we add more power. The driver may like some power oversteer so he can steer the car with the throttle, but as a rule this will exact some penalty in exit speed.

The limiting lateral acceleration at the front or rear wheel pair depends in part on the relationship between normal force on the wheel pair and the percentage of the car's mass that the wheel pair must control. Let's look at how normal force varies at the front and rear on some hypothetical cars, at 0.5g forward acceleration. The load transferred from the front wheel pair to the rear wheel pair due to forward acceleration is given by: $\Delta F_n = W a_x h_{cg} / L_{wb}$ where:

ΔF_n = absolute change in front or rear wheel pair normal force due to longitudinal acceleration

W = total vehicle weight

a_x = longitudinal (x axis) acceleration

h_{cg} = height of vehicle overall center of gravity

L_{wb} = length of wheelbase

Working in English units, we use pounds for W, express a_x in g's, and obtain ΔF_n in lbf. With metric units, we would classically use the vehicle's mass in kg for W, express a_x in m/sec^2, and obtain ΔF_n in newtons. However, since our wheel scales will probably read in kg, we may find it more convenient to use g's for a_x and get ΔF_n in kg.

Suppose our vehicle has a CG height equal to 1/5 the wheelbase. That's a fairly short, high car, perhaps a sprint car or a midget. We now have a value of 0.2 for h_{cg} / L_{wb}. If a_x = 0.5g, then $\Delta F_n = W(0.5)(0.2) = 0.1W$.

If our car weighs 1000 lb and has 50% static rear weight, then assuming no turn banking and neglecting aerodynamic effects, our front normal force is 500 lb in steady-state cornering. If we accelerate forward at 0.5g, ΔF_n = 100 lb and total dynamic normal force on the front wheel pair is 400 lb. This means that the front end has a limiting lateral acceleration a bit greater than 80% of what it had in steady-state cornering. I say a bit greater than 80% because a tire's coefficient of friction usually increases a bit as normal force diminishes.

Now let's suppose we have the same situation, except the car has 60% static rear. ΔF_n is still 100 lb, so we now have front normal force going from 400 lb to 300 lb. Therefore, the front end's limiting lateral acceleration is now a bit greater than 75% of its steady-state capability – less than in the previous example.

If the car has 70% static rear, front normal force goes from 300 lb to 200 lb, and front lateral acceleration capability is a bit greater than 67% of steady-state.

If we look at these three cars at $a_x = 1.0g$, we have front end lateral acceleration capabilities slightly greater than 60%, 50%, and 33% of steady-state. At $a_x = 1.5g$, the first car has front end lateral acceleration capability that is >40% of steady-state, the second car has >25%, and the third has **zero**; it's at the point of impending wheelstand.

What happens at the rear wheels is somewhat more complex. With more static rear, the percentage increase in normal force is less for a given a_x, but the forward force required to produce that a_x is also a smaller portion of the tire's overall vector force capability. In general, it is harder to induce power oversteer in tail-heavy cars.

My point here is that tail-heavy cars put power down better, both in a straight line and when cornering, but as the car becomes more tail-heavy the unloading of the front wheel pair becomes greater percentagewise for a given a_x, and the car becomes more prone to power understeer. At some point, power understeer will limit power application on exit before wheelspin will. When we have such a condition, the car may actually achieve better a_x on exit with less static rear percentage.

It will be apparent that as h_{cg} decreases, or L_{wb} increases, ΔF_n decreases for a given a_x. This means that a lower or longer car can have more static rear percentage without encountering wheelstanding or power push. It also means that a lower, longer, more tail-heavy car will perform more consistently as grip varies.