Physics Lecture 26 - Examining the New BSA Wheels and Wheel History

Introduction

Several months ago in the spring of 2009 a new wheel was made available by the BSA supply store system. This wheel, herein called the STD2009 wheel, has characteristics of a racing wheel in that the moment of inertia has been substantially reduced compared to the formerly used wheel, called the STD1999 wheel. The STD1999 wheel had been the latest PWD standard wheel for about the last 10 years. Only recently has the scout shop in my area had the new wheel, and it has sold out quickly compared to the older wheel. The new wheel has a significantly thinner tread section causing a smaller amount of rotational energy to be used during acceleration compared to the STD1999 wheel. Depending slightly on the shape of the ramp used, on a 42 ft track, a car with the new wheels (with all other factors constant) will beat a car using the older 1999 wheels by about half a car length at the finish line. The unfortunate part is that in some cases the local scout shops sell both old and new wheels. So, in spite of your local racing rules, the availability of both types of wheels has created an unlevel playing field. This lecture will:

1) Discuss the "official" wheels manufactured and distributed by the BSA supply organization over the last 20 years.
2) Analyze the effects on race time of wheel differences.
3) Suggest that the BSA supply organization take advantage of physics expertise in the design of PWD kits.

20 Years of BSA Wheels

Fig 1 shows the last 4 wheels provided by the BSA supply organization since somewhat before 1990. All 4 wheels have nominally the same bore hole size, outer diameter, and tread width. The wheel labeled <1990 was the standard wheel used in 1990 and earlier, with earlier denoted by a <. The appearance of the STD <1990 wheel was shiny, even without polishing. All wheels are polystyrene, as determined by infrared reflectometry. The STD<1990 was difficult to machine, exhibiting a layered or onion peel type of constituency. About 1991 a new similar wheel was introduced, STD1991, of much smoother constituency. Note STD<1990 and STD1991 have recessed spokes.

Fig 1 - *The last 4 wheels available in BSA shops since before 1990 - outer view.*

Fig 2 - *The last 4 wheels available in BSA shops since before 1990 - inner view.*

In **Fig 2** an inner view is shown, and notice how thin the tread is in STD1991 compared to STD1990 and in STD2009 compared to STD1999. Note also the narrower hub on STD2009 with more of a coned shape compared to a flat hub surface on the other wheels. Official BSA lettering also appears on the outside of the STD1999 and STD2009 wheels.

Fig 3 shows the top or front view of the tread surface. The STD<1990 tread surface shows a rather sharp seam or ridge circling the center that in some cases could be quite pronounced. The mold injection point appeared to be on the tread but the finished wheel also appeared to have two definite halves that were joined at the center seam. Sometimes the two halves would be slightly offset. The STD1991 and the STD1999 both show the typical injection blemishes in the tread surface, typically only a few mils higher than an average circular cross section (see [Lecture 22]() on wheel roundness). The new STD2009 wheel did make the improvement to inject the molten polystyrene not in the tread but into a non-critical area as seen by the 3 injection "bumps" separated by 120 degrees in **Fig 2**.

