Physics Lecture 23 - Sam Houston Area Council PWD Rules - National ?

INTRODUCTION

There are many versions of Pinewood Derby (PWD) car construction rules in existence today, but just like in most sports, only a unique set of rules can provide a "level" playing field that can ensure fairness in competition for widely dispersed participants. This lecture will point out several inconsistencies in the way PWD rules are created and applied, and it will suggest ways to remove such inconsistencies. About 17 years ago the author was asked by the Sam Houston Area Council (SHAC) of the BSA to devise a set of rules that would provide a more level playing field for a wide range of PWD participants. SHAC, at about 170,000 members including 100,000 Cubs, is the largest of the 300 or so councils in the BSA. There resulted a set of construction rules that was much more restrictive regarding the amount of modification that could be done to wheels and axles. Our objective in this lecture is to review past rules and to present and justify the new SHAC rules. Hopefully this lecture will stimulate discussion that could someday lead to one National BSA PWD rule set. Send comments to : pwdauthor@pinewoodderbyphysics.com . Let's start with the first rules and then, on page 2, we will present the SHAC rules. Our topics will be discussed in order as:

THE FIRST SET OF RULES

In **Figure 1** we show a photo of the cover of Don Murphy's book on the Pinewood Derby, such book describing how he originated the race. The book contains the following rules (all but rule 1 deal only with construction).

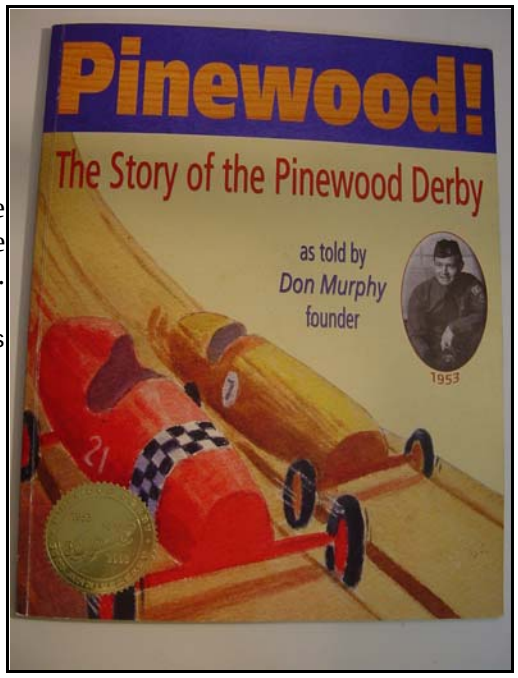

Figure 1 - *Don Murphy's book describing the original PWD racing scene.*

1. The Pinewood Derby is open to all boys from ages 8 to 10, inclusive. Entrants will race in three classes:

   Class A - 10 year olds
   Class B - 9 year olds
   Class C - 8 year olds

2. Entrant must build car with the help of his father.

3. Only one kit can be furnished to registered entrant.

4. Width - Over-all width shall not exceed 2-3/4 inches.

5. Length - Over-all length shall not exceed 7-3/4 inches.

6. Weight - Shall not exceed 5 ounces.

   (a) No loose materials of any kind are permitted in the car. The car may be hollowed out and built up to the maximum weight by the addition of wood or metal only, provided it is securely built into the body or chassis.

7. Only your official furnished kit may be used. Wheel bearings, washers, and bushings are prohibited.

8. Springing - The car shall not ride on any type of spring.

9. Details - Detail such as steering wheel, driver, decals, and painting is permissible as long as this detail does not cause the car to exceed the official maximum weight.

10. Attachments - The car must be freewheeling with no starting devices.

11. Lubrication - Do not use any lubricant or graphite on wheels or axles.

12. Inspection - Every car must pass inspection by the Official Inspection Committee before it may compete. The inspectors have the right to disqualify those cars that do not follow the rules as stated herein.

DRAFT - SAM HOUSTON AREA COUNCIL PWD CAR INSPECTABLE CONSTRUCTION RULES

CUB DIVISION

I. Material and Size

1. Only official BSA kits including wood block, wheels and axles may be used. Cars must be recently built in the past year.
2. An area between the front wheels on the car bottom of width 1" and length 3/4" shall be unpainted bare wood.
3. No loose or flexible materials of any kind are permitted in or on the car. The car may be hollowed out and built up to the maximum weight by the addition of wood or metal only, provided it is securely built into the body or chassis. As seen from the side, over half the car body (usually the front part) must consist of or be enclosed by wood.
4. Length and Width - The car must fit into an inspection box 7" x 2-3/4".
5. Clearances - The car must be less than 4" in height and must roll freely without binding while straddling a strip of width 1-3/4" and height 3/8" when rolled on a level plane surface.
6. Wheelbase may be changed from the precut slot distances in the kit block.

