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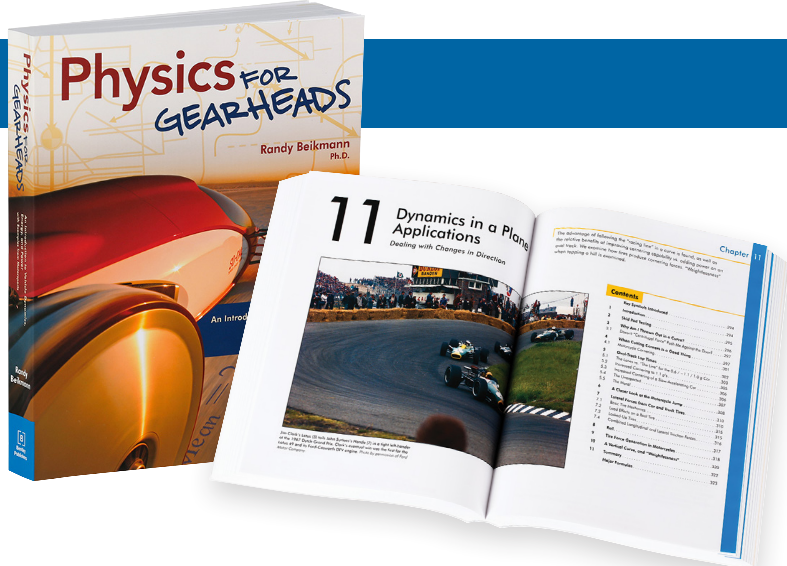

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Physics FOR GEARHEADS™

An Introduction to Vehicle Dynamics, Energy, and Power

with Examples from Motorsports

by Randy Beikmann

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There is no better way to learn physics than by having a problem to solve

As a gearhead, you have a secret advantage when it comes to understanding physics: you see it at work every time you solve a problem with your car or watch a motorsports event. The experience you already have tuning cars or motorcycles is your virtual physics lab. **Physics for Gearheads** will show you that if you can learn about cars, you can learn about physics.

Whether your interest is in increasing your engine's horsepower, getting more miles per gallon, or shaving tenths off your lap time on track day, you can use physics to gain insight into the problem and formulate a solution. **Physics for Gearheads** not only explains physics principles in language you can understand, it demonstrates how to use physics to your advantage.

Randy Beikmann is an automotive engineer working at the top of the industry. And he loves physics. Through his masterful teaching, physics doesn't look foreign—it looks like common sense.

Note on the units of measurement used in Physics for Gearheads: Beikmann speaks the language of US auto enthusiasts by using primarily British units throughout the book, while also providing the tools to convert to metric.

For teacher resources, visit
https://www.facebook.com/PhysicsForGearheads

Chapters

Randy Beikmann holds a Ph.D. in mechanical engineering from the University of Michigan. He is a technical specialist in automotive noise and vibration at the General Motors Milford Proving Ground, where he has worked since 1983. He has published numerous papers on powertrain noise and vibration and has helped design and teach classes at GM within his engineering specialty. He currently holds three patents.

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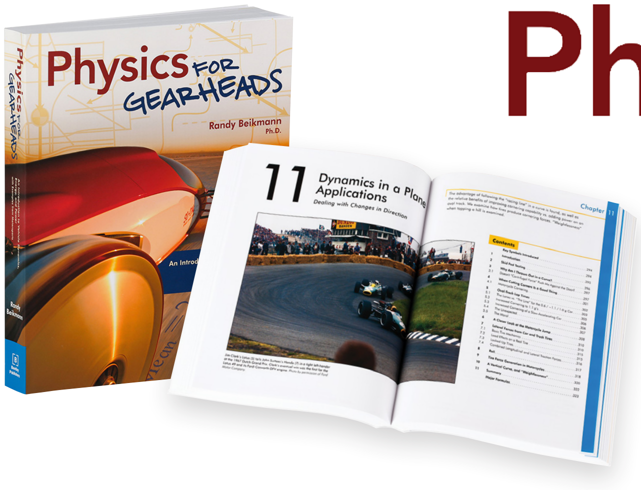


Physics FOR GEARHEADS™

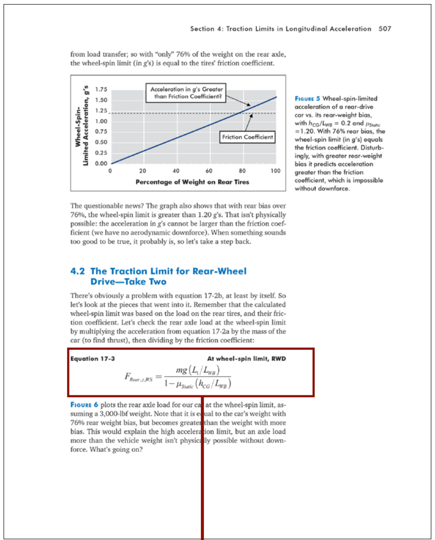
Supports access and inclusion for different learning styles and visualization of physics by approaching concepts in multiple ways

"Physics For Gearheads, *written by a genuine Ph.D that works for GM's Milford Proving Grounds, is 600 pages of fascinating facts, information on vehicle dynamics, energy, aero and other 'egghead' stuff ...a reference book that will be with you for years."*

– MC2 Magazine

"If, like me, you are a gearhead who enjoys building things, this book is a godsend of practical equations that, once understood, will allow you to raise your intuitive abilities to a higher level ...This book is written so well that you don't have to be a math wiz to understand what you're being told."