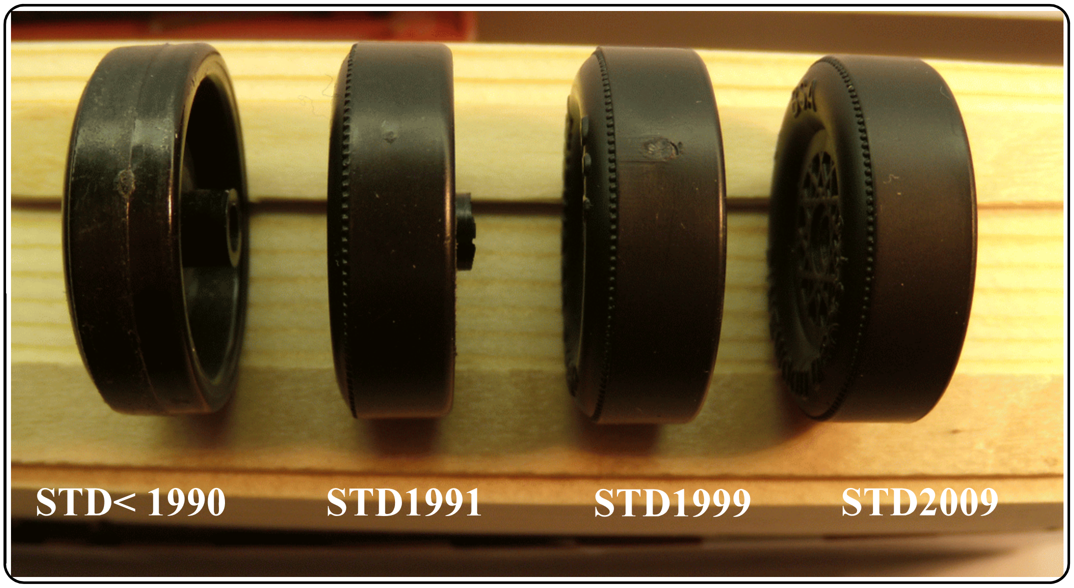


Fig 3 - *The last 4 wheels available in BSA shops since before 1990 - top view.*

Fig 4 shows cross sections of all 4 wheels sanded and painted for comparison. Notice that the tread thickness becomes progressively thinner from left to right. The tread part of the wheel is by far the main contributor to the rotational inertia of the wheel, called moment of inertia. The mid-part of the outline can vary slightly depending on how the cut intersects the raised lettering. The mass concentrated around the hub bore hole gets somewhat larger in STD1999 compared to STD<1990 and STD 1991, but somewhat smaller in STD2009. However, the hub mass has negligible effect on the moment of inertia. Such mass, located a small distance from the spin axis (center of bore hole) at a radius of about 0.1 inch has over 1000 times a smaller effect than mass located at about a 10 times larger radius in the tread area. The STD2009 also has a countersunk depression around the bore opening on the wheel outside apparent in **Fig 1**.

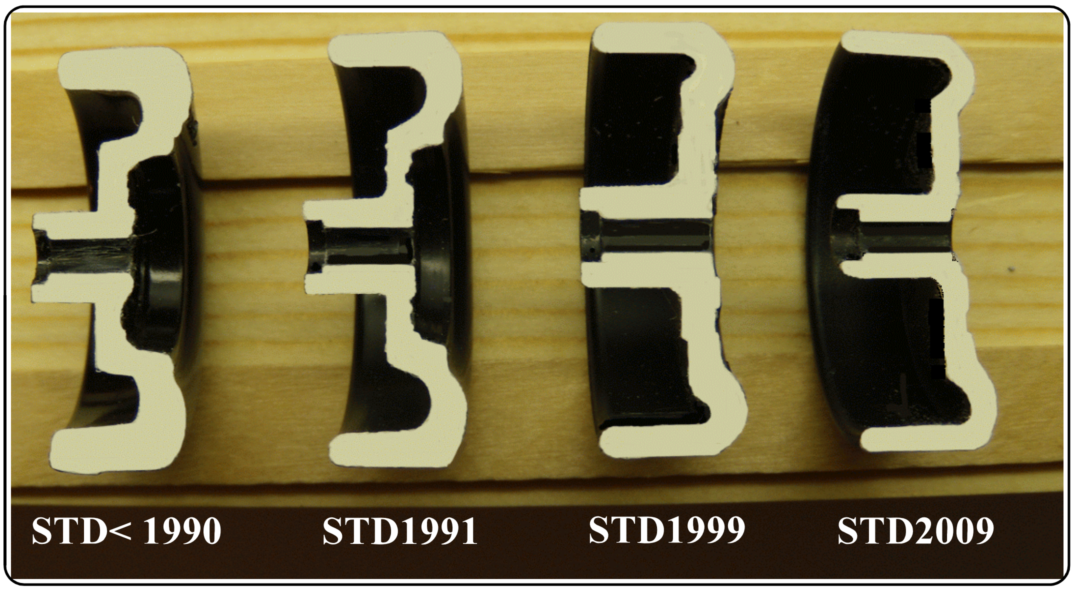


Fig 4 - *Cross sections of all 4 wheels sanded and painted white for comparison.*

Table 1 shows how the wheel properties have changed over the years. In particular, notice the substantial change in moment of inertia (and mass or weight) between STD1999 and STD2009. We will now focus on the smaller moment of inertia and hub area of the new 2009 wheel compared to the still available wheel introduced in 1999.