II. Weight and Appearance

1. The car nose must be flat(not pointed) for at least ½" where it contacts the guide post. Wet paint or glue are not allowed.
2. Weight of total car shall not exceed 5.0 ounces or 143 grams as read on the official race scale.
3. Detail such as steering wheel, driver, decals, and painting is permissible on the car body as long as this detail is rigid and does not cause the car to exceed the official maximum weight.

III. Wheels and Axles

1. Only official BSA wheels and axles may be used.
2. Wheel bearings, spacers, hubcaps, or bushings are prohibited.
3. The car shall not ride on springs nor have any propulsive force other than gravity.
4. Only the tread surface and width for Scout wheels may be modified. The tread surface may be smoothed down flat and parallel to the axle such that the diameter of the wheel is not less than 1.150". Wheel diameters larger than 1.200" are not allowed. Tread width may be shaved slightly from the wheel inside only to a minimum of 0.275".
5. The inside of the axle nail head and adjacent shaft may be smoothed to remove burrs. The diameter of the axle may not be reduced to less than 0.085" at any point where the wheel bore hole surface could touch the axle.

IV. Lubrication

1. Solid powders or flakes, e.g., graphite or Teflon , or ordinary oils may be used but only if absolutely no excess is visible.
2. All lubrication is to be done away from race and track areas or in designated workshop or race preparation areas only.

OPEN DIVISION

Only rule **III. Wheels and Axles**, is suspended for the OPEN division. Thus, these cars may have modified wheels/axles.

Clarification Notes

I-1. Tiger Cubs may use precut wood bodies or bodies pre-drilled for weights. Large hole drilling or body sawing is difficult for this age.

I-2. This allows inspection for wood construction, identifies the car front, and forms a location where a permanent ink can be stamped.

I-3. This rule is to discourage machined metal or plastic body chassis. Secure means body able to withstand dropping from 4 ft.

I-4. Some kit body blocks may slightly exceed 7.00". Box sizes are thus generally slightly larger, typically 7.00+0.02" by 2.75+0.01".

I-5. The car height must clear under an overhead finish timer. The 1-3/4" x 3/8" strip test ensures car will clear the track center guide strip.

I-6. There are several problems with restricting builder to just slot positions. Wheel camber is not guaranteed horizontal, and the slot separation can vary up to ½" in different kits. Using 2 taped wheels as a drill guide allows easy hand drilling of true 0.086" holes anywhere.

II-1. A flat nose is required for fair starting and finish line sensing. Wet paint on the nose could stick to the starting post giving a boost.

II-2.. The number 5.0 is 5.0499 rounded off, or if scale has metric with more significant figures then 143.0 grams is 5.044 ounces, also equivalent to 5.0 ounces when rounded. Cars reading either 5.1 oz or 143 grams or over must either return to work table or enter in the OPEN.

II-3. Banners, flags, or string type detail for example may interfere with cars in adjacent lanes.

III-1. Speed is very sensitive to the type wheels. Allowing non-standard hobby-store wheels would clearly be unfair. Such run in the OPEN.

III-4. The BSA wheels will be inspected if necessary with a metal template to ensure they are not violating these specifications.

III-5. The BSA axles will be inspected with a metal template if necessary to ensure they are not violating this specification.

IV-1. The no oil rule in the past was caused by poor plastic wheels or aromatic content in the oil. Oils no longer cause problems. Also, a properly applied thin film of graphite, or a film of oil, is not visible and cannot be inspected. Both lubricants perform similarly in friction reduction.