– Speedreaders.info



Section 4: Traction Limits in Longitudinal Acceleration 507

from load transfer; so with "only" 76% of the weight on the rear axle, the wheel-spin limit (in g's) is equal to the tires' friction coefficient.

Figure 5 Wheel-spin-limited acceleration of a rear-drive car vs. its rear-weight bias, with $h_{CG}/L_{WB} = 0.2$ and $\mu_{Static} = 1.20$. With 76% rear bias, the wheel-spin limit (in g's) equals the friction coefficient. Disturbingly, with greater rear-weight bias it predicts acceleration greater than the friction coefficient, which is impossible without downforce.

The questionable news? The graph also shows that with rear bias over 76%, the wheel-spin limit is greater than 1.20 g's. That isn't physically possible: the acceleration in g's cannot be larger than the friction coefficient (we have no aerodynamic downforce). When something sounds too good to be true, it probably is, so let's take a step back.

4.2 The Traction Limit for Rear-Wheel Drive—Take Two

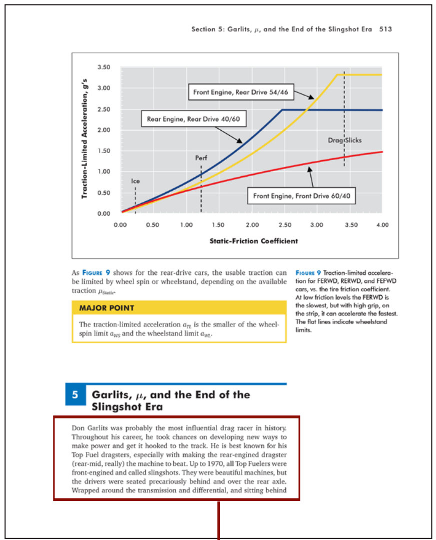
There's obviously a problem with equation 17-2b, at least by itself. So let's look at the pieces that went into it. Remember that the calculated wheel-spin limit was based on the load on the rear tires, and their friction coefficient. Let's check the rear axle load at the wheel-spin limit by multiplying the acceleration from equation 17-2a by the mass of the car (to find thrust), then dividing by the friction coefficient:

Equation 17-3 **At wheel-spin limit, RWD**

$$F_{Rear,z,WS} = \frac{mg\left(L_1/L_{WB}\right)}{1-\mu_{Static}\left(h_{CG}/L_{WB}\right)}$$

Figure 6 plots the rear axle load for our car at the wheel-spin limit, assuming a 3,000-lbf weight. Note that it is equal to the car's weight with 76% rear weight bias, but becomes greater than the weight with more bias. This would explain the high acceleration limit, but an axle load more than the vehicle weight isn't physically possible without downforce. What's going on?

Physics is put to math



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As **Figure 9** shows for the rear-drive cars, the usable traction can be limited by wheel spin or wheelstand, depending on the available traction μ_{Static}.

Figure 9 Traction-limited acceleration for FERWD, RERWD, and FEFWD cars, vs. the tire friction coefficient. At low friction levels the FERWD is the slowest, but with high grip, on the strip, it can accelerate the fastest. The flat lines indicate wheelstand limits.

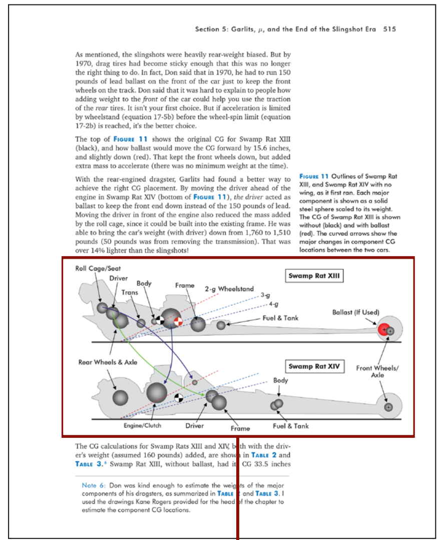
MAJOR POINT

The traction-limited acceleration a_{TL} is the smaller of the wheel-spin limit a_{WS} and the wheelstand limit a_{WL}.