Table 1. *Properties of standard BSA wheels, last 20 years*

Wheel	STD <1990	STD 1991	STD 1999	STD 2009
Mass (g)	3.500	3.205	3.620	2.636
Mom Inertia (g cm^2)	5.566	4.810	5.097	3.926

STD1999 *vs* STD2009

Fig 5 shows a closeup of the STD1999 wheel compared to the STD2009 wheel. The newer 2009 wheel does have one modest advantage compared to the earlier wheel on the left. The 3 tread injection points on the STD2009 wheel are not in the tread area and do not create a bump on the tread as occurs on the STD1999 wheel. However, Lecture 21 shows that such a bump, typically only a few thousandths of an inch high, has a negligible effect on car finish times. In **Fig 6** there is shown a cross-sectional comparison graph of the 2 wheels. This type of wheel graph is used for calculating the moment of inertia of a wheel as explained in detail in Lecture 5. The cone-shaped inner hub reduces the thrust friction between wheel and body only slightly because the average spin radius of contact R_2 is slightly smaller than the average radius R_1 on the 1999 wheel (see large black *vs* red arrows). However, the counter-sunk depression inside the axle head increases the average contact radius (R_2), and thus the transmitted friction drag, compared to the smaller average contact radius (R_1) of the STD1999 wheel.

Fig 5 - *Closeup view of the STD1999 and STD 2009 wheels..*

N	1999 Z_S	2009 Z_S	r
1	0	0	0.01
2	0	0	0.03
3	12.4	10.2	0.05
4	15.4	14.2	0.07
5	17.4	17.4	0.09
6	17.6	13.3	0.11
7	18.0	3.5	0.13
8	5.0	3.5	0.15
9	4.2	3.2	0.17
10	4.2	3.2	0.19
11	4.2	3.2	0.21
12	4.7	3.5	0.23
13	4.2	3.3	0.25
14	4.5	3.4	0.27
15	4.2	3.5	0.29
16	4.2	3.5	0.31
17	4.2	3.5	0.33
18	4.4	3.8	0.35
19	6.3	4.7	0.37
20	6.2	5.5	0.39
21	6.8	5.0	0.41
22	6.5	4.7	0.43
23	5.5	3.9	0.45
24	5.0	3.8	0.47
25	5.0	3.8	0.49
26	16.5	3.8	0.51
27	18.1	8.3	0.53
28	18.1	17.8	0.55
29	16.9	16.9	0.57
30	14.6	14.6	0.59