RULES FROM THE BOX

In every official Cub Scout kit containing a wooden block, four or five axles, and wheels, there is a small sheet of paper with the following rules:

CAR SPECIFICATIONS

- **Width 2-3/4"** ● **Length - 7"** ● **Weight - Not over 5 ounces**
- **Width between wheels 1-3/4"**
- **Bottom clearance between car and track 3/8"**

RULES

Wheel bearings, washers and bushings are prohibited. The car shall not ride on springs. Only official Cub Scout Grand Prix Pinewood Derby wheels and axles are permitted. Only dry lubricant is permitted. Details, such as steering wheel and driver are permissible as long as these details do not exceed the maximum length, width, and weight specifications. The car must be free-wheeling, with no starting devices. Each car must pass inspection by the official inspection committee before it may compete. If, at registration, a car does not pass inspection, the owner will be informed of the reason for failure, and will be given time within the official weigh-in time period to make the adjustment. After final approval, cars will not be reinspected unless the car is damaged. In handling or in a race.

DISCUSSION OF RULES

The Original Rules vs. the rules from the box, especially wheel clearance and lubrication.

The original rules, and the somewhat more current "Rules from the Box", are pretty similar regarding car construction. One difference is the original had a car length 3/4" longer. Also, the original rule that the father "must" help the Cub has been relaxed in that now a 100% Cub-built car is perfectly acceptable and even commendable. And, of course, these days any guardian or family approved adult could be the Cub's assistant.

The "**Width between wheels - 1 3/4**"" is new, but confusing, since the wheel pairs don't have a common width and because of play they may be pulled apart or pushed together by various amounts. Usually the rule is interpreted as the maximum separation (wheels pulled apart) should at least be 1-3/4" to ensure no binding with the 1-5/8" track guide strip. And the bottom 3/8" clearance rule was added to ensure guide strip height (1/4") clearance. There will be more detail later with drawings.

For some reason the 1953 rule of "no lubrication" has been changed over the years in the box rules to "dry lubricant only". If we read further into the last paragraph on the sheet contained in the PWD car kit, it says, " Do not use regular oil or silicone spray as it may soften the plastic." It is likely that either the early wheels were not made of the modern polystyrene plastic or some aromatic-containing oils were tried that indeed can soften the plastic. The truth is that there is absolutely no polystyrene wheel damage with silicone oils or other commonly used lubricating oils as tested on wheels since 1990 and with data as explained in **Lecture 19.** Plus oils are a lot less messy than graphite. And, a lot of research has shown that oils and graphites have about the same lubricating ability in the journal bearing formed by the wheel bore and axle. Moreover, you cannot see a film of oil so it is not inspectable. We can conclude that the "dry lubricant only" rule is based on either hearsay or outmoded information and should be eliminated. This would level the playing field even more because good oils are a lot easier to obtain and apply than are good graphites.

Wheel and axle modification in the 1991 SHAC Rules

As stated in the Introduction, the reason I was asked to add rules regarding modified wheel/axles was our first SHAC race, wherein my son's car won by several car lengths, rather embarrassing to some of the race officials. Both the axles and wheel bore diameters of the car were reduced without the use of washers or bushings. The axles were filed and ground with honing stones to about half their original diameter. The bore hole size was reduced by liquifying the wheel around the old bore hole with an aromatic solvent and letting the wheel plastic set up around a polished drill bit shaft. The race inspectors agreed that since the wheel and axles were still the originals, no rules were violated. The items III-4 and III-5 in the draft SHAC rules trace back to 1991 where limits were put on the amount of reduction allowed in wheel diameter and tread width and also axle diameter. Before we discuss the wheel and axle modifications, lets consider another race that points out the need for this rule.

The 2005 National PWD Race in Irving, TX

My nephew, a Cub in the Los Angeles Western Region Council, in early 2005 heard about the National PWD race at scout headquarters and asked if I would help him build a car for the race. He, and his parents, felt a demonstrably fast car would have a good chance of getting picked by their council executive to represent them in Irving. So immediately a lot of work was begun to find out what the race rules were. It turned out that the race rules were the "Rules from the Box". The local Mustang District in the Dallas area was in charge of setting up the track and running the race. I contacted them and discussed what to do about wheel/axle modifications allowed by these rules**,** but it appeared many of these folks were already aware of this and were indeed modifying their wheels and axles to make faster cars as allowed by the "box rules". Most all the 300 plus Council Executives and many secretaries were present at the meeting honoring the Cubs 75th anniversary, but only about 100 brought a car from their council. Of course, many councils chose one of their fastest cars as based on their local versions of the rules, some of which did not allow substantial wheel/axle modification. And some councils used a random drawing to pick their cars. I was in the vicinity at the scout museum in Irving donating a copy of my book and was invited to attend the race at the Gaylord Hotel in Grapevine. My nephew's car had arrived from LA in good shape and I watched it run. It had a combination of all four major speed factors, including a special graphite, lightened wheels, tungsten-loaded center of mass in the far rear, and a streamlined shape. None of the competition had all four factors so again a car I designed for a Cub won by several car lengths. Unfortunately, there was substantial unhappiness, and there should have been, because many of the cars used different rules. However, in any race, the first thing to do is to check the rules under which you are racing and modify the car accordingly before you turn it in. So here again is a reason to adopt a national set of rules, to level the playing field, just as was learned in SHAC in 1991. The National Council was of the opinion that the race was only symbolic, and not to be taken that seriously, but that did little to sooth the ruffled feathers of many parents.