5 Garlits, μ, and the End of the Slingshot Era

Don Garlits was probably the most influential drag racer in history. Throughout his career, he took chances on developing new ways to make power and get it hooked to the track. He is best known for his Top Fuel dragsters, especially with making the rear-engined dragster (rear-mid, really) the machine to beat. Up to 1970, all Top Fuelers were front-engined and called slingshots. They were beautiful machines, but the drivers were seated precariously behind and over the rear axle. Wrapped around the transmission and differential, and sitting behind

Physics is described with narrative



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As mentioned, the slingshots were heavily rear-weight biased. But by 1970, drag tires had become sticky enough that this was no longer the right thing to do. In fact, Don said that in 1970, he had to run 150 pounds of lead ballast on the front of the car just to keep the front wheels on the track. Don said that it was hard to explain to people how adding weight to the *front* of the car could help you use the traction of the *rear* tires. It isn't your first choice. But if acceleration is limited by wheelstand (equation 17-5b) before the wheel-spin limit (equation 17-2b) is reached, it's the better choice.

The top of **Figure 11** shows the original CG for Swamp Rat XIII (black), and how ballast would move the CG forward by 15.6 inches, and slightly down (red). That kept the front wheels down, but added extra mass to accelerate (there was no minimum weight at the time).

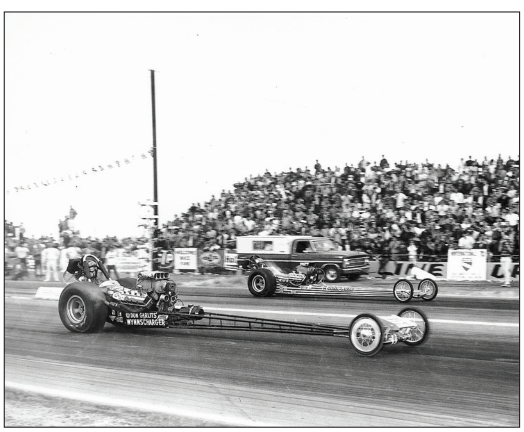
With the rear-engined dragster, Garlits had found a better way to achieve the right CG placement. By moving the driver ahead of the engine in Swamp Rat XIV (bottom of **Figure 11**), *the driver* acted as ballast to keep the front end down instead of the 150 pounds of lead. Moving the driver in front of the engine also reduced the mass added by the roll cage, since it could be built into the existing frame. He was able to bring the car's weight (with driver) down from 1,760 to 1,510 pounds (50 pounds was from removing the transmission). That was over 14% lighter than the slingshots!

Figure 11 Outlines of Swamp Rat XIII, and Swamp Rat XIV with no wing, as it first ran. Each major component is shown as a solid steel sphere scaled to its weight. The CG of Swamp Rat XIII is shown without (black) and with ballast (red). The curved arrows show the major changes in component CG locations between the two cars.

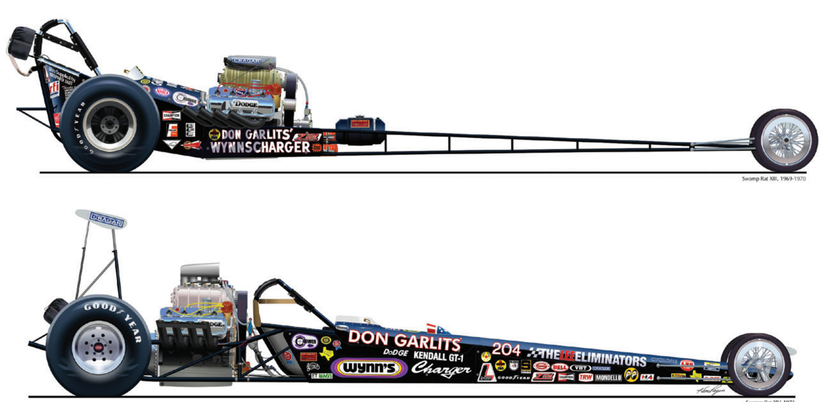
The CG calculations for Swamp Rats XIII and XIV, both with the driver's weight (assumed 160 pounds) added, are shown in **Table 2** and **Table 3**.[6] Swamp Rat XIII, without ballast, had its CG 33.5 inches

Note 6: Don was kind enough to estimate the weights of the major components of his dragsters, as summarized in **Table 2** and **Table 3**. I used the drawings Kane Rogers provided for the head of the chapter to estimate the component CG locations.

Physics is mapped to graphics



Garlits in Swamp Rat XIII racing "Kansas John" Wiebe in 1970, at Beeline Dragway near Phoenix.



The two Don Garlits cars that turned drag racing on its ear in 1970-71: Swamp Rat XIII, his last front-engined car, and Swamp Rat XIV, the first successful rear-engined one. We'll explain why with quasi-statics. Illustration "Transformation – Don Garlits' Wynn's Chargers, 1969-1971" (2004, Kane Rogers)