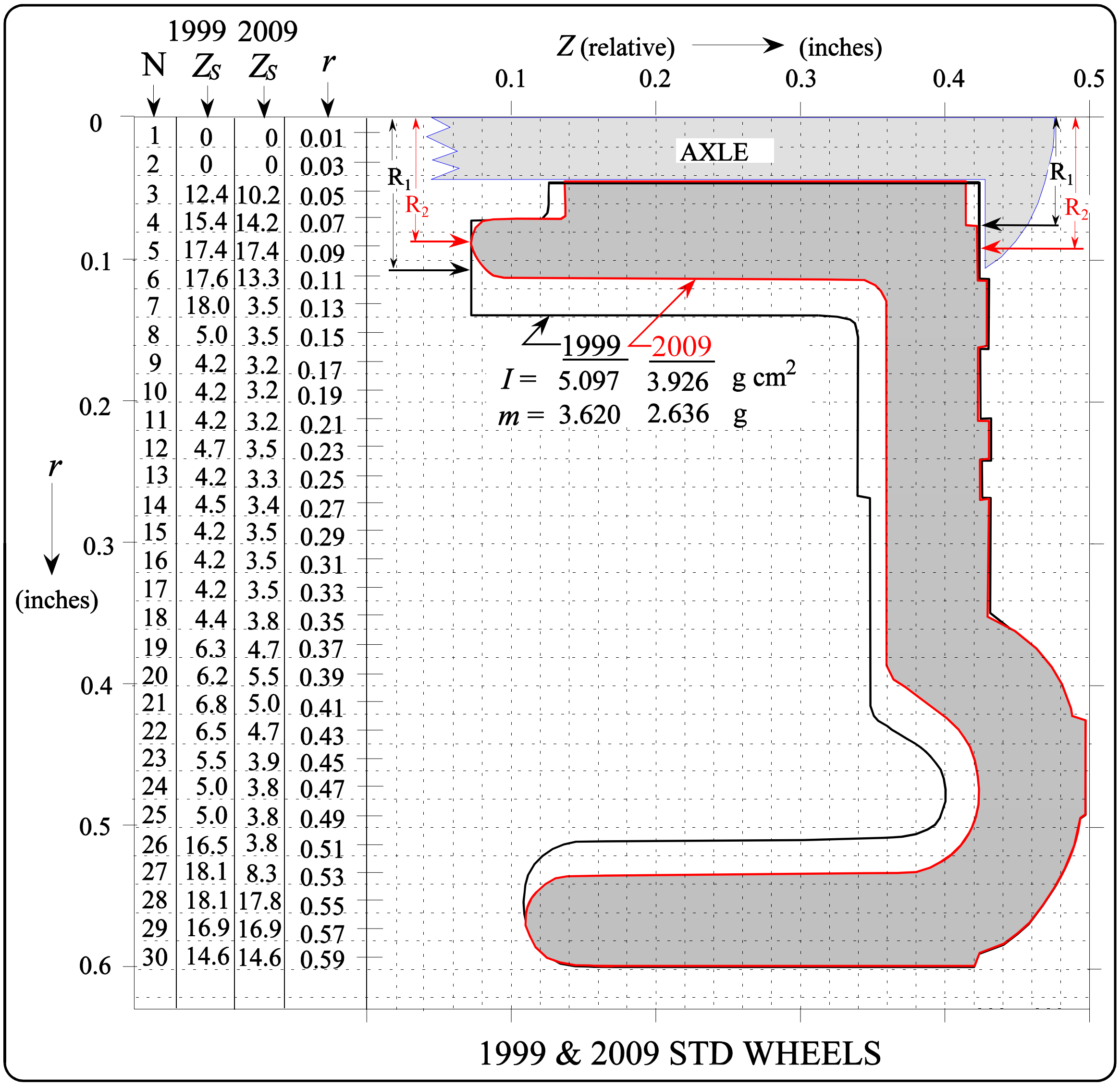
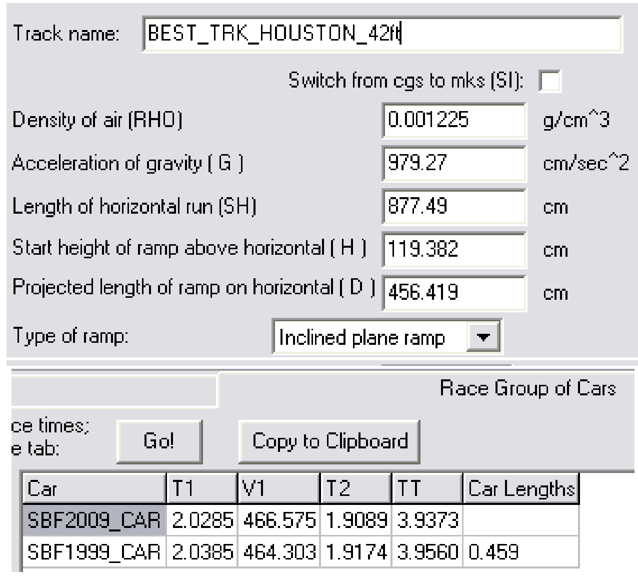


Fig 6 - *Comparing the cross sectional changes in the 1999 and 2009 standard wheels. Zoom in this Adobe pdf page to get a better view.*

Racing the STD1999 *vs* STD2009 wheeled cars.