Figure 2 - *The National Champion car.*

Details of wheel/ axle modification Rules

Figure 3 shows how sanding or scraping the tread on a 1999 BSA kit wheel is allowed to take the overall diameter down very slightly to 0.045" less than the original wheel. Also, the curved part of the tread inside rim that normally rubs against the guide strip may be trimmed back about 0.035" until the flat part of the tread is reached. Notice the flat part of the tread may not be reduced in width from its original 0.275". Even with this slight wheel sanding, the **Virtual Race** shows the shaved wheel car could be 0.2 car lengths faster at the finish line.

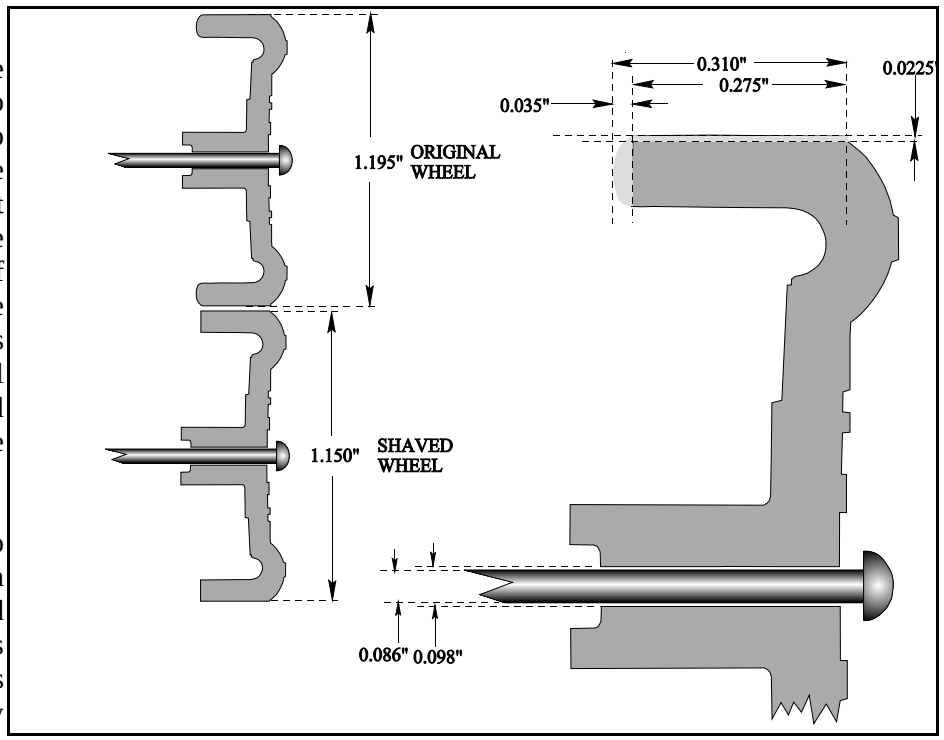

Figure 3 - *Cross section of a 1999 BSA wheel showing wheel/axle specifications.*

Notice that the axle diameter is not allowed to be less than 0.085". Some axle shafts, even when deburred, are up to 0.004" out of round near the axle head, but the smallest diameter is still larger than 0.085". The axle shaft itself is usually close to 0.086", and it would take many hours of polishing with a fine grit size on the order of # 1500 to reduce the axle diameter to less than 0.085". It should be noted that a smaller axle diameter per se will not make the car faster, as explained in **Lecture 4.** Rather, a smaller bore hole will make the car go faster. But bore holes cannot readily be inspected, thus the use of the axle diameter limit rule is to ensure the wheel bore is no smaller.

What Should the Wheel Base Distance Be?

Also needed is a consistent rule about distance between front and rear wheels. The National Race cars in 2005 showed that practice in the USA is approximately 50/50 between shorter wheel base as fixed by the block axle slots and a longer wheel base using drilled axle holes. **Fig 4** shows kit blocks can have substantially different slot spacing. Hammering the axles into the slots and gluing them in place prevents being able to unplug the wheel/axle by pulling in order to separately lubricate the wheel and the axle. Thus slot mounted wheels are slow. Wheels and axles, separately lubed, may be reassembled and plugged back into the hole anytime a fresh lubrication is needed, and such cars have considerably more speed. **Fig 5** from **Lecture 14** shows it is easy, even for younger Cubs, to hand drill a perpendicular hole of the correct size anywhere in a soft pinewood wood block by using 2 spare wheels taped together as a No. 44 drill bit guide. Theoretically, there is very little difference in finish times for cars identical in every respect except wheel base. Actually, the weight of the front wheels when moved rearward add a tiny bit to the car's overall potential energy and final speed but amounting to only 0.1" improvement at the finish line. On the other hand, the longer wheel base may reduce center strip bumping which in itself could also increase final speed slightly. Thus, wheel separation per se is pretty much a toss up with no clear advantage. Also, one can't inspect to see if a slot is used vs. a drilled hole because of slots legally filled with wood putty, paint, etc. Therefore many will allow drilled holes as long as they are about the slot distance apart.

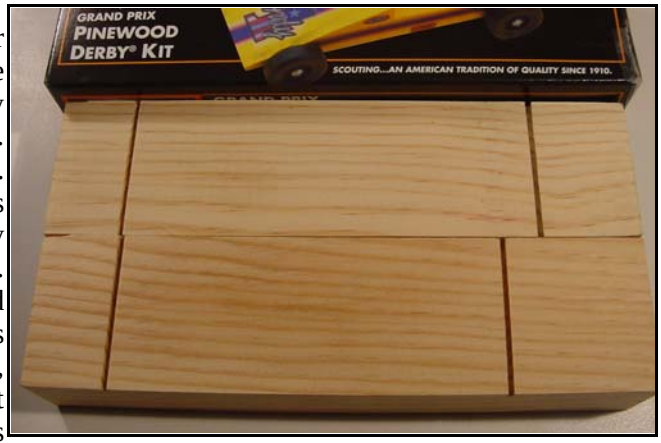

Figure 4 - *Slot spacing in blocks can be substantially different. Here the slots to the right vary by 1/2*".

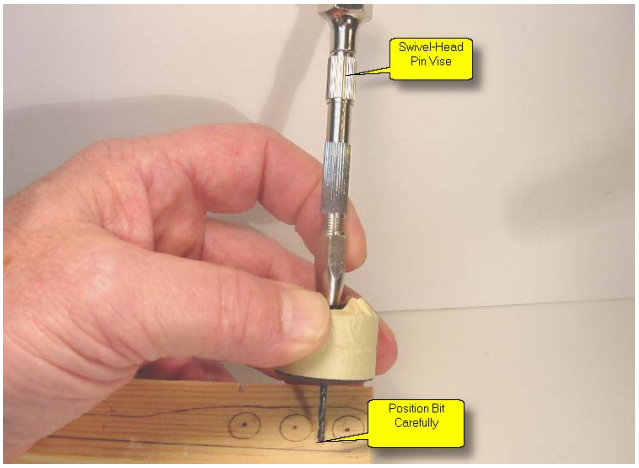

Figure 5 - *Hole starting with guide made from 2 wheels.*

By way of summary:

- A drilled hole allows plugging in or unplugging wheels for a proper and less messy lube job on separated axles and wheels.
- Kits can have a variable rather than constant slot spacing (Fig 4)
- Axles in slots still allow wheel camber (tilting) which can slow the car.
- There is no advantage in car speed by using either wheel base.
- With slot mounting of axles it is more difficult to get a perpendicular hole than when using the simple hand drill and wheel guide.

Should there be a rule that the block in the kit box must be used?