We will use the Virtual Race program to race two of the SBF cars described in Lecture 10. The STD1999 wheel moment of inertia calculation of 5.097 in **Fig 2** will be used as compared to the close but less accurate 5.123 value used in the Lecture10 demonstration. So 5.097 is put into a car named SBF1999 and an identical virtual car is built except using 3.926 for the moment of inertia and is named SBF2009. All other 11 parameters are identical. The cars are run on a 42 ft Best Track similar to the one described in Lecture 20. **Fig 7** shows that the new STD2009 wheels are indeed substantially faster by almost half a car length at the finish line. Of course, we know from Lecture 25, that if you make the coast length long enough, the SBF1999 car will eventually catch up. That is little consolation to the unhappy youngster who was stuck with the STD1999 type wheels on his (or her) car.


Track name: BEST_TRK_HOUSTON_42ft
Switch from cgs to mks (SI):
Density of air (RHO) 0.001225 g/cm^3
Acceleration of gravity (G) 979.27 cm/sec^2
Length of horizontal run (SH) 877.49 cm
Start height of ramp above horizontal (H) 119.382 cm
Projected length of ramp on horizontal (D) 456.419 cm
Type of ramp: Inclined plane ramp
Race Group of Cars
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Car	T1	V1	T2	TT	Car Lengths
SBF2009_CAR	2.0285	466.575	1.9089	3.9373	
SBF1999_CAR	2.0385	464.303	1.9174	3.9560	0.459

Fig 7 - *Race results on a 42 ft Best Track*

Fig 8 shows detail of the car separation during the race, with the red SBF2009 car about a quarter of a car length ahead at the end of the ramp (darker shade) and finishing about half a car length ahead of the black SBF1999 car.

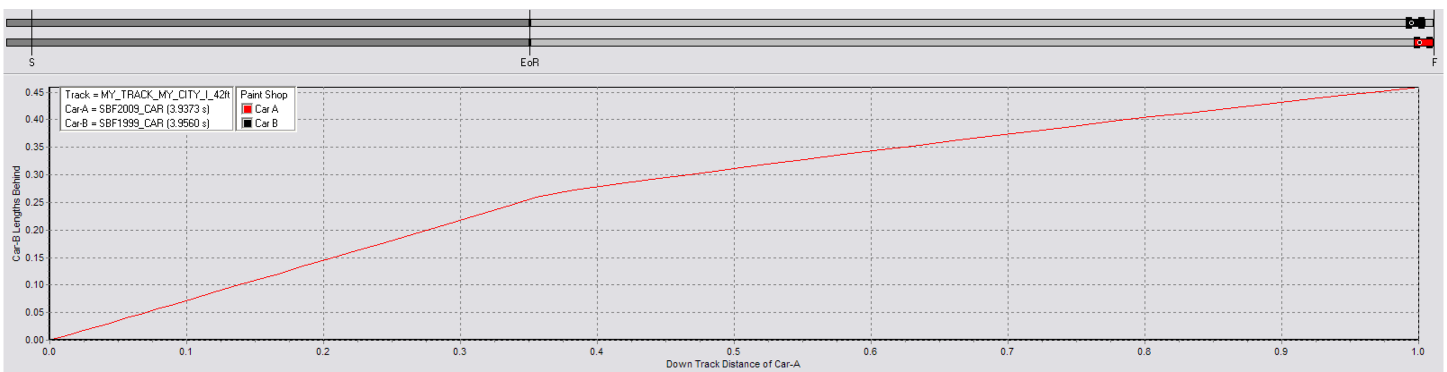

Fig 8 - *The SBF2009_CAR ramp acceleration gives a 1/4 car length end-of-ramp advantage over its heavier wheeled twin and wins by almost half (0.459) a car length at the finish---Track is a 42 ft Best Track.*