Notice that the "Rules in the Box" state that "Only official Cub Scout Grand Prix Pinewood Derby wheels and axles are permitted". Nowhere in this rule does it say that only the wooden block contained in the kit may be used for the car body. This is appropriate, since there is no procedure given to inspect at race time (or any time) to determine what the actual source of the wood is. The originator of those rules that specifically say to use the BSA kit block likely had in mind the benefit to the BSA Scout Shop if the body blocks are purchased there rather than from a lumber yard or obtained from scrap wood. But this reason does not hold up under examination as the kit must be purchased anyway to obtain the official wheels and axles. Moreover, the wheels and axles are also sold at the scout shops in separate kits without the wood block for about the same price. And again, where the wood comes from in no way can measurably affect car speed. What many have done, such as the WIRL (Woodcar Independent Racing League), is to specify that a rectangular patch between the front wheels shall be left as unpainted bare sanded wood. This allows the inspector to verify that at least wood is used without scraping paint. Moreover, it allows a rubber stamp to print an ID such as "SHAC 2008" to prevent the same cars from running year after year. In the proposed National or SHAC rules , on page 2, the rule "Only official BSA kits including *wood block*... may be used" is left in for historical purposes, and will cause most to go ahead and use the kit wood, because it is implied by the bare unpainted patch rule that perhaps that rule is enough for an astute inspector to determine the wood source. Also notice we have a footnote to the subject rule that allows the Tiger Cubs to use precut wood bodies from Hobby Shops or other sources such as the Internet. And there are available pre-drilled wood bodies that allow lead worm to be inserted in the provided 3/8" holes for weighting purposes. The Tigers are pretty young and usually should not be expected to have the skills to use special large non-splintering brad point or Forstner drill bits and /or wood saws (especially band saws). But in no way should hobby store-type wheels and axles be used by any Cub because some of these lighter wheels offer a clearly unfair speed advantage.

More about the 1-3/4" wheel width rule?

As stated earlier, this rule was added in the past to the "Rules in the Box"simply to guarantee that the wheels would not bind against the center guide strip. And, as already mentioned, the rule is widely misinterpreted. In **Fig. 6 A**, there is shown a typical car and track cross-sectional end view. The body is 1-3/4" wide and as shown evenly straddles the 1-5/8" wide guide strip. Of course, in an actual race, the car may move some either to the right or to the left. The difference between the body width and the guide strip is 1/8"total or 1/16" on each side when centered. So, when the wheels are pushed against the body by hand like in case **A**, to form the minimal separation between the wheel tread insides and the track, on each side there is more than 1/16" because each wheel hub protrudes an additional 0.040" more than the tread and the hub is the part that contacts the body. So the net clearance between the wheel tread and guide strip is 0.1025" on each side when centered.

Consider case **B** in **Fig. 6.** A common "play" distance that keeps the wheel from being pinched between the body and the axle head is about 0.050", roughly the thickness of a stack of 5 playing cards. So when the wheels are running at maximum separation against the inside of the axle heads, the clearance has grown to 0.1525" on each side.

Case **C** in **Fig. 6** shows the situation which is the common sense interpretation of the 1-3/4" width rule. Namely, the car must pass inspection for at least a 1-3/4" separation by seeing if it will roll over freely (no binding) by clearing the length of a 1-3/4" wide rectangular slab (the slab could be 3/8" high to check the height clearance rule simultaneously). In Case **C**, we show as an example about the smallest practical clearance as 0.005" on each side between the wheels and test strip. But notice to be able to take advantage of the 1-3/4" width rule with wheels at maximum separation (against axle heads), the wheels would be partly inside the 1-3/4" body. Nevertheless, as can be seen by the guide strip dashed outline, there would still be plenty of clearance, over 1/16", between the wheels and guide strip. Therefore, one will find many builders that will "notch" the body, or use a narrower body as shown by the vertical dashed lines or a really narrow body with wooden dowel spar extensions to hold the axle nails.

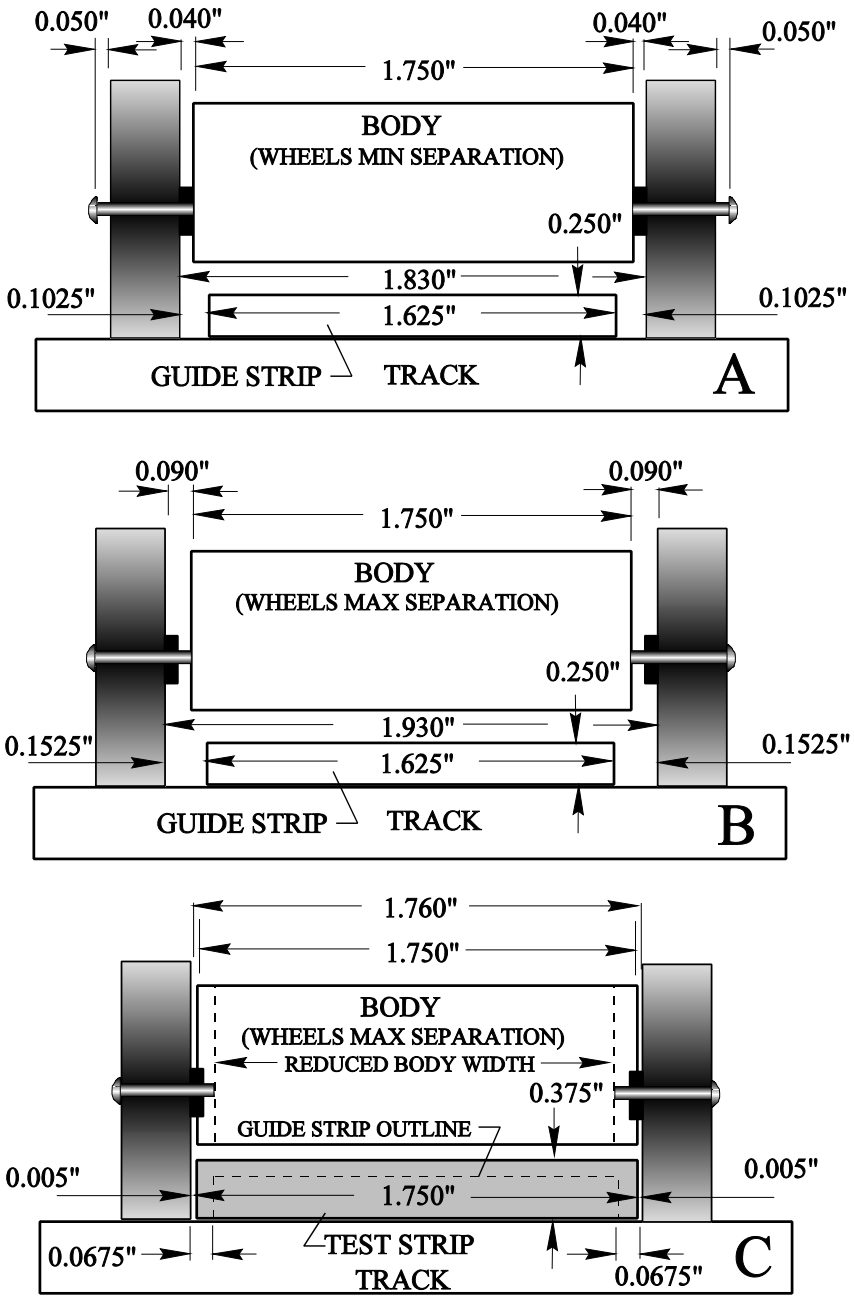

Figure 6. *Measurements related to the 1-3/4" width rule.*

Now such an arrangement as in case **C** works well, but some rules are written that claim the 1-3/4" width rule applies to the distance between wheel hubs. Therefore these folks insert a rule that the body wood (or whatever) where the axles are inserted itself must be at least 1-3/4" wide. This has the effect of forcing a builder's car to run a sloppy race, because that extra clearance, as in case **B**, close to a full 1/3 inch, can allow the car to start a "wiggle" motion that builds up and slows the car down considerably. It also increase the randomness or repeatability of a car's race time which confuses the ability to have a clear winner in a close race. The intent of the guide strip to help a car track straight is therefore compromised. As matter of fact many builders have learned that letting wheels on one side rub against the center strip really increases speed, and the technique is called "rail riding". So the 1-3/4" wheel width rule as written on page 2 as the common sense interpretation should be the one uniformly applied.

INSPECTION TOOLS

Figure 7 - *An inexpensive but accurate scale.*

Figure 8 - *The car length and width box and the wheel clearance slab.*

Figure 7 shows an inexpensive (less than $40) kitchen scale that does both grams and ounces but has 3 significant figure accuracy in the gram mode. Here 141 grams is just under 5.0 oz. (5.00000 oz = 141.748 grams).

Figure 8 shows a car length and width box that measures conformance to these rules by simply grasping the car body with the thumb and middle finger and setting the car in the box. At the bottom is the 1-3/4" wide by 3/8" high wheel clearance slab for rolling the car over to check proper clearances. Also shown is a dial caliper usually used by the box/slab builder to check distances.

Figure 9 shows several items related to wheel/axle inspection. First, the car builder, after sanding or scraping the wheel tread flat, can measure how much wheel plastic was removed by the yardsticks shown at the top. Simply take two spare fresh wheels, (1) in the figure, and squeeze them firmly between the two straight yardsticks. Then test the shaved wheel (2) with a stack of four playing cards (3)(about 0.011" each), which should just fit in the crack between the wheel and ruler. Item (4) is a template made of 0.050" aluminum for the inspector to use to test wheel diameter and item 8 is an axle test template with a 0.085" slot in its left end. Items (9) and (10) are No 44 and 45 bits of dia. 0.086" and 0.082" respectively used to gauge the slot width as made by the sapphire file (7). The right side of (8) has 2 blackened scribe marks for checking tread width (arrows). The fine tooth hobby saw (5) and round file (6) help in template making. An experienced inspector can test a car in about 30 seconds. Templates are not used unless a wheel or axle looks suspicious. Probably fewer than 1 in 10 cars require more than just visual wheel/axle checking.

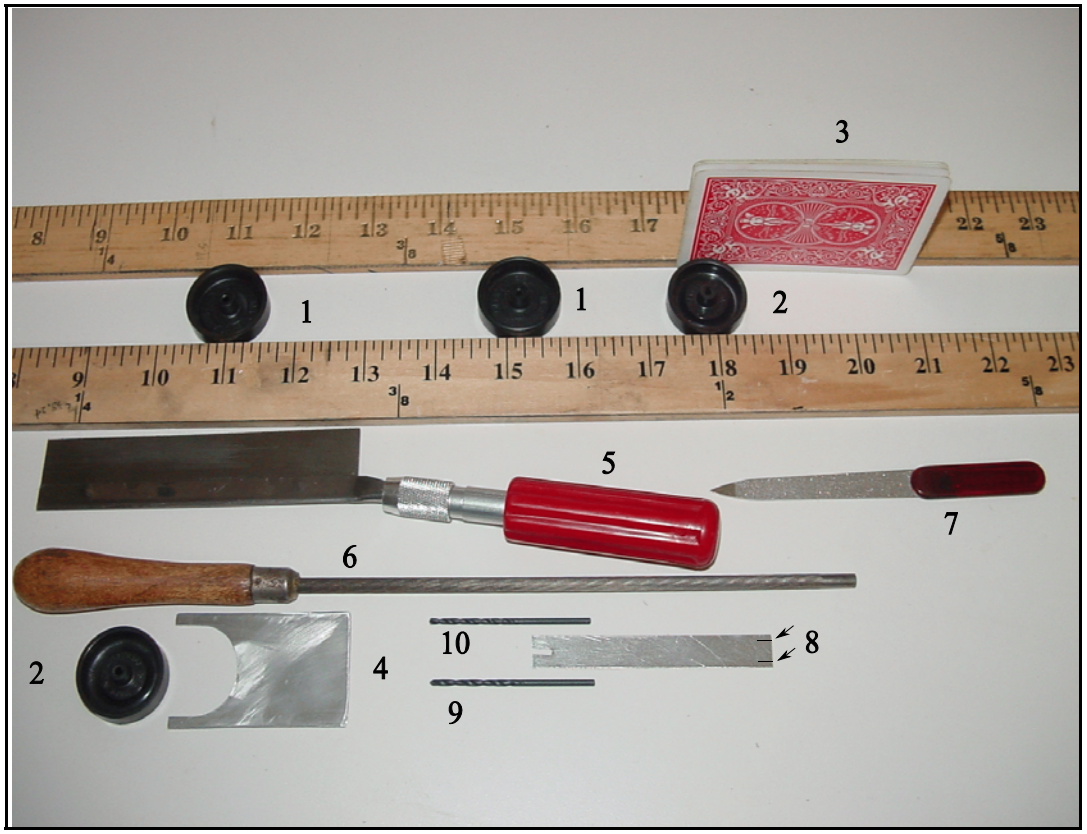

Figure 9 - *Wheel/axle measuring templates and related tools.*