As explained earlier, there is no other significant effect such as transmitted friction or air drag that differs between the 2 wheels. It appears that the myth of "sliding friction drag force depends on the apparent contact area" is busy again. It is likely that the new rounded and coned hub was thought to lessen the contact area and hence the rubbing friction against the car body, when the fact is that at a constant thrust force there is no detectable change in transmitted frictional sliding drag force between wheel/body with different contact areas (Lecture 2). It is only the radius at which such horizontal thrust force is applied that makes a difference. So with a smooth axle head underside and a smooth car body, there will, on the average during a race, be about as much inner wheel hub contact with the body as wheel outer hub contact with the axle head underside resulting in a near cancellation of the black and red arrows of **Fig 6.** If the area of automobile brake shoes is increased relative to the brake drum inside surface, you will observe the same stopping action at the same pedal pressure. Such thrust friction around the PWD hub is at any rate much less than the predominant friction between the load carrying axle shaft bottom surface and the top of the horizontal bore hole surface on which it rests. As a matter of fact, no matter what physically allowable parameters you put into a car, high wheel/axle friction, weight different than 5 oz, large aerodynamic drag, or different center of mass position, a change in the wheel moment of inertia as in **Fig 8** will always show up as about a ½ car length difference at the finish line. These PWD wheel forces are analyzed in great detail in Section **7.11** of the Physics of the Pinewood Derby book.

NEWSLETTER DISCUSSION

As a newsletter topic we will discuss the following message from the Northeast Region BSA Supply Group. When a complaint, about the wheel change and the subsequent unleveling of the PWD racing field, was made to the supply group organization of the BSA, the following message was received:

Background:

12 years ago we began supplying new official wheels from a new mold. During this turnover/introduction there were actually 3 wheel versions in the market.

Four technical internet resellers conducted and published a very technical study. At that time, all of them had published Pinewood Derby books, guides or how to''s.

Their summary finding: There is no distinct advantage or disadvantage to one wheel over the other.

Since last month, any PWD item shipped into the NDC containing wheels was from our new mold. The old mold has been retired.

Again, there is no distinct advantage or disadvantage to one wheel over the other. Preparing a car is what matters. Factors like axle preparation and alignment, reaching maximum weight (5 oz.) polishing and applying graphite determine speed. All wheels in BSA derby kits are Official.

Vince Manno
Regional Sales Manager-Northeast Region
Supply Group-Boy Scouts of America
Charlotte, NC

It is apparent that the "summary finding", namely that "There is no distinct advantage or disadvantage to one wheel over the other" is not based on sound physics. And, the statement that "At that time, all of them had published Pinewood Derby books, guides or how to''s" is disturbing in that unsound physics may be being taught as fact to our youngsters. This may not totally be the fault of the BSA supply group, but certainly at least must be the fault of those dogmatic "internet resellers" who continue to propagate certain myths and superstition as fact to parents, children, and evidently even to BSA officials and others involved in PWD racing. Has anyone heard of this "very technical study"?

Now this "summary finding" may be several years ago, but the BSA supply group should consider a new finding based on experimental and engineering physics. Towards this end, a copy of the 522 page textbook *The Physics of the Pinewood Derby* was donated to the BSA museum in Irving, Texas back in May of 2005 at the 75th Anniversary meeting. It was hoped the book would capture the attention of a BSA supply group. However, the book is no longer on display at the museum. Phone messages to the Regional Sales Manager above have so far been unanswered. In order to increase awareness of the need to get accurate physics involved in the BSA PWD racing scene, for the sake of our youngsters, please go to Contact on home page and leave a message to be anonymously published with others in an upcoming newsletter. And, to further gain support for your help teaching kids proper use of physics in PWD racing, when you comment and/or read this lecture, enter the 8 code letters **helpkids** in the online store checkout process and you will get the new Virtual Race VII at half price plus shipping. If you are a BSA pack leader that will use the Virtual Race to teach kids, contact me for a free Virtual Race CD. Offer good until February 28, 2010.

Regards